Copeland®
brand products

Refrigeration Manual

Part 5 - Installation and Service

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This is the fifth and last of a series of publications comprising the Emerson Climate Technologies, Inc. Refrigeration Manual.

Part 1 — Fundamentals of Refrigeration
Part 2 — Refrigeration System Components
Part 3 — The Refrigeration Load
Part 4 — System Design
Part 5 — Installation and Service

The installation and service information is intended as a guide to good installation practice, and as an aid in analyzing system malfunctions. The section on service fundamentals is designed to serve as an introduction to various service procedures for beginning service men, students, salesmen, and others, needing a basic understanding of service techniques.

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PART 5
INSTALLATION AND SERVICE

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SECTION 24
INSTALLATION

RECOMMENDED INSTALLATION PROCEDURES

It is quite probable that a majority of operating failures on field installed systems can be traced to careless or inadequate installation procedures. The following instructions have been prepared to help the installation and/or service engineer systematically cover the many points which must be considered to provide each installation with trouble free performance.

These instructions are general in nature, and have been primarily for field installed and connected systems normally utilizing compressors 2 horsepower in size or larger. However, the procedures can be applied to almost any type of field installed system, utilizing only those procedures which apply to the specific installation.

Design and Application

A location for the compressor should be selected which provides good ventilation, even when remote condensers are to be used, since the motor-compressor and discharge lines give off heat. Air cooled compressors must be provided with forced convection air cooling.

Air cooled condensers must be located to insure adequate air for condensing purposes. Care must be taken to avoid recirculation of air from one condenser to another.

Water cooled units must be provided with an adequate supply of water to maintain desired condensing temperatures. In order to avoid concentration of impurities, fungus, and scaling in cooling towers and evaporative condensers, a continuous waste bleed to a drain of approximately 2 gallons per hour per horsepower must be provided so that a continuous addition of fresh make-up water will be required.

Units and compressors must be level to insure proper lubrication.

Refrigerant suction lines must be sized to maintain adequate velocities for proper oil return.

Handling and Receiving of Equipment

Responsibility should be assigned to a dependable individual at the job site to receive material. Each shipment should be carefully checked against the bill of lading. The shipping receipt should not be signed until all items listed on the bill of lading have been accounted for.

Check carefully for concealed damage. Any shortage or damages should be reported to the delivering carrier. Damaged material becomes the delivering carrier's responsibility, and should not be returned to the manufacturer unless prior approval is given to do so.

When uncrating, care should be taken to prevent damage. Heavy equipment should be left on its shipping base until it has been moved to the final location.

The packing list included with each shipment should be carefully checked to determine if all parts and equipment have been received. Any accessories such as starters, contactors or controls should be fastened to the basic unit to avoid loss and prevent possible interchanging with other units.

Installation, Electrical

The supply power, voltage, frequency, and phase must coincide with the compressor nameplate. All wiring should be carefully checked against the manufacturer's diagrams. Field wiring must be connected in accordance with the National Electric Code, or other local codes that may apply.

Check to insure proper:

(a) Wire Sizes to handle the connected load.

(b) Fuses recommended for compressors. (See Emerson Climate Technologies, Inc. Electrical Handbook)

(c) Magnetic starters, contactors, and motor protection devices approved by Emerson Climate Technologies, Inc.

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(d) Operation of oil pressure safety control.

(e) Direction of rotation and speed of fans and/or water pumps.

(f) Wiring with no grounded lines or controls.

Installation, Refrigerant Piping

Take extreme care to keep refrigeration tubing clean and dry prior to installation. The following procedures should be followed:

(a) Do not leave dehydrated compressors filter-driers open to the atmosphere any longer than is absolutely necessary. (One or two minutes maximum suggested.)

(b) Use only refrigeration grade copper tubing, properly sealed against contamination. Water tubing often contains wax and other troublesome contaminants.

(c) Permanent suction line filters and liquid line filter-driers are recommended in all field installed systems.

(d) Suction lines should slope ˚ inch per 10 feet towards the compressor.

(e) Suitable P-type oil traps should be located at the base of each suction riser to enhance oil return to the compressor.

(f) When brazing refrigerant lines, an inert gas should be passed through the line at low pressure to prevent scaling and oxidation inside the tubing. Dry nitrogen is preferred.

(g) Use only a suitable silver solder alloy or 95/5 solder on suction and liquid lines, and a high temperature silver solder alloy only on discharge lines.

(h) In order to avoid damage to the internal joints in vibration eliminators, line connections to vibration eliminators should be made with a silver solder alloy such as Easy-Flo having a melting temperature of 900°F. to 1200°F.

(i) Limit the soldering paste or flux to the minimum required to prevent contamination of the solder joint internally. Flux only the male portion of the connection, never the female. After brazing, remove surplus flux with a damp cloth.

(j) If vibration absorbers are to be installed in suction or discharge lines they must be applied according to the manufacturer's recommendations. With Copelametic® motor-compressors, the preferred position is parallel to the crankshaft, as close to the compressor as possible. Vibration eliminators may be installed in a vertical position if joints are sealed against trapping of condensation which might damage the vibration absorber bellows due to freezing. Filling of the joints with soft solder as a means of sealing is recommended. Installation of the vibration absorber in a horizontal plane at right angles to the crankshaft is not acceptable since the resulting stress from compressor movement may cause failure of the bellows or of the refrigerant line.

(k) Two evacuation valves are necessary. One should be in the suction line and one in the liquid line at or near the receiver.

(l) After all lines are connected, the entire system must be leak tested. The complete system should be pressurized to not more than 175 psig with refrigerant and dry nitrogen (or dry CO_2). The use of an electronic type leak detector is highly recommended because of its greater sensitivity to small leaks. As a further check it is recommended that prior to charging, the system be evacuated to a pressure of 1 PSIA or less, and sealed for 12 hours. Any leakage of air into the system will cause the vacuum reading to decrease. If an air leak is indicated, the system should again be leak tested, and leaks repaired. For a satisfactory installation, the system must be leak tight.

(m) After the final leak test, refrigerant lines exposed to high ambient conditions should be insulated to reduce heat pick-up and prevent the formation of flash gas in the liquid lines. Suction lines should be insulated, if exposed, to prevent condensation.

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Installation, Plumbing

Good practice requires the following:

(a) Lines should be sloped adequately to drain by gravity any water accumulated from condensing, defrosting, or cleaning operations.

(b) All plumbing connections should be made in accordance with local plumbing codes.

(c) Condensate lines from refrigerated fixtures must be trapped and run to an open drain. They must not be connected directly to the sewer system.

IF THE SYSTEM IS WATER-COOLED:

(d) Water pipe sizes should be adequate to provide the required flow at the lowest inlet pressure anticipated.

(e) Control devices such as solenoid valves, modulating valves, or hand valves that could cause hydraulic hammer should be protected by a stand-pipe and air pocket to absorb this shock. Electrical or pressure operated water control valves should be installed between the water supply and the condenser inlet—never between the condenser and the drain. If water supply pressure is excessive, a pressure reducing valve must be used since the allowable working pressure of water valves is normally 150 psig. Pressures above this level can also cause damage to the condenser.

(f) The water pump must be checked for rotation and proper performance.

(g) Check for water leaks.

Evacuation

A good high vacuum pump should be connected to both the low and high side evacuation valves with copper tube or high vacuum hoses (¼" ID minimum). If the compressor has service valves, they should remain closed. A high vacuum gauge capable of registering pressure in microns should be attached to the system for pressure readings.

A shut off valve between the gauge connection and the vacuum pump should be provided to allow the system pressure to be checked after evacuation. Do not turn off vacuum pump when connected to an evacuated system before closing shut off valve.

The vacuum pump should be operated until a pressure of 1,500 microns absolute pressure is reached—at which time the vacuum should be broken with the refrigerant to be used in the system through a drier until the system pressure rises above "0" psig.

Repeat this operation a second time.

Open the compressor service valves (if supplied) and evacuate the entire system to 500 microns absolute pressure.

Raise the pressure to 2 psig with the refrigerant and remove the vacuum pump.

Under no conditions is the motor-compressor to be started or operated while the system is under a high vacuum. To do so may cause serious damage to the motor windings because of the reduced dielectric strength of the atmosphere within the motor chamber.

Check-Out and Start Up

After the installation has been completed, the following points should be covered before the system is placed in operation.

(a) Check electrical connections. Be sure they are all tight.

(b) Observe compressor oil level before start-up. The oil level should be at or slightly above the center of the sight glass. Use only oil approved by Emerson Climate Technologies, Inc.

(c) Remove or loosen shipping retainers under motor-compressors. Make sure hold down nuts on spring mounted compressors are not touching the compressor feet.

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(d) Check high and low pressure controls, water valves, pressure regulating valves, oil pressure safety controls, and all other safety controls, and adjust if necessary.

(e) Check thermostat for normal operation.

(f) Suitable tags or other means should be provided to indicate refrigerant used in the system. Some Copeland® brand condensing unit nameplates have two detachable corner tabs. One should be removed so that the nameplate indicates the refrigerant used.

(g) Wiring diagrams, instruction bulletins, etc., attached to motor-compressors or condensing units should be read and filed for future reference.

(h) Make the proper refrigerant connections and charge the unit with the refrigerant to be used. Weigh the refrigerant drum before charging so an accurate record can be kept of the weight of refrigerant put in the system. If the refrigerant must be added to the system through the suction side of the compressor, charge in vapor form only. Liquid charging must be done in the high side only.

(i) Observe system pressures during charging and initial operation. Do not add oil while the system is short of refrigerant, unless oil level is dangerously low.

(j) Continue charging until system has sufficient refrigerant for proper operation. Do not overcharge. Remember that bubbles in a sight glass may be caused by a restriction as well as a shortage of refrigerant.

(k) Do not leave unit unattended until the system has reached normal operating conditions and the oil charge has been properly adjusted to maintain the oil level at the center of the sight glass.

Operational Check-Out

After the system has been charged and has operated for at least two hours at normal operating conditions without any indication of malfunction, it should be allowed to operate over-night on automatic controls. Then a thorough recheck of the entire system operation should be made as follows:

(a) Check compressor head and suction pressures. If not within system design limits, determine why and take corrective action.

(b) Check liquid line sight glass and expansion valve operation. If there are indications that more refrigerant is required, leak test all connections and system components and repair any leaks before adding refrigerant.

(c) When applicable, observe oil level in compressor crankcase sight glass, and add oil as necessary to bring level to center of the sight glass.

(d) Thermostatic expansion valves must be checked for proper superheat settings. Feeler bulbs must be in positive contact with the suction line. Valves with high superheat settings produce little refrigeration and poor oil return. Too little superheat causes low refrigeration capacity and promotes liquid slugging and compressor bearing washout. Liquid refrigerant must be prevented from reaching the crankcase. If proper control cannot be achieved with the system in normal operation, a suction accumulator must be installed in the suction line just ahead of the compressor to prevent liquid refrigerant from reaching the compressor.

(e) Using suitable instruments, carefully check line voltage and amperage at the compressor terminals. Voltage must be within 10% of that indicated on the compressor nameplate. If high or low voltage is indicated, notify the power company. The current normally should not exceed 120% of the nameplate rating. If amperage draw is excessive, immediately determine the cause and take corrective action. On three phase motor-compressors, check to see that a balanced load is drawn by each phase.

(f) All fan motors on air cooled condensers, evaporators, etc. should be checked for proper

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rotation. Fan motor mounts should be carefully checked for tightness and proper alignment. If belt drives are used, check the belt tension. All motors requiring lubrication should be oiled or greased as necessary.

(g) Check defrost controls for initiation and termination setting, and length of defrost period. Check crankcase heaters if used.

(h) Check winter head pressure controls for pressure setting.

(i) Check crankcase pressure regulating valves, if any, for proper setting.

(j) Adjust water valves on water cooled systems to maintain desired condensing temperatures. Check water pumps for proper rotation.

(k) Install instruction card and control system diagram for use of store manager or owner.

Identification

Each refrigerated fixture and cooler coil should be numbered starting at No. 1. These numbers should be not less than ˚” in height and should be stenciled or marked neatly on the fixture in an inconspicuous location easily available to the serviceman. The compressors or condensing units serving the fixtures should be marked with the numbers of the cases and coils served with figures not less than 1” in height.

