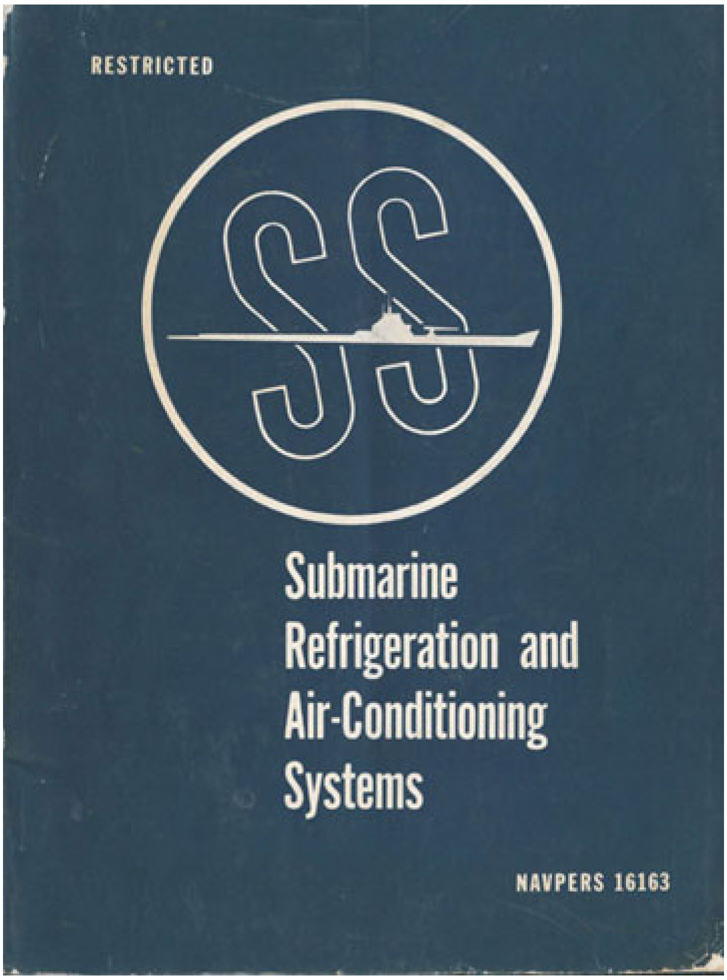
The Fleet Type Submarine Online Refrigeration and Air-Conditioning Systems



Folks,

Submarine Refrigeration and Air-Conditioning Systems, Navpers 16163, is one of a series of submarine training manuals that was completed just after WW II. The series describes the peak of WW II US submarine technology.

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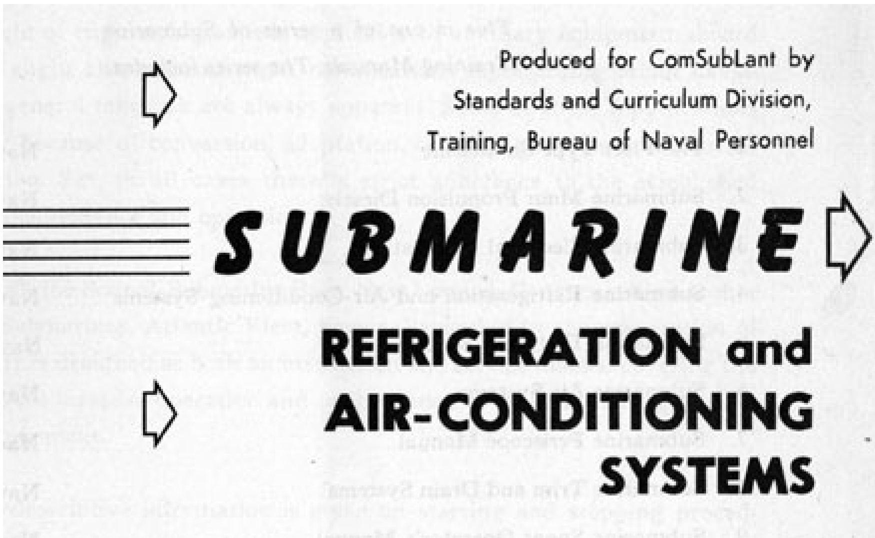
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SUBMARINE

REFRIGERATION and
AIR-CONDITIONING
SYSTEMS

December 1945

~~RESTRICTED~~

This is one of a series of Submarine Training Manuals. The series includes:

1. The Fleet Type Submarine — NavPers 16160
2. Submarine Main Propulsion Diesels — NavPers 16161
3. Submarine Electrical Installations — NavPers 16162
4. Submarine Refrigerating and Air- — NavPers

PREFACE

In the field of engineering as it is applicable to auxiliary equipment aboard a submarine, slight changes and slight modifications representing minor deviations from a general textbook are always apparent. Some of these modifications are necessary because of conversion, adaptation, or redesign; others because of experimentation. Yet, in all cases there is strict adherence to the established principles of maintenance and operation.

The Submarine School, Submarine Base, New London, Connecticut, and other activities of Submarines, Atlantic Fleet, have collaborated in the preparation of this manual. It is designed as both an instruction and service manual covering the established procedures for operation and maintenance of air-conditioning and refrigerating equipment.

Detailed descriptive information is given on starting and stopping procedures, installation and repair techniques, and inspection routines.

The manual is presented in two parts: Part 1, Refrigeration; and Part 2, Air Conditioning. Each part includes the theory of operating and servicing of the equipment, and assembly and disassembly procedures and repair routines. Free use is made of job sheets outlining in chronological order the steps necessary for the successful completion of the more common maintenance and service conditions. A glossary of terms and an index are included for easy reference.

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PART 1
REFRIGERATION

1
GENERAL INTRODUCTION

A. PURPOSES AND NEED

1A1. General. In many respects, the United States Submarine Service is the most exacting of all the services in our armed forces. The physical requirements for its personnel are of necessity rigid. In order to maintain these high physical standards, and for other reasons, it is necessary that working and living conditions aboard submarines be the best possible. The food must be not only the finest, but it must be preserved in the best way. Agreeable living conditions and wholesome food go a long way toward maintaining the health and morale of the entire personnel at peak levels.

1A2. Preservation of food. Certain kinds of food, such as meat and dairy products, deteriorate rapidly at ordinary temperatures. They can be preserved only at low temperatures. Refrigeration prevents, or at least retards, the formation of molds and the growth of bacteria and other microorganisms that cause the for normal diet can be preserved by means of proper refrigeration.

1A3. Palatability of foods and beverages at low temperatures. It is not sufficient that foods be nutritious and in good condition to be fully enjoyed. They must also be palatable. Some foods and beverages are more palatable when consumed in a chilled condition. Tepid drinking water supplies the human body with needed moisture equally as well as cold water, but it is hardly refreshing in hot weather. Who can enjoy the sticky sweetness of melted ice cream? Refrigeration thus increases the enjoyment of certain foods.

1A4. Air-conditioning and ventilation. Of as great importance as the foods a sailor eats is the air he breathes. The air on board ship, as well as the foods, often needs to be cooled. Moreover, during long dives, the air in submarines is used over and over again, and therefore requires proper conditioning.

spoilage of stored food. Obviously, the length of time that a submarine can remain at sea is controlled to some extent by the length of time that perishable foods necessary

1A5. Protection of equipment. Too much moisture in the air may interfere with the proper operation of electrical equipment. It is therefore necessary to prevent moisture from condensing on such equipment.

B. COLDNESS AND HEAT DEFINED

1B1. Coldness and heat are relative terms. Strictly speaking, coldness is not a distinct condition separate from hotness. The two terms are purely relative, without exact meanings. They merely express temperature conditions with reference to a standard. This standard usually is the temperature of the human body, which is normally 98.6 degrees Fahrenheit. If a person picks up a piece of ice, he says the ice is cold; he means that its temperature is lower than the temperature of his hand. If he drinks a cup of coffee, he says the coffee is hot; he means merely that its temperature is higher than that of his mouth. Nevertheless, the ice is warmer than liquid air, for example, and the coffee is cooler than boiling water.

In discussing matters pertaining to refrigeration and air-conditioning, often it is preferable to use the expression cooling, rather than the awkward expression removing heat. After all, refrigeration and air-conditioning deal with the maintenance of conditions best suited to the health and comfort of the human body, and are concerned with temperatures that human beings refer to in ordinary usage as cool and hot. In this manual, when cooling is used, it is understood that the operation actually consists of removing heat.

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2
REFRIGERATION

A. METHODS OF REMOVING HEAT

2A1. General. Refrigeration is the process of removing heat from matter. The matter may be a solid, a liquid, or a gas. Removing heat from the matter cools it, or lowers its temperature. There are a number of ways of lowering temperatures, some of which are of historical interest only.

2A2. Some older methods. Lowering of temperature may be accomplished by the rapid expansion of gases under reduced pressures. Thus, cooling may be brought about by compressing air, removing the excess heat produced in compressing it, and then permitting it to expand.

Evaporation also has a cooling effect. The canvas-covered water bottle, or canteen, is familiar to all. The canvas cover is drenched with water and placed in a draughty shaded place, where the moisture begins to evaporate. Heat is required to change this water from liquid to vapor; some of this heat that is absorbed comes from water in the bottle. The water vapor carries away heat from the bottle, in turn cooling the water within.

2A4. Ice. Ice has been used in refrigeration since ancient times and it is still widely used. Refrigeration by means of ice depends upon either natural or forced circulation of air. The circulating air passes around blocks of ice. Some of the heat of the circulating air is transferred to the ice, thus cooling the air. The heat absorbed by the ice melts it. The chilled air then passes around other articles, absorbing some of their heat, and thus cooling them. A continuous cycle of refrigeration is maintained, but as a result of this process, the ice is melted and more ice must be supplied at regular intervals. On board a submarine, ice would last only a few days.

2A5. Mechanical refrigeration. Under certain conditions, some liquids boil at temperatures actually lower than the freezing point of water. In a suitable mechanical system, such liquids can draw heat from surrounding substances and thus cool them. Cooling by this method is known as mechanical refrigeration.

2A6. Refrigerant defined. In mechanical refrigeration, a refrigerant is a substance capable of transferring heat that it absorbs at low temperatures and pressures to a condensing medium; in the

A lowering of temperatures is produced by adding certain salts, such as sodium nitrate, sodium thiosulfate (hypo), and sodium sulfite to water. The same effect is produced, but to a lesser extent, by dissolving common salt or calcium chloride in water.

The mixing of common table salt (sodium chloride) with cracked ice lowers the temperature of the mixture several degrees.

2A3. Two common methods of refrigeration. The methods just discussed are limited to small-scale operation. Two common methods by which large-scale refrigeration is obtained include: 1) the use of ice, and 2) the use of mechanical devices.

region of transfer, the refrigerant is at higher temperatures and pressures. By means of expansion, compression, and a cooling medium, such as air or water, the refrigerant removes heat from a substance and transfers it to the cooling medium.

The process of mechanical refrigeration offers so many important advantages over ice that it has taken first place. On shipboard it is invaluable.

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3
THEORY OF HEAT

A. INTRODUCTION

3A1. General. When a substance is cooled, something called coldness is not added to it, but rather heat is taken out of it. In order to understand and operate refrigerating machinery, it is necessary to know a few simple facts about heat.

3A2. Three states of matter. Matter is any thing that occupies space and has weight. Matter can exist in three different physical states: solid, liquid, and gaseous. A common example is water, which can assume all three states: as a solid-ice; as a liquid-water; and as a gas-steam.

Theoretically, all substances can be converted from one to another of the three states by the addition or withdrawal of heat. However, chemical compounds differ in the ease or difficulty with which they may be changed from one to another of the three physical states. Some, like water, can very readily be converted into each of the three states; others, like paper, oxidize, or burn, at high temperatures and cannot be converted into all three. Before paper burns, it changes to a gas, but never to a liquid. The science of refrigeration depends upon changes in physical state through heating or cooling.

3A3. Definition of heat. Heat is a form of energy. It cannot be seen, shaped, or touched, nor can it be created or destroyed. It is known only through its effects on the human body, on the air, and on other matter.

B. MEASUREMENT OF HEAT

3B1. Intensity and quantity. Heat is measured 1) by its intensity, and 2) by the quantity of it possessed by a substance. This is readily understood by comparing a spoonful of hot water with a pailful of warm water. The hot water in the spoon has a greater intensity of heat, but the warm water in the pail possesses a larger quantity

is calibrated to register the freezing point of water at 0 degrees, and its boiling point at 100 degrees. It is used in most countries except the United States and the British Empire, and is used universally in scientific work.

3B5. Reading the thermometer. In recording thermometer readings, the general practice is to use a small superior circle instead

of heat, though at a lower intensity.

3B2. Thermometer. Intensity of heat is measured by an ordinary thermometer, with which everyone is familiar. Two methods of dividing and numbering the thermometer scale are in common use: the Fahrenheit and the centigrade. The conditions discussed in the following paragraphs are for pure water under sea-level barometric pressure.

3B3. Fahrenheit scale. Thermometers calibrated in the Fahrenheit scale register the freezing point of water at 32 degrees, and its boiling point at 212 degrees. Such thermometers are used in civil life and in most engineering practice, including refrigeration, in the United States and the British Empire.

3B4. Centigrade scale. The centigrade thermometer of the term degree, and to indicate the type of thermometer by the initial letter of its name. Thus 212 degrees F means two hundred twelve degrees on the Fahrenheit scale, and 100 degrees C means one hundred degrees on the centigrade scale.

Temperatures below zero degrees are recorded with a minus (-) sign before the number, thus -50 degrees F. In speech, such temperatures are said to be one degree below zero, two degrees below zero, and so forth.

3B6. Absolute, or Kelvin scale. Still another system of indicating temperatures has been found useful in certain scientific and engineering work. This scale begins at absolute zero, a temperature at which a substance possesses no heat. Obviously, if the temperature

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of a substance is lowered by removing heat, there must be some point at which no more heat remains to be removed. Absolute zero has been approached very closely in physical laboratories, but has not yet been reached.

The absolute scale is customarily calibrated in centigrade divisions. Absolute zero is 273.16 degrees below zero centigrade. This is equal to 459.69 degrees Fahrenheit below zero, the lowest temperature that can exist. It is impossible for anything to become colder than scale to centigrade, use the following conversion formula:

$C = 5/9 (F - 32)$

To change a reading on the centigrade scale to Fahrenheit, use this conversion formula:

$F = 9/5 C + 32$

3B8. The British thermal unit. The quantity of heat possessed by a substance is measured in terms of the British thermal unit, abbreviated Btu. A Btu is the quantity of heat required to raise the temperature of 1 pound of

this. On the absolute, or Kelvin, scale there are no minus degrees, and absolute temperatures are marked with a K for Lord Kelvin who devised the system. The freezing point of water is 273.16 degrees K, and the boiling point 373.16 degrees K.

3B7. Relations between various thermometer scales. A temperature read on one type of thermometer can be stated in terms of any other type by using conversion formulas.

To change a reading on the Fahrenheit

pure water 1 degree Fahrenheit at or ear 39.10 degrees F. This is the temperature at which water is at maximum density. For example, to raise the temperature of 5 pounds of water from 39 degrees to 49 degrees F, or from 160 degrees to 170 degrees F requires 5 x 10 = 50 Btu. For all practical purposes, the Btu is considered constant between 32 degrees and 212 degrees F, though it does vary a slight amount.

C. DIFFERENT KINDS OF HEAT

3C1. Definitions of terms. It is convenient to have special terms by which to refer to heat in different substances and in various operations.

3C2. Specific heat. Specific heat is the number of Btu that must be added to a unit weight of a substance to raise the temperature of that substance one degree Fahrenheit. Since most substances held to a constant weight vary in volume, varying numbers of additional Btu are required to result in a change of temperature of 1 degree Fahrenheit per pound.

Technically, the specific heat of a substance is the ratio of the amount of heat required to change the temperature of a unit weight of that substance 1 degree to the amount of heat required to change the temperature of the same weight of water one degree. Since the

closely related to specific heat. The specific heat of a substance is the heat necessary to raise the temperature of 1 pound of the substance 1 degree; the thermal capacity of a substance is the amount of heat necessary to raise the temperature of its whole mass 1 degree. Hence, thermal capacity equals the specific heat of a substance multiplied by its mass. Thermal capacity may be said to express the total capacity of a given quantity of a substance for absorbing and storing heat. Thermal capacity is stated, not as a ratio, but as a certain number of Btu.

3C4. Sensible heat. When the heat that is applied to a substance merely raises its temperature, but does not change its physical state, such heat is called sensible heat. It is the heat which, added to or subtracted from a substance, produces the changes in

specific heat of water is, by definition, equal to 1, the specific heats of other substances are expressed as decimals. A few examples are: ice, 0.504; cast iron, 0.119; alcohol, 0.70; machine oil, 0.40. Thus, it takes only about half as much heat to change the temperature of a pound of ice 1 degree as it does to change the temperature of a pound of water.

3C3. Thermal capacity. Thermal capacity is

temperature indicated on a thermometer. It is the heat concerning which human senses also can give some information, at least within certain ranges. For example, if a person puts his finger into a cup of water, his senses readily tell him whether it is cold, cool, tepid, hot, or very hot.

Human senses are not sufficiently discriminating to give precise information about the

extreme temperatures of ice and steam and other substances having temperatures beyond the range of human sensory mechanisms. Ice merely seems cold and steam seems hot, what ever their temperatures may be. The term sensible heat is applied to the various temperatures of a solid (as ice), or a vapor (as steam), or a gaseous state (as air), indicated on a thermometer. The term sensible heat does not apply to the process of conversion from one physical state to another.

3C5. Latent heat. For heat during the conversion from one physical state to another, a different term is used. This term is latent heat and it is used in two forms: 1) latent heat of fusion in the conversion of a liquid to a solid, or vice versa; and 2) latent heat of vaporization in the conversion of a liquid to a vapor, or vice versa.

3C6. Latent heat of fusion. If heat is applied to a piece of ice

heat removed is latent heat of fusion, and it is used entirely in converting the liquid to a solid, that is, in changing its physical state.

3C7. Value of latent heat of fusion. For the same amount of substance, exactly the same quantity of latent heat of fusion must be added in converting from a solid to a liquid, or must be removed in converting from a liquid to a solid. All substances differ in the quantity of latent heat required per unit amount. The latent heat of fusion for pure water at 32 degrees F, in liquid form or as ice, at sea-level pressure, is 143.33 Btu per pound.

3C8. Latent heat of vaporization. Similarly, if heat is applied to a container filled with cold water, the temperature of the liquid water gradually rises, as seen on a thermometer placed in it. The heat causing the rise in temperature is sensible heat. No physical change of state takes place in the water-it remains a liquid-until the

at a low temperature, say 0 degrees F, the temperature of the ice gradually rises. This change in temperature, which is indicated by a thermometer placed on the ice, is caused by sensible heat, as stated previously. No change of state occurs during this rise in temperature-the ice remains a solid. But as more heat is added to the ice, a temperature is finally reached at which the ice begins to melt, or turn into a liquid. This added heat now changes the physical state of the water from the solid state to the liquid state. The thermometer on the ice stops rising and remains throughout the melting period (at sea level barometric pressure) at 32 degrees F, In other words, the heat added does not cause any rise in the temperature, but is used entirely in converting the solid to the liquid state.

Heat, when used in the conversion of a solid to a liquid, is called latent heat of fusion, the word latent meaning hidden or not indicated on a thermometer as a temperature change.

But note that at the instant the last bit of ice melts, if we continue to apply heat, the temperature immediately begins to rise. The heat is now again called sensible heat.

The reverse process also takes place. If liquid water at 32 degrees F, and at sea-level atmospheric pressure, is cooled, it is converted (frozen) to ice. All during this freezing process, no change of temperature occurs-all the temperature rises to 212 degrees F. At this point, the liquid begins to boil, then turns into steam (vapor) and the temperature stops rising. Throughout the boiling, or vaporization, of the liquid water, its temperature remains unchanged at 212 degrees F. All the heat that is added to it during boiling is latent heat of vaporization, which acts entirely to change the physical state of water from a liquid to a vapor state.

The reverse process also takes place. If steam at 212 degrees F and at sea-level pressure, is cooled, it converts (condenses) to liquid water. Throughout this condensation process, no change in temperature occurs. All the heat removed is latent heat of vaporization, which is used entirely in condensing the vapor to a liquid, that is, in changing its physical state

3C9. Value of latent heat of vaporization. For the same amount of substance, exactly the same quantity of latent heat of vaporization must be added in changing it from a liquid to a vapor as must be removed in changing it from a vapor to a liquid. All substances differ in the quantity of latent heat required per unit amount. For pure water at 212 degrees F, it liquid form or as vapor, at sea-level pressure the latent heat of vaporization is 970.4 Btu per pound. This value varies, of course, for different pressures and temperatures of the same substance.

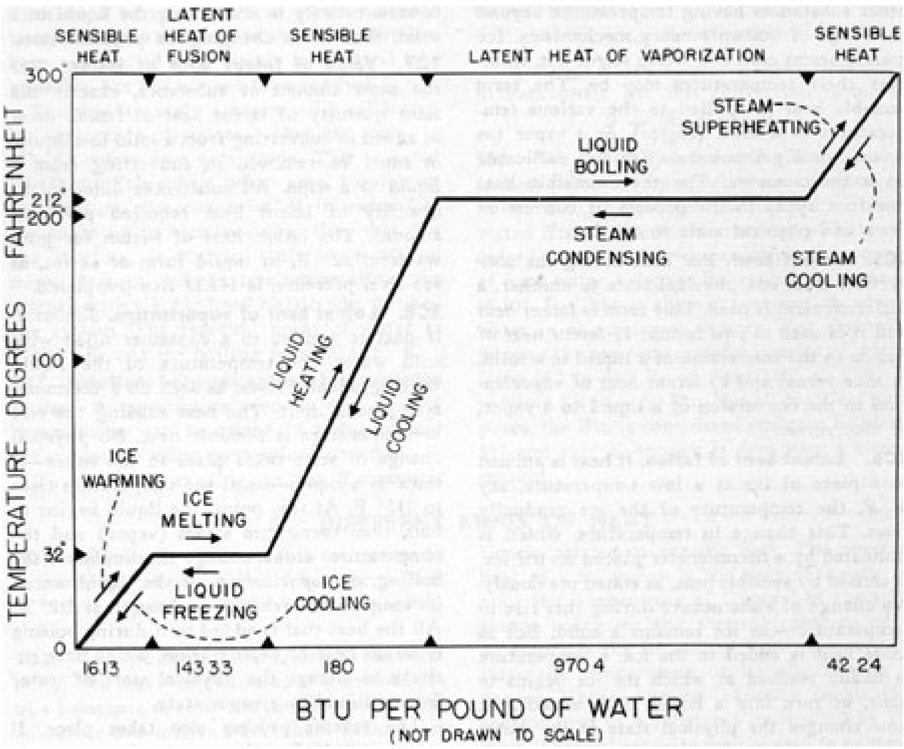

Figure 3-1. Simple heat diagram.

3C10. Total heat. The term total heat is used with two different meanings and care must be used in reading any text in order that the meaning intended is properly understood. These two usages are as follows:

Strictly speaking, the total heat of a substance is the total heat energy calculated from absolute zero in Btu. It is the specific heat x mass x absolute temperature. However, since there is no instrument for measuring heat directly on this absolute scale, and since it would also require high numbers, other starting points are arbitrarily chosen. For liquid water and steam, the arbitrary starting point is 32 degrees F. For the refrigerant Freon 12, it is -40 degrees F. For example, in a table of data for Freon 12, a column is headed "Heat Content From -40 degrees F." The figures in the column represent the number of Btu per pound of liquid or vapor Freon 12 at various temperatures. For practical purposes, we are interested only in differences in total heat at the start and end of the, process. Consequently the choice of the point on which to base the measurement is relatively unimportant.

In refrigeration and air-conditioning, the total heat of a substance or of the air in a room is all the heat present, that is:

Total heat = Sensible heat + Latent heat

3C11. Heat content. The term heat content is sometimes used in discussion. It means the total heat present in a substance.

3C12. Simple heat diagram. In Figure 3-1,

the data on the changes of state with variation of temperature, and the number of Btu required in such changes for a pound of water, are gathered in a simple graph through a range from 0 degrees to 300 degrees F. This graph is schematic only and is not drawn to scale.

D. PRESSURE

3D1. Atmospheric pressure. Everything on or in the earth is subject to pressures of various sorts. For example, everything open to the air is under what is called atmospheric pressure. This pressure is caused by the weight of the air above us. With the air near sea level at 32 degrees F, the weight, or pressure, of a column of air 1 inch square in cross-sectional area at the base and reaching from sea level to the upper limit of the earth's atmosphere is 14.696 pounds. This value varies slightly from day to day because of changing conditions in the atmosphere. For practical engineering purposes, standard sea level pressure is considered as 14.7 pounds per square inch.

3D2. Mercury barometer. A mercury barometer is an instrument for measuring atmospheric pressure. It is a vertical glass tube a little over 30 inches long. The upper end is closed, and the lower end is inserted in a small open dish. Both tube and dish contain mercury. The weight of the mercury column in the vertical tube exactly balances the atmospheric pressure on the mercury in the open dish. At sea level pressure of 14.7 pounds per square inch, the mercury column

a small airtight metal box, with a partial vacuum inside, and a flexible side that can move slightly under varying outside (atmospheric) pressures. This motion is communicated by a delicate lever system to a pointer which indicates the atmospheric pressure on a circular scale.

3D4. Converting barometer readings to pressure in pounds per square inch. Aneroid as well as mercury barometers are calibrated in inches. At mean sea level and air temperature of 32 degrees F, the mercury column stands at 29.921 inches, corresponding to an air pressure of 14.696 pounds per square inch. Since 14.696/29.921 is equal to 0.491, to convert a barometer reading in inches to pressure in pounds per square inch, multiply the height of the mercury column in inches by 0.491.

3D5. Variation of pressure and boiling point with altitude. If an uncovered container filled with fresh water at mean sea level is heated until the water boils, a thermometer inserted in the water shows that its temperature is 212 degrees F, and a barometer shows that the atmospheric pressure is approximately 14.7 pounds per square inch.

stands at a height of 29.921 inches above the surface of the mercury in the dish, regardless of the size of the cross-section of the mercury column or of the area of the surface of the mercury in the dish. Any variation in atmospheric pressure is indicated by a change in the height of this mercury column. The scale alongside the tube is usually divided into inches or some other unit of length. The space above the top of the mercury in the closed end of the tube is a nearly perfect vacuum. Since it contains no air or other substance, the pressure is practically zero.

3D3. Aneroid barometer. An aneroid barometer is another instrument for measuring atmospheric pressure. It is mechanical in nature, much smaller than the mercury barometer, and less liable to derangement. It consists of

However, if the pot of boiling water is on a hilltop 1,000 feet above sea level, the thermometer shows that the water boils at 210 degrees F when the barometer reads approximately 14.14 pounds' pressure.

Similar variations in boiling point and barometric pressure are observed at different heights, as indicated in the following table:

Altitude Above Sea Level in Feet	Pressure in Pounds per Square Inch	Boiling Point of Water in Degrees Fahrenheit
Sea level	14.70	212
2,000	13.57	208
4,000	12.49	204
6,000	11.54	200
8,000	10.62	196

3D6. Pressure-temperature relationship for change of state. It is not these variations of pressure and temperature at different altitudes to which special attention is here

directed, but the relationship between the temperature of vaporization and the corresponding pressure. For it is not necessary to go to different heights to obtain different pressures. Different pressures may be obtained by mechanical means at any location.

For example, a boiling liquid and its vapor may be contained in an airtight metal cylinder with a piston. By pushing in or pulling

to straighten. Hence this pressure is taken as the zero point of the gage.

3D9. Gage pressure. The pressure indicated by a pressure gage of this type is in reality the difference between the vapor pressure in side and the air pressure outside the curved tube. Readings from such a gage are always designated as gage pressure.

Pounds per square inch. For convenience, this term is indicated

out the piston, the pressure within may be increased or decreased. If the piston is pushed in, thus increasing the pressure inside, a thermometer shows that the change of state from liquid to vapor requires a temperature higher than 212 degrees F. If the piston is pulled out, thus decreasing the pressure within, the thermometer shows that the change of state from liquid to vapor takes place at a temperature lower than 212 degrees F. Many types of such mechanical arrangements are in common use.

This relationship of vaporization temperature and pressure, which varies for different substances, follows an exact law, and may be tabulated accurately for each substance.

3D7. Pressure gage. Pressures within an air tight system of pipes, tanks, and cylinders, are usually measured by a type of gage known as the Bourbon-tube pressure gage. In this gage there is a small tube, flattened (not round) in cross-section, and curved to about three-quarters of a circle. One end of this curved tube is firmly fixed to the mounting, or case; the other end is free and slightly movable. A delicate lever system which turns a pointer on a circular scale is attached to the free end. The fixed end of this tube is joined by its connections to the vapor system and made part of that system. Increases in vapor pressure tend to straighten the curved tube, thus rotating the pointer. The scale is marked to indicate the pressure values in units of pounds per square inch. by its abbreviated form psi. Often, where the meaning is unmistakable, the word pounds alone is used; for example, 20 pounds' pressure, but 20 pounds per square inch pressure is meant.

3D10. Absolute pressure. The term absolute pressure is used to designate the true total pressure inside the enclosed vapor system. Suppose the pressure gage stands at 6 pounds. Then, since zero gage pressure means 14.7 pounds inside (to balance 14.7 pounds air pressure outside the tube), the total, or absolute pressure of the vapor is 14.7 pounds plus 6 pounds, or 20.7 pounds. If an accurate knowledge of the pressure is required, the atmospheric pressure, converted from a barometer reading, is used instead of the 14.7-pound standard.

3D11. Vacuum, or negative, gage pressure. As stated, the standard atmospheric pressure of 14.7 pounds per square inch is taken as the zero point on the pressure gage. A gage dealing only with increases in that pressure has a single scale marked from 0 to 300 pounds or some other upper limit, and is read in psi gage pressure.

But pressures may decrease below atmospheric pressure as well as increase. Pressures below 14.7 pounds per square inch are known as partial vacuums. This term is used merely for convenience in referring to pressures below ordinary atmospheric pressure, since such a pressure is far from approaching a vacuum or even a partial vacuum.

3D8. Reading the pressure gage. The scale on the Bourbon-tube pressure gage is marked with zero to correspond to standard atmospheric pressure. Consequently, zero gage pressure equals 14.7 pounds per square inch. When the pressure of the vapor inside the curved tube is 14.7 pounds per square inch, it is equal to the atmospheric pressure outside the tube, and there is no tendency for the curved tube

A gage that registers pressures lower than standard atmospheric pressure is called a vacuum gage. Such gages are graduated to read in inches of vacuum. Approximately 30 inches of vacuum equal zero pounds' absolute pressure.

3D12. Compound gage. A compound gage is

sometimes called a compound pressure and vacuum gage. It also is in frequent use. The gage has an extended range, covering pressures both below and above atmospheric pressure. The scale is graduated to the left and right of zero (atmospheric pressure). Above atmospheric pressure, readings are in psi; below atmospheric pressure, readings are in inches of vacuum. Freon gages are normally of this type.

E. VAPORIZATION

3E1. Ebullition and evaporation. There are two kinds of vaporization, ebullition and evaporation.

3E2. Ebullition. Ebullition is the technical term for ordinary boiling. It is a rapid and visible process. By looking into an uncovered container of boiling water, one can see that ebullition (bubbling) is taking place. Starting from the bottom and sides, large and small bubbles rise to the surface and break out of the liquid.

3E3. Evaporation. Evaporation is a slow and invisible process which takes place only from the surface of a liquid. Under ordinary conditions, evaporation

This process is called sublimation and consists of changing from a solid directly to the vapor state, without passing through the intermediate liquid state. Ice and snow, even when much below the freezing point, slowly disappear without melting; Washed clothing, hung outdoors in a temperature below 32 degrees F, first freezes stiff, and then dries soft. Both these phenomena are caused by sublimation. Sublimation has little application to refrigeration engineering. It has, however, considerable use in the small-scale cooling of bottled goods, ice cream, and other foodstuffs by the use of solid carbon dioxide (dry ice) which sublimes to a vapor under atmospheric pressure.

cannot be seen. Any liquid in an uncovered container will gradually evaporate, its level falling very slowly until all the liquid is gone. Water vapor continually evaporates from the surfaces of all open bodies of water, rivers, lakes, and seas. Wet clothing or washed articles hung on a line dry by evaporation.

Since evaporation is a form of vaporization, it results in the removal of latent heat. Therefore, it is a cooling process, though a slow one. When a person goes in bathing on a cool day with a wind blowing, it is the evaporation process that makes him feel uncomfortable, rather than the temperature itself. The human body gets rid of excess heat and moisture naturally and continually by evaporation. Some liquids evaporate much faster than water; for example, alcohol.

3E4. Sublimation. There is a third method of converting from one physical state to another.

3E5. Vapor and gas. The terms vapor and gas both refer to matter in the physical state that is neither solid nor liquid. There is, how ever, a definite distinction between them.

A vapor condenses very readily to the liquid state under small changes of temperature or pressure or both, and constantly does so under ordinary conditions in nature. It may be said to be very close to the liquid state, although it is a vapor. A gas, on the other hand, exists under ordinary conditions in the gaseous state. To change it to the liquid state, special laboratory apparatus with extreme changes of pressure and temperature is required. A gas may be said to be far removed from the liquid state, and cannot change to it under ordinary natural conditions.

In refrigeration, the word gas is frequently used instead of the more correct term vapor.

F. PHYSICAL CONDITIONS OF VAPORS AND LIQUIDS

3F1. State and condition. The term state is used to refer to the three forms of matter: solid, liquid, and gas or vapor. However, a substance in any one of these three states may be found in different conditions, and hence the term condition is also used.

3F2. The two conditions of vapor. A vapor ordinarily exists in either of two conditions, either as saturated vapor or as superheated vapor.

3F3. Saturated vapor. A saturated vapor is one that is at the temperature corresponding

to the boiling point of the substance at any given pressure. The boiling liquid and its saturated vapor are always at the

However, if a vapor is not in contact with a boiling liquid, either because the liquid has all been converted into vapor, or because

same temperature. Saturated vapors may be either wet or dry.

a. Wet saturated vapor. When a vapor contains some liquid particles, in the form of fine mist or tiny droplets, it is called wet saturated vapor.

b. Dry saturated vapor. When no liquid particles are present, the vapor is said to be dry saturated vapor. In practice, vapors are usually wet. It is not easy to produce a completely dry vapor, because boiling, by its agitation of the liquid and the rising bubbles of vapor, always throws a number of liquid particles out beyond the surface of the liquid. Some of these liquid particles remain suspended and are carried by the vapor. Also, in any long piping system a small loss of heat through the pipes themselves is probable. This causes some condensation, with the resulting appearance of liquid mist in the vapor.

3F4. Superheated vapor. Saturated vapor and the boiling liquid with which it is in contact have only one temperature, and that temperature is the result of the existing pressure. the vapor has been separated from contact with the boiling liquid, further application of heat produces a rise in the temperature of the vapor under the same given pressure. Such a vapor is called superheated vapor.

The quantity of superheat in such a vapor is equal to the difference between its temperature and the temperature of its saturated vapor at the same pressure. For example, superheated vapor at 20 degrees F above its saturated temperature is said to contain 20 degrees of superheat.

3F5. Saturation temperature. If a liquid is heated, it finally boils at a temperature that is the result of the pressure present. Such a temperature is called the saturation temperature corresponding to the given pressure. This term is frequently used in air-conditioning and means merely the boiling point or the condensation point at the given pressure.

3F6. Saturated liquid. A liquid that is at the saturation temperature corresponding to a given pressure, and is under that pressure, is termed a saturated liquid.

G. EXPANSION AND CONTRACTION OF SUBSTANCES

3G1. Variation of size with change in temperature. In general, all substances-solids, liquids, and gases-decrease in volume when cooled and increase in volume when heated. In gases and vapors, the amount of change is large; in liquids and solids it is small. In all cases, unless provision is made to allow for the expansion.

3G3. Expansion and contraction of the change of state. At their melting points, substances follow no general rule regarding expansion and contraction. Some metals, like iron, bismuth, and antimony, contract on melting and

great forces are produced and it is necessary in all engineering construction to allow for the operation of these forces. Different substances vary in the amount of change in volume they undergo for the same difference in temperature.

3G2. Expansion and contraction of water. Water contracts as it is cooled, until the temperature 39.2 degrees F is reached. At this point, the change in volume reverses, and if the water is further cooled, the volume increases instead of continuing to decrease. When water freezes into ice, an enormous force is brought into play. This force is sufficient to split large rocks, burst iron pipes, and even steel tanks, expand on solidifying; but most others, like gold, silver, and copper, expand on melting and contract on solidifying. All liquids, however, expand greatly when changing into vapor, unless constrained mechanically, as in a closed container. An example of this expansion is the large clouds of "steam" continually rising from a container of boiling water.

3G4. Specific volume. The specific volume of a substance is a number that indicates the number of cubic feet occupied by 1 pound of that substance at a given temperature and pressure. Specific volume varies greatly for

different substances and for the same substance at different temperatures and pressures. For example, the specific volume of liquid boiling water at atmospheric pressure is 0.0167 cubic feet per pound, and of steam at the same pressure it is 26.79 cubic feet per pound. Thus, water in changing its state from liquid to vapor at ordinary atmospheric pressure increases in volume 1604 times (26.79 / 0.0167).

H. HEAT TRANSFER

3H1. Heat travels. Heat travels, and its flow can be definitely felt as it comes from the sun or from a fire. Heat moves from one place to another in one of three ways: 1) by radiation, 2) by convection, and 3) by conduction. These three processes may take place singly or in combination. time a breath is taken. The air breathed, after having picked up some heat in the lungs, passes out again in a current, carrying heat with it.

3H4. Conduction of heat. The transfer of heat energy from one molecule to another, either of the same substance or of different substances, is called conduction. A molecule of a substance is the

3H2. Radiation of heat. In radiation, heat is transmitted through empty space (a vacuum), as from the sun to the earth's atmosphere. Heat, light, electricity, radio, x-rays, are all known to, be energy in the form of transverse vibrations. Physically, they differ only in their wave lengths, but their physical effects are quite different, as is evident by comparing heat with radio waves. In radiation, nothing but energy really travels. Radiation is the propagation of energy of vibration. Radiation also takes place through air and transparent substances. Radiation does not heat the air through which it passes; it heats only the object upon which it falls. Not only the sun, but all other objects such as flames, stoves, electric light bulbs, our bodies, machines, foods, streets, buildings, walls, and the earth itself radiate heat to some extent.

3H3. Convection of heat. In convection, heat actually does travel. Convection is the movement through space of heat-containing particles of a substance in the form of a cur rent of heat-containing particles. This current may be small or large. Examples include: a current of warm air in a room; a current of hot water, steam, or other fluid in a pipe; a current of warmer water flowing in the ocean, such as the Gulf Stream. The human body gives off excess heat not only by radiation, but also by conduction and convection every

smallest particle of a substance that retains the special qualities of that substance. Any further subdivision of a molecule separates it into the atoms of which it is composed. Physical contact is necessary for the conduction of heat, and the conduction takes place from the region of higher temperature to the region of lower temperature. For example, if a person holds a bar of iron in his hand with one end of the bar in a fire, the heat passes by conduction from the fire into the end of the bar, then by conduction along the bar, and finally by conduction to the hand. In each case, the energy moves from a region of higher temperature to a region of lower temperature.

3H5. Thermal conductance. Suppose that two bars are held, one of iron and one of copper, of exactly the same size and temperature. If an end of each bar is placed in a fire at the same time, it will be noticed that heat reaches the hand through the copper bar much more quickly than it does through the iron bar. It is thus evident that some substances conduct heat more-readily than others. This characteristic of a substance is called its thermal conductance or heat conductance. The low thermal conductance of some substances is of great value in both heating and refrigerating, in preventing a flow of heat.

I. INSULATION OF HEAT

3I1. Need for insulation. It is comparatively easy to heat or cool articles or enclosed spaces. However, it is not so easy to keep them hot or cold very long. Heat constantly tends to flow from higher to lower temperature levels.

If it is desired that a substance or an

enclosed space be kept hot, it is necessary to prevent the heat already present from flowing out. If it is desired that a substance be kept cold, it is necessary to prevent heat from flowing in. Fortunately, this can be done, to a fairly successful extent, by making use of the low thermal conductance of certain substances.

3I2. Good conductors and poor conductors. Different substances vary greatly in heat conductance. In general, metals are good conductors, natural liquids are poor conductors, and gases very poor conductors. Nonmetallic solids are usually poor conductors. Poor conductors are also called heat insulators.

3I3. Insulators. Poor conductors include such substances as cork, wood, sawdust, paper, brick, fur, feathers, felt, animal wool, asbestos, glass, rubber, plastics, cotton, water, and dead air spaces.

Most solids that are poor conductors are also porous in nature (with important exceptions like glass, rubber, and the plastics), and the air pores, or air cells, are small in size. Much of the insulating quality of these substances results from the

3I5. Insulation of cold pipes. Low-temperature pipe lines must be thoroughly insulated to prevent heat from entering the refrigerant contained therein. The usual insulation is a cork composition molded into sections that fit snugly around the pipes and fittings. Other materials, such as rock wool and mineral wool, are also molded in the same way. Fittings in elude bends, elbows, and tees.

Before applying the cork covering, all pipe lines should be carefully cleaned and all rust scrubbed away to a clean metal surface with a stiff wire brush.

If possible, the hangers or braces that support the pipes should be placed around the outside of the covering. If the hangers are attached directly to the pipes, heat travels by conduction through them to the pipe. Moisture may also enter along such hangers and freeze, causing the covering to burst. When molded sections of covering are placed on pipes, the sections should be staggered and all end joints thoroughly coated with waterproof cement. Longitudinal joints should come at the top and bottom of pipes, and not at the sides. After the covering is placed properly, all seams

presence of in numerable tiny pockets of enclosed air, and from the fact that air is a poor conductor of heat. The air cells must be small; if they are not, the insulating quality is diminished, because the larger spaces of air permit heat to pass through by radiation and convection.

314. Low-temperature insulation. The requirements for low-temperature insulation are somewhat different from those for high-temperature insulation. Any water vapor present in the air tends to condense into liquid drops or film on a cold surface. This is commonly called sweating. This sweated water penetrates a porous insulating material and fills the air cells, thus greatly lessening its insulating ability. It may even freeze there, and ice is a poor insulator of heat. Insulating materials for use with refrigerating systems are therefore manufactured especially to resist the penetration of moisture and to be durable in the presence of conditions of high moisture.

should be rubbed flush and smooth with brine putty and the whole surface of the covering painted with asphalt paint.

Cold-water pipes are frequently insulated with fibrous materials, such as felted hair or various vegetable fibers. Such fibrous materials, when used for insulating, must be completely covered with canvas or similar fabric, and painted to make the covering waterproof.

316. Repair of cold pipe insulation. In the event of damage to the insulation covering a pipe, if molded sections are not available, use whatever materials may be at hand to prevent 1) the entrance of heat, and 2) the entrance of moisture. In general, this requires water proofing by whatever means may be available. Particular attention must be given to the seams.

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4
PRINCIPLES OF MECHANICAL REFRIGERATION

A. GENERAL EXPLANATION

4A1. Brief statement of principles. The mechanical refrigeration system used on board a submarine is a vapor refrigerating system. In this refrigerating process, the refrigerant passes alternately through its liquid and vapor states. Such a refrigerant, therefore, must have special qualities. It must boil at a low temperature and it must be able to change its state readily from liquid to vapor, and vice versa. Above all, it must be a safe refrigerant. Safety is more important in submarines than in other types of vessels.

In the liquid state, the refrigerant picks up heat from the substances or from the air in a space, and in so doing, vaporizes. The vapor carrying the excess heat is then transferred to another location where it discharges that heat, and, in so doing, reverts back to the liquid state.

The mechanical system in which the

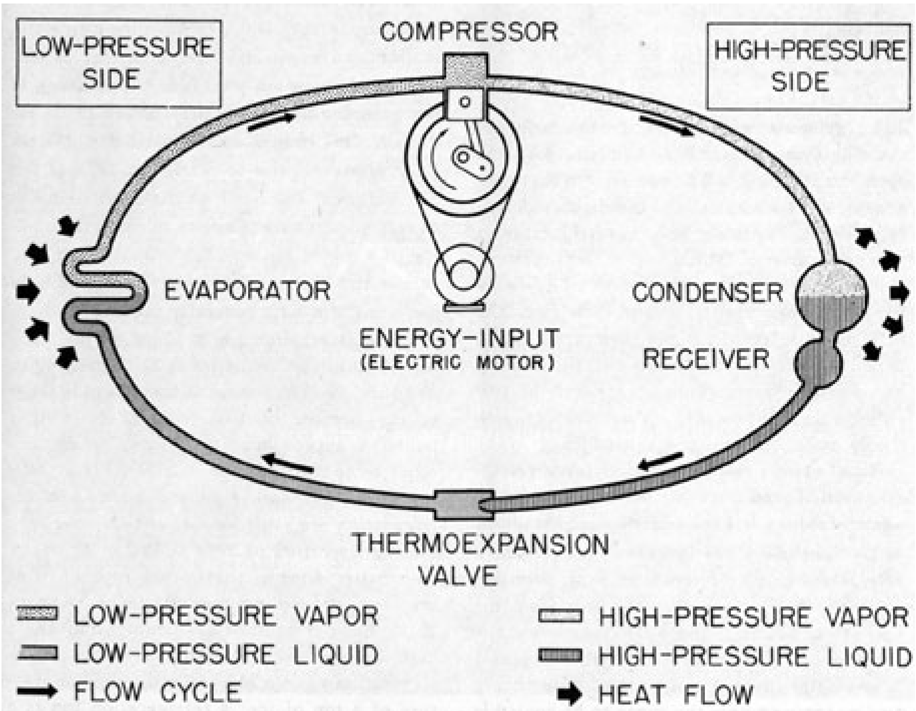


Figure 4-1. Schematic refrigeration cycle.

refrigerant is contained is a single airtight circuit of pipes and mechanisms through which the refrigerant is pumped continuously. The same quantity of the refrigerant is used over and over. This requires an input of energy which is supplied by an electric motor. The complete operation is called the refrigeration cycle, a schematic diagram of which is shown in Figure 4-1.

Figure 4-1 shows the disposition of the essential elements of the system for a complete refrigeration cycle. These elements include evaporator, compressor, condenser, receiver, and thermostatic expansion valve. The liquid refrigerant picks up heat and vaporizes in the evaporator. The vapor then goes to the compressor, where it is compressed to a pressure at which its temperature is above that of the water flowing through the condenser. The compressed vapor then goes to the condenser where sufficient heat is transferred to the water to cause the refrigerant vapor to condense. The condensed refrigerant, now a liquid, flows next to the receiver, and then through the thermostatic expansion valve to the evaporator. A detailed description of the cycle is given in Chapter 6.

B. TYPES OF REFRIGERANTS

4B1. Definition of a refrigerant. A refrigerant is a substance capable of carrying heat which is picked up at a low temperature level and is compressed to a high temperature, whereupon the heat can be removed by the condensing medium, which is either cold water or cold air.

4B2. Primary refrigerants. In the main circulating system described in Section 4A1, the refrigerant changes its state from a liquid to a vapor and back again, and is called a primary refrigerant. There are several refrigerants of this type, most of which boil at temperatures below the freezing point of water. They vary greatly in their properties and their cost. The refrigerant selected for any given installation depends upon the conditions therein. Among the primary refrigerants are: Freon are not used aboard a modern submarine.

4B4. Refrigeration ton, RT. Some unit of measurement by which to measure heat elimination and to specify the capacities of different refrigeration machines is necessary. It has been found that a fairly large unit is required. This unit is called, variously, the refrigeration ton, ton of refrigeration, and ton refrigeration. Inasmuch as the expression ton of refrigeration leads one to think of the making of a ton of ice, and has caused much con fusion, the term refrigeration ton is gradually becoming the most generally used.

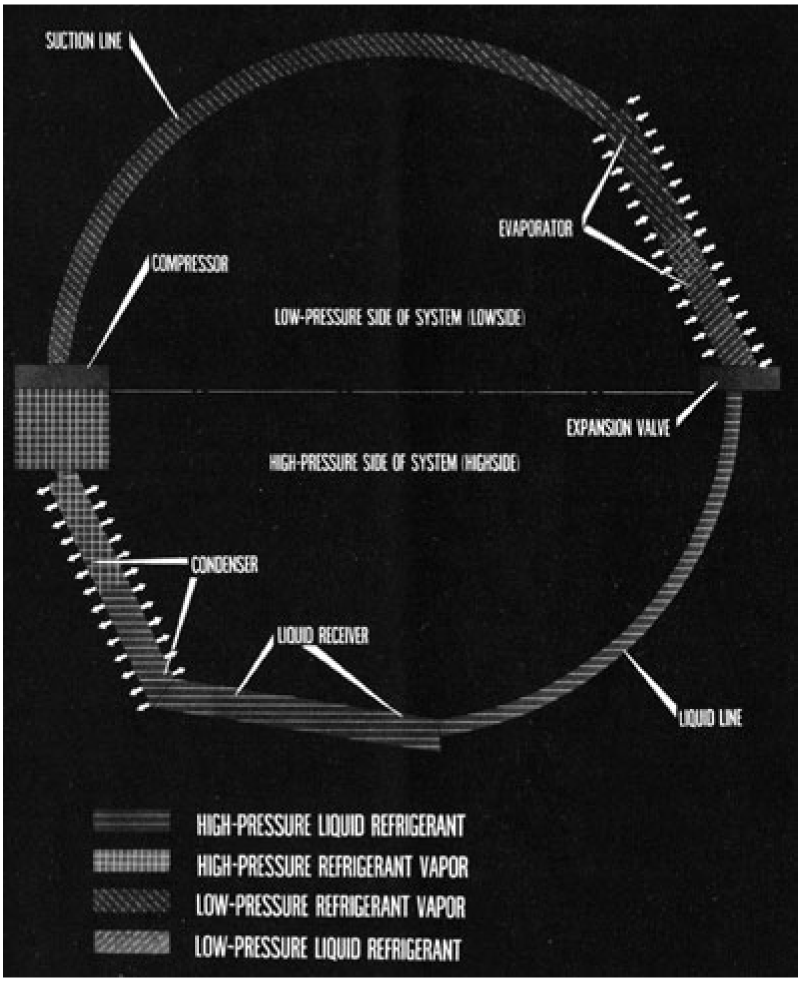
The refrigeration ton is based on the cooling effect of one ton of ice at 32 degrees F melting in 24 hours. The latent heat of fusion of ice (that is, the number of Btu

12 (dichlorodifiuoromethane), carbon dioxide, ammonia, sulfur dioxide, and others.

Naval vessels use only one primary refrigerant; dichlorodifluoromethane, the common name of which is Freon 12, or F-12 for short.

4B3. Secondary refrigerants. A secondary refrigerant usually consists of a salt solution, or brine, that is used to carry heat from the space to be cooled to the coils that contain the primary refrigerant. This type of refrigerant is generally used in large ice-manufacturing equipment, or where the space to be cooled is remote from the ice machine. Secondary refrigerants

required to melt 1 pound) is approximately 144 Btu. The number required to melt one ton is 2000 x 144 = 288,000 Btu. Hence, one standard commercial refrigeration ton is defined as the transfer in a cooling operation of 288,000 Btu in 24 hours. In smaller time periods, this rate of heat transfer for cooling would be the same as 12,000 Btu per hour, or 200 Btu per minute. It must be emphasized again that a ton of refrigeration has no reference to the manufacture of a ton of ice; a refrigeration ton is a rate of heat transfer, and not a weight.



NavPers 17022, Amphib 39

Figure 4-1a. Graphic diagram of mechanical refrigeration cycle.

