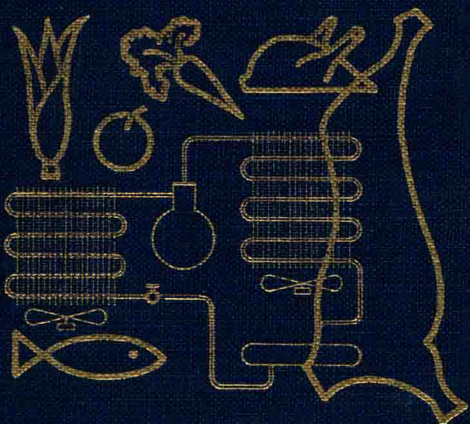

COLD AND FREEZER STORAGE MANUAL

SECOND EDITION

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SECOND EDITION

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avi

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Preface

W.A. Woolrich, coauthor of the first edition of this manual, died in February, 1977. This edition is being written after his death. Due to changing concepts of cold and freezer storage refrigeration and energy conservation, a complete revision of the original text seems to be indicated. This volume will attempt to introduce information and ideas consistent with economies that are now demanded in a world beset with uncertainties of future power sources and energy costs.

Since the advent of this manual in 1970, rather startling changes have occurred in the concept of the supply of energy. The world has become aware of the fact that available energy from the normal sources is not infinite and that there are very definite indications that it will become a very scarce and expensive commodity. The development of new sources of energy will surely take place, but in the intervening time, the efficient use of energy must be a prime consideration. Users of energy can no longer afford to be careless or wasteful. Increased power costs, as well as possible forced conservation, will dictate the use of more efficient systems. Since no startling refrigeration developments appear imminent, it becomes necessary to utilize existing components more wisely in the future than was done in the past.

One of the objects of the second edition will be to stress design concepts which will allow better and more efficient use of equipment, insulation and other facets influencing operational costs of refrigerated spaces. In most instances, this will mean a higher first cost of equipment compared to some of the standard designs now in use. However, with rapidly increasing energy costs, the higher equipment costs may prove to be the most economical in the overall concept.

Many of the trends in refrigeration design, when viewed in the light of the past forty or fifty years, would indicate that in recent years, system efficiencies have been sacrificed in the interests of a lowered first cost. This has been particularly true through the era of low cost power. The cost of power was not high enough to warrant highly efficient equipment, which was costly to buy, and energy supplies seemed limitless. This trend must now be reversed since power costs are constantly increasing and since it is being discovered that energy sources, at least those which we are presently using, are not limitless. The equipment exists. It is only a matter of choosing the correct components to fit the job.

Over the years, cold and freezer storage use has expanded continuously and now represents a very respectable segment of the food and related industries concerned with the processing and distribution of perishables. It is universal and so common that it escapes specific notice except when a breakdown occurs to interrupt its use. It is difficult to imagine the country without refrigeration.

This manual is an attempt to express, in lay language, some of the design concepts for cold storage installations. It is not a technical treatise; but designed to give prospective owners and operators of cold storage facilities, large or small, a better insight into the design aspects that might be expected when constructing new, or modernizing old cold storage warehouses.

The text represents some 45 years of observation and active participation in the refrigeration and cold storage field. Opinions expressed are those gained in this period. It is realized that there may be a great variety of methods used to achieve sound design. Honest opinions will vary greatly regarding the best selection of equipment and systems. This edition is an attempt to put in some order, design practices and equipment selection methods observed through many years in the refrigeration industry.

Both English and metric measurements are indicated in most sections of the text. The complete International System (SI) of units has not been used. Since this volume is intended as a liaison between designers and owners and operators, it is believed that simple metric or English units are better understood at the present writing since the present rate of conversion to SI units is somewhat slow and certainly not fully understood by most individuals (including this writer).

Since this volume is not intended as a text for calculations, only whole numbers will be used where practical. The results will be within an accuracy range which is sufficient for the discussions following.

