What is Refrigeration?

Refrigeration is the process of removing heat from one substance and transferring it to another substance. Or Refrigeration may be defined as the process of achieving and maintaining a temperature below that of the surroundings, the aim being to cool some product or space to the required temperature.

1. Natural Refrigeration

In olden days refrigeration was achieved by natural means such as the use of ice or evaporative cooling. In earlier times, ice was either:

1. Transported from colder regions,

2. Harvested in winter and stored in ice houses for summer use or,

3. Made during night by cooling of water by radiation to stratosphere.

2. Artificial Refrigeration

Refrigeration as it is known these days is produced by artificial means.

2.1 Vapour Compression Refrigeration Systems:

The basis of modern refrigeration is the ability of liquids to absorb enormous quantities of heat as they boil and evaporate. Professor William Cullen of the University of Edinburgh demonstrated this in 1755 by placing some water in thermal contact with ether under a receiver of a vacuum pump. The evaporation rate of ether increased due to the vacuum pump and water could be frozen. This process involves two thermodynamic concepts, the vapour pressure and the latent heat. A liquid is in thermal equilibrium with its own vapor at a pressure called the saturation pressure, which depends on the temperature alone. If the pressure is increased for example in a pressure cooker, the water boils at higher temperature. The second concept is that the evaporation of liquid requires latent heat during evaporation. If latent heat is extracted from the liquid, the liquid gets cooled. The temperature of ether will remain constant as long as the vacuum pump maintains a pressure equal to saturation pressure at the desired temperature. This requires the removal of all the vapors formed due to vaporization. If a lower temperature is desired, then a lower saturation pressure will have to be maintained.
by the vacuum pump. The component of the modern day refrigeration system where cooling is produced by this method is called evaporator.

If this process of cooling is to be made continuous the vapors have to be recycled by condensation to the liquid state. The condensation process requires heat rejection to the surroundings. It can be condensed at atmospheric temperature by increasing its pressure. The process of condensation was learned in the second half of eighteenth century. U.F. Clouet and G. Monge liquefied SO\textsubscript{2} in 1780 while van Marum and Van Troostwijk liquefied NH\textsubscript{3} in 1787. Hence, a compressor is required to maintain a high pressure so that the evaporating vapours can condense at a temperature greater than that of the surroundings.

![Fig. 1.1. Apparatus described by Jacob Perkins in his patent specification of 1834. The refrigerant (either or other volatile fluid) boils in evaporator B taking heat from surrounding water in container A. The pump C draws vapour away and compresses it to higher pressure at which it can condense in tubes D, giving out heat to water in vessel E. Condensed liquid flows through the weight loaded valve H, which maintains the difference of pressure between the condenser and evaporator. The small pump above H is used for charging the apparatus with refrigerant.](image)

Examples:

**Domestic refrigeration systems**

**Air conditioning systems**
2.2 Vapour Absorption Refrigeration Systems

Fig. 14.7: Basic vapour absorption refrigeration system with a solution heat exchanger on a pressure vs temperature diagram

Figs. 14.2: a) Vapour compression refrigeration system (VCRS)
    b) Vapour Absorption Refrigeration System (VARS)
2.3 Steam Jet Refrigeration System:

![Schematic of a steam jet refrigeration system](image1)

**Thermoelectric Refrigeration Systems**

![Schematic of a thermoelectric refrigeration system](image2)
2.5. Air Standard Cycle analysis

Air cycle refrigeration systems belong to the general class of gas cycle refrigeration systems, in which a gas is used as the working fluid. The gas does not undergo any phase change during the cycle; consequently, all the internal heat transfer processes are sensible heat transfer processes. Gas cycle refrigeration systems find applications in air craft cabin cooling and also in the liquefaction of various gases. In the present graph gas cycle refrigeration systems based on air are discussed.

Air cycle refrigeration system analysis is considerably simplified if one makes the following assumptions:

i. The working fluid is a fixed mass of air that behaves as an ideal gas
ii. The cycle is assumed to be a closed loop cycle with all inlets and exhaust processes of open loop cycles being replaced by heat transfer processes to or from the environment
iii. All the processes within the cycle are reversible, i.e., the cycle is internally reversible
iv. The specific heat of air remains constant throughout the cycle

An analysis with the above assumptions is called as cold Air Standard Cycle (ASC) analysis. This analysis yields reasonably accurate results for most of the cycles and processes encountered in air cycle refrigeration systems. However, the analysis fails when one considers a cycle consisting of a throttling process, as the temperature drop during throttling is zero for an ideal gas, whereas the actual cycles depend exclusively on the real gas behavior to produce refrigeration during throttling.