Service Record

A permanent data sheet should be prepared on each installation, with a copy for the owner and the original for the installing contractor’s files. If another firm is to handle service and maintenance, additional copies should be prepared as necessary.

The form of the data sheet may vary, but a complete record of sizes and identification of all components used in the installation, together with any pertinent information should be included. Following is a suggested check-off list:

(a) Compressor manufacturer, model, and serial number.

(b) Equipment manufacturer, model, and serial number.

(c) Design operating temperatures.

(d) Condensing unit model, and serial number. (If package condensing unit.)

(e) If remote condenser, type, manufacturer, model, fan data.

(f) Refrigerant and weight of charge.

(g) Electrical service, volts, cycles, phase, wire size.

(h) Control circuit, voltage, fuse size.

(i) Contactor or starter, manufacturer, model, size, part number.

(j) Compressor motor protection, type, size, part number.

(k) Data on capacitors, relays, or other electrical components.

(l) Pressure control, type, size, model number, setting.

(m) Oil pressure safety control, type, model number.

(n) Defrost control, type, manufacturer, model number, setting.

(o) Data on miscellaneous refrigeration components such as pressure controls, winterizing controls, oil separators, crankcase heaters, solenoids, valves, etc.

(p) Liquid line drier, manufacturer, size, model number, connections.

(q) Schematic diagram of refrigerant piping.

(r) Final settings on all pressure, regulating, and safety controls.

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FUNDAMENTALS OF EVACUATION AND DEHYDRATION

Although millions of dollars have been spent on refrigeration research, many of the reactions inside air conditioning and refrigeration systems are still a mystery. We do know that the presence of moisture, heat, and oxygen under certain conditions can result in many forms of system damage. Corrosion, sludging, copper plating, oil breakdown, carbon formation, and eventual compressor failure can be caused by these contaminants.

The absence of any one of the three, or its reduction to an acceptable level can greatly extend compressor life and slow down harmful reactions. If all three can be controlled, then a sound foundation has been made for a trouble free installation.

Copeland® brand compressors are carefully tested to determine limits within which operation is possible without creating excessive heat in the compressor. But under the best operating conditions, heat is going to be produced as a natural consequence of compression of the refrigerant gas. Discharge temperatures in excess of 200°F. are unavoidable. Therefore, major efforts must be directed at preventing moisture and air from entering the system.

Moisture In A Refrigeration System

Moisture exists in three forms; as a solid when it is frozen into ice, as liquid water, and as a vapor or gas. It is extremely rare that moisture will enter a refrigeration system in the form of ice or water. It is the invisible water vapor that exists in the air around us that creates the real hazard.

The ability of air to hold water vapor increases with the temperature of the air. On a hot, humid summer day, the air may be actually loaded with moisture. Relative humidity is the term commonly used to express the percentage of saturation, that is, the existing moisture content of the air expressed as a percentage of the maximum moisture that the air could contain at a given temperature.

The relative humidity determines the dew point, or the temperature at which moisture will condense out of the air. Condensation occurs on the outside of a cold glass of water in a warm room, and it can occur in exactly the same fashion inside a cold evaporator which has been opened and exposed to the atmosphere.

Despite the fact that water vapor exists as part of the air around us, it acts quite independently of the air. Vapor pressure is independent of air pressure, and its speed of movement is astonishing. This means that water vapor cannot be stopped by air movement.

Obviously it is impossible to prevent water vapor from entering the system anytime it is opened to the atmosphere. However, if the temperature of the exposed part of the system is above the dew point, or if the time of exposure is short, the amount of moisture actually entering the system will be small. If a new drier is installed in the liquid line each time the system is opened for maintenance, the drier will normally have sufficient capacity to lower the moisture in the system to a safe level.

However, at the time of original installation, or after exposure for long periods during maintenance, the amount of moisture in the system may be greater than a drier's effective capacity. In such cases, evacuation is the only effective means of removing large quantities of moisture from the system, and to successfully dehydrate a system by evacuation, pressures within the system must be reduced to levels which will cause the trapped moisture to vaporize.

Air In A Refrigeration System

The air we breathe is primarily composed of nitrogen and oxygen. Both elements remain in a gaseous form at all temperatures and pressures encountered in commercial refrigeration and air conditioning systems. Therefore, although these gases can be liquefied under extremely low temperatures, they may be considered as non-condensable in a refrigeration system.

Scientists have discovered that one of the basic laws of nature is the fact that in a combination of gases, each gas exerts its own pressure independently of others, and the total pressure existing in a system is the total of all the gaseous pressures present. A second basic characteristic of a gas is that if the space in which it is enclosed remains

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constant, so that it cannot expand, its pressure will vary directly with the temperature. Therefore, if air is sealed in a system with refrigerant, the nitrogen and oxygen will each add their pressure to the system pressure, and this will increase as the temperature rises.

Since the air is non-condensable, it will usually trap in the top of the condenser and the receiver. During operation the compressor discharge pressure will be a combination of the refrigerant condensing pressure plus the pressure exerted by the nitrogen and oxygen. The amount of pressure above normal condensing pressures that may result will depend on the amount of trapped air, but it can easily reach 40 to 50 psig or more. Any time a system is running with abnormally high head pressure, air in the system is a prime suspect.

Nitrogen is basically an inert gas and does not easily enter into chemical reactions. Oxygen, however, is just the reverse, and at the slightest opportunity will combine with other elements. Rust, corrosion, and burning are all common oxidation processes.

In the refrigeration system, oxygen and moisture quickly join in a common attack on the refrigerant and oil, and can cause corrosion, copper plating, acid formation, sludging, and other harmful reactions. Tests have shown that in the presence of heat, the combination of air and moisture is far more apt to cause breakdown of the refrigerant and oil mixture than greatly increased amounts of moisture alone.

Pressure - Temperature - Evaporating Relationships

Anyone familiar with refrigeration knows that refrigerants follow a definite fixed pressure-temperature relationship, and that at a given pressure the refrigerant will boil or vaporize at a corresponding saturation temperature. Water follows exactly the same pattern, and this is the basis for dehydration by evacuation.

The pressure which determines the boiling points of refrigerants and water is absolute pressure, normally expressed in terms of psia, which is defined as the pressure existing above a perfect vacuum.

The atmosphere surrounding the Earth is composed of gases, primarily oxygen and nitrogen, extending many miles above the surface of the Earth. The weight of that atmosphere pressing down on the Earth creates the atmospheric pressure we live in. At a given point, the atmospheric pressure is relatively constant except for minor changes due to changing weather conditions. For purposes of standardization and as a basic reference for comparison, the atmospheric pressure at sea level has been universally accepted, and this has been established at 14.7 pounds per square inch, which is equivalent to the pressure exerted by a column of mercury 29.92 inches high.

At very low pressures, it is necessary to use a smaller unit of measurement since even inches of mercury are too large for accurate reading. The micron, a metric unit of length, is commonly used for this purpose, and when we speak of microns in evacuation, we are referring to absolute pressure in units of microns of mercury. Relationships of the various units of measurement are as follows:

1 pound per sq. in.	= 2.03 inches mercury
1 inch mercury	= .491 pounds per sq. in.
1 inch mercury	= 25,400 microns mercury
1 inch	= 25,400 microns
1 millimeter	= 1,000 microns
1 micron	= .001 millimeter

The refrigeration serviceman's bourdon tube gauge reads 0 pounds per square inch when not connected to a pressure producing source. Therefore the standard relationship has been established that absolute pressure is equal to gauge pressure plus 14.7 psi. Pressures below 0 psig are actually negative readings on the gauge, and are referred to as inches of vacuum. The gauge is calibrated in the equivalent of inches of mercury.

Factors Affecting Vacuum Pump Performance

A vacuum pump suitable for refrigeration work must not only be capable of pulling a high vacuum, but must be capable of maintaining that vacuum on the system for prolonged periods. As moist air is pumped through the vacuum pump, the moisture will seek to condense in the vacuum pump oil sump, and once the oil is saturated, water vapor

(continued on p. 24-9)

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Table 49

BOILING POINT OF WATER AT VARYING PRESSURES

Absolute Pressure			Boiling Point Of Water	Corresponding Gauge Pressure At Sea Level		Absolute Pressure			Boiling Point Of Water	Corresponding Gauge Pressure At Sea Level	
PSIA	In. Hg	Microns Hg		PSIG	In. Vac.	PSIA	In. Hg	Microns Hg		PSIG	In. Vac.
14.7	29.92	759,968	212° F.	0	0	.30	.62	15,748	65° F.	-	29.3
12.24	24.92	632,968	203° F.	-	5	.26	.52	13,208	60° F.	-	29.4
9.78	19.92	505,968	192° F.	-	10	.21	.42	10,668	54° F.	-	29.5
7.33	14.92	378,968	179° F.	-	15	.16	.32	8,128	47° F.	-	29.6
4.88	9.92	251,968	161° F.	-	20	.11	.22	5,588	37° F.	-	29.7
2.41	4.92	124,968	133° F.	-	25	.06	.12	3,048	23° F.	-	29.8
.95	1.92	48,768	100° F.	-	28	.04	.08	2,000	15° F.	-	29.84
.45	.92	23,368	77° F.	-	29	.03	.06	1,500	9° F.	-	29.86
.41	.82	20,828	74° F.	-	29.1	.02	.04	1,000	1° F.	-	29.88
.35	.72	18,288	69° F.	-	29.2	.01	.02	500	-12° F.	-	29.90

The above table clearly illustrates the reduction of the boiling point of water with a reduction of pressure. It is clear that at normal room temperatures, dehydration by evacuation requires pressures below 0.40 psia, which means a corresponding vacuum reading at sea level of 29.2 inches of mercury. At pressures above that, boiling simply would not take place. From a practical standpoint, much lower pressures are necessary to create a temperature difference to the boiling water so that heat transfer can take place, and also to offset pressure drop in the connecting lines, which is extremely critical at very low pressures. Pressures from 1,500 to 2,000 microns are required for effective dehydration, and equipment to accomplish this is normally described as being designed for high vacuum work. Heat should be applied to systems which are known to contain free water to aid in evacuation.

Table 50

COMPARISON OF GAUGE AND ABSOLUTE PRESSURES AT VARYING ALTITUDES

Altitude	PSIG	PSIA	Pressure In Inches Hg	Boiling Point Of Water	Refrigerant Boiling Points		
					R-12	R-22	R-502
0 ft.	0	14.7	29.92	212° F.	-22° F.	-41° F.	-50° F.
1000 ft.	0	14.2	28.85	210° F.	-23° F.	-43° F.	-51° F.
2000 ft.	0	13.7	27.82	208° F.	-25° F.	-44° F.	-53° F.
3000 ft.	0	13.2	26.81	206° F.	-26° F.	-45° F.	-54° F.
4000 ft.	0	12.7	25.84	205° F.	-28° F.	-47° F.	-56° F.
5000 ft.	0	12.2	24.89	203° F.	-29° F.	-48° F.	-57° F.

It is important to remember that gauge pressures are only relative to absolute pressure. The table shows relationships existing at various elevations assuming that standard atmospheric conditions prevail. Obviously, a given gauge pressure at varying elevations may actually reflect a wide variation in actual absolute pressures.

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escaping from the oil may prevent the pump from achieving a high vacuum. Unless the pump is specifically designed to prevent this condition, the oil may become saturated before one evacuation job is completed.

In order to prevent condensation, some vacuum pumps have a vented exhaust or gas ballast feature. Basically this involves allowing a small bleed of atmospheric air to enter the second stage of a two stage pump, or the discharge chamber of a single stage pump prior to the discharge stroke to prevent condensation of water during compression.

Since reciprocating pumps lose efficiency at vacuums greater than 27 inches of mercury, rotary pumps are primarily used for high vacuum work. Single stage vacuum pumps are available which are capable of pulling a very high vacuum, but in general they are vulnerable to oil contamination, and if the exhaust is vented to protect the oil, then the pump's efficiency is reduced. Although single stage pumps may be quite satisfactory for small systems, for best high vacuum performance in refrigeration usage a two stage vacuum pump with gas ballast on the second stage is recommended.

Even at extremely low pressures, it is essential that the system to be evacuated is at a temperature high enough to insure boiling of any water to be removed. With pressures of 2000 microns and below, normal room temperatures of 70°F. to 80°F. are adequate. Evacuation of temperatures below 50°F. is not recommended.