5
FREON 12

A. SAFEST SHIPBOARD REFRIGERANT

5A1. Advantages of Freon 12. Freon 12 is, directly the result of a search for the perfect refrigerant, and it more nearly approaches that ideal than, any other so far discovered. The chemical name of Freon 12 is dichlorodifluoromethane. Its chemical symbol is $CC1_2F_2$, which means that it contains one part carbon, two parts chlorine, and two parts fluorine. In manufacturing Freon 12, fluorine is substituted for part of the chlorine in carbon tetrachloride, and the result is Freon 12, with byproducts. This substitution has the remarkable effect of lowering the boiling point by 120 degrees, At atmospheric pressure, Freon 12 boils at -21.66 degrees F and freezes at -311 degrees F. Its latent heat of vaporization at atmospheric pressure is about 72 Btu per pound.

Freon 12 has so many advantages that it is used almost universally on ships today. Its advantages are as follows:

1. It is a safe refrigerant.

2. It is nonflammable:

3. It is nonexplosive.

4. It is noncorrosive.

5. Its vapor is nontoxic in quantities up to 20 percent by 12. At the low-pressure point of its refrigeration cycle, it operates at pressures only slightly above atmospheric pressure, thus reducing the possibility of air entering the system in the event of leakage.

5A2. Disadvantages of Freon 12. Freon 12 has a few disadvantages, but they are far outweighed by its advantages. The disadvantages are:

1. While Freon 12 is nonflammable, it de composes in contact with an open flame at high temperature (1000 degrees F.), giving rise to phosgene, a highly toxic gas, and other decomposition products.

2. It is an excellent loosener of scale and dirt that may be left in or may get into the system. Such material is carried around in the system and is finally deposited in the strainers. However, some damage may also result during its journey. In installation or repair, great care should be taken to prevent the entry of any foreign matter into the system.

3. It does not mix with water. One important reason why air must be kept out of the system is that air almost always contains some water vapor. This water vapor tends to condense and freeze, thus interfering with correct operation,

volume.

6. It will not harm foods, fabrics, furs, and so forth.

7. It is odorless in concentrations of 20 percent or less by volume. In high concentrations if has a slight odor of carbon tetrachloride, of which it is a derivative.

8. It is tasteless.

Additional advantages for operation:

9. It has a low boiling point, -21.66 degrees F atmospheric pressure.

10. It acts rapidly in freezing other substances; its latent heat at 5 degrees F is 69.47 Btu, or much lower than that of other refrigerants.

11. At the high-pressure point of its refrigeration cycle, it operates at comparatively low pressure; hence, the equipment does not require heavy mechanical construction.

and damaging various valves and other parts of the system,

4. It is absorbed by lubricating oil.

5. SPECIAL NOTE. Liquid Freon 12 must not be spilled on the skin, and extreme care must be taken to prevent even tiny drops from getting into the eyes. The extreme cold produced by Freon 12, nearly 22 degrees below zero Fahrenheit, is such that even a tiny drop may cause the moisture in the tissue of the eyeball near it to freeze, and possibly result in serious injury to the eye. Moreover, because of the readiness with which lubricating oil absorbs Freon 12, there is always some Freon 12 in the oil of refrigerating and air conditioning systems. It is advisable not to

PROPERTIES OF SATURATED FREON VAPOR
A. S. R. E. STANDARD

Temp.	Pressure		Volume		Density		Heat content from -40 degrees			Entropy from -40 degrees		Temp.
Deg. F t	Abs. lb./in.^{2} p	Gage lb./in.^{2} p_d	Liquid ft.^{3}/lb. v_f	Vapor ft.^{3}/lb. v_g	Liquid lb./ft.^{3} $1/v_f$	Vapor lb./ft.^{3} $1/v_g$	Liquid Btu./lb. h_f	Latent Btu./lb. h	Vapor Btu./lb. h_g	Liquid Btu./lb. deg. F. s_f	Vapor Btu./lb. deg. F. s_g	Deg. F. t
-40	9.32	10.92*	0.0106	3.991	94.58	0.2557	0	73.50	73.50	0	0.17517	-40
-38	9.82	9.91*	.0106	3.727	94.39	.2683	0.40	73.34	73.74	0.00094	.17490	-38
-36	10.34	8.87*	.0106	3.553	94.20	.2815	0.81	73.17	73.98	.00188	.17463	-36
-34	10.87	7.80*	.0106	3.389	93.99	.2951	1.21	73.01	74.22	.00282	.17438	-34
-32	11.43	6.66*	.0107	3.234	93.79	.3092	1.62	72.84	74.46	.00376	.17412	-32
-30	12.02	5.45*	0.0107	3.088	93.59	0.3238	2.03	72.67	74.70	0.00471	0.17387	-30
-28	12.62	4.23*	.0107	2.950	93.39	.3390	2.44	72.50	74.94	.00565	.17364	-28

-26	13.26	2.93*	.0107	2.820	93.18	.3546	2.85	72.33	75.18	.00659	.17340	-26
-24	13.90	1.63*	.0108	2.698	92.98	.3706	3.25	72.16	75.41	.00753	.17317	-24
-22	14.58	0.24*	.0108	2.583	92.78	.3871	3.66	71.98	75.64	.00846	.17296	-22
-20	15.28	0.58	0.0108	2.474	92.58	0.4042	4.07	71.80	75.87	0.00940	0.17275	-20
-18	16.01	1.31	.0108	2.370	92.38	.4219	4.48	71.63	76.11	.01033	.17253	-18
-16	16.77	2.07	.0108	2.271	92.18	.4403	4.89	71.45	76.34	.01126	.17232	-16
-14	17.55	2.85	.0109	2.177	91.97	.4593	5.30	71.27	76.57	.01218	.17212	-14
-12	18.37	3.67	.0109	2.088	91.77	.4789	5.72	71.09	76.81	.01310	.17194	-12
-10	19.20	4.50	0.0109	2.003	91.57	0.4993	6.14	70.91	77.05	0.01403	0.17175	-10
-8	20.08	5.38	.0109	1.922	91.35	.5203	6.57	70.72	77.29	.01496	.17158	-8
-6	20.98	6.28	.0110	1.845	91.14	.5420	6.99	70.53	77.52	.01589	.17140	-6
-4	21.91	7.21	.0110	1.772	90.93	.5644	7.14	70.34	77.75	.01682	.17123	-4
-2	22.87	8.17	.0110	1.703	90.72	.5872	7.83	70.15	77.98	.01775	.17107	-2
0	23.87	9.17	0.0110	1.637	90.52	0.6109	8.25	69.96	78.21	0.01869	0.17091	0
2	24.89	10.19	.0110	1.574	90.31	.6352	8.67	69.77	78.44	.01961	.17075	2
4	25.96	11.26	.0111	1.514	90.11	.6606	9.10	69.57	78.67	.02052	.17060	4
5**	26.51	11.81	.0111	1.485	90.00	.6735	9.32	69.47	78.79	.02097	.17052	5**
6	27.05	12.35	.0111	1.457	89.88	.6864	9.53	69.37	78.90	.02143	.17045	6
8	28.18	13.48	.0111	1.403	89.68	.7129	9.96	69.17	79.13	.02235	.17030	8
10	29.35	14.65	0.0112	1.351	89.45	0.7402	10.39	68.97	79.36	0.02328	0.17015	10
12	30.56	15.86	.0112	1.301	89.24	.7687	10.82	68.77	79.59	.02419	.17001	12
14	31.80	17.10	.0112	1.253	89.03	.7981	11.26	68.56	79.82	.02510	.16987	14
16	33.08	18.38	.0112	1.207	88.81	.8288	11.70	68.35	80.05	.02601	.16974	16
18	34.40	19.70	.0113	1.163	88.58	.8598	12.12	68.15	80.27	.02692	.16961	18
20	35.75	21.05	0.0113	1.121	88.37	0.8921	12.55	67.94	80.49	0.02783	0.16949	20
22	37.15	22.45	.0113	1.081	88.13	.9251	13.00	67.72	80.72	.02873	.16938	22
24	38.58	23.88	.0113	1.043	87.91	.9588	13.44	67.51	80.95	.02963	.16926	24
26	40.07	25.37	.0114	1.007	87.68	.9930	13.88	67.29	81.17	.03053	.16913	26
28	41.59	26.89	.0114	0.973	87.47	1.028	14.32	67.07	81.39	.03143	.16900	28
30	43.16	28.46	0.0115	0.939	87.24	1.065	14.76	66.85	81.61	0.03233	0.16887	30
32	44.77	30.07	.0115	.908	87.02	1.102	15.21	66.62	81.83	.03323	.16876	32
34	46.42	31.72	.0115	.877	86.78	1.140	15.65	66.40	82.05	.03413	.16865	34
36	48.13	33.43	.0116	.848	86.55	1.180	16.10	66.17	82.27	.03502	.16854	36
38	49.88	35.18	.0116	.819	86.33	1.221	16.55	65.94	82.49	.03591	.16843	38
40	51.68	36.98	0.0116	0.792	86.10	1.263	17.00	65.71	82.71	0.03680	0.16833	40
42	53.51	38.81	.0116	.767	85.88	1.304	17.46	65.47	82.93	.03770	.16823	42
44	55.40	40.70	.0117	.742	85.66	1.349	17.91	65.24	83.15	.03859	.16813	44
46	57.35	42.65	.0117	.718	85.43	1.393	18.36	65.00	83.36	.03948	.16803	46
48	59.35	44.65	.0117	.695	85.19.	1.438	18.82	64.74	83.57	.04037	.16794	48

* Inches of mercury below one atmosphere.

** Standard ton temperatures.

PROPERTIES OF SATURATED FREON VAPOR
A. S. R. E. STANDARD

Temp.	Pressure	Volume	Density	Heat content	Entropy from	Temp.

							from -40 degrees			-40 degrees		
Deg. F t	Abs. lb./in.^{2} p	Gage lb./in.^{2} p_d	Liquid ft.^{3}/lb. v_f	Vapor ft.^{3}/lb. v_g	Liquid lb./ft.^{3} $1/v_f$	Vapor lb./ft.^{3} $1/v_g$	Liquid Btu./lb. h_f	Latent Btu./lb. h	Vapor Btu./lb. h_g	Liquid Btu./lb. deg. F. s_f	Vapor Btu./lb. deg. F. s_g	Deg. F. t
50	61.39	46.69	0.0118	0.673	84.94	1.485	19.27	64.51	83.78	0.04126	0.16785	50
52	63.49	48.79	.0118	.652	84.71	1.534	19.72	64.27	83.99	.04215	.16776	52
54	65.63	50.93	.0118	.632	84.50	1.583	20.18	64.02	84.20	.04304	.16767	54
56	67.84	53.14	.0119	.612	84.28	1.633	20.64	63.77	84.41	.04392	.16758	56
58	70.10	55.40	.0119	.593	84.04	1.686	21.11	63.51	84.62	.04480	.16749	58
60	72.41	57.71	0.0119	0.575	83.78	1.740	21.57	63.25	84.82	0.04568	0.16741	60
62	74.77	60.07	.0120	.557	83.57	1.795	22.03	62.99	85.02	.04657	.16733	62
64	77.20	62.50	.0120	.540	83.34	1.851	22.49	62.73	85.22	.04745	.16725	64
66	79.67	64.97	.0120	.524	83.10	1.909	22.95	62.47	85.42	.04833	.16717	66
68	82.24	67.54	.0121	.508	82.86	1.968	23.42	62.20	85.62	.04921	.16709	68
70	84.82	70.12	0.0121	0.493	82.60	2.028	23.90	61.92	85.82	0.05009	0.16701	70
72	87.50	72.80	.0121	.479	82.37	2.090	24.37	61.65	86.02	.05097	.16693	72
74	90.20	75.50	.0122	.464	82.12	2.153	24.84	61.38	86.22	.05185	.16685	74
76	93.00	78.30	.0122	.451	81.87	2.218	25.32	61.10	86.42	.05272	.16677	76
78	95.85	81.85	.0123	.438	81.62	2.284	24.80	60.81	86.61	.05395	.16669	78
80	98.76	84.06	0.0123	0.425	81.39	2.353	26.28	60.52	86.80	0.05446	0.16662	80
82	101.7	87.00	.0123	.413	81.12	2.423	26.76	60.23	86.99	.05534	.16655	82
84	104.8	90.1	.0124	.401	80.87	2.495	27.24	59.94	87.18	.05621	.16648	84
86**	107.9	93.2	.0124	.389	80.63	2.569	27.72	59.65	87.37	.05708	.16640	86**
88	111.1	96.4	.0124	.378	80.37	2.645	28.21	59.35	87.56	.05795	.16632	88
90	114.3	99.6	0.0125	0.368	80.11	2.721	28.70	59.04	87.74	0.05882	0.16624	90
92	117.7	103.0	.0125	.357	79.86	2.799	29.19	58.73	87.92	.05969	.16616	92
94	121.0	106.3	.0126	.347	79.60	2.880	29.68	58.42	88.10	.06056	.16608	94
96	124.5	109.8	.0126	.338	79.32	2.963	30.18	58.10	88.28	.06143	.16600	96
98	128.0	113.3	.0126	.328	79.06	3.048	30.67	57.78	88.45	.06230	.16592	98
100	131.6	116.9	0.0127	0.319	78.80	3.135	31.16	57.46	88.62	0.06316	0.16584	100
102	135.3	120.6	.0127	.310	78.54	3.224	31.65	57.14	88.79	.06403	.16576	102
104	139.0	124.3	.0128,	.302	78.27	3.316	32.15	56.80	88.95	.06490	.16568	104
106	142.8	128.1	.0128	.293	78.00	3.411	32.65	56.46	89.11	.06577	.16560	106
108	146.8	132.1	.0129	.285	77.73	3.509	33.15	56.12	89.27	.06663	.16551	108
110	150.7	136.0	0.0129	0.277	77.46	3.610	33.65	55.78	89.43	0.06749	0.16542	110
112	154.8	140.1	.0130	.269	77.18	3.714	34.15	55.43	89.58	.06836	.16533	112
114	158.9	144.2	.0130	.262	76.89	3.823	34.65	55.08	89.73	.06922	.16524	114
116	163.1	148.4	.0131	.254	76.60	3.934	35.15	54.72	89.87	.07008	.16515	116
118	167.4	152.7	.0131	.247	76.32	4.049	35.65	54.36	90.01	.07094	.16505	118
120	171.8	157.1	0.0132	0.240	76.02	4.167	36.16	53.99	90.15	0.07180	0.16495	120
122	176.2	161.5	.0132	.233	35.72	4.288	36.66	53.62	90.28	.07266	.16484	122
124	180.8	166.1	.0133	.277	75.40	4.413	37.16	53.24	90.40	.07352	.16473	124
126	185.4	170.7	.0133	.220	75.10	4.541	37.67	52.85	90.52	.07437	.16462	126
128	190.1	175.4	.0134	.214	74.78	4.673	38.18	52.46	90.64	.07522	.16450	128
130	194.9	180.2	0.0134	0.208	74.46	4.808	38.69	52.07	90.76	0.07607	0.16438	130

132	199.8	185.1	.0135	.202	74.13	4.948	39.19	51.67	90.86	.07691	.16425	132
134	204.8	190.1	.0135	.196	73.81	5.094	39.70	51.26	90.96	.07775	.16411	134
136	209.9	195.2	.0136	.191	73.46	5.247	40.21	50.85	91.06	.07858	.16396	136
138	215.0	200.3	.0137	.185	73.10	5.405	40.72	50.43	91.15	.07941	.16380	138
140	220.2	205.5	0.0138	0.180	72.73	5.571	41.24	50.00	91.24	0.08024	0.16363	140

allow such contaminated oil to remain on the hands. Never touch the face with oily hands, especially near the eyes.

a. REMEDIES. If Freon 12 should come in contact with the eyes, the following first aid treatment should be given immediately:

1) Do not rub the eyes.

2) Put drops of sterile mineral oil in the eyes as an irrigant; if no sterile oil is available, use any clean oil.

3) If any irritation at all continues, the eyes should be washed with either a weak boric acid solution or a sterile salt solution, not exceeding 2 percent sodium chloride (table salt).

4) The person should receive medical attention at once.

B. SAFETY PRECAUTIONS

5B1. Keep Freon 12 out of eyes. Human beings are so constituted that familiarity with danger causes a gradual loss of consciousness of it. But remember that this does not cause Freon 12 to lose its freezing power. Always wear goggles in charging, testing, or repairing a Freon 12 system (see remedies in Section 5A2a).

5B2. Keep lubricating oil used in plant away from eyes. Invariably some Freon 12 is dissolved in lubricating oil used in the system. If such oil comes in contact with the eyes it is likely to cause damage by freezing the tissues.

5B3. Do not drop Freon 12 cylinders. Care must be taken not to drop a Freon 12 cylinder, either accidentally, or when putting it down. A fall or hard

5B4. Do not fill Freon 12 cylinders beyond 80 percent capacity. The pressure-temperature relationship of Freon 12 is so positive that a rise in temperature always means a corresponding increase in pressure. Therefore, always leave at least 20 percent of the Freon 12 cylinder unfilled in order to provide a cushioning effect in case the pressure should increase.

5B5. Keep open flame away from Freon 12 cylinders. Open flame must be kept away from Freon 12 cylinders and they must not be heated above 120 degrees F. The safety plugs on these cylinders melt at 157 degrees F.

5B6. Never attempt to taste Freon 12. Since its freezing power is extremely high, never attempt to taste Freon 12.

bump may cause damage to the valve, or change the pressure within.

C. FREON 12 CYLINDERS

5C1. Storing Freon 12. Freon 12 is transported and stored in cylinders, often called bottles. In the cylinders, Freon 12 is a liquid (with some gas also present), because, although it vaporizes at -21.66 degrees F under atmospheric pressure, it is charged into the cylinder under a pressure of 70 to 75 psi, and under this pressure Freon 12 remains in the liquid state. This particular pressure is used because it corresponds to a temperature of 70 degrees to 74 degrees F, which is ordinary room temperature.

Standard Navy Freon 12 cylinders contain 50 pounds of liquid Freon 12. The cylinders weigh 35 pounds when empty, and 85 pounds when containing the proper amount of Freon 12. All Navy Freon 12 cylinders are marked for identification, with a black body and a yellow neck. The test pressure for Freon 12 cylinders is 350 pounds. The bottoms of the cylinders are concave, so that in case of accident, they push out and keep the cylinder from blowing up.

D. THE PROPERTIES OF FREON 12

5D1. Table of Freon 12 properties. The tables on pages 19 and 20 list the various properties of Freon 12 that may be needed in refrigeration work or in the operation of systems for temperatures ranging from -40 degrees to 140 degrees Fahrenheit.

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6
REFRIGERATION CYCLE OF FREON 12

A. GENERAL THEORY

6A1. Main elements in the cycle. In Section 4A1, a brief statement of the principles of mechanical refrigeration was given. In this section, a detailed explanation of the full cycle of operations is presented.

In the circuit of mechanisms through which the refrigerant Freon 12 flows, there are five main elements. Starting from the point where we wish to remove heat, they are: 1) evaporator, 2) compressor, 3) condenser, 4) liquid receiver, and 5) expansion valve. In addition, various control and safety devices are connected into the circuit.

6A2. The heat pump. The refrigerant cycle is more easily understood when it is compared to the flow of water. Everyone knows that water naturally flows downhill that is, it always flows from a higher level to a lower level under the pull of gravity. If it is necessary to raise water from a lower level to a higher one, it must be either carried up or pumped up through a pipe. In either case, work is done on the water, or in other words, energy is used. In the same way, heat always flows naturally from a region of higher temperature to a region of lower temperature. If the desire is to move heat from a region of lower temperature to a region of higher temperature, it is necessary to do work on it-to use energy. Therefore, the compressor in the cycle might be called a heat pump by means of which heat is pumped up-thermometer.

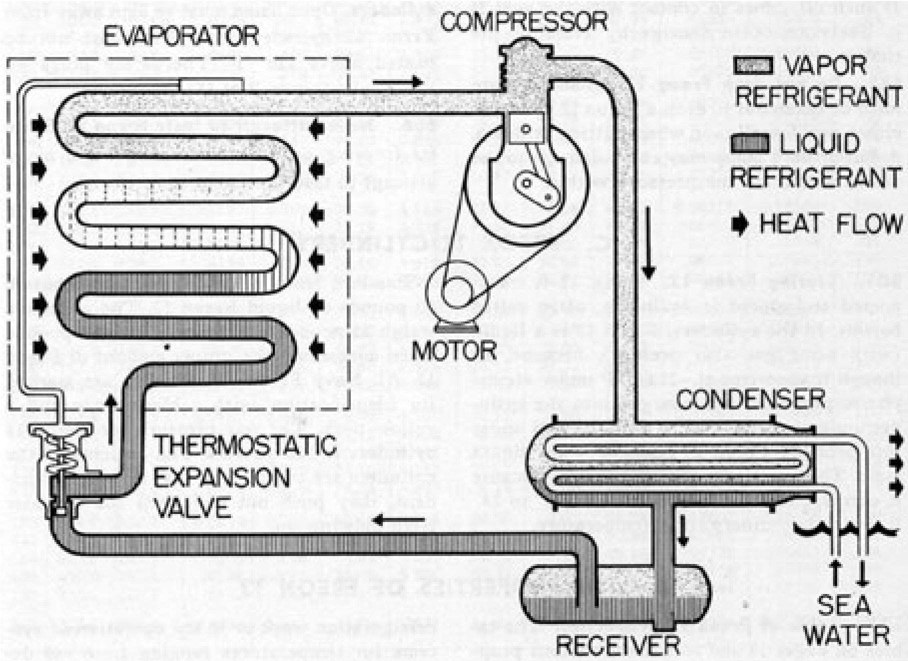


Figure 6-1. Mechanical refrigeration cycle.

In mechanical refrigeration, the compressor is, in effect a heat pump. In the compressor, work is done on the refrigerant by means of an electric motor which turns the compressor shaft, making the pistons move back and forth in the cylinders, The pistons compress the low-pressure vapor entering the cylinders to a high-pressure vapor.

Since, according to the law of conservation of energy, energy cannot be destroyed but can only be altered in form, it must appear somewhere. The input of energy has come through the electric motor by means of the crankshaft and pistons, and by their motion it is transferred to the vapor by increase in pressure. In that vapor, the input energy can appear only in the form of heat, which results in a rise in the temperature of the vapor.

and its temperature therefore rises, as explained in Section 6A2.

6A6. Through the condenser. The freon vapor, now at high pressure, passes next into the condenser, where the vapor passes around the tubes through which sea water is continuously pumped. Here the excess heat flows by conduction through the walls of the tubing from the higher temperature vapor to the relatively lower temperature sea water, and here the unwanted heat leaves the primary refrigerating system and is finally carried away. The excess heat thus flowing out of the vapor is both superheat and latent heat of vaporization, and therefore the vapor condenses back to the liquid state. The liquid Freon 12 is now at high pressure and high temperature.

6A7. Through the receiver. The liquid Freon 12 goes now into the receiver, or tank. The liquid in this receiver acts as a seal between the vapor in the condenser and the

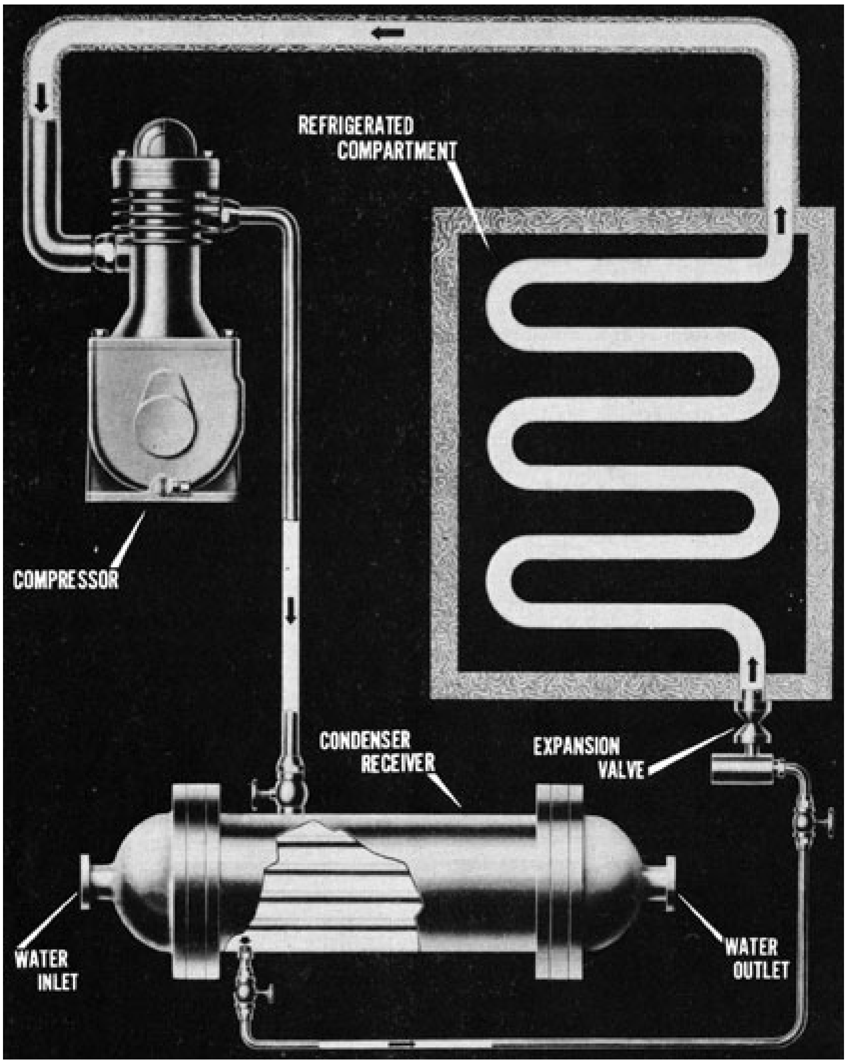
6A3. The Freon 12 cycle. Let us follow through the cycle of operation, starting from the point where the heat to be removed enters the refrigerating system. This point is the location of the evaporator. Figure 6-1 is a highly simplified diagram of the main mechanical elements in the cycle.

6A4. Through the evaporator. The evaporator is simply a bank, or coil, of copper tubing. It is filled with Freon 12 at low pressure and temperature. Heat flowing from the air spaces or articles to be cooled into the coil causes the liquid Freon 12 to boil. Boiling can take place only as a result of the entrance into the liquid of its latent heat of vaporization, and this latent heat can come only from the surrounding substances. Hence the temperatures of the surrounding substances are lowered. The latter portion of the evaporator coil is therefore filled with Freon 12 vapor at low-pressure, carrying with it the unwanted heat.

6A5. Through the compressor. This vapor does not remain in the evaporator. The compressor is operating and the suction which it exerts (on the evaporator side of its circuit) pulls the heat-laden vapor out of the evaporator, through the piping, and into the compressor. The compressor, therefore, is the mechanism that keeps the Freon 12 in circulation through the system. In the compressor cylinders, the Freon 12 is compressed from a low-pressure vapor to a high-pressure vapor, liquid as it flows into the next element, the expansion valve, so that the liquid Freon 12 in the expansion valve may be free of vapor. Remember that the whole system is a single circuit in which the fluid flows around and around.

6A8. Through the expansion valve. The liquid Freon 12 enters the expansion valve at high-pressure and high temperature. This valve regulates the flow of the refrigerant into the evaporator. The liquid outlet from this expansion valve is a small opening called the orifice. In passing through the orifice, the liquid is subjected to a throttling action, and there is dispersed into a finely divided form. The Freon 12 is now again a liquid at low pressure and low temperature, and is again entering the evaporator, its cycle completed, and ready to be repeated. Every part of the cycle is, of course, taking place simultaneously and continuously throughout the circuit as long as refrigeration is wanted. The entire operation is automatic.

6A9. Low-pressure side. That portion of the cycle from the orifice of the expansion valve through the evaporator up to and including the intake side of the compressor cylinders is called the low-pressure side. The dividing



NavPers 17130, E-39, E-134

Figure 6-1a. Diagram of principle of refrigeration.

line between the low- and high-pressure sides is the discharge valve of the compressor.

6A10. High-pressure side. The remainder of the cycle from the discharge valve of the compressor through the condenser, receiver, and expansion valve to its orifice is called the high-pressure side. The dividing line between the high- and low-pressure sides is the thermostatic expansion valve.

B. HEAT ACTION IN THE VARIOUS ELEMENTS OF THE CYCLE

6B1. In the evaporator. The evaporator is the point at which the heat from articles or air to be cooled enters the refrigerating system. This heat causes the

4. It compresses the low-pressure vapor to a high-pressure vapor, whereby the condensation point is raised to such a degree that the

Freon 12 to boil, and the rapid boiling carries tiny droplets of the liquid into the vapor. The Freon 12 at this stage is therefore a wet vapor. However, the design of the system is such that a little more heat is admitted to the evaporator than is required to produce saturated vapor. An additional superheat (about ten degrees) also enters the vapor in the evaporator. This super heat is kept fairly constant by the expansion valve. The superheat eliminates the wetness of the vapor, and prevents excessive frosting of lines and compressor and the possibility of carrying liquid over into the compressor. It also increases the efficiency of operation.

6B2. In the compressor. So far, the temperature of the boiling Freon 12 has not been raised (except for the slight superheat), because the heat entering it in the evaporator is latent heat of vaporization which serves only to turn the liquid into a vapor. But in the compressor, after the vapor has passed through the intake, or suction, valve, it is sealed off from its originating liquid. The heat now entering the vapor by the compression in the compressor, or heat pump, is more than sufficient to raise its temperature to the boiling point that corresponds to the new higher pressure. Thus the high-pressure vapor is further superheated.

6B3. Purposes of the compressor. The compressor serves several purposes

1. By suction, it removes the vapor from the evaporator as vapor can be condensed by the available cooling water.

5. It produces a difference of pressure on the two sides of the expansion valve, thereby causing a steady and positive flow of the refrigerant through that valve.

6B4. Necessity for the compressor. The compressor is an essential part of every mechanical refrigerating system. The question is often asked: Why is it necessary to compress refrigerants? Fundamentally, the reason is this: All the liquids used as refrigerants possess the peculiar property of boiling at low temperatures under atmospheric pressure. If one of these liquids were in an uncovered dish in the open air, it would boil briskly without any fire under it. Even on a cold day, the mere heat in the air is enough to make it boil. It was seen in Section 3D6, that the boiling point of a liquid varies with the pressure on it. By confining a liquid refrigerant in an airtight container (a refrigerating system is such an airtight container), we can increase or decrease the pressure on the liquid and thus place its boiling temperature at any degree we desire. By increasing the pressure on a vapor, we cause its condensation point to rise.

Now the refrigerant liquid in the evaporator has boiled at a low temperature. This low temperature vapor must give up its excess heat and condense back to the liquid state before it can be used again. Another such liquid cannot be used a second time for this purpose, for that would need still another, and so on endlessly. It is, necessary to use an easily available

rapidly as it is formed so that there is always room for more vapor.

2. The steady suction tends to maintain a practically constant pressure in the evaporator; hence, the temperature of the refrigerant therein remains fairly constant.

3. It keeps fluid circulating in the system, thus maintaining continuous refrigeration.

fluid, such as air or water. But the ordinary temperatures of water or air are considerably above the condensation temperature of the vapor. Fortunately, when a vapor is compressed, its temperature rises. Therefore,

the vapor is compressed so that its temperature rises to such a degree above the ordinary temperature of the available water that the heat can transfer (in the condenser) from the now higher-temperature vapor to the water.

6B5. In the condenser. The excess heat enters the refrigerant while it is in the evaporator. Since the refrigerating system is a continuous circuit in which a given quantity of Freon 12 flows around and around, it is necessary to remove this excess heat before it can return to the evaporator. The condenser is the point at which this heat is removed.

In the condenser, the refrigerant passes around the tubes through which sea water is pumped. A fresh supply of sea water is continuously pumped through, and is not used again as is the primary refrigerant.

The unwanted heat transfers by conduction through the walls of the tubes from the refrigerant remains constant while the latent heat is departing during condensation. The condensed liquid, in the bottom of the condenser shell or tank, is not in contact with the entering section of the tubing through which the water flows. The heat in the refrigerant liquid is now sensible heat and therefore it drops again in temperature by a small additional amount. The whole operation within the condenser is a constant-pressure process.

a. Necessity for subcooling in the condenser. Subcooling, or lowering the temperature of the liquid refrigerant below its saturation, or boiling, point, is essential before it reaches the expansion valve. This subcooling is necessary to insure that vapor mist or vapor bubbles are not contained in the condensed liquid. If the condensed liquid were allowed to remain at its saturation temperature probably only vapor bubbles would be present, either as a result of being carried uncondensed from the compressor vapor, or as a result of

vapor to the sea water. More heat is discharged here than enters the refrigerant in the evaporator, for extra heat equaling the work done upon the vapor enters the vapor while it is being compressed.

It should be remembered that the temperature of the vapor, when it gets into the condenser, depends upon the temperature of the cooling medium, that is, the sea water. The compressor must produce a pressure on the vapor always high enough to make the vapor condense at the temperature in the condenser. Therefore; the condensing temperature that exists in the condenser determines the minimum discharge pressure of the compressor.

Naturally, the sea water inside the condenser does not remain at the same temperature. The heat leaving the vapor enters the water, and the water temperature rises. How ever, the continuous flow of water through the tube prevents this rise from getting too high. Actually the rise within the condenser is only a few degrees.

The heat transfer inside the condenser, therefore, is as follows: First the temperature of the vapor drops as the superheat leaves it. When it reaches the condensation point corresponding to the pressure, the vapor becomes a saturated vapor, and as such, if further heat is removed, it must condense. The temperature some slight evaporation in the line from the receiver to the expansion valve. Subcooling in the condenser prevents this possibility.

1. The orifice in the expansion valve is designed to pass the correct amount of liquid refrigerant to furnish the desired cooling. If vapor mist is mixed with the liquid, a smaller amount of liquid passes through the expansion valve, and the system cannot produce its full rate of refrigeration.

2. Refrigeration is produced only by the alternate evaporation and condensation of the refrigerant. If any vapor passes around the cycle uncondensed, it produces no refrigeration, and the energy used in pumping it through the system is wasted.

Thus it is evident that the subcooling in the condenser plays a most important part in the efficient operation of the system.

6B6. In the receiver. No heat action takes place within the receiver, that is, the receiver plays no part in the heat cycle. It serves as a momentary storage for the liquid refrigerant that leaves the condenser, and as a seal between the vapor in the condenser and the liquid as it flows into the expansion valves. In some types of condensers, the bottom part of the shell or tank is used as a receiver.

6B7. In the thermostatic expansion valve. The purposes of this valve are 1) to control the quantity of liquid refrigerant passing into the evaporators; 2) to maintain a constant pressure on the refrigerant so that the super heat is held practically constant regardless of the suction pressure; 3) to disperse the liquid; and 4) to prevent the liquid from surging toward the compressor. The total heat present remains constant.

a. Theory of operation. Consider a refrigerant evaporator in an air-conditioning unit operating with Freon 12 at 37 psi suction pressure. The Freon 12 temperature at saturation at 37 psi is 40 degrees. As long as any liquid exists at this suction pressure, the temperature remains at 40 degrees.

Freon 12 moving along within a coil absorbs heat from the air outside the coil until (B, Figure 6-2) it has absorbed its latent heat of evaporation. At this point all the liquid has evaporated and the vapor is saturated. Any additional heat absorbed from the surrounding air raises the temperature of the vapor but the pressure remains at 37 psi. When the suction gas or vapor reaches the point of the thermal bulb attachment (C), it is superheated according to the thermal valve setting; for example, 10 degrees.

Neglecting heat transfer loss from the suction line to the thermal bulb, the temperature of the liquid Freon 12 within the bulb is 50 degrees, the temperature of the suction gas at this point. The pressure within

b. Thermostatic expansion valve action. If the superheat in the suction gas increases, as in the case of an increase in load, the thermal bulb temperature and its corresponding pressure increase, exerting a greater pressure on the diaphragm. This causes the valve to open to allow a sufficient increase in flow of refrigerant to restore the superheat to 10 degrees. If the superheat decreases because of a falling off in the load, the pressure in the thermal bulb, and consequently, in the power element, decreases and tends to close the valve. The flow of refrigerant is throttled enough to increase the superheat to 10 degrees. Thus, it is evident that the function of the thermostatic expansion valve is twofold: 1) automatic expansion control, and 2) prevention of the liquid refrigerant from surging back to the compressor.

Close control of superheat results in the greatest coil efficiency. However, superheat should never be maintained below 5 degrees because of the danger of the liquid refrigerant surging back to the compressor. Nor should a coil be operated with superheat in excess of 15 degrees because of the inefficiency of operation beyond that point.

the bulb, and consequently within the power assembly, is 46.7 psi (P_1). This force tends to push the valve diaphragm down, opening the valve. Opposing this force is the pressure, 37 psi (P_2), with the evaporator at 40 degrees evaporator temperature, and the force (P_S) exerted by the spring on the diaphragm. To keep the valve in equilibrium at 10 degrees superheat, this spring is externally adjusted to exert a force of 9.7 psi on the diaphragm.

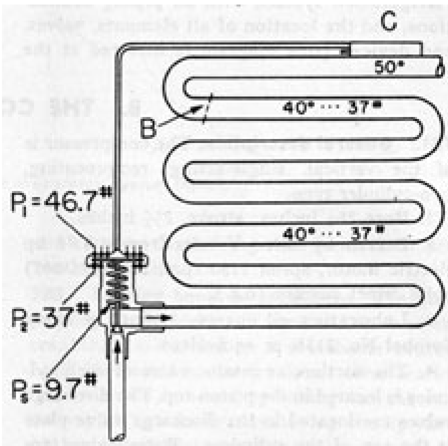


Figure 6-2. Superheat action In evaporator.

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7
DETAILS OF REFRIGERATION SYSTEM

A. DESCRIPTION OF PLANT

7A1. Equipment on submarines. The cooling equipment of submarines consists of two separate systems, one for refrigeration proper, and the other for air-conditioning. The refrigeration plant is described here. The air-conditioning plant is described in Chapters 13 to 20 inclusive.

7A2. The refrigeration plant. The capacity of the refrigeration plant is one-half refrigeration ton when operating at 460 rpm with 5 gallons of water at 85 degrees F per minute circulating through the condenser, and a suction pressure corresponding to an evaporation temperature of -5 degrees F. The system consists of the main elements connected to a circuit by piping, with various valves, gages, and controls necessary for automatic operation. Each item is described in detail later, with illustrations showing construction or operation. In addition, Figure 7-1 shows the complete refrigeration system, with all piping connections, and the location of all elements, valves, and devices (this diagram is inserted at the end of the book). The main elements and accessories are as follows:

1. One compressor, York-Navy Freon 12, enclosed single-acting vertical, two cylinders, 2 5/8-inch bore x 2 1/2-inch stroke.

2. One condenser, York-Navy Freon 12, horizontal shell-and-tube 4-pass, 6 9/16 x 30 inches.

3. One receiver, York-Navy Freon 12, 6 x 36 inches.

4. One Kramer Trenton Model 71L ice cuber in a Victor insulated cabinet.

5. One water cooler. This is not an integral part of the refrigeration system. It consists of a pipe leading out of the water storage tank into the cool room where in a few coils it chills the water before it goes out to the scuttlebutts.

6. Two evaporators (see Figure 7-2). The evaporators consist of the main refrigerant piping coiled back and forth on the overhead of the insulated boxes to provide a large area of cooling surface. One evaporator is in the cool room and the other in the refrigeration room.

B. THE COMPRESSOR

7B1. General description. The compressor is of the vertical, single-acting, reciprocating, two-cylinder type.

1. Bore 2 5/8 inches; stroke, 2 1/2 inches.

2. Driven by three V-belts from a 1.75 hp electric motor, speed 1750 rpm, 250 (175-345) volts direct current (d.c.).

3. Lubricating oil charge, 5 pints of Navy Symbol No. 2135, or equivalent.

4. The suction, or intake, valve of each cylinder is located in the piston top. The discharge valves are located in the discharge valve plate at the top of the cylinders. These valves are of the flex-action diaphragm type and are easily accessible. The tops and upper portion of the sides of the cylinders are finned for air-cooling.

A sectional view of this compressor is shown in Figure 7-3 and an exploded view in Figure 7-4. In the following description, numbers in parentheses correspond to index numbers in these figures.

7B2. Crankcase. The crankcase (1, Figures 7-3 and 7-4) is a single cast-iron case, designed with smooth curved lines for strength and for elimination of unequal stresses. It has a large oil capacity to provide good lubrication and ample heat dissipation. The crankcase opens at only one end, for shaft removal, to keep the points of possible leakage at a minimum. The construction is especially rugged around the bearing areas. A drain for removing oil and a sight glass for checking the oil level in the crankcase are provided.

7B3. Crankshaft. The crankshaft (26) is made of die-forged open-hearth steel. It is short, has great rigidity, and is so designed that it needs no counterweights. The thrust face on the dead end of the shaft is centrifugally

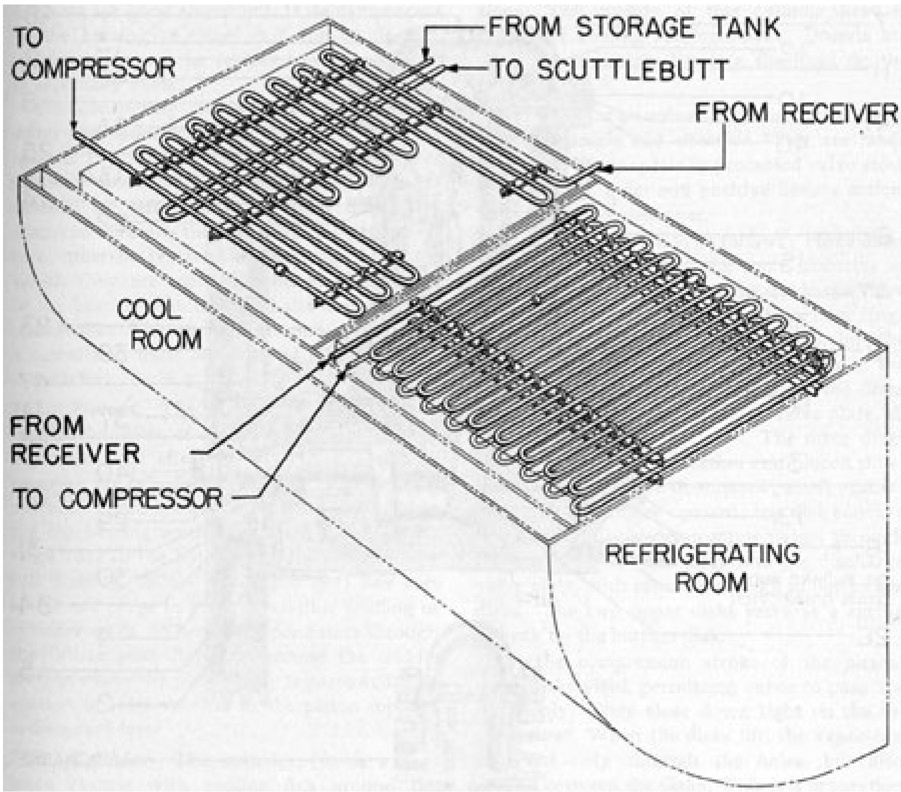

Figure 7-2. Refrigeration evaporator, typical layout.

lubricated by oil that comes in through holes bored in the shaft. Note that endwise play of the crankshaft is controlled by the thickness of the gasket (39) between the bearing head and the crankcase, at the power end of the shaft. For repair, the entire crankshaft, with rods and pistons attached, is removed and replaced as a unit through the opening at the top of the crankcase, after the cylinder casing has been removed.

7B4. Crankshaft main bearings. The crank shaft main bearings (3) are die-cast sleeve type babbitt bearings, diamond bored to mirror finish, with ample oil-ways for lubrication. Note that these bearings are interchangeable. The bearings are inserted by a light press fit, and a lug on the bearing shell locks them, preventing rotation.

7B5. Bearing head to crankcase. The main bearing at the drive, or flywheel, end of the crankshaft is carried on a detachable bearing head (2) bolted to the crankcase. The bearing head may be removed by taking out the capscrews (47), after first removing the flywheel (34) and shaft seal assembly (31).

7B6. Connecting rods. The connecting rods (15) are made of malleable iron I-section, with full-floating piston pins (24). The piston pin bushings (20) are of bronze with oil holes. At the crank pin end, the connecting rod bearings are of centrifugally cast babbitt, diamond bored to mirror finish simultaneously with the

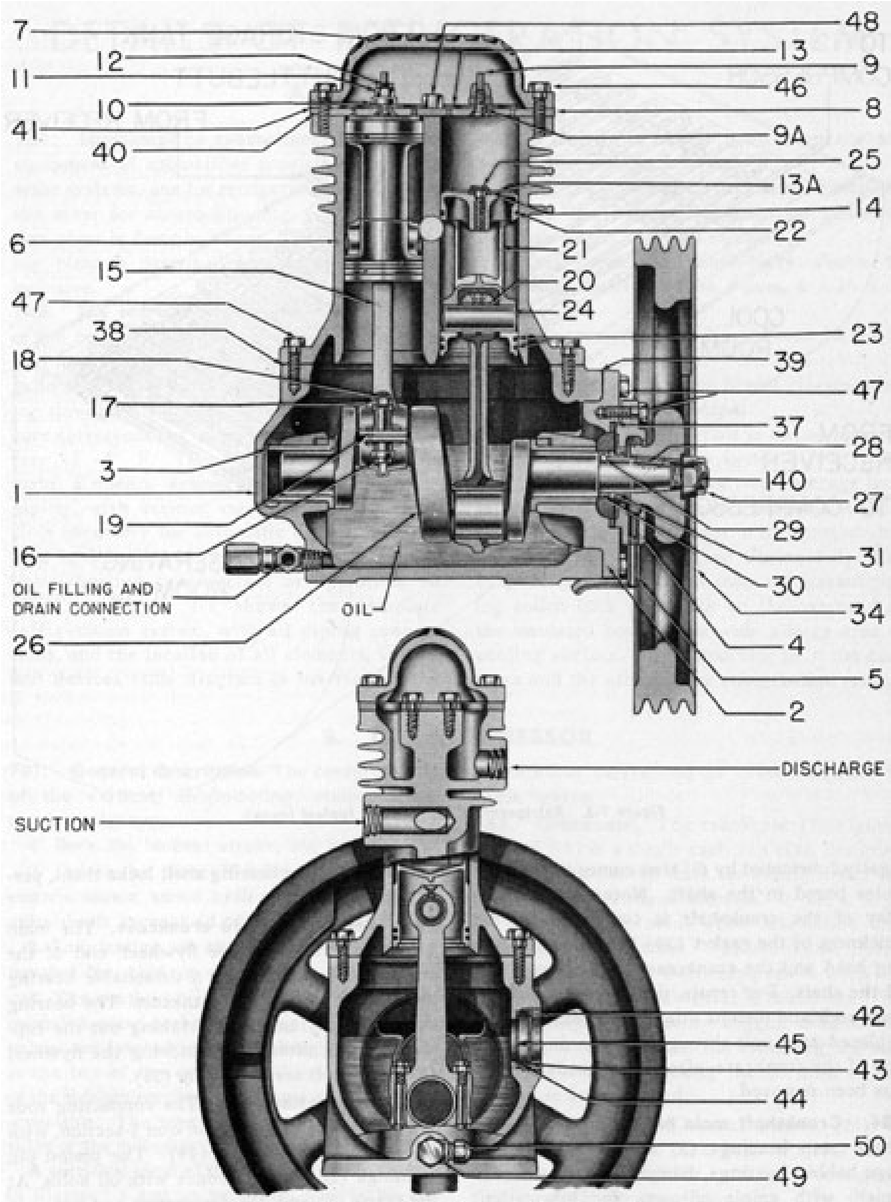

Figure 7-3. Compressor, sectional view.

bushing for good alignment. If damage occurs to the bearing at either end, the whole connecting rod must be replaced as a unit, as it is especially made.

The connecting rod is replaced as follows After the connecting rod bearing is cast, the babbitt is split, and the cap is attached at a predetermined bolt tension. Each bolt is marked by reference to its own hole. The diamond boring is then done. The bolts, Therefore, must be replaced in the exact holes for which they are marked, otherwise distortion of the bearing results. The bolts are not inter changeable. The cap is positioned by means of a dowel

The outside of this cylinder head is finned for cooling reinforcement. Dowels are used for accurately locating the head on the cylinder.

7B11. Discharge valves. The discharge valves (13) are simple and effective. They are, made of highest grade specially processed valve steel, with low lift, quiet and positive flexure action, and large vapor passages.

Their construction is as follows: Three disks of spring metal, nearly the same diameter as the piston, lie assembled on the discharge valve plate. The valve plate and the disks have rings of small holes for the vapor to pass, but the holes in

that must be removed before the cap is detached.

7B7. Pistons. The pistons (21) are of cast nickel-iron alloy, of double-trunk type providing cross-head effect for even distribution of pressure on cylinder walls, with large bearing surface. There is one compression ring (22) in the top bearing section, and two ventilated oil rings (23) in the bottom bearing section. The full floating hollow piston pin (24) has soft metal end plugs to prevent possible scuffing of cylinder walls. When the vapor enters through the intake port, it passes around the middle section where the piston body is narrowed. The suction or inlet valve is in the piston top and is discussed later.

7B8. Cylinder. The cylinder (6) is a one piece casting with cooling fins around the upper part. It is bolted to the crankcase. The intake and outlet ports are located on opposite sides of the cylinder between the two cylinders. Locating dowel pins are provided for placing the cylinder accurately on the crankcase. The gasket (38) between these two parts is of lead coated copper.

7B9. Discharge valve plate. The discharge valve plate (8) that carries the two discharge valves, has holes coinciding with bolt holes in the cylinder head. The same bolts fasten both parts to the cylinder. In addition, this plate has two capscrews (48) that attach it to the interior cylinder wall.

the valve plate and the holes in the disks do not coincide, so that when the disks are down tight on the discharge valve plate, all passage is completely closed. The three disks are slightly dished in section and placed thus bottom disk concave downward; small spacer; middle disk concave upward; top disk concave downward. A hold-down screw passes through the center of this assembly into the discharge valve plate, with pressure enough to flatten the disks. The two upper disks serve as a spring to back up the bottom disk.

On the compression stroke of the piston, these disks yield, permitting vapor to pass up ward only. They close down tight on the reverse flow. When the disks lift, the vapor can flow not only through the holes, but also around between the disks. This is a precaution against slugging or violent pulsations. In assembling the discharge valve, the small holes in the disks must be aligned.

7B2. Suction valves. The suction valves (13A) are located at the top of the pistons. The suction valve diaphragms are similar in action to the discharge valve diaphragms, but the size of the holes and their distances from the center are different; hence, the suction and discharge diaphragms are not interchangeable. (In the 4-inch bore x 4-inch stroke air-conditioning compressor, the two sets of diaphragms are alike and therefore interchangeable.) In assembling the suction valve, the holes in the diaphragms must be aligned. A Dardellet self locking screw (25) is used for the center hold down. This requires a special

7B10. Cylinder head. The cylinder head (7) has a high-domed construction to provide a cushioning effect in reducing pressure pulsations.

screwdriver and valve hold-down bushing for installation.

