Overview of Refrigeration Systems

An Online Continuing Education Course for Engineers

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OVERVIEW OF REFRIGERATION SYSTEMS

Modern refrigeration has many applications, such as preserving medicine, blood, and the most important application, the preservation of food. Most foods kept at room temperature spoil rapidly. This is due to the rapid growth of bacteria. Refrigeration preserves food by keeping it cold, which greatly slows down the growth of bacteria. In days past, blocks of ice were used in iceboxes to refrigerate food and other items. These iceboxes were small and not very practical. Today, mechanical refrigeration systems make transportation, storage, and use of refrigerated goods easy and practical.

HEAT AND REFRIGERATION PRINCIPLES

REFRIGERATION is the process of removing heat from an area or a substance and is usually done by an artificial means of lowering the temperature, such as the use of ice or mechanical refrigeration. MECHANICAL REFRIGERATION is defined as a mechanical system or apparatus so designed and constructed that, through its function, heat is transferred from one substance to another. Since refrigeration deals entirely with the removal or transfer of heat, some knowledge of the nature and effects of heat is necessary for a clear understanding of the subject.

NATURE OF HEAT

Heat is a form of energy contained to some extent in every substance on earth. All known elements are made up of very small particles, known as atoms, which, when joined together, form molecules. These molecules are particular to the form they represent. For example, carbon and hydrogen in certain combinations form sugar and in others form alcohol.

Molecules are in a constant state of motion. Heat is a form of molecular energy that results from the motion of these molecules. The temperature of the molecules dictates to a degree the molecular activity within a substance. For this reason, substances exist in three different states or forms—solid, liquid, and gas. Water, for example, may exist in any one of these states. As ice, it is a solid; as water, it is a liquid; and as steam, it is a gas (vapor).

When heat is added to a substance, the rate of molecular motion increases, causing the substance to change from a solid to a liquid, and then to a gas (vapor). For example, in a cube of ice, molecular motion is slow, but as heat is added, molecular activity increases, changing the solid "ice" to a liquid "water" (fig. 1). Further application of heat forces the molecules to greater separation and speeds up their motion so that the water changes to steam. The steam formed no longer has a definite volume, such as a solid or liquid has, but expands and fills whatever space is provided for it.

Heat cannot be destroyed or lost. However, it can be transferred from one body or substance to another or to another form of energy. Since heat is not in itself a substance, it can best be considered in relation to its effect on substances or bodies. When a body or substance is stated to be cold, the heat that it contains is less concentrated or less intense than the heat in some warmer body or substance used for comparison.

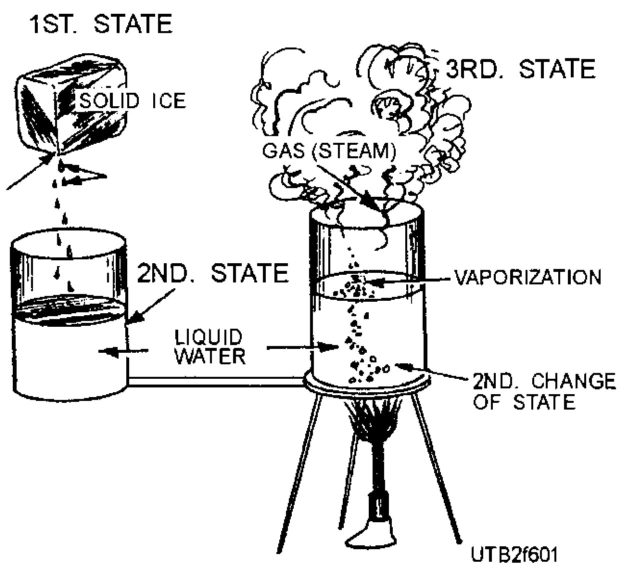


Figure 1.—The three states of matter.

UNITS OF HEAT

In the theory of heat, the speed of the molecules indicates the temperature or intensity of heat, while the number of molecules of a substance indicates the quantity of heat.

The intensity and quantity of heat may be explained in the following simple way. The water in a quart jar and in a 10-gallon container may have the same intensity or temperature, but the quantity of heat required to raise these amounts of water to a higher uniform temperature (from their present uniform temperature) will differ greatly. The 10 gallons of water will absorb a greater amount of heat than the quart jar of water.