ELLIOTT HALLOWELL
Dallas, Texas

April 10, 1980

Section I

Refrigeration and Refrigerants

Contents

1

Principles of Refrigeration

The refrigeration system is the life blood of any cold storage operation. A good system can be a great satisfaction; a poor system generates problems. Anyone who contemplates becoming involved in the planning, construction or operation of a cold storage facility should have, at least, a nodding acquaintance with the principles of refrigeration. It is not the intent of this volume to expound on these principles at great length; but rather to supply the reader with enough basic information to allow him to communicate, with some intelligence, with designers and engineers in the understanding and evaluation of equipment offered. There are usually several choices in equipment selection, all of which may be equally good and depend on the desires of the plant designer. Other options may have pecularities that make them desirable for some applications but not for others. Some knowledge of refrigeration is essential to the proper selection of various options that may be offered.

DEFINITIONS

In refrigeration terminology, there are numerous terms used that are germane to the refrigeration industry and may have a somewhat different meaning than that normally assigned to the term. Appendix 1 contains a number of these terms with explanations, and it is hoped in good lay English. There are a few expressions that are frequently used in discussing refrigeration that require a more complete explanation than found in the appendix. The following definitions cover some of these terms which are used frequently in any discussion concerning refrigeration.

Refrigerant

In the compression refrigeration cycle, the refrigerant is a fluid that reacts to heat and pressure in very much the same manner that water reacts when it changes from a liquid to steam by boiling or from a vapor (steam) to a liquid by condensation. The chief difference between water and refrigerants used in cold room operations is that the refrigerant reacts at a lower temperature level than water.

When heat is applied to water, in an open vessel, the water temperature will rise to 212°F (100°C), at which point it will begin to boil and will continue to boil at this temperature until all of the water is boiled into steam. If further heat is applied to the steam, the steam temperature may be raised and this is called superheat. In a like manner, if heat is applied to a refrigerant such as ammonia and at atmospheric pressure, it will boil at −28 F (−33 C). In refrigeration parlance, the term boiling is quite often expressed as evaporation and means the same thing.

Like water, as pressure is increased on the evaporating refrigerant, the temperature at which it evaporates (boils) will be increased. As an example, if the pressure on evaporating ammonia is raised to about 16 psig (1.12 kg/cm^2), the evaporating temperature will be raised to 0°F (−18°C).

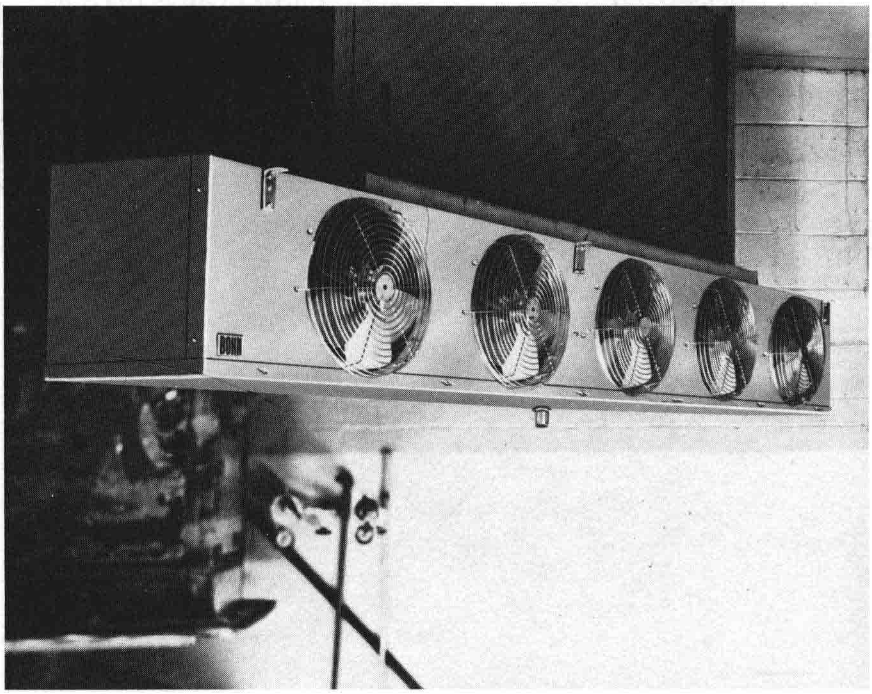
Refrigerants, in the same manner as water, have the ability to be condensed back into a liquid by the removal of heat when they are in a vapor state (steam). The condensation temperature can be controlled as required by varying the pressure on the vapor. This principle is made use of in the compression cycle of refrigeration.