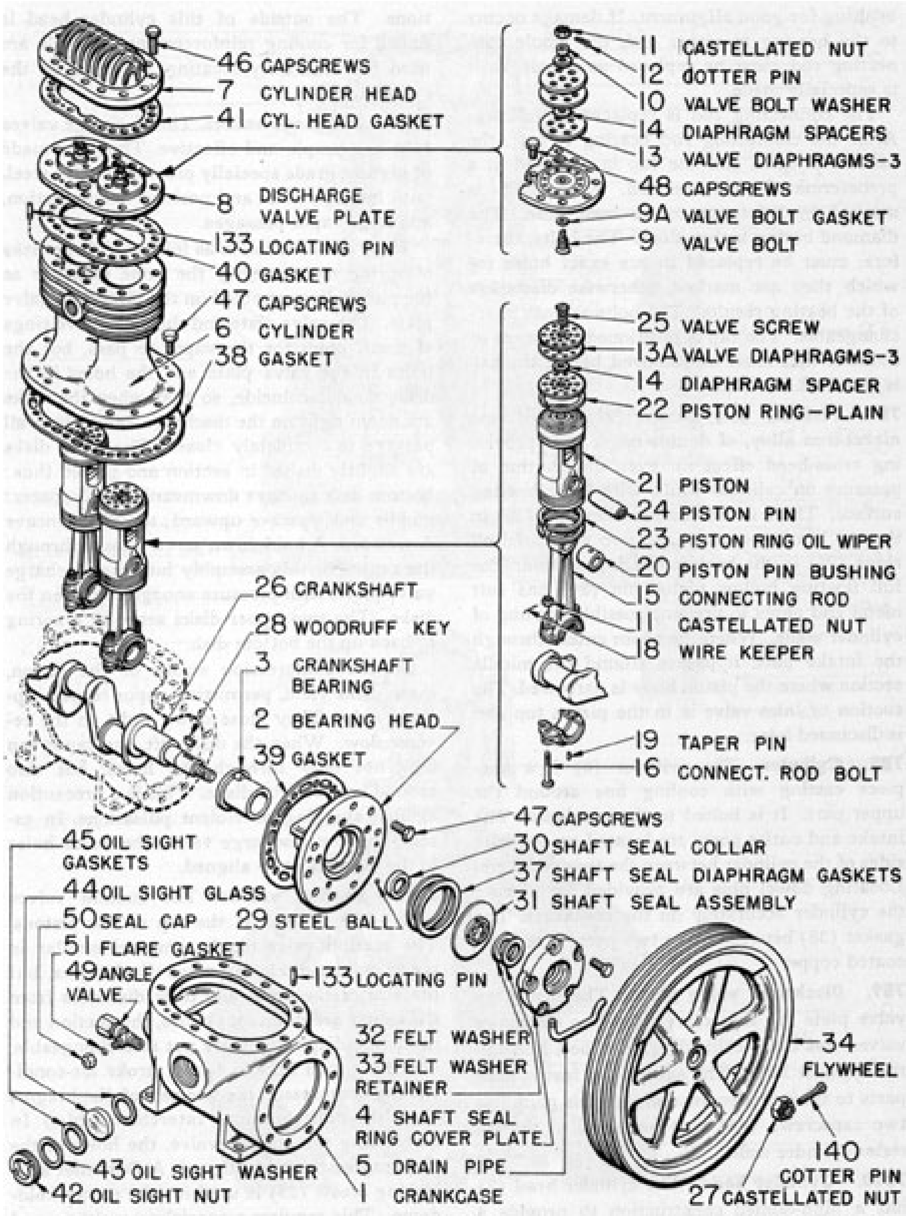

Figure 7-4. Compressor, exploded view.

An additional safety feature is a small hole through the side of the piston near the top. When starting the compressor, this hole permits Freon 12 under excessive pressure to flow through. In normal operation, at

are lubricated by means of small holes in the seal face, carrying oil across the contact surfaces. This seal is below the oil level in the crankcase and oil flows by gravity into the seal from the shaft bearing. Therefore, a slight

designated pressure, this small hole is kept sealed by lubricating oil.

7B13. Gaskets. Lead-coated copper is used for gaskets, and no special materials are required. However, at three points it is most important that the correct specified thickness be used. These points are:

1. Between discharge valve plate and cylinder. This gasket (40) determines the clearance between the piston top and the cylinder head; this clearance is only a few thousandths of an inch.

2. Between crankshaft main bearing head and crankcase. This gasket (39) determines the thrust collar clearance and the endwise play of the shaft.

3. Between bearing head and shaft seal ring cover plate. This gasket (37) controls the seal tension diaphragm tension.

7B14. Crankshaft seal. The crankshaft seal assembly (31) is the patented York Balanseal construction, one of the salient features of the York-Navy compressor, It has few parts and no springs, and is easily serviced.

The seal between the shaft and the crankcase is made by the shaft seal collar (30). Around the shaft and rotating with it, is a fixed collar held in place by a steel ball (29), the seal face of which is lapped to a fine finish. Against the rotating seal face of this shaft collar, another seal collar, or seal ring, presses. This collar has a similarly lapped face and is held stationary by a spring seepage of oil always appears on the outside of the seal.

7B15. Lubrication. The main shaft bearings and seal are flooded. The thrust bearings, receive a constant stream of oil from the centriforce oiler. The piston pin bearings and cylinder walls are lubricated by the usual splash-vapor method. The seal collar face is kept oiled by the rotation of the shaft. A number of pin-point depressions are arranged in a spiral path on the seal collar face, and oil working into these depressions provides uniform lubrication across the face.

7B6. Miscibility of oil and Freon 12 vapor. Freon 12 mixes readily with oil. However, no chemical reaction takes place, so that no harm is done to either. This mixing has a definite pressure-temperature relationship. For example, with an oil temperature of 60 degrees F and a pressure of 40 pounds gage, DTE heavy medium oil absorbs Freon 12 vapor to about 60 percent by weight.

The absorption increases with elevation in pressure, lowering of temperature, and length of compressor shutdown. Therefore, if there is a long shutdown, the oil absorbs so much Freon 12 that a high oil level appears in the sight glass. Actually the amount of oil may be below normal.

CAUTION. It is possible that even after a prolonged shutdown this oil and Freon 12 mixture may fill the crankcase. If the compressor is started under such conditions, damage to some part or parts is probable. Even if the oil-Freon 12

diaphragm attached to the crankcase. The diaphragm is under tension in the assembly and holds the two sealing faces together at a definite pressure.

The construction, operation, and adjustment of this seal are described in Sections 10K1 to 10K7.

Seals are designed for either clockwise or counterclockwise operation and are not inter changeable. Submarine installations are counterclockwise seals.

The rubbing faces of the two seal collars

mixture does not fill the crankcase, starting may cause a sudden lowering of pressure in the crankcase, producing a violent boiling and foaming of the oil as the Freon 12 vapor leaves. This in turn would result in a loss of oil from the crankcase. Special care should be taken to check this matter after any shutdown. Moreover, gathering of frost on the crankcase indicates

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a lowering of temperature within, caused by too low pressure or some other possible cause, in which case the same troubles might arise. Frost should not be permitted to form on the compressor crankcase, and in the event that

it does, the system should be checked immediately.

NOTE. Because of the ready mixing of oil and Freon 12, oil must never be used in testing for Freon 12 leaks (see also Section 11F3).

C. CONDENSER AND PUMP

7C1. The condenser. The condenser is a four-pass water-cooled condenser of conventional shell-and-tube construction. The shell is made of brass, 30 inches long and 6 9/16 inches in diameter (see Figure 7-5). The condensing water enters and leaves at the same end in four sets of six tubes each, the tube ends being belled for better entrance. The heads are semispherical with baffle-plates cast enbloc to return the water flow. The water

vessel submerges to a depth at which sea pressure is greater than the test pressure of the water side of the condenser. This depth is approximately 500 feet.

It is good practice to secure the plant and sea valves when submerging below 300 feet or when expecting a depth charge attack, and to open the vent on the water side of the condenser. This aids in preventing damage to the condenser during depth charging. At both ends of the condenser, two zinc fingers, or

enters the lower-left set of tubes, returns through the lower-right set, goes back again through the upper-right set, and flows out finally through the upper-left set. The Freon 12 vapor enters the condenser shell at the top, flows around these water tubes, condenses, and drips to the bottom where the liquid Freon 12 exists. Vents and drains are provided.

The condenser is of such size that when the refrigerating system is operating at -5 degrees F evaporation temperature and is supplied with 10 gallons per minute of 85 degrees F water, for each refrigeration ton, the head pressure does not exceed 125 pounds gage. The condensing water enters at 85 degrees F and leaves at 88 degrees F, with a velocity of 73.5 feet per minute through tubes. The flow of water through the condenser should be controlled by regulating the opening of the discharge valve on the condenser. The desired temperature can be maintained by controlling the flow of water through the condenser. If water at too low a temperature is allowed to flow through the condenser, it may be impossible to maintain the desired discharge pressure of the refrigerant at the compressor.

Never attempt to control the flow of water or regulate the temperature of the water through the condenser by the inlet valve. The inlet valve should be kept fully open at all times. The water side of the condenser is tested to 236 psi. Therefore, the suction to sea, through which cooling water is supplied rods, extend into the water side. They are screwed in securely from the outside so that they may be removed easily and inspected without having to remove the heads. These zinc fingers act as protectors, that is, they tend to protect the other metal parts from the corrosive action of the water caused by electrolytic action induced by stray electric currents in the metal parts. These zinc fingers should be inspected at least once a month and replaced when deterioration reaches 50 percent. A zinc finger when new and at four stages of increasing deterioration is illustrated in Figure 7-6.

7C2. Condenser water pump. The cooling water that condenses the Freon 12 vapor is supplied by a volute type of centrifugal pump. In the centrifugal pump, the intake water enters into the center, of the impeller on the axis of the pump. This impeller is carried on a shaft, both bearings of which are on one side, opposite the inlet. The impeller lies in a plane perpendicular to the axis. An exploded view of the pump is shown in Figure 7-7.

The impeller is of the enclosed type, that is, the water flows in passages inside the impeller (see Figure 7-7). The shaft is directly connected to a motor and turns at high speed. This speed imposes a centrifugal force on the water in the impeller passages. This centrifugal force causes the water to flow at high velocity from the eye, or inlet, of the impeller

to the condenser, can be left open until the

outward toward the periphery. This outward flow under centrifugal force creates a "suction" at the eye which pulls the feed water into the pump.

The inner surface of the case that surrounds the impeller has a volute, or spiral-shaped section, that is, an increasing radius around the circumference. The small inset in Figure 7-7 shows a sectional view of the case and volute interior. The volute case is designed to produce an even flow of water around the periphery and to reduce the velocity of flow gradually as the water flows from the impeller to the discharge outlet of the pump. This reduction

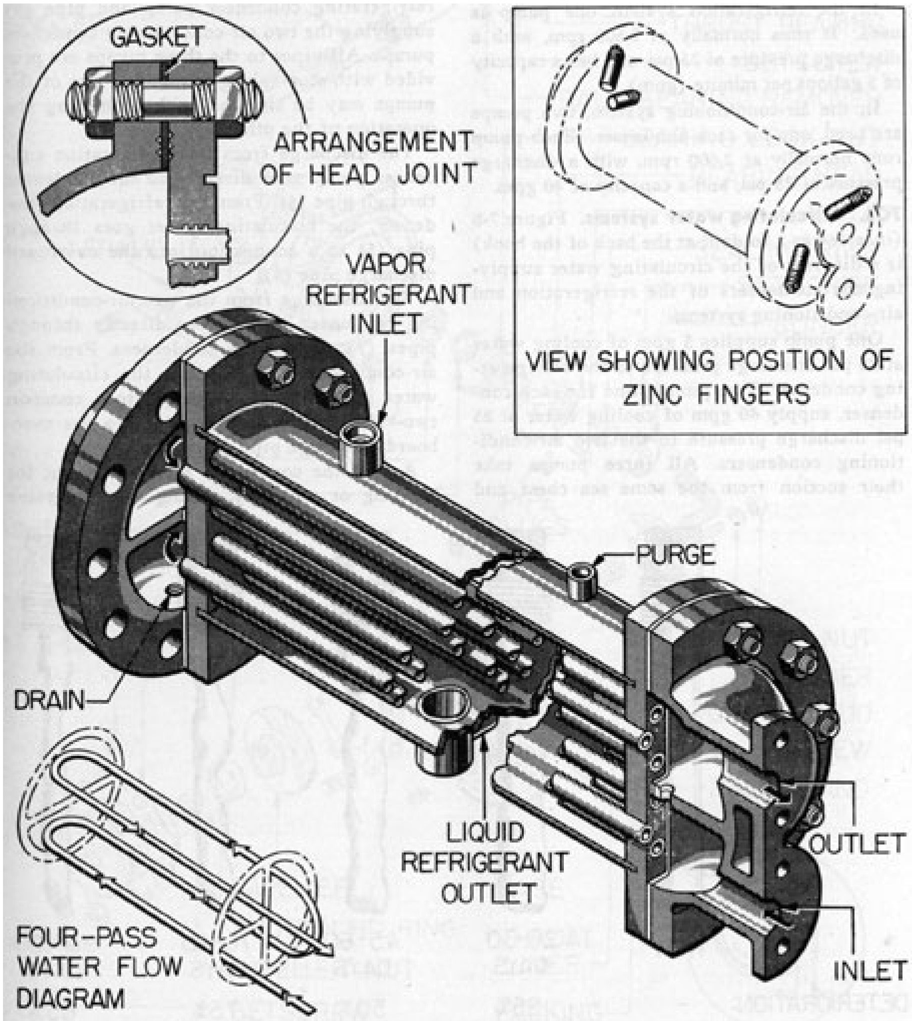


Figure 7-5. Condenser.

in velocity changes the velocity head into pressure head.

strainer through pipes (1) and (2). In pipe (2) a hose valve (10) is connected for emergency water feed to the system through the

The advantages of the centrifugal type pump are: 1) the flow from it is continuous; 2) the flow can be throttled without building up an excessive pressure, or overloading the motor; and 3) it operates at speeds normal to an electric motor; hence, it may be directly connected.

In the refrigeration system, one pump is used. It runs normally at 3,500 rpm, with a discharge pressure of 25 psi, and has a capacity of 5 gallons per minute (gpm).

In the air-conditioning system, two pumps are used, one for each condenser. Each pump runs normally at 2,600 rpm, with a discharge pressure of 25 psi, and a capacity of 40 gpm.

7C3. Circulating water systems. Figure 7-8 (inserted as a foldout at the back of the book) is a diagram of the circulating water supplying the condensers of the refrigeration and air-conditioning systems.

One pump supplies 5 gpm of cooling water at 25 psi discharge pressure to the refrigerating condenser. Two pumps, one for each condenser, supply 40 gpm of cooling water at 25 psi discharge pressure to the two air-conditioning condensers. All three pumps take their suction from the same sea chest and inlet side of the strainer. This connection normally is used to supply water to the system while the vessel is in dry dock.

Two separate suction lines lead from the basket-type strainer: pipe (3) supplying the refrigerating condenser pump and pipe (6) supplying the two air-conditioning condenser pumps. All pipes to the three pumps are provided with stop valves so that any one of the pumps may be shut off without halting the operation of the others.

The discharge from the refrigeration condenser pump goes directly to the condenser through pipe (4). From the refrigeration condenser, the circulating water goes through pipe (5) to a connection into the overboard discharge pipe (9).

The discharge from the two air-conditioning condenser pumps goes directly through pipes (7) to the two condensers. From the air-conditioning condensers, the circulating water goes through pipes (8) to a common two-valve manifold, and then into the overboard discharge pipe (9).

Any of the condensers may be cut out for cleaning or repair by closing the stop valve

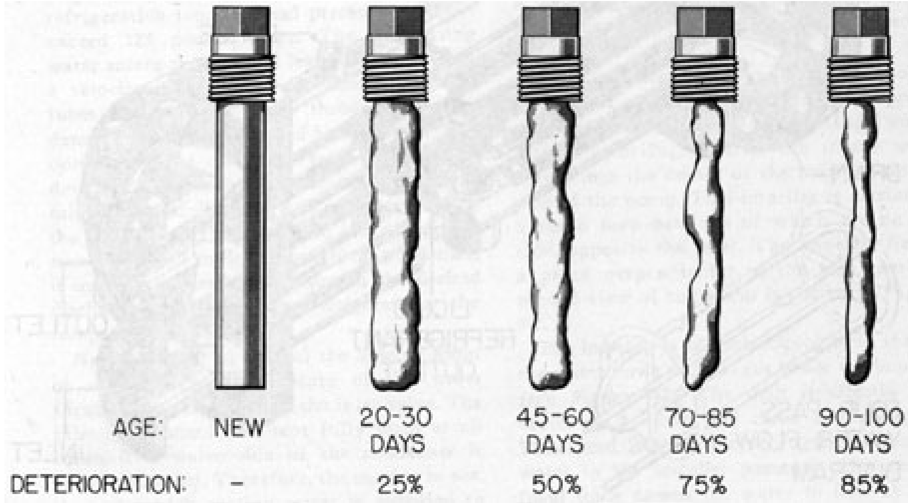


Figure 7-6. Zinc fingers for condenser, showing stages of deterioration.

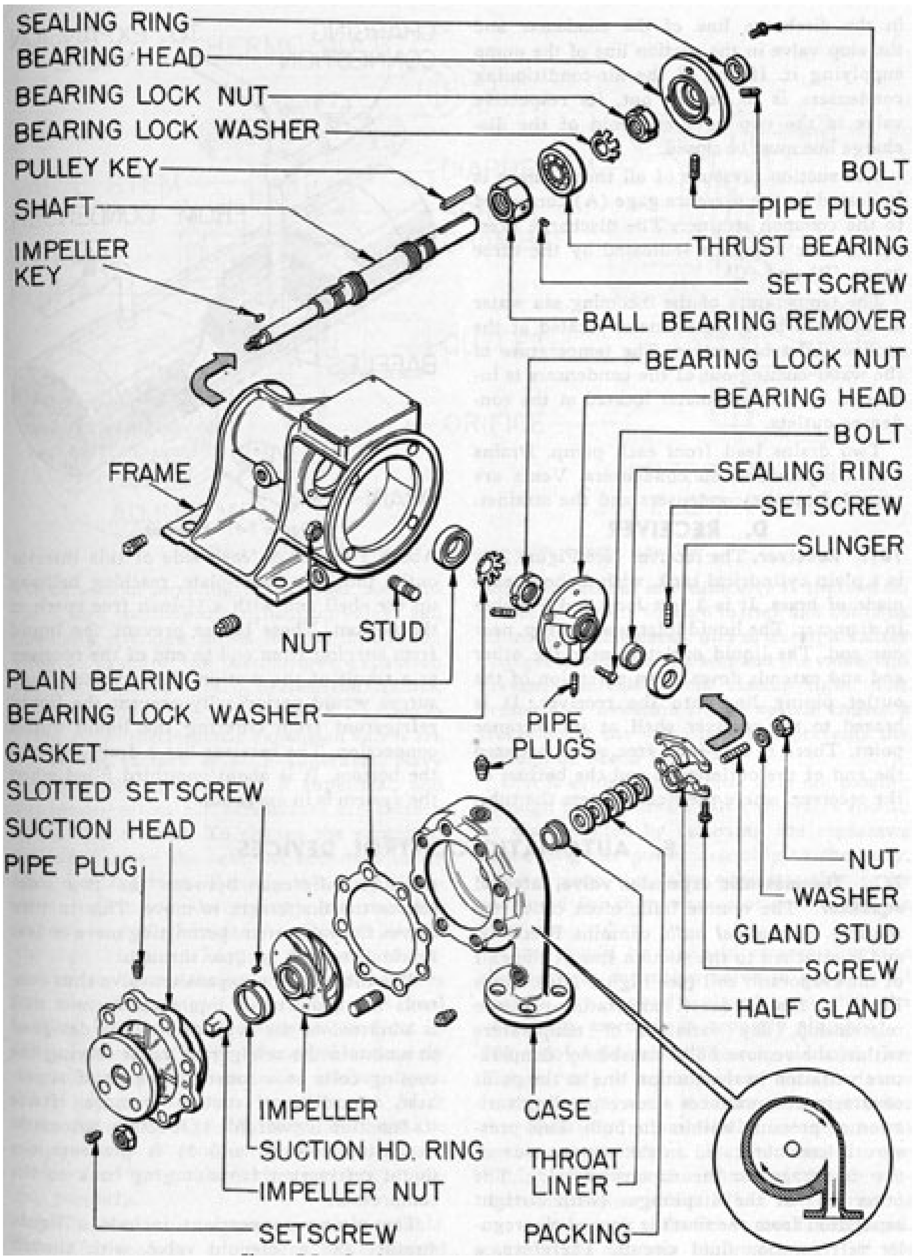


Figure 7-7. Condenser water pump, exploded view.

in the discharge line of the condenser and the stop valve in the suction, line of the pump supplying it. If one of the air-conditioning condensers is to be cut out, its respective valve in the two-valve manifold of the discharge line must be closed.

The suction pressure of all three pumps is indicated by the pressure gage (A) connected to the common strainer. The discharge pressure of the pumps is indicated by the three gages (B) and (C).

The temperature of the incoming sea water is indicated by a thermometer located at the strainer inlet connection. The temperature of the water coming out of the condensers is indicated by a thermometer located at the condenser outlets.

Two drains lead from each pump. Drains also are provided on condensers. Vents are provided on the condensers and the strainer.

D. RECEIVER

7D1. Receiver. The receiver (see Figure 7-9) is a plain cylindrical tank, with dished heads made of brass. It is 3 feet long and 6 inches in diameter. The liquid inlet is at the top, near one end. The liquid outlet is near the other end and extends down as an extension of the outlet piping line into the receiver. It is brazed to the receiver shell at its entrance point. There is a 1/2-inch free space between the end of the outlet tube and the bottom of the receiver, where the liquid enters the tube.

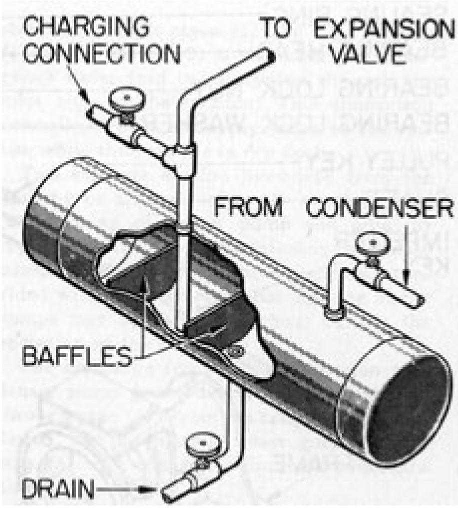


Figure 7-9. Receiver.

About 3 inches on each side of this interior outlet tube is a baffle-plate, reaching halfway up the shell and with a 1/2-inch free space at the bottom. These baffles prevent the liquid from surging from end to end of the receiver as a result of the motion of the vessel. Such surges would periodically prevent the liquid refrigerant from entering the liquid outlet connection. The receiver has a drain valve in the bottom. It is about one-third filled when the system is in operation.

7E1. Thermostatic expansion valve, internal equalizer. The remote bulb, often called the thermo-, or **thermal bulb**, contains Freon 12, and is attached to the suction line at the exit of the evaporator coil (see Figure 7-10). Since Freon 12 has an exact temperature-pressure relationship, any variation of temperature within the remote bulb, caused by temperature variation in the suction line at the point of attachment, produces a corresponding variation of pressure within the bulb. This pressure is communicated to the upper side of the diaphragm in the expansion valve. The other side of the diaphragm (with airtight separation from the first) is part of the regular refrigeration fluid circuit. Therefore, a pressure difference between the two sides causes the diaphragm to move. This in turn moves the valve stem, permitting more or less liquid Freon 12 to flow through.

The thermostatic expansion valve thus controls the quantity of liquid refrigerant that is admitted to the evaporator. It is designed to maintain the refrigerant vapor leaving the cooling coils at a constant degree of super heat, regardless of suction pressure. Hence its function is twofold: 1) it acts as automatic expansion control, and 2) it prevents the liquid refrigerant from surging back to the compressor.

The piping connections include a liquid strainer and a solenoid valve, with shutoff

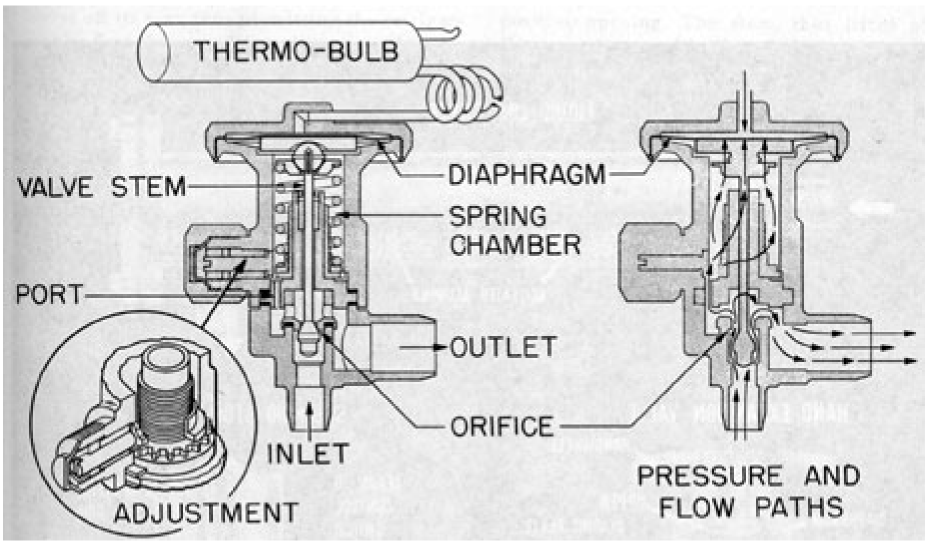


Figure 7-10. Thermostatic expansion valve, internal equalizer.

valves used in servicing the strainer, solenoid valve, and thermostatic expansion valve; and manually operated valves for function without any difficulty if the system is free of dirt or foreign matter and contains no moisture. However, dirt or foreign matter

use if it is desired to examine the thermostatic expansion valve or solenoid valve, or to clean the strainer.

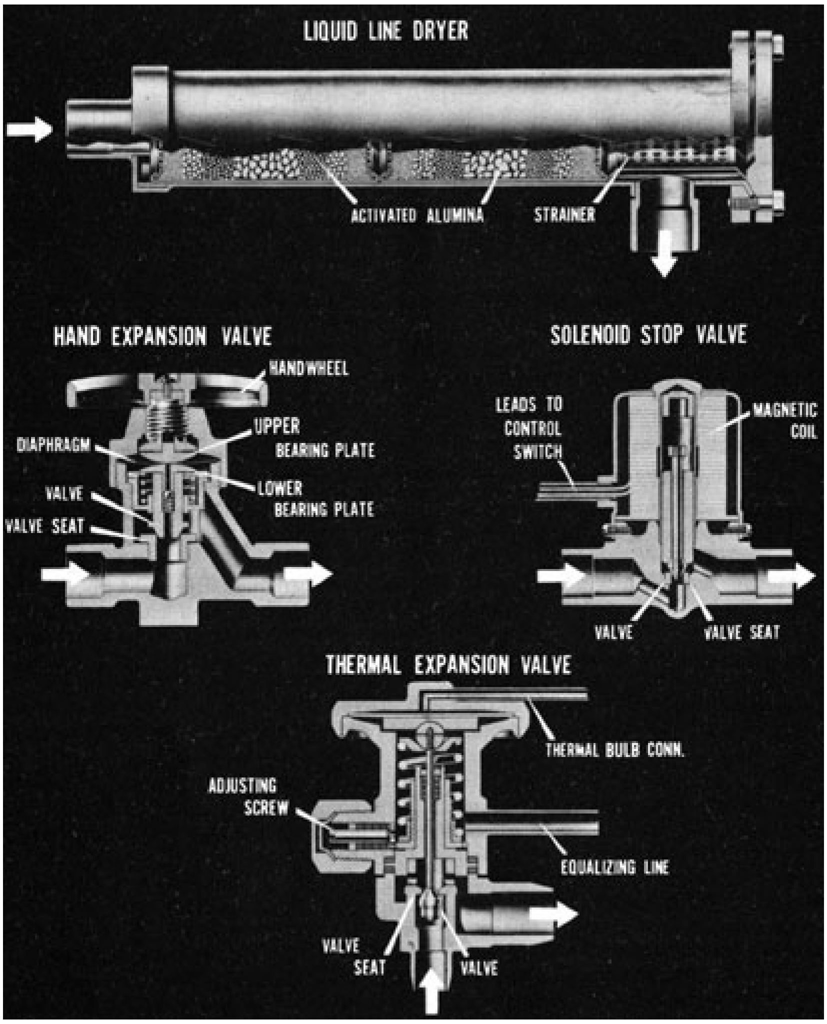
a. Adjusting the thermostatic expansion valve. Some thermostatic expansion valves are set in the factory at 5 degrees F superheat. Navy specifications call for 10 degrees F superheat, and expansion valves for submarines are factory set at this amount. To change the superheat setting, remove the seal nut and manipulate the adjusting stem. Turning this stem clock wise (tightening the spring) increases the superheat and reduces the flow of liquid through the valves. Turning the stem counter clockwise reduces the superheat and increases the flow through the valve. After this final setting, it is seldom necessary to readjust it. These valves are made to control accurately the amount of superheat in the suction vapor. They will not withstand rough usage; After they are once adjusted, they must not be played with or readjusted, unless there is distinct evidence that they are not functioning properly.

b. Thermostatic expansion valve trouble. The thermostatic expansion valve should may get in between the seat and the valve, and prevent the valve from closing tight. The presence of moisture in the system causes a freeze-up at the valve port and prevents the passage of Freon 12.

If it is evident that Freon 12 is not passing through the expansion valve, the valve should be disassembled by removing the capscrews connecting the power assembly to the body. This permits the valve cage assembly to be examined for the presence of such things as frost, ice, or dirt.

Care should be taken in reassembling the thermostatic expansion valve to see that all gaskets are properly placed, and that the valve cage assembly is properly aligned.

7E2. Solenoid valve. The solenoid valve (see Figure 7-11) is an important control device in the system, since it is the valve that halts the operation automatically in response to operating conditions. It is located in the liquid refrigerant line ahead of the thermostatic expansion valve. When the current is on, the magnetic coil of the valve is energized, causing the plunger to retract and lift the



NavPers 17130, E-40, E-135

Figure 7-10a. Typical refrigeration control devices.

valve off its seat, thus permitting the refrigerant to flow through. When the space that the thermostat controls reaches the desired temperature, the thermostatic control device breaks the electrical circuit, and the magnetic coil releases the plunger, instantly closing the valve and completely stopping the flow of refrigerant.

A breakaway pin under spring pressure acts as a kickoff when the electrical circuit is interrupted, assuring positive closing of the valve.

The valve-closing part is a small piston, separate from the valve stem. This piston has a loose fit, so that when it is closed, the high-pressure liquid may flow up between it and the body wall, positive opening. The stem, thus lifted off the secondary seat in the piston, enables the high pressure above the piston to flow out through the piston opening. Since the closing pressure on the piston is thus removed, the incoming liquid flow causes the piston to rise, fully opening the valve.

The magnetic coil is extra powerful and does not need Fusetron protection on alternating current. A surge protector is included for direct current in excess of 50 volts. The coil does not overheat or burn out under normal service.

The coil and leads are waterproof, which prevents failure caused by condensation of moisture in low-temperature or high-humidity compartments.

exerting this pressure downward on the piston top to maintain a complete and tight closure.

The valve stem also is separate from the plunger. When the magnetic coil is energized, the plunger snaps up, striking a hammer blow against the upper flange of the stem to insure

The solenoid valve should be located in a horizontal line, with the direction of refrigerant flow corresponding to the arrow on the valve body, and the coil in a vertical lane above the valve.

Liquid Freon 12 should never be permitted

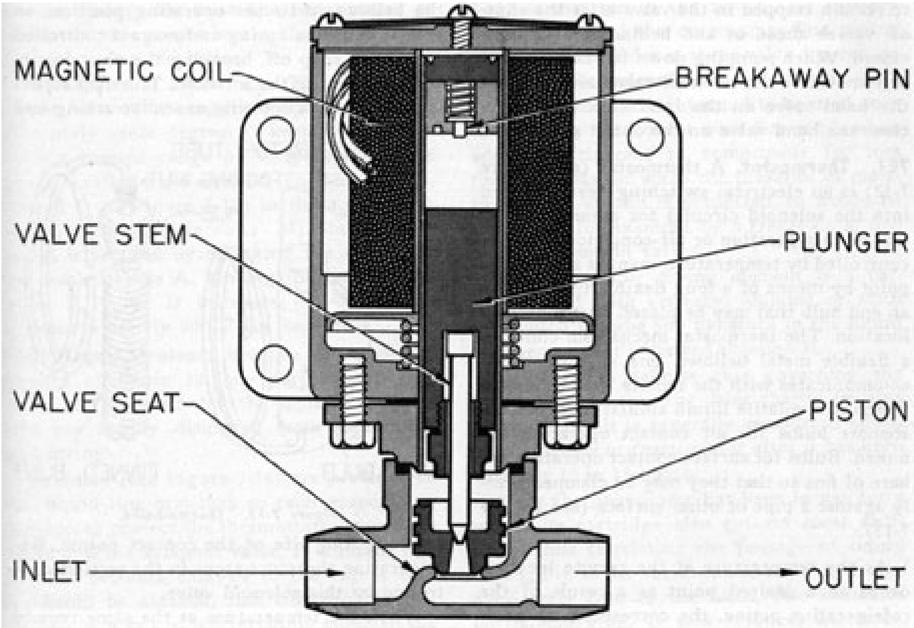


Figure 7-11. Solenoid valve.

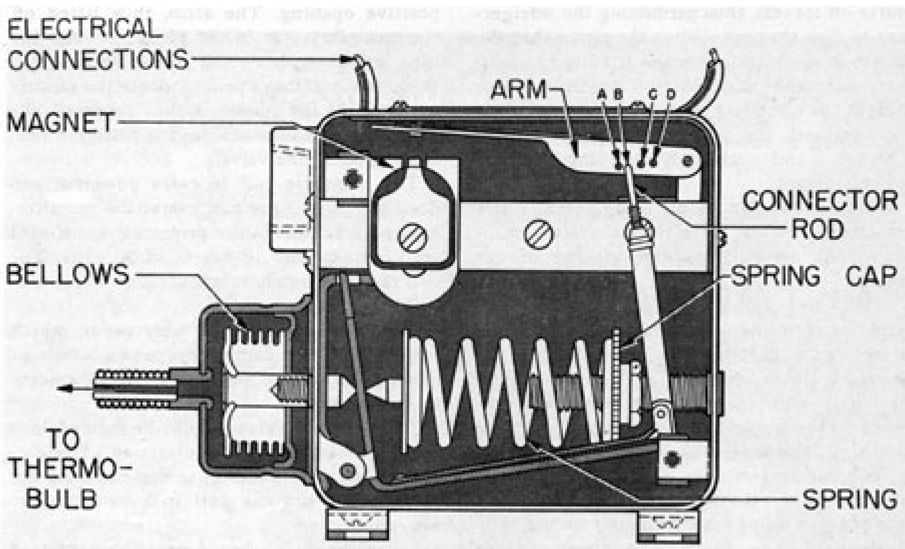


Figure 7-12. Thermostat.

to remain trapped in the valve after the shut off valves ahead of and behind it have been closed. When pumping down for examination or removal of the

the bellows to degrees (its set operating position, so that it causes a spring-and-magnet-controlled contact to snap off, breaking the electric circuit and

solenoid valve, always close the hand valve on the inlet side first; later close the hand valve on the outlet side.

7E3. Thermostat. A thermostat (see Figure 7-12) is an electrical switching device (wired into the solenoid circuit) for automatic control of refrigeration or air-conditioning. It is controlled by temperature changes at a remote point by means of a long flexible tubing with an end bulb that may be placed at any desired location. The thermostat mechanism contains a flexible metal bellows, one side of which communicates with the remote bulb tubing in which is a volatile liquid similar to Freon 12. Remote bulbs for air contact operation are finned. Bulbs for surface contact operation are bare of fins so that they may be clamped firmly against a pipe or other surface (see Figure 7-13).

As the temperature at the remote location drops to a desired point as a result of the refrigeration action, the corresponding pressure of the liquid within the tubing moves closing the solenoid. The snap action is rapid, thus preventing excessive arcing and

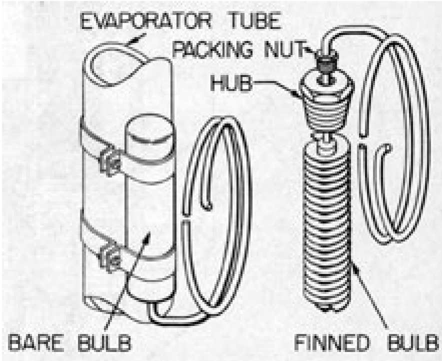


Figure 7-13. Thermo-bulbs.

insuring long life of the contact points. Refrigeration therefore stops in the section controlled by this solenoid valve.

When the temperature at the same remote location rises above the desired point, the

reverse action takes place. The switch snaps on, closing the electric circuit, thus opening the solenoid valve and starting refrigeration again. By this means, the refrigeration is maintained economically at a desired temperature. When all solenoid valves are closed, the compressor is stopped by the low-pressure cutout switch.

The liquid strainer can be tested by placing the hand alternately on the strainer and on its inlet line. If the strainer feels distinctly colder than the line, it is a sign of partial clogging and the screen probably needs to be cleaned. All pressures should be checked. If frost gathers on the strainer shell, it is a sign of bad clogging, and the screen should be cleaned immediately.

On some installations, the thermostats used on the refrigerating boxes have two contact points. One contact point controls the solenoid valve on the meat or vegetable room, and the other is connected to the solenoid valve on the ice cuber. The ice cuber does not have a thermostat, and the solenoid is wired in parallel with the meat and vegetable room thermostats. If the contact points on either the meat or vegetable room thermostats are closed, the ice cuber solenoid valve is open.

a. Temperature adjustment. To dower the temperature at which the thermostat breaks the circuit, causing the solenoid valve to close, turn the spring cap (see Figure 7-12) counterclockwise. This decreases the tension on the spring. To raise the temperature at which the thermostat breaks the circuit, turn the spring cap clockwise.

b. Differential adjustment. The thermostat cannot, of course, keep the temperature at one absolutely exact degree. It keeps it within a certain limited range of temperatures. The range is called a differential. The holes (A, B, C, and D in Figure 7-12) in the arm permit variation of the differential. Minimum differential is secured by attaching the connector rod hook in hole A. Moving the hook to the holes B, C, or D increases the differential by approximately 20 degrees F for each hole.

7E4. Liquid strainer. Because of the solvent quality of Freon 12, any particles of grit, scale, and so forth that the system may

To clean a liquid line strainer, shut off the manually operated stop valves ahead of and behind it and open the manual bypass valve a slight amount in order not to interrupt refrigeration. Loosen the cap, or cover plate, which is bolted to one end of the liquid strainer and remove the internal screen. Dip the screen in an approved cleansing solvent and blow it out with air. Also blow out the inside of the strainer body with air.

IMPORTANT. When placing the strainer back in the line, blow a little Freon 12 vapor through it to remove the air before closing the cover plate joint.

7E5. Dehydrator. A dehydrator (see Figure 7-15) is inserted in the liquid line between the receiver and the evaporator. The piping connection includes a three-valve bypass, so that it can be isolated when not in use.

The dehydrator is intended to be used only in charging the system with Freon 12, when adding refrigerant to compensate for loss through leaks, or when the presence of moisture in the system is suspected, as would be evidenced, for example, by a freeze-up at one of the expansion valves.

The dehydrator drying element is a cartridge filled with activated alumina or silica gel, which absorbs any moisture in the liquid refrigerant that is passed through it.

There is no definite rule governing the length of time that the drier charge remains effective, but it is generally considered advisable to

contain are readily dislodged from the piping and fittings.

Strainers (see Figure 7-14) are provided in the liquid line branches to each evaporating surface, to protect the thermostatic expansion valve and the solenoid valve. If a liquid line strainer becomes clogged to the extent that it should be cleaned, this condition is evidenced by a loss of refrigerating effect in the room or surface on the line that it protects.

renew or reactivate it after it has been used for 12 to 15 hours.

After the dehydrator has been in use for a while, its cartridge also gathers some sediment, thus restricting the passage of liquid through it. If the outlet end of the dehydrator shell feels cold to the hand, this indicates partial clogging. If this coldness increases, the cartridge should be replaced. If frost

gathers on the shell, it is a sign of bad clogging and the cartridge should be replaced at once.

Reactivation of a used cartridge is accomplished by subjecting it to heat (300 degrees F) in a ventilated oven for 12 hours; then sealing the ends of the cartridge, and allowing it to cool.

IMPORTANT. After placing the cartridge back in the shell, blow a little Freon 12 vapor through it from the inlet side, to free the shell of air; then tighten the end cap.

7E6. Low-pressure cutout. The low-pressure cutout and high-pressure cutout switches are similar in mechanism to the thermostat.

The low-pressure cutout, or suction pressure, switch (see Figure 7-17) is located on the compressor base or on a panel adjacent to it. The tubing leading to its bellows is connected into

points to prevent short cycling of the compressor.

Where solenoid valves controlled by thermostats are used in multiple evaporator installations, set the suction pressure switch to stop the compressor after the last solenoid valve has closed, and to start the compressor again when one or more of the solenoid valves have opened.

7E7. High-pressure cutout. The high-pressure cutout switch (see Figure 7-18) also is located on the compressor base or on a panel adjacent to it. The tubing leading to its bet lows is connected to the high-pressure line at the discharge port. Its wiring is connected to the pilot circuit of the compressor motor starter. This switch serves as a safety device to prevent dangerously high pressure from developing within the system. When the discharge pressure rises to the setting of this

the suction line at the intake port. Its wiring is connected into the pilot circuit of the compressor motor starter. When all the solenoid valves have closed, thus halting the refrigerant flow, the suction pressure drops until it reaches the setting of the low-pressure cutout, which is about 2 psi. When the suction pressure reaches this point, the switch opens, thus stopping the compressor.

If, for any other reason, the pressure in the low-pressure line should drop, the cutout switch stops the compressor at 2 psi. When one or more of the solenoid valves open, the suction pressure will rise, causing the switch to close and start the compressor. This switch has a differential of about 18 psi. That is, it stops the compressor when the low pressure drops to 2 psi, and snaps on at about 20 psi, restarting the compressor. The low-pressure cutout provides automatic control of the system. It halts the system when the desired degree of coolness in all spaces has been reached, thus making possible economical operation, and it prevents the rooms from getting too cold.

a. Pressure adjustment. To raise the low-pressure cutout point, turn the spring cap to increase the compression of the spring. To lower the low-pressure cutout point, turn the spring cap to decrease the compression of the spring.

In some cases it may be desirable to increase the

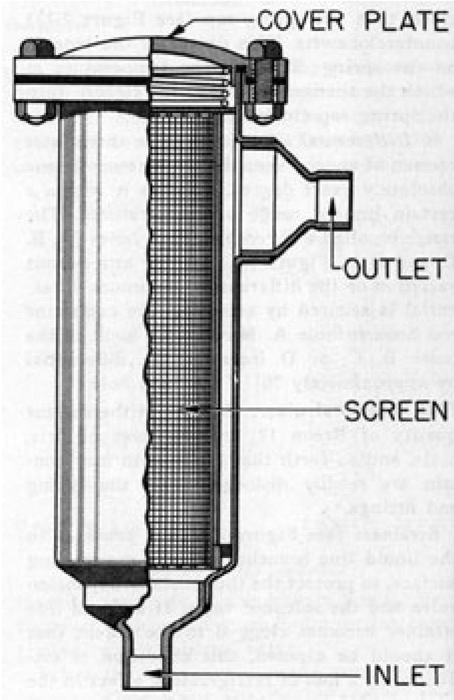
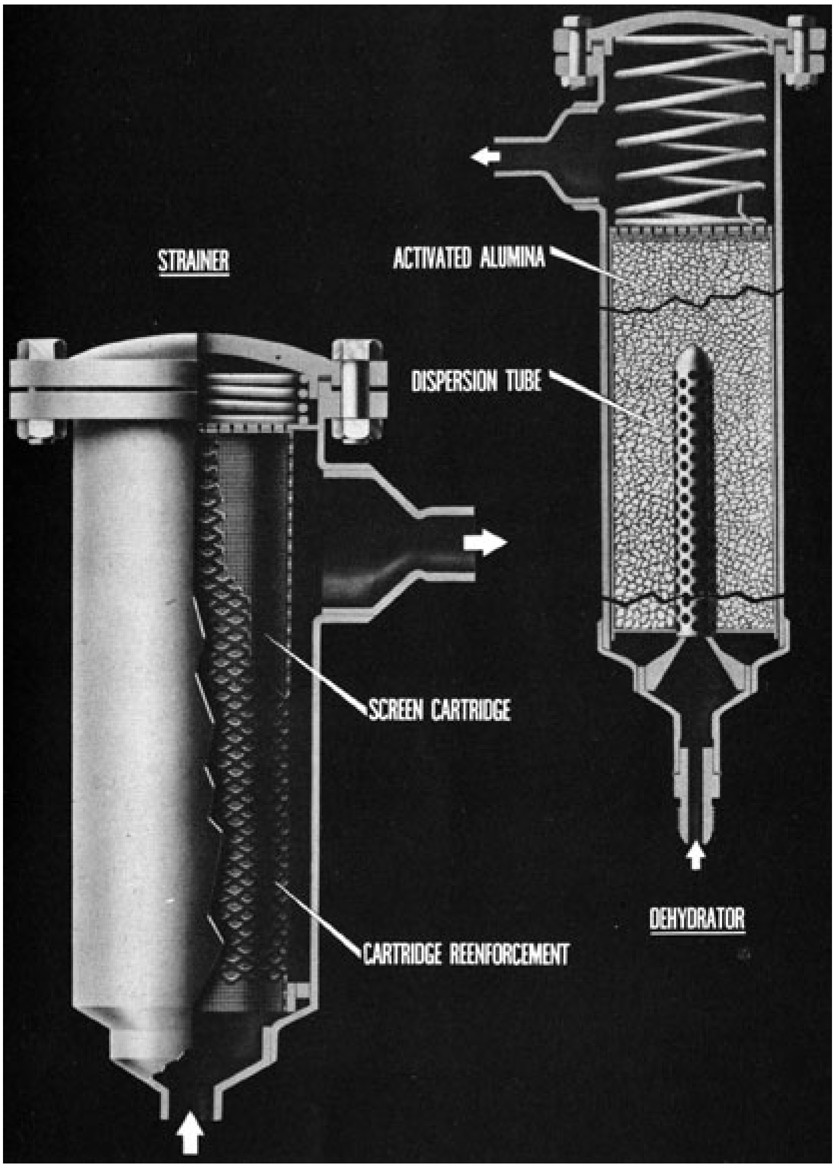


Figure 7-14. Liquid strainer.

differential between the cutin and cutout



NavPers 17022, Amphib 104
Figure 7-14a. Dehydrator and liquid trainer, York ice machine.

switch, which is usually 150 psi, the switch opens, stopping the compressor and shutting down the system. This switch has a differential of about 25 psi. When the high pressure falls to 125 psi, the switch closes, automatically starting the compressor again.

7E8. Relief valve. The relief valve is of the conventional positive self-seating type, located on the discharge line from the compressor. It is furnished with interconnecting piping, and serves to vent excessively high discharge pressure to the suction, or low-pressure, side of the compressor. The relief valve acts as a safety device, and in the event that the

a. Pressure adjustment. To raise the high-pressure cutout point, turn the spring cap to increase the compression of the spring. To lower the high-pressure cutout point, turn the spring cap to decrease the tension of the spring.

high-pressure cutout switch should fail to stop the compressor, it comes into operation at 200 psi, preventing any further rise in pressure and bypassing this back to the low-pressure side.

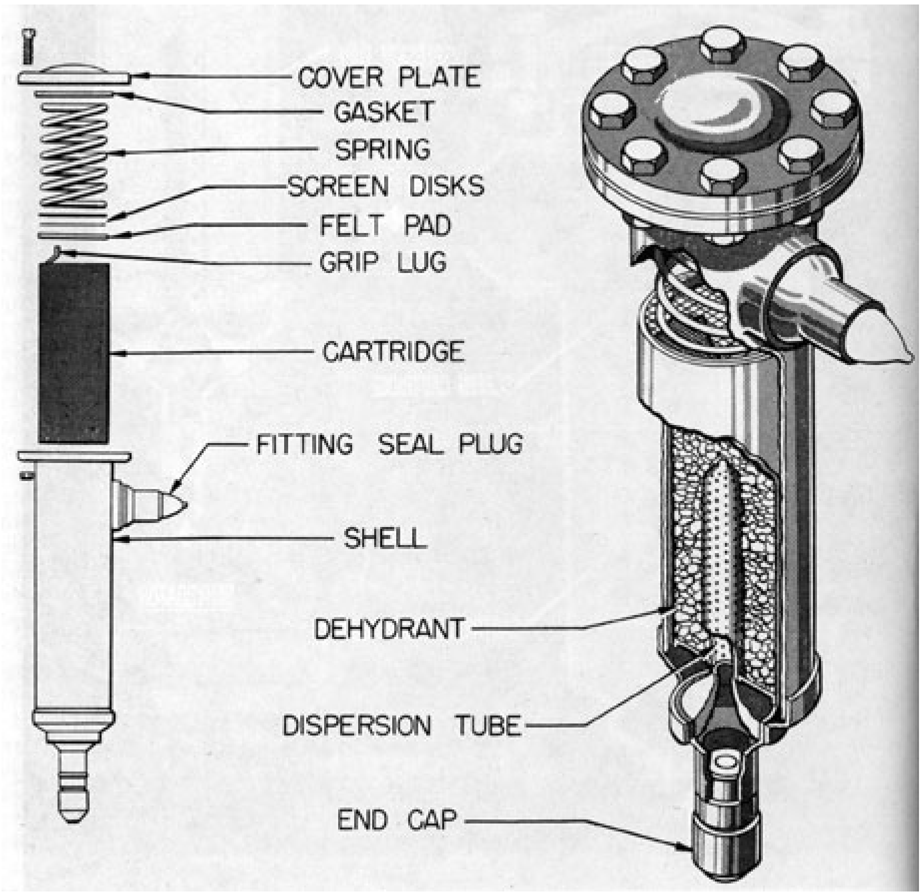
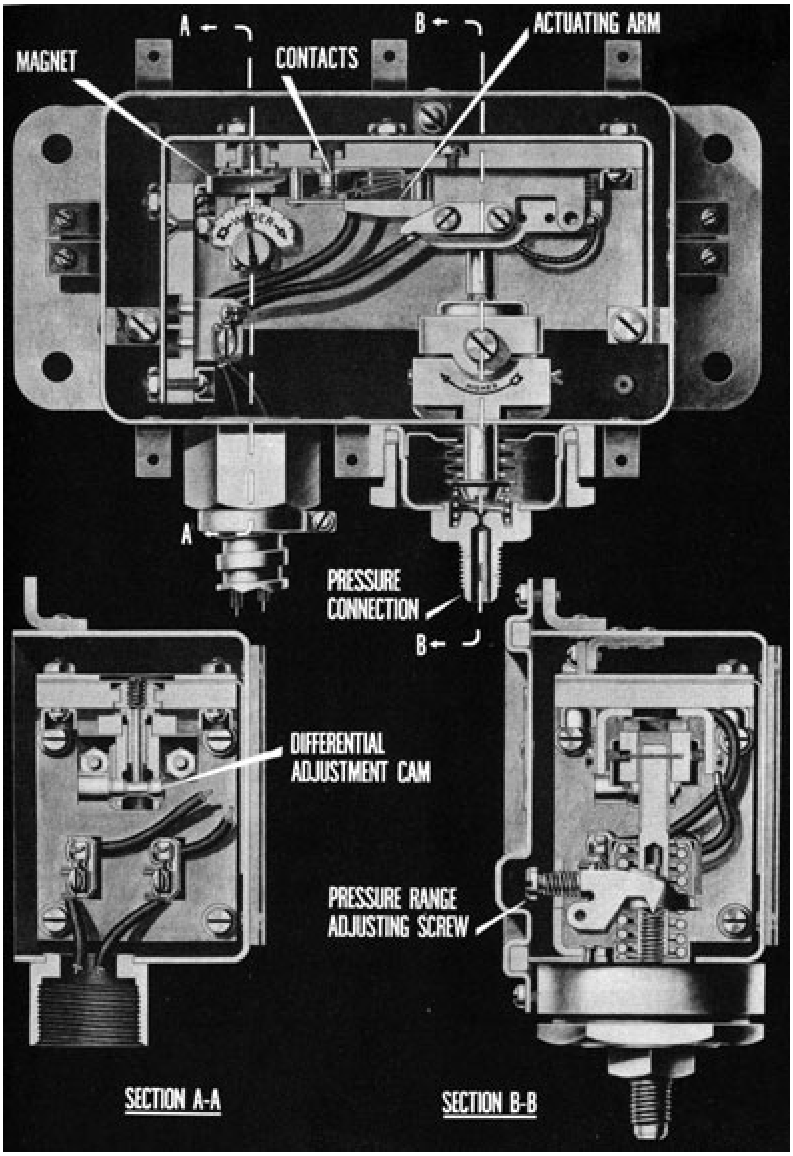


Figure 7-15. Dehydrator.