*Schematic of a simple aircraft refrigeration cycle*
What is Heat?

Heat is a form of energy.

Heat is a form of energy. Every object on earth contains heat energy in both quantity and intensity.

Quantity and Intensity

Heat intensity is measured by its temperature, commonly in either degrees Fahrenheit (°F) or degrees Celsius (°C). If all heat were removed from an object, the temperature of the object would decrease to -459.6°F [-273.2°C].

This temperature is referred to as “absolute zero” and is the temperature at which all-molecular activity stops. The quantity of heat contained in an object or substance is not the same as its intensity of heat. For example, the hot sands of the desert contain a large quantity of heat, but a single burning candle has a higher intensity of heat.

These two different masses of water contain the same quantity of heat, yet the temperature of the water on the left is higher. Why? The water on the left contains more heat per unit of mass than the water on the right. In other words, the heat energy within the water on the left is more concentrated, or intense, resulting in the higher temperature. Note that the temperature of a substance does not reveal the quantity of heat that it contains.

In the English system of units, the quantity of heat is measured in terms of the British Thermal Unit (Btu). The Btu is defined as the quantity of heat energy required to raise the temperature of 1 lb of water by 1°F. Similarly, in the metric system of units, the quantity of heat is measured in terms of the kilocalorie (kilogram-calorie or kcal). The kcal is defined as the amount of heat energy required to raise the temperature of 1 kg of water 1°C. Alternatively, in the System International (SI) metric system, heat quantity can be expressed using the unit kiloJoule (kJ). One kcal is equal to 4.19 kJ.
Principles of Heat Transfer

Methods of Heat Transfer

Conduction, convection, and radiation. The device shown is a baseboard convector that is commonly used for heating a space. It can be used to demonstrate all three processes of transferring heat. Hot water flows through a tube inside the convector, warming the inside surface of the tube. Heat is transferred, by conduction, through the tube wall to the slightly cooler fins that are attached to outside surface of the tube.

Conduction is the process of transferring heat through a solid. The heat is then transferred to the cool air that comes into contact with the fins. As the air is warmed and becomes less dense, it rises, carrying the heat away from the fins and out of the convector. This air movement is known as convection current.

Convection is the process of transferring heat as the result of the movement of a fluid. Convection often occurs as the result of the natural movement of air caused by temperature (density) differences. Additionally, heat is radiated from the warm cabinet of the convector and contacts cooler objects within the space.

Radiation is the process of transferring heat by means of electromagnetic waves, emitted due to the temperature difference between two objects. An interesting thing about radiated heat is that it does not heat the air between the source and the object it contacts; it only heats the object itself.
Rate of Heat Flow

In refrigeration, as in heating, emphasis is placed on the rate of heat transfer, that is, the quantity of heat that flows from one substance to another within a given period of time. This rate of heat flow is commonly expressed in terms of Btu/hr—the quantity of heat, in Btus, that flows from one substance to another over a period of 1 hour.

Similarly, in the SI metric system of units, the rate of heat flow is expressed in terms of kilowatts (kW), which are equivalent to kJ/sec. Kilowatts describe the quantity of heat, in kJ, that flows from one substance to another over a period of 1 second.

**Ton of Refrigeration**

In the English system of units, there is a larger and more convenient measure of the rate of heat flow. It is called a **ton of refrigeration**. One ton of refrigeration produces the same cooling effect as the melting of 2000 lb of ice over a 24-hour period.

When 1 lb of ice melts, it absorbs 144 Btu. Therefore, when 1 ton (2000 lb) of ice melts, it absorbs 288,000 Btu (2000 x 144). Consequently, 1 ton of refrigeration absorbs 288,000 Btu within a 24-hour period or 12,000 Btu/hr (288,000/24). So, 1 ton of refrigeration is defined as the transfer of heat at the rate of 12,000 Btu/hr [3.517 kW].

![Diagram of heat flow](image-url)
Enthalpy ($h$): Energy due to both heat and pressure.