If a great deal of moisture must be removed from a system by the vacuum pump, the oil may become saturated with moisture despite the gas ballast feature or the best pump design. Once this has occurred, the only solution is to change the oil in the vacuum pump. Even with the best vacuum pump, frequent oil changes are necessary to maintain efficiency. It is recommended that the oil be changed before each major evacuation.

If there is any possibility that large amounts of water may be trapped in a system, the lines should be blown out with dry nitrogen prior to attaching the vacuum pump. This will not only aid in prolonging the life of the pump, it will materially decrease the time required to evacuate the system. If it is known that a system is saturated with water, for example after the rupture of tubes in a water cooled condenser, a special low temperature moisture trap should be installed in the suction line ahead of the vacuum pump intake. Suitable traps are available from vacuum pump manufacturers.

One factor that is not fully appreciated by most servicemen is the critical nature of the pressure drop that occurs due to restrictions in the line during evacuation. For field evacuation with portable vacuum pumps, lines connecting the vacuum pump to the system should be a minimum of ¼ in. I.D. on small systems, and on larger systems at least ½ in. I.D. copper tubing should be used. Evacuating valves are recommended for every system. These should be installed in both the suction and liquid lines, and should be at least as large as the connecting lines. The typical serviceman's manifold and charging hose will cause sufficient restriction to prevent a high vacuum being reached, and compressor service valves are also unsatisfactory for high vacuum work. If restrictions exist in the connecting lines, gauges at the vacuum pump will reflect pump pressure, but will not give a true picture of pressures in the system.

The speed with which a system may be evacuated depends on both the displacement of the vacuum pump and the size of the connecting lines and fittings. A good high vacuum pump has a very high pumping efficiency down to absolute pressures of 1,000 microns and below, possibly as high as 85% to 90% or more. This means that a vacuum pump with 1 CFM displacement may still be capable of pumping up to .9 CFM with a suction pressure of 1,000 microns and discharging to atmosphere.

However, a vacuum pump's performance can be greatly reduced by the size of connecting lines and fittings. In the low or medium vacuum range, this may not greatly affect a pump's efficiency, but at pressures below 5,000 microns the pump's net capacity can decrease rapidly. The following comparison is based on one pump manufacturer's catalog information on pumping speed of rotary vacuum pumps.

It is interesting to note that more efficiency can be gained by increasing the connecting line size on a 1 CFM pump from ¼ in. I.D. to a larger size than

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Basic Pumping Speed with no restriction on inlet	Net Pumping Speed with 6 foot connection		
	¼" I.D.	⅜" I.D.	½" I.D.
Inlet pressure, 2,000 microns			
1 CFM	.37 CFM	.74 CFM	.93 CFM
2 CFM	.46 CFM	1.18 CFM	1.75 CFM
5 CFM	.54 CFM	1.84 CFM	3.7 CFM
Inlet pressure, 1,000 microns			
1 CFM	.23 CFM	.60 CFM	.87 CFM
2 CFM	.26 CFM	.83 CFM	1.5 CFM
5 CFM	.29 CFM	1.11 CFM	2.95 CFM

can be gained by putting a 5 CFM pump on the same ¼ in. connection.

Calculations to determine pull down time are quite complicated, since the pump's efficiency changes with the reduced pressure, and the size and length of the connecting lines may greatly affect the performance of a given pump. The following estimate of pull down time is based on one manufacturer's catalog data, but because of the assumptions that must be made in the calculation, the figures are at best an approximation.

The above table provides a good comparison of relative pump performance. It is quite clear that if a connecting line no larger than ¼ in. I.D. is to be used, there is little to be gained by going to a larger vacuum pump. For large systems it is obvious that both a good sized vacuum pump and a large connecting line are necessary if the required time is to be held to a minimum. The pull down time will vary directly with the internal volume of a given system, so for smaller systems the 1 CFM pump may be perfectly satisfactory.

ESTIMATED TIME REQUIRED FOR SYSTEM PULL DOWN

based on 5 cubic feet internal volume

Pump Displ.	Conn. Line (6')	Final absolute pressure	
		1,500 microns	500 microns
1 CFM	¼" I.D.	57 min.	78 min.
2 CFM	¼" I.D.	39 min.	56 min.
5 CFM	¼" I.D.	28 min.	43 min.
1 CFM	⅜" I.D.	40 min.	51 min.
2 CFM	⅜" I.D.	22 min.	29 min.
5 CFM	⅜" I.D.	12 min.	16 min.
1 CFM	½" I.D.	37 min.	45 min.
2 CFM	½" I.D.	19 min.	23 min.
5 CFM	½" I.D.	8 min.	10 min.

Measurement of Vacuum

As indicated earlier, the refrigeration serviceman's gauge reads pressure only in relation to absolute pressure, and a given gauge reading may cover a wide range of actual pressures. For this reason, and also because the ordinary bourdon tube compound gauge is not designed for the extreme accuracy required in evacuation work, a special vacuum gauge is required for high vacuum readings.

For accurate pressure readings in the micron range for refrigeration use, a thermocouple vacuum gauge is recommended. This type of gauge is relatively inexpensive, easy to operate, rugged enough for field use, and requires little or no maintenance. The advantage of this gauge where moisture may be encountered in a system is that it measures not only the pressure due to residual gases, but also the pressure contributed by any water vapor remaining in the system. The McLeod type gauge is widely used in laboratory work, and is highly accurate for readings where moisture is not a factor, but it is not recommended for use in refrigeration work since it will not measure the pressure due to water vapor.

Triple Evacuation

In order to insure a complete evacuation, Emerson Climate Technologies, Inc. recommends a triple evacuation, twice to 1,500 microns and the final time to 500 microns. The vacuum should be broken to 2 psig each time with the same type of refrigerant to be used in the system.

It is quite possible that the original evacuation, if not continued for a sufficient period of time may not completely remove all of the air and moisture from the system. Breaking the initial vacuum with dry refrigerant allows the fresh refrigerant to absorb and mix with any residual moisture and air, and the succeeding evacuation will remove a major portion of any remaining contaminants. If for example, each evacuation removed only 98% of the contents of the system, and any remaining contaminants mixed thoroughly with the refrigerant used to break the vacuum, after the triple evacuation the remaining contaminant percentage would be 2%

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x 2% x 2% or .0008%. The residual contaminants have been reduced to such a low level they no longer are a danger to the system. This illustrates why triple evacuation is increasingly important if the vacuum pump is not of the highest efficiency, or if the evacuation time is not adequate to insure complete evacuation.

Many manufacturers use process pressures of 50 to 100 microns. However, in field evacuation, pressures in this range are very difficult to reach, particularly if refrigerant has been allowed to mix with oil in the system. The refrigerant will escape from the oil very slowly, and the time required to reach such low pressures might be quite unreasonable. The triple evacuation method to a pressure of 500 microns is practical under field conditions, and represents a specification that can be met.

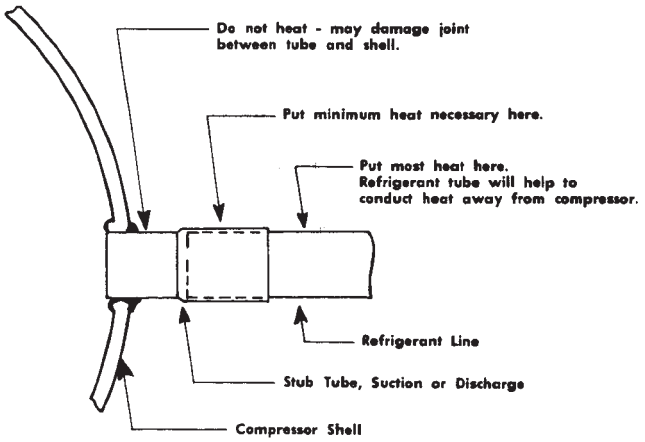
For manufacturers having process equipment, the use of dry air with a dew point below -60°F. in place of refrigerant for dehydration in connection with a triple evacuation to the pressures described above is also highly recommended.

To evacuate a system properly requires time and care. Any slight carelessness in protecting the sealed system can undo all the precautions taken previously. But the slight extra effort required to make an evacuation properly and completely will pay big dividends in reduced maintenance and trouble free operation.

BRAZING CONNECTIONS ON WELDED MOTOR-COMPRESSORS

Suction and discharge line connections to welded motor-compressors are normally made by brazing the refrigerant lines directly into stub tubes on the compressor with a silver brazing alloy. Occasionally the joint between the stub tube and the steel shell is damaged by overheating during factory or field installation when the refrigerant line connections are made. This type of damage can be avoided by proper care during the brazing operation.

The connection between the stub tube and the shell is made with a 35% silver brazing alloy which has a melting range of 1125°F. to 1295°F. The temperature of this joint must be kept below this range during the line brazing operation to avoid damage.



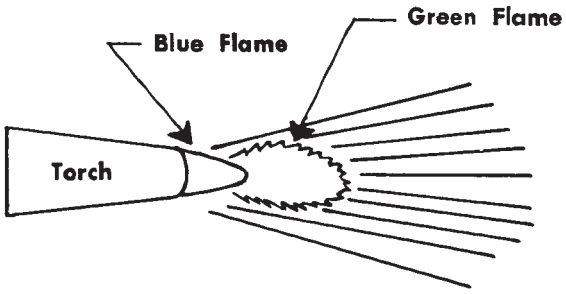
TYPICAL BRAZED CONNECTION TO COMPRESSOR STUB TUBE

Figure 111

Figure 111 illustrates a typical suction line connection. The torch flame should be used primarily on the refrigerant line, with only enough heat applied to the stub tube to make the connection properly. Heat will be conducted into the joint area from the refrigerant line. The torch fame should have a greenish “feather” extending from the tip of the inner blue cone as illustrated in Figure 112. Heat should be applied to both sides of the tube, and the flame should be moved continuously in a circular motion to distribute the heat, and prevent overheating of the tubing. Compressors with damaged joints usually show evidence of the torch flame having been allowed to burn directly on the compressor shell and the stub tube-shell joint.

Emerson Climate Technologies, Inc. recommends that a low melting point alloy such as Easy-Flo or Easy-Flo 45 be used in making the line joint rather than a higher melting point alloy such as Sil-Fos. The heat necessary to make a Sil-Fos joint is somewhat greater than required for Easy-Flo, making it more difficult to avoid overheating. Another advantage of a lower temperature brazing alloy is the reduced annealing effect which takes the place, thus resulting in a stronger joint.

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RECOMMENDED BRAZING FLAME

Figure 112

To assure a sound, leak tight tubing connection without overheating, the surfaces must be properly cleaned and a suitable flux must be used. A low temperature brazing flux that is fully liquid and active below the flow point of the silver brazing alloy is required. Only the male connection should be fluxed, and only enough flux should be used to adequately cover the surface. Excess flux allowed to enter the system can cause starting failures on PSC motors, plug filters and valves, and may cause other complications due to chemical reactions.

INSTALLATION OF SUCTION AND DISCHARGE LINE VIBRATION ABSORBERS

In order to prevent the transmission of noise and vibration from the compressor through the refrigeration piping, vibration eliminators are often required in the suction and discharge lines. On small units where small diameter soft copper tubing is used for the refrigerant lines, a coil of tubing may provide adequate protection against vibration. On larger units, flexible metallic hose is frequently used.

Metallic vibration absorbers should be selected to have the same or greater internal diameter than the connecting piping. Because of the convolutions of the inner wall of the absorber, excessive refrigerant gas velocity can cause whistling and noise problems.

Unless properly installed, stress resulting from line movement may cause failure of the vibration absorber, and possibly can lead to line breakage. Because of its construction, a metallic vibration absorber can easily adjust to movement in a radial direction, but it must not be subjected to stress in either compression or extension. Some manufacturers recommend using two vibration absorbers at right angles, but normally this is not necessary on Copeland® brand compressors.

Emerson Climate Technologies, Inc. recommends installation parallel to the crankshaft, as close to the compressor as possible. The starting torque of the motor will tend to rock the compressor from side to side when starting, and mounting parallel to the crankshaft will allow the absorber to easily adjust to the movement.

Vibration absorbers may be installed in a vertical position if the joints are sealed against trapping of condensation which might damage the bellows due to freezing. Filling of the joints with soft solder as a means of sealing is recommended. Flexible metal hoses are available with a neoprene jacket which protects the absorber against any possible damage from condensation or moisture.