NavPers 17022, Amphib 106

Figure 7-16. Low- and high-pressure control switch, York ice machine.

7E9. Packless valves. A number of packless stop valves (two-way and angle types) are inserted in the refrigerating circuit at various places. A two-way valve is illustrated in Figure 7-19. This type is of the packless design and contains a puncture- and blowout-proof diaphragm that seals off the fluid flow chamber from the outside handle stem space. The lower stem is separate and is kept in contact with the upper stem, or handle part, by a spring; the sealing diaphragm is located between the two parts.

The combination bypass and check valve incorporated in the lower stem provides automatic opening under any pressure regardless of spring tension or spring size. This feature eliminates the necessity of applying pressure on the lower end of the stem seat and consequently makes this valve a multidirection universal packless valve.

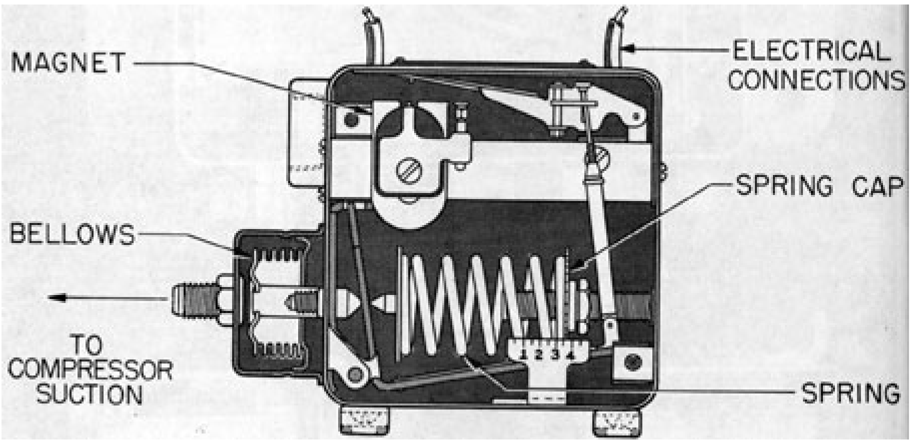


Figure 7-17. Low-pressure cutout switch.

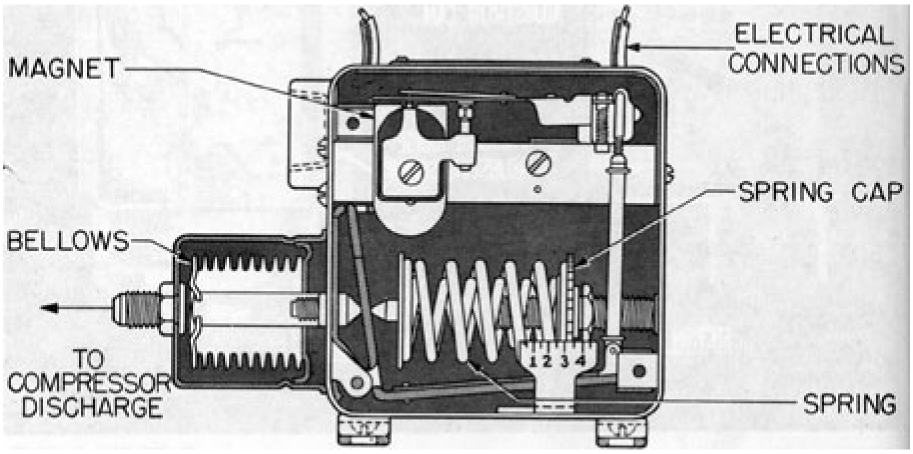


Figure 7-18. High-pressure cutout switch.

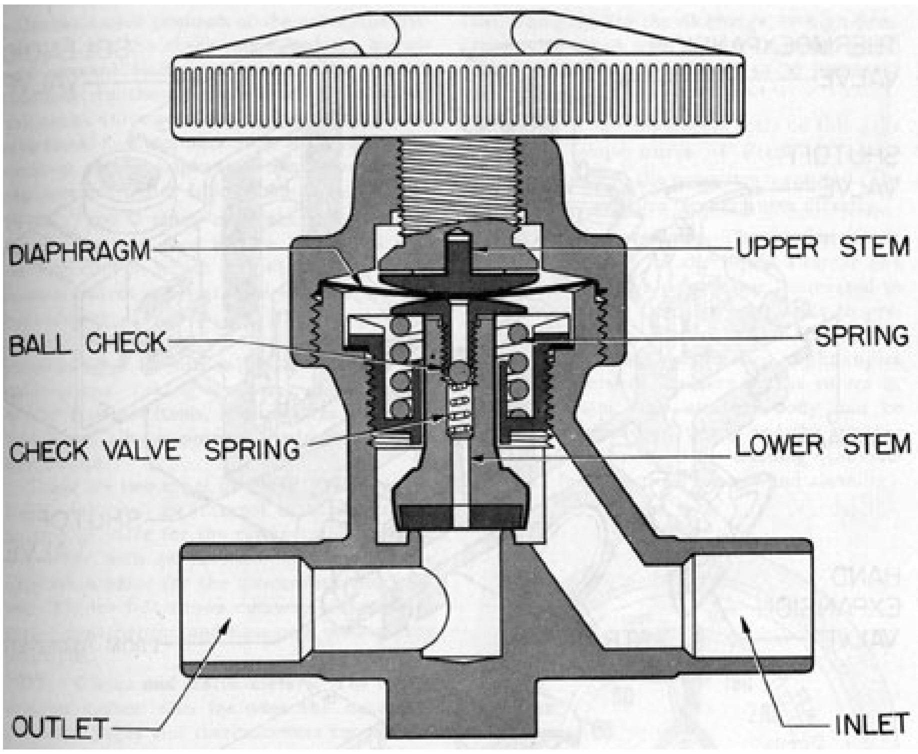


Figure 7-19. Packlass valve.

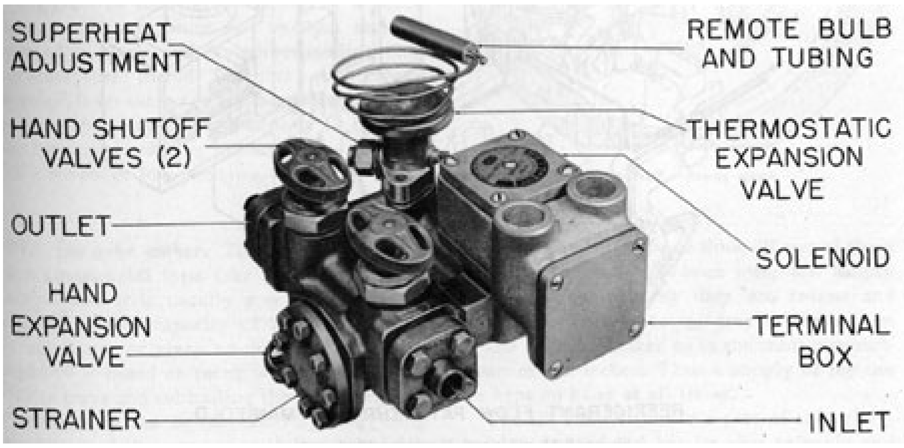


Figure 7-20. Type Q Navy manifold, exterior.

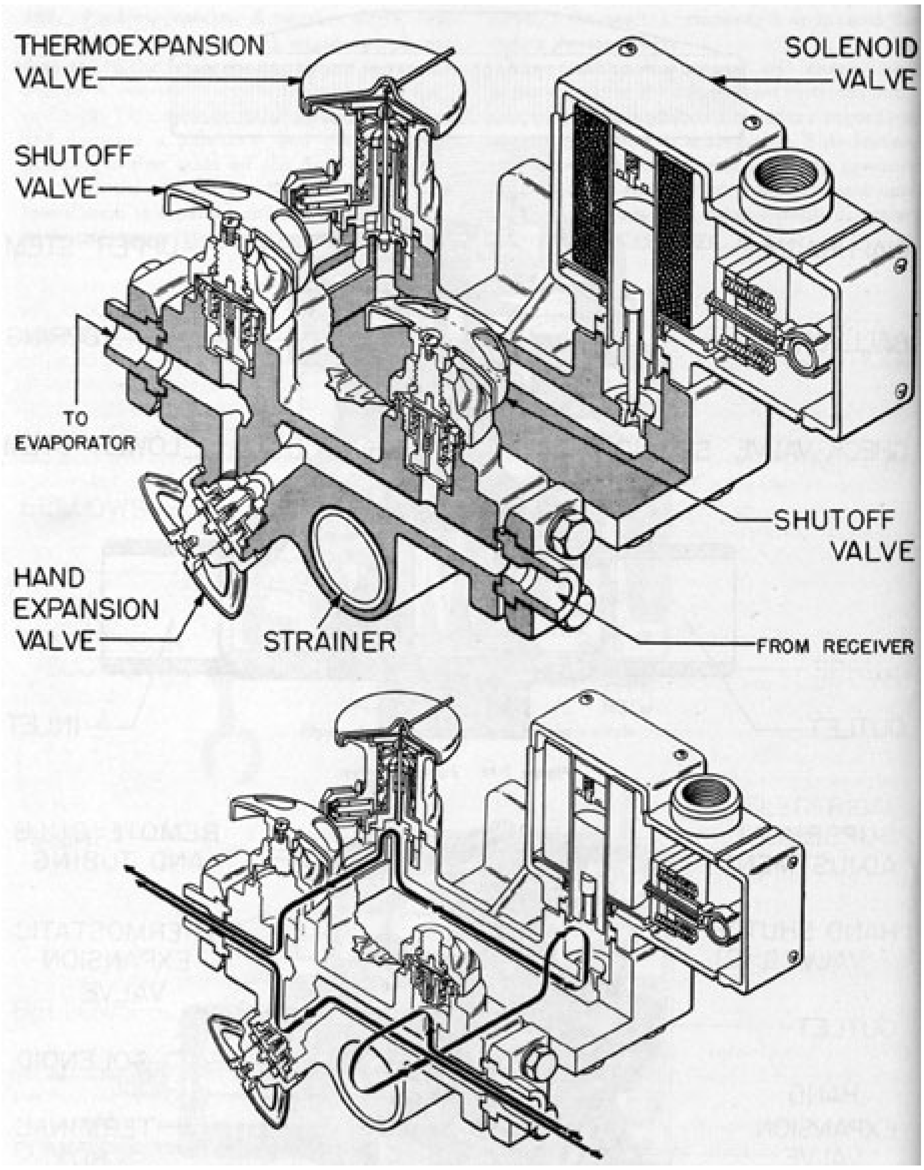


Figure 7-21. Type Q Navy manifold, cutaway.

In the closed position of the valve, the diaphragm and the check valve seal the bypass and psi. The gage for the discharge, or high-pressure, side (and the separate testing gage) reads to

prevent leakage to the auxiliary valve chamber. In the open position of the valve, the check valve seals the bypass, with a positive metal-to-metal back seat, and permits the removal of the diaphragms for inspection or replacement under full pressure.

7E10. Type Q Navy manifold. The Type Q Navy manifold (see Figure 7-20) is a new development in which several of the separate control valves are contained in a single compact casing. These include the thermostatic expansion valve, solenoid, strainer, hand expansion valve, shutoff valves, and flanged line connections. Taking the place of assemblies of the separate items, it eliminates 20 joints, which are always potential refrigerant leakage points.

There are two types of Type Q Navy manifolds, one with an internal equalizer on the expansion valve for the refrigeration system, the other with an external equalizer on the expansion valve for the air-conditioning system. Figure 7-21 shows cutaway views of interior construction and flow path through the manifold.

7E11. Gages and thermometers. The refrigeration system also includes the necessary pressure gages and thermometers for observing the pressures and temperatures at various places in the circuit.

Figure 7-22 illustrates the dial of a Freon 12 gage. The pressure and vacuum scale is printed in black, and the corresponding 300 psi. Both read to 30 inches of vacuum.

NOTE. The temperature scale on this gage indicates temperatures of Freon 12 corresponding only to the pressures measured. The gage cannot measure temperatures directly.

7E12. Suction strainer. The suction vapor strainer is similar to the liquid strainer and is located near the compressor, connected to the suction inlet line. Its purpose is to prevent scale, dirt, or foreign matter from entering the compressor, where they might injure the finely finished surfaces of the valves or cylinder walls. The strainer body can be opened by unbolting its cap and the strainer screen can be removed for cleaning (see Section 9F1 for directions on care and cleaning).

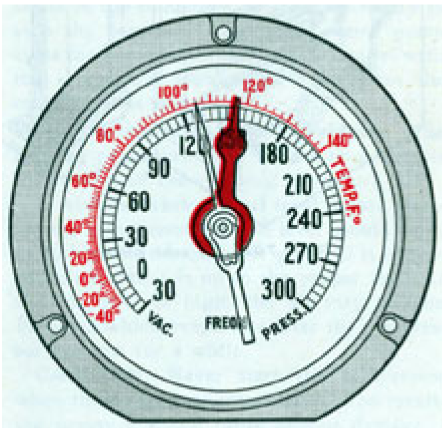


Figure 7-22. Freon Gage.

temperature scale in red. The short pointer, red in color, is an extra nonworking, or stationary, pointer that may be set manually to indicate the maximum working pressure. The gage for the suction, or low-pressure, side reads to 150

F. ACCESSORIES

7F1. Ice cube maker. The ice cube maker is of a commercial type (see Figure 7-23). On submarines it is usually a seven-tray cuber, and has a rated capacity of 15 pounds of ice in six hours or sixty pounds per day. This capacity is based on using water at 100 degrees F to fill the trays and subcooling the ice 15 degrees. The capacity can be increased by staggering the filling of the trays, that is, instead of filling all seven trays at one time, fill two of them at a time at about one-hour intervals. Empty the trays as soon as they are frozen and put the ice in the storage tray in the bottom of the ice cube maker or in the meat compartment of the icebox. Thus a supply of ice can be kept on hand at all times.

The ice cube maker is a part of the refrigerating system and has its own solenoid and

expansion valve (see Figure 7-1). The solenoid valve is wired into the electrical circuits of the solenoid valves of the cool room and refrigerating room in such a way that if either one of these two solenoid valves remains energized, the ice cube solenoid valve also remains energized. If both of these solenoid valves shut down, halting the refrigeration system, the ice cuber also stops operation.

7E2. Wardroom refrigerator. The wardroom refrigerator is designed especially for submarine installation and is built into the vessel. The refrigerating unit is located to the left of the box under the sink. The outstanding feature of this machine is that the condenser is air-cooled (see Figure 7-24). The refrigerator is for daily preservation of food used in the wardroom.

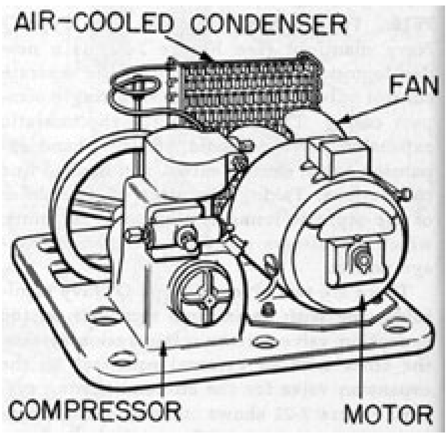


Figure 7-24. Wardroom

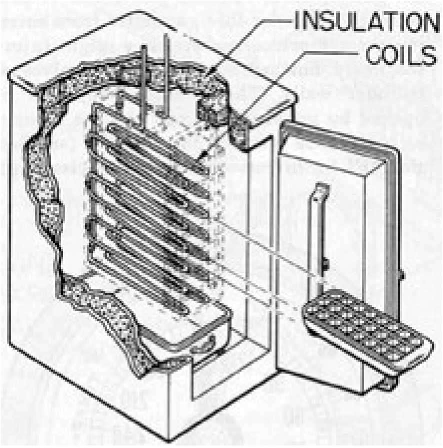


Figure 7-23. Ice cube maker.

refrigerator unit.

7F3. Scuttlebutt. A water coil in the cool room supplies cold water for the wardroom scuttlebutt. Care should be taken to keep the temperature of the cool room above freezing in order not to freeze the water in the coil.

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Figure 7-1. REFRIGERATION PIPING DIAGRAM.

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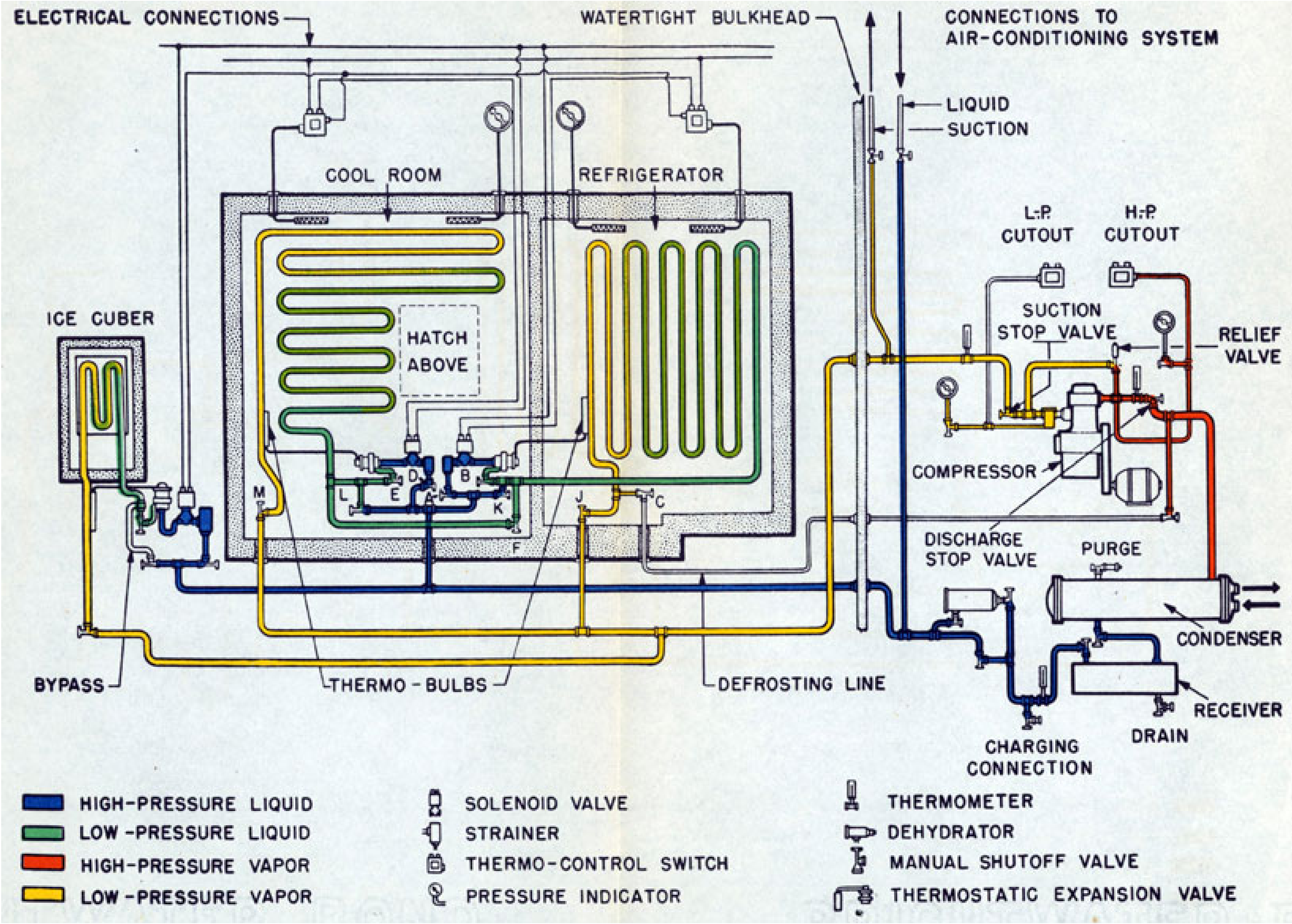
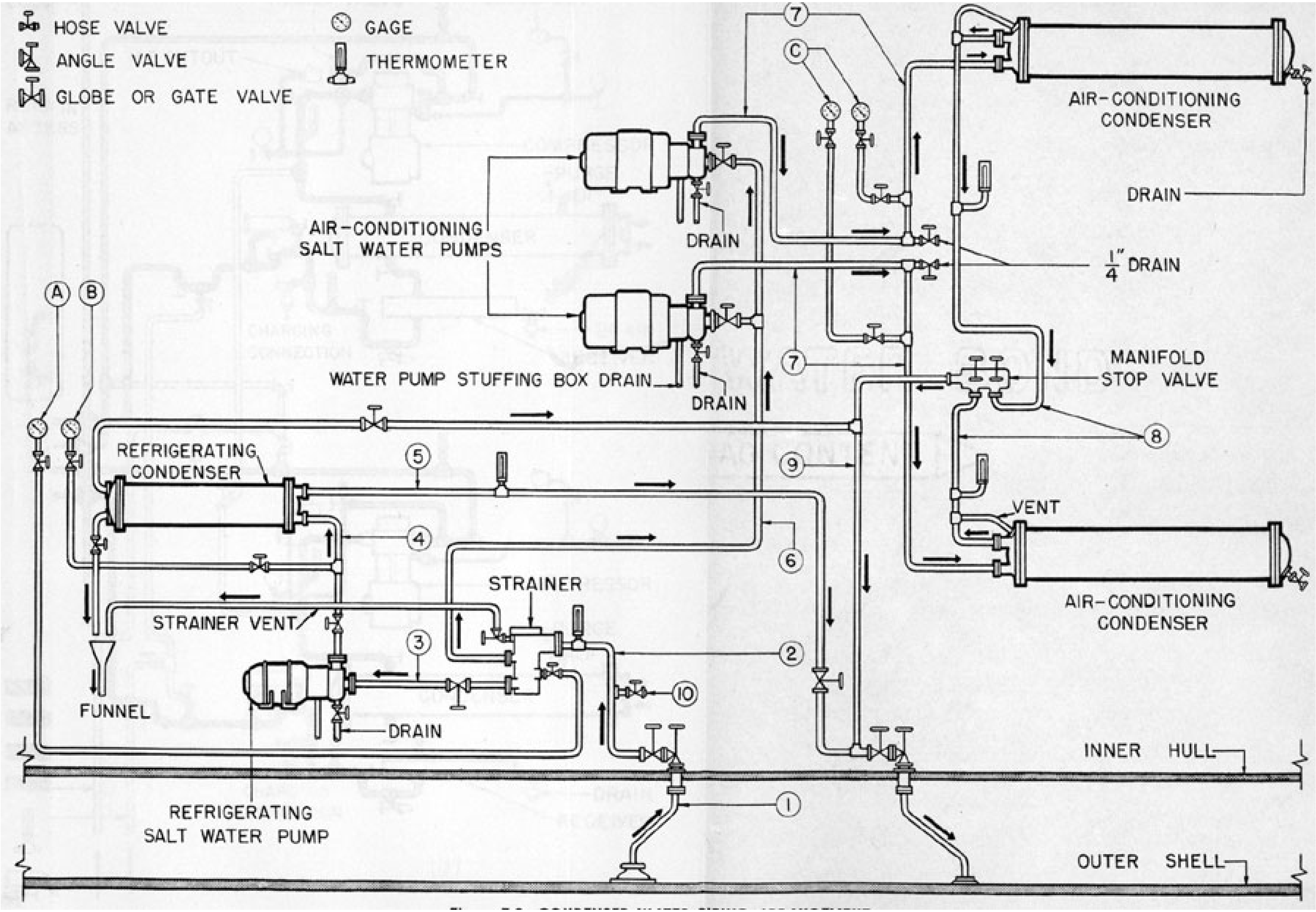

ELECTRICAL CONNECTIONS
WATERTIGHT BULKHEAD
CONNECTIONS TO AIR-CONDITIONING SYSTEM
LIQUID
SUCTION
COOL ROOM
REFRIGERATOR
L.P. CUTOUT
H.P. CUTOUT
SUCTION STOP VALVE
RELIEF VALVE
ICE CUBER
HATCH ABOVE
COMPRESSOR
DISCHARGE STOP VALVE
PURGE
CONDENSER
RECEIVER
DRAIN
CHARGING CONNECTION
BYPASS
THERMO-BULBS
DEFROSTING LINE
HIGH-PRESSURE LIQUID
LOW-PRESSURE LIQUID
HIGH-PRESSURE VAPOR
LOW-PRESSURE VAPOR
SOLENOID VALVE
STRAINER
THERMO-CONTROL SWITCH
PRESSURE INDICATOR
THERMOMETER
DEHYDRATOR
MANUAL SHUTOFF VALVE
THERMOSTATIC EXPANSION VALVE

Figure 7-8. CONDENSER WATER PIPING ARRANGEMENT.

Sub Refrig. Home Page


HOSE VALVE
ANGLE VALVE
GLOBE OR GATE VALVE
GAGE
THERMOMETER
7
C
AIR-CONDITIONING CONDENSER
DRAIN
1/4" DRAIN
AIR-CONDITIONING SALT WATER PUMPS
DRAIN
WATER PUMP STUFFING BOX DRAIN
DRAIN
7
MANIFOLD STOP VALVE
8
A
B
REFRIGERATING CONDENSER
5
9
VENT
4
6
AIR-CONDITIONING CONDENSER
STRAINER
STRAINER VENT
3
2
10
FUNNEL
DRAIN
INNER HULL
1
REFRIGERATING SALT WATER PUMP
OUTER SHELL

8
OPERATION AND TROUBLES

A. REFRIGERATION OPERATING DATA

8A1. Low-pressure side. Evaporator data: 1) gage pressure from 2 to 20 pounds; 2) temperature from -10 degrees F to 20 degrees F.

8A2. High-pressure side. Condenser data: 1) gage pressure approximately 105 psi; 2) temperature 93 degrees F; at condenser cooling water temperature 83 degrees F.

8A3. Condenser water flow. 1) Ten gallons per minute per refrigeration ton of 85 degrees F water; 2) a suction pressure corresponding to a temperature of -5 degrees F.

8A4. Low-pressure cutout. 1) Cutout at 2 psi; 2) cutin at 15 to 20 psi; 3) about 18 psi differential.

8A5. High-pressure cutout. 1) Cutin at 125 psi; 2) cutout at 150 psi. 8A6. Thermostat settings (approximate).

a) Refrigerator room: 1) cutout at 15 degrees F;

2) cutin at 20 degrees F.

b) Cool room: 1) cutout at 38 degrees F; 2) cutin at 40 degrees F.

B. OPERATION

8B1. Stopping the compressor. When stop ping the system, the procedure varies according to the length of the shutdown. A short shutdown is a period up to four hours. If the shutdown is for a longer period-for example, overnight-the oil in the crankcase absorbs Freon 12 and a special starting procedure is necessary.

8B2. Shutting down for a short period. In shutting down for a short period, proceed in the following manner:

7. Close the valves that control the cooling water in the condenser. It is not necessary to stop the condenser circulating water pump since the pump motor is wired in parallel with the compressor motor and stops when the compressor is stopped.

8B3. Starting after a short shutdown. The starting procedure after a short shutdown is the reverse of the stopping procedure.

1. Always check the oil level before starting the compressor. The oil level should be 1/2 to 3/4 high in

1. Remove the cap nut on the suction stop valve with the special wrench.

2. Rack off slightly on the packing gland nut. This relieves pressure on the gland and also reduces friction wear when the valve stem is worked.

3. With the wrench on the valve stem, slightly close the suction stop valve. The decrease in suction pressure slowly opens the low-pressure cutout switch.

4. When the motor stops, press the STOP button on the main compressor switch. This prevents the system from restarting accidentally.

5. Close the compressor discharge stop valve. This closes off the compressor from the rest of the system.

6. Close the receiver outlet valve. This traps most of the Freon 12 in the receiver and keeps it there during the shutdown.

the oil sight glass. If, it is low, add oil to bring it up to the proper level. If the oil level is high, the oil may contain Freon 12 which evaporates after the compressor has run for a while.

CAUTION. Never start the compressor when the entire crankcase is full. The resulting pressure would cause serious damage.

2. If the oil is at its proper level, open the condenser water supply valve.

3. Open the compressor discharge stop valve.

4. Open the receiver outlet valve.

5. Turn the compressor flywheel over several times by hand. This clears the cylinder of any oil and liquid Freon 12 that may have collected during the shutdown.

6. Start the compressor at the main switch.

7. With the compressor running, slowly open the compressor suction stop valve.

Watch the suction pressure gage dial and avoid rapid changes in pressure. When the suction stop valve is completely open, the system is in normal operation and under the control of the automatic mechanisms.

8. Tighten the packing gland nut and replace the cap nut on the suction stop valve.

9. Open the vents on the water side of the condenser to allow

7. Now start the compressor according to the procedure given in Section 8B3. As the system operates, the Freon 12 separates from the oil and remains in the system. The oil that has been pumped out of the crankcase returns to it.

8B5. Shutting down for a long period. Shutting down for a long period is sometimes called pumping down, since the procedure pumps most of the

any air that might be present to escape.

10. Close the vents.

NOTE. On some installations, continuous vents are installed, in which case Steps 4 and 10 are not necessary.

8B4. Starting after a long shutdown. After a long shutdown, overnight or longer, the crankcase may appear to be filled with oil. This indicates that a considerable amount of Freon 12 has been absorbed by the oil while the compressor was not running. Damage is likely if the compressor is started in this condition. Therefore, some of the oil and Freon 12 mixture must be pumped out of the crankcase before starting. The procedure for this operation is as follows:

1. Close the compressor suction stop valve.

2. Connect a 3/8-inch line between the suction pressure gage stop valve and the crankcase oil drain stop valve.

3. Open the suction pressure gage stop valve and the oil drain stop valve.

4. Slowly turn the compressor flywheel by hand. Do not start the compressor motor. Keep turning the compressor by hand until the oil level can be seen in the sight glass.

5. Close the suction pressure gage stop valve and the oil drain stop valve.

6. Disconnect the 3/8-inch line from the compressor.

Freon 12 out of the coils of the evaporator and stores it in the receiver. Pumping down should be done whenever the plant is taken out of service overnight or longer.

1. Wedge the low-pressure cutout switch. This prevents the motor from stopping when the pressure drops below the normal setting.

2. Close the receiver outlet valve. The compressor now draws most of the refrigerant out of the liquid line and the evaporator and places it in the receiver.

3. When the suction pressure reaches zero, push the STOP button on the control panel.

4. Close the compressor suction and discharge stop valves.

5. Close the condenser water supply valves.

6. When restarting, do not forget to remove the wedge from the low-pressure cutout switch.

8B6. Operating difficulties. Faulty operation of the system is indicated by definite symptoms. These symptoms may be caused by one or more incorrect conditions which must be eliminated in a step-by-step process of methods of correction. The following chart of symptoms, their causes and correctives, assists the operator in correcting faulty operation quickly and efficiently.

TROUBLE DIAGNOSIS CHART		
SYMPTOM	**CONDITION MAY BE CAUSED BY**	**CORRECTION**
High head pressure	1. Air or noncondensable gas in system 2. Inlet warm water 3. Insufficient water flowing through condenser 4. Condenser clogged or scaled up 5. Too much liquid in receiver, condenser tubes submerged in liquid refrigerant	1. Purge air from condenser 2. Increase quantity of condensing water 3. Increase quantity of water 4. Clean condenser tubes 5. Draw off liquid into service drum
Low head pressure	1. Too much water flowing through condenser 2. Water too cold, unthrottled 3. Loose thermal bulb 4. Leaky discharge valve	1. Reduce quantity of water 2. Reduce quantity of water 3. Check and tighten thermal bulb 4. Remove head, examine valve diaphragm; replace if found defective
High Suction pressure	1. Overfeeding of expansion valve 2. Leaky suction or discharge valve 3. Hand bypass open or, if in use in place of expansion valve, open too much	1. Regulate expansion valve; check bulb attachment 2. Remove head, examine valve disks; replace if worn 3. Check hand bypass valve
Low suction pressure	1. Restricted liquid line and expansion valve or suction screens 2. Insufficient gas in system 3. Moisture in system, causing freezing of expansion valve	1. Pump down, remove, examine, and clean screens 2. Check for gas shortage 3. Wrap hot cloths around expansion valve and cycle through dehydrator

	4. Too much oil circulating in system 5. Improper adjustment of expansion valves 6. 1/4-inch or more frost on evaporator coils	4. Check for too much oil in circulation; remove oil 5. Adjust valves to give greater flow 6. Defrost

TROUBLE DIAGNOSIS CHART (Continued)		
SYMPTOM	**CONDITION MAY BE CAUSED BY**	**CORRECTION**
Compressor short cycles (on high-pressure cutout)	1. Insufficient water flowing through condenser, clogged condenser cutout 2. High-pressure cutout incorrectly set 3. System overcharged with refrigerant	1. Determine if water has been secured; check for scaled or fouled condenser 2. Check setting of high-pressure cutout 3. High-pressure cutout may be tripping as a result of insufficient condenser capacity because tubes are submerged
Compressor short cycles (on low-pressure cutout)	1. Coils in refrigerators clogged with frost 2. Liquid, suction, or expansion valve screens clogged 3. Thermal bulb on expansion	1. Defrost coils 2. Pump down and clean screen 3. Detach thermal bulb from suction line and hold in palm of one hand with the other hand gripping the suction line; if flooding through is observed, bulb has not lost its charge; if no flooding through is noticed, replace expansion valve

	valve has lost charge	
Compressor runs continuously	1. Shortage of refrigerants 2. Discharge valve leaks badly	1. Test refrigerant; if short of liquid, add amount necessary; test for leaks 2. Remove head of compressor, and repair or replace valves
Compressor noisy	1. Vibration because not bolted to foundation rigidly 2. Too much oil in circulation, causing hydraulic knock 3. Slugging due to flooding back of refrigerant 4. Wear of parts such as piston pins, bearings, etc. 5. Flywheel loose	1. Bolt down rigidly 2. Check oil level 3. Expansion valve open too wide, close; thermal bulb incorrectly placed or loose, check 4. Determine location of cause; repair or replace compressor 5. Check key, tighten flywheel nut

TROUBLE DIAGNOSIS CHART (Continued)		
SYMPTOM	**CONDITION MAY BE CAUSED BY**	**CORRECTION**
Compressor will not start	1. Overload tripped, fuses blown 2. Switch out 3. No charge of liquid in system operated	1. Reset overload, replace fuses and examine for cause of condition 2. Throw in switch

	by low-pressure control 4. Dirt or foreign matter on control points of either high- or low-pressure cutouts	3. With no liquid in system, there is insufficient pressure to throw in low-pressure control; recharge system with liquid; stop leaks 4. Check and clean points
Head gasket leaks	1. Head bolts stretched, or washers crushed	1. Examine gaskets, replace if necessary; tighten head bolts; replace washers
Cylinders and crankcase sweating	1. Too much oil in circulation; too much refrigerant in circulation 2. Hand bypass valve open or, if in use in place of expansion valve, open too much	1. Examine for conditions of refrigerant and oil charge; correct anything wrong 2. Check hand bypass valve

8E7. Electric system. As electric energy is a main factor in refrigeration, a good service man should have a working knowledge of the electrical controls, their functions, how they are energized, and what voltage and amperage they carry. However, this does not imply that the auxiliary man should attempt electrical repairs. This work should be accomplished under the supervision of the electrical department.

Main power for refrigeration and air-conditioning systems is controlled from the auxiliary board in the control room. This switch energizes both systems through two 30-ampere fuses to the refrigeration control panel in the pump room and through four 60-ampere fuses, two for each unit, to the air conditioning system.

box in the pump room, it is divided into two branches: one branch goes through the three steps on the starter, then to the motor of the compressor; the other branch goes through the starter control side of the panel through two separate fuses. The current from these fuses goes through a selector switch that can be set to operate the plant either manually or automatically. When this switch is on automatic, the current passes through a number of controls that are wired in series with each other. These controls are as follows: from selector switch to and through the holding-in coils of the starter, through the low-pressure cutout, and high-pressure cutout. Therefore, any of these controls, or a burned-out holding-in coil can stop the compressor. The selector switch is so made that it makes a number of contacts with only two positions.

When electric current reaches the starter

C. DEFROSTING

8C1. Defrosting the refrigerating room. As in a household refrigerator, the cooling coils of a submarine refrigeration room gradually accumulate a covering of frost from moisture in the air condensing and freezing on the coils. Frost acts as a heat insulator, reducing the cooling efficiency of the system and requiring longer running of the compressor. Therefore, this frost must be removed periodically, and defrosting is one of the important routine operations.

The refrigeration room evaporator is the one that frosts. The cool room evaporator coils normally are not cold enough to frost.

Defrost as often as necessary. Never let more than 1/8 to 1/4 inch of frost accumulate on the coils. Defrosting is simple and should be done frequently.

For defrosting, a special piping connection that conveys hot vapor from the compressor to the evaporator is used. This special piping branches off from the discharge line between compressor and condenser, goes through the wall of the refrigerator room, and connects to the suction line at the outlet of the evaporator coils, where shutoff valves are provided.

2. Stop the compressor. 3. Close the liquid supply valves (A, B, and L).

4. Open the liquid supply valves (K, D, and E).

5. Open the hot vapor line valves (C) and the suction shutoff valve (M).

6. Close the suction shutoff valve. (J).

7. Start the compressor.

Part of the hot vapor flows through the valve (C) into the refrigerator room evaporator. This evaporator then acts as a condenser and the vapor condenses at a temperature high enough to melt the frost. The refrigerant passes as a liquid through valves (K) and (D) to the expansion valve on the cool room evaporator and enters the cool room evaporator coils in the normal way. That is, the Freon 12 is now a liquid and in the cool room evaporator it boils off, changes to a vapor, and goes through valve (M) back to the suction side of the compressor.

The ice tuber should be left in a normal operating condition, and should not be de frosted when defrosting the refrigerating room. The hatch of the cool room should be left open during defrosting operations, so that an abundance

Defrosting is done while the system is running. The hot vapor introduced into the coils melts the frost in less than half an hour.

See Figure 7-1 for location of valves referred to by letter in the procedure for defrosting, which is as follows

1. Close the king valve on the receiver, and pump the system down to about 5 psi.

of heat is supplied to the cool room evaporator to insure a complete boiling off of the liquid refrigerant in the evaporator. When all the frost is off the refrigerator room coils, restore the system to regular operation.

8C2. Defrosting the ice tuber. To defrost the ice tuber, close the liquid supply valve and the suction valve. Open the door of the ice tuber.

9
CARE AND MAINTENANCE

A. GENERAL INFORMATION

9A1. Checking the system. A regular routine of checking a refrigeration system, or systems, should be established to insure proper care and operation. Make a systematic check every two weeks of all pressures and temperatures throughout the system. Such a check determines the need for any, corrective measures before the condition becomes acute.

9A2. Opening a charged system. Whenever it is necessary to open a fully charged system for investigation or repair, the final evacuation should be to a pressure slightly above atmospheric pressure (1 to 2 pounds' gage) to prevent air from entering the system. If the final pressure should reach a point lower than zero pounds' gage, sufficient refrigerant should be admitted to the evacuated part to raise the pressure to between 1 and 2 pounds' gage. Connections may then be broken, and the necessary investigation or repairs made. If more than a few minutes must elapse after breaking the connections, the open ends of the system should be plugged.

When connecting the part to the system again, make one joint circulating water valves wide in order to run with the lowest possible head pressure and to condense all condensable vapors.

3. Shut down the compressor.

4. Close the discharge valve on the compressor.

5. Close the stop valve from the condenser to the receiver.

6. Attach a small hose to the air purge valve on the condenser.

7. Insert the other end of the hose in a glass jar or vessel filled with water or light Freon oil.

8. Crack the purge valve on the condenser. If air is in the system, large air bubbles will show in the water. When all the air is out, small bubbles will show in the water, and a sharp cracking sound will be heard. These small bubbles are Freon. The purge valve should now be closed, and the system put into normal operation.

The other method of testing for air in the system is by observation of temperatures as follows:

1. Operate the system for 30 minutes. Observe the pressure and temperature as indicated on the high-pressure Freon 12 gage.

first and blow out the part under investigation with gas from the system, then quickly finish making up the other joint.

Refrigerant charging lines, although of small size and short length, should be purged with refrigerant gas immediately before actual charging is started.

9A3. Purging air from system. After a system has been open for repair, it is advisable to check for air in the system before proceeding with regular operation. Either of two methods may be used for checking for air. The preferred method is as follows:

1. Close the liquid king valve from the receiver.

2. Pump down the system to 5 inches of vacuum.

NOTE. While pumping down, open the

2. Compare the temperature corresponding to the discharge pressure, as noted in red figures on the dial of the pressure gage, with that shown on the liquid. If it is more than 5 degrees lower than the temperature corresponding to the discharge pressure, the system should be purged.

3. While the system is operating, purge air by cracking the purge valve on the condenser. Purge at intervals until the air is expelled from the system. This is indicated by a temperature difference of about 5 degrees.

9A4. Testing far leaks. If leakage is suspected in any of the joints or other parts, use the testing procedure detailed in Section 11F.

B. EVAPORATOR

9C1. Cleaning evaporator coils. The evaporator coils of the refrigeration system should be cleaned only with a clean dry cloth each time the coils are defrosted.

C. COMPRESSOR

9C1. Starting the compressor after a prolonged shutdown. IMPORTANT. Before starting a Freon 12 compressor that has been idle for some time, observe the height of the oil level in the compressor crankcase. If the oil level is above the oil sight bull's eye, a considerable quantity of remove the seal cap. To permit the valve stem to operate freely, loosen the valve stem packing gland. When opening or closing the valve by means of a wrench on the valve stem, or when tightening the internal packing gland with a wrench, it is essential to exercise every precaution not to scratch or

Freon 12 has been condensed in the crankcase and absorbed by the oil. The amount of Freon 12 mixed with the oil depends upon the temperature of the oil and the length of the shutdown period. The oil and Freon 12 solution may entirely fill the compressor crankcase. If the compressor is started under such conditions, the shaft seal diaphragm may be broken or the seal assembly distorted. Excess oil and Freon 12 solution may be drained from the crankcase by the following procedure:

1. Temporarily connect a 3/8-inch line from the compressor oil drain valve to the suction pressure gage valve.

2. Close the suction stop valve.

3. Open the oil drain valve and the suction pressure gage valve; then slowly rotate the compressor by hand. Do not start the compressor motor. Continue rotating the compressor by hand until the oil level can be seen in the oil sight glass.

It is expected that oil which leaves the compressor crankcase will return to the compressor during normal operation. However, after the system has been placed in operation, check the oil level over a period of several hours. Do not allow the compressor to operate with a low oil level in the crankcase.

9C2. Stop valves. If the stop valves on the compressor are of the double packed type, the valve stem is packed with a conventional stuffing box and a steel cap is provided to screw otherwise mar the gasket seat which is the top edge of the valve body. Remember that valves made of brass are soft as compared to the steel used in the wrenches. Any scratches or burrs raised on this gasket seat by careless operation of the wrench are certain to impair the efficiency of the gasket joint.

If a valve of this type is manipulated frequently, the gasket should be inspected occasionally to see that it is in good condition.

If this gasket shows signs of flattening or of being scored, it should be renewed. The seal cap over the valve stem should provide an absolute seal against leakage, providing the gasket surface is not damaged and providing the gasket is in first-class condition.

IMPORTANT. Each time the valve is manipulated, the packing gland should be tightened, the seal cap drawn tight, and the gasket joint tested for leakage.

CAUTION. If the internal packing gland on the stop valve stems is not kept properly tightened, it is possible in opening the valve to back out the stem far enough to compress this packing from the inside and thus raise the valve stem higher than the normal full open position. The seal cap might then bear hard against the valve stem where the valve is open farther than normal, before it would seat properly on the gasket. Therefore, care should be taken to see that the internal packing gland is tight, and that the valve is not open farther than its normal full open position.

over the stem as a second seal against leakage around the stem. This seal cap seats on the top face of the valve body with a copper ring gasket or fiber gasket between.

9C3. Operation of stop valves. In order to manipulate the stop valves, it is necessary to

9C4. Difficulty of checking the oil level. As stated in Section 7B16, the greater the amount of Freon 12 absorbed by the oil, the higher the apparent oil level. The amount of refrigerant in the mixture is greater after a prolonged

shutdown period. Therefore, a check of the oil level immediately after a prolonged shutdown is worthless for determining the actual working oil level.

9C6. Best time to check the oil level. The best time to check the oil level is after a prolonged period of operation, because then there is the least amount of refrigerant mixed with the oil. During the period of operation, the refrigerant is pumped out of the oil until only the normal quantity remains in solution. This check should be made with the compressor stopped.

9C6. Checking the oil level after a prolonged shutdown. If the apparent oil level is observed after a prolonged shutdown period and is above the sight glass in the side of the compressor, it is a good indication that a considerable amount of Freon 12 has been absorbed by the oil while the compressor has not been running. If this is the case, start the compressor as described in Section 8B4. If the oil level is lower than 1/4 up on the glass, it is almost certain that the actual

In adding oil, it is recommended that the level be raised only 3/4 up the glass.

9C8. Adding oil. To add oil to the compressor crankcase, use the small oil pump designed for this purpose and proceed as follows:

1. Remove the protector cap from the end of the oil pump and wipe the pump cylinder clean.

2. Insert the oil pump into the can of oil to be used.

3. Connect the pump discharge hose to the compressor crankcase oil charging valve, but do not tighten.

4. Hold the pump firmly, being careful not to strike the bottom of the oil can hard enough to puncture it. Displace the air in the oil pump connections by several strokes of the pump handle until oil appears at the oil charging valve. Then tighten the flare nut attaching the oil hose to the charging valve and open the valve.

IMPORTANT. Use Navy Oil, Symbol No. 2135, or equivalent.

5. Pump oil into the compressor crankcase until the oil covers 4 of the bull's-eye sight glass.

working oil level is far too low. Add sufficient oil to raise the oil level to 3/4 up on the glass in the side of the crankcase. The compressor should now be started and checked as described in Section 9C7.

9C7. Checking the oil level when running. To check the oil level when the compressor has been running on its normal cycle with no prolonged shutdown:

1. Wait until the end of a period of operation, or if the operation is continuous, wait until it has operated at least half an hour.

2. As soon as the compressor stops, turn the flywheel until the two tapped holes for the flywheel puller are in a vertical line and observe the oil level in the bull's-eye sight glass. It nay be necessary to wait a few minutes until the oil settles in the crankcase.

The ideal oil level is from 1/2 to 3/4 up in the glass, checked as outlined above.

CAUTION. Do not remove oil from the crankcase because of an apparent high level unless it is known that too much oil has been added previously. If the oil level, checked as above, is lower than 1/4 up the glass, add oil.

6. Close the charging valve tightly, replace the valve seal cap, and disconnect the pump hose, taking care not to spill oil on the deck. Replace the flare seal cap on the oil charging valve outlet.

7. Place the protector cap on the oil charging pump when the pump is not in use.

NOTE. When steel or iron pipes and fittings are used for Freon 12 mains, condenser, or evaporator, a sample of oil from the crankcase should be taken at least every six months, and if it proves to be contaminated with scale or foreign matter, all the oil must be removed. If clean copper tubing is used for the Freon 12 mains, condenser, and evaporator, and reasonable care has been exercised against dirt entering the system during its installation, the oil in the compressor crankcase probably is not contaminated sufficiently to require renewal between overhaul periods; but if the compressor is ever disassembled and left open to the atmosphere longer than six hours, the oil must be renewed, since it will have absorbed sufficient water from the atmosphere to make

renewal necessary. The cleanness of used oil is easily determined by observation. Pour a sample of oil into a glass and allow it to stand for a few minutes until the oil foam has dissolved.

If particles of scale or foreign matter are visible either on the surface or in suspension, the oil is dirty and should not be used, Drain the crankcase and add new oil.

D. CONDENSER

9D1. Condenser shutdown. If there is a possibility of obtaining a freezing temperature in the condenser compartment during the shutdown period of any condenser, it is necessary that the condenser be thoroughly drained of water, to prevent a freeze-up that would damage the condenser tubes.

9D2. Cleaning the condenser. The condenser tubes should be inspected every three months, to determine whether or not cleaning is required.

All condensers should be cleaned before the vessel leaves the harbor for war patrol.

To clean the condenser tubes, shut off the water supply and discharge valves and drain the tubes; then remove the heads.

Use a water lance and soft rubber plugs to clean the condenser tubes. Care must be taken that the protective film of corrosion-resisting preparation on the inner surfaces of the tubes is not destroyed during the cleaning process. Inspect the zinc fingers at regular monthly intervals. Renew the fingers when they show 30 percent deterioration.

These instructions have been taken from the York instruction book, but in actual operation it has been found that the condenser gives very little trouble, and if the system has not been operated in shallow waters, there is little chance of the condenser becoming dirty. The operating temperatures are insert the exploring tube of a leak detector. If this simple test shows the presence of Freon 12 gas, the exact location of the leak or leaks may be determined as follows:

1. Remove the water heads and listen at each section for the hissing sound that indicates gas leakage. This assists in locating the section of tubes to be further investigated. If the location is not definite, all the tubes must be investigated. If the probable location of the leaky tubes is determined, treat that section in the following manner

2. Wash the tube heads, and with a cloth or a ball of cotton, clean all the tubes (while wet) until the inner walls are dry and shining; then hold the exploring tube in one end of each condenser tube long enough (about 10 seconds) to draw in fresh air. As soon as fresh air is drawn into the tube, drive a cork into each end of the tube. Repeat this with all the other tubes in the suspected section, or if necessary, with all the tubes in the condenser. Then let the condenser remain in this condition for 48 hours before doing anything further.

NOTE. It is against submarine instructions to have carbon tetrachloride on board. However, the condenser may be overhauled or tested outside the submarine. If the condenser is being tested for leaks outside the submarine, carbon tetrachloride should not be used in cleaning the tube heads or tubes, as its fumes give the same flame discoloration as Freon 12,

low enough so that scale does not form in the tubes. Unless there is a definite indication that the condenser is plugged up, it is opened only for inspection at regular overhaul periods.

9D3. Defecting condenser leaks. In order to prevent serious loss of refrigerant through leaky tubes, it is advisable to test the condensers for leakage once every two weeks. The test should always be conducted on a condenser that has not been in use for at least 12 hours. There is always a small air pocket in the top of the heads. Slowly open the vent valves on the water side, one at a time, and and serve only to confuse the investigation.

3. After the tubes have been corked up for 48 hours, get three men on the job, one to remove corks at one end, one to remove corks at the other end and handle the exploring tube, and the third man to watch the color of the flame in, the lamp. Start with the top row of tubes in the section being investigated, remove the corks simultaneously at each end of the tube, and insert the exploring tube for 5 seconds; this is long enough to draw into the lamp any Freon 12 gas that is bottled up in the tube.

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4. Mark any leaky tubes for later identification.

5. Leakage of any of the tube joints is indicated by the presence of oil at the joint after tire 48-hour period.

The procedure described is a laborious one, but it is the only method found to date that can give conclusive evidence, and it has given satisfactory results in most cases in which it has been used.

E. THERMOSTATIC EXPANSION VALVE

9E1. Indications of need of cleaning. When the thermostatic expansion valve is working properly, the temperature of the pipe on the outlet side of the valve is much lower than the temperature of the pipe on the inlet side. if this temperature difference does not exist when the plant is in operation, it is an indication that the valve seat is dirty and clogged with foreign matter.

9E2. Cleaning. If the valve seat is dirty or clogged, the best admit liquid to the evaporator coils during the period required for repairs, being careful not to open the bypass wide enough to allow liquid Freon 12 to carry over to the compressor.

After the necessary repairs have been made, be sure that all internal parts are thoroughly clean and dry. Place the valve bonnet assembly on the valve body and pull up the bolts hand tight. Open slightly the stop valves on each side of the thermostatic expansion valve long enough to expel the air

remedy is to close the stop valves on each side of the thermostatic expansion valve and remove the valve bonnet assembly from the valve body to obtain access to the internal parts. Do not pinch the small remote bulb tubing.