The amount of heat added to, or subtracted from, a body can best be measured by the rise or fall in temperature of a known weight of a substance. The standard unit of heat measure is the amount of heat necessary to raise the temperature of 1 pound of water 1°F at sea level when the water temperature is between 32°F and 212°F. Conversely, it is also the amount of heat that must be extracted to lower by 1°F the temperature of a pound of water between the same temperature limits. This unit of heat is called a British thermal unit (Btu). The Btu's equivalent in the metric system is the calorie, which is the amount of heat required to raise one gram of water 1° Celsius.

Suppose that the temperature of 2 pounds of water was raised from 35°F to 165°F. To find the number of Btu required to increase the temperature, subtract 35 from 165. This equals a 130° temperature rise for 1 pound of water. Since 2 pounds of water were heated, multiply 130 by 2, which equals 260 Btu required to raise 2 pounds of water from 35°F to 165°F.

MEASUREMENT OF HEAT

The usual means of measuring temperature is a thermometer. It measures the degree or intensity of heat and usually consists of a glass tube with a bulb at the lower portion of the tube that contains mercury, colored alcohol, or a volatile liquid. The nature of these liquids causes them to rise or fall uniformly in the hollow tube with each degree in temperature change. Thermometers are used to calibrate the controls of refrigeration. The two most common thermometer scales are the Fahrenheit and the Celsius.

On the Fahrenheit scale, there is a difference of 180° between freezing (32°) and the boiling point (212°) of water. On the Celsius scale, you have only 100° difference between the same points (0° freezing and 100° boiling point).

Of course, a Celsius reading can be converted to a Fahrenheit reading, or vice versa. This can be expressed in terms of the following formula:

$$F = (C \times 1.8) + 32$$

To change Fahrenheit to a Celsius reading, the terms of the formula are as follows:

$$C = (F-32) -f 1.8$$

TRANSFER OF HEAT

Heat flows from a substance of higher temperature to bodies of lower temperature in the same manner that water flows down a hill, and like water, it can be raised again to a higher level so that it may repeat its cycle.

When two substances of different temperatures are brought in contact with each other, the heat will immediately flow from the warmer substance to the colder substance. The greater the difference in temperature between the two substances, the faster the heat flow. As the temperature of the substances tends to equalize, the flow of heat slows and stops completely when the temperatures are equalized. This characteristic is used in refrigeration. The heat of the air, of the lining of the refrigerator, and of the food to be preserved is transferred to a colder substance, called the refrigerant.

Three methods by which heat may be transferred from a warmer substance to a colder substance are conduction, convection, and radiation.

SPECIFIC HEAT

SPECIFIC HEAT is the ratio between the quantity of heat required to change the temperature of 1 pound of any substance 1°F, as compared to the quantity of heat required to change 1 pound of water 1°F. Specific heat is equal to the number of Btu required to raise the temperature of 1 pound of a substance 1^{o}F. For example, the specific heat of milk is .92, which means that 92 Btu will be needed to raise 100 pounds of milk 1^{o}F. The specific heat of water is 1, by adoption as a standard, and specific heat of another substance (solid, liquid, or gas) is determined experimentally by comparing it to water. Specific heat also expresses the heat-holding capacity of a substance compared to that of water.

A key RULE to remember is that .5 Btu of heat is required to raise 1 pound of ice 1^{o}F when the temperature is below 32°F; and .5 Btu of heat is required to raise 1 pound of steam 1°F above the temperature of 212°F.

SENSIBLE HEAT

Heat that is added to, or subtracted from, a substance that changes its temperature but not its physical state is called SENSIBLE HEAT. It is the heat that can be indicated on a thermometer. This is the heat human senses also can react to, at least within certain ranges. For example, if a person put their finger into a cup of water, the senses readily tell that person whether it is cold, cool, tepid, hot, or very hot. Sensible heat is applied to a solid, a liquid, or a gas/vapor as indicated on a thermometer. The term *sensible heat* does not apply to the process of conversion from one physical state to another.