A good refrigerant should have the ability to absorb a high quantity of heat when vaporizing, should operate at reasonable pressures and should be a stable compound throughout the range in which it is used. Some common refrigerants are ammonia and Refrigerants 11, 12, 22, 500 and 502.

The temperature at which a refrigerant will evaporate is predicated by the characteristics of the refrigerant and the pressures imposed on it during vaporization. Each refrigerant has its own properties. Tables and charts are available giving the properties of all common refrigerants and these are used extensively in designing various components of the refrigerating system as well as the complete system itself.

Evaporation – Evaporator

In refrigeration terms, the cooling effect in a cold storage room is obtained by the controlled boiling, or evaporation, of a liquid refrigerant. The pressure at which the refrigerant evaporates is controlled which, in turn, controls the evaporating temperature. The refrigerant is evaporated inside of a pipe coil or other vessel and, in the case of a room cooling coil, room air is forced over the outside of the coil. This fan coil unit is commonly called an evaporator. Heat is transferred from the room to the evaporator by means of the room air which is mechanically forced over the outside of the evaporator surface. The heat is then transferred through the metal of the evaporator to the refrigerant which absorbs the heat by evaporation (boiling). Again, this can be seen as a parallel action to that of water in a boiler being evaporated, or boiled, by the addition of heat; the main difference being that a refrigerant normally acts at a much lower temperature range than water. The term "evaporator" is a logical term to describe a cooling coil since the refrigerant is evaporated within the coil. Fig. 1.1 illustrates a cooling fan coil unit of the type commonly used in cold room cooling.

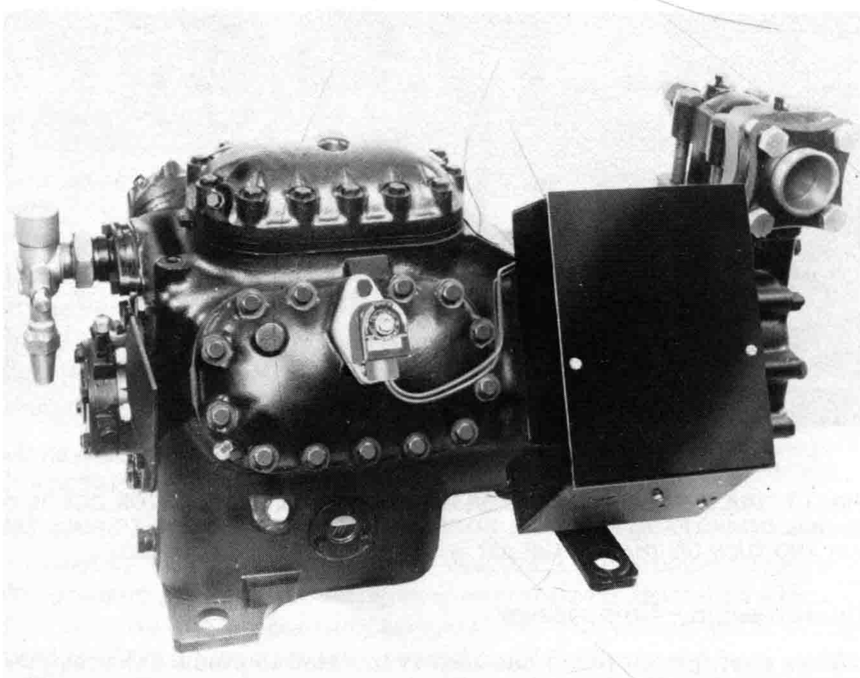


Courtesy Bohn Heat Transfer Division

FIG. 1.1. MULTI-FAN UNIT USED FOR ROOM COOLING. EVAPORATOR COIL IS IN CASING BEHIND FANS. FANS PULL ROOM AIR OVER THE COLD COIL TO COOL THE AIR AND THEN DISCHARGE THE AIR INTO THE ROOM BEING COOLED.

