Fundamental Refrigeration

A Low-Tech, Low-Stress Introduction to the Mechanical Refrigeration Vapor Compression Cycle

By George Gunter

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Preface

Fundamental Refrigeration

This text has been designed for individuals that are experiencing their first introduction to refrigeration and air-conditioning systems.

The book covers a broad range of information relating to refrigeration and air-conditioning systems. Although I use R-22 throughout the book for illustrative purposes, the principles and theory of refrigeration remain the same with all high pressure refrigerants. This book is based on several years of experience as an instructor and trainer for schools and industry.

During that experience several questions for clarification and description have been repeatedly addressed, and some not asked. I have attempted to describe, in some detail, the questions that were not asked.

I have kept the theory and mathematics, to what I believe to be the absolute minimum without suffering any loss of pertinent information.

The theory and concepts presented are in agreement with accepted industry standard information, but also contain opinions and observations that belong solely to me.

The illustrations and tables, except where noted, are all original sketches done by me. Any similarities to specific products are purely coincidental and unintentional.

This book should provide the reader with a good overall understanding of the concepts and provide for a foundation of knowledge. That knowledge should be augmented with further study in specific detail to continue in the refrigeration and air-conditioning industries.

George Gunter

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I would like to thank Linric Company, Dyer Instruments, and the Air-conditioning Research Institute for their generous contributions to the contents of this book.

Special thanks to my friends Bill Held and Sue Montera for their help, insight and encouraging comments.

Most crucial, though, would be thanks to my wife Cathy for her support, enduring help and patience during the writing of this book.

This work is dedicated to my daughter: Janetta Jean.

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Chapter 1:

Simple Heat Transfer

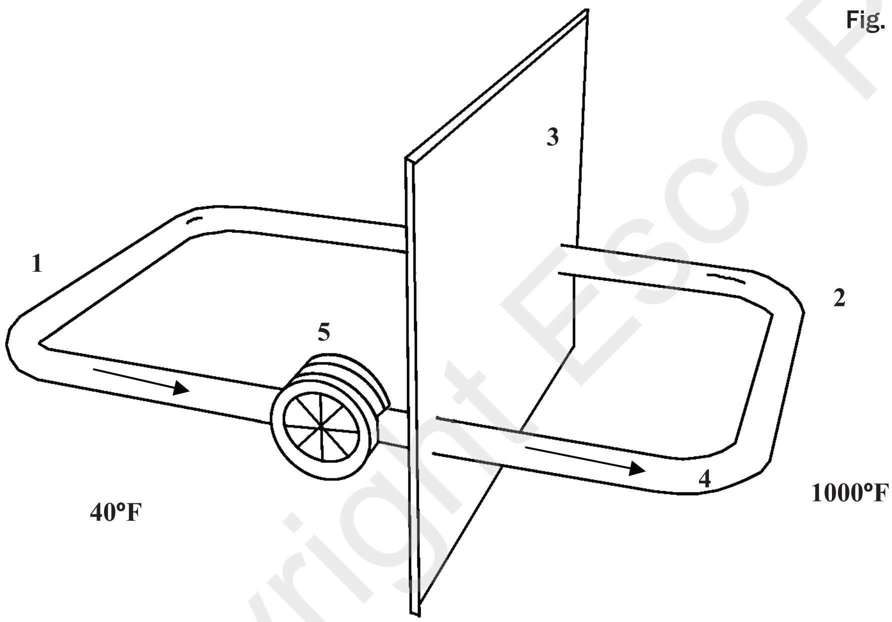
System Development

To begin examining the mechanical refrigeration cycle we need to develop a system that contains:

1) A source of energy. (heat to be specific)
2) A system of piping to contain the process. (a looping process)
3) And some location to deposit the energy that will not affect the operation of the process.

Our new system:

Fig. 1-1



I added a couple of items to our system to aid with the new process. Covering the items in order, the item labeled number 1 is reference to the cooler area around the process. (40 degrees)

The item labeled 2, is the source of heat energy that will be the "load" on our system.

Item number 3 is there to separate the two parts of the process. It could be a wall, a roof, a building or possibly mere distance.

Item number 4 is the transport fluid that is needed to carry the energy on its way. The fluid for this first example will be air.

Item number 5, that stands out in the middle, is a magical pump. Not very technical, but we need not worry about what the pump is for now, just that it will pump anything we need it to.

Examining how the New System Works

Before we examine how the system will work, we need to point out some observations.

The air inside the pipe is independent of the surrounding air outside the pipe. The air is only affected by the external temperatures of the pipe, and the force of the pump circulating it at constant pressure.

The pipe will be the same temperature as the ambient air that surrounds the pipe on the outside. We are assuming that the "load" is great enough to overcome the process in the pipe. So, the pipe on the right side of the wall is going to be 1000 degrees Fahrenheit, and the pipe on the left-hand side is going to be 40 degrees Fahrenheit.

Let's begin the analysis!

Beginning at the pump, the air in the pipe moves into the section that is exposed to the 1000 degree temperature. The air immediately begins to warm up to the temperature of the pipe.