LATENT HEAT

LATENT HEAT, or hidden heat, is the term used for the heat absorbed or given off by a substance while it is changing its physical state. When this occurs, the heat given off or absorbed does NOT cause a temperature change in the substance. In other words, sensible heat is the term for heat that affects the temperature of things; latent heat is the term for heat that affects the physical state of things.

To understand the concept of latent heat, you must realize that many substances may exist as solids, as liquids, or as gases, depending primarily upon the temperatures and pressure to which they are subjected. To change a solid to a liquid or a liquid to a gas, ADD HEAT; to change a gas to a liquid or a liquid to a solid, REMOVE HEAT. Suppose you take an uncovered pan of cold water and put it over a burner. The sensible heat of the water increases and so does the temperature. As you continue adding heat to the water in the pan, the temperature of the water continues to rise until it reaches 212°F. What is happening? The water is now absorbing its latent heat and is changing from a liquid to a vapor. The heat required to change a liquid to a gas (or, the heat that must be removed from a gas to condense it to a liquid) without any change in temperature is known as the LATENT HEAT OF VAPORIZATION.

Now suppose you take another pan of cold water and put it in a place where the temperature is below 32°F. The water gradually loses heat to its surroundings, and the temperature of the water drops to 32°F until all the water has changed to ice. While the water is changing to ice, however, it is still losing heat to its surroundings. The heat that must be removed from a substance to change it from a liquid to a solid (or, the heat which must be added to a solid to change it to a liquid) without change in temperature is called the LATENT HEAT OF FUSION. Note the amount of heat required to cause a change of state (or the amount of heat given off when a substance changes its state) varies according to the pressure under which the process takes place. Figure 2 shows the relationship between sensible heat and latent heat for one substance - water at atmospheric pressure.

To raise the temperature of 1 pound of ice from 0°F to 32°F, you must add 16 Btu. To change the pound of ice at 32°F to a pound of water at 32°F, you add 144 Btu (latent heat of fusion). There is no change in temperature while the ice is melting. After the ice is melted, however, the temperature of the water is raised when more heat is applied. When 180 Btu are added, the water boils. To change a pound of water at 212°F to a pound of steam at 212°F, you must add 970 Btu (latent heat of vaporization). After the water is converted to steam at 212°F, the application of additional heat causes a rise in the temperature of the steam. When you add 44 Btu to the steam at 212°F, the steam is superheated to 300°F.

TOTAL HEAT

TOTAL HEAT is the sum of sensible heat and latent heat. Since measurements of the total heat in a certain weight of a substance cannot be started at absolute zero, a temperature is adopted at which it is assumed that there is no heat; and tables of data are constructed on that basis for practical use. Data tables giving the heat content of the most commonly used refrigerants start at 40°F below zero as the assumed point of no heat; tables for water and steam start at 32°F above zero. Tables of data usually contain a notation showing the starting point for heat content measurement.

DAY-TON OF REFRIGERATION

A day-ton of refrigeration (sometimes incorrectly called a ton of refrigeration) is the amount of refrigeration produced by melting 1 ton of ice at a temperature of 32°F in 24 hours. A day-ton is often used to express the amount of cooling produced by a refrigerator or air-conditioner. For example, a 1-ton air-conditioner can remove as much heat in 24 hours as 1 ton of 32°F ice that melts and becomes water at 32°F.

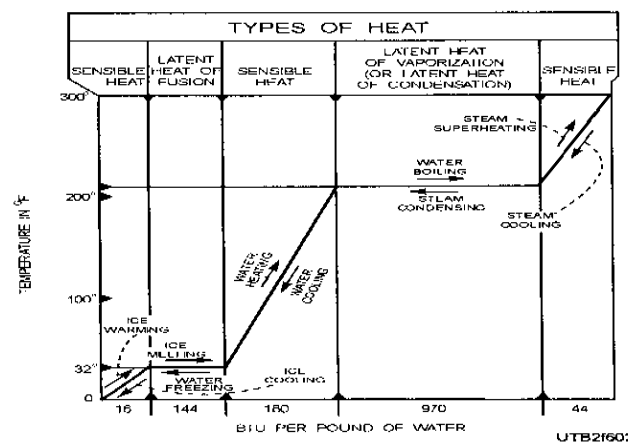


Figure 2.—Relationship between temperature and the amount of heat required per pound (for water at atmospheric pressure).