Compression - Compressor

After a refrigerant liquid has been evaporated to produce the required refrigerating effect, it is in the form of a vapor, or gas. Refrigerants, being expensive, cannot be thrown away at this point but must be converted back into a liquid for use again in the evaporator. The first step in this process is the compression of the gas, by means of the refrigerant compressor, from its evaporating pressure to a higher level. Since the refrigerant boiling and condensing temperatures are proportional to the pressure imposed on the refrigerant, the compression of the refrigerant vapor actually raises the corresponding level of the temperature so that the vapor may be condensed back into a liquid by the extraction of heat from an easily obtainable medium such as air or water. Thus, the heat from the cold room is removed at a low temperature level by the refrigerant in the evaporator, the refrigerant being vaporized in the process. The compressor then raises the evaporated liquid (gas) to a higher pressure level where the heat may be removed easily and the vapor condensed into a liquid. The power required to drive the compressor is actually the power to raise the refrigerant from one level of pressure to another higher level and is not equivalent to the work done by the refrigerant. To repeat, heat is removed at a low level, the level is then raised by the compressor and the heat discarded at the higher level. It is from the raising of pressure by the compressor that this recovery and refrigeration cycle is known as the "compression cycle." Fig. 1.2 illustrates a simple refrigeration compressor.

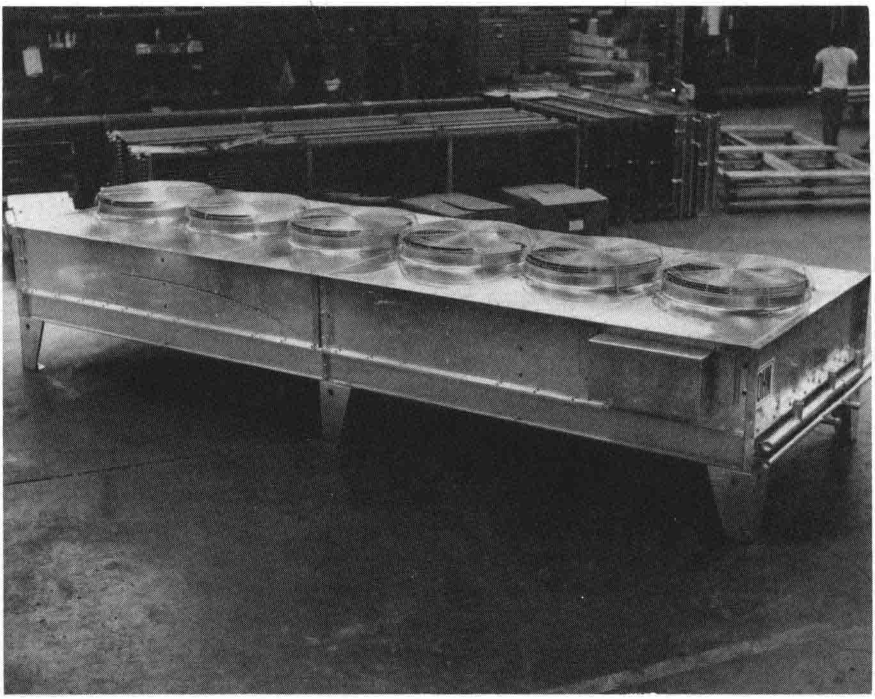


Courtesy Copeland Corporation

FIG. 1.2. SIMPLE MULTI-CYLINDER REFRIGERATION COMPRESSOR OF THE SEMI-HERMETIC TYPE COMPLETE WITH DRIVING MOTOR, JUNCTION BOX AND SERVICE VALVES.

Condensation - Condenser

When the refrigerant vapor is compressed to a higher pressure by the compressor, it flows into another vessel, or set of coils, called the condenser. The elevated pressure, with its corresponding higher temperature equivalent, is high enough so that a medium such as air or water will cause heat from the refrigerant vapor to flow into the medium. The extraction of heat causes the refrigerant vapor to condense back into a liquid form. The condensed liquid refrigerant then normally flows from the condenser into another vessel called a receiver where it is stored for another journey through the evaporator. Fig. 1.3 and Fig. 1.4 show an air cooled and water cooled condenser, respectively.