Energy is needed to heat the air. This energy is in the form of heat. The heat energy is readily available from the 1000 degree room.

If the air in the pipe were already 1000 degrees, there would be no transfer of energy. **The heat energy can only travel from a higher temperature to a lower temperature.**

The air continues through the pipe to the left-hand side of the wall. The pipe in that section of the system is 40 degrees. The higher temperature air releases its' energy to the lower temperature pipe. This in turn releases energy to the surrounding air.

The air, now "cooled", continues to the pump to be re-circulated through the process.

Quantifying the Process

The air in our system can only pick up a fixed amount of energy. This quantity of energy is based on a concept referred to as **specific heat.**

All fluids, which you will encounter with refrigeration, have a specific heat value. Look at this as the limiting figure for the amount of heat energy that can be "picked up" by the fluid.

More technical explanations can be found in text books and engineering manuals, but I like to think of specific heat as the size of the "bucket". Big buckets can hold a lot of energy, and little buckets hold less.

> The specific heat figure, for some substances, can remain relatively constant through a range of temperatures as long as the substance remains in its' present state (gas, liquid, etc.). Air is such a substance.

Since specific heats are a unit of measurement, they are bound by certain conditions to keep them uniform. A specific heat value is the amount of energy that will raise **one pound of the substance 1 degree Fahrenheit.**

The specific heat for the air in our system is .24 the energy that is picked up by the air is measured by temperature increase. This kind of energy is called **sensible heat.** The term "sensible" is used as it relates to the sense of touch.

Now, our little system has a seemingly unlimited amount of energy available to work with. In the "real world" this is never the case. In our modern society, it may appear that some things are so readily available that they can never be exhausted. Electricity just flows from the wall whenever we want to use the toaster, but anyone who has been in a blackout, or forgot to pay the electric bill, knows this is not the case.

To demonstrate a real world scenario, we now need to place limits on our system. Although the limits we will use may not be practical, the limits will be measurable.

If our magic pump pumps the air at a rate of 100 pounds per minute, then the heat energy being transported will be the quantity of 100 pounds multiplied by the specific heat of .24 times the temperature difference of 960 degrees.

$$100 \times .24 \times (1000-40)=23{,}040 \text{ Btu per minute. } \{Q = M * Cp * DT\}$$

Don't be intimidated by the equation. It is very straight forward once you take the time to understand it. The form $Q = M * Cp * DT$ is just a common representation of the same mathematical expression written before it.

The term "Q" represents "Quantity" of heat energy. It is measured in "Btu" per minute. The "M" is for "Mass" in pounds of the air. The "Cp" is a common representation of the "specific heat value" and the "DT" is the temperature difference from the beginning to the end of the process. The triangle is a Greek symbol for "delta" and a short cut for writing "difference".

> "Btu" stands for British thermal Unit. It is a unit of measure of a quantity of heat. It was originally derived to place a value on the energy needed to produce a ton (2000 lbs.) of ice in a twenty-four hour period. A quantity of 288,000 Btu was the amount arrived at. This can be reduced to an hourly rate of 12,000 Btu per hour, the common term for a "ton" of refrigeration capacity.

Summarizing the Process

Our system transports 23,040 Btu per minute with air moving at a rate of 100 pounds per minute and a temperature difference of 960 degrees. According to the relationship $Q = M * Cp * DT$ and the fact that the specific heat of air is .24, the equation works out to be 23,040 Btu per minute.

You should take note that there is one final aspect of the entire process that I have yet to mention, <u>time</u>. All processes in refrigeration will have to have a **quantity; an energy value and a time based rate.**

The whole purpose of mechanical refrigeration is to remove a quantity of heat energy from one place and deposit the energy somewhere else in an acceptable amount of time.

Improving the Process

If we wanted to improve the process to transport more energy in the same amount of time, we could select a substance with a higher specific heat value.

We could evacuate all the air from the pipe and fill the system with water. Water has a specific heat value of one. Coincidentally, water is the index for the specific heat scale. All other specific heat values are in reference to water.

Our magic pump will now be pumping the water at a rate of 100 pounds per minute at a constant pressure. The pressure will be extremely high to prevent the water from becoming steam when it encounters the 1000 degree section of the system. This process is quite impractical, but for this moment of discussion humor me.

Our improved heat transfer system now has a fluid with a higher specific heat value. According to the relationship Q = M * Cp *DT the new calculation is: 100 x 1 x (1000 – 40) = 96,000 Btu per minute. The air was only capable of 23,040 Btu per minute.

The water is over 4 times better than air at transporting heat energy!

Now, back to reality. We will reduce the pressure of the magic pump to operate at 14.696 psig (pound per square inch gauge equivalent to atmospheric pressure at sea level.)

Water at a pressure of 14.696 and a temperature of 1000 degrees would most definitely be steam. Water at atmospheric pressure will boil rapidly at a temperature of 212 degrees Fahrenheit.