Table 51

MELTING POINTS OF TYPICAL COMMERCIAL BRAZING COMPOUNDS

Type	Typical Commercial Description	Silver Content	Starts To Flow	Free Flowing At
Silver Solder	Easy-Flo, Unibraze 50	50%	1160	1175
Silver Solder	Easy-Flo 45, Unibraze 45	45%	1125	1145
Silver Solder	Easy-Flo 35, Unibraze 35	35%	1125	1295
Phosphor-Copper-Silver	Sil-Fos, Unibraze 15	15%	1185	1300 - 1460
Phosphor-Copper-Silver	Sil-Fos, Unibraze 5	5%	1185	1300 - 1485
Phosphor-Copper	Phos-Copper, Unibraze 0	—	1300	1450

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Installation of an angle 45° from the vertical and parallel to the crankshaft is acceptable, although horizontal or vertical installation is preferred. A 45° angle installation at right angles to the compressor crankshaft can actually act as a brace, causing compression stress, and is not acceptable.

Installation in the horizontal plane at right angles to the crankshaft is not acceptable, since compressor movement would tend to either compress or extend the absorber, and early failure of the absorber or connecting fittings could result.

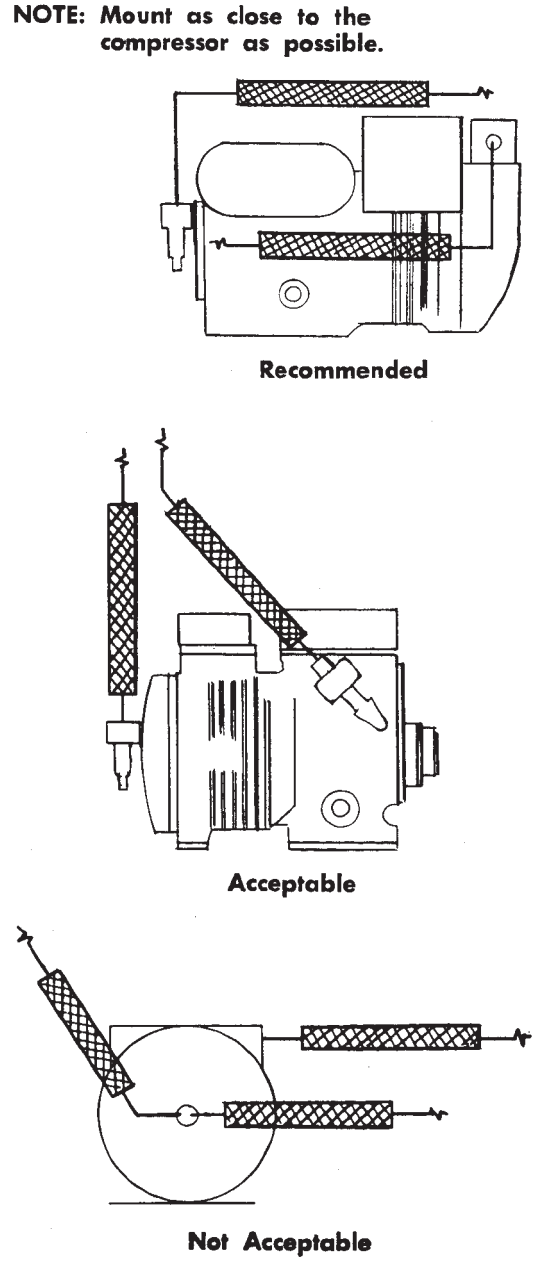
The line connected to the end of the absorber opposite the source of vibration should be firmly anchored to a solid member. No movement will then be transmitted into the refrigerant lines beyond. Where a vertical or 45° mounting is used, the piping must be arranged so that sufficient allowance for movement is made. As a convenient means of checking the installation, a spring mounted compressor should be free to bottom solidly on the mounting pad or mounting snubber without stressing the absorber. The refrigerant lines should be in proper alignment prior to installation of the absorber, and sufficient space should be allowed so that it can be installed without being either stressed or compressed.

Internal joints of metallic vibration absorbers are often made up with a brazing compound which has a melting point of approximately 1,300°F. In order to avoid damage to the internal joints, line connections should be made with a silver solder alloy having a melting temperature below 1,200°F.

TYPICAL INSTALLATION SPECIFICATIONS

On large field installed refrigeration and air conditioning systems, it is advisable to have a written specification covering the work to be done and the responsibilities of each party. The specification is an aid in assuring a clear understanding of the contractor's responsibility prior to the start of the job, so that disputes and disagreements may be eliminated.

Specifications may vary from a short paragraph covering the scope of the work to a detailed description of the work to be done. The following specification is typical of the type frequently used on supermarket or other large commercial refrigeration installations, and is readily adaptable to different types of applications.



INSTALLATION OF VIBRATION ABSORBERS

Figure 113

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Typical Specification

Large Commercial Refrigeration and Air Conditioning Installation

1. Definition of Terms

   1.1 "Contractor" shall mean the refrigeration installation contractor.

   1.2 "Owner" is _____.

   1.3 "Manufacturer" shall mean the company or companies which will supply various equipment such as fixtures, compressors, coils, etc.

   1.4 "Refrigeration Installation" shall mean the necessary labor and all parts and accessories necessary to complete the work outline in this specification.

2. Scope of Work

   2.1 These specifications are intended to cover the installation of compressors, condensers, coils, condensing units, fixtures, and all other fittings, devices, and accessories required to complete the refrigeration systems as shown or called for on the refrigeration plans and schedules. The omission from these specifications or from the refrigeration plans and schedules of express reference to any parts necessary for the complete installation is not to be construed as releasing the contractor from responsibility for furnishing such parts.

   2.2 For details of installation refer to the fixture plan, refrigeration schedule, floor plan, plumbing plan, electric plan, air conditioning, heating, and ventilating plan, manufacturer's installation instructions, and to applicable codes and ordinances.

   2.3 The Contractor shall furnish and install any necessary refrigerant piping, fittings, vibration eliminators, line valves, solenoid valves, crankcase pressure regulating valves, thermostatic expansion valves, dehydrators, strainers, sight glasses, moisture indicators, refrigerant, oil, filters, insulation and all fittings and accessories necessary to make a complete installation unless otherwise specified, together with all labor required to complete the installation and perform the service covered by this specification. The Contractor is responsible for unloading, assembling, and installing all fixtures, coolers, coils, compressors, condensing units, air conditioners, condensers, and other refrigeration equipment unless otherwise specified. The Contractor shall also arrange for the removal of crating and packing materials, and shall leave the uncrating area and the compressor room clean and neat.

   2.4 The Contractor shall familiarize himself with the project, and shall cooperate with other contractors doing work on the building. If any conflict, interference, or discrepancies come to the attention of the contractor, he shall notify the owner immediately before proceeding any further with the installation.

   2.5 No additional payment over and above the contract price will be made unless the Contractor receives a written order by the Owner or his representative for the addition.

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2.6 Equipment and services shall be furnished as follows:

	To Be Furnished By		
	Owner	Contractor	Others
Refrigerated fixtures			
Coils for coolers			
Air conditioning units			
Air conditioning temperature controls			
Air cooled condensers			
Compressors			
Condensing units			
Refrigeration system controls			
Coolers & freezers (walk in)			
Coolers & freezers (reach in)			
Ventilation and exhaust fans and controls			
Cooling tower and controls			
Plumbing			
Sheet metal, duct work, dampers, etc.			
Motor starters and protectors			
Electrical wiring, disconnect switches and connections			

3. Fees, Permits, Licenses, and Insurance

3.1 All necessary permits and licenses incident to the work and required by local ordinance shall be secured and paid for by the contractor. All equipment shall be installed in strict compliance with all local building codes and ordinances.

3.2 The Contractor shall not commence work under this contract until he has obtained all the insurance required hereunder, and has filed certificates to that effect with the Owner. The Contractor shall indemnify and hold harmless the Owner for any and all claims, suits, losses, damages, or expenses on account of bodily injury, sickness, disease, death, and property damage as a result of the Contractor's operations, acts, omissions, neglect or misconduct in connection with this project. Insurance coverage shall include but is not limited to

(a) Contractor's Public Liability Insurance
(b) Contractor's Contingent Liability Insurance
(c) Property Damage Insurance
(d) Automotive Public Liability Insurance
(e) Automotive Property Damage Insurance

4. Refrigerant Piping Materials

4.1 Unless otherwise specified, all refrigeration piping shall be refrigeration grade Type L or Type K hard drawn degreased sealed copper tubing. Alternate proposals may be submitted for the use of Type L refrigeration grade soft copper tubing for long underfloor runs only providing runs are straight and free from kinks and bends.

4.2 Extreme care shall be taken to keep all refrigerant piping clean and dry. It shall be kept sealed except when cutting or fabricating. Each length shall be inspected and swabbed with a cloth soaked in refrigeration oil if any dirt, filings, or visible moisture are present.

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4.3 All sweat-type fittings shall be wrought copper or forged brass. All elbows and return bends shall be of the long radius type. If flare fittings are required, they shall be of the frost proof type, (except on connections not subject to condensation), and constructed of forged brass. Soldered joints are preferred and shall be used wherever practical.

5. Refrigerant Piping Installation

5.1 Tubing shall be installed in a neat, workmanlike manner with horizontal runs sloped toward the compressor at a rate of 1" per 20'. All lines shall be supported at intervals of not more than 8' and suitably anchored. Rubber grommets shall be used between tubing and clamps to prevent line chafing.

5.2 Where vertical risers of more than 5 feet occur in a suction line, the riser shall be trapped at the bottom.

5.3 Where a branch suction line enters a main suction line it shall enter at the top. Piping shall be arranged so refrigerant or oil cannot drain from the suction line into the coil.

5.4 Individual fixture or unit suction and liquid lines shall be of the size recommended by the Manufacturer as shown in the applicable installation and service instructions. Liquid and hot gas refrigerant lines shall be sized in accordance with good industry practice to avoid excessive pressure drops. Branch and main suction lines shall be sized to maintain adequate velocities to properly return oil to the compressor under minimum load conditions at the lowest saturated suction pressure to be expected.

5.5 All joints in the compressor discharge line shall be brazed with a suitable high temperature silver solder alloy containing not less than 15% silver. Use only a suitable silver solder alloy on all copper to copper connections in the suction line and liquid line. At any copper to brass joint where damage could occur from excess heat use 95/5 solder. Use a solder with at least 35% silver content on all copper to steel, brass to steel, or steel to steel joints. During the brazing operation, dry nitrogen must be bled through the piping at very low pressure to prevent oxidation and scaling.

5.6 In order to avoid damage to the internal Silfos joints in vibration eliminators, line connections to vibration eliminators are to be made with a silver solder alloy such as Easy-Flo having a melting temperature of 900°F. to 1,200°F. (well below the 1,300°F. melting point of Silfos).

5.7 To prevent contamination of the line internally, limit the soldering paste or flux to the minimum required. Flux only the male portion of the connection, never the female.

5.8 Suction lines from low temperature cases shall be insulated where run below the floor level. All exposed suction lines, both low and medium temperature, shall be insulated as necessary to prevent condensation.

5.9 Insulation shall be of the cellular type such as Armstrong "Armaflex" or equal, shall fit the tubing snugly, and shall be applied and sealed in accordance with the Manufacturer's instructions.

5.10 The refrigerant piping shall be adequately protected. Permanent guards shall be installed as required to protect the piping and fittings from damage. Metal pipe sleeves shall be provided where tubing passes through a concrete wall or floor, and the space around the tubing shall be filled with a mastic insulating compound.

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5.11 Arrange the piping so that normal inspection and servicing of the compressor and other equipment is not hindered. Do not obstruct the view of the crankcase oil sight glass, or run piping so that it interferes with removal of the compressor or other components.

5.12 Tubing installed in trenches or conduit under the floor must be level to prevent oil trapping. Guard against deformation or damage from trucks carrying heavy loads, or cement being poured.

6. Installation of Accessories

6.1 Vibration eliminators shall be installed in the suction and discharge lines of all compressors with spring or flexible mounting. The vibration eliminator must be applied according to the Manufacturer's recommendations. For Copelametic® compressors, the vibration eliminator should be mounted parallel to the crankshaft, as close to the compressor as possible. Installation in a horizontal plane at right angles to the crankshaft is not acceptable, since the resulting stress from compressor movement may cause failure of the vibration absorber. If installed in a vertical position, the eliminator joints must be sealed against dripping from condensation to protect from freezing.