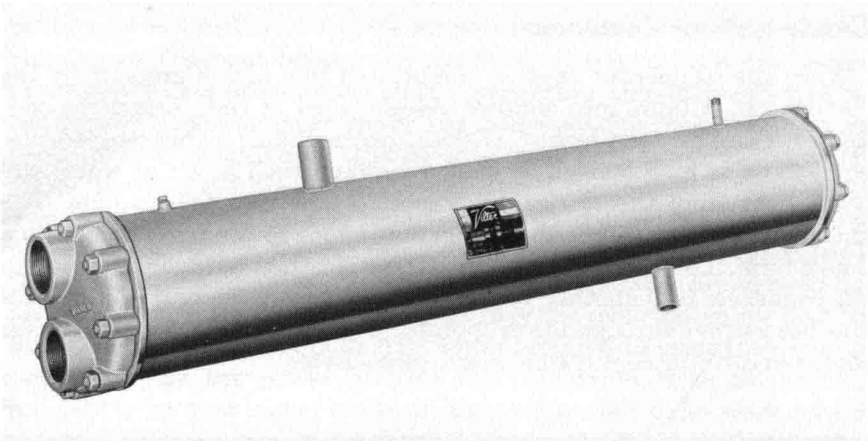


Courtesy Bohn Heat Transfer Division

FIG. 1.3. VIEW OF AN AIR COOLED CONDENSER WITH MULTIPLE FANS. CYCLING OF FANS IS SOMETIMES USED FOR COLD WEATHER CONTROL OF CONDENSING TEMPERATURE.

Temperature

Temperature indicates the level of heat, or how hot or cold an object may be. It does not indicate any specific amount of heat but is only a



Courtesy Vilter Manufacturing Company

FIG. 1.4. EXTERIOR VIEW OF WATER COOLED REFRIGERANT CONDENSER. SHELL IS FILLED WITH SMALL TUBES AND CONDENSING WATER IS DIRECTED THROUGH TUBES IN VARIOUS NUMBERS OF PASSES BY WEBBING IN HEADS. REFRIGERANT IS CONDENSED WITHIN THE SHELL AND DRAINED OUT AT BOTTOM.

measure of the heat intensity. Temperatures are measured by thermometers of one type or another. The most commonly used scales are the Fahrenheit, which was devised by a man named Fahrenheit, and the Centigrade scale which was devised by a man named Celsius. In the International System, the Centigrade scale is officially called the Celsius scale.

The Fahrenheit scale is based on water freezing at 32°F and boiling at 212°F, all at atmospheric pressure. The spread is 180 degrees between the freezing and boiling points of water. The Celsius scale is based on water freezing at 0°C and boiling at 100°C. The spread of temperature on the Celsius scale is based on 100 degrees between the freezing and boiling of water. The Celsius degree is of greater magnitude than the Fahrenheit by a ratio of 180 to 100 or 9/5. Temperatures may be freely changed from one scale to the other by the following formulas.

$$\text{Celsius} = 5/9 \times (\text{Fahrenheit degrees} - 32)$$
$$\text{Fahrenheit} = (9/5 \times \text{Celsius degrees}) + 32$$

Tables are also available giving conversions from Fahrenheit to Celsius and Celsius to Fahrenheit. One will be found in the appendix of this volume.

Specific Heat

Specific heat is a useful tool in determining cooling or heating requirements of substances other than water. It is assumed, for all practical purposes, that water has a specific heat of unity, or 1. In essence, specific heat is the ratio of the quantity of heat to raise or lower the temperature of a given weight of a substance compared to the amount of heat required to raise or lower the same weight of water through the same temperature range as the substance, usually one degree. The specific heat is usually expressed as a decimal: i.e. 0.75, 0.80 etc.

Heat Units

In the United States, the common heat quantity has been the British Thermal Unit and is usually abbreviated as Btu. By definition, one Btu is the amount of heat required to raise, or lower, the temperature of 1 pound of water 1 degree Fahrenheit.