But more importantly, the water has become a vapor (gas) rather than a liquid. Water can exist in three states of matter; solid, liquid, and gas (vapor). This transformation is where "it's" at. In order to change a substance into another form of itself, while remaining the same substance, takes many more times the energy than just raising the temperature of the substance one degree.

> Although it may not be practical, all fluids can exist in three states of matter, solids, liquids and gas. Water, perhaps the most familiar of all, exhibits these three states rather commonly. When water is boiled at atmospheric pressure, the temperature of the water temperature is 212 degrees until all the water is boiled away. If the pressure is increased to 35 psig the water will not boil.

Now is the time to introduce the term **latent heat**. If sensible heat is the term used to describe the heat energy that causes temperature change, then latent heat is the term to describe the heat energy to cause the *physical change of state.* It is sometimes referred to as hidden heat because it cannot be measured with a thermometer, but I would rather you not try to think of it that way.

The term “heat” always brings to mind temperature change and thus the terms become confusing by definition. Think of “latent heat” as the ***hidden energy,*** the treasure, the secret that we must discover to do some real usable work with our refrigeration process.

Also remember that “heat” is a form of energy, and energy can be used in many different ways. If we heat up a pile of wood to a couple of hundred degrees, it will be warm for a short period of time then cool to the ambient temperature. However, if we heat the wood to its kindling point, the wood will begin to burn and release its hidden energy. The heating value of dry wood is over 8,000 Btu per pound!

Latent Heat

First we need to point out there are four types of latent heat; the latent heat of fusion, latent heat of sublimation, latent heat of evaporation, and the latent heat of condensation. The two latter of the four are the ones we are concerned with in refrigeration work.

We know when water boils it becomes a vapor, when vapor condenses on a cooler surface it returns to a liquid. If the surface is cool enough, the water will freeze and become a solid.

There are the three states of matter; solid, liquid and gas. We will be concentrating only on the changes from liquid to gas and gas to liquid.

When the water vaporizes it requires 970 Btu per pound of heat energy to cause the change the condition of the substance from liquid to vapor. The energy that causes the change is then contained in the steam. *There is no change in temperature during the boiling process of the water.* This process is the ***latent heat of vaporization*** *(evaporation).*

When the steam encounters a lower temperature it will condense back to a liquid releasing the 970 Btu per pound of energy that it once carried. The energy is transported in the steam to a lower energy potential. This process is the ***latent heat of condensation.***

970 Btu per pound! That’s a slight bit more than 1 Btu per pound that water exhibits without changing states.

Using the formula again, Q = M * Cp *DT \100 x 970 x (1000-40) = 93,120,000 Btu per minute. That’s over 4000 times the heat energy that air could move!

To say the least, we should now see the value of condensing and evaporating the substance that we choose for a refrigerant.

All the refrigerants display different properties and evaporate or condense based on temperature and pressure relationships. In the next section we will discuss the temperature and pressure relationship and why it is so important.

Later, we will modify our heat transport system to accommodate what we have learned about the secrets behind mechanical refrigeration.

Chapter 1 Review Questions

The simple system presented in the first couple of pages represents the basic elements needed to move energy from the right hand side of the wall (item 3) to the left hand side of the wall.

This is the function of a mechanical refrigeration system. The system is contained inside of the piping (item 4) so that it can be controlled.

1. In this first example, the one source of energy that we have to add to the system in order to move the air in the pipe comes from the ____.
2. There are two other sources of energy in the example. What temperatures are those energy sources?
3. In the first example, the 1000-degree and the 40-degree energy sources are unlimited. If the amount of each of these sources was a 'limited' amount, say two equal size rooms, would the 40-degree side eventually become 1000 degrees?
4. What would you guess the temperature of the two rooms would eventually become if no other energy were affecting the rooms?
5. The heat energy will travel from a 1000-degree source to the 40-degree source with no apparent mechanical device to make it happen. This would be true even if there was no 'magic pump' in the system. The pump only helps by making the process take less time. If an ice cube is 32-degrees and is place in a room that is 20-degrees, which direction will the heat travel?
6. If the ice cube is losing energy, will it melt?
7. If the ice cube is placed in an 80-degree room, will it melt then?
8. Is the Ice cube in the 80-degree room gaining or losing energy?
9. Substances with larger specific heat values, or 'buckets', can move more heat energy at a time than ones with smaller values. If the speed, or 'rate', that energy moves is controlled by the temperature difference, how would the system be affected if the 'magic pump' started pumping slower, in effect moving less of a mass of air?
10. We learned that latent heat is where the real value is when it comes to moving energy. Burning wood released a large amount of energy. What do you suppose is the greatest draw back to that kind of change in state?

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For those entering the HVACR field, this should be your first book!

Fundamental Refrigeration covers all the basic principles and theories of refrigeration and air conditioning systems. Written in easy to understand language, this book contains a wealth of necessary fundamental knowledge.

A low-tech, low stress introduction to the mechanical vapor compression cycle. Covering a broad range of information about refrigeration and air conditioning systems, this book is not only for those entering the field, but also for seasoned professionals who want a solid review of the basic principles.

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