6.2 A solder type combination liquid sight glass and moisture indicator shall be installed in each system and located for easy visibility.

6.3 If liquid line driers are not otherwise specified, they shall be of the filter-drier type, and of the size recommended by the Manufacturer. Drier cartridges shall not be installed until the second evacuation has been completed.

6.4 Two evacuation fittings are necessary. One should be in the suction line at the inlet side of the suction line filter, and one should be in the liquid line at the outlet side of the filter-drier. If properly valved, the connection in the liquid line may serve as a charging valve. After evacuation and charging, the fittings are to be capped or removed. Connections should be at least $^{3}/_{8}$" and preferably ˚" in size.

6.5 A permanent suction line filter shall be installed in each compressor suction line. A pressure fitting must be provided ahead of the filter, preferably in the shell, to facilitate checking the pressure drop. If the pressure drop across the filter is in excess of 1 psig after the initial 24 hours of operation, the suction line filter cartridge shall be replaced, or if the filter is of the sealed permanent type, the filter shall be replaced.

7. Drain Connections

7.1 Unless otherwise specified, condensate drains from coils and cases to the floor drain will be the responsibility of the Contractor. No drain line shall be smaller than the coil drain pan connection. All drain lines shall be hard copper tubing except for those in reach-in coolers. Lines should be sloped adequately to drain by gravity any water accumulated from condensing, defrosting, or cleaning operations. All condensate lines from refrigerated fixtures must be trapped and run to an open drain. They must not be connected directly to the sewer system. If necessary for cleaning, threaded unions shall be provided in the most accessible location near the fixture.

8. Testing, Evacuation, and Charging

8.1 The Contractor shall notify the Owner 24 hours in advance of any test so that the Owner and/or Manufacturer's representative may be present for the test if desired.

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8.2 When the refrigeration connections have been completed, the system shall be tested at a minimum of 150 psig with the compressor suction and discharge valves closed, and all other valves in the system open. (If local codes require higher test pressures, such codes must be complied with). Leak testing shall be performed with an electronic leak detector, unless the use of a halide torch is specifically authorized by the Owner. Refrigeration piping will not be acceptable unless it is gas tight. If any leaks are found, isolate the defective area, discharge the gas and repair the leaks, and then repeat the test. When testing has been completed, release all pressure freely to the atmosphere.

8.3 The system shall be evacuated with a vacuum pump specifically manufactured for vacuum duty, having a capability of pulling a vacuum of 50 microns or less. Evacuation of the system must never be done by the use of the refrigeration compressor. The pump should be connected to both the low and high side evacuation valves with copper tube or high vacuum hoses. ($^1/_4$" I.D. minimum). The compressor service valves should remain closed. A high vacuum gauge capable of registering pressure in microns should be attached to the system for pressure readings. Hermetic or accessible-hermetic motor compressors must not be operated during evacuation because of the reduced dielectric strength of the atmosphere within the motor chamber. To check system pressure, a hand valve must be provided between the pressure gauge and the vacuum pump which can be closed to isolate the system and check the pressure.

8.4 Evacuate each system to an absolute pressure not exceeding 1,500 microns. Install a drier of the required size in the liquid line, open the compressor suction and discharge valves, and evacuate to an absolute pressure not exceeding 500 microns. Leave the vacuum pump running for not less than two hours without interruption. Raise the system pressure to 2 psig with refrigerant, and remove the vacuum pump.

8.5 Refrigerant shall be charged directly from the original drums through a combination filter-drier. Each drier may be used for a maximum of three cylinders of refrigerant, and then must be replaced with a fresh drier. Charge the system by means of a charging fitting in the liquid line. Weigh the refrigerant drum before charging so that an accurate record can be kept of the weight of refrigerant put in the system. If refrigerant is added to the system through the suction side of the compressor, charge in vapor form only.

9. Start-Up

9.1 Compressors and condensing units will normally be delivered to the job with sufficient oil for the average installation. Check all compressors for proper oil level, and if necessary add sufficient oil to bring the level to the center of the crankcase sight glass. Use only the refrigeration oil recommended by the compressor manufacturer. All oil must be delivered to the job in factory sealed, unopened containers.

9.2 Before operating any motor or other moving parts, they are to be lubricated with the proper oil or grease as necessary.

9.3 Remove or loosen shipping retainers under motor compressors. Make sure hold down nuts on spring mounted compressors are not touching the compressor feet, and are not more than 1/16" above the mounting foot.

9.4 Check high and low pressure control cut-in and cut-out points. Check water valve settings. Adjust if necessary.

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9.5 After the compressor is started, continue charging until system has sufficient refrigerant for proper operation. Do not overcharge. During start-up, no compressor is to be left operating unattended and unwatched until the system is properly charged with refrigerant and oil.

9.6 Do not add refrigeration oil while the system is short of refrigerant unless oil level is dangerously low. If oil has been added during charging, carefully check the compressor crankcase sight glass after reaching a normal operating condition to be sure the system does not contain an excessive amount of oil which can cause slugging or loss of refrigerating capacity.

9.7 The temperature controls shall be set to maintain the following temperatures in the center of the fixture before stocking:

FIXTURE	TEMPERATURE °F.	
	(Minimum)	(Maximum)
Meat walk-in cooler	31	33
Meat holding cooler	29	31
Self-Service meat counter	31	33
Dairy walk-in cooler	36	38
Self-Service dairy case	36	38
Produce walk-in cooler	38	40
Self-Service produce counter	38	40
Self-Service beverage case	38	40
Frozen food storage cooler	-15	-10
Self-Service frozen food case	-5	0
Self-Service ice cream case	-15	-10
Meat preparation room	54	56

10. Operation and Check-Out

10.1 The Contractor shall be responsible for the proper adjustment of all controls in the system, including the controls on each refrigeration circuit, air temperature controls in the machine room, remote condenser or water tower controls, water regulating valves, or such other controls as may be required.

10.2 The Contractor shall check the compressor overload protectors with the manufacturer's specifications, and inform the Owner if they are incorrect.

10.3 The Contractor shall furnish a competent refrigeration service mechanic to check and make any necessary adjustments to the controls during the time the fixtures are being stocked. The mechanic shall remain at the store for at least 8 hours during the first day the store is open for business beginning 1 hour before opening time.

11. Identification and User Instruction

11.1 Each refrigerated fixture and cooler coil should be numbered starting at No. 1. These numbers shall be not less than 1" in height and shall be stenciled or marked neatly on the fixture in an inconspicuous location easily available to the serviceman. The compressors or condensing units serving the fixtures should be marked with the numbers of the cases and coils served with figures not less than 1 ½" in height.

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11.2 All switches, starters, and controls shall be identified as to the fixture or condensing unit they serve.

11.3 The Contractor shall turn over to the Owner one copy of all manufacturer's literature furnished with each piece of equipment. Within 30 days after the store is opened, the Contractor shall instruct the store management on the proper operation, care and upkeep of all equipment.

11.4 A permanent data sheet shall be prepared on each installation with two copies for the Owner and the original for the installing Contractor's files. The data sheet shall contain a complete record of sizes and identification of all components used in the installation together with any pertinent information. The data sheet should include but is not limited to the following:

A. Compressor manufacturer, model, and serial number.
B. Fixture manufacturer, model, and serial number.
C. Design operating temperatures.
D. Condensing unit model, and serial number. (If package condensing unit)
E. If remote condenser, type, manufacturer, model, fan data.
F. Refrigerant and weight of charge.
G. Electrical service, volts, phase, cycles, wire size.
H. Control circuit, voltage, fuse size.
I. Contactor or starter, manufacturer, model, size, part number.
J. Compressor motor protection, type, size, part number.
K. Data on capacitors, relays, or other electrical components.
L. Pressure control, type, size, model number, setting.
M. Oil pressure safety control, type, model number.
N. Defrost control, type, manufacturer, model number, setting.
O. Data on miscellaneous refrigeration system components such as pressure controls, winterizing controls, oil separators, crankcase heaters, solenoid valves, valves, etc.
P. Liquid line drier, manufacturer, size, model number, connections.
Q. Schematic diagram of refrigerant piping.

12. Warranty and Guarantees

12.1 All equipment and material supplied and installed by the Contractor shall be guaranteed for one year from the date of the store opening. The Contractor shall provide the necessary labor, materials, and incidental expenses to maintain the equipment in proper operation for a period of one year from the date the store opens for business, without additional cost to the owner. (Temperature rises caused by improper stocking or abnormal air currents shall not be the responsibility of the Contractor). The service shall not include repairs or replacements due to damage by fire, earthquake, tornado, the elements or act of God, or damage caused by misuse of the system by the Owner, power failures, broken glass, or lightning.

12.2 Official acceptance of the completed job shall be when the job is complete in every detail and has been run under load conditions with satisfactory performance for a period of at least one week.

12.3 In the event any equipment furnished by the Owner is found to be defective, the Owner will compensate the Contractor for the labor and material used in replacing the equipment or repairing the defects.

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12.4 The first year service shall include at least three complete lubrications at approximately 4 month intervals. At the time the equipment is lubricated, each system shall be checked for proper adjustment, and any necessary repairs or corrections shall be made.

12.5 Approximately 30 days prior to the expiration of the one year warranty period, the Contractor shall make a final inspection, checking each system for proper adjustment, and correcting any deficiencies, and shall write the Owner a letter certifying that each system is free of leaks and is operating at the specified temperature.

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SECTION 25
SERVICING COPELAND® BRAND COMPRESSORS

Emerson Climate Technologies, Inc. manufacturers both welded and accessible hermetic (Copelametic®) motor-compressors. Welded compressors cannot be repaired internally in the field, and service operations on these compressors are limited to external electrical components and normal system repairs.

Copelametic® motor-compressors are specifically designed for field accessibility if required. Removable heads, stator covers, bottom plates and housing covers allow access for easy field repairs in the event of compressor damage.

The description of service operations that follows is general in nature, but those sections dealing with internal maintenance apply only to Copelametic® compressors.

NAMEPLATE IDENTIFICATION

The model number designation on Copeland® brand compressors and condensing units provides a basic identification of the electrical and physical characteristics. The model numbering system for Copelametic® compressors is shown in Figure 114, for welded compressors in Figure 115, and for condensing units in Figure 116.

For example, model number 4RH1-2500-TMK-105 identifies a Copelametic® motor-compressor as follows:

4	Identifies compressor family
R	Identifies refrigerant cooled
H	Identifies 3020 CFH displacement
1	Identifies basic physical characteristics
2500	Identifies nominal 25 HP
T	Identifies three phase
M	Identifies Thermotector motor protection
K	Identifies 208/220/440/3/60 motor winding
105	Identifies specific bill of material identifying valves or other optional features

The serial number provides both an identification number and a record of the date of manufacture. It is comprised of 8 digits. The first two identify the year of manufacture. The third digit is a code letter identifying the month of manufacture, the twelve months of the year being denoted by the first twelve letters of the alphabet (A for January, B for February, etc.). The last five digits are assigned in numerical order during each month's production.