It is a rate of removing heat, rather than a quantity of heat. A rate can be converted to Btu per day, hour, or minute. To find the rate, proceed as follows:

- Per Day: Multiply 2,000 (number of pounds of ice in 1 ton) by 144 (latent heat of fusion per pound) = 288,000 Btu per day

- Per Hour: 288,000 (Btu per day) -f 24 (hours in a day) = 12,000

So, a "1-ton" air-conditioner would have a rating of 12,000 Btu per hour.

PRESSURE

PRESSURE is defined as a force per unit area. It is usually measured in pounds per square inch (psi). Pressure may be in one direction, several directions, or in all directions, as shown in figure 3. The ice (solid) exerts pressure downward. The water (fluid) exerts pressure on all wetted surfaces of the container. Gases exert pressure on al I inside surfaces of their containers.

Pressure is usually measured or
one of two different sca
many pounds per squa
indicates the pressure ab
surrounding the gauge. T
read as so many pounds
(psia) and indicates the
zero pressure (a perfect va

Atmospheric Pressure

Atmospheric pressure is the
of air above a point on, abo
At sea level, ATMOSPHER
psia, as shown in figure 4.
atmospheric pressure decrea
every 2,343 feet. Below sea
and depressions, atmospheri
Pressures underwater differ
only because the weight of the water must be added to the pressure of the air.

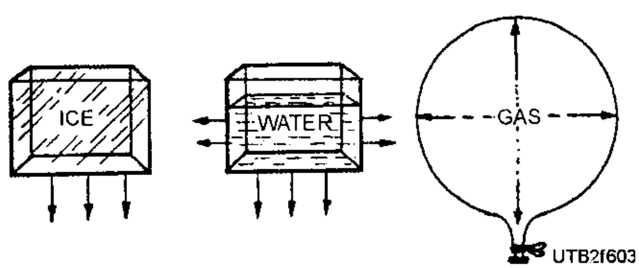
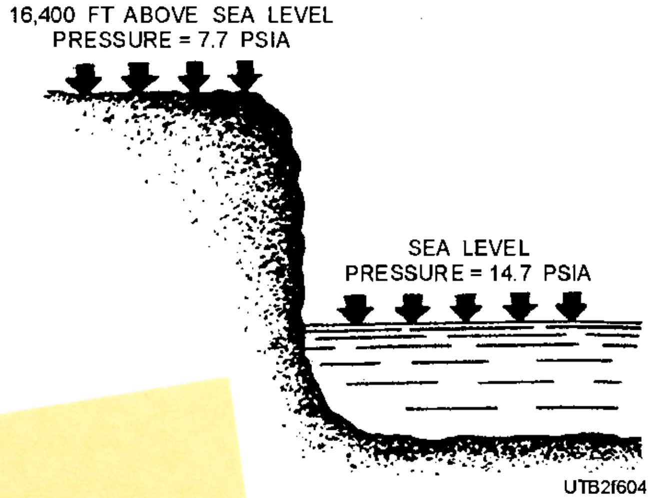


Figure 3.—Exertion of pressures.



Atmospheric pressure.

between the readings of a
ig and calibrated in psia. As
ien the psig gauge reads 0,
the atmospheric pressure
. In other words, the psia
psig reading plus the
7 psia at 16,400 feet), or,
e psia reading minus the

...ALE (PSIA)	GAUGE SCALE (PSIG)	INCHES OF MERCURY	INCHES OF WATER
44.7	3 0	NOT USED	NOT USED
24.7	1 0	NOT USED	NOT USED
14.7	0	0	0
0	NOT USED	-30	-408

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Figure 5.—Pressure relationship.

For pressure less than the atmospheric pressure (partial vacuums), a measuring device with a scale reading in inches of mercury (Hg) or in inches of water (H_2O) is used. A perfect vacuum is equal to -30 inches of mercury or -408 inches of water (fig. 5). In refrigeration work, pressures above