Saturated Liquid: Adding heat to (or dropping the pressure of) a saturated liquid will cause it to boil (begin changing to a vapor)

Saturated Vapor: Removing any heat from a saturated vapor will cause it to begin to condense (change to a liquid)

Latent Heat

The quantity of heat that must be added to the water in order for it to evaporate cannot be sensed by an ordinary thermometer. This is because both the water and steam remain at the same temperature during this phase change.

This kind of heat is called latent heat, which is dormant or concealed heat energy. Latent heat is the energy involved in changing the phase of a substance—from a liquid to a vapor in this example. Or Heat absorbed (or released) when a liquid changes phase without any temperature change.

Sensible Heat

In contrast, sensible heat is heat energy that, when added to or removed from a substance, results in a measurable change in temperature. Refrigerants can absorb a significant amount of heat when they change phase; much more than if they just change temperature. Different substances have different specific temperatures at which these phase changes occur, and different quantities of heat are required for this change to take place. They also have different capacities for absorbing heat. This capacity is a property of the substance called specific heat.

Specific Heat

Suppose equal quantities of two different liquids, A and B, both at room temperature, are heated. The gas burners are lighted and adjusted so that each is burning exactly the same quantity of gas over the same time period, ensuring that each container of liquid receives the same quantity of heat. After a period of time, the thermometer in the container of liquid A indicates 140°F [60°C], while the thermometer in the container of liquid B indicates 200°F [93.3°C]. Even though equal quantities of the two liquids were supplied with exactly the same quantity of heat, why does liquid B reach a higher temperature than liquid A?

The reason is that liquid B has less capacity for absorbing heat than liquid A. This capacity for absorbing heat is called specific heat. The specific heat of a substance is defined as the quantity of heat, in Btus, required to raise the temperature of 1 lb of that substance 1°F.

Similarly, in metric units, specific heat is defined as the quantity of heat, in kJs, required to raise the temperature of 1 kg of that substance 1°C.
whether the refrigerant is a liquid, vapor, or mixture depends on where you are on the "h, h" diagram.

If you know two properties of a substance, you can determine all the other properties.
Refrigeration System

The frozen display case example used in the last period demonstrates that, at a given pressure, refrigerants absorb heat and change phase at a fixed temperature. It also shows how these refrigerants are “consumed” in the cooling process, either melting into a liquid or evaporating into a vapor. This period discusses how the refrigerant can be recovered and reused to continue the refrigeration cycle.

Airflow

A rudimentary refrigeration system could hypothetically be constructed using a drum of liquid refrigerant at atmospheric pressure, a coil, a collecting drum, and a valve to regulate the flow of refrigerant into the coil. Opening the valve allows the liquid refrigerant to flow into the coil by gravity. As warm air is blown over the surface of the coil, the liquid refrigerant inside the coil will absorb heat from the air, eventually causing the refrigerant to boil while the air is cooled. Adjustment of the valve makes it possible to supply just enough liquid refrigerants to the coil so that all the refrigerant evaporates before it reaches the end of the coil. One disadvantage of this system is that after the liquid refrigerant passes through the coil and collects in the drum as a vapor, it cannot be reused. The cost and environmental impacts of chemical refrigerants require the refrigeration process to continue without loss of refrigerant.

Additionally, the boiling temperature of R-22 at atmospheric pressure is -41.4°F [-40.8°C]. At this unnecessarily low temperature, the moisture contained in the air passing through the coil freezes on the coil surface, ultimately blocking it completely.
Refrigeration System

Closing the Cycle
To solve the first problem, a system is needed to collect this used refrigerant and return it to the liquid phase. Then the refrigerant can be passed through the coil again.

This is exactly what happens in a typical mechanical refrigeration system. Liquid refrigerant absorbs heat and evaporates within a device called an evaporator. In this example system, air is cooled when it passes through the evaporator, while the heat is transferred to the refrigerant, causing it to boil and change into a vapor. As discussed in the previous period, a refrigerant can absorb a large amount of heat when it changes phase. Because of the refrigerant changing phase, the system requires far less refrigerant than if the refrigerant was just increasing in temperature. The refrigerant vapor must then be transformed back into a liquid in order to return to the evaporator and repeat the process.
Refrigeration System