Use the manually operated bypass valve to from the line, and bolt the valve together securely.

After all connections have been made and tested for leakage, close the manually operated bypass valve tightly. Open the stop valves on each side of the thermostatic expansion valve and operate as usual through the thermostatic expansion valve.

F. SUCTION LINE STRAINER

9F1. Cleaning the suction strainer. The suction vapor strainer in the suction line at the compressor serves to prevent scale or foreign matter from entering the compressor. To clean the strainer screen proceed as follows:

1. Pump out the compressor.

CAUTION. Before the strainer is opened, be sure the gage shows slightly above atmospheric pressure. Use accurate gages.

2. Mark the strainer body cover so that it can be replaced in its original position. The gasket should also be replaced in its original position.

3 Remove the strainer body cover, with draw the strainer, and immediately replace the cover on the strainer body to prevent foreign matter or moisture from the air from getting into the system.

4. Clean the strainer and spring by washing them in approved cleaning solvent; dry them in the air.

5. Clean the strainer seat inside the strainer body, being careful to wipe out any particles that may drop down into the strainer body. Use only chamois or lint-free cloth. If this strainer seat is dirty, the screen does not seat properly and dirt may pass through into the compressor.

6. Reassemble the strainer in the body with the spring in place.

7. See that the cover gasket is in good condition.

8. Bolt the cover on the body, drawing up the capscrews evenly.

G. CARE OF V-BELTS

9G1. Alignment and tension. To insure long life and satisfactory operation of the V-belts, the The main steps used to align and apply the V-belts are as follows:

motor pulley and flywheel must be in exact alignment and the belts must be under proper tension.

1. Preparatory to aligning the drive, find the magnetic center of the rotor. This may be done by running the motor idle and measuring

from the inside face of the motor pulley to some fixed point on the motor frame. This distance must be maintained during the alignment procedure.

2. Loosen the bolts that hold the motor to the base.

3. Move the motor on the rail base forward far enough for the belts to slip over the pulley and flywheel without stretching.

4. Proceed with the alignment, keeping in mind that the face of the motor pulley must be parallel with the face of the flywheel, that the belt grooves must be in alignment, and that the rotor must be on its magnetic center.

5. By means of the adjusting screws on the motor base, move the motor back until the belts are reasonably tight. To have the proper tension, a belt should have about a 1-inch sag when applying thumb pressure halfway between the pulley and the flywheel. When this condition is obtained, tighten the bolts holding the motor to the base. Belt dressing should not be used on the belts and the belts should never be cut and spliced.

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10
SERVICE INSTRUCTIONS, YORK COMPRESSORS

A. GENERAL INSTRUCTIONS

10A1. Precautions. The York Balanseal compressors, 2 5/8- and 4-inch bore, are so designed that any competent mechanic can service them in the field. Good judgment should always be used in the analysis of service troubles and specific instructions should be followed as directed.

It is important that the following precautions be observed:

1. Before dismantling the compressor, be sure that the faulty operation of the installation is not caused by trouble in some other part of the system.

2. Dismantle only the part of the compressor necessary to correct the fault.

3. Never open any part of the compressor while it is under vacuum; be sure that there is some pressure inside as indicated by a reading above zero on the gage. Be sure that the gage is accurate. If any part of the system is opened while under vacuum, that is, when the pressure inside is lower than the pressure outside, air will enter the system. This air nearly always contains some moisture, which freezes and interferes with the operation, or even causes damage. It is also important that air or moisture be prevented from coming in contact with machined parts after they have been exposed to Freon 12.

4. Internal machined parts of the compressor, such as the valves, pistons, shaft seal, and crankshaft, must be protected from the atmosphere immediately upon being removed from the compressor. Corrosion occurs quickly if this precaution is neglected. As soon as removed, each part must be wrapped in paper.

5. IMPORTANT. To disassemble or reassemble the compressor, use only the tools specified for the particular operation involved.

10A2. Direction of rotation. The shaft seal on submarine installations is designed for counterclockwise rotation of the compressor as viewed from the flywheel end. The compressor must not be operated in the opposite direction.

B. OPENING COMPRESSOR FOR REPAIRS

10B1. Pumping down for repairs. Before opening a compressor for examination or repair, it is necessary to pump down the system.

a. Pumping Freon 12 out of the compressor. To pump Freon 12 out of the compressor, proceed in the following manner:

1. Close the suction stop valve.

2. If the compressor is operated normally under suction pressure control, block the suction pressure switch in its running position. This can be done without disturbing the adjustment. Open the compressor discharge valve about two turns of the stem.

4. Start the compressor and let it run until the greatest vacuum possible is obtained.

5. Stop the compressor and immediately close the discharge stop valve. The procedure outlined in Step 4 and the first part of Step 5 should be repeated if the pressure indicated by the suction gage rises rapidly to 15 psi or more above zero pressure, for such a rise indicates that considerable Freon 12 remains in the crankcase oil. Do not expect to retain zero pounds' pressure on the suction gage, because Freon 12 vapor is continually released from the oil in the crankcase.

6. After the vacuum is pumped, wait until the pressure builds up to 2 or 3 pounds above zero pressure before opening any part of the compressor or its connections.

7. Before proceeding with any work on the compressor, see that the main disconnect switch is open. After examination or repair, remember to unblock the suction pressure switch before resuming operation.

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b. Evacuating air from the compressor. To evacuate air from the compressor after completing its reassembly, proceed as follows:

NOTE. During examination or repair, the compressor suction and discharge stop valves have been closed to trap the Freon 12 charge in the system.

1. Break the discharge gage valve line to the atmosphere.

2. Start the compressor and let it run until the greatest vacuum possible is obtained.

3. Stop the compressor and immediately crack the suction stop valve to blow Freon 12 gas through the compressor valves and purge the air above the discharge valve through the open gage line. Then close the discharge gage line and the suction stop valve.

C. COMPRESSOR VALVES

10C1. Indications of faulty valves. Faulty compressor valves in the air-conditioning compressors may be indicated either by a gradual or sudden decrease in the expected compressor capacity. Either the compressor fails to pump at all, or the suction pressure cannot be pumped down to the proper pressure. This causes the compressor to run for prolonged periods, or even continuously. Short shutdown periods may indicate leaky compressor valves, if the faulty operation is not caused by any of the conditions listed above.

10C2. Analysis of faulty valves. Before opening a compressor for valve inspection or replacement, the auxiliary man should be definitely sure that the faulty operation of the system is caused- by the valves. Therefore, before assuming that the compressor valves must be serviced, carefully check each of the following possible causes of trouble:

1. Be certain that the Freon 12 system is fully charged.

2. Be certain that the expansion valve is in a normal operating condition.

3. The suction pressure cutout switch should be adjusted to stop the compressor when the suction pressure drops to 2 psi; the compressor should not start until the pressure setting at which it should start the compressor, 20 psi, is reached.

4. The temperature control switch (room type thermostat), The compressor should not be opened for inspection until each of the above possible sources of faulty operation has been eliminated. The correct method of disassembling and reassembling each part of the compressor is outlined below under the respective headings.

10C3. Compressor discharge valves. There is no satisfactory field method of analyzing the efficiency of the compressor discharge valves. except by the process of elimination. The serviceman must analyze and eliminate all possible sources of trouble in other parts of the system before opening the compressor for valve inspection or replacement.

10C4. Removing the discharge valve assembly. To remove the discharge valve assembly, proceed as follows (see Figures 7-3 and 7-4):

1. Pump out the compressor.

2. Remove the cylinder head (7), using care not to damage the thin metal gasket (41). Do not use a screwdriver or similar tool to pry off the cylinder head. Tapping the head lightly around the edge helps to loosen the joint. As the cylinder head is lifted, the gasket may adhere to both the head and the discharge valve plate (8). Use a knife blade or other flat instrument to help release the gasket.

3. Remove the capscrews (48) that hold the discharge valve plate and lift off the valve assembly, using the same precaution with the

provided for the purpose of cutting off refrigeration in the rooms when the desired temperature has been reached, closes the solenoid valve and stops the admission of liquid to the evaporator.

5. The compressor motor should be run at its rated speed. A low speed reduces the capacity of the compressor.

gasket (40) as explained in Step 3 above.

4. Handle the gaskets with care, placing them aside where they will not be damaged. The same gasket (40), or one of exactly equal thickness, must be used in replacing the discharge valve assembly. This is important because the thickness of this gasket determines the clearance between the valve plate and the

piston when at the top of its stroke. This clearance is only a few thousandths of an inch.

10C5. Disassembling the discharge valve assembly. Whenever the discharge valves are found to be defective, replace the entire discharge valve assembly with a new one and return the defective assembly to a tender or base for repair. Generally, if the valve operation is faulty, the valve plate as well as the valve diaphragm is defective; if the valve diaphragm is broken, the valve plate will be scratched or marred. In either case, the valve seats on the discharge valve plate must be relapped. This lapping process requires highly specialized machinery and cannot be done in the field.

If disassembling the discharge valve assembly cannot be avoided, proceed as follows (see Figures 7-3 and 7-4):

1. Remove the cotter pin (12) from the valve bolt (9).

6. Place the valve bolt washer (10) in position with the rounded edge of the washer against the valve.

7. See that the holes in the discharge valve diaphragms are in alignment while the assembly is being tightened.

8. Draw the castellated nut firm with a 6 inch wrench, holding the flat projection above the nut with another wrench. If the cotter pin hole through the nut does not match the hole in the valve bolt, try another nut if available; otherwise dress the face of the nut with fine emery cloth. Care must be exercised not to put too much strain on the valve bolt.

10C7. Installing the discharge valve assembly. In installing the discharge valve assembly, proceed in the following manner (see Figures 7-3 and 7-4):

1. Thoroughly wash the valve assembly in approved cleaning solvent. Give the valve assembly a final rinse in approved cleaning solvent, and dry in air without wiping.

2. While loosening the castellated nut (11), hold the valve bolt with a wrench on the fiat projection above the nut. Take care that the wrench does not slip and damage the valve or valve plate.

3. Note that the valve diaphragm (13) seats on two narrow concentric surfaces machined on the valve plate. These surfaces are very finely lapped and must not be scratched.

4. Note that the gasket (9A) seals the joint between the valve bolt and the under side of the discharge valve plate.

10C6. Reassembling the discharge valve. In reassembling the discharge valve, proceed in the following manner (see Figures 7-3 and 7-4):

1. Thoroughly wash each individual part in approved cleaning solvent, giving a final rinse in approved cleaning solvent, and dry in air without wiping.

2. Place the first valve diaphragm (13) in position on top of the discharge valve plate, with the concave side down.

3. Place the diaphragm spacer (14) on top of the first valve diaphragm.

4. Place the second valve diaphragm on top of the spacer with concave side up.

5. Place the third valve diaphragm on top of the second valve diaphragm with concave side down.

2. Clean the gaskets, the surface on top of the cylinder, and the cylinder head. 3. Place the proper thin metal gasket (40) in position on top of the cylinder.

CAUTION. The thickness of this gasket determines the clearance between the top of the piston at the top of its stroke and the bottom surface of the discharge valve plate. For this reason it is important to use either the original gasket or a new gasket whose thickness is the same as the original. These gaskets are available in three thicknesses: 0.010 inch, 0.015 inch, and 0.020 inch. When the discharge plate gasket (40) is in position on top of the cylinder block, check the clearance between the surface of the gasket and the suction valve when the pistons are at the top of their stroke. The clearance between the top surface of the gasket and each suction valve should be 0.015 to 0.025 inch for the 2 5/8-inch compressor, and 0.015 to 0.030 inch for the 4-inch compressor.

4. Place the discharge valve assembly in position, making sure that the port through the plate coincides with the cylinder discharge port.

5. Fasten the valve plate with the two capscrews (48), using a wrench with a leverage that does not exceed 9 inches.

6. Place the cylinder head gasket (41) and cylinder head (7) in position, making sure that no dirt has fallen on the discharge valves. Tighten all cylinder head capscrews evenly, to insure a tight joint and to prevent distorting the cylinder head or twisting off the capscrew heads.

IMPORTANT. To insure a tight gasket joint between the cylinder head and the discharge valve plate without an excessive strain on the cylinder head capscrews, see that the gasket surface on the cylinder head is flat. To determine whether the cylinder head gasket surface is flat, place the cylinder head on a surface plate and test the flatness with a 0.0015-inch thick feeler gage. If the gasket surface of the cylinder head is uneven, use a new cylinder head. If no new cylinder head is available, resurface the gasket surface by hand scraping.

7. Break the discharge gage valve line to the atmosphere. Crack the suction stop valve to blow Freon 12 through the compressor valves, and purge the air out through the open gage valve. Close the discharge gage valve line and the suction stop valve. Then close the discharge gage valve line and the suction stop valve.

8. Open the discharge stop valve and test for leaks.

9. If there are no leaks, open the suction stop valve, and the compressor is ready for normal operation.

suction valve efficiency until after the compressor has been in operation for a minimum of three days, as it may be necessary for the valve to wear in.

10C9. Removing the suction valve assembly. To remove a compressor suction valve, proceed in the following manner (see Figures 7-3 and 7-4):

1. Pump out the compressor.

2. Remove the cylinder head (7).

3. Remove the discharge valve plate assembly (8).

4. Rotate the flywheel until the piston-from which the suction valve is to be removed is about 1 inch below the top of the cylinder, so that the screwdriver bushing may be inserted in the cylinder bore.

5. Use the T-handled screwdriver with its guide bushing, and remove the valve screw (25).

6. Rotate the flywheel until the piston is at top dead center and remove the valve diaphragms (13A) and the diaphragm spacer (14).

7. Tag each part as it is removed, so that the parts can be replaced in their original position.

10C10. Inspection of the suction valve assembly. In inspecting the-suction valve assembly, proceed in the following manner:

1. Examine the valve seats on the piston and the valve diaphragm. If either of the narrow concentric

10C8. Compressor suction valves. The compressor suction valves may be checked for leakage in the following manner:

1. Close the suction stop valve.

2. Start the compressor.

3. Continue to run the compressor by blocking the suction pressure control switch in the running position. This may be done by means of a screwdriver placed under the main operation lever. If a vacuum of approximately 20 inches can be readily pumped, as indicated by the suction gage, the compressor suction valves are satisfactory.

NOTE. A vacuum cannot be maintained after the compressor stops, because of the Freon 12 being released from the oil in the crankcase.

Do not attempt to check the compressor

valve seats on top of the piston is marred, the piston must be replaced.

2. Examine the suction valve screw. If the head is not perfectly round and free from burrs on the underside and edges, it must be renewed. A flat side on the screw head is apt to cause the valve to break.

NOTE. If a suction valve has been broken, a new suction valve screw should be used with the new valve.

3. Before replacing a broken suction valve; be certain that all the small pieces of the broken valve are accounted for; if necessary, remove the cylinder. Small pieces of the broken valve may drop through the suction valve port in the top of the piston and lodge in the cylinder, in the trunk of the piston, or in the suction connection between the strainer and the cylinder. If these pieces are not removed, the piston and cylinder surfaces will be damaged, and the new suction valves may be cut or broken when

the pieces are drawn through the compressor valves. To protect the compressor against such damage, the cylinder and suction strainer should be removed, and the internal parts thoroughly cleaned. Particular care should be taken to clean the suction connection between the suction strainer body and the compressor cylinders.

NOTE. If a suction valve is only cracked, or all the parts of a broken valve can be found, it is

burrs down with a light hammer or small steel rod. This insures a clean job and does not impair the strength of the screw as would filing or grinding.

8. Install the discharge valve plate assembly (8).

9. Replace the cylinder head (7) and prepare the compressor for operation.

10C12. Discharge valve plate gasket data. The table below

not necessary to remove the cylinder.

10C11. Installing the suction valve assembly. In installing the suction valve assembly, proceed as follows (see Figures 7-3 and 7-4):

1. Thoroughly wash each individual part in approved cleaning solvent, giving a final rinse in approved cleaning solvent, and dry in air without wiping.

2. Place the first valve diaphragm (13A) in position on top of the piston with the concave side down.

3. Place the diaphragm spacer (14) on top of the first valve diaphragm.

4. Place the second valve diaphragm on top of the spacer with concave side up.

5. Place the third valve diaphragm on top of the second valve diaphragm with the concave side down.

6. Install the suction valve screw (25) through the center hole of the valve diaphragms, and screw into the head of the piston by hand. The suction valve screw may fit tightly the full length of its threads. With screwdriver bushing in place, firmly seat the valve screw with the T-handled screwdriver. Use careful judgment in tightening this screw.

7. Closely examine the head of the suction valve screw and remove all traces of burrs from it. Do not file, scrape, or grind off indicates the thickness of the discharge valve plate gaskets required when the pistons are flush with or below the top of the cylinders. This table is to be used only when installing lead-coated copper gaskets. Take indicator readings as close as possible to the suction valve screw.

2 5/8-INCH COMPRESSOR

Piston flush with top of cylinder, use one 0.015 gasket.

Piston flush to 0.005 below top of cylinder, use one 0.015 gasket.

Piston 0.005 to 0.010 below top of cylinder, use one 0.010 or one 0.015 gasket.

Piston Clearance with Gaskets in Place

Distance between top of suction valve and a line horizontal with top of discharge valve plate gasket: minimum 0.015; preferred 0.020; maximum 0.025.

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Piston flush with top of cylinder, use one 0.015 gasket.

Piston flush to 0.010 below top of cylinder, use one 0.015 gasket.

Piston 0.010 to 0.015 below top of cylinder, use one 0.010 or one 0.0.15 gasket.

Piston Clearance with Gaskets in Place

Distance between top of suction valve and a line horizontal with top of discharge valve plate: minimum 0.015; preferred 0.025; maxi mum 0.030.

the burrs because of the danger that emery dust or metal filings may get into the cylinder. Peen the

D. COMPRESSOR CYLINDERS

10D1. Removing the cylinders. In removing the cylinders, proceed in the following manner (see Figures 7-3 and 7-4):

1. Pump out the compressor.

2. Disconnect the discharge piping at the compressor.

3. Disconnect the suction piping at the compressor.

4. As soon as each connection referred to in Steps 2 and 3 is disconnected, close all openings to prevent air and dirt from entering.

5. Carefully wipe all dirt from the cylinders and around the capscrew heads so that none is apt to fall into the crankcase when the cylinder is removed.

6. Remove the discharge valve assembly.

7. Rotate the flywheel until one of the pistons is at the bottom of its stroke.

8. Unbolt the cylinder from the crankcase and blow off all dirt or paint that may have been loosened in removing the capscrews.

9. Raise the cylinder enough to insert a knife blade or other fiat instrument to help release the gasket (38) from the cylinder. If the cylinder is removed without this precaution, the gasket may be torn. A new gasket of equal thickness must be used when the cylinder is again installed, because the thickness of this gasket assists in determining the clearance between the top of the piston, when at the top of its stroke, and the bottom of the discharge valve plate.

pistons and the discharge valve plate. Hence it is important to use a gasket with a thickness, equal to the original. These gaskets are available in two thicknesses, 0.010 inch and 0.015 inch. It is necessary to determine whether the original gasket was 0.010- or 0.015-inch thick. The correctness of the choice of the gasket is further checked when Step 9 is reached.

5. Lubricate the pistons and cylinder bores with new Freon 12 compressor oil, Navy Symbol No. 2135, or its equivalent.

6. Make sure that the suction and discharge connections on the cylinder face in the proper direction to match the adjacent piping; then with the cylinder held directly above the crankcase, lower it to enter the pistons one at a time. No difficulty should be encountered if the piston rings are

10. Slowly lift the cylinder straight up, and at the same time support each piston as, it leaves the cylinder bore. If an auxiliary man must do this without assistance, he should pull the cylinder toward him as it is raised, so that each connecting rod rests against the crankcase as it leaves the cylinder. This is important, as the pistons are liable to be damaged if permitted to fall against the edge of the crankcase,

CAUTION. When lifting the cylinder off the pistons, be careful not to twist it, as this is liable to bend the connecting rods; a slight twisting motion exerts considerable bending force because of the leverage on the rods,

11. Place the cylinder on a clean sheet of paper or on a clean bench.

10D2. Installing the cylinders. In installing the cylinders, proceed in the following manner (see Figures 7-3 and 7-4):

1. Thoroughly wash all parts in approved cleaning fluid, rinse clean with approved cleaning fluid, and permit to dry without wiping.

2. Make sure that all internal parts are properly tightened, that the piston rings are free in their grooves, and that the oil in the crankcase is clean and covers 1/2 to 3/4 of the bull's-eye sight glass.

3. See that the gasket surface on the crankcase is clean, dry, and free of oil.

centered and the highest piston is entered first.

CAUTION. Do not twist the cylinder as it is lowered, because of the danger of bending the connecting rods.

7. After all the piston rings are entered, the cylinder may be pushed steadily down until the locating pins on the crankcase properly center it.

8. Bolt the cylinder to the crankcase, carefully drawing all the capscrews evenly.

9. Place the discharge plate gasket (40) in position on top of the cylinder and check the clearance between the gasket and each suction valve when the pistons are at the top of their stroke. The clearance between the top of the gasket and each suction valve should be 0.015 inch to 0.025 inch for the 2 5/8-inch compressor; and 0.015 to 0.030 inch for the 4-inch compressor.

10. Clean and install the discharge valve plate assembly.

11. Reconnect all the piping connections in the proper manner.

12. Pump the air out of the compressor.

13. Open the discharge stop valve and test all joints that were disconnected.

14. If there are no leaks, open the suction stop valve, and the compressor is ready for normal operation.

15. Wipe the oil from the outside of the compressor. The compressor gaskets may then be

4. Clean the gasket and place it in position on the crankcase.

CAUTION. The thickness of this gasket assists in determining the clearance between examined for oil, as an indication of leakage, the next time the installation is inspected.

E. COMPRESSOR PISTONS

10E1. Removing the pistons. For access to the pistons, remove the cylinder. (See Figures 7-3 and 7-4.) There is no locking device on the piston pins. The piston pins are placed centrally in the holes at assembly, so that the two ends are clear. Soft metal plugs are provided in each end of the piston pin, so that if the piston pin works to one side or the other, the soft plugs prevent scoring of the cylinder wails.

1. Remove the cylinder (6).

2. Rotate the crankshaft (26) so that the piston to be removed is at the top of its stroke.

3. Use a wood or soft metal rod to drive out the piston pin (24). It is best to have a rod with a countersunk end to fit the rounded end of the piston pin.

CAUTION. Support the piston centrally and back it up with a wood block while driving out the piston pin, in order to cause no strain on the connecting rod. If this precaution is neglected, the rod may be bent, due to the enormous leverage on the rod which is supported only by the crank pin. Even an imperceptible bend in the rod may be sufficient to cause binding of the piston in

4. Place the piston on a sheet of clean paper.

10E2. Installing the pistons. To install the pistons, proceed in the following manner (see Figures 7-3 and 7-4):

1. Rotate the crankshaft (26) until the connecting rod to which the piston is to be attached is at the top of its stroke.

2. Clean the parts thoroughly with approved cleaning fluid, rinse in clean approved cleaning fluid, and permit to dry without wiping.

3. The piston pins (24) are ground to such close tolerance that extreme care must be exercised in lining up the hole in the rod with the hole in the piston, to prevent raising a burr on either the piston pin or the hole in the piston, or the bushing in the rod.

CAUTION. Be sure to support the piston at its middle narrow section and back it up with a wood block while driving the piston pin in to prevent bending the rod, or burring the bushing, as discussed in Section 10E1. The piston pin is shorter than the diameter of the piston; be sure to center the piston pin in the piston so that it clears the cylinder wall on both sides.

the cylinder and subsequent trouble. Also, unless the piston is properly supported, it is apt to bump against the rod and raise burrs on the end of the piston pin bushing.

4. See that the rings and ring grooves are clean, and that the rings are free and snug fitting in the grooves; then install the cylinder.

F. COMPRESSOR CRANKSHAFT

10F1. Removing the crankshaft. When it is necessary to remove the crankshaft, the piston, connecting rods, and crankshaft may be removed as a complete assembly. To remove the crankshaft proceed in the following manner (see Figures 7-3 and 7-4):

1. Pump out the compressor.

2. Remove the flywheel (34).

3. Remove the cylinder (6).

4. Remove the shaft seal (31).

5. Unbolt and remove the bearing head (2), using the two jacking screws in the tapped holes provided in the bearing head. While removing the bearing head, keep an even tension on the jacking screws to prevent binding the head in the crankcase. As the bearing head comes loose, support the flywheel end of the shaft to prevent damage to the shaft when the weight of the bearing head is supported only by the shaft.

6. While holding the pistons so that none falls against the crankcase and is damaged, slide the shaft forward out of the rear main bearing. Work the flywheel end of the shaft through the opening left by the bearing head, and at the same time raise the rear end of the shaft until it clears the back edge of the crankcase. The assembly may then be lifted out and placed on a sheet of clean paper.

10F2. Installing the crankshaft. To install the crankshaft assembly, proceed in the following manner (see Figures 7-3 and 7-4):

1. See that the inside of the crankcase (1) is clean. Clean all parts with approved cleaning

fluid, rinse in clean approved cleaning fluid, and dry without wiping.

2. Slip the shaft in place in the same way as in removing it.

3. Use the same gasket (39), or one of the same thickness, when to pull the bearing in until the bearing head capscrews engage the thread.

5. As soon as the capscrews engage the thread, use them to draw the head in place, being

installing the bearing head. This gasket determines endwise clearance in the shaft. The gasket for the 2 5/8-inch compressor is minimum 0.007, preferred 0.009, maximum 0.012. The gasket for the 4-inch compressor is minimum 0.009, preferred 0.011, maximum 0.014.

4. Slide the bearing head over the shaft and use particular care to enter it squarely. This bearing head fits with small clearance in the crankcase opening, and time is saved if it is carefully started. While forcing the bearing head into place, tap lightly all around the edge of the head flange. Use two cylinder head capscrews careful to draw evenly on all screws.

6. While pushing against the flywheel end of the crankshaft, check with a thickness gage the clearance between the face of bearing head (2) and the shoulder on the crank throw. This clearance must not be less than 0.007 inch nor more than 0.012 inch for the 2 5/8-inch compressor; and not less than 0.009 nor more than 0.014 inch for the 4-inch compressor. To adjust this clearance, change the thickness of gasket (39) between bearing head and crankcase.

7. Install the cylinder (6).

8. Install the shaft seal. Do not neglect to adjust the shaft seal if new bearings, shaft, or seal have been installed.

G. CONNECTING RODS

10G1. Removing the connecting rods. If a connecting rod becomes defective in any way, the complete connecting rod should be replaced with a new one. The piston pin bushing cannot be properly applied to the rod in the field, and no field repair of the crank end bearing should be attempted. These bearings are not adjustable, and any attempt made in the field to fit by filing is apt to result in excessive clearance of incorrect rod lengths, which might cause damage to the compressor valve assembly. To remove the connecting rods, it is advisable to remove the crankshaft assembly. To remove a connecting rod, proceed in the numbered, and proceed in the following manner (see Figures 7-3 and 7-4):

1. Clean all parts with approved cleaning fluid, rinse with approved cleaning fluid, and let dry without wiping.

2. Assemble the rod on the crank pin with the dowel pins properly entered.

3. Draw the connecting rod bolts (16) finger tight only. Then insert drift pin through the holes which extend through the bearing cap and tap lightly on the dowel pins. This locates the cap accurately while the bolts are still loose enough to permit the cap to shift.

following manner (see Figures 7-3 and 7-4):

1. Remove the crankshaft assembly (26).

2. Remove the piston (21).

3. Remove the connecting rod bolts (16), wire keepers (18), and castellated nuts (11).

4. To loosen the connecting rod bearing cap, insert a drift pin in the dowel pin holes that extend through the rod side of the bearing. Then tap the drift pin.

10G2. Installing the connecting rods. To install the connecting rods, note that the parts of each rod are correspondingly lettered or

4. Tighten the bolts evenly and tap again on the dowel pins. Peen the holes as they were originally, to lock the dowels.

5. If the pin hole in the nut does not align with the hole in the bolt, dress the face of the nut with emery cloth. Do not back off on the nut to align the holes.

6. Attach the piston (21) to the rod (15). NOTE. It may be more convenient to install the crankshaft assembly before attaching the pistons to the rods.

7. Install the crankshaft assembly and complete the assembly of the compressor.

H. CRANKSHAFT BEARINGS

10H1. Front main bearing. The crankshaft main bearings cannot be repaired. The only reason for removing either crankshaft main bearing is to replace it with a new one when

it has become worn to such an extent that it no longer gives satisfactory operation.

a. Removing the front main bearing. To remove the front main bearing, proceed in the following manner:

1. Remove the bearing head.

2. With a wood or soft metal rod, drive the defective bearing out of the bearing head.

b. Installing a new front main bearing. To install a new front main bearing, proceed in the following manner:

5. Install the bearing head and complete the assembly of the compressor.

10H2. Rear main bearing. To remove the rear main bearing, proceed in the following manner:

1. Remove the crankshaft assembly.

2. Use a blunt chisel to crush the bearing flange near one of the oil grooves. After the bearing is crushed, it may be withdrawn. Use care not to damage the bearing bore in the exchange.

1. Clean the bearing and head with approved cleaning fluid, rinse with clean approved cleaning fluid, and let dry without wiping.

2. Oil the bearing and hole in the head with new Freon 12 compressor oil, Navy Symbol No. 2135, or equivalent.

3. Carefully enter the bearing squarely in the hole, and be sure that the bearing key, cast on the bearing, lines up exactly with the key way in the bearing head. To do this, lay a steel scale or similar straightedge along the key on the bearing, and scribe a line the full length of the bearing. Enter the bearing with this line placed on the corner of the keyway.

4. Drive the bearing into the bearing head, tapping lightly all around the bore to keep it from binding. While driving the bearing in, use a block of wood to protect the end of the bearing to prevent raising burrs or distorting it. When the bearing is in place, the flange of the bearing must be tight against the bearing head.

3. Place the new bearing in position, following the instructions given for the front main bearing.

4. Install the crankshaft, and complete the assembly of the compressor.

NOTE. Another method of removing the rear bearing is by using a puller. The puller can be constructed as follows: Use a tap that can be threaded into the bearing and weld a round piece of 1-inch steel stock to it. Thread the other end of the steel rod. The rod should be long enough to extend about 3 inches through the front opening of the crankcase. A cross-bar drilled to fit the 1-inch rod is placed across the front of the crankcase in a horizontal position. Screw the tap into the bearing and take a strain on the rod by screwing a 1-inch nut on the free end of the shaft, taking up very slowly. Care should be taken that the tap is screwed into the bearing far enough so that it does not pull out when tension is applied to the puller.

I. OIL SIGHT GLASS

10I1. Removing the oil sight glass. The only reasons for which the glass is removed are a broken glass or defective gaskets. If the glass is broken so that pieces may have dropped inside the crankcase, it is necessary to remove the cylinder and clean the inside thoroughly. To remove the oil sight glass, proceed in the following manner (see Figures 7-3 and 7-4):

care not to destroy the spanner wrench slots in the nut.

4. Insert the tip of a knife blade under the washer (43) and gaskets (45) to loosen them.

10I2. Installing the oil sight glass. To install the sight glass, proceed in the following manner:

1. Clean all the parts with approved cleaning fluid, rinse with

1. Pump out the compressor.

2. Attach a piece of tubing to the oil drain valve and drain the oil into a bucket. Avoid spilling oil on the deck.

3. Remove the oil sight nut (42), taking

clean approved cleaning fluid, and let dry without wiping.

2. Arrange the parts as originally assembled and tighten the lock nut.

3. Pump clean oil into the crankcase.

4. Pump the air out of the crankcase.

J. FLYWHEEL

10J1. Removing the flywheel. To remove the flywheel, proceed in the following manner (see Figures 7-3 and 7-4):

1. Open the compressor disconnect switch. Remove the V-belts.

2. Unscrew the flywheel lock nut and mount the flywheel puller. Tapped holes are provided in the flywheel hub (34) for the pulley screws.

3. Apply even tension on the screws until the flywheel is free on the tapered shaft. Remove the flywheel and save the Woodruff key.

10J2. Installing the flywheel. To install the flywheel, proceed in the following manner (see Figures 7-3 and 7-4):

1. Mount the flywheel (34) on the shaft with the Woodruff key (28) in place.

2. Draw the flywheel tight on the tapered shaft by means of the lock nut (27); do not drive the flywheel into place because of danger of damage to the rear main bearing and to the shaft seal adjustment.

3. Be sure that the lock nut is tight. On some compressors, the lock nut is locked by means of a cotter pin (140). If the cotter pin cannot be inserted, remove the nut and dress the face of the nut with emery cloth. Do not back off on the nut to align the cotter-pin holes.

4. Put on the V-belts, and the compressor is ready for operation.

K. COMPRESSOR CRANKSHAFT SEAL

10K1. The shaft seal. The lubricating oil in the compressor fills the crankcase to a level just above the top of the crankshaft

This spiral line of holes will, of course, differ in direction of winding, according to whether the rotation is clockwise or

bearings. Therefore, a seal is necessary to prevent the oil from leaking out between the shaft and its bearing.

The rear end of the shaft, that is, the end opposite the flywheel or power end, is completely enclosed by the one-piece crankcase. No oil can leak from this end, so only one seal is needed. (See Figures 7-3 and 7-4.)

The seal mechanism is composed of two parts, a collar (30) rotating with the shaft, and a diaphragm assembly (31). The diaphragm is stationary, being rigidly fixed to the crankcase, and carries a ring similar to the shaft collar. There are really two individual parts to this seal, a rubbing seal part and a non rubbing seal part. They are described separately.

a. Rubbing seal. The contact face between collar and ring, at right angles to shaft axis, is the rubbing seal, the two parts having been accurately lapped together at the factory. Since the ring is stationary, while the collar rotates, the two parts are in contact under pressure. The rubbing contact thus set up between them must be lubricated. Lubrication is facilitated by a spiral line of small pockets or holes bored in the ring face, which insures that oil flowing into the seal is carried properly across the whole contacting face.

counterclockwise. Submarine installations use counterclockwise rotation. The outermost hole of the spiral must be in the five o'clock position, as observed by the operator facing the flywheel, when the diaphragm is installed. The small amount of oil required to lubricate the rubbing surfaces, after passing the seal, is carried to the compressor base from the seal cover plate by an oil drain pipe (5).

The success of this seal depends upon the accuracy of the machining and lapping together of the two contact surfaces and upon the pressure of the ring against the collar maintained by the diaphragm. The action of the diaphragm in producing this pressure is described in Sections 10K5 and 10K6.

b. Nonrubbing seal. The shaft collar (30) is pressed against a shoulder of the shaft by the spring diaphragm, acting through the seal ring (31). The collar is keyed stationary to the shaft by a small steel ball which projects half way into each. The face between collar and shaft shoulder, that is, opposite the rubbing face, is also a seal, called the nonrubbing seal. This must be an absolute seal, and the collar must therefore be lapped to the crankshaft collar with the greatest care.

10K2. Shaft seal leakage. For the reason explained previously, a small amount of oil

may be expected to seep from

level, it is safe to assume that the

the seal. Before compressor is replaced because of apparent oil leakage from the shaft seal, consider the following (see Figures 7-3 and 7-4):

1. Do not use a halide torch to test the shaft seal for Freon 12 leaks. Oil from the seal contains some Freon 12, the release of which causes a false indication if the seal is tested with a halide torch.

2. The oil leakage from the shaft seal may be considered excessive if the compressor requires an additional charge of oil within a period of six months. Before it is assumed that the oil has leaked past the seal, be certain that the design of the cooling system has not caused the oil to be trapped in the evaporator coils. in general, series feed evaporators, or parallel feed evaporators with thermal expansion valves, permit oil to return to the compressor with the Freon 12 gas after the initial oil requirement of the evaporators has been satisfied.

3. If oil occasionally spurts from the shaft seal, the fault is probably due either to the system's hook-up or to the operating conditions rather than to the seal. If this condition occurs, be certain that the arrangement of the system does not permit an excessive accumulation of oil or liquid Freon 12 in the compressor crankcase. Liquid Freon 12 may tend to accumulate in the compressor crankcase when the temperature around the compressor is lower than the temperature in the evaporator coils. This condition may exist shaft seal is not leaking.

When excessive leakage at the shaft does exist and replacement is necessary, both shaft seal collar (30) and shaft seal assembly (31) must be replaced. Do not attempt to replace one part without also replacing the other. These parts are lapped together and are not interchangeable.

10K3. Removing the shaft seal. To remove the shaft seal, proceed in the following manner (see Figures 7-3 and 7-4):

1. If the shaft seal is broken or permits an excessive leakage of oil, do not attempt to pump out the Freon 12 contained in the compressor, because air containing moisture may be drawn into the system through the damaged seal. When this condition exists, close the compressor suction and the discharge stop valves, and bleed the pressure to the atmosphere through the pressure gage valves.

2. Attach a piece of tubing to the oil drain valve and drain the oil from the crankcase into a bucket. As the oil is saturated with Freon 12, it foams considerably while being drained. Avoid spilling oil on the deck. Leave the oil drain valve open while working on the seal so that Freon 12 escaping from the oil remaining in the crankcase cannot build up a pressure sufficient to blow out the seal unexpectedly while removing it.

3. Remove the V-belts and flywheel (34). NOTE. After removing the flywheel lock nut (140), rotate the shaft until the keyway is on top. This brings the shaft seal collar locating ball (29)

during the winter months if the compressor is in an unheated room.

4. IMPORTANT. Do not assume that an apparent accumulation of oil on the compressor base indicates an excessive leakage of oil from the shaft seal. What may appear to be a large quantity of oil from the shaft seal may in reality be some of the condensate from the compressor suction line with a film of oil over it, oil from the compressor motor, or a mixture of both. Rather than judge the shaft seal leakage by the mixture of oil and water on the compressor base, check the compressor crankcase oil level to determine the amount of oil actually remaining in the crankcase. If the oil has not dropped appreciably below the normal

on top so that the ball does not drop out and get lost when the seal collar is removed.

4. Unbolt and remove the shaft seal cover plate (4).

5. Carefully remove the shaft seal assembly (31) by grasping it with the fingers. If this assembly is not easily dislodged, work the shaft in and out while tapping lightly all around the edge of the assembly. If this fails to loosen the shaft seal assembly, create a slight pressure in the compressor crankcase by opening the suction or discharge stop valve; press against the seal to prevent it from being blown from the compressor.

CAUTION. When the shaft seal assembly

is removed, the shaft seal collar (30) usually follows it. As the shaft seal assembly is with drawn with one hand, support the shaft seal collar with the other, holding the collar with the thumb and one finger on its edges. Be careful not to drop either part and do not touch the sealing surface of the seal collar or seal ring of the shaft seal assembly. Lay the parts on a sheet of clean paper.

6. Do not disturb the shaft seal diaphragm gaskets (37), except to remove any thin edges that may have been squeezed out.

7. Save the shaft seal collar locating ball (29). If necessary,

b. Lapping the shaft seal collar to the shaft shoulder. To lap the shaft seal collar to the shaft shoulder, proceed in the following manner (see Figures 7-3 and 7-4):

1. Clean the surface of the shaft shoulder with a chamois or hard cloth, saturated with approved cleaning fluid. Wash the shaft seal collar in approved cleaning fluid.

2. Lap the back of the shaft seal collar (30) to the crankshaft shoulder. It is important that this lapping be done carefully and thoroughly because this joint must be an absolute seal.

IMPORTANT. Use levigated alumina, jeweler's rouge, or powdered Bon Ami, mixed with

this ball may be lifted from its socket with a toothpick or any small sharpened piece of wood.

10K4. Repairing the shaft seal. Both the shaft seal collar (30) (see Figures 7-3 and 7-4), and the shaft seal assembly (31) must always be renewed when either is renewed. These parts are furnished in sets and should not be separated.

a. Faulty shaft seal. A faulty shaft seal may be attributed to any one or a combination of the following causes:

1. Ruptured seal diaphragm. This causes the complete failure of the shaft seal, and necessitates replacement of the shaft seal assembly.

2. Dirt between the seal surfaces. Small particles of dirt between the seal surfaces can be readily removed by lapping.

3. Seal surfaces cut or scored. Unless the defect can be completely removed by lapping, the seal assembly (31) and the seal collar (30) must be replaced. The shaft shoulder is hardened; if the ground surface is damaged beyond field repair, the crankshaft (26) must be replaced.

4. Seal surfaces not parallel. To determine whether or not the seal surfaces are parallel, wash the surfaces with approved cleaning fluid, permit them to dry without wiping, apply a small amount of Prussian blue, and then rub the surfaces together. Unless the surfaces can be lapped to form a full contact of color over the whole surface of the seal, the seal assembly (31) Freon 12 compressor oil, Navy Symbol No. 2135, or equivalent, to form a smooth paste. Use the paste sparingly to avoid getting it into the shaft bearing. As the lapping operation proceeds, use progressively thinner paste until only oil is used. When the lapping is completed, the shaft seal collar should be in position on the shaft, so that the recess for the shaft seal collar locating ball (29) is opposite the corresponding recess in the shaft shoulder.

3. After lapping, thoroughly clean the shaft shoulder with a piece of chamois or clean hard cloth saturated with approved cleaning fluid, and let it dry without wiping. With the shaft shoulder and the shaft seal collar perfectly clean and dry, rub the two surfaces against each other as a final lapping operation. End the final lapping with the shaft collar in position on the shaft so that the recess for the shaft seal collar locating ball (29) is opposite the corresponding recess in the shaft shoulder.

4. The surfaces are properly lapped when the surface of both the shaft shoulder and the shaft seal collar form a perfect contact and are free from scratches or other imperfections. It is preferable to make this examination with the aid of a good magnifying glass.

IMPORTANT. Do not lap a new shaft collar to a new shaft seal ring. This is done at the factory. However, if required, a used shaft seal assembly may be lapped to a shaft seal collar in the same manner as explained earlier.

10K5. Installing the shaft seal. IMPORTANT. The performance

and the seal collar (30) should be replaced.

5. Incorrect shaft seal tension. A definite initial deflection of the shaft seal diaphragm is essential to maintain the correct pressure between the seal surfaces.

and life of the shaft seal depend upon the care with which the following instructions are observed. The importance of the proper diaphragm tension and

the limitations as stated in these instructions should not under any circumstances be over looked.

When assembled, the shaft seal diaphragm must be under a definite tension. This tension depends upon the deflection secured by bolting the shaft seal cover plate (4, Figures 7-3 and 7-4) over the diaphragm with the proper thickness of gaskets (37) in the gasket recess. The thinner the gaskets used, the greater the deflection, and vice versa. The gaskets are available in three normal thicknesses: 0.005 inch, 0.010 inch, and 0.015 inch. However, these gaskets vary from 0.014 inch to 0.016 inch, so that different thicknesses can be secured by combining gaskets of varying thicknesses.

1. If a new shaft seal assembly is used, lap the shaft seal collar (30) to the crankshaft shoulder.

2. Clean the sealing surface of the shaft shoulder with a chamois or hard cloth, saturated with approved cleaning fluid, and let it dry without wiping.

3. Thoroughly wash each part, taking particular care to clean with a matchstick the small holes in the sealing face of the shaft

When the seal cover plate is removed, the diaphragm, being of spring metal, recovers from the deflection, standing flat and perpendicular to the shaft axis. If the diaphragm ring is held in contact against the shaft collar, there is a space (Y) between the gasket and the top of diaphragm, exactly equal to the deflection (X), as shown in Sketch B.

A steel ring gage (of the shape of such a gasket) can now be placed between the gasket and the diaphragm. If the ring gage has exactly the thickness (Y), the whole seal can be bolted together. The diaphragm ring will touch the shaft collar but will not press against it because the diaphragm will have no deflection. This assembly with steel ring gage is shown in Sketch C.

If the operator knew that the conditions shown in the assembly of Sketch C were a result of a chosen gasket and the same ring gage, he would know that when he removed the ring gage and reassembled the seal, he would get the desired deflection (X). Unfortunately, it is impossible to tell from the outside whether or not there is any deflection of the diaphragm. The diaphragm ring might just be touching the shaft

seal assembly (31). Rinse the parts in approved cleaning fluid, and let them dry in air without wiping. Any discoloration on the sealing surfaces of either shaft seal assembly or shaft seal collar should be removed with a soft pencil eraser. These parts must then be washed again in approved cleaning fluid.

CAUTION. After the final rinse, do not touch the sealing surfaces.

10K6. Determining the shaft seal pressure. The action of the diaphragm in producing the required pressure between the seal ring and the seal collar is illustrated in Figure 10-1.

When bolted on, the shaft seal diaphragm must cause the diaphragm ring to press against the shaft collar. This pressure depends upon the deflection given to the diaphragm when the shaft seal cover plate (4, Figures 7-3 and 7-4) is bolted over the diaphragm. The required deflection is the result of having gaskets of the proper thickness in the gasket recess. The thinner the gaskets, the greater the deflection, and vice versa. In Figure 10-1, Sketch A, this deflection (X) is shown exaggerated.

collar, or it might be pressing hard against it, but it would be impossible to tell which. However, by using two different ring gages instead of one, the operator can find out by the following method:

First, it is obviously impossible always to select a gasket combination of absolutely the correct thickness. A certain tolerance must be permitted. This tolerance, however, is limited, and in order to keep within its limits two steel ring gages are used, one a maximum thickness ring gage (slightly thicker than Y), and the other a minimum thickness ring gage (slightly thinner than Y). A comparison of these two gages shows the limited tolerance permitted and the extreme care with which the gaskets must be selected.

Moreover, by the use of these two ring gages, the operator determines whether or not the diaphragm has the proper deflection. The method of using them is based upon the following considerations:

If the seal is assembled with the maximum ring gage on the proper thickness of gaskets, that is, with the same gaskets referred to in

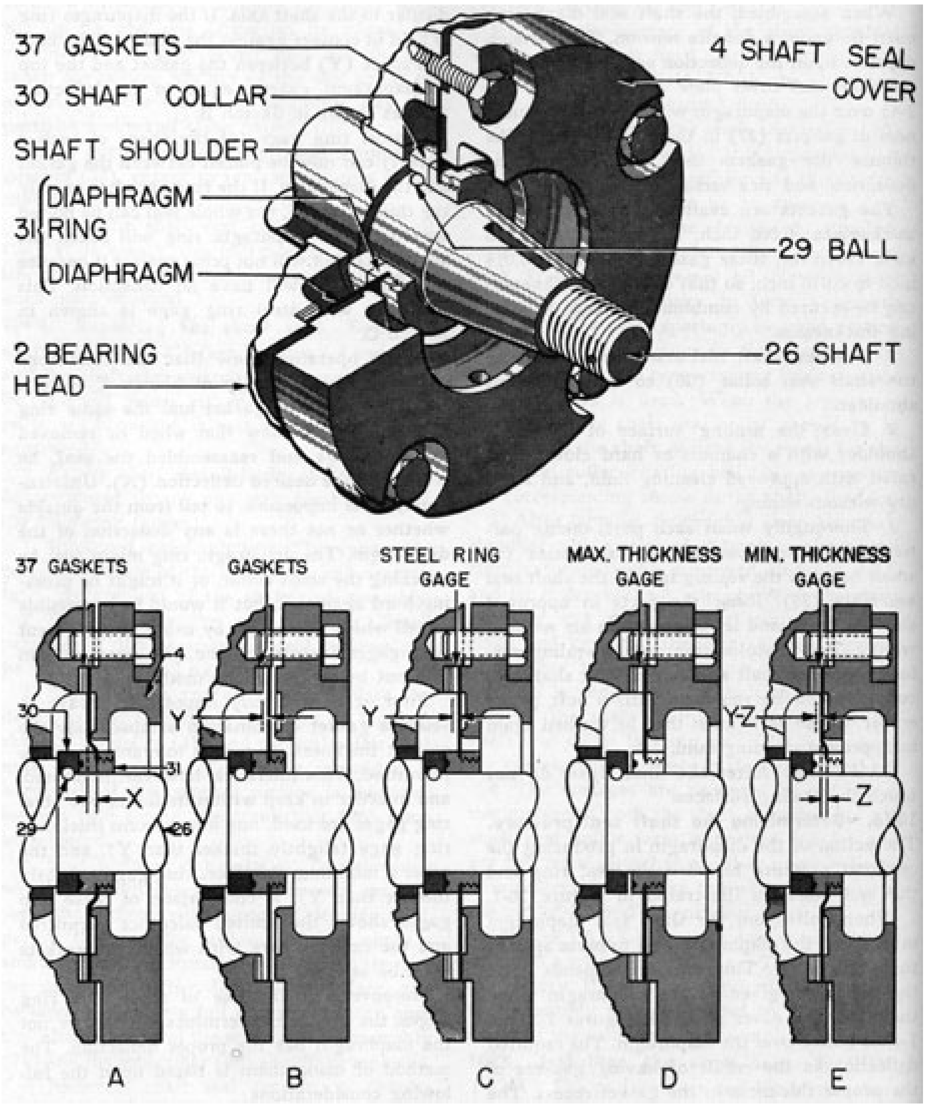

Figure 10-1. Enlarged view of crankshaft seal.

Sketches A, B, and C, the shaft seal ring is held away from the shaft seal collar (30), as shown in Sketch D. This condition is easy to observe, because the shaft seal ring can be moved perceptibly inward toward the seal collar; a few thousandths of an inch can be perceived.

If the seal is assembled with the minimum thickness ring gage on the same thickness of gaskets, the shaft seal ring is held firmly against the shaft seal collar (3) with a slight deflection of the diaphragm, as shown in Sketch E. This condition can also be easily observed because the shaft seal the gasket recess. The original gaskets, or some of the same total thickness, should be used for the first trial, as they are nearly correct for the new parts.

3. Place the maximum thickness ring gage in the recess on the gaskets.

4. Place in position the locating ball (29), the seal collar (30), and the seal assembly (31), taking care not to touch or mar the sealing surfaces.

5. Bolt the seal cover plate (4) in position, taking care to pull the capscrews evenly all the way around and as tight as if

ring cannot be moved, and when tapped lightly with the point of a screwdriver, or similar small steel rod, it rings with a solid metallic sound, being held firmly against the seal collar.

Hence, since the thickness of the maximum thickness ring gage is equal to the maximum permissible deflection, any gasket combination that provides a definite perceptible movement of the shaft seal ring when assembled with the maximum thickness ring gage, and that responds with a solid metallic sound on tapping when assembled with the minimum thickness ring gage, is within the allowable limits.

10K7. Adjusting the shaft seal. The correct maintenance of a perfect seal depends upon the care with which the adjustment is made to produce the proper pressure. First, be sure that Section 10K6 is thoroughly understood. Then follow the routine given below, omitting no steps (see Figure 10-1):

1. After the shaft seal collar (30) has been lapped to the shaft shoulder (this lapping operation is, of course, unnecessary if the original shaft and shaft seal are installed, wash all parts with approved cleaning fluid. Use care to clean with a matchstick the small holes in the sealing face of the shaft seal ring. Rinse the parts in approved cleaning fluid and let them dry in air without wiping. Any discoloration on the sealing surfaces of either shaft seal ring (31) or shaft seal collar (30) should be removed with a soft pencil eraser. These parts assembling the seal for normal operation.

6. With a screwdriver, or other small steel rod, push in on the seal ring. If the seal ring can be moved in perceptibly, the thickness of the gasket combination chosen is greater than the minimum permissible. That is, the gasket is not too thin, but it may be too thick; this is determined when checked with the minimum thickness ring gage. If the seal ring cannot be moved in perceptibly, tap it lightly with the screwdriver. If this tapping produces a solid metallic sound, the gasket is too thin, and further trial is necessary with thicker gaskets. However, if the tapping produces a hollow, loose sound, the sealing may be just touching or separated from the seal collar by only a fraction of a thousandth of an inch. This indicates that the thickness of the gaskets is close to the minimum permissible, and a gasket combination of 0.001 inch or 0:002 inch thicker would be better.

7. When a combination of gaskets is found that, when assembled with the maximum thickness ring gage, permits the seal ring to be moved perceptibly, remove the maximum thickness ring gage and reassemble the seal with the minimum thickness ring gage in place taking care to draw the capscrews evenly all around and as tight as if assembling the seal for normal operation.