The manufacturer of the motor used in the motor-compressor is also shown by a code letter preceding the serial number. Code letters are as follows:

C	Century
D	Delco
E	Emerson
G	General Electric
S	A. O. Smith
W	Wagner

To illustrate, a typical serial number might be C 69G19417. This would indicate:

C	Century Motor
69G	Manufactured in July, 1969
19417	Identification number

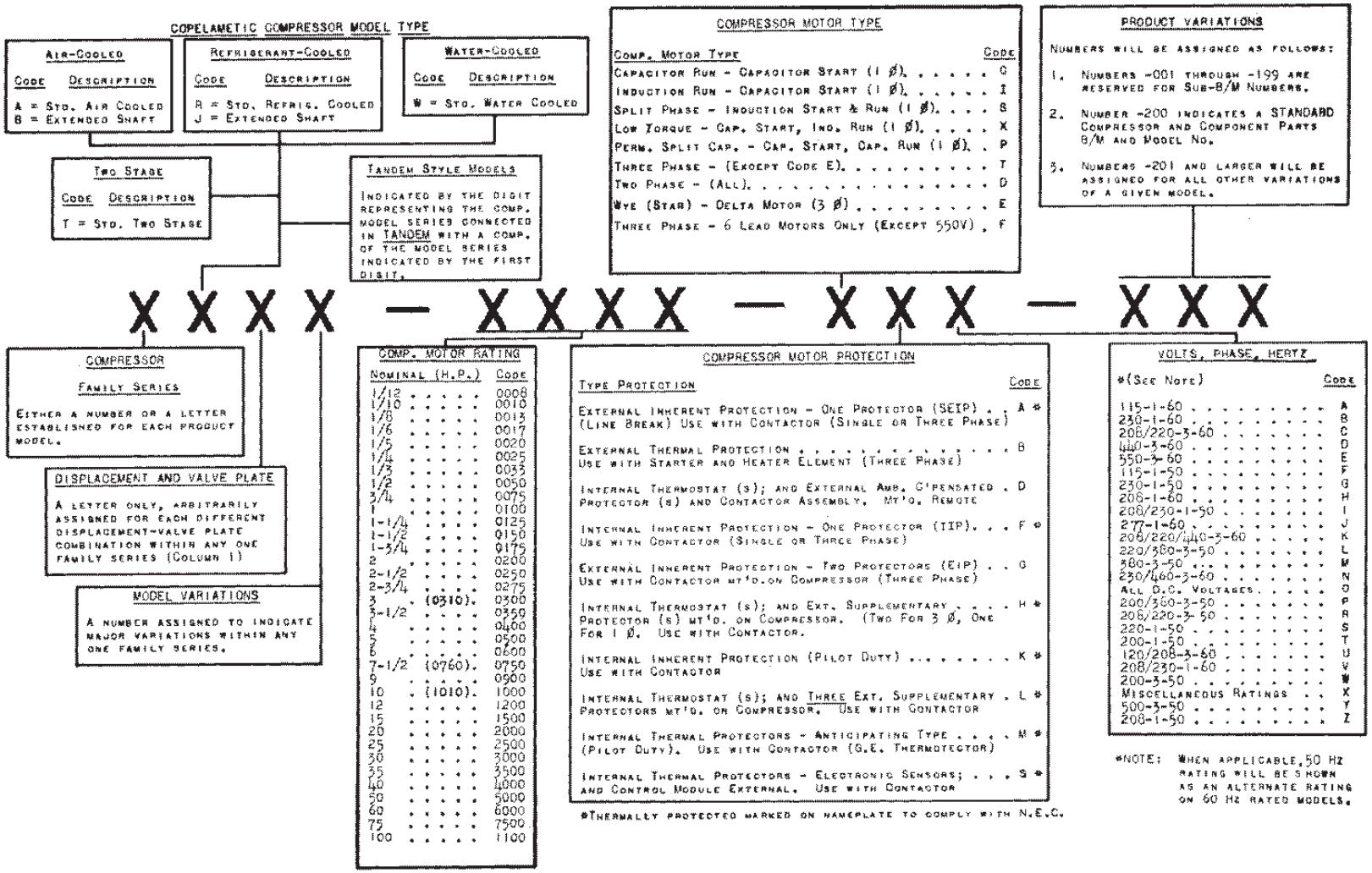
The motor electrical characteristics are also stamped on the nameplate. The motor may be operated at voltages plus or minus 10% of the nameplate rating.

Most Copeland® brand motor-compressors have a basic nameplate rating for both locked rotor and full load amperes based on motor test data. The designation full load amperage persists because of long industry precedent, but in reality a much better term is nameplate amperage. On all welded compressors, all new motors now being developed for Copelametic® compressors, and on most of the motors developed with inherent protection or internal thermostats, nameplate amperage has been arbitrarily established as 80% of the current drawn when the motor protector trips. The 80% figure is derived from standard industry practice of many years' standing in sizing motor protective devices at 125% of the current drawn at normal load conditions.

(continued on p. 25-5)

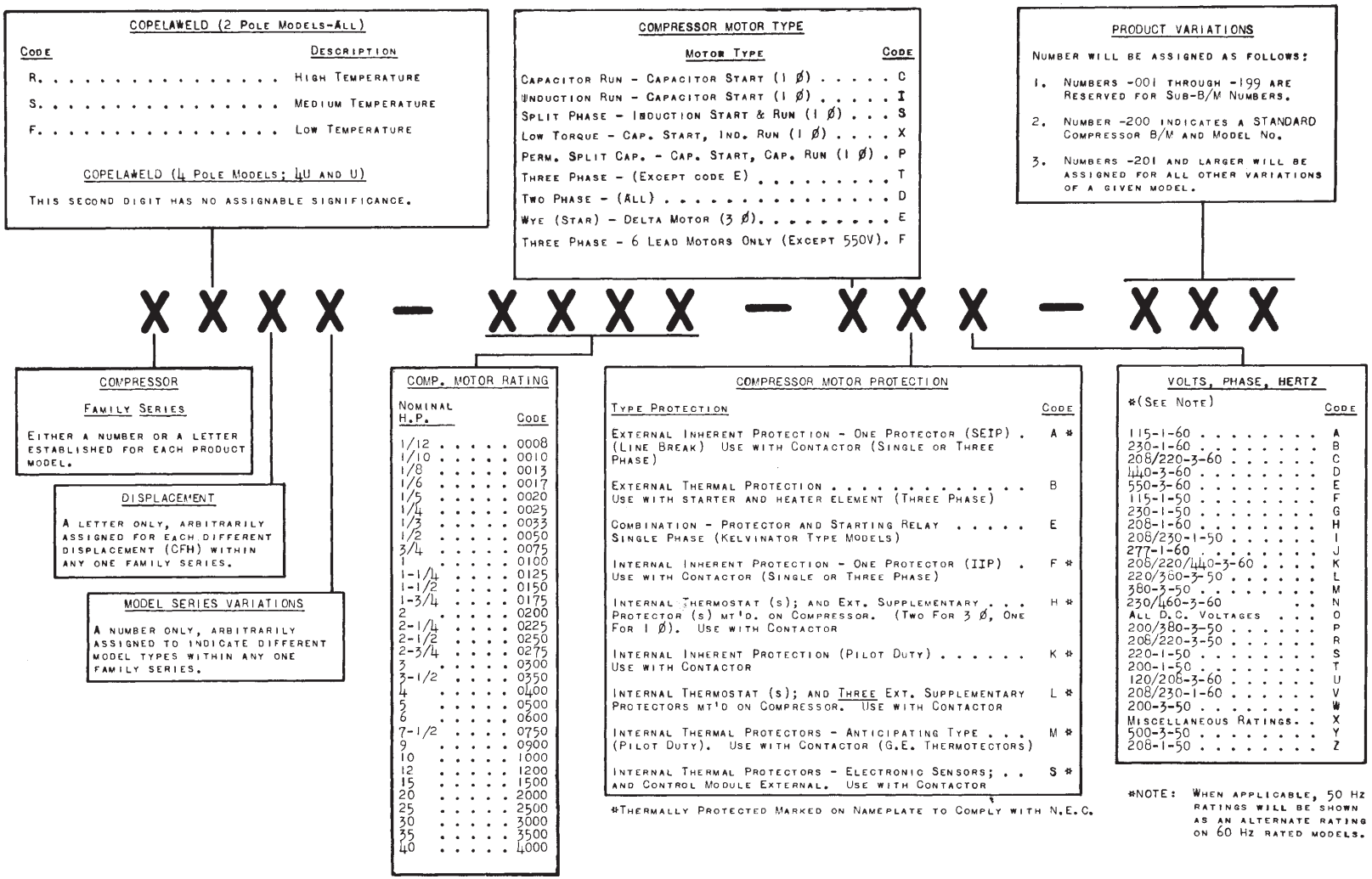
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COPELAMETIC COMPRESSOR NAMEPLATE NOMENCLATURE

Figure 114

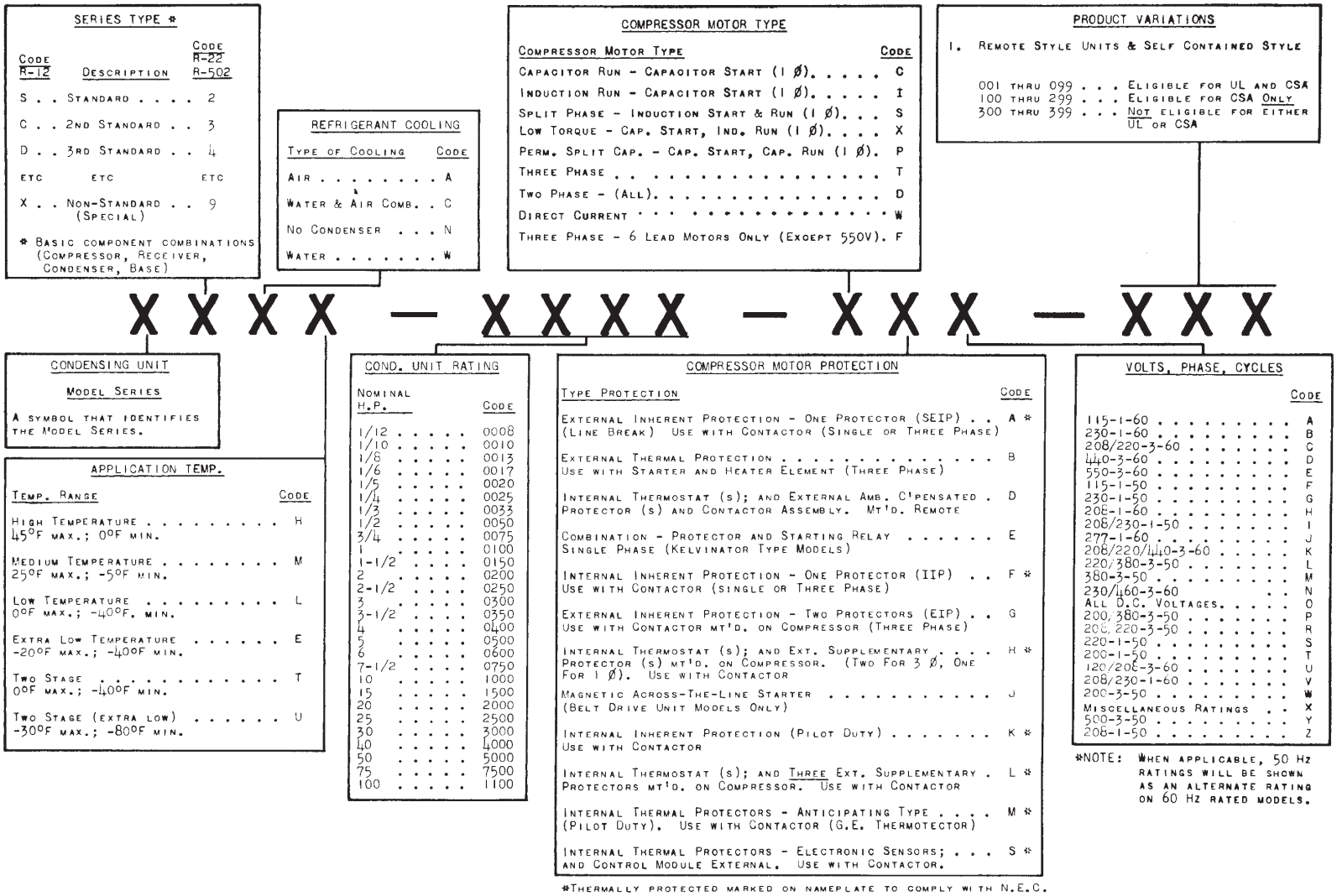


COPELAWELD COMPRESSOR NAMEPLATE NOMENCLATURE

Figure 115

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CONDENSING UNIT NAMEPLATE NOMENCLATURE

Figure 116

In order for the motor to meet Emerson Climate Technologies, Inc. standards, the trip point must be beyond the prescribed operating limits of the compressor, and is determined during qualification tests by operating the compressor at established maximum load conditions and lowering the supply voltage unit the trip point is reached. Use of the standard 80% factor enables the service and installation engineer to safely size wiring, contactors, or other external line protective devices at 125% of the nameplate rating, since the motor-compressor protector will not allow the amperage to exceed this figure.

In most instances, the motor-compressor is capable of performing at nominal rating conditions at less than rated nameplate amperage. Because of standardization, one motor frequently is used in various compressor models for air-cooled, suction-cooled, water-cooled, high temperature, medium temperature, low temperature, R-12, R-22, or R-502 applications as required. Obviously on many applications there will be a greater safety factory than on others.