The liquid refrigerant absorbed heat from the air while it was inside the evaporator, and was transformed into a vapor in the process of doing useful cooling. Earlier in this clinic, we demonstrated that if the heat is then removed from this vapor, it will transform (condense) back to its original liquid phase. Heat flows from a higher temperature substance to a lower temperature substance. In order to remove heat from the refrigerant vapor, it must transfer this heat to a substance that is at a lower temperature. Assume that the refrigerant evaporated at -41.4°F [-40.8°C]. To condense back into liquid, the refrigerant vapor must transfer heat to a substance that has a temperature less than -41.4°F [-40.8°C]. If a substance were readily available at this cooler temperature, however, the refrigerant would not be required in the first place. The cooler substance could accomplish the cooling by itself. How can heat be removed from this cool refrigerant vapor, to condense it, using a readily available substance that is already too warm for use as the cooling medium? What if we could change the temperature at which the refrigerant vapor condenses back into liquid?
Vapor-Compression Cycle

IDEAL CYCLE
An ideal reversible cycle based on the two temperatures of the system, can be drawn on a temperature–entropy basis.

![Diagram of the vapor-compression cycle](image)

*Figure 2.1 The ideal reversed Carnot cycle: (a) circuit and (b) temperature–entropy diagram*
Evaporator

Condenser

Compressor

Figure 2.4 Pressure–enthalpy, $P-h$ diagram, showing vapour compression cycle
A compressor, condenser, and expansion device form the rest of the system that returns the refrigerant vapor to a low-temperature liquid, which can again be used to produce useful cooling. This cycle is called the vapor-compression refrigeration cycle.

In this cycle, a compressor is used to pump the low-pressure refrigerant vapor from the evaporator and compress it to a higher pressure. This hot, high-pressure refrigerant vapor is then discharged into a condenser. Because heat flows from a substance at a higher temperature to a substance at a lower temperature, heat is transferred from the hot refrigerant vapor to a cooler condensing media, which, in this example, is ambient air. As heat is removed from the refrigerant, it condenses, returning to the liquid phase. This liquid refrigerant is, however, still at a high temperature. Finally, an expansion device is used to create a large pressure drop that lowers the pressure, and correspondingly the temperature, of the liquid refrigerant. The temperature is lowered to a point where it is again cool enough to absorb heat in the evaporator.

**Basic Refrigeration System**

This diagram illustrates a basic vapor-compression refrigeration system that contains the described components. First, notice that this is a closed system. Refrigerant piping connects the individual components. The suction line connects the evaporator to the compressor, the discharge line connects the compressor to the condenser, and the liquid line connects the condenser to the evaporator. The expansion device is located in the liquid line. Recall that the temperature at which refrigerant evaporates and condenses is related to its pressure. Therefore, regulating the pressures throughout this closed system can control the temperatures at which the refrigerant evaporates and then condenses. These pressures are obtained by selecting system components that will produce the desired balance. For example, select a compressor with a pumping rate that matches the rate at which refrigerant vapor is boiled off in the evaporator. Similarly, select a condenser that will condense this volume of refrigerant vapor at the desired temperature and pressure.
Placing each component in its proper sequence within the system, the compressor and expansion device maintain a pressure difference between the high-pressure side of the system (condenser) and the low-pressure side of the system (evaporator).

This pressure difference allows two things to happen simultaneously. The evaporator can be at a pressure and temperature low enough to absorb heat from the air or water to be cooled, and the condenser can be at a temperature high enough to permit heat rejection to ambient air or water that is at normally available temperatures.
THE COMPRESSOR

is one of the four essential components of the compression refrigeration system; the others include the condenser, evaporator, and expansion device. The compressor circulates refrigerant through the system in a continuous cycle. There are two basic types of compressors: positive displacement and dynamic.

Positive-displacement compressors

Increase the pressure of refrigerant vapor by reducing the volume of the compression chamber through work applied to the compressor’s mechanism: reciprocating, rotary (rolling piston, rotary vane, single screw, and twin-screw), scroll. These compressors have the following features:

1. The pressure ratio is high.
2. The capacities are limited

Dynamic compressors

Increase the pressure of refrigerant vapor by a continuous transfer of angular momentum from the rotating member to the vapor followed by the conversion of this momentum into a pressure rise. Centrifugal compressors function based on these principles. These compressors have the following features:

1. The pressure ratio is lower or medium.
2. The capacities are high.

Table (2.1) types and capacity of compressors

<table>
<thead>
<tr>
<th>Compressor type</th>
<th>Rating T.R</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Rolling piston</td>
<td>0.25 - 12</td>
</tr>
<tr>
<td>2 scroll</td>
<td>2.5 - 16</td>
</tr>
<tr>
<td>3 Reciprocating</td>
<td>0.10 - 100</td>
</tr>
<tr>
<td>4 Screw</td>
<td>75 - 450</td>
</tr>
<tr>
<td>5 Centrifugal</td>
<td>325 - 1500</td>
</tr>
</tbody>
</table>
Compressor has two parts:

1. **The motor**: stator and rotor, AC or DC current, the stator consists of start winding and running winding must take care for the type of wire and insulation selection with high resistant to heat and oil. and must be put over load for the high current protection.