8. With a screwdriver, or other small steel rod, tap on the seal ring. If this tapping produces a solid metallic sound, the gaskets chosen are correct and no further trial is necessary However, if the

must then be washed again in approved cleaning fluid.

CAUTION. After the final rinse, do not touch the sealing surfaces.

2. Place a trial thickness of gaskets (37) in

tapping produces a hollow loose sound, the gasket thickness is too great and further trial is necessary with thinner gaskets.

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9. If further trial with thinner gaskets is necessary when checking with the minimum thickness ring gage, a recheck must be made with the maximum thickness ring gage.

10. This alternate checking with maximum thickness ring gage must be repeated until such combination of gaskets is found that, when checked with the maximum thickness ring gage, permits the seal ring to be moved

perceptibly; or causes it to produce a hollow, loose sound when tapped; or when checked with the minimum thickness ring gage, causes it to produce a solid metallic sound when tapped.

11. When the proper thickness of gaskets has been determined, proceed with the installation of the shaft seal. Refer to Section 10K1.

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11 INSTALLATION

A. HANDLING FREON 12

11A1. Precaution. Since Freon 12 is practically odorless and nontoxic, it is not necessary to wear a gas mask when servicing equipment that contains it. However, it is essential that proper protection be afforded the eyes by the use of goggles or large-lensed spectacles to eliminate the possibility of liquid Freon 12 coming in contact with the eyes and causing injury by freezing the tissues of the eyes. This protection is necessary and should be taken whenever loosening a connection on a system in which Freon 12 is confined.

11A2. Remedies. If liquid Freon 12 should come in contact with the eyes, the person suffering the injury should be taken at once to an eye specialist. Avoid rubbing or irritating the eyes and give the following first-aid treatment immediately:

1. Irrigate the eyes with drops of sterile mineral oil.

2. If irritation continues, wash the eyes with weak boric acid solution or sterile salt solution not exceeding 2 percent sodium chloride (common table salt).

B. MOISTURE, DIRT, AND AIR

11B1. Important. In a refrigerating or air conditioning system there is no room for any thing but the refrigerant and oil inside the compressors, condensers, receivers, and evaporators, or in the tubing, fittings, or valves that connect the various pieces of apparatus.

The refrigerant used in these systems, Freon 12, is a powerful solvent that readily removes from the inside of pipes, valves, and fittings, any dirt, scale, sand, or moisture that has been allowed to remain in them during installation. These foreign compressor operates satisfactorily and gives many years of service free of trouble.

Most service troubles are caused by lack of adequate precautions during erection and installation. It is of extreme importance that the installation man know the necessity of keeping the system internally clean, as well as the use of the proper material for tubing, joints, and fittings.

The condition of the compressor lubricating oil, especially its color and appearance, is a good

substances are soon swept along with the suction gas into the compressor, and are a distinct hazard to the bearings, pistons, cylinder walls, valves, and lubricating oil. Scoring of moving parts frequently occurs when the compressor is run for the first time, starting with minor scratches that increase progressively until they seriously affect the operation of the compressor, eventually rendering it unfit for further use.

If the system is carefully and properly installed, excluding all foreign matter, the indication of the degree of contamination of the system.

The installation of some systems may be complicated by the many trades involved and the unavoidable delays that may occur between the start and the completion of the installation. Therefore, extraordinary precautions must be taken to prevent the entrance of foreign matter into any part of the system. It is most important that all openings in tubing, piping, fittings, and other parts of the system be promptly sealed during the time that no work is being performed on them.

C. INSTALLATION OF UNITS

11C1. Installation of the condensers, evaporators, receivers, and auxiliary equipment. These major units are generally located or installed prior to the running of connecting mains. This part of the installation should conform to the plans and specifications for the individual system involved.

CAUTION. All openings on these major units must remain sealed until the connections to them are actually made.

D. INSTALLATION OF REFRIGERANT MAINS

11D1. Copper tubing and copper pipe specifications. Copper tubing and copper pipe should conform to the standards of the Navy specifications. It should be cleaned, deoxidized, dehydrated, and sealed by the manufacturer before shipment, and thereafter should remain sealed at all times. When it becomes necessary to cut expected; therefore, the condition of the wheels must be checked regularly. Always ream the tube ends to remove the burrs. Even with sharp wheels, great care must be taken to prevent crushing or denting of the tubing. With a dull wheel, considerable pressure is necessary to cut the tube; this may result in the formation of a heavy burr, or neck, at the cut. Also, the outside of the tubing is upset or

sections of its seal all open ends of the remaining portions.

11D2. Stock tubing. When stock tubing or pipe must be used, the following instructions should be carefully observed.

With a strong blast of dry air, thoroughly blow out each length or coil of tubing. With a cloth swab attached to copper wire, pull the swab back and forth in the tube until it is clean and shiny, then seal the ends of the tube. A swab for this purpose is easily made by kinking the copper wire or coiling it like a corkscrew and winding a piece of flannel around it tightly so that it passes through the tube with just enough friction to clean the tube but not to become lodged. Do not use waste or other material that might leave lint.

After each tube or pipe has been thus cleaned, the two open ends should be sealed against the entrance of moisture or dirt by covering the ends with a small piece of canvas taped securely in place.

11D3. Cutting tubing and pipe. In cutting copper tubing or pipe, care must be exercised to prevent filings or cuttings from entering the pipe. Some effective means should be used to clean out the small particles of copper that do enter the tube or pipe. Finely divided copper that can pass through the suction strainer collects in the compressor crankcase lubricating oil, where, together with small quantities of air and moisture, it may promote oil gumming and sludging and often cause chemical reaction.

bulged a little at the cut. This must be dressed with a sharp fine file to permit the tubing to enter the fitting freely;

When cutting copper tubing with a hacksaw, it is important to use sharp blades; blades with 32 teeth per inch give the best results. Dull blades tear the tubing and leave troublesome burrs. The tubing must be cut square, and all burrs removed with a sharp fine file from both inside and outside. Hold the tubing so that the filings will not drop in the length of tubing where they cannot be removed.

11D4. Preparing ends of tubing and pipe joints. When making soldered and brazed joints, it is necessary to brighten the ends of the tubing or pipe to make a good bond. This brightening should be accomplished with a wire brush or with crocus cloth.

Do not under any circumstances use sand paper, emery cloth, or steel wool for dressing the ends of tubing or pipe, as this material is certain to enter the tubing or pipe and is eventually carried back to the crankcase of the compressor, where it may be a direct cause of seal, bearing, cylinder wall, or piston failure.

11D5. Use of flux. Under no consideration should acid be used in soldering. Care must be exercised to choose a type of flux having a residual substance that does not form an acid. Care must also be exercised while making the joints to prevent flux from entering and piling up on the inside of the tubing or pipe, since it would eventually be washed back to the compressor crankcase.

These particles may also be carried by the lubricating oil to the seal, bearings, and cylinder walls, and thus cause seal and bearing failure, or scoring of the cylinder walls and pistons.

When cutting copper tubing with a wheel cutter, it is extremely important to use only sharp wheels. The soft copper wears the edge of these wheels more quickly than might be

Fittings that are not properly sized and that fit imperfectly are difficult to solder or braze. Consequently, there is danger of piling up filler metal as well as flux inside the tubing or pipe.

11D6. Making soldered or brazed joints. A soldered joint, as well as a brazed joint, requires

a temperature sufficiently high to cause oxidation within the tubing or pipe, and consequently some means must be provided to maintain a neutral atmosphere within the tube or pipe. Oil pumped nitrogen gas should be blown through the tubing or pipe being soldered or brazed, and continued after the joint is made until the copper is brought down below its oxidation temperature.

Copper oxide is one of the substances that, in combination with air and moisture, produces gumming and sludging of the lubricating oil and causes a chemical reaction such as copper plating of the working parts of the compressor.

If a system has once been charged with Freon 12 refrigerant and develops a leak, it is necessary to blow out any traces of the refrigerant vapor and oil from that part of the system before attempting to repair the leak.

The temperature level necessary in soldering is sufficient in the

quality noncorrosive flux to the end of the tubing and the valve body socket.

3. Insert the tubing in the valve socket until it is tightly seated against the shoulder.

4. To preheat the tubing, apply the torch in a sweeping, fanning motion. It is necessary to heat about 2 inches of tubing beyond the valve port.

5. Following the preheating stage, gradually fan the torch flame toward the valve port.

6. Quickly fan the flame around the end of the valve port. This heats the valve port and the tubing to the desired temperature.

7. After the flux has melted, touch the joint with the soldering wire. If the joint is hot enough, the wire melts, flows, and seals the joint.

8. After the solder has been applied, quickly apply a wet cloth over the valve body and the soldered joint.

11D7. Making SAE flare joints. Before preparing the flare, be sure

presence of copper to cause the disintegration of Freon 12, creating harmful acids and general contamination of the system.

Oil pumped nitrogen gas should be used to blow out the section to be repaired. A small amount of this gas should be permitted to flow during the soldering to create an inert atmosphere.

When making the soldered joint between tubing and valves, especially those of the diaphragm packless type, it is important to protect the diaphragm and the composition seat disk in the lower stem from damage caused by excessive heat. To provide maximum protection to internal parts, the following instructions should be carefully followed. The time that heat is being applied should be a matter of seconds.

Preliminary to heating the connection, open the valve wide by turning the handwheel counterclockwise until the stem is all the way back, then turn the handwheel forward clock wise about 1/4 turn. This moves the lower stem and disk away from contact with the valve body and thus minimizes the danger of heat being transferred to the valve seat. The steps in the soldering operation are:

1. Thoroughly clean the end of the tubing and the socket connection in the valve body.

2. Apply a thin coat of properly mixed high

to slip the flare nut over the tube end. To make a satisfactory flare joint, the flare must be as full as possible but small enough to clear the threads of the flare nut. The flare must be of uniform thickness, smooth, and free from tool marks, splits, ridges, high spots, and so forth. To get a full flare, the tubing must be cut square; to get a smooth flare, the burrs must be removed and new filings cleaned out of the inside of the tube.

The flare seat of the fitting connector must be bright and free from dents or scratches. If it has been damaged in any way, scrap the fitting. Do not attempt to correct a damaged flare seat by filing or sandpapering. The flare seat of the fitting and the inside of the tubing flare must be clean and dry when they are connected.

The SAE flare can best be made by the use of a swivel-headed flaring tool that remains stationary and does not tear or scar the face of the flare in the tubing. Do not use oil as a lubricant on the face of the flare, either in making up the flare or in drawing it up. It is impossible to remove oil from the surface of the flare by drawing up the flare joint. This oil would eventually be dissolved by the Freon 12 in the system, causing a leak at this joint. These joints must be clean and free from foreign matter.

SAE fittings are, shipped and packed with special protective caps that should not be removed until making up the joint, otherwise the faces are easily damaged.

a. Tightening flare joints. When tightening a flare joint, always use two wrenches: one to turn the nut, and the other to hold the fitting, valve, or flange. If only one wrench is used, the chances are that the connecting tubing, the joint, the fitting, or the flange will be strained, resulting in a leak.

The required pull on the wrenches for tightening the various sizes of flare joints is a matter of experience. The pull necessary for a 5/8-inch joint is obviously too great for a 3/8-inch joint.

11D8. Bending copper tubing or pipe. CAUTION. Do not use rosin, sand, or any other type of filler inside a piece of tubing or pipe in order to make a bend.

Bends can be made by various types of external forms or tools particularly designed for this kind of work. These tools may have a tendency to distort the tubing or pipe at the point of the bend from a true circular cross section; however, this slight distortion is not serious from the standpoint either of appearance or of pressure drop.

11D9. Cleaning copper tubing or pipe. In the event that the outside of the copper tubing or pipe is discolored and the specifications call for brightening such tubing, do not under any externally by means of a wire brush or crocus cloth.

11D10. Securing and handling copper tubing or pipe. In general, the specifications for the installation call for proper securing, anchoring, or hanging of the suction and liquid lines. Care must be exercised to permit sufficient flexibility between the compressor and the first set of hangers or points at which the lines are secured, to permit a certain amount of freedom and relieve any possible strain in the joints of these lines at the compressor.

11D11. Copper tubing and pipe fitting specifications. The special type of copper tube or copper pipe fitting designed for refrigeration service differs from the ordinary plumbing type of fitting in that the tolerances are held much closer to permit tight capillary joints of the soldered and brazed type. In the event that only standard tubing is available, the joint section should be enlarged or decreased by a suitable tool.

In all cases, fittings should be of the forged type, to eliminate porosity. All SAE flared fittings should be of the forged brass type, as those machined from ordinary bar stock are not substantial and eventually succumb to what is known as season cracking. It must be remembered that such fittings are under a considerable load when drawn tight.

11D12. Use of thread compound. The use of thread compound is not recommended. Any threaded

circumstances clean it with an acid bath. Such tubing or pipe should be installed as it is, and any brightening or polishing can be done or screwed joints must be seal welded or silver brazed.

E. INSTALLATION OF THERMOSTATIC EXPANSION VALVE

11E1. Function of the thermostatic expansion valve. The thermostatic expansion valve is used to control the flow of liquid Freon 12 refrigerant to the evaporator. This device plays a most important part because it is absolutely necessary to control the flow of refrigerant, not only to obtain the proper amount of refrigeration in each evaporator, but also to prevent liquid refrigerant from flooding out of the evaporator and going to the compressor in liquid form. Liquid refrigerant flowing to the compressor can cause damage in several ways, one of which is to bring about a condition wherein the lubricating oil is forced out of the compressor crankcase into the system. This results in the compressor operating without proper lubrication, damaging the cylinder walls, pistons, bearings, and seal.

The thermostatic expansion valve consists of the body housing, the operating mechanism, a capillary tube, and a thermal bulb. The thermal bulb is clamped to the suction line adjacent to the outlet of the evaporator in order to feel the temperature at this point. The thermal bulb is filled with a charge of liquid that is responsive to temperature change. The pressure

from the liquid in the bulb actuates the needle valve controlling the flow of liquid refrigerant.

11E2. Application of heat for soldered or brazed joints. Before applying heat to make up soldered connections, remove the power assembly and all gaskets. Keep heat away from all parts except the main body inlet and outlet.

11E3. Attaching the thermal bulb to the evaporator suction line. It is absolutely necessary that the thermal bulb be clamped tightly to the suction where the suction line enters a warm room, because heat from the warm room will reach the bulb by conduction and cause faulty thermo-valve action.

If the thermal bulb is not securely attached to the suction line with the thermal bulb clamp, erratic operation results. Liquid maybe flooded out of the evaporator and returned to the compressor, causing damage.

11E4. Locating the thermal bulb. It is preferable to place the thermal bulb as near the outlet of the evaporator and as high as possible on the suction line, using

line from the evaporator in order to respond quickly to temperature changes at this point, because it is this feature that causes the expansion valve to function properly. Special clamps are packed with the thermostatic expansion valve and must be used to fasten the thermal bulb. On pipe lines under 7/8-inch o.d., attach the bulb on top center of the pipe. On lines 7/8-inch o.d., or larger, attach the bulb about 45 degrees away from top center.

Clean the pipe or tubing thoroughly before attaching the remote bulb. Then draw up the clamp tight so that the bulb makes a firm positive contact with the suction pipe. It is also advisable to insulate both bulb and pipe together for a distance of at least 18 inches. Do not fasten the bulb on the suction line in a cold location immediately ahead of the point care to avoid placing it in any trapped portion.

In some cases, certain obstructions cannot be overcome and it may be necessary to run the suction line from the evaporator in as convenient a way as possible, resulting in traps which must be avoided when attaching the thermal bulb. Furthermore, the suction line at this point should be straight. Do not locate the thermal bulb at a point where the suction line is bent, as this results in poor contact.

CAUTION. The entire thermostatic expansion valve assembly, including the capillary tube and thermal bulb, must be treated as a delicate instrument as it will not withstand rough handling.

F. TESTING FOR LEAKS

11F1. Evacuating the system. CAUTION. Do not under any consideration use the condensing unit for evacuating the system. The condensing unit leaves the factory with the compressor absolutely clean and free of foreign matter. If the compressor were used in the evacuation process, foreign matter would be brought back from the evaporators and refrigerant mains and damage the compressor before it starts on its regular cycle of operation.

Evacuation of the system is accomplished by the following

4. Run the vacuum pump until the lowest vacuum possible is obtained; then stop the pump, and close the liquid charging valve.

The time required for this preparation varies with the capacity of the compressor and the amount of surface to be pumped out, but, in general, a few hours suffice.

If it is impossible to obtain a 29-inch vacuum, probably it is because of one of the following reasons:

a) Presence of excess moisture in the system.

procedure:

1. It is necessary to use an auxiliary vacuum pump capable of pulling at least 29 inches of vacuum.

2. Connect the suction side of the vacuum pump to the liquid charging valve, allowing the pump to discharge to the atmosphere,

3. Open all valves on the system to be evacuated.

b) Presence of absorbed refrigerant in the oil in the crankcase.

c) Leakage of air into the system. If there is a leak in the system, it should be found and stopped.

After the desired vacuum has been obtained, allow it to remain overnight. If the system has not lost more than 2 or 3 inches of vacuum

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by the next morning, it may be considered reasonably tight.

11F2. Charging the system with nitrogen gas and Freon 12 mixture for leak detection. After the preliminary evacuation, it is recommended that the system be tested for leaks by introducing sufficient Freon 12 refrigerant to raise the system pressure to approximately 10 psi; then test for leaks with the halide torch. If the system is found to be tight at this pressure, introduce sufficient oil pumped nitrogen gas to raise the system pressure to the required test pressure. The nitrogen gas drum should then have its connection broken from the system so that no accident may occur due to the building up of excessive pressure as a result of a leaky valve at the gas drum. The system should again be tested for leaks at the high-pressure level.

11F3. Use of oil. Oil should never be used in testing for Freon 12 leaks. Oil is unreliable for bubbles. When the joint is so located that a part of it is not visible, use a pocket mirror. It sometimes takes a full minute or more for bubbles to appear at a small leak. Questionable spots should be covered with lather and examined again.

11F5. Use of halide torch. Freon 12 leaks are detected by a specially designed torch known as a halide torch. (See Figure 11-1.) Atmosphere suspected of containing Freon 12 gas is drawn through an exploring hose into the burner by injector action. The air sample passes over a copper reactor plate in the burner chamber which is heated to incandescence by the flame. When Freon 12 gas is not present,

because of the capacity of the oil for absorbing Freon 12. If a small leak should exist where oil has been applied, the Freon 12 is absorbed by the oil and shows no indication by bubbles until after the oil is saturated with Freon 12. Furthermore, if an attempt is made to test a leaky joint that has been tested previously with oil, using a halide torch, a false indication in the halide torch results because Freon 12 is released from the oil.

11F4. Use of soapsuds. A halide torch is so sensitive that, if there are any bad leaks, the atmosphere around the apparatus becomes so contaminated with Freon 12 that it is impossible to locate the source of the leak with the aid of the torch. This condition prevails especially if the apparatus is located in a small or poorly ventilated room. Under such conditions, the halide torch is of little value in discovering the exact location of the leak, and soapsuds must be used.

To prepare soapsuds for testing, use a soap and water solution of about the consistency of liquid hand soap, which lathers freely, or work up a lather on a wet brush by rubbing the brush on a cake of soap. A few drops of glycerine added to the solution make the lather remain wet longer. When applying the soap suds, paint the soap lather on the joint all the way around and examine the joint thoroughly

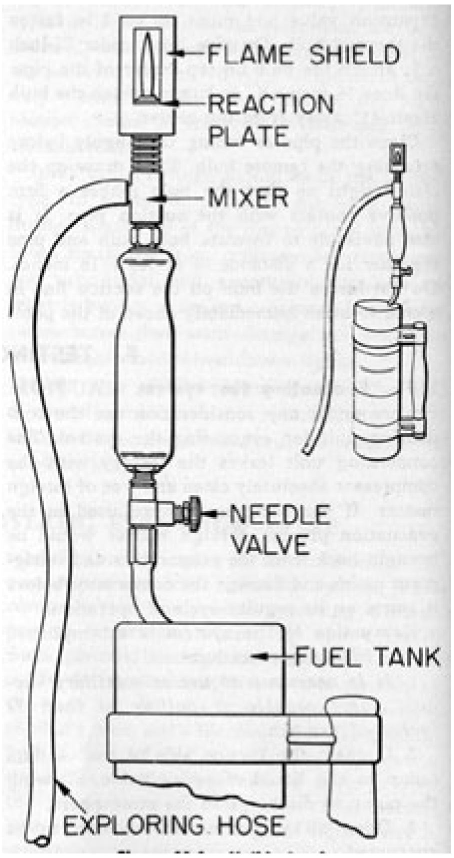

Figure 11-1. Halide torch.

the color of the flame is a faint being tested, to prevent dilution of

blue, almost invisible in the flame shield. If even a minute trace of Freon 12 is present, the torch flame changes from its normal faint bluish color to a dull but unmistakable green as the air sample comes in contact with the reactor plate.

The shade of green depends upon the relative amount of Freon 12 present, being pale for small concentrations and deeper for heavier concentrations. Excessive quantities of Freon 12 color the flame a vivid purple, and may even extinguish it by crowding out the supply of oxygen in the air. A number of halide torches are available on the market, most of which use acetylene gas or alcohol as a fuel. The acetylene burning Prest-O-Lite torch manufactured by the Linde Air Products Company is supplied for most Navy installations.

11F6. Directions for using halide torch. Several precautions must be observed in using the Prest-O-Lite leak detector to obtain best results. They are:

1. Be sure the reactor plate is in place.

2. Adjust the flame low enough so that it does not extend beyond the top of the burner chimney. A small flame is much more sensitive than a large flame. If difficulty is experienced in lighting the torch with the small gas flow necessary, block the end of the exploring hose until the flame ignites, then gradually open.

3. If the flame persists in burning with a white or yellow color, the the sample by stray air currents.

6. Move the end of the exploring hose slowly around each joint. There is a definite time lag between, the instant that the air enters the exploring hose and the time that it hits the reactor plate. Leak testing cannot be hurried.

7. If a green tinge is noted in the flame at any point, repeat the test in the same vicinity until the source of the Freon 12 is determined. Use soap bubbles if necessary to find the exact point at which a leak is occurring.

8. Do not use the torch in an atmosphere known to be heavy with Freon 12 as this tends to foul it.

11F7. Finding leaks. Always follow a definite order in testing for leaks, so that no joints are missed.

Find every leak. Even the smallest leak is not to be considered negligible. However insignificant the leak may seem, it eventually empties the system of its charge to the point of faulty operation. Because Freon 12 is practically odorless, the first indication is the loss of refrigerating effect. The extra time spent in testing all threaded, flared, soldered, and valve cap gasket joints made in the field, as well as the factory fabricated connection, is justified.

The system must never be recharged until all leaks are discovered and completely repaired. Upon locating one leak do not assume that it alone is responsible for the difficulty. Thoroughly retest the complete installation.

exploring tube is partially blocked with dirt and should be cleaned.

4. Try the torch in an atmosphere in which there is known to be a small amount of Freon 12, to make sure that it is finally working properly. Check to see that air is being drawn into the exploring tube, by holding the end of the tube to the ear from time to time.

5. Hold the exploring tube close to the joint

11F8. Procedure after system has been tested for leaks. After the system has been tested and found to be tight, it should be evacuated with the vacuum pump to 29 inches of vacuum, discharging the mixture of Freon 12 and nitrogen to the atmosphere. Make sure that the ventilating system is in proper operation during this procedure.

G. CLEANING REFRIGERANT MAINS, EVAPORATORS, AND AUXILIARY EQUIPMENT BEFORE OPERATION

11G1. Operation of compressor before cleaning the system. The compressor should not, under any circumstances, be operated until the system has been thoroughly cleaned by the special process described here. If it is necessary for any reason to check the operation of the motor, the belt guard and the belts should be removed and the motor operated alone.

11G2. Necessity for system cleaner. Although every precaution is taken to keep the system absolutely clean during installation, a

certain amount of foreign matter enters it, and this must be removed before the system is permitted to operate. Foreign matter can be successfully removed from the system by means of the York system cleaner, which is a special surge drum containing a filter, screen, and a large body of activated alumina dehydrating agent. The system cleaner is connected to the suction side of the system by means of a special adapter assembled in the suction strainer housing. This permits breaking into the system at this point

valves on the circuit to be cleaned should be open, except the purge and drain valves. With water circulating through the condenser, charge the weighed amount of liquid Freon 12 into the system. Since the Freon 12 charge is adequately distilled by the cleaning process described in the following paragraphs, it should be allowed to remain in the system for the normal refrigerating cycle.

11G6. Cleaning procedure. Foreign matter that usually returns to a compressor is intercepted by the York system cleaner. The

without disturbing any other connection.

11G3. Connecting the York system cleaner. Connecting lines to and from the York system cleaner are attached to a special adapter that is temporarily assembled in the suction strainer housing. Suitable adapters are available for the various types and sizes of suction strainer housings.

The choice of connecting lines between the system cleaner and the adapter depends upon local conditions. Use flexible armored tubing or plain copper tubing. These lines should be selected as large in diameter as practical, taking into consideration the size of the openings in each adapter.

The system cleaner should be located as close as possible to the compressor.

The outlet of the adapter must be connected to the inlet of the system cleaner and the outlet of the system cleaner connected to the inlet of the adapter. For convenience of installation, the adapter is provided with two outlets. In addition to this, the adapter can be rotated in several positions.

The system cleaner may be installed at any time before final evacuation of the entire system. The suction and discharge stop valves of the compressor must remain closed up to this time, isolating both the compressor and the system cleaner.

11G4. Final evacuation. Before starting the system cleaner, the entire plant, including the

return of this foreign matter is accelerated by actually flushing Freon 12 in its liquid state through the evaporators, mains, and auxiliary parts, back into the cleaner.

All liquid refrigerant and vapor entering the York system cleaner must pass through a fine mesh screen, a cloth filter bag, and a relatively large charge of activated alumina. Therefore, removal of moisture, as well as other foreign matter, is effected. Liquid refrigerant passing through this part of the cleaner collects in the large sump at the bottom. Only pure dry refrigerant vapor is pumped from this sump to the compressor.

11G7. Step by step operation for cleaning. The compressor is now put in operation for the first time. Each individual evaporator circuit should be flushed out with liquid Freon 12 by warming the thermal bulb of the expansion valve and opening the hand bypass valve (if furnished). If a solenoid valve is in the liquid control circuit, make sure that its thermostat holds it open.

If several evaporator circuits are connected to one compressor, clean each circuit separately. Start work at the evaporator at the greatest distance from the compressor, mean while isolating the other evaporators. Proceed progressively toward the compressor with the cleaning of all the other evaporator circuits, thereby preventing foreign matter from being deposited in a cleaned evaporator.

compressor and system cleaner, should be evacuated with an auxiliary vacuum pump to at least 29 inches of vacuum.

11G5. Charging the refrigerant circuit with Freon 12 for system cleaning. Purge the flexible charging connection with Freon 12, then connect it to the charging valve. All

Care must be taken that the level of liquid refrigerant in the York system cleaner is held sufficiently low so that it is not drawn into the compressor. This must be constantly observed through the sight glasses. It is necessary to provide heat at the bottom of the system cleaner by means of an electric

hot plate, radiant heater, trip heater, or by standing the cleaner in a container of warm water.

In heating, care must be exercised not to create so violent an evaporation that spilling over of the liquid to the compressor results. The proper liquid level to insure that only vapor returns to the compressor is maintained by controlling the liquid through the evaporator, by throttling the stop valve on the inlet to the cleaner, or by controlling the heat applied to the cleaner.

The oil level in the compressor crankcase must be carefully watched and maintained at approximately its original height by the addition of pure clean compressor oil when necessary.

11G8. Maintenance of the York system cleaner. The filter cloth and screen should be cleaned by immersing in approved cleaning solvent after each complete system cleaning. Replacement of the charge of activated alumina depends upon the quantity of moisture removed from the system.

oil may collect in the bottom of the system cleaner shell. This should be washed out with approved cleaning solvent after each cleaning operation.

Activated alumina must always be kept tightly sealed to prevent absorption of moisture from the atmosphere.

The length of time required to clean each evaporator circuit varies, depending upon such factors as size and length of lines. The flushing procedure should be not less than one-half hour per evaporator circuit.

11G9. Removal of the York system cleaner. After cleaning the last evaporator circuit in each system, the compressor suction stop valve should be closed and the refrigerant remaining in the sump of the system cleaner should be pumped out, but not below atmospheric pressure.

The inlet and outlet valves of the system cleaner are then closed and the adapter is removed from the suction strainer body. Finally, the suction strainer cover plate is put in place.

A certain amount of fine foreign matter and

H. ADDING AND REMOVING FREON 12

11H1. Charging Freon 12. To charge additional Freon 12 in the system, proceed as follows (NOTE. Observe and practice the precautions listed under Handling Freon 12 in Section 11A1):

1. If the Freon 12 charge has been lost, pump a vacuum on the entire system.

2. Mount the Freon 12 cylinder on a portable platform scale, preferably in an inclined position with its head lower than its base.

3. Connect the Freon 12 cylinder to the Freon 12 charging connection.

4. Slightly open the valve on the Freon 12 service cylinder, and test charging connections for leaks with soapsuds.

5. Open the charging valve and the Freon 12 cylinder valve, and charge in sufficient Freon 12 to create 60 pounds of pressure. In a new system or one in which there may be leaks, it is advisable to check all connections with the halide torch before adding any more Freon 12.

6. Close the liquid valve at the outlet of the receiver, run the compressor, and charge sufficient Freon 12 into the system. Be sure that the compressor suction, discharge stop valves, and the valve between the condenser and the receiver are open.

NOTE. When the system includes two compressors, condensers, and receivers, close both liquid valves at the outlet of the receivers, and run both compressors with suction and discharge stop valves open.

7. The liquid charging valve must be closed sufficiently to provide a pressure at the charging connection lower than the pressure in the Freon 12 cylinder, so that the Freon 12 will flow from the cylinder into the line. By observing the change in weight of the cylinder, the weight of charge added can be obtained.

11H2. Refrigerant charging connections. The charging valve, which may be of either the packless angle or globe type, is located in the liquid line between the receiver and the dehydrator.

The Freon 12 cylinder is preferably mounted on scales in an inclined position with the top

lower than the base to enable

2. Close the discharge stop valve

the operator to determine accurately the amount of refrigerant charged into the system.

The charging connection consists of a flexible section with a 6-inch length of 3/8-inch o.d. copper tubing soldered to each end.

The flexible section is made up of a seamless bronze bellows tube, reinforced and protected on the outside by heavy bronze wire braid. The ends of the bellows tube and bronze wire braid are fitted with copper ferrules, to which are soldered the 6-inch lengths of copper tubing. The outer ends of these tubes are flared and fitted with standard 3/8-inch SAE flare nuts.

A 3/8-inch male SAE flare to 3/4-inch female pipe-threaded adapter is furnished for connecting to a standard Freon 12 cylinder valve.

11H3. Removing Freon 12. If a system has been overcharged with Freon 12 or if the charge is to be transferred from the system, proceed in the following manner:

1. Start the compressor and pump down the evaporator pressure to zero psi, with the liquid valve out of the receiver closed.

and an liquid valves at the cooling coils.

3. Connect an empty Freon 12 cylinder to the liquid charging valve.

NOTE. Be sure that the cylinder is large enough to prevent danger of overfilling. Before connecting the cylinder to the Freon 12 system, set it in an ice-water bath to cool the cylinder thoroughly.

4. Open the liquid charging valve and the Freon 12 cylinder valve. Then slowly open the liquid outlet valve at the receiver. The cooled Freon 12 cylinder drains Freon 12 from the system until the pressure in the cylinder is equal to the pressure in the system. To remove the remaining Freon 12 from the system, it is necessary to use a second empty cold cylinder. The colder the cylinder, the less Freon 12 will remain in the system.

CAUTION. After disconnecting the Freon 12 cylinder from the system, weigh it to be certain that is has not been overcharged. The net and gross weights are stamped on the cylinder, and include the weight of the cast iron protecting cap.

I. FINAL ADJUSTMENTS

11I1. Final adjustment of stop valves and controls. After the system has been thoroughly cleaned, each evaporator circuit must be checked to make sure that the expansion valve thermal

During the final adjustment period, the level of the oil in the compressor crankcase must be constantly observed as it may be pumped over to the evaporators faster than it is returned, until final

bulb is properly located and securely clamped to the suction line. If hand-operated bypass valves are furnished, they must be closed tightly and locked to prevent them from being opened except in case of emergency, and then only by authorized operators who realize the extreme danger of flooding liquid back to the compressor.

If a solenoid valve is in the liquid control circuit, make sure that its thermostat holds it open during the period of adjustment.

The condensing unit is now placed in operation and the suction pressure switch is blocked in the running position to insure continuous operation.

On air-cooled condensing units, the compressor discharge pressure should be maintained at approximately 150 psi during the final adjustment period, by controlling the air to the condenser.

adjustments are made and normal operating conditions are obtained.

CAUTION. If the oil level should fall below the bull's-eye, add oil temporarily. It may be necessary to withdraw some of the oil thus added when normal conditions prevail.

The condition of the compressor lubricating oil, especially its color and appearance, is a good indication of the effectiveness of the system cleaner. The color can be observed at the compressor crankcase bull's-eye, or a sample can be drawn off the crankcase drain valve and compared to new clean oil.

11I2. Adjustment of thermostatic expansion valves. To obtain full evaporator capacity and at the same time prevent liquid refrigerant from returning to the compressor, it is necessary that the proper superheat adjustment be made on each evaporator circuit. Navy specifications call for 10 degrees of superheat.

Superheat means the difference in temperature between the liquid entering the evaporator circuit and the vapor leaving the evaporator circuit. This is best determined by the use of clip-on thermometers located on the tubing entering the evaporator circuit and the tubing leaving the evaporator circuit. These clip-on thermometers, to be effective, must be attached tightly against a clean bare spot on the tubing.

If the specifications call for insulation of any lines, this

1. The system must have full charge of refrigerant.

2. Expansion valve adjustment cannot be hurried.

3. Allow sufficient time for the valves to react after each adjustment.

4. Sufficient time must be allowed after each valve adjustment to allow the thermometers to register the true temperatures.

insulation should be applied before attempting to adjust the expansion valves. If the thermal bulbs are to be insulated, this also should be done before valve adjustment.

Thermostatic expansion valves for submarine installation are factory set for 10 degrees of superheat. The conditions of some installations may be such that 10 degrees of superheat are not accurately produced. Each evaporator circuit should therefore be separately checked, and if necessary, the expansion valve in the circuit adjusted. To change the superheat setting, remove the seal nut and manipulate the adjusting stem (see Figure 7-10). Turning the stem clockwise increases the superheat; turning the stem counterclockwise reduces the superheat.

When making the adjustment, observe the following precautions:

5. The compressor must be operating con tenuously, with a constant discharge pressure.

6. All evaporators must be in operation.

7. Because of the peculiarities of some applications, the system may not respond to the thermostatic expansion valve adjustment out lined. Special consideration must be given to such cases.

NOTE. Under normal conditions, the superheat setting of an expansion valve does not get out of adjustment. When the equipment is originally installed, the installation is under the supervision of a refrigerating engineer. The practice of experimenting with the superheat setting of the expansion valve should be discouraged. This setting should not be changed until all other possible troubles in the system have been eliminated.

12
STOWAGE OF FOODS

A. GENERAL PRINCIPLES

12A1 Classification of foods. In long-term cold storage of foodstuffs, great care is taken to maintain air temperature at the degree best suited to each kind of food, and many different rooms with varying temperatures are required.

However, in a submarine this would be impractical. Moreover, the storage is for short terms only when the requirements for preservation are not so strict. For submarine storage, foods may be classed in three main groups 1) meats, including poultry and fish; 2) dairy products; and 3) vegetables, including fruits.

12A2. Temperature requirements in food storage. Meats, poultry, and fish are best kept at temperatures below 32 degrees F; dairy products, vegetables, and fruits, at a temperature a few degrees above freezing. Bananas are an exception among fruits, as they cannot be kept at temperatures below 55 degrees F. Oranges, lemons, grapefruit, tomatoes, and melons also must be stored at a temperature around 50 degrees F.

Meats are stored by two methods: 1) cooler storage, and 2) freezer storage.

While most persons know that food is preserved by being kept in a cold place, it is not so well known that the humidity of the air is also a major factor in proper storage. Foods contain a large percentage of water, and they evaporate moisture just as human beings do. In general, about 60 percent of the weight of meats is the result of their water content. Vegetables and fruits contain from 80 to over 90 percent water. Dairy products are more variable: butter contains only about 10 percent water, cheese 35 percent, eggs 73 percent, and milk 87 percent.

If vegetables and fruits were stored in fairly dry air, they would wilt and become worthless quickly, for moisture evaporates from them constantly (except the citric acid fruits, from which moisture evaporates slowly). However, the storage room air is not likely to be dry, and the very fact that moisture evaporates constantly from these foodstuffs makes up for the loss of moisture in the air resulting from condensation by the refrigeration process. Thus they themselves keep up a fair balance. In addition, fruits and vegetables can and do absorb moisture, which helps prevent wilting.

Cooler storage has a temperature slightly above freezing. It is a method which needs careful watching and control of humidity and ventilation. Meat for current consumption is stored at 36 degrees F to 40 degrees F.

Freezer storage may be either near freezer storage with temperatures around 27 degrees F, or sharp freezer storage with temperatures around 10 degrees F. This is always necessary for long-term storage, since at temperatures below 10 degrees F, most bacteria and molds cannot grow. Meats frozen at this temperature are always preserved in best conditions of appearance, tenderness, and flavor. At 10 degrees F, meats may be preserved for several months, while at 27 degrees F there is some bacterial growth on the surface within 30 days. Poultry and fish should be sharp frozen. After being frozen, fish should be dipped in salt water for a few minutes in order to form a slight layer of salt-ice over the surface.

12A3. Humidity requirements in food storage.

Meats, however, cannot absorb moisture, and once too much evaporation has taken place, a permanent shrinkage and loss of weight result. The flavor, too, is greatly impaired. On the other hand, if too little evaporation from meats takes place, because of a high (92 percent or over) relative humidity of the air, two deleterious conditions arise. One is called sliming, and is brought about by excess moisture on the surface from the meat juices. The other is sweating, from the condensation of air moisture on the surface. Either of these two conditions is favorable to the growth of bacteria and results in spoiling of the meat.

Meats keep best at relative humidities of from 85 to 90 percent.

Another objectionable condition eventually appears after a considerable storage period, even if the humidity of the air is maintained

at the best level. This condition is the growth of molds, a group of tiny plants known also as fungi. However, molds grow chiefly on the surface, in contrast to bacteria which spread all through the meat. If molds are cut away, the rest of the meat remains in good condition.

rooms and to avoid the formation of dead air spaces.

There is a natural inclination, when taking on food supplies for a war patrol, to stack them closely, in order to carry as much as possible. Nothing is gained in doing this, if subsequently a large percentage

If molds appear on meat, the mold growth below the surface is about equal to the height of the molds above the surface, and the meat should be trimmed away sufficiently to remove all of the subsurface growth. But molds do not grow if the meat is stored at temperatures considerably below freezing.

If sterilamp tubes are available, they are a decided advantage in the cold storage of food stuffs. Over 80 percent of the radiation of these lamps is in the ultraviolet region and acts as an effective germicide and fungicide. Food stuffs may therefore be stored at considerably higher temperatures without deterioration, which results in more economical operation of the plant.

12A4. Ventilation requirements in food storage. In addition to the requirements of proper temperature and humidity, there is also the matter of proper ventilation. Foods need ventilation to be preserved well, just as people need it for comfort. If the air becomes stagnant, a blanket of high relative humidity is built up, thus preventing necessary evaporation.

12A5. Correct storage of food. Foodstuffs must be stowed in such a way that space is left for air circulation. This requires attention to two points. First, the boxes, cartons, or sacks must not be piled up solidly in large stacks, but rather in rows or small stacks with some air space between them. Moreover, if of the food must be thrown out because of spoilage.

Portable electric fans may be placed in the food storage rooms to assist in the circulation of air.

12A6. Prevention of odors in food storage. A highly important factor in food storage is the matter of odors. Butter and eggs are a source of annoyance in this respect, for they pick up foreign odors easily. They must never be stored in the same room with cabbage, or any other foodstuff having a pronounced odor.

12A7. Storage of quick-frozen foods. Quick freezing of foods is a great advance in the science of food preservation. The time will come, no doubt, when all or nearly all food stuffs will be prepared in this way. Not only is the food kept more easily, but much more food can be stored in a given space.

12A8. Food storage rooms in a submarine. Only two rooms in a submarine are available for cold storage of perishable foods. These are the cool room, entered through a hatch, and the refrigeration room, entered by a door from the cool room. These two rooms have fully insulated walls, floors, and ceilings (see Figure 7-2).

The cool room is maintained at a temperature of 40 degrees F, the refrigeration room at 15 degrees F. Meats, poultry, and fish are stored in the refrigeration room. Vegetables, fruits, and dairy products are stored in the cool room.

12A9. Cooling of drinking water. Water for drinking is carried by a

foodstuffs are piled solidly in large stacks, the outer layers of such stacks act as insulation, so that the interior parts of the stacks cannot be cooled. Second, all the rows of small stacks should be placed in the same direction, in order to follow the natural circulation of air in the pipe leading from the fresh water tank, through the cool room, to scuttlebutts. It is chilled to a satisfactory drinking temperature in the cool room.

B. COOLING OF FOODS

12B1. Navy requirements on precooling. All foodstuffs to go into cold storage in a submarine are expected to be delivered aboard precooled. However, frequently food must be taken aboard in a location where precooling is not available. In such case, a considerable load is placed on the refrigeration system in reducing the temperature of the foods to the proper storage level. It is therefore important to know what this load is in refrigeration tons so that the refrigeration system may not be over loaded. It is easily calculated, as follows:

12B2. Method of calculating food cooling loads. Case 1. Cooling foods to a temperature not below freezing. The following values must be known:

1. Weight of the food in pounds.

2. Temperature drop in degrees.

3. Specific heat of the food above freezing.

Multiplying these values gives the total heat removed in Btu. Dividing by 288,000 gives the number of refrigeration tons used (see Section 4B4).

Example. 400 pounds of tomatoes are received at 75 degrees F. They are to be cooled to 40 degrees F. The specific heat of tomatoes is 0.95 and the temperature drop is 35 degrees. Therefore:

Example. 4,000 pounds of beef are received at 72 degrees F. The beef is to be frozen and stored at 15 degrees F. The specific heat of beef above freezing is 0.77 and below freezing is 0.41.

4,000 X 40 X 0.77 = 123,200
4,000 X 102 = 408,000
4,000 X 17 X 0.41 = 27,880

Heat removed from 72 degrees to 32 degrees F is	123,200 Btu
Latent heat removed during freezing is	408,000 Btu
Heat removed from 32 degrees to 15 degrees F is	27,880 Btu

Total heat removed is	559,080 Btu

((400 x 35 x 0.95) / 288,000) - .046 TR

Case 2. Cooling foods to a temperature below freezing. The following values must be known:

1. Weight of the food in pounds.

2. Temperature drop to 32 degrees F.

3. Specific heat of the food above 32 degrees F.

4. Latent heat of the food.

5. Temperature drop from 32 degrees F to desired low level.

6. Specific heat of the food below 32 degrees F. In this case, simply compute separately the heat removed in the drop from the high temperature to freezing, in the drop from freezing to the low temperature, and the latent heat removed during the freezing; then divide the sum of these by 288,000.

Then 559,080/288,000 is 1.94 refrigeration tons.

This means almost four days full load on the refrigeration system. It shows plainly the necessity of obtaining precooled supplies, for the refrigeration system is always well loaded in taking care of supplies already stored.

12B3. Specific heats of foods. In order to make such calculations, it is necessary to have a table giving the relevant data for various foods. In the following table, the specific, heat below freezing is given only for such foodstuffs as need to be stored at a temperature below 32 degrees F.

PROPERTIES OF MEATS AND FISH				
Food	**Specific Heat Above Freezing**	**Latent Heat**	**Specific Heat Below Freezing**	**Percent Water**
Bacon	0.50	28	0.30	20
Beef	0.77	102	0.41	72
Fish, fresh	0.82	110	0.43	76
Lamb	0.81	95	0.67	67
Pork, fresh	0.51	65	0.30	46
Pork, salt	0.46	15	*	12
Poultry	0.80	85	0.42	60
Veal	0.70	89	0.39	63

*Will not freeze at normal freezing temperature because of salt content.

PROPERTIES OF DAIRY PRODUCTS				
Food	**Specific Heat Above Freezing**	**Latent Heat**	**Specific Heat Below Freezing**	**Percent Water**
Butter	0.64	15	0.34	10
Eggs	0.76	105	0.40	73
Oleomargarine	0.65	14	0.35	9
Ice Cream	0.78	96	0.45	67
Cheese	0.64	50	*	35
Milk	0.90	127	*	87
Buttermilk	0.92	131	*	91

*Should not be frozen. Fresh milk should be stored at 35 degrees to 38 degrees F; never above 40 degrees F.

12B4. Properties of fruits and vegetables. These foodstuffs should not be frozen, as freezing ruins them. The specific heat above freezing of fruits and vegetables may be taken as 0.90 for all practical purposes. These foodstuffs contain a large percent of water: green corn, 75 percent; potatoes, 80 percent; and the others, from 85 to 90 percent.

12B5. Water content of foods. The percentages of water contained in foods as shown by the property tables indicate the considerable intake of water with foods, a fact that is usually unnoticed.

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PART 2

AIR-CONDITIONING

13
INTRODUCTION

A. NEED AND PURPOSES

13A1. Air-conditioning. Air-conditioning is a field of engineering dealing with the design, construction, and operation of equipment used in establishing and maintaining desirable in door air conditions. These conditions vary according to the special requirements of the installation, which may be in a theater, factory, store, submarine, or any other enclosure occupied by human beings.

In the modern engineering practice of air conditioning, two phases are involved:

1. Actual conditioning of air, that is, the alteration under control of its temperature, humidity, purity, and oxygen content.

2. Ventilation, or replacement of stale air in an enclosure by conditioned air. These two aspects of air-conditioning are discussed separately in detail.

13A2. Need for air. Human beings are air breathing animals. inhales and exhales a large number of cubic feet of air per day.

13A3. Purposes of air-conditioning. Apart from this merely mechanical reaction, considerations of health, efficiency, and morale require that the air should be fit to breathe. This necessitates, among other things, the removal of fumes from a ship's galley, engine room, battery room, and water closets. Stale air must then be replaced by fresh air. More over, the body gives off excess heat and moisture by means of the air that is breathed and the air in contact with the surface of the body. It becomes obvious, therefore, that proper air-conditioning within the enclosed quarters of a ship is important, and that during the long dives of a submarine it is of even greater importance.

Air-conditioning is also needed for the protection of equipment, especially electrical apparatus. The large amount of moisture in the air

As such, man's lungs work unceasingly, awake or asleep. No one can hold his breath longer than a minute or two. The mechanism of the body demands that air, regardless of whether it is fresh or stale, be pumped in and out of the lungs continuously. The muscles that do the pumping operate automatically and no effort of will can stop them for longer than a couple of minutes at most. As a result, every person given off daily from the bodies of the crew, from cooking, batteries, and bilges, would condense on any cool surface if it were not removed by air-conditioning. This moisture, is extracted from the air by the air conditioning equipment, and is run into a tank. It is not suitable for drinking, cooking, or bathing, but is suitable for the washing of clothes.

B. AIR AS AFFECTED BY HUMAN PRESENCE

13B1. Oxygen content of the air. What we call air is not a single substance, but is a physical mixture of various gases. About 1/5 of ordinary outdoor air is oxygen; a little less than 4/5 is the inert gas nitrogen; about 0.03 percent is carbon dioxide; and the balance, less than 1 percent, is composed of the gases argon, helium, krypton, neon, xenon, and hydrogen. These are the components of dry air. Usually some water vapor is present also, varying greatly from day to day according to the weather.

It is oxygen, of course, that is used by the body. Measurements have shown that for each lungful of air breathed in by a person, only 4 percent of the oxygen in it is absorbed by the blood. It is therefore, evident that the air in a room can be circulated and breathed for a considerable period without ill effects.

13B2. Odors. Odors are always present, though the human sense of smell is not a keen one and usually is not aware of them. Almost everything gives off an odor, machinery, clothing, leather, books, food, the human

body, even when clean and newly bathed, flowers, and perfume. The odor in an enclosed space is a combination of all such odors and is carried by the air. However, it is well known that even if an odor is noticed on entering a room, a person rapidly becomes unaware felt because the surface of the body is large, measuring about 29 square feet for the aver age adult male. The body also gives off considerable moisture, but the amount varies greatly according to the activity.

Under normal conditions a person takes in somewhat more than 3

of it because the sense of smell is easily fatigued.

13B3. The heat and moisture contributed by human presence. An adult, when engaged in light work, as in a submarine, gives off on an average of about 500 Btu per hour. In comparison, a 25-watt electric light bulb gives off 85 Btu per hour; a 60-watt bulb, 205 Btu per hour; and a 200-watt bulb, 682 Btu per hour. The heat from a bulb can be felt by the hand at a distance of several inches, because the heat-giving surface is concentrated in a small area. The heat from a human body cannot be pounds of water per day, in beverages and food. Since the body is maintained at an average condition of equilibrium, this means that he gives off the same quantity per day, and much of this is evaporated directly into the air. If his activity or the air temperature is such as to cause a greater loss of water through perspiration, he feels thirsty and drinks more to maintain the balance. In a small enclosure, or room, the rise in temperature and moisture of the air caused by the presence of a number of people is considerable.

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14
DETAILS OF AIR-CONDITIONING SYSTEM

A. DESCRIPTION OF PLANT

14A1. The air-conditioning cycle. The Freon 12 refrigerant cycle in the air-conditioning system is the same as that in the refrigeration system. In general, the mechanical circuit of equipment is also similar; the main difference is that the air is brought by forced ventilation through ducts to the evaporators and returned through ducts to the rooms.

14A2. The air-conditioning plant. The air conditioning plant consists of the following main elements:

1. Two compressors, York-Navy Freon 12, enclosed single-acting vertical, two cylinders 4-inch bore x 4-inch stroke, rated at 4 refrigeration tons each.

2. Two condensers, York-Navy Freon 12, horizontal shell-and-tube 4-pass type.

3. Two receivers, York-Navy Freon 12 type.

4. Four evaporators, with finned cooling coils in two casings.

5. Two conning tower evaporators, in one casing.

14A3. Double system arrangement. The main elements are connected as two and air distribution system, which are described later.

14A4. Interconnection of double system. The two systems, while ordinarily set to operate individually, are interconnected. On the 200 class submarines, the interconnecting pipes run between 1) the discharge lines of the compressors; 2) the outlet lines of the condensers; 3) the inlet or suction lines to the compressors. Shutoff valves in these interconnecting, pipes permit any of the main elements to be cut out of one system and put into the other, in case of necessity.

Figure 14-1 shows these interconnecting pipes and valves clearly; they are left uncolored in the diagram for the sake of clarity. The colored piping indicates the circuits in which an actual flow of refrigerant is taking place during normal operation. There is no flow in the interconnecting pipes unless their shutoff valves are opened; normally they are closed. On the 300 class submarines, the inter connecting pipes run between 1) the discharge lines of the compressors, and 2) the outlet lines of the condensers. There is no interconnection between the suction lines of the compressors.

separate systems, each containing all necessary valves, gages, and controls for automatic operation. The cooling coils of these two systems, how ever, are placed side by side in an evaporator casing and, though appearing to be a single unit of coils, are nevertheless entirely separate. Thus either of the two systems may be operated alone, with its cooling action taking place in the evaporator casing. There are two such casings, located in different rooms in the submarine. Figure 14-1 (inserted at the back of the book) shows the complete system, with all piping connections and the location of all elements, valves, and devices. This diagram illustrates clearly the double arrangement. A separate diagram shows the ducts

14A5. The capacity of the air-conditioning system. The capacity of the system is 8.0 refrigeration tons with the two compressors operating at 330 rpm; and 6.4 refrigeration tons with the two compressors operating at 265 rpm; 10 gallons per minute of 85 degrees F water per refrigeration ton are circulated through condensers; and suction pressure corresponds to an evaporation temperature of 35 degrees F. Since most of the mechanical parts are the same as those in the refrigerating system, only the different parts are described.