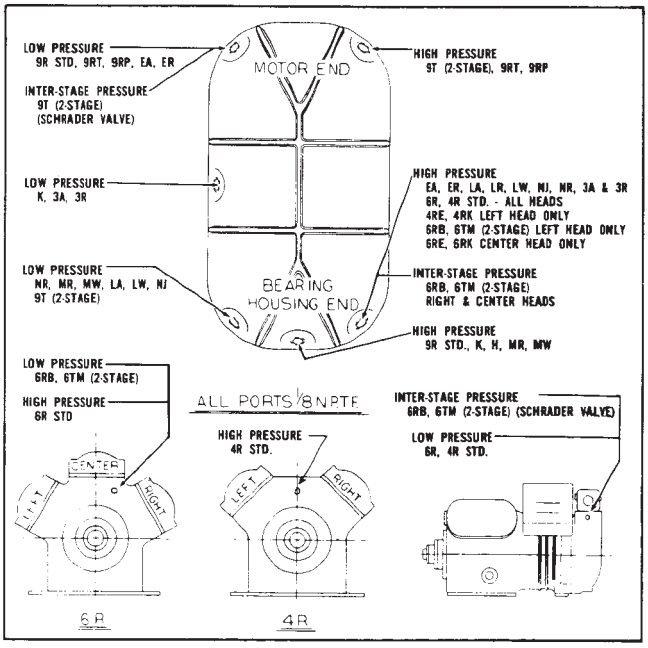
When Copeland® brand motor-compressors are listed with U. L., the basic compressor nameplate rating is listed as a maximum. This allows O.E.M. users to list a lower unit nameplate rating should the unit electrical load be less than the original compressor rating. Frequently this permits the use of smaller fuses and wire sizes.

In order to avoid any conflict in the nameplate ratings of the compressor and the unit in small packaged equipment, some welded compressors now have no full load rating stamped on the nameplate, and are assigned an "80% of trip amps" rating on specification sheets. All welded compressors carry a locked rotor rating on the nameplate, and all Copelametic® compressors have both a locked rotor and a full load amperage rating on the nameplate.

IDENTIFICATION OF PORT LOCATIONS IN HEADS OF COPELAMETIC® MOTOR-COMPRESSORS

In addition to the service ports normally available on suction and discharge compressor service valves, on Copelametic® compressors high and low pressure ports are provided in the compressor head. These provide a convenient connection for high and low pressure controls, and unlike the ports in service valves, cannot be accidentally closed off.

The port locations in various compressor models are shown in Figure 117.



HEAD POSITIONS WHEN VIEWED FROM BEARING HOUSING END OF COMPRESSOR

IDENTIFICATION OF PORT LOCATIONS IN HEADS OF COPELAMETIC COMPRESSORS

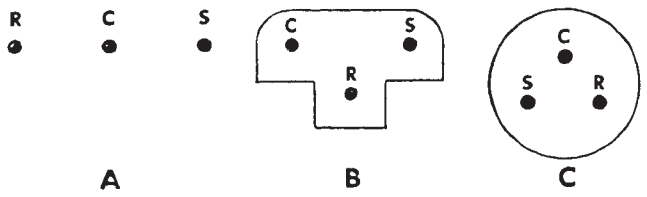
Figure 117

IDENTIFICATION OF MOTOR TERMINALS ON SINGLE PHASE COMPRESSORS

The terminal plates on Copelametic® compressors are stamped with the terminal identification, and identifying the common, run, and start terminals is seldom a problem. This is also true where tee blocks are used on welded compressors, but many welded compressors are manufactured with a Fusite terminal which may have no permanent identification.

Fig. 118 shows the various motor terminal configurations used by Copeland® brand products.

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VARIOUS COPELAND BRAND
MOTOR TERMINAL CONFIGURATIONS

Figure 118

Type A illustrates the individual terminal posts used on smaller horsepower Copelametic® compressors. Type A follows no standard industry pattern and applies only to Copelametic® compressors. The terminals are in the order shown when viewed from the stator cover end of the compressor (the end on which the terminal box is mounted).

Type B is a tee block used on larger horsepower compressors, both Copelametic® and welded. Type C is a Fusite connection, normally used with push-on type terminals.

Both Type B and Type C for production convenience and easy identification, follow the general industry rule of identifying common, start, and run terminals, always in that order, in the same fashion as reading a book. In other words, reading from left to right, and from top to bottom, the terminals are always C, S, and R.

PROPER VALVE PLATE AND HEAD GASKETS FOR 3, 4, AND 6 CYLINDER COMPRESSORS

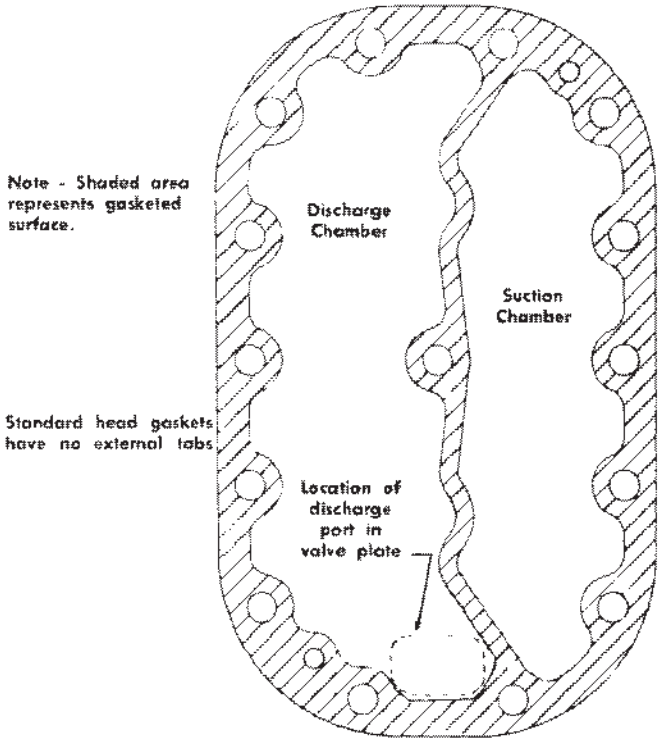
Occasionally when quick delivery of either new or replacement motor-compressors is required from a wholesaler's stock, and the exact model is not on hand, compressor heads may be changed in the field in order to utilize available stock compressors.

WARNING
When compressor heads are changed to convert standard, capacity control, or two-stage compressors to some other model, the correct gaskets must be used to insure proper performance and prevent damage to the compressor.

The correct head gasket must exactly match the inner face of the head being used.

Standard Compressor Heads

Figure 119 is an inside view of a typical standard Copelametic® compressor head, showing the inner webbing. The discharge port is located in the valve plate in the area indicated, and the proper gasket matches the inner face of the head.



TYPICAL STANDARD COPELAMETIC®
COMPRESSOR HEAD

(Inside view - 4RA, 6RA, 4RH, 6RH)
(The standard gasket is also used on compressors equipped with internal unloaders)

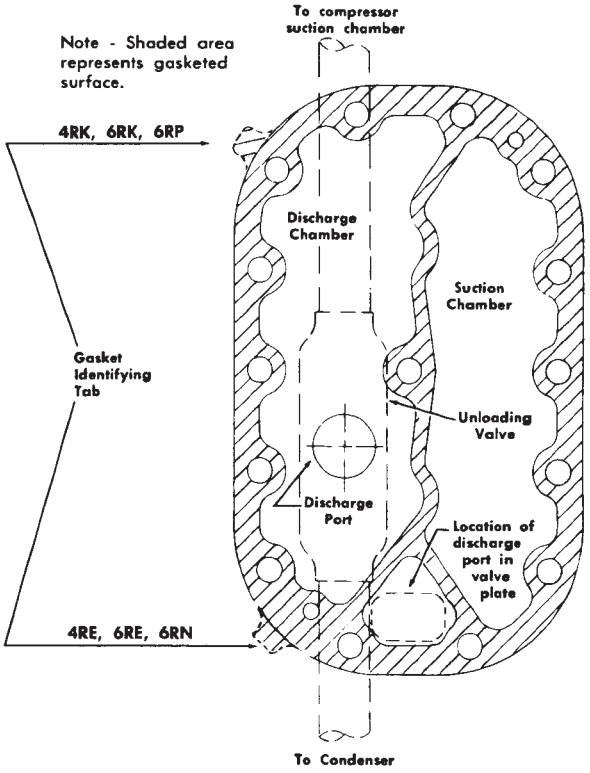
Figure 119

External Capacity Control Heads

Figure 120 is an inside view of a Copelametic® head equipped with an external unloading valve. The valve is mounted on a discharge port located in the top of the head. The normal discharge port area is fenced off by the "Y" in the inner webbing.

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The proper gasket exactly matches the inner face of the head, the gasket for the external unloading head being externally identified by the tab shown in Figure 120.



TYPICAL COPELAMETIC COMPRESSOR HEAD WITH EXTERNAL UNLOADING VALVE

(Inside view - 4RE, 6RE, 6RN, 4RK, 6RK, 6RP)

Figure 120

Since the area enclosed by the "Y" in the webbing is exposed to discharge pressure from the other cylinders, any leakage from the discharge port in the valve plate into the discharge chamber of an unloaded head can flow directly back to the suction chamber. Such leakage can cause the compressor suction pressure to rise immediately when the compressor is pumped down if the unloader valve is not tightly seated.

When a standard heat is replaced with a head equipped with an external unloading valve, the gasket must be changed and the correct gasket must be installed to prevent overheating of the compressor.

In the event unloading is not desired on a cylinder bank equipped with a head designed for unloading, both the cylinder head and gasket must be replaced. The correct gasket must be installed to prevent damage to the compressor.

A new internal type unloader is currently under development which will also require a special head, but the inner face of the head will be the same as a standard head, and the standard gasket may be used for the unloaded head as well.

Two Stage Heads, 3 Cylinder

On two stage compressors, special heads are necessary to provide the necessary separation of the two stages of compression. Figure 121 is an inside view of a typical Copelametic® head for a 3 cylinder two stage compressor.

Refrigerant vapor is returned directly from the suction line to the port in the cylinder head opening into the low stage suction chamber, and is then discharged by the low stage cylinders into the low stage discharge chamber. The gas (at interstage pressure) then enters the interstage manifold, is desuperheated by liquid refrigerant fed by the desuperheating expansion valve, and is discharged into the compressor motor chamber. The high stage suction gas follows the normal suction gas flow path from the motor chamber to the high stage suction chamber, and is then discharged to the condenser through the high stage discharge chamber.

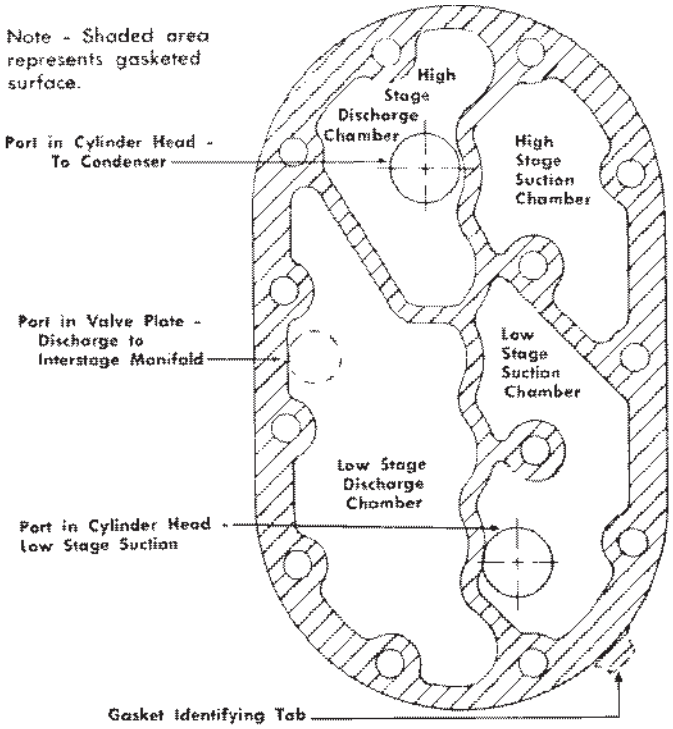
The proper gasket exactly matches the inner webbing of the head, and must be used to prevent leakage between stages and possible overheating of the compressor motor.

Two Stage Heads, 6 Cylinder Compressor

On 6 cylinder two stage compressors, different heads must be used on the high and low stage cylinders. When viewed from the bearing housing end of the compressor (the end on which the oil pump is mounted) the center and right cylinder banks are low stage, and the left cylinder bank is high stage.