2. **The engine**: consist of the; crank, arms, piston, pin beam, cylinder case, valves outlet chamber, inlet chamber, housing, supporting, bearing, oil lubrication, high pressure safety valve.

When the motor and engine be in one container we called it **hermetic or closed type**: no maintenance can be done.

![Figure(2.2) hermetic compressor](image)

And when the motor and engine be in separated container we called it **open type or sime-hermetic**: can do the maintenance.

![Figure(2.3) open type or sime-hermetic compressor](image)
Another kind of classification:

i. Low Back Pressure.
ii. High Back Pressure.

We must study:

1. The parts
2. Type of operation
3. The lubrication method
4. The losses type
5. Control
Single Phase Compressor

Motor Types

Tecumseh hermetic compressors contain motors designed for specific requirements of starting torque and running efficiency. There are four general types of single phase motors, each distinctly different from the others. Each type of motor may have two to four different configurations depending on the compressor components.

A. Resistance Start—Induction Run (RSIR)

This motor, also known as a split-phase motor, is used on many small hermetic compressors up through 1/3 HP. The motor has low starting torque and must be applied to completely self-equalizing capillary tube systems such as household refrigerators, freezers, small water coolers, and dehumidifiers.

This motor has a high resistance start winding which is not designed to remain in the circuit after the motor has come up to speed. A relay is necessary to perform the function of disconnecting the start winding as the motor comes up to design speed.

Three types of relays are used with this motor:

- a current relay,
- a wired-in Positive Temperature Coefficient (PTC) relay, or
- a module Positive Temperature Coefficient (PTC).

![Figure (2.5) RSIR motor diagram with current relay.](image)

![Figure (2.6) RSIR motor diagram with wired-in PTC relay.](image)
B. Capacitor Start—Induction Run (CSIR)
The CSIR motor is similar to RSIR except a start capacitor is included in series with start winding to produce a higher starting torque. This is commonly used on commercial refrigeration systems through 3/4 HP. Two types of relays are used with this motor:
• a current relay, or
• a potential relay.

![CSIR motor diagram](image)

Figure (2.7) CSIR motor diagram.

C. Capacitor Start and Run (CSR)
This motor arrangement uses a start capacitor and a run capacitor in parallel with each other and in series with the motor start winding. This motor has high starting torque, runs efficiently, and is used on many refrigeration and air conditioning applications through 5 HP. A potential relay removes the start capacitor from the circuit after the motor is up to speed. This motor may use either:
• an external thermal protector, or
• an internal thermal protector.

![CSR motor diagram](image)

Figure (2.8) CSR motor diagram.

D. Permanent Split Capacitor (PSC)
Here a run capacitor is in series with the start winding. Both run capacitor and start winding remain in the circuit during start and after motor is up to speed. This normal starting torque motor is sufficient for capillary and other self-equalizing systems. No start capacitor or relay is necessary. For additional starting torque, a proper start assist kit may be added (see Figure 3-6). Some start assist kits may include:
• a wired-in Positive Temperature Coefficient (PTC) relay, or
• a module Positive Temperature Coefficient (PTC) relay.

This motor may use either:
• an external thermal protector, or
PSC motors are basically air conditioning compressor motors and are very common up through 5 HP.

PSC Motor Starting
Products Company has pioneered in encouraging the development of Permanent Split Capacitor compressor motors. This type of motor eliminates the need for potentially troublesome and costly extra electrical components (start capacitors and potential motor starting relays). (See Figure 2-11.)