B. THE COMPRESSORS

14B1. General description. Each of the two compressors is quite similar to the refrigeration system compressor. No separate illustration of them is given, since the main difference

lies only in the size, which is as follows:

1. Bore, 4 inches; stroke, 4 inches.

2. Drive, by 5 V-belts from a two-speed 4.9- to 4.1-hp electric motor, 250 (175-345) volts direct current (d.c.).

3. Lubricating oil charge, 10 pints of Navy Contract Oil, Symbol No. 2135, or equivalent.

dished and assembled in the following order; bottom disk, concave downward, small spacer; middle disk, concave upward; top disk, concave downward. The disks are 3 3/4 inches in diameter and contain three concentric circles of 5/32-inch holes, that must be aligned in assembly.

It is not good practice to permit a Freon 12 compressor to remain idle for an extended period of time. Compressors should be

14B2. Suction and discharge valves. Attention is called to the fact that in the 4 x 4 air conditioning compressor, the valve diaphragms or disks are exactly alike in both valves, and hence are interchangeable when new. Each valve has three disks, slightly

operated at least once a week. Therefore, if duplicate or standby compressors are furnished, they should be operated alternately, changing from one to the other at least every week.

C. THERMOSTATIC EXPANSION VALVE

14C1. The thermostatic expansion valve. Two types of this valve are in use, one for refrigerating, called the internal equalizer; and the other for air-conditioning, called the external equalizer. A general description is given first, then a detailed description of each type.

The remote bulb assembly (sometimes called the power assembly) contains Freon 12, and is attached to the suction line at the exit of the evaporator coil. Since Freon 12 has an exact temperature-pressure relationship, any variation in temperature of the suction line at the point of attachment produces a corresponding variation of pressure within the bulb. This pressure is communicated to the upper side of the diaphragm in the expansion valve. The lower side of the diaphragm (with airtight separation from the upper) is part of the regular refrigeration fluid circuit. Therefore any pressure difference between both sides causes the diaphragm to move. This, in turn, moves the valve stem, permitting more or less liquid Freon 12 to flow through.

1. Automatic expansion control.

2. Prevention of liquid refrigerant from surging through the evaporator to the compressor. It acts also to disperse the liquid Freon 12 in small droplets for easier and quicker evaporation and divides the high- and low-pressure sides of the system at this point.

The piping connections include a liquid strainer and a solenoid valve, with shutoff valves for servicing the strainer, solenoid valve, or thermostatic expansion valves; also manually operated valves and bypass for use in case it is desired to examine the thermostatic expansion valves, solenoid valve, or to clean the strainer.

14C2. Internal equalizer. This type of expansion valve is illustrated in Figure 7-10. After the liquid Freon 12 enters the valve and passes through the orifice, it is at low-pressure level of the evaporator. A port, or channel, bored through the valve seat retainer makes the spring chamber a part of the low-pressure line. The low-pressure refrigerant entering the spring chamber adds its pressure to the pressure of the

The thermostatic expansion valve controls the quantity of liquid refrigerant that is admitted to the evaporator according to changes in the superheat of the suction vapor leaving the evaporator.

This valve is designed to maintain a constant degree of superheat in the refrigerant vapor leaving the cooling coils, regardless of suction pressure. Thus its function is two fold: spring on the diaphragm. Opposing this combined internal pressure is the pressure from the remote bulb on the other side of the diaphragm.

14C3. External equalizer. An expansion valve is installed at the entrance of the evaporator tubing, and its bulb is attached at the exit of the evaporator tubing. Theoretically, the pressure inside the evaporator should be

constant. Any loss of pressure between the two ends of the evaporator coil would be of great importance as far as the proper working of the expansion valve is concerned.

In a refrigeration system, the evaporator tubing is usually of fair-sized diameter. Any pressure drop therein would be negligible. But in an air-conditioning system, the evaporator tubing is likely to be of smaller diameter, with restricted return bends. More over, the tubing is arranged in several separate banks joined by distributor headers from the single entrance pipe coming from the receiver. Such conditions cause a sizable pressure drop between the two ends of the evaporator, which, if not corrected, produce a material increase in the superheat of the vapor.

The external equalizer is designed to offset this undesired condition. Figure 14-2 illustrates the external equalizer type of expansion valve. In this type, the coil just beyond the point of greatest pressure drop. This point is usually just beyond the distributor header at the entrance end of the evaporator, because most of the drop occurs across this small region. With this supplementary connection, the pressure on the underside of the valve diaphragm approximates the mean evaporator pressure. The pressure drop across the distributor header still exists, of course, but its effect on the valve diaphragm has been balanced out, so that the superheat is back to normal, and the capacity of the system is not decreased.

14C4. Adjusting the thermostatic expansion valve. Navy specifications call for 10 degrees of superheat and this setting is usually made at the factory. If it becomes necessary to adjust the superheat setting, remove the seal nut and manipulate the adjusting stem. Turning this stem clockwise (tightening the spring) increases the superheat and reduces the flow through the valve. Conversely, turning the stem counterclockwise

port in the seat retainer is eliminated. Instead, there is an opening through the wall of the valve directly into the spring chamber. Fastened to this opening is a small diameter tubing, the other end of which communicates with the evaporator

reduces the superheat and increases the flow of liquid through the valve. Once set, it is seldom necessary to readjust.

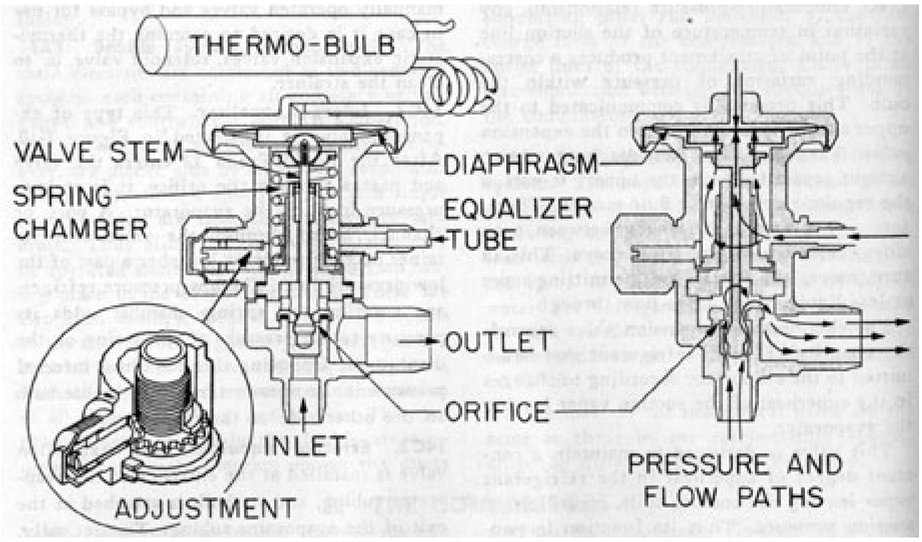


Figure 14-2. Thermostatic expansion valve, external equalizer.

14C5. Thermostatic expansion valve trouble. The thermostatic expansion valve should function without any difficulty if the system is free of dirt or foreign matter and contains no moisture. Presence of dirt or foreign matter between the seat and the valve prevents it from closing tight. Likewise, the presence of moisture in the system causes a freeze-up at the valve port and blocks the passage of Freon 12.

The system does not operate satisfactorily unless there is at least a 60-psi differential in pressure, between the high-pressure and low-pressure sides of the valve.

If it is evident that no Freon 12 is passing through the expansion valve, the valve should be disassembled, after closing the proper cut out valves, by removing the capscrews connecting the power assembly to the body. This permits the valve cage assembly to be examined for the presence of frost, ice, or dirt.

Due caution should be taken in reassembling the thermostatic expansion valve to see that all gaskets are properly placed, and that the valve cage assembly is properly aligned. Gaskets must be of the prescribed material.

It should be noted that these valves are delicate instruments and do not withstand rough usage. They should be handled with care.

D. SUCTION PRESSURE REGULATING VALVE

14D1. Purpose. The suction pressure regulating valve (see Figure 14-3), used only in the air-conditioning system, is a constant pressure device. Four of these were formerly used in the complete system, there being one installed in the suction line from each bank of the air-conditioning evaporators. On the 300 class submarines, only one of these valves is now used, and it is located in the pump room, on the suction line of the No. 1

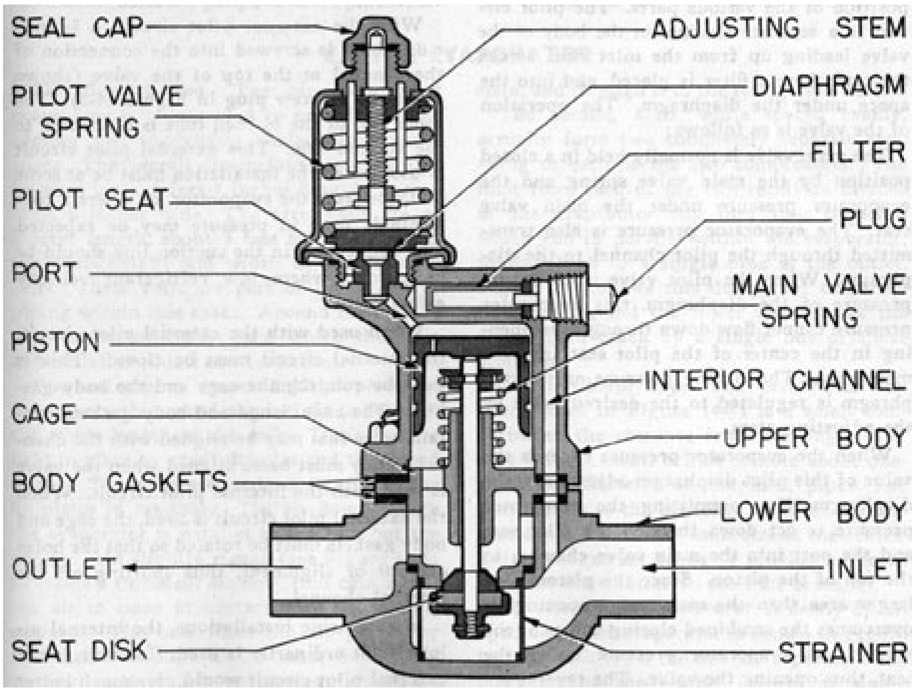


Figure 14-3. Suction pressure regulating valve.

air-conditioning unit. Normally this valve is by passed and is cut into the system only during the time that the No. 1 air-conditioning unit is cross-connected to the refrigerating system.

By having a suction pressure regulating valve installed in the suction line of the No. 1 air-conditioning unit, it is possible to operate the refrigerating system, with a suction pressure of about 5 pounds, and at the same time, to operate the No. 1 air-conditioning system, with a suction pressure of 35 pounds. when the evaporator pressure falls below the setting of the pilot adjustment.

However, in actual operation, this action does not take place in complete steps of opening and closing. Normally, the piston assumes an intermediate floating position, responding to fluctuations in the evaporator pressure; these fluctuations are balanced out and the resulting pressure is maintained at a substantially constant value asset by the adjusting stem. Since Freon 12 has a strict pressure-temperature relationship, this

The suction pressure regulating valve serves the purpose of maintaining a substantially constant vaporizing temperature in the evaporator coil to which it is connected, regardless of the temperature prevailing in the suction line itself, or of sudden load changes or suction pressure fluctuations.

14D2. Operation. The type of constant pressure valve used is known as a pilot-operated piston valve. Figure 14-3 shows the disposition of the various parts. The pilot circuit is a separate channel in the body of the valve leading up from the inlet side, across the top where a filter is placed, and into the space under the diaphragm. The operation of the valve is as follows:

The main valve is normally held in a closed position by the main valve spring and the evaporator pressure under the main valve seat. The evaporator pressure is also transmitted through the pilot channel to the diaphragm. When the pilot valve is closed by pressure of the diaphragm, this evaporator pressure cannot flow down through the opening in the center of the pilot seat into the main valve. The closing pressure on the diaphragm is regulated to the desired value by the adjusting stem.

When the evaporator pressure exceeds the value of this pilot diaphragm adjustment, the diaphragm lifts, permitting the evaporator pressure to act down through the pilot seat, and the port into the main valve chamber to the top of the piston. Since the piston is of larger area than automatic action maintains the temperature within the evaporator coil at a nearly constant level.

14D3. Internal and external pilot circuits. The suction pressure regulating valve may be used with either an internal or external pilot circuit. As an internal pilot circuit, it is used as described, with the evaporator pressure coming through the internal channel in the valve body, and the plug inserted.

With the external pilot circuit, a 3/8-inch o.d. tubing is screwed into the connection of the channel at the top of the valve (shown closed by a screw plug in Figure 14-3). The other end of the 3/8-inch tube is connected to the suction line. This external pilot circuit is used when the installation must be at some distance from the evaporator, or where a considerable drop in pressure may be expected. The connection in the suction line should be at a point where low refrigerant velocity exists.

When used with the external pilot circuit, the internal circuit must be closed. This is done by rotating the cage and the body gaskets. The cage flange and body gaskets contain holes that may be aligned with the channel. They must be so aligned when the valve is used with the internal pilot circuit. When the external pilot circuit is used, the cage and body gaskets must be rotated so that the holes are out of alignment, thus shutting off the internal channel.

In submarine installations, the internal pilot circuit ordinarily is used. However, if the external pilot circuit would give much better

the main valve opening, it overcomes the combined closing forces of the spring and evaporator pressure under the seat, thus opening the valve. The reverse action takes place

operation of the system, the external tubing is easily attached.

14D4. Adjustment. The suction pressure regulating valve is designed to operate properly at light loads. A minimum differential of 2 pounds between evaporator and suction pressures is sufficient for proper operation.

The pressure adjustment range runs from 2 psi to 70 psi. Rotating the adjusting stem clockwise gives a higher pressure setting, and vice versa. One complete turn of the adjusting stem changes the setting by approximately 4 pounds.

When adjusting, insert a pressure gage in the external pilot tube connection, first removing the plug or tubing. Be sure to allow ample time for the system to stabilize itself between adjustments. If the valve fails to respond to an adjustment, check the suction pressure to make sure that the compressor is actually capable of producing a pressure lower than that desired in the evaporator, remembering that a 2-pound differential is sufficient.

Be sure to replace the seal cap after adjustment.

14D5. Cleaning. All service operations may be performed on this valve without removing it from the line. The pilot channel filter may be removed for cleaning, using a screwdriver. The entire pilot valve housing may be removed by using an ordinary wrench on the hexagon at the top. The diaphragm and pilot seat may be cleaned, if necessary, with a soft, clean cloth.

The main upper body is removed by taking out the four capscrews. Note that the piston has a loose fit and slides freely in the housing; be careful that it does not drop. The cage and inlet strainer may now be lifted out for cleaning.

In reassembling, be sure to replace all gaskets. Be sure that the holes in the cage flange and body gaskets are properly placed, in line with the channel for the internal pilot circuit, and out of line for the external pilot circuit.

E. THE EVAPORATOR

14E1. Construction. The air-conditioning evaporator is

main, and through it to the refrigerant within.

constructed to provide a large cooling and condensing surface in a small space. The overall dimensions are, roughly forward coils, 5 feet 7 inches long, 11 inches high, 9 inches wide. The after coils are of shorter length, about 3 feet 6 inches, but of the same height and width as the forward coils. These coils are part of the Freon 12 piping within this space. Around the coils is the evaporator casing into which the inlet and outlet air ducts are connected.

The coil piping passes through plates or fins of very thin metal, stacked six to the inch the whole length of the coils. These fins are held in place by small dimples and tin-tipped solder. The coils are wedged tightly to the fin plates in assembly. The air flow through the evaporator is parallel to the fins, but the fins are bent slightly zigzag (see Figure 14-4) to create a turbulent air flow, thus causing all the air to come in contact with the cooling surfaces. The heat, from the air passes by conduction through all of these fins to the cooling coils proper or banked refrigerant

The cooling coils, while spaced evenly, actually form two completely separate sets, going to each of the two compressors. The inlet from each of the two receivers divides at the distributor cup into four branches which run in parallel within the evaporator, joining back to a single pipe at the outlet. Figure 14-4 shows this double set construction clearly, and the lower view shows the coiled path taken by a single one of these branches.

a. Distributor cup. The distributor cup (not shown in Figure 14-4) is a small compartment, the entrance from the single inlet pipe being a small orifice or hole about one third the diameter of the inlet pipe. The four outlets to the branches from the distributor cup are about the same size as the orifice. This arrangement tends to provide an equal pressure distribution in the four branches.

14E2. New type evaporator. A newly developed design of evaporator is shown in Figure 14-5. In this type, the fins are separate small disks around the piping, instead of single

plates across the whole evaporator. This construction permits quicker and better cleaning. There is also a new type of distributor cup, an inner cup, that overflows and fills the outer cup, and goes out into the branches, the ends of which project down into the cup.

These ends have small holes at the top of the cup and are open at the lower extremity (see enlarged view in Figure 14-5).

The reason for this new design of cup is that while theoretically there should be no throttling action or expansion of liquid into

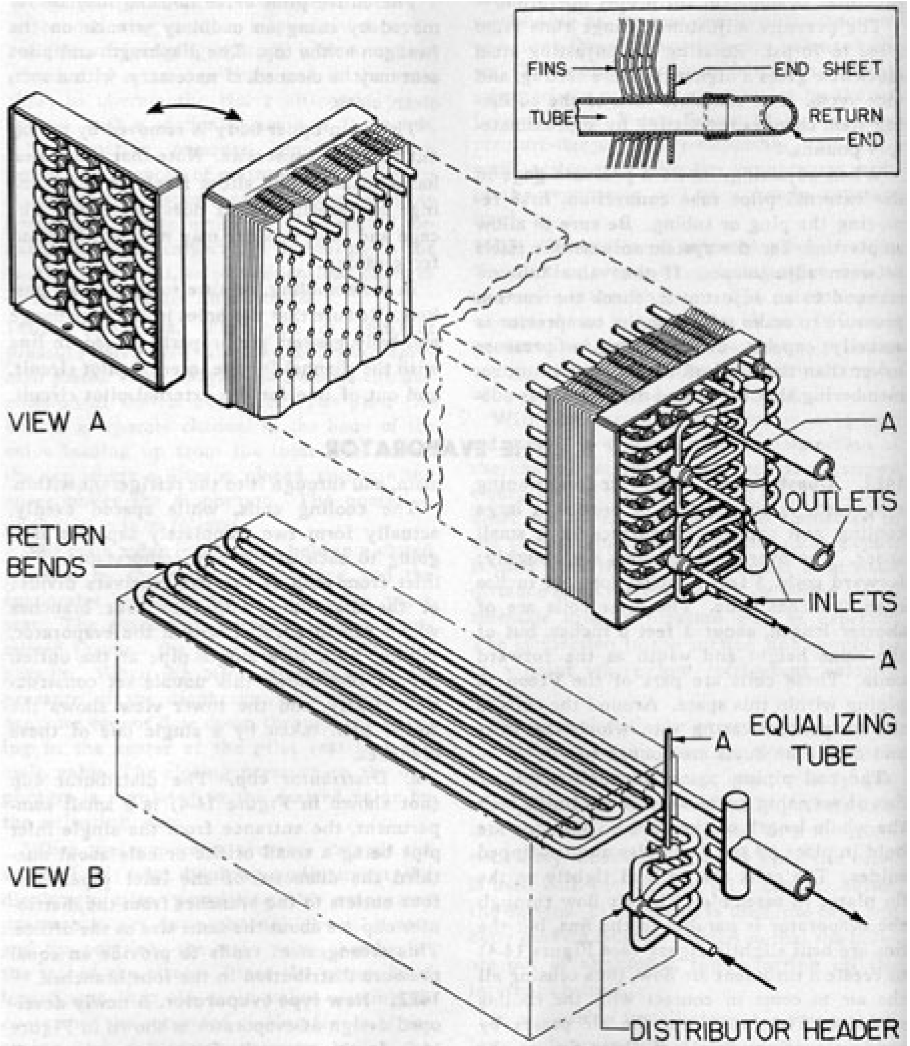


Figure 14-4. Air-conditioning evaporator.

flashgas while flowing into a cup, practically, there usually is some. The holes into the branch ends at the top of the cup permit any such flashgas to be distributed equally into the four branches. This design also has a low-pressure drop across the distributor header. In installation, these cups should be set upright and not turned on their sides, which would cause gas binding, and some of the branches would lack their proper share of liquid.

14E3. Conning tower evaporators. Two evaporators, contained in a single casing, are located in the conning tower. They are connected to the liquid and suction lines of No. 1 and No. 2 air-conditioning plants, respectively. Each evaporator has its own expansion valve and solenoid valve; however, there is no thermostat. The solenoid valve is controlled by a hand-operated switch and can be operated manually only.

The installation and design of conning

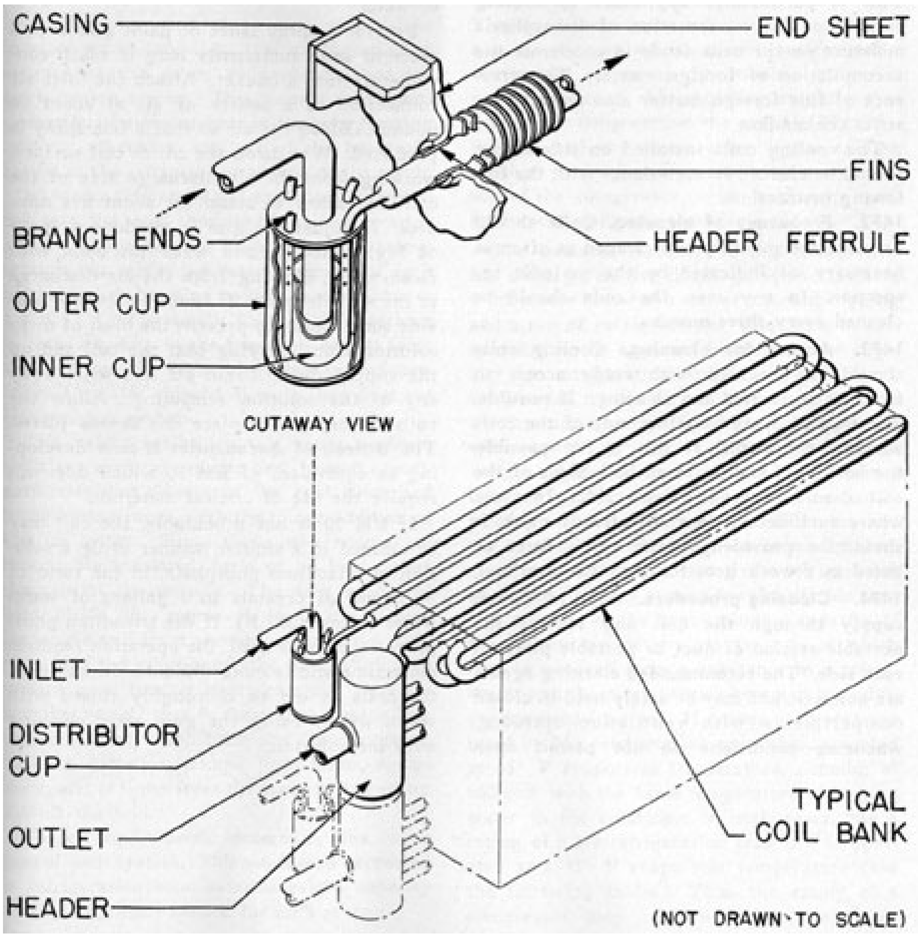


Figure 14-5. Air-conditioning evaporator, new type.

tower air-conditioning units vary with each class of vessel. Therefore, no detailed description can be given to cover each installation.

F. CLEANING THE EVAPORATOR

14F1. Maintenance and cleaning of cooling coils. An accumulation of dust or organic material on the surfaces of a cooling coil decreases the quantity of heat that can be transferred, and lowers the operating efficiency of the coil. Even a thin film on the surface reduces the capacity to an undesirable extent. This is particularly applicable to cooling coils since the condensation of atmospheric moisture on the coils tends to accelerate the accumulation of foreign matter. The presence of this foreign doors and hatches in the compartment.

When cleaning the cooling coils, do not shut off the compressors as cleaning agent RM 70 is volatile.

Prepare a bucket of RM 70 solution, a nontoxic solvent, in warm water (about 110 degrees F) in the ratio of 4 ounces of RM 70 to 1 gallon of water.

Provide a spray lance or paint gun with a piece of hose sufficiently long to reach conveniently into a bucket. Attach the inlet air connection to a source of air at

matter also tends to restrict the air flow.

The cooling coils installed on submarines should be cleaned in accordance with the following instructions.

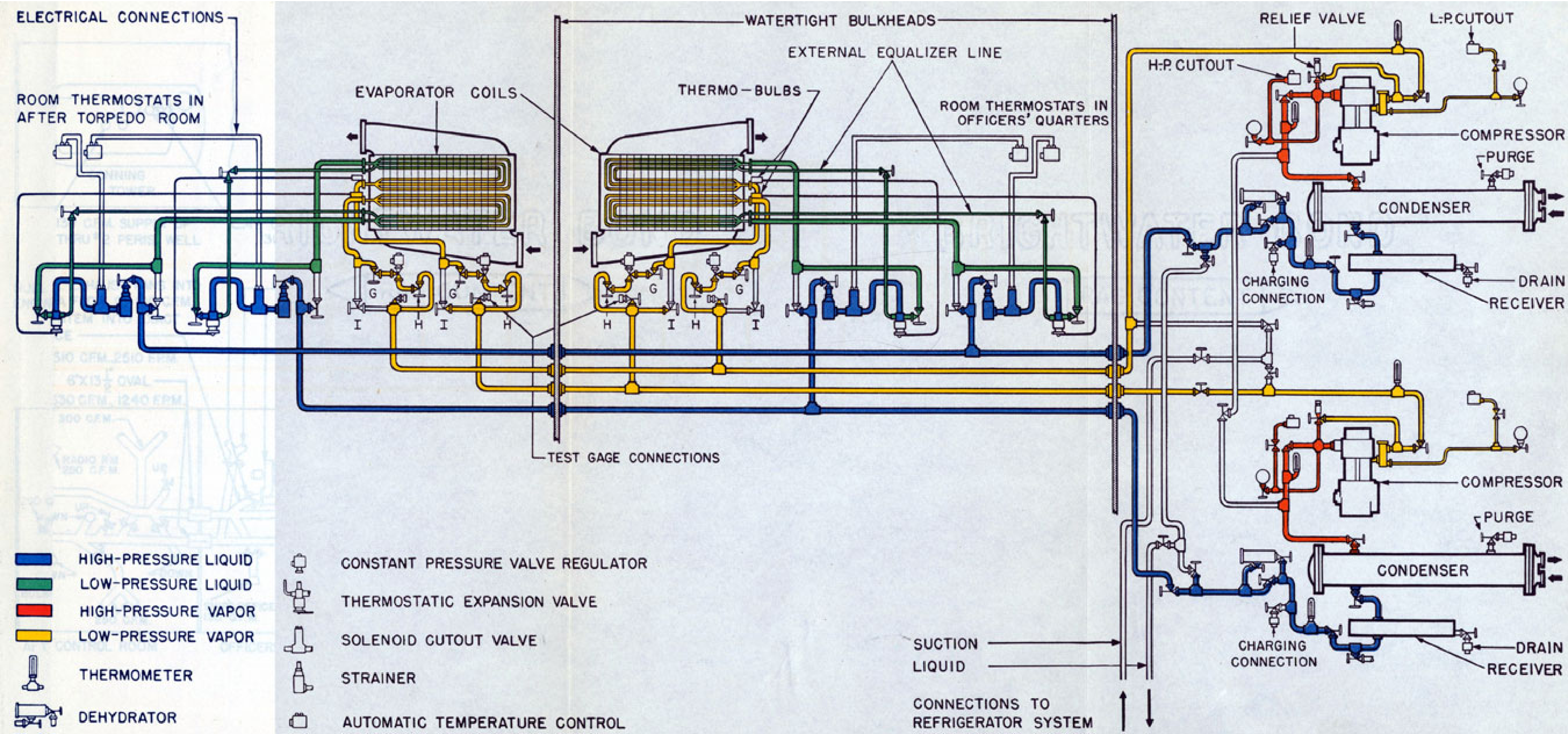
14F2. Frequency of cleaning. Coils should be inspected monthly and cleaned as often as necessary, as indicated by the periodic inspection. In any case, the coils should be cleaned every three months.

14F3. Access for cleaning. Cooling coils should be provided with ready access to facilitate inspection and cleaning. If possible, a section of ducts on either side of the coils should be portable. If this is not possible, the bottom of the ducts on both sides of the coil should be readily removable. In cases where such access does not already exist, it should be provided by the ship's' force or listed as a work item for the next overhaul.

14F4. Cleaning procedure. Shut off the air supply through the coil and remove the portable section of duct or portable plate on each side. The recommended cleaning agents are nontoxic and may be safely used in closed compartments with ventilation operating, whenever conditions do not permit open about 60 pounds. Bleed the air so that a fine spray is produced. Wet down the entire coil surface, working from the air discharge side of the coil, and allow to stand for about five minutes. Readjust the gun to produce a spray of high velocity, and wash the coils with clean water, blowing from the air discharge to the air inlet side. If found necessary, provide some means to prevent the blast of dirty solution from carrying past the coil and up the supply duct. Drain off and wipe away any of the solution remaining. Allow the coils to dry and replace the access plates. The Bureau of Aeronautics is now developing an equivalent of RM 70 which does not require the use of critical materials.

If RM 70 is not procurable, the coil may be cleaned in a similar manner using a solution of trisodium phosphate, in the ratio of 1/2 pound of crystals to 3 gallons of warm water (about 100 degrees F). If the trisodium phosphate solution is used, the operation requires more time and is more difficult. In addition, the coils should be thoroughly rinsed with warm water, using the gun, after cleaning with the solution.

Figure 14-1. AIR-CONDITIONING PIPING DIAGRAM. Sub Refrig. Home Page



15
INTERCONNECTION OF SYSTEMS

A. RELATION OF CAPACITIES

15A1. Necessity for compressors of different capacities. The air-conditioning system and the refrigeration system aboard a submarine are designed as two separate and distinct systems. Each is capable of performing its task independent of the other. However, in practice it is desirable that these two systems be interconnected so that the air-conditioning compressor can serve as a standby for the refrigeration system. This insures continuous operation of a compressor in the refrigerating system; otherwise, spoilage of the foodstuffs stored in the refrigerating rooms might result.

In earlier references and explanations within this text, the rated capacity of the refrigeration system compressor has been given as 1/2 refrigeration ton, while the rated capacity of each of the air-conditioning system compressors is given as 4 refrigeration tons. This difference in rated capacity of the two units results from the fact that the air-conditioning system performs a greater of the compressor is the amount of work, expressed in refrigeration tons, that a compressor is capable of doing under a given set of operating conditions. A change in the operating conditions causes a corresponding change in the rated capacity of the compressor. Therefore, the relation between the capacity of a compressor on a refrigeration system and a compressor on an air-conditioning system is a comparison of the operating conditions of evaporator temperature, the speed of the compressor, and the temperature of the cooling medium for each system, and not a comparison of the compressor or its maximum work load under optimum conditions.

The misunderstanding of this relationship has often given rise to the question: Is there a difference between a ton of air-conditioning and a ton of refrigeration? The cause of this question is the apparent increase in the capacity in refrigeration tons developed by a compressor on an air-conditioning unit over the capacity developed by the same compressor when operating on a refrigerating unit. It would appear that there were a difference between a refrigeration ton and an air-conditioning ton. Actually there is no difference and the term air-conditioning ton is not in common usage. The basic rating of a refrigeration or air-conditioning system in refrigeration tons is a

amount of work than does the refrigeration system.

The refrigeration system must perform sufficient work to remove heat from the comparatively small space of the cool room and refrigerating room, with the minor addition of the ice tuber.- Since these two rooms are thoroughly insulated, little or no heat enters them from the outside. The only source of heat inside the rooms is from the stowed foodstuffs and from persons entering for supplies. On the other hand, the air-conditioning system must remove heat generated throughout the vessel, that is, heat that passes into the air of the vessel from the crew, engines, cooking, batteries, electric light bulbs, equipment, and at times from the surrounding water outside the hull.

These requirements determine the work load of each system. This work load expressed in refrigeration tons determines the capacity of the compressor needed for each system.

15A2. Relation of capacities. The capacity measure of the heat-removing capacity of the system and determines the rate at which heat is removed from a substance in a refrigerator and the rate at which heat and humidity are removed from air. However, a compressor rated at 2.95 refrigeration tons when operated at -5 degrees F evaporator temperature, running at 600 rpm with the same temperature of cooling water in the condenser in both cases, has a rating of 8.348 refrigeration tons if it is operated at a 35 degrees F evaporator temperature (see the following tables). Thus the rating of a compressor may vary with the evaporator temperature; also the rating of a compressor

may vary with the speed of the compressor and the temperature of the cooling water flowing through the condenser.

The operating temperature of the evaporator (suction

requirement also increases under these same pressure conditions, although, as seen in the table for the 4 x 4 inch compressor, the relative power per refrigeration ton decreases.

Since Freon 12 has a positive pressure temperature relationship, it may also

pressure) has the greatest effect on the number of refrigeration tons that the compressor may develop. Refer to the table of properties of saturated Freon 12 vapor, Section 5D1. This table illustrates why the capacity of a compressor varies with the evaporator temperature (suction pressure), with constant compressor speed and condensing temperature. For example, at 0 degrees F the density of 1 pound of Freon 12 vapor is 0.6109 and at 40 degrees F the density is 1.263. In other words, the compressor handles approximately twice the gas at 40 degrees F that it does at 0 degrees F. Therefore, more refrigeration tons are developed at the higher evaporator temperature (suction pressure). The following tables illustrate this fact and also the effect of varying temperatures of the cooling water.

The figures given in the tables are obtained from engineering tests and computations.

The functional reason for this variation in capacity is that the capacity of a refrigeration machine is influenced by the operating pressures. The capacity increases as the suction pressure increases. The capacity decreases as the discharge pressure increases. The power correctly be said that the capacity increases as the evaporator temperature increases. Tables such as the previous ones are given in terms of the evaporator temperature, rather than suction pressure, because the temperature of the space cooled by the evaporator is the primary consideration.

The table does not give decrease of capacity against increase of discharge pressure, but against increase of condenser water temperature. The discharge pressure depends upon the temperature of the condensing water, as stated in Section 6B5. The condensing water temperature is of primary interest because it varies according to geographical location and season of the year. Therefore, although increase in discharge pressure decreases the capacity, it may be said that the capacity decreases as the condenser water temperature increases.

The discharge pressure also varies according to the speed of the compressor, but the usual practice is to operate the compressor at a relatively constant speed.

COMPARISON OF REFRIGERATION AND AIR-CONDITIONING

COMPRESSOR RATINGS		
CHARACTERISTIC	REFRIGERATION	AIR-CONDITIONING
Bore	2 5/8 inches	4 inches
Stroke	2 1/2 inches	4 inches
Cylinders	2.	2.
Displacement	27.10	100.50
Rpm	600.	600.
TR at -5 degrees F evap. temp.	0.742	2.95
TR at 35 degrees F evap. temp.	2.17	8.348
Bhp at 5 degrees F evap. temp.	1.89	6.94
Bhp at 35 degrees F evap. temp.	2.42	8.95

VARIATION IN COMPRESSOR RATINGS IN TR AND BHP FOR 4 X 4 INCH, 2-CYLINDER COMPRESSOR										
Evaporator Temperature	**Condensing Water Temperature in Degrees Fahrenheit**									
	90 deg.		**95 deg.**		**100 deg.**		**105 deg.**		**110 deg.**	
	Tr	**Bhp**	**Tr**	**Bhp**	**Tr**	**Bhp**	**Tr**	**Bhp**	**Tr**	**Bhp**
-20 deg.	2.2	5.9	2.1	6.0	2.0	6.1	1.8	6.2	1.7	6.3
-15 deg.	2.6	6.3	2.4	6.4	2.3	6.5	2.1	6.7	2.0	6.8
-10 deg.	3.0	6.7	2.9	6.8	2.1	7.0	2.5	7.1	2.4	7.2
-5 deg.	3.5	7.0	3.4	7.2	3.2	7.3	3.0	7.5	2.8	7.7
0 deg.	4.2	7.5	4.0	7.6	3.8	7.8	3.5	8.0	3.3	8.2
5 deg.	4.8	7.8	4.6	8.0	4.4	8.2	4.1	8.4	3.9	8.6
10 deg.	5.6	8,0	5.3	8.3	5.0	8.5	4.8	8.7	4.5	8.9
15 deg.	6.3	8.3	6.0	8.6	5.7	8.8	5.4	9.1	5.1	9.3
20 deg.	7.1	8;5	6.7	8.8	6.4	9.1	6.1	9.4	5.7	9.7
25 deg.	7.9	8.6	7.5	9.0	7.2	9.3	6.8	9.7	6.5	10.0
30 deg.	8.8	8.7	8.4	9.1	8.0	9.5	7.6	9.9	7.3	10.3
35 deg.	9.8	8.8	9.4	9.2	9.0	9.6	8.6	10.1	8.2	10.5
40 deg.	10.9	8.7	10.5	9.2	10.1	9.7	9.7	10.2	9.3	10.7
45 deg.	12.2	8.7	11.7	9.2	11.3	9.8	10.8	10.3	10.4	10.9
Ratings at 650 rpm. To obtain capacity rating of any intermediate speed proportion directly to compressor rpm.										

B. INTERCONNECTION OF SYSTEMS

15B1. Cross-connection of air-conditioning and refrigeration systems. In an emergency necessitating the securing of the refrigerating compressor, it is possible to cross-connect at least one of the air-conditioning compressors, condensers, and receivers to the refrigerating system evaporator, and maintain the desired temperatures in the refrigeration rooms. On some classes of vessels, either of the air-conditioning compressors may be cross connected to the refrigeration system; on other classes only the No. 1 air-conditioning compressor can be used. As the arrangement and location of valves and lines vary on each installation, no detailed description can be given here. It is never necessary or desirable to cross-connect the refrigerating compressor to the air-conditioning evaporators.

In cross-connecting the air-conditioning compressor to the refrigerating evaporator, several major adjustments must be made on all installations. Reset the low-pressure cutout switch on the air-conditioning compressor so that it does not stop the compressor until the suction pressure drops down to 2 psi. Normally this cutout is set to stop the compressor when the suction pressure on the air-conditioning evaporator reaches 32 psi. If the compressor is to operate both the air-conditioning system and the refrigerating system, the bypass around the suction pressure regulating valve should be closed, the stops opened, and

the valve cut into the system. With the suction regulating valve in operation, a 32-psi suction pressure in the air-conditioning evaporator is maintained while the compressor is operating at the lower suction pressure necessary on the refrigerating system. The operation of the two systems in this manner is desirable because the capacity of the air-conditioning compressor is much more than is needed to maintain the refrigerating Leave in the main switch supplying current to the refrigerating compressor. With a wooden pencil or other insulated material, lift the overload relay cutout located on the bot tom left side of the half-ton compressor control panel, to the OFF position, making sure that the overload relay cutout stays up. Then turn the selector switch on the half-ton system to either MANUAL or AUTOMATIC. This insures a supply of current to the thermostatic controls.

15B2. Cross-connection of air-conditioning systems. On some classes of vessels, it is possible to

rooms at the desired temperatures.

Another point that must be checked is that electric current is supplied to the thermostatic control circuit on the refrigeration system; otherwise, the solenoid valves remain closed and no refrigerant flows through the system. On some vessels, the thermostatic control circuits are energized from the 110-volt lighting circuit. In this case, the main switch to the refrigeration compressor may be pulled and the thermostatic control circuits energized through the refrigerating control panel. When the main switch is pulled on the refrigerating compressor, it interrupts the supply of current to the thermostatic control circuits. In this case, the following procedure should be followed:

operate the No. 1 compressor and condenser on the No. 2 evaporator, and vice versa. The air-conditioning systems on the 300 class submarines are cross-connected by the compressor discharge lines and the high-pressure liquid lines only. There is no cross-connection between the suction lines. Because of this arrangement, in the air-conditioning system the No. 1 compressor can be connected to the No. 2 condenser, and the No. 2 compressor can be connected to the No. 1 condenser. But the No. 1 compressor cannot be connected to the No. 2 evaporator, or the No. 2 compressor to the No. 1 evaporator.

16
THEORY OF AIR-CONDITIONING

A. AIR AND WATER VAPOR

16A1. Definition. Psychrometry (sy-krometry) means literally, the measurement of cold, from the Greek psychros, cold. It is the special name that has been given to the modern science that deals with air and water vapor mixtures. The amount of water vapor in the air has a great influence on human comfort. Such atmospheric moisture is called humidity, and the common expression, "It isn't the heat, it's the humidity," is an indication of the popular recognition of the discomfort-producing effects of moisture-laden air in hot weather.

16A2. Air and humidity a physical mixture. The water vapor in the air is not absorbed or dissolved by the air. The mixture is a simple physical one, just as sand and water are mixed. The temperature of the water vapor is always the same as that of the air.

16A3. Saturated air. If a tin can is filled with sand to the top, there is still room into which water can flow between the sand grains. If the can of sand is then filled with water to the top, that sand is holding all the water it is able to hold. It is said that the sand is saturated with water.

everyone is familiar, is also the condensation of dew from moist air on the cold surface of the pipes.

16A5. Condensation of saturated air. Condensation of water vapor from the air can take place at any air temperature, providing the temperature is below its dewpoint. In nature, moisture is condensed on foliage and other surfaces as dew if the air temperature is above 32 degrees F. If the temperature of the surface is below freezing, the moisture condenses as frost. Above the earth's surface it is mist. and when the mist is very thick, it is called a fog. If such condensation on dust particles is high in the air, the fog is then called a cloud. Under certain conditions of sudden cooling with much condensation, the droplets grow so large that they can no longer float in the air, and then they fall as rain. Sometimes a layer of air at a temperature below 32 degrees F exists high in a storm area; through this cold layer, raindrops may be carried down and up several times by air currents until they freeze and fall as hail. In cold weather when the temperature is below 32 degrees F, condensation on the dust in the air forms snowflakes.

In the same way, air can hold different amounts of water vapor, and when it is holding all the vapor it is able to hold, it is called saturated air.

The amount of moisture at the saturation point varies with the temperature of the air; the higher the temperature, the more moisture the air can hold.

16A4. Dewpoint. The saturation point is more usually called the dewpoint, for if the temperature of the saturated air falls below its dewpoint, some of the water vapor in it must condense to liquid water, generally in drops. The dew that appears early in the morning on foliage when there is normally a drop in temperature, if the air is moist, is such a condensation, and is, as is readily recognized, the source of the term dewpoint. The sweating of cold water pipes, with which almost

16A6. Difference between water vapor and water drops. The question is sometimes asked If the air contains moisture, why does the moisture not freeze when the temperature is below 32 degrees F? The answer is that only a liquid can freeze and a vapor is not a liquid. Drops of water, however small they may be, are merely small masses of liquid. In a mist or fog, the drops are so small that they float in the air, but they are nevertheless liquid. Air moisture does indeed freeze sometimes, if that moisture is in the state of liquid drops, and then it takes the form either of hail, or of sleet which is partially frozen moisture. Liquid moisture in the air (for example, mist) may exist in the form of drops subdivided so small as to be imperceptible to the human eye as individual drops; yet each single drop is

formed of a great multitude of molecules. In a vapor or gas, the subdivision actually consists of single molecules.

16A7. Intermolecular distance determines state. The fundamental difference between the three states of matter-solid, liquid, and gaseous-is the distance between the molecules. In a solid, they are close and hold to one another, so that each has little or no freedom of motion. In a vapor or gas, the molecules are so far apart that all mutual attraction is lost, and each has complete freedom of they take on the liquid state and become visible. If this is in the air, the finely sub divided liquid appears as mist, fog, cloud, or rain. If the molecules come still closer, they finally get close enough to take on the solid state, that is, the liquid water freezes. It is apparent, therefore, that water vapor in the air cannot freeze, for as the molecules get closer, they first pass through the liquid state. Thus, only a liquid can freeze.

Water vapor can, however, condense directly to the solid state under certain conditions. This is not freezing, for the vapor does

motion, except as bounded by a container. Solids and liquids are visible to the human eye, but vapors and gases, with few exceptions, are invisible. Water vapor is invisible. The visible white cloud arising from a tea kettle or steam pipe is not really vapor or steam although it is usually called steam, but is formed of minute liquid droplets, that have condensed on striking the cooler air. They re-evaporate in a few minutes and are invisible again.

16A8. Formation of frost. When molecules of water vapor come sufficiently close together, not become a liquid. The required condition is a surface at or below the freezing temperature, on which the water vapor arranges itself in solid geometrical forms or designs, called crystals. If the cold surfaces are extended, such as the ground, glass windows, and so forth, the crystals are called frost. Frosting always appears on the cooling coils (evaporators) of mechanical refrigerating systems. This frost must be removed periodically since it has some insulating quality and lessens the refrigerating capacity.

B. HEAT OF THE AIR

16B1. Sensible heat of air. The heat of air is considered from three standpoints. First, sensible heat is that measured by household, or dry-bulb, thermometers. This is the temperature of the air itself, without regard to any humidity it may contain. It may be well to emphasize this by stating that sensible heat is the heat of dry air.

16B2. Latent heat in air. Second, air nearly always contains more or less moisture. Conditions of complete absence of moisture rarely occur, perhaps only in desert regions. Any water vapor present, of course, contains the latent heat which made it a vapor. Such latent heat of the moisture in the air may be spoken of as the latent heat in the air.

16B3. Total heat of air. Third, any mixture of dry air and water vapor, that is, air as we usually find it, does contain both sensible heat and latent heat. The sum of the sensible heat and latent heat in any sample of air is called the total heat of the air. It is usually measured from zero degrees as a convenient starting point.

C. THE THREE AIR TEMPERATURES

16C1. Need for three air temperatures. Inasmuch as air-conditioning deals with these various heats of the air and the temperature is the temperature of the sensible heat of the air, as measured by an ordinary thermometer. Such a thermometer

condensation of the moisture in it as well three -different temperatures are needed to understand and control the operations. These are the dry bulb, wet-bulb, and dewpoint temperatures.

16C2. Dry-bulb temperature. The dry-bulb is called in psychrometry, or air-conditioning engineering, a dry-bulb thermometer, because its bulb is dry, in contrast to the wet-bulb type next described.

16C3. Wet-bulb temperature. A wet-bulb

thermometer is an ordinary thermometer with a cloth sleeve, of wool or flannel, placed around its bulb and then wet with water. The cloth sleeve should be clean and free from oil and thoroughly wet with clean fresh water. The water in the cloth sleeve is caused to evaporate by a current of air at high velocity, and the evaporation, withdrawing heat from the thermometer bulb, lowers the temperature, as then measured, a certain number of degrees. The difference between the dry-bulb and wet-bulb temperatures is called the wet-bulb depression. If the air is saturated, evaporation cannot take place, and the wet-bulb temperature is the same as the dry-bulb. Complete saturation, however, is not usual, and a wet bulb depression is normally to be expected.

16C4. Wet-bulb temperature measures total heat. The wet-bulb thermometer indicates the total heat of the air being measured. If air at several different times or different places is measured and the wet-bulb temperatures found to be the same for all, the total heat would be the same in all, though attached so that the thermometers may be whirled in the air, thus providing the high velocity air current for evaporation. Such a device is called a sling psychrometer. The psychrometer must be whirled around rapidly, at least four times per second. When the wet bulb thermometer is examined at intervals, its temperature reading will be found to be dropping; when no further drop is observed, that reading gives the correct wet-bulb temperature.

16C6. Dewpoint temperature. The dewpoint depends upon the amount of water vapor in the air. If air at a certain temperature is not saturated, that is, if it does not contain the full quantity of water vapor it can hold at that temperature, and the temperature of that air falls, a point is finally reached at which the air is saturated for the new, lower temperature and condensation of the moisture then begins. This point is the dewpoint temperature of the air for the quantity of water vapor present,

16C7. Relation of dry-bulb, wet-bulb, and dewpoint temperatures. The definite

their sensible heats and respective latent heats might vary considerably. Again, in any given sample of air, if the wet-bulb temperature does not change, the total heat present is the same, even though some of the sensible heat might be converted to latent heat, or vice versa.

16C5. Sling psychrometer. In air-conditioning work, the two thermometers, wet-bulb and dry-bulb, are usually mounted side by side on a frame, to which a handle or short chain is

relation ships between the three temperatures should be clearly understood. These relationships are:

1. When the air contains some moisture but is not saturated, the dewpoint temperature is lower than the dry-bulb temperature, and the wet-bulb temperature lies between them.

2. As the amount of moisture in the air increases, the differences between the temperatures grow less.

3. When the air is saturated, all three temperatures are the same.

D. HUMIDITY

16D1. Humidity. The word humidity is often used in speaking generally of the moisture, or water vapor, in the air. It has, besides, two technical meanings in the forms absolute humidity and relative humidity.

16D2. Absolute humidity and specific humidity. Humidity in air is expressed according to its weight. The weight of the moisture that air can contain depends upon the temperature of the air, and is independent of the pressure of the air. This weight is usually given in grains, there being 7,000 grains to the pound. Absolute humidity is the weight of water vapor in grains per cubic foot of air. Specific humidity is the weight of water vapor in grains per pound of dry air. This second form is more generally used. It should be understood that the weight of moisture in grains refers only to moisture in the actual vapor state, and of in any way to any moisture that may be present in the liquid state, such as fog, rain, dew, or frost.

16D3. Relative humidity. Relative humidity is the ratio of the weight of water vapor in a sample of air to the weight of water vapor that same sample of air contains when saturated. This ratio is usually stated as a percentage. For example, if the air were fully

saturated, its relative humidity would be 100 percent. If the air contained no moisture at all, its

same, but the ability of the air to evaporate liquid moisture is quite different at the two temperatures.

relative humidity would be zero percent. If the air were half saturated, its relative humidity would be 50 percent.

16D4. Importance of relative humidity. As far as comfort and discomfort resulting from humidity are concerned, it is the relative humidity and not the absolute or specific humidity that is the important factor. This can be most easily understood by an example.

It should be understood that moisture always travels from regions of greater wetness to regions of lesser wetness, just as heat travels from regions of higher temperature to regions of lower temperature. If the air above a liquid is saturated, the two are in equilibrium and no moisture can travel from the liquid to the air, that is, the liquid cannot evaporate. If the air is only partially saturated, some moisture can travel to the air, that is, some evaporation can take place.

Suppose the specific humidity of the air to be 120 grains per pound of dry air. This is the actual weight of the water vapor in that air. If the dry-bulb temperature of the air is 76 degrees F, the relative humidity is nearly 90 percent, that is, the air is nearly saturated. The body perspires but the perspiration does not evaporate quickly because the air already contains nearly all the moisture it can hold. The general feeling of discomfort is a warning that the environment under such conditions is not suitable for the best maintenance of health. This ability to evaporate moisture is indirectly indicated by the relative humidity. It is for this reason that extreme importance is placed upon control of relative humidity in air-conditioning.

16D5. Psychrometric chart. There is a relationship between dry-bulb, wet-bulb, and dew point temperatures, and specific and relative humidity. Given any two, the others can be calculated. However, the relationship can be shown on a chart, and in air-conditioning it is customary to use the chart, since it is far easier than calculating. Such a chart is called a psychrometric chart, and a simple form of it is given in Figure 16-1. In this chart, note that the wet-bulb temperature scale and dew point temperature scale lie along the same line; which is, of course, the 100 percent relative humidity line. But note that the dewpoint temperature lines run horizontally. The wet bulb temperature lines run obliquely down to the right.

To use the chart, take the point of intersection of the lines of the two known factors, interpolating if necessary. From this intersection point, follow the lines of the unknown factors to their numbered scales and read the measurement.