Figure 123 is an inside view of a typical low stage head for a 6 cylinder compressor, while Figure

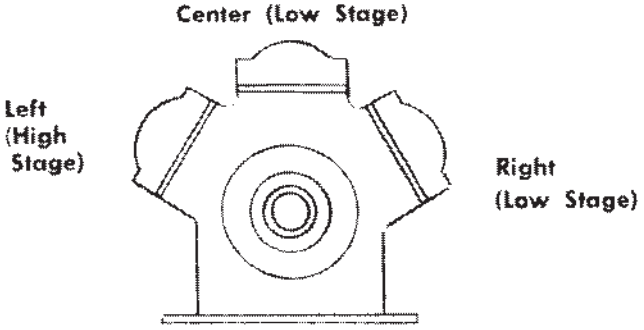
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TYPICAL TWO STAGE COPELAMETIC CYLINDER HEAD FOR 3 CYLINDER COMPRESSOR

(Inside view - 9TK, 9TL, 9TH)

Figure 121

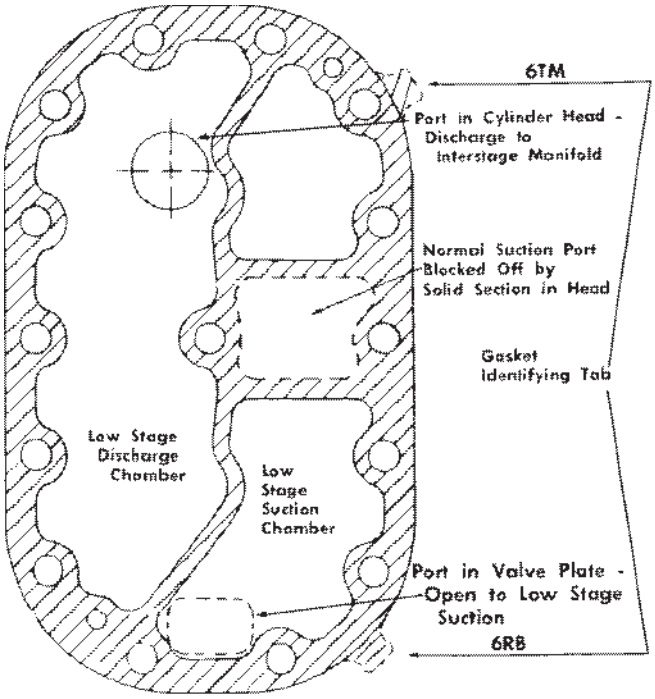


6 CYLINDER COMPRESSOR VIEWED FROM THE OIL PUMP END

Figure 122

124 shows an inside view of a typical high stage head.

Refrigerant vapor is returned from the suction line to the normal discharge chamber on the compressor.



TYPICAL LOW STAGE COPELAMETIC CYLINDER HEAD FOR 6 CYLINDER COMPRESSOR

(Inside view - 6RB, 6TM)

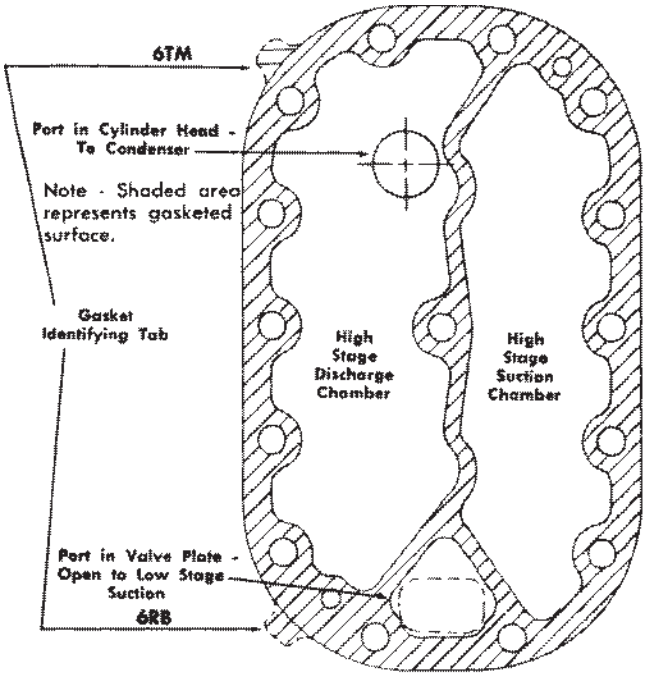
Figure 123

The vapor enters the low stage suction chamber through the port at the end of the valve plate, and is discharged from the low stage cylinders into the low stage discharge chamber. The gas (at interstage pressure) then enters the interstage manifold, is desuperheated by liquid refrigerant fed by the desuperheating expansion valve, and is discharged into the compressor motor chamber.

The low stage head is made with the area over the normal suction port blocked off. The proper gasket exactly matches the inner face of the head with the exception that the gasket outlines the solid area, but does not cover it completely.

The high stage head on two stage 6 cylinder compressors is similar to the head used on an unloaded head on 6 cylinder compressors, and takes the same head gasket. The high stage suction gas follows the normal suction gas flow path from the motor chamber to the high stage suction chamber,

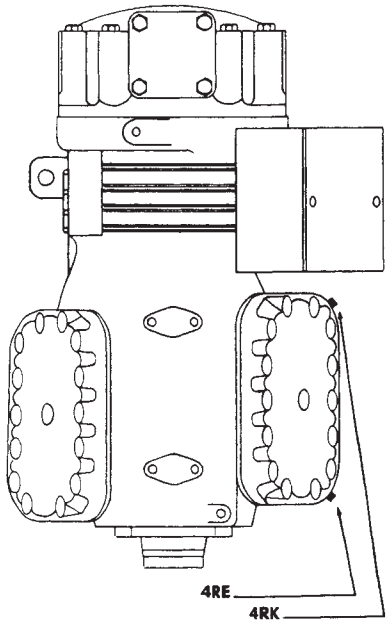
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TYPICAL HIGH STAGE COPELAMETIC CYLINDER HEAD FOR 6 CYLINDER COMPRESSOR

(Inside view - 6RB, 6TM)

Figure 124



GASKET TAB LOCATION ON EXTERNAL CAPACITY CONTROL 4 CYLINDER COMPRESSORS

Figure 125

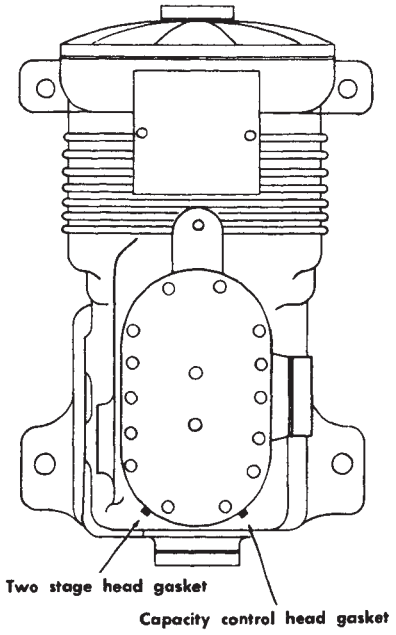
and is then discharged to the condenser through the high stage discharge chamber.

Identification of Head Gaskets

As a means of easily identifying head gaskets, and as a guide to proper installation, tabs have been provided on gaskets used on capacity control and two stage heads on 3, 4, and 6 cylinder compressors. In the even there is a question as to whether the proper gasket has been installed, the external tab provides a convenient means of checking without having to remove the compressor head.

Standard head gaskets have no tab, and follow the configuration of the head. The position of the tab when the gasket is properly installed on external capacity control and two stage compressors is illustrated in Figures 125, 126, 127, and 128.

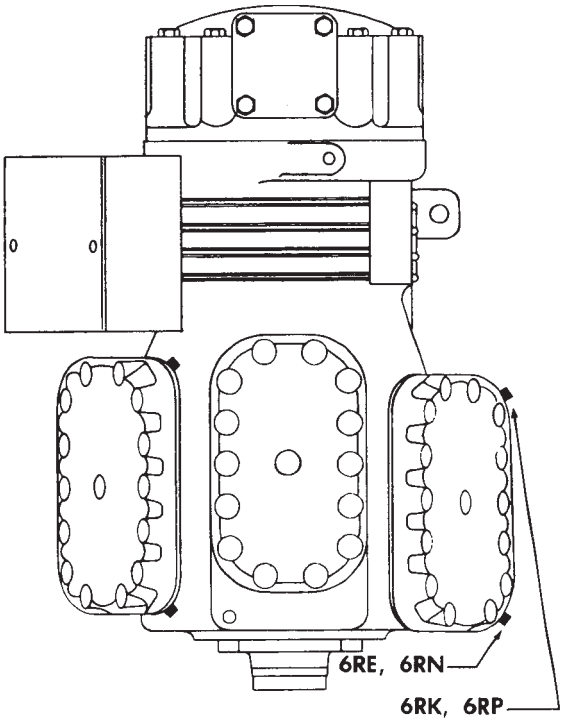
Any time a compressor head is changed, the proper gaskets must be used to prevent damage to the compressor. Compressor failures or compressor damage due to use of improper



GASKET TAB LOCATION ON TYPICAL MODEL "9" 3 CYLINDER COMPRESSOR

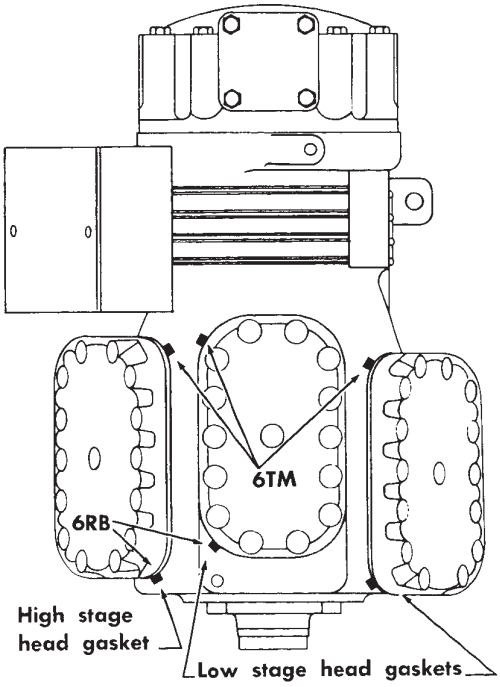
Figure 126

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GASKET TAB LOCATION ON EXTERNAL CAPACITY CONTROL 6 CYLINDER COMPRESSORS

Figure 127



GASKET TAB LOCATION ON TYPICAL 6 CYLINDER TWO STAGE COMPRESSOR

Figure 128

gaskets will be considered as misuse not covered by the Emerson Climate Technologies, Inc. warranty, and regular replacement charges will apply.

COPELAND® BRAND OIL PUMPS

On all Copelametic® compressors 5 HP and larger in size, and on 3 HP "NR" models, compressor lubrication is provided by means of a positive displacement oil pump. The pump is mounted on the bearing housing, and is driven from a slot in the crankshaft into which the flat end of the oil pump drive shaft is fitted.

Oil is forced through a hole in the crankshaft to the compressor bearings and connecting rods. A spring loaded ball check valve serves as a pressure relief device, allowing oil to bypass directly to the compressor crankcase if the oil pressure rises above its setting.

Since the oil pump intake is connected directly to the compressor crankcase, the oil pump inlet pressure will always be crankcase pressure, and the oil pump outlet pressure will be the sum of crankcase pressure plus oil pump pressure. Therefore, the net oil pump pressure is always the pump outlet pressure minus the crankcase pressure. When the compressor is operating with the suction pressure in a vacuum, the crankcase pressure is negative and must be added to the pump outlet pressure to determine the net oil pump pressure. A typical compound gauge is calibrated in inches of mercury for vacuum readings, and 2 inches of mercury are approximately equal to 1 psi.

For example:

Crankcase Pressure	Pump Outlet Pressure	Net Oil Pump Pressure
50 psig	90 psig	40 psi
8" vacuum (equivalent to a reading of minus 4 psig)	36 psig	40 psi

In normal operation, the net oil pressure will vary depending on the size of the compressor, the temperature and viscosity of the oil, and the amount of clearance in the compressor bearings. Net oil pressures of 30 to 40 psi are normal, but adequate