To fully realize the capabilities of this simplified type of compressor motor, it is necessary to understand its starting and operating characteristics and the field conditions which can affect it. The following conditions affect PSC motor starting:

- **Low voltage**: Reduces motor starting and running torque. A 10% voltage drop reduces a motor’s starting ability by 19%. Low voltage can cause no start; hard start, light flicker, and TV screen flip flop. Minimum starting voltage for the compressor when it is attempting to start (locked rotor) is:
Table (2.2): Minimum Starting Voltage

<table>
<thead>
<tr>
<th>Serial Label Voltage</th>
<th>Min. Voltage for Start</th>
</tr>
</thead>
<tbody>
<tr>
<td>115</td>
<td>103</td>
</tr>
<tr>
<td>208</td>
<td>188</td>
</tr>
<tr>
<td>230</td>
<td>207</td>
</tr>
<tr>
<td>230/208</td>
<td>198</td>
</tr>
<tr>
<td>265</td>
<td>239</td>
</tr>
</tbody>
</table>

Equalized system pressure: Head and suction pressures must be equal and not more than 170 psig. Refrigeration metering device (cap tube or TX valve) should equalize system pressures within 3 minutes. Unequal system pressure may be caused by excessive refrigerant charge, short cycling thermostat, or system restriction.

• **Circuit breaker or fuse trips:** Branch circuit fuses or circuit breakers sized too small will cause nuisance tripping.
• **Electrical components:** A failed run capacitor will not allow the compressor to start, and it will trip the thermal protector.

**Hermetic Compressor Thermal Protectors**

Hermetic compressor motors are protected from overheating by thermal protectors built into or mounted in contact with the compressor motor. The thermal protector device (see Figure 2-12), when firmly attached to the compressor housing, quickly senses any unusual temperature rise or excess current draw. The bi-metal disc within the thermal protector (see Figure 2-13) reacts to either excess temperature and/or excess current draw by flexing downward, and disconnecting the compressor from the power source.

![Figure (2.12) External thermal protector.](image1)

![Figure (2.13) Bi-metal disc.](image2)
Figure (2.14) AE refrigeration compressor showing (1) hermetic terminal, (2) thermal protector, (3) thermal protector clip, (4) push-on relay, (5) protective terminal cover, and (6) bale strap.

Figure (2.15) Refrigeration compressor with the thermal protector and relay assembled.
Compressor Motor Starting Relays
A hermetic motor starting relay is an automatic switching device to disconnect the motor start capacitor and/or start winding after the motor has reached running speed. Never select a replacement relay solely by horsepower or other generalized rating. Select the correct relay from the Electrical Service Parts Guide Book. There are two types of motor starting relays used in refrigeration and air conditioning applications: the current responsive type and the potential (voltage) responsive type.

A. Current Type Relay
When power is applied to a compressor motor, the relay solenoid coil attracts the relay armature upward causing bridging contact and stationary contact to engage. This energizes the motor start winding. When the compressor motor attains running speed, the motor main winding current is such that the relay solenoid coil de-energizes allowing the relay contacts to drop open thereby disconnecting motor start winding. The relay must be mounted in true vertical position so armature and bridging contact will drop free when relay solenoid is de-energized.

B. PTC Type Relay
Solid state technology has made available another type of current sensitive relay—a PTC starting switch. Certain ceramic materials have the unique property of greatly increasing their resistance as they heat up from current passing through them. A PTC solid state starting device is placed in series with the start winding and normally has a very low resistance. Upon startup, as current starts to flow to the start winding, the resistance rapidly rises to a very high value thus reducing the start winding current to a trickle and effectively taking that winding out of operation. Usage is generally limited to domestic refrigeration and freezers. Because it takes 3 to 10 minutes to cool down between operating cycles, it is not feasible for short cycling commercial applications.
C. Potential Type Relay
Generally used with large commercial and air conditioning compressors (capacitor start, capacitor run) to 5 HP. Relay contacts are normally closed. The relay coil is wired across the start winding and senses voltage change. Starting winding voltage increases with motor speed. As the voltage increases to the specific pickup value, the armature pulls up, opening the relay contacts, de-energizing the start winding capacitor. After switching, there is still sufficient voltage induced in the start winding to keep the relay coil energized and the relay starting contacts open. When power is shut off to the motor, the voltage drops to zero, the coil is de-energized, and the start contacts reset. When changing a compressor relay, care should be taken to install the replacement in the same position as the original.

Figure (2.18) Potential type relay.