Example 1. Given a dry-bulb temperature of 70 degrees F and a wet-bulb temperature of 60 degrees F. What are the dewpoint temperature and the relative humidity? Note the intersection of the two given lines. From this intersection, follow horizontally along the dewpoint line (by interpolation) to the dewpoint scale. Answer. The dewpoint

Nature has, however, given the human body extraordinary powers of resistance, and the body can take a great deal of punishment without permanent harm, though its efficiency drops for the time being.

But if the dry-bulb temperature is 86 degrees F, the relative humidity is only 64 percent. That is, although the absolute amount of moisture in the air is the same, the relative amount is less, because at 86 degrees F the air can hold more water vapor than it can at 78 degrees F. The body is now able to evaporate its excess moisture and the general feeling is much more agreeable, even though the air temperature is ten degrees hotter.

In both cases, the specific humidity is the temperature is 53.6 degrees F; the relative humidity is 36 percent, read by interpolating the intersection point between curved relative humidity lines.

Example 2. If the dewpoint remains at 53.6 degrees F, what is the relative humidity if the air is then raised to the dry-bulb temperature of 80 degrees F? Answer. Follow the dewpoint line horizontally to the 80 degrees F dry-bulb temperature line, where interpolation reads 40.5 percent.

Example 3. Given a dry-bulb temperature of 80 degrees F and a dewpoint temperature of 70 degrees F. What is the relative humidity if the dry-bulb

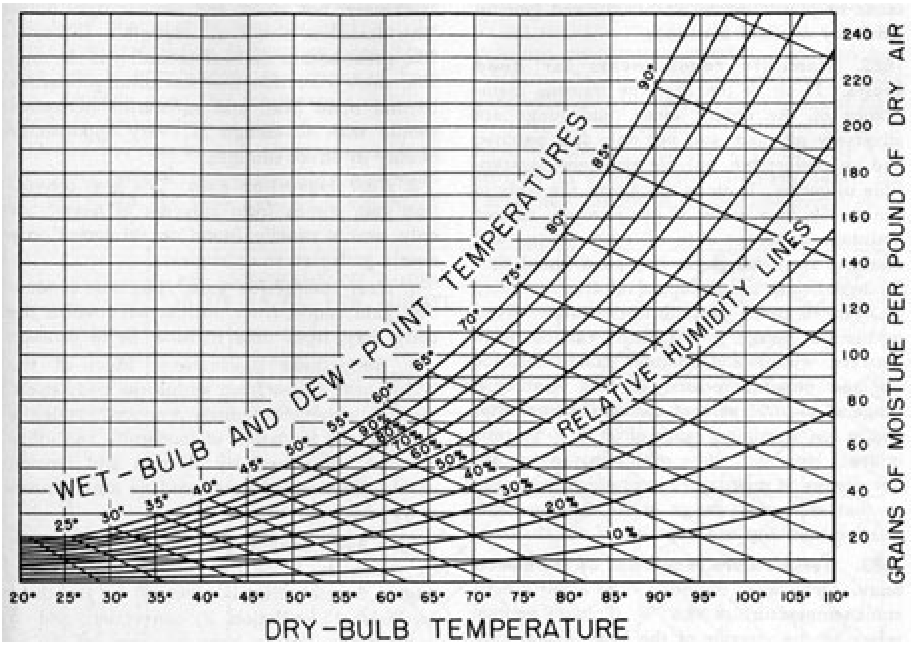


Figure 16-1. Psychrometric chart.

temperature of the air is then raised to 90 degrees F? Answer. Note the intersection of the dewpoint 70 degrees F line running horizontally from the of 110.5 grains per pound. The various weights of water vapor that air at 70 degrees F holds for any percentage of saturation can be found by following horizontally

dewpoint scale to the vertical 80 degrees F line. Follow from the intersection horizontally to the 90 degrees F dry-bulb line and the relative humidity is 52 percent.

The actual weight of any amount of water vapor in air at any temperature can be read on the chart from the scale at the right edge. For example, take the 70 degrees F dry-bulb temperature line. The intersection on this line of the various relative humidity percentage lines, followed horizontally to the right, gives the number of grains of water vapor per pound of dry air. At the bottom is zero moisture, or completely dry air. At the top is 100 percent saturation, such air at 70 degrees F holding a maximum to the right from any relative humidity percentage point on the 70 degrees F dry-bulb line.

Example 4. What is the actual weight of water vapor (specific humidity) in air at 85 degrees F dry-bulb and 70 degrees F wet-bulb temperature? Answer. About 85.5 grains per pound of dry air.

The various manufacturers of air-conditioning apparatus issue free large detailed psychromatic charts that are convenient for the accurate solution of problems. Such charts are one of the most valuable tools an air conditioning man can have.

E. FACTORS AFFECTING HUMAN COMFORT AND EFFICIENCY

16E1. Comfort. In air-conditioning practice, the term comfort is used to mean not comfort in the sense of mere pleasure, such as relaxing in a soft armchair, but rather comfort in the

sense of physiological well-being and general efficiency of mind and body.

16E2. Humidity requirements for good health. If air is too dry, the mucous membranes of the mouth, nose, and lungs are adversely affected, and not only feel parched and uncomfortable, but are also more susceptible to germs. If air is too moist, the body is constantly in a state of perspiration, cannot maintain a proper rate of evaporation, and machinery, hot pipes, and electric light bulbs (this latter in small or negligible amount). The great source of heat radiation is the sun. The sun's radiation has healthful properties beyond mere heat, and submarine personnel should take advantage of every opportunity to stay in direct sunlight.

2. Heat convection gain. The heat convection gain comes from currents of heated air only, and is usually found on shipboard only near a galley stove or engine.

clothing stays damp. It has been found that for best health conditions, a relative humidity of from 40 to 60 percent is desirable. Even within this range, a distinction can be made between winter and summer conditions, for the best possible results. In cold weather a range of 40 to 50 percent of relative humidity, and in hot weather a range of 50 to 60 percent is best. However, these optimum ranges cannot always be maintained in practical working, so that an overall range of 30 to 70 percent relative humidity is acceptable, if not the best.

16E3. Temperature regulation of the human body. Ordinarily, the body is at a fairly constant temperature of 98.6 degrees F. This, of course, refers to the interior of the body and not to the skin surfaces, which vary in temperature. Nature has so evolved the human body that any serious departure from this normal temperature of 98.6 degrees F is dangerous to health. Even a change of one degree, up or down, is noticeable. But since the body is continually receiving a heat gain from surrounding and interior processes, there must also be a continuous outgo of heat to keep a balance. Fortunately, the body is equipped to maintain this balance automatically, and on the whole does, an extraordinarily good job.

16E4. Body heat gains. The body gains heat by 1) radiation, 2) convection, and 3) conduction, and 4) as a byproduct of physiological processes that take place inside the body.

3. Heat conduction gain. The heat conduction gain comes from objects with which the body may, from time to time, be in contact.

4. Body heat production. Most of the body's heat comes from within the body itself. Heat is being continuously produced inside the body by the oxidation of foodstuffs and other chemical processes, by friction and tension within the muscle tissues, and by other causes as yet not well known.

16E5. Body heat losses. The heat given off by the body is of two kinds, sensible and latent. Sensible heat is given off by the three methods: 1) radiation, 2) convection, and 3) conduction. Latent heat is given off 4) by evaporation.

1. Heat radiation loss. The body is usually at a higher temperature than that of its surroundings, and therefore radiates heat to walls, floors, ceilings, and other objects. The temperature of the air does not influence this radiation, except as it may alter the temperature of such surroundings.

2. Heat convection loss. Heat is carried away from the body by convection currents, both by the air coming out of the lungs, and by exterior air currents. These may exist in the air itself or be caused by a person's moving about.

3. Heat conduction loss. Since the body is usually at a higher temperature than that of its surroundings, it gives up heat by conduction through bodily contact with them.

1. Heat radiation gain. The heat radiation gain comes from our surroundings, but since heat always travels from regions of higher temperature to regions of lower temperature, such surroundings must have a temperature higher than 98.6 degrees F for the body to receive heat from them. Indoor heat radiation is gained from heating devices, stoves, operating

4. Heat loss by evaporation. Under normal air conditions, the body gets rid of much excess heat by evaporation. When the body perspires, liquid water comes through the pores to the outer surface of the skin. There it immediately begins to evaporate, and it does

so by withdrawing heat from the body. Inside the body the heat is sensible heat; in the process of evaporation, it becomes latent heat. The rate of evaporation, and hence of heat loss, depends upon the temperature, relative humidity, and motion of the air.

Ordinarily, that is, with air at not too high a temperature and relative humidity, and when not too active, the body gets rid of its excess

heat by radiation, convection, and conduction. When engaged in work or exercise, the body develops much more internal heat, and perspiration begins. But perspiration rapidly evaporates if the relative humidity is not high. If, however, the relative humidity of the air is high, the moisture cannot evaporate, or does so only at a slow rate. In such cases, the excess heat cannot be removed by evaporation,

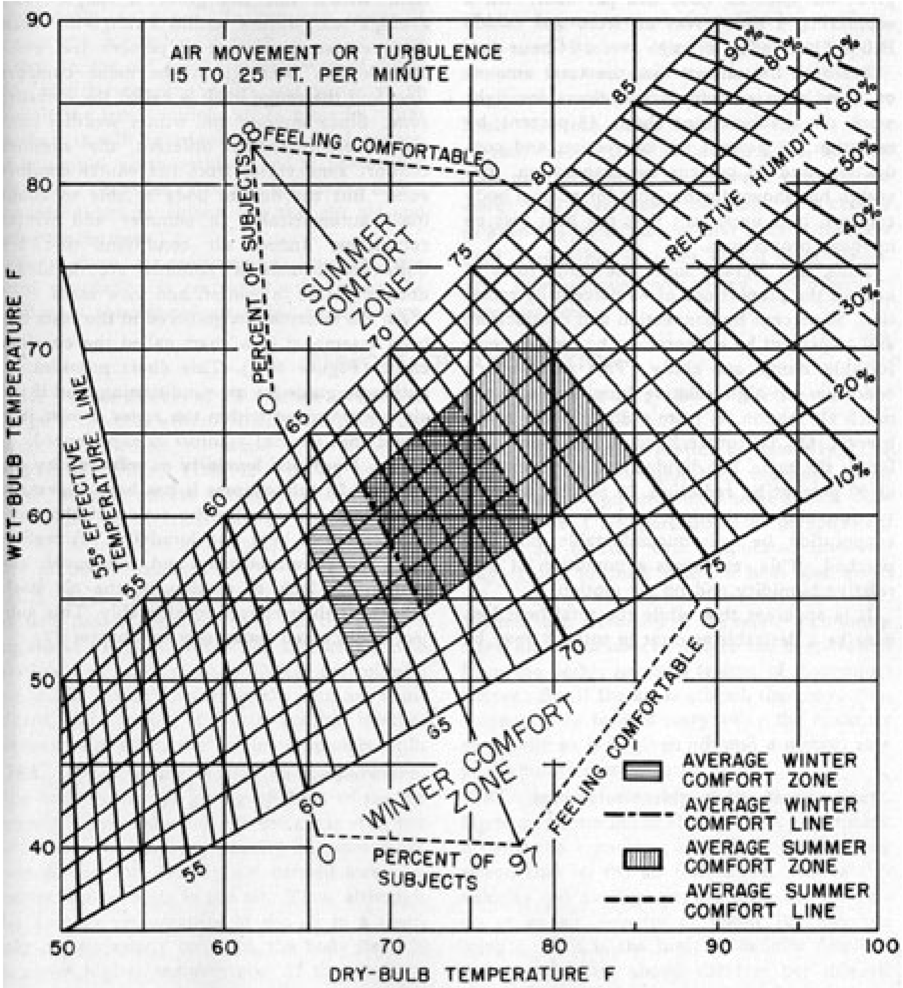


Figure 16-2. Comfort chart.

and the body is dependent on radiation, convection, and conduction to eliminate its excess heat; this, of course, it cannot do and discomfort follows.

16E6. Amount of body heat loss. The amount of heat given off by the body varies according to its activity. When seated at rest, the aver age adult male gives off about 380 Btu per hour. When working at fullest exertion, he gives off 4,000 to 4,800 Btu per hour. On a submarine, a man gives off from 500 to 600 Btu per hour as an average over a 24-hour day.

Research has shown that the total amount of heat loss is so given off as to produce distinct discomfort. It is essential that the, air-conditioning be so controlled as to enable these heat losses to occur in the best proportions to produce comfort.

16E7. Comfort zones. Extensive research has shown that a normal feeling of comfort is experienced by most persons in air at different temperatures, relative humidities, and air motion, within not too great a range. The average temperature within a range in which the greatest percentage of persons feel comfortable has been given the name comfort line, and the range itself is called the comfort zone. Since summer and winter weather conditions are markedly different, the summer

divided as follows for light work on a submarine: about 45 percent by radiation, 30 percent by convection and conduction, and 25 percent by evaporation. Research has shown further that for normal body comfort, it is important that the heat loss be in these proportions.

Thus, if a person loses the same total of heat in the proportions of 40 percent by radiation, 50 percent by convection and conduction, and 10 percent by evaporation, he feels uncomfortable, damp, and chilly. This represents a condition of high relative humidity and too much air motion, as from a direct draft or fan breeze. On the other hand, if the total heat loss is the same, but divided in the proportions of 30 percent by radiation, 25 percent by convection and conduction, and 45 percent by evaporation, he feels uncomfortable, hot, and parched. This represents a condition of low relative humidity and no air motion.

It is apparent that while the total heat loss may be a desirable amount in total, it may be comfort zone varies from the winter comfort zone. But the human body is able to adapt itself automatically to summer and winter conditions. Indoor air conditions that are quite comfortable in summer are decidedly uncomfortable in winter, and vice versa.

All the information gathered in the tests has been assembled in a chart called the comfort chart (Figure 16-2). This chart provides an authentic guide for air-conditioning, and if the air is maintained within the zones shown, it is found that general comfort is experienced.

16E8. Heat and humidity as affected by air motion. In this chapter it has been necessary to explain individually the action of the various factors of heat and humidity. In reality, they act simultaneously and, moreover, the motion or lack of motion of the air itself influences their effects considerably. This subject is discussed separately in Chapter 17.

17
VENTILATION

A. NEED FOR VENTILATION

17A1. Definition. The term ventilation is an old one, certainly long in use before air-conditioning was developed. It is derived from the Latin ventilare, meaning to whip up a breeze with wings or a fan. In common usage it means the supplying of fresh air to enclosed areas. In the old days, the only way of doing this was by opening doors and windows to permit the fresh outdoor air to blow in. That method is still in widespread use, of course. It is simple, costs nothing, and is reasonably efficient, provided that a sufficient cross current exists to siphon out the old air and bring in the new.

In modern air-conditioning, however, the term ventilation is restricted and means the motion of conditioned air inside an enclosure, fresh air being blown by electric fans through ducts or mains to the locations where it is needed, while the old air is removed by similar ducts and fans.

17A2. Importance of air motion for comfort. It is a well-known fact that when the air in a room is motionless, it soon feels stuffy to its occupants, even though the air may be quite fresh. On the other hand, air that is kept stirred, even if it is somewhat stale, at least does not feel stuffy, and though perhaps too warm, it is nevertheless bearable. It is chiefly to keep the air in motion that electric fans are used during hot weather in subways, street cars, offices, household rooms, and other in door quarters.

B. EFFECTS OF AIR MOTION

17B1. Three effects of air motion. When the air in a room is stirred, three effects on the human body result, all adding up to a feeling of greater comfort. One is a purely sensory effect, another affects humidity, and the third affects the room temperature. The three are body is carried away by convection and not permitted to build up.

17B4. Effect of air motion on humidity. The body is always evaporating moisture, even though the evaporation may be at such a slow rate that it is not perceptible as perspiration. If the

closely interrelated and depend upon the velocity of the air motion.

17B2. Sensory effect of air motion. Air in motion has a definite action on the sensory organs in the skin. When the air has a gentle motion, a velocity of 20 to 50 feet per minute, the tactile sensory nerves in the skin are stimulated, and a feeling of greater comfort is experienced than when the air is completely still.

17B3. Effect of air motion on temperature. The body is always giving off heat to the air around it by conduction. If the air is still, the air close to the body gradually becomes more heated, and this heat is not carried away by convection currents in the air. Thus, although the average temperature of the air in a room may remain nearly constant, the body itself is in air of higher temperature. If the air is in motion, however, the heat coming from the air is still, this evaporated moisture stays close, forming with the heat also given off, a damp hot blanket around the body. Within such a blanket as the relative humidity rises, air is less able to absorb the evaporation from the body; hence a feeling of discomfort ensues. But if the air is stirred, the convection currents thus formed carry away the moisture as rapidly as it is given off, and a normal rate of evaporation is restored.

17B5. Interrelationship of the three effects. Up to an air motion of about 60 feet per minute, a person is conscious only of the stimulating effect, that is, the air feels alive. Above this velocity, an average person feels comfortable up to an air velocity of about 100 feet per minute. This is the limit of definite comfort. At air velocities above 120 feet per minute, the air motion does more than the mere

removal of moist air from the vicinity of the body; it causes evaporation at a rate greater than normal. Such evaporation can take place only by using up additional body heat; as a result, the body feels cold and uncomfortable.

17B6. Limits of air motion. Thus, while the air needs to be kept in motion, there are necessary limits, from about 15 or 20 feet per minute to about 100 feet per minute. In general, if When indoors, the body can stand a consider ably greater air current from the front than from the rear or above. The higher air velocity limit should, for comfort, be avoided on the back of the body, on the head, and also on the feet, and still higher velocities indoors should be avoided for reasons of health.

17B8. Difference between indoor and outdoor air motion. It should be noted that the conditions described above apply only

an air current is definitely perceptible, that is, if it attracts attention, then it is too much for comfort and may be a hazard to health.

In air-conditioning, air with a motion of 15 to 25 feet per minute is called relatively still air, because though it is not completely still, it does not readily attract attention.

The upper limit of 100 feet per minute is suitable for persons at rest or doing light work, as is normally the case in a submarine. When engaged in heavier work or exercise, a somewhat higher velocity of air motion may be accepted with comfort; but any substantial increase, while it may be momentarily cooling, is likely to be hazardous to health.

17B7. Direction of air current for comfort.

indoors. There is a surprising difference between the effects of air motion indoors and outdoors. A person can stand much greater air motion outdoors than indoors, without feeling discomfort. A strong draft indoors would be a mere pleasant breeze outside.

17B9. Location of air motion. It should be noted that the air motion or comfort lies within the layer occupied by a person, from the floor to a little over his head. Naturally the air coming out of the air-conditioning ducts into the rooms and quarters is at a considerably higher velocity, but the direction of these inlet currents should be and usually is so arranged that they do not strike directly on the occupants.

C. AIR CURRENTS IN VENTILATION

17C1. Natural convection. When air is warmed, it expands. Therefore, a unit volume of warm air becomes lighter and rises, or tends to rise. When air is cooled, it contracts, and a unit volume of it becomes heavier and sinks, or tends to sink. In an enclosed space, if air masses of different temperatures are present, and if no extraneous forces such as fans are present to move them about, the mass of warm air rises and the mass of cool air drops. A current thus created by masses of air moving in opposite directions because of differences

actually move the air, currents are set up. Such currents are caused, not by the relative weights of the air, but by extraneous forces, and hence are called forced convection currents. Air-conditioning operates by forced convection.

17C3. Natural ventilation. When ventilation occurs by natural means, that is, by fresh air blowing in through open windows, doors, portholes, ordinary ventilators, or air ducts not containing a fan, and the used air finds an outlet, the method is called natural ventilation. Natural ventilation depends largely upon natural convection. Unfortunately, natural

in their relative weights is called a natural convection current.

If a heater is near the floor on one side of a room, warm air rising from it draws cooler air along the floor to take its place. A continuous circuit of air around the room, created by natural convection currents, is set up.

17C2. Forced convection. If, on the other hand, forces such as fans act on the air and convection currents and drafts always take the most direct paths possible, and many places in a group of rooms such as in a building or in a ship, are bypassed and left as dead-air pockets.

A ship is a difficult structure to ventilate by natural means. A submarine in particular,

because of its shape, construction, and purpose, is impossible to ventilate by natural ventilation.

17C4. Forced ventilation. Fortunately, it is no longer necessary to rely on natural ventilation. Forces can be brought to bear on the air to move it wherever desired. Fresh or newly conditioned air is pumped by fans through ducts to interior enclosed spaces, and used air and fumes are pumped out through separate ducts. Since such ducts can be led wherever necessary, thorough ventilation is thus assured. Such ventilation is known as forced ventilation.

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18
DISTRIBUTION SYSTEM

A. AIR DUCTS

18A1. Air distribution diagram. The arrangement of the air duets throughout a submarine is shown in Figure 18-1, inserted at the back of the book. The diagram is largely self-explanatory and needs no detailed description.

Note the location of the two air-conditioning coolers, or evaporators, in the crew's quarters and the after machinery compartment. The cooling coils are readily accessible for cleaning. The compressors are located in the pump room.

Part of the system is a suction main that exhausts fumes and used air, and part is a pressure main through which fresh or conditioned air is blown into the compartments. Small arrows on Figure 18-1 indicate the direction of air flow in these ducts;

Dampers, located at most of the inlet and exhaust points of the ducts, are manually set to control the rate of air flow into and out of the rooms at such points.

18A2. Insulation of ducts. The supply air ducts are insulated to prevent heat gain during passage of the newly conditioned air to the rooms. The supply ducts in the engine room and the supply ducts from

18A3. Fans. Four motor-driven suction fans in the exhaust main, two in the officer's quarters, and two in the crew's messroom, each pull air at the rate of 500 cubic feet per minute. Their main purpose is battery ventilation, but the suction created in the duct is sufficient to provide some degree of exhaust from the galley, scullery, showers, water closets, and other parts of the forward and after battery compartments.

The submarine ventilation supply is provided by one motor-driven fan, located in the forward machinery compartment, that delivers air through the two evaporators, or air-conditioning coolers, to the various room outlets of the ducts at the maximum rate of 4,000 cubic feet per minute. The exhaust ventilation through air ducts is provided by another motor-driven fan located in the forward machinery compartment. This forced exhaust ventilation through ducts is not provided in the after torpedo room and maneuvering room, from which exhaust air flows through bulkhead ventilators. The individual rates at which the air is exhausted and delivered in the various compartments is shown in Figure 18-1.

the discharge side of the forward air-conditioning cooler to the after bulkhead of the forward torpedo room are provided with 1/2-inch insulation. All other mains and branch ducts are cork painted.

18A4. Ventilation data. The following table shows, for each room, or compartment, the net volume in cubic feet, the air supplied in cubic feet per minute, and the number of minutes required to change the air in the room.

COMPARTMENT	NET VOL. CU. FT.	AIR SUPPLIED CFM	MIN. TO CHANGE
For'd. Torpedo Room	3800	200	19.0
Officers' W.C. in For'd. Torpedo Room	75	100 exh	0.7
Officers' Shower	80	100 exh	0.8
Officers' Quarters	1914	*530	3.5
Control Room	1970	550	3.6
Conning Tower	660	130	5.1
Pump Room	1485 1585	*500	3.0 3.2
Radio Room	351	250 exh	1.4
Dry Stores	340 224	50	6.8 4.5
Crew's Mess Room and Galley	1235	*700	1.8
Main Magazine Compartments	440	50	8.8
Normal Storeroom or Spec. 4-In. Mag.	130	25	5.2
Crew's Quarters	1500	750	2.0
Crew's Washroom	500	200 exh	2.5
Crew's W. C.'s	101	100 exh	1.0
Forward Machinery Compartment	2190	**2685	0.8
Aft Machinery Compartment	2050	*1315	1.5
Maneuvering Room	1695	*1190	1.4
Motor Room	1244	100	12.4
W.C. in Maneuvering Room	70	50	1.4
Aft Torpedo Room	2673	290	9.2

* Includes natural supply from other compartments as well as direct mechanical supply from main.
** Includes 2560 cfm discharge from ship's exhaust ventilator set as well as direct mechanical supply from main.

B. OPERATION

18B1. Handling of the air duct system. Under various conditions while running on the surface or submerged, it is necessary to set certain main dampers that close, open, or partly close the main air ducts, to open or close the outboard hull valves, and to operate or stop the compressors. In Figure 18-1, the following letters are used to identify and locate these valves and, dampers .(the same letters are used in the Key and in the Table of Operating Conditions):

1. A	Main engine air induction valve
2. B	Ventilation supply hull valve
3. D and E	Engine induction hull valves
4. F and G	Dampers in the cross-connection between the supply and exhaust blowers

KEY FOR TABLE OF OPERATING CONDITIONS

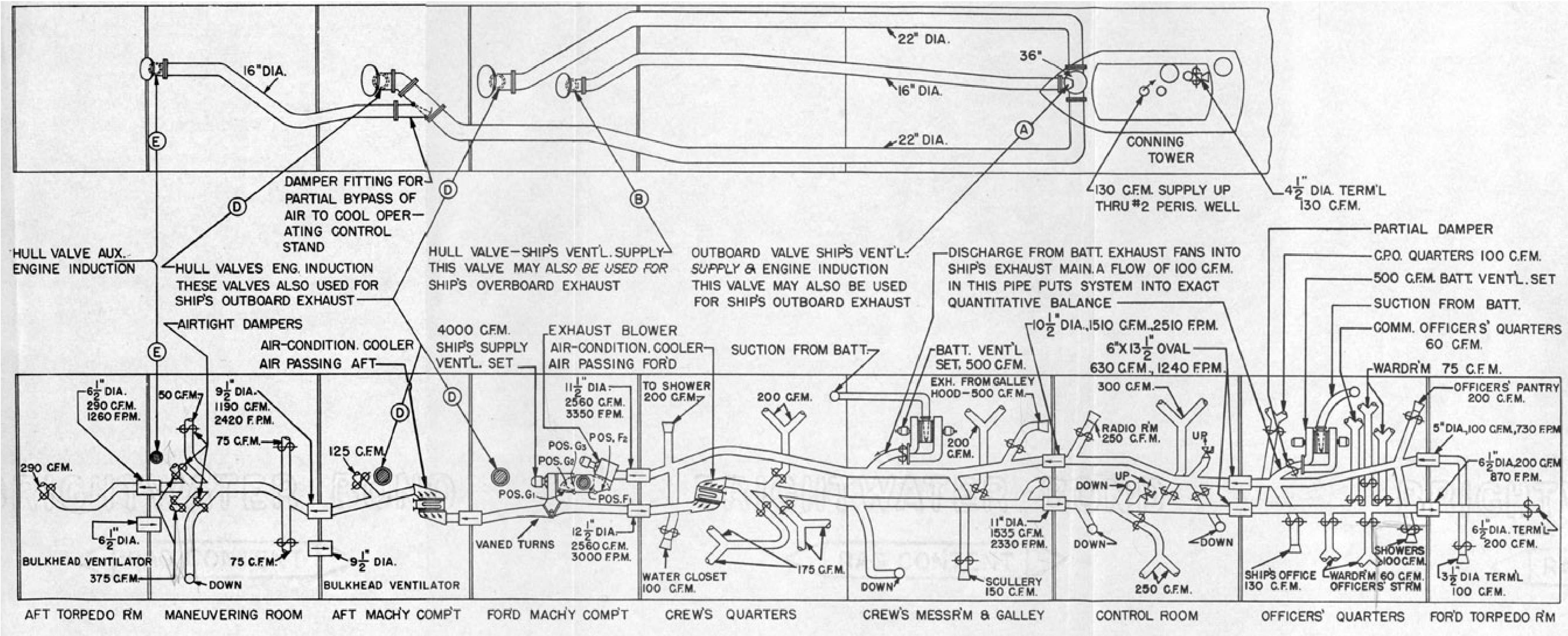
A,B,D,E,F,G	Valves and dampers as indicated on Figure 18-1
Yes	Operating, referring to air-conditioning unit
No	Not operating, referring to air-conditioning unit
O	Open, referring to valves
C	Closed, referring to valves
F_1, F_2	Different positions of damper F
G_1, G_2, G_3	Different positions of damper G

TABLE OF OPERATING CONDITIONS

NO.	CONDITION OF VESSEL	CONDITION OF VENTILATION	AIR-CONDITIONING UNIT OPERATING	POSITION OF VALVES AND DAMPERS A, B, D, E, F, G
1	On surface, engine stopped	Supply outboard, exhaust outboard via mach. com't. and hatches	Yes or No	O O C C F_1 G_1
2	On surface, engine stopped	Ship's exhaust discharge recirculated to ship's supply suction with additional outside air make-up	Yes	O O C C F_2, G_1
3	On surface, engine stopped	Supply inboard via hatches and mach. comp't. Exhaust	No	O O C C F_2 G_3

		outboard via normal supply pipe		
4	On surface, engine running	Supply outboard, exhaust to engine	Yes or No	O O O O F_1 G_1
5	On surface, engine running	Ship's exhaust discharge recirculated to ship's supply suction with additional outside air make-up	Yes	O O O O F_2 G_1
6	Submerged	Recirculation without air-conditioning	No	C C C C F_2 G_2
7	Submerged	Recirculation with air-conditioning	Yes	C C C C F_2 G_2

Figure 18-1. AIR DISTRIBUTION SYSTEM. Sub Refrig. Home Page



19
PRACTICAL AIR-CONDITIONING OF A SUBMARINE

A. HEAT AND HUMIDITY

19A1. Heat gains inside a submarine. With all the discussed facts in mind, the general picture of air-conditioning in a submarine may now be considered. Let it be assumed that the air in question contains enough oxygen for the needs of all the occupants within the given space. A supply of oxygen compressed in cylinders is carried on board submarines to be released into the air if this need arises.

There is continuous production of heat, given off to the air by hot engines, storage batteries, galley stove, electric lights, electric heaters, other devices, and human occupants.

19A2. Moisture gains inside a submarine. There is also continuous production of moisture, given off to the air by evaporation from four main sources: 1) storage batteries, 2) cooking; 3) human occupants, and 4) the bilges. This production of moisture averages about 1000 pounds of water per day under ordinary conditions.

19A3. Elimination of heat and moisture. If the submarine is running on the surface, it is an easy matter to discharge this

the submarine is warmer than the ocean water, the interior heat of the vessel gradually passes through the shell into the water. The temperature of the air inside drops and, when it reaches the dewpoint, the water vapor in the air begins to condense on every available surface. For this reason, the interior surfaces of a submarine are coated, wherever practicable, with cork paint, to prevent or reduce this condensation to a minimum. The beginning of the condensation, however, depends upon the dewpoint, and this can be controlled by air-conditioning. Therefore, air-conditioning is just as essential for this purpose as for the comfort of the crew. It is always advisable to lower the dewpoint before a dive, if possible.

19A6. Gain of heat from ocean to ship. On the other hand, if the ocean is warmer than the submarine, there is a passage of heat from the water into the ship., However small this may be, it adds to the interior heat. The same result occurs if the loss of heat from this vessel to the ocean is less than the interior heat production. In hot summer weather, especially in tropical and subtropical regions, the air

excess heat and moisture outboard. But if the submarine is submerged, it cannot be discharged outboard, and must be eliminated during recirculation of the air.

19A4. Transfer of heat between submarine and ocean. A submarine is practically all metal, and metal is an excellent conductor of heat. In addition, the surface area of a submarine is fairly large. Moreover, the ocean is filled with convection currents, either natural currents or currents caused by the vessel's motion. These facts combine to make the heat transfer between submarine and ocean an active process. Even when the temperature difference between the vessel and the ocean is small, the total heat transfer is considerable because of the large contact area.

19A5. Loss of heat from ship to ocean. If temperature in a submarine may rise to fairly high levels.

19A7. Refrigeration capacity of a submarine. In a submarine, only a few cubic feet of space are available for air-conditioning machinery, and the cooling capacity is of necessity limited. It should be clearly understood that the purpose of the air-conditioning system is not to cool the submarine as a whole.

19A8. Humidity in a submarine. However, there is room enough for sufficient air-conditioning machinery to control the dewpoint, that is, to set it at any desired temperature. Control of the dewpoint means control of the relative humidity, and it is the relative humidity, more than the mere temperature of

the air, that causes discomfort. With a build up of a thousand pounds of moisture per day in the air of a submarine, relative humidity becomes a factor of major importance.

B. THE DEWPOINT

19B1. Lowering the dewpoint. The dewpoint of a sample of air is the temperature at which that air is saturated with moisture. If the temperature of the air is then further lowered, some of the moisture must condense out.

Suppose that the air in a room is so high in relative humidity as to be uncomfortable. The method at which a given sample of air holds all the water vapor it can. If the temperature is lowered when the air is at its dewpoint, water must condense out of that air.

When air is at its dewpoint, the dry-bulb and wet-bulb temperatures are both the same as the dewpoint temperature, the air is saturated, and its relative

of reducing this relative humidity is as follows:

The air in the room is drawn by fans into and through the ducts to the air-conditioning evaporator. There, in passing over the cooling coils, its temperature drops below its dewpoint and part of its water vapor condenses out, inside the evaporation cabinet. The condensed water is not permitted to get back into the air, but is drained off into a tank. The air, now lower in moisture content and slightly lower in temperature also, continues its flow through the ducts and is finally blown out into the room again. This conditioned air mixes with the moisture and warmer air still in the room, resulting in an over-all condition that is drier than the original unconditioned air.

19B2. Heat action in the evaporator. When some of the moisture in the air is condensed out of it in the evaporator, the condensation is caused by the passage of latent heat from the water vapor in the air to the refrigerant inside the cooling coils. This removal of latent heat reduces the total heat of the humidity of the air. Refer again to the psychrometric chart. While the lowering of the dry-bulb temperature by itself means an increase in relative humidity, this increase resulting from the lowering of -total heat, or wet-bulb temperature, is always less in the range of high air temperatures within which high relative humidity is uncomfortable. The resultant humidity is 100 percent. The dewpoint is a factor through which all relationships are correctly seen, and by the use of which the operation of air-conditioning becomes simple.

19B4. Two actions on the air. The whole subject is perhaps none too easy to grasp at first glance, so it may be well to draw special attention to a point that is usually overlooked, but which is really the vital matter in the operation of air-conditioning. It should be clearly realized that the air is being separately acted on in two different places where the conditions are quite different. One place is in the room itself; the other is in the evaporator casing.

The room is the place a person occupies and sees, and it is where he feels the satisfactory or unsatisfactory quality of the air. But the conditioning of the pair does not take place in the room. The actual conditioning of the air takes place inside the evaporator casing. The environment in the two places is very different. While in the room, the water vapor of the air is usually warm and, to a certain extent, free and expansive; but when it passes along with the air through the ducts to the evaporator, it suddenly is confined in a small cabinet where it is cold. So it compresses together and forms liquid drops (see Sections 16A7 and 16A8).

19B5. Summary of air-conditioning principles. In a room, the air continuously gains heat and moisture. In an evaporator, the air is quickly and considerably cooled and loses moisture.

relative humidity is therefore always decreased.

19B3. Importance of dewpoint. It becomes evident that in air-conditioning the significant viewpoint is not the dry-bulb or ordinary air temperature, but the wet-bulb temperature, or, preferably, the dewpoint. The latter is preferable, because the dewpoint is the temperature

To be sure, when the air returns from the evaporator to the room, it may lower the temperature therein by a few degrees, but

the essential requirement is either 1) the reduction of relative humidity, or 2) the prevention of condensation in the room.

In the first case, the relative humidity in the room is reduced by causing condensation in the evaporator, that is, by cooling the air to below its dewpoint in the evaporator.

In the second case, condensation in the room is prevented by lowering the dewpoint of the air in the room, and this again is done by cooling the air, and hence removing some of the moisture by condensation, in the evaporator.

When a submarine loses heat to the ocean, the temperature of the air inside begins to drop. If the dewpoint of the air is high, it is not long before the temperature of the air drops to the dewpoint, and condensation in the compartment begins. This condensation appears as a film of liquid water or droplets on all available cool surfaces. The interior surfaces begin to sweat; and that means, always, a potential danger from short circuits or grounds in electric systems. Remember that the dewpoint is the temperature at which the water vapor in the air begins to condense.

C. AIR-CONDITIONING IN DIFFERENT CLIMATES

19C1. Various climatic conditions encountered. A submarine may be on patrol in tropical, arctic, or temperate waters. The atmospheric conditions and water temperatures vary greatly in these different regions, and require different operation of the air-conditioning system.

efficient rate. When the air-conditioning compressors operate at 33 psi suction pressure and 117 psi discharge pressure, the compressors are at their best. These pressures can be obtained by adjusting the speed of the fan, the compressor, or both. For example, if the fan is running at 3/4 speed and the compressor at slow speed, with a suction

19C2. General rule for air-conditioning. However, it is possible to set up a general rule, as follows: Operate the fans or blowers at such speed that the air leaving the outlet sides of the evaporators is always below the dewpoint; and adjust the louvers to give the best distribution of air throughout the vessel.

The adjustment of the louvers for best air distribution naturally varies in different classes of submarines, and even in different vessels of the same class. Practical experience in each submarine must dictate the fine points of louver adjustment. If they are opened and closed frequently in accordance with individual caprice, proper air-conditioning of the vessel cannot result.

19C3. Air-conditioning in temperate climate. The handling of air-conditioning in temperate climates is comparatively easy. It usually requires attention only to the general rule stated in Section 19C2. The blowers need not be operated at full speed, and may often be operated at minimum speed. The louvers may be partly closed.

It is important that the operator should frequently note the suction pressure and suction temperature at the compressors, in order to keep the system operating at its most pressure rising to 45 psi, the compressor should be speeded up until the pressure drops to around 33 psi. The fan should not be slowed down until the compressor is running at full speed, and the suction pressure is still up around 45 to 50 psi. Then the fan can be reduced in speed. It should not, however, be reduced below 1/4 speed on the rheostat; otherwise proper ventilation will be lost.

19C4. Air-conditioning in arctic climate. In arctic regions and in cold winter weather in temperate regions, the main problem is the prevention of condensation within the submarine. Reference to the psychrometric chart (Figure 16-1) shows that at lower temperatures, the dry-bulb, wet-bulb, and dewpoint temperatures are closer together than they are at higher temperatures. This means that a drop of fewer degrees causes condensation. Much closer attention to the temperatures, therefore, is required in cold weather.

A usual condition is a low dry-bulb temperature in the vessel with a wet-bulb temperature close to it. The shell of the vessel and other metal parts are usually colder than the dewpoint by only a degree or two. Moisture condenses on such surfaces, or, in other words,

the vessel sweats, necessitating the use of the air-conditioning when the large area of open water surfaces in the bilges is

system to dry it out.

Under these conditions, if an attempt is made to dry the vessel by operating the compressors at low speed and the blowers at 1/2 speed, the suction pressure will be about 18 to 20 psi. If this pressure is continued for a considerable time, the coils accumulate a coating of frost inside, and eventually become so plugged up as to prevent air from passing through. To prevent this, operate the compressors at slow speed, and the fans at full speed. The suction pressure then rises to 25 psi or more, and the frosting stops, while the drying of the vessel continues.

The proper method of starting the air conditioning system, when the injection water is at low temperature, is to operate with manual control instead of automatic. If the system is run on automatic control, it short cycles, because of low head pressure; that is, the suction pressure drops to 20 psi and the compressor stops on the low-pressure cutout. In a short time, the suction pressure builds up to 40 psi, the compressor starts, and runs a few minutes; then the suction pressure drops back to 20 psi, and the low-pressure cutout stops the compressor, alternating or short cycling this way every few minutes. This causes overheating of the starter and in due time burns out the motor. In operating manually, run the air-conditioning compressors for ten minutes, with the condenser water discharge valve closed, or until a head pressure of about 100 psi considered. The plant must be run so as to obtain maximum comfort and protection of equipment against moisture, both of which are obtained by abstracting the largest possible quantity of water vapor from the air. This condensing or wringing process is accomplished by always maintaining the temperature of the discharge air from the evaporators below the dewpoint.

Recent experiments on the ventilation of submarines in the tropics have shown that improved results are obtained, at least on some types of vessels, by ventilation in any of the following ways:

1. Run the supply blowers at highest speed allowable without overloading the motors.

2. Run the air-conditioning compressors at highest speed allowable without overloading the motors.

3. Shut off the supply outlets to the control room and conning tower when the upper conning tower hatch is open; close the door between the control room and the forward battery compartment.

4. Close all exhaust terminals from the forward torpedo room to the forward engine room while charging batteries, except the galley range terminal when the range is being used.

5. Remove the air spreader plates over the wardroom supply outlet on all Portsmouth submarines of the SS228 class and up. These spreader plates force air out into

has been obtained. The reason for this is that there must be a difference of 60 psi between the high- and low-pressure sides to operate an expansion valve. The compressors can then be switched to automatic operation.

19C5. Air-conditioning in the tropics. In hot climates, the air-conditioning system usually must be operated at maximum capacity. In general, the best procedure is to operate the compressors at full speed and the blowers at such speed that the temperature of the air from the discharge side of the evaporators is below the dewpoint. The conditions of high air temperature in the tropics are naturally adverse to effective air-conditioning, especially

the passage way and allow no circulation of air in the wardroom.

6. Bypass all back-pressure regulators on both air-conditioning coils.

7. Cause the thermostat cutout to be wide open at all times in hot climates.

8. Use the normal fuel oil tank outboard of the forward battery compartment early in patrol in order to have sea water, which has a higher heat conductivity constant than oil, next to the pressure hull.

9. Shut off as many lights forward as possible. Use a fluorescent tube if available. A 20-watt tube furnishes twice the light with only about one-tenth the amount of heat as a 50-watt electric light bulb. The forward battery compartment has three times as many

lights on at all times as the after battery compartment.

10. Leave the air-conditioning condenser circulating water suction and discharge valves wide open.

11. Close the supply outlets to the engine rooms. Make no attempt to cool the engine room with the ventilation system.

12. Do not use the present system for exhausting air from the after part of the submarine when submerged. Close all engine room doors and the after engine room exhaust bulkhead

engine rooms through the engine air induction lines in the superstructure, by way of the main induction valve aft of the conning tower. One ship reports air as being cooler throughout since using this system.

13. Run only one conning tower air-conditioning coil at a time.

14. Secure the conning tower air-conditioning coil when the upper conning tower hatch is open.

15. Rig all reserve fuel oil tanks to the main ballast tanks as soon as fuel is used. On diving, a considerable amount of heat is

flapper; with the supply blower, take a suction from the maneuvering room and taken from the pressure hull by water filling the tanks.

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INSPECTION SCHEDULE

A. DAILY INSPECTION SCHEDULE

1. Check all motors for overheating.

2. Check the temperature of all motor bearings.

3. Check the oil level in the crankcases of the compressors two or three times a day; if the level is low, new oil should be added.

4. Check for excessively high and low refrigerant pressures.

5. Check the crankcases for low temperatures or excessive Freon 12.

B. WEEKLY INSPECTION SCHEDULE

1. Check all fans for unusual noise and vibration.

2. Check all regularly operated valves and compressor seals for leaks.

3. Check proper tension of V-belts.

4. Check the oil level on motor bearings add oil if necessary.

5. Check all ball bearings; add grease when necessary.

6. Check the oil level in fan bearings; add oil if necessary.

7. Check the flywheels and pulleys.

8. Clean the evaporator coils if dirty.

9. Clean and dust all equipment.

C. MONTHLY INSPECTION SCHEDULE

1. Check the compressors for any unusual vibration; check the mountings.

2. Check the clearance between rotor and stator on all motors.

3. Check the V-belts for wear, and clean off all oil and dirt.

4. Check entire systems carefully for refrigerant leaks.

6. Check and clean the condenser tubes when refrigerant or water temperatures indicate the need.

7. Inspect the evaporator coils; clean at least every three months; oftener if necessary.

8. Check all pressures and temperatures throughout all systems, valves, and devices.

5. Check and clean all automatic control and safety devices, also all switch contacts.

9. Inspect the zinc fingers in the condensers; replace when deteriorated 30 percent or more.

D. YEARLY INSPECTION SCHEDULE

1. Remove motor and bells; check and clean windings.

2. Wash out all motor bearings, and refill with new motor oil.

3. Wash out all fan bearings; check clearance; refill with new oil.

4. Test insulation of motor leads and windings. 5. Check rusting of metal parts on all equipment; repair piping and equipment when ever necessary.

6. Drain crankcases of compressors, and wash out thoroughly.

7. Test all gages.

8. Inspect all insulation coverings of cold pipes, especially seams. Replace all rusted binding wires and rotted covering cloths; add seam-filler where necessary.

21
GLOSSARY

Air-conditioning. The process by which the heat and humidity of the air in an enclosed space are maintained within certain limits, the air may also be filtered and purified in the process.

Air, latent heat in. The latent heat of vaporization of the water vapor in air.

Air, saturated. Air that contains all the water vapor it can hold at a given temperature.

Air, sensible heat of. The heat of the air only, without regard to the heat of any water vapor that may be mixed with the air.

Air, total heat of. The sum of both the latent heat and the sensible heat in any sample of air.

British thermal unit. A measure of heat quantity, defined as the quantity of heat required to raise the temperature of one pound of pure water one degree Fahrenheit at 39.10 degrees F. the amount of heat required varies slightly at other temperatures, but for practical engineering purposes, is usually considered as constant. (Abbreviation, Btu.)

Condensation. The change of state from a vapor to a liquid.

Heat load. The amount of heat to be removed from a space to be air-conditioned or refrigerated to satisfy the requirements of the given installation. The total heat load is the sum of various separate heat loads coming from such sources as: sensible heat, latent heat, crew, electric lights, electrical equipment, engines and stoves, sunlight, and foodstuffs.

Heat, quantity of. The quantity of heat possessed by a substance depends on the size, nature, and temperature of that substance; it is measured in British thermal units.

Heat, sensible. The heat that raises the temperature of a substance but does not change its physical state. It is measured by the thermometer.

Heat, specific. The heat required to raise the temperature of a unit mass of a substance one degree. Vapors and gases have two specific heats, one when the volume is held constant, and one when the pressure is held constant.

Heat, total. In air-conditioning, the term means the total heat, including both sensible and latent heat, to be eliminated from an air conditioned space. The term heat content is frequently used as a synonym for it. In the purely scientific field, the term total heat means the total heat energy

Dewpoint. The temperature at which water vapor in any sample of air begins to condense.

Ebullition. Vaporization or change of state from a liquid to a vapor in a rapid, active, and visible process; also called boiling.

Evaporation. Vaporization or change of state from a liquid to a vapor in a slow, inactive, and invisible process.

Freezing. The change of state from a liquid to a solid.

Heat. A vibratory form of energy, perceptible to human beings as the sensations to which the names cold, cool, warm, hot, and similar terms are applied.

Heat, intensity of. That characteristic of heat, the variations in which are indicated by such terms as cold and hot, or measured by numbers on the scale of a thermometer.

Heat, latent. The heat that changes the physical state of a substance; see Latent heat of vaporization and Latent heat of fusion.

present in a substance on the absolute scale.

Heat transfer. The flow or transmission of heat from a region of higher temperature to a region of lower temperatures.

Heat transfer by conduction. The transmission of heat from one part to another of a single body or substance; or from one body or substance to another in contact with it.

Heat transfer by convection. The carrying of heat from one location to another by the molecules of a substance in motion.

Heat transfer by radiation. The transmission of heat energy through space by the propagation of wave forms in a medium.

Humidity. Water in the physical state of vapor mixed in the air. Humidity is invisible; humidity does not include any water present in liquid form, however finely divided, such as

mist or fog. The space that drops of liquid water occupy does not contain air.

Humidity, absolute. The weight of water vapor, usually stated in grains per cubic foot of air.

Humidity, relative. The ratio of the weight of water vapor in a sample of air to the weight of water vapor that same sample of

Pressure, head. The pressure produced by the pistons of a compressor.

Pressure, negative. In engineering practice, a pressure below normal atmospheric or 14.7 psi, is called a negative pressure, or partial vacuum; usually stated in inches of vacuum.

air contains when saturated; usually stated as a percentage.

Humidity, specific. The weight of water vapor, usually stated in grains per pound of dry air.

Insulator. Any material that transmits heat at a very slow rate.

Latent heat of fusion. The heat that changes the physical state of a substance from a liquid to a solid, or from a solid to a liquid; no temperature change is shown by a thermometer during the conversion process.

Latent heat of vaporization. The heat that changes the physical state of a substance from a liquid to a vapor, or from a vapor to a liquid; no temperature change is shown by a thermometer during the conversion process.

Melting. The change of state from a solid to a liquid.

Pressure. The result of the action of an external force on an enclosed fluid, which may be a liquid, vapor, or gas; usually expressed in pounds per square inch.

Pressure, absolute. The true total pressure inside an enclosed vapor system, that is, the gage reading plus standard atmospheric pressure of 14.7 psi.

Pressure, atmospheric. The pressure exerted by the earth's atmosphere. For engineering purposes, usually taken as that which normally exists at sea level, 14.7 pounds per square inch.

Psychrometer. An instrument for deter mining wet-bulb temperature. The form most generally used, called the sling psychrometer, has a wet-bulb and a dry-bulb thermometer attached to a small support. By means of a handle or chain, the device can be swung around rapidly. The strong current of air thus caused evaporates the moisture in the sleeve of the wet-bulb thermometer, whereby the wet-bulb temperature is indicated.

Refrigerant. A substance capable of carrying heat, which it picks up at a low temperature level, and is then compressed to a higher pressure and temperature, where the heat can be removed by the condensing medium, air or water.

Refrigeration ton. A unit used in measuring the elimination of heat; one refrigeration ton is the removal of the heat that would be required to melt one ton of ice at 32 degrees F in 24 hours.

Saturation temperature. The temperature at which a liquid substance boils under a given pressure.

Specific volume. The number of cubic feet occupied by one pound of a substance at a given pressure and temperature.

State of a substance. A substance may exist in three different physical states: solid, liquid, and gaseous. For example, water (H_2O) can exist in all three states, depending upon temperature and pressure: solid (ice); liquid; and gaseous (steam, or water vapor). A substance may change its state on

Pressure, back. In refrigeration, back pressure is the difference between the vapor pressure in the suction line (including the evaporator) and the head pressure of the compressor.

Pressure, gage. The pressure indicated by a pressure gage; the zero mark on a pressure gage in reality means an interior pressure of 14.7 psi, corresponding to normal atmospheric pressure.

variation of temperature or pressure, or both.

Superheat. The heat above saturation temperature in a vapor.

Temperature, dewpoint. The temperature at which the water vapor present in the air begins to condense, depending upon the amount of humidity of the air.

Temperature, dry-bulb. The temperature of the sensible heat of the air, as measured by an ordinary, or dry-bulb, thermometer.

Temperature, saturation. The temperature at which a liquid substance boils under a given pressure.

Temperature, wet-bulb. The temperature indicated by a thermometer around the bulb of which is placed a wet cloth sleeve; a strong current of air, causing evaporation at the wet bulb, lowers the thermometer reading by a definite amount, called the wet-bulb depression, which depends upon the amount of moisture present in the air.

Thermal capacity. The capacity, or ability, of a substance to receive and store heat; equals the specific heat of a substance times its mass.

Thermal conductance. The heat conduction power of a substance; substances with a very low thermal conductance are called insulators.

water and 100 degrees at the boiling point, at standard sea-level atmospheric pressure,

Thermometer, Fahrenheit. An instrument for measuring temperature in which the scale is numbered 32 degrees at the freezing point of pure water and 212 degrees at the boiling point, at stand and sea-level atmospheric pressure.

Vapor, dry. A saturated vapor containing no suspended mist or liquid.

Vapor, saturated. A vapor that is at the temperature corresponding to the boiling point of a substance at a given pressure.

Vapor, superheated. A vapor the temperature of which is above the boiling point of the substance for a given pressure.

Vapor, wet. A saturated vapor that contains some suspended liquid in the form of mist.

Thermometer, centigrade. An instrument for measuring temperature in which the scale is numbered zero at the freezing point of pure

Vaporization. The change of state from a liquid to a vapor.

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Figure 7-1. REFRIGERATION PIPING DIAGRAM.

Figure 7-8. CONDENSER WATER PIPING ARRANGEMENT.

Figure 14-1. AIR-CONDITIONING PIPING DIAGRAM.

Figure 18-1. AIR DISTRIBUTION SYSTEM.

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