In the metric system, weights are in kilograms (2.2 lbs) and heat units are in calories. The heat unit is the kilogram-calorie. The common refrigeration quantity in the English system is the ton of refrigeration. Since ice was one of the first substances used for refrigeration, it was only natural to equate refrigeration with ice melting effect. The ton of refrigeration is defined as the amount of heat required to melt one ton (2000 lbs) of ice at 32°F (0°C) in 24 hours. To melt one pound of ice at 32°F (0°C) requires 144 Btu. Therefore, 1 ton of refrigeration may be defined as 2000 lbs × 144 Btu/lb = 288,000 Btu per 24 hours; or 12,000 Btu per hour, or 200 Btu per minute. This is a rate of cooling. The term "ton of refrigeration" is applicable to cooling at any temperature and is, of course, not confined to ice melting. The ice melting equivalent serves only to define a quantity of heat.

Heat Transfer

All refrigeration involves heat transfer in one form or another and is normally concerned with the removal of heat, or flow of heat out of an object or area to lower the temperature of the object or area. Heat always flows from a warm to a cold body. It cannot flow uphill. Heat may be transferred in three ways and is usually transferred by a combination of the three ways. The three methods of transfer are conduction, convection and radiation.

Heat transfer by conduction is the transfer of heat through a substance, or touching substances. It may be illustrated by the heating of one end of a metal rod. Heat will flow by conduction to the other end of the rod and warm it. Heat is also transferred from the outside of the tube or vessel by conduction through the metal tube wall.

Heat transfer by convection in a cold room means cooling by air currents transferring heat from warm walls or products to the surface of the refrigerated cooling coil. The heat is removed from the air by conduction through the coil metal to the refrigerant within the coil and the cooled air circulates back through the room, usually by forced fan circulation, where it picks up more heat for cooling by the refrigerated coil.

Heat transfer by radiation is usually more active in heating than cooling. The sun warms the earth by the radiation of heat. A heated ceiling will heat objects below by radiation even though the surrounding air may be quite cool. A heated floor will radiate heat and will also set up air currents which transfer heat by convection. An example of radiation heat is that of the sun melting an ice layer on concrete even though the air temperature is well below freezing. A limited amount of cooling may be done in a cold room by radiation from walls and products to the colder refrigerated coil. The major portion of cooling however, is normally accomplished by convection to the coil and conduction of heat through the coil to the refrigerant.

Absolute Pressure

Two pressure nomenclatures are used more frequently in refrigeration calculations. These are gauge pressure (psig) and absolute pressure (psia) expressed in pounds per sq in. In the metric system, pressures can be expressed in kilograms per square centimeter (kg/cm^2). Gauge pressure is the pressure indicated on a standard pressure gauge. This indicates the pressure inside of an enclosed vessel compared to the atmospheric pressure outside the vessel. There is a second ingredient in the pressure picture however; and that is the pressure of the atmosphere from the stratosphere to the surface of the earth. This pressure varies somewhat depending on atmospheric conditions and is the pressure indicated by a barometer. Most people are familiar with the barometer from its use in weather predictions. This pressure is usually indicated in inches of mercury pressure and will average about 30". This means that the pressure of the atmosphere will push a column of mercury to a height of 30". This is equivalent to approximately 14.7 psi (1.03 kg/cm^2). To obtain absolute pressure, the weight of the atmosphere must be added to the gauge pressure. For most computations, the Figure of 14.7 psi (1.03 kg/cm^2) as atmospheric pressure is sufficiently accurate. The absolute pressure is important in a number of computations such as compression ratios. Pressures below 0 psig are often said to be in a vacuum. This is not true. These pressures are less than atmospheric and are frequently referred to a vacuum in this sense but zero pressure absolute is the theoretical lowest point of pressure that can be achieved. All pressures are positive with reference to absolute pressure. Pressures below atmospheric are frequently expressed in inches of mercury. One inch of mercury is equal to slightly less than 0.5 lbs per sq in pressure (.035 kg/cm^2).