Table (2.3): Facts about Starting Relays

<table>
<thead>
<tr>
<th>Relay Type</th>
<th>Compressor Motor Type</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current Relay</td>
<td>RSIR and CSIR</td>
<td>• Sense starting current to main (run) windings</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Contacts normally open</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Contacts close and then release in less than 1 second as motor starts</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Must be installed vertically since contacts open by gravity</td>
</tr>
<tr>
<td>PTC Relay</td>
<td>RSIR and PSC</td>
<td>• Sense starting current to start winding</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Solid state device whose resistance increases with heat from current as motor starts</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Takes 3 to 10 minutes to cool down between operating cycles</td>
</tr>
<tr>
<td>Potential Relay</td>
<td>CSR</td>
<td>• Sense voltage generated by start winding</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Contacts normally closed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Contacts open in less than 1 second as motor starts</td>
</tr>
</tbody>
</table>
Selecting Capacitors
Never use a capacitor with a lower voltage rating than that specified. A higher voltage rating than that specified is acceptable.

A. Start Capacitor Bleeder Resistors
Modern high power factor, low current single phase compressor motors which require start and run capacitors used with potential type relays can create electrical circuits which could cause starting relay damage resulting in compressor failure.

The high voltage stored in the start capacitor could discharge across the contacts of the starting relay thus welding them and preventing the relay from functioning. Capacitor failure and/or start winding failure could result. To eliminate this, start capacitors are equipped with bleeder resistors wired across the capacitor terminals. No start capacitor used in conjunction with a potential relay and run capacitor should be installed without such a bleeder resistor.

In an emergency where no bleeder resistor equipped capacitors are available, then a two watt 15,000 ohm resistor can be obtained and soldered across the capacitor terminals.

B. Start Capacitor Substitution
If the specified start capacitor is not available, you may use the next larger sized MFD capacitor at the same or higher voltage rating. Do not add excessive starting capacitance.

C. Run Capacitors
Since January 1979, capacitors provided have contained non-PCB oils or have been constructed using non-PCB impregnated metallized paper electrodes and polypropylene dielectric. These capacitors are protected against case rupture, if failure occurs, by a device within the capacitor can. The operation of this safety device could cause the terminal end to bulge outward 1/2". Suitable head space and/or rubber caps should be provided when installing such capacitors.

In some instances, for reasons of both space and economics, it is advantageous to use two capacitors whose MFD values add up to the total amount specified. In these cases, the capacitors should be connected in parallel. Rated voltage for each should not be less than that specified. The tolerance on a run capacitor is ±10%, and therefore only one rating figure is given. You should not go below this figure on any application. You may exceed this figure by a small amount, and the limits are shown in this table:
Table (2.4): Limits for Run Capacitor Ratings

<table>
<thead>
<tr>
<th>Specific Rating</th>
<th>Maximum Addition</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 to 20 MFD</td>
<td>+ 2 1/2 MFD</td>
</tr>
<tr>
<td>20 to 50 MFD</td>
<td>+ 5 MFD</td>
</tr>
<tr>
<td>Over 50 MFD</td>
<td>+ 10 MFD</td>
</tr>
</tbody>
</table>

Remember the voltage rating of all capacitors must be the same or greater than the original rating. If you do not know the voltage, use 370 volt capacitors on 115 volt units and 440 volt capacitors on 230 volt units.

Table (2.5): Facts About Capacitors

<table>
<thead>
<tr>
<th>Capacitor Type</th>
<th>Compressor Motor Type</th>
<th>Characteristics</th>
</tr>
</thead>
</table>
| Start Capacitor| CSIR and CSR          | Designed to operate for only a few seconds during start  
|                |                       | • Taken out of start winding circuit by relay  
|                |                       | • Excessive start capacitor MFD increases start winding current, increases start winding temperature, and may reduce start torque  
|                |                       | • Capacitors in CSR motors should have 15,000 ohm, 2 watt bleed resistor across terminals  
|                |                       | • Capacitor rated voltage must be equal to or more than that specified  
|                |                       | • Capacitor MFD should not be more than that specified |
| Run Capacitor  | RSIR, CSR, and PSC    | • Permanently connected in series with start winding  
|                |                       | • Excessive MFD increases running current and motor temperature  
|                |                       | • Fused capacitors not recommended for CSR and not required for PSC motors  
|                |                       | • Capacitor rated voltage must be equal to or more than that specified  
|                |                       | • Capacitor MFD should not exceed limits shown in Table 3-8 |
Identification of Terminal Pins:

Figure (2.20) terminal pins of household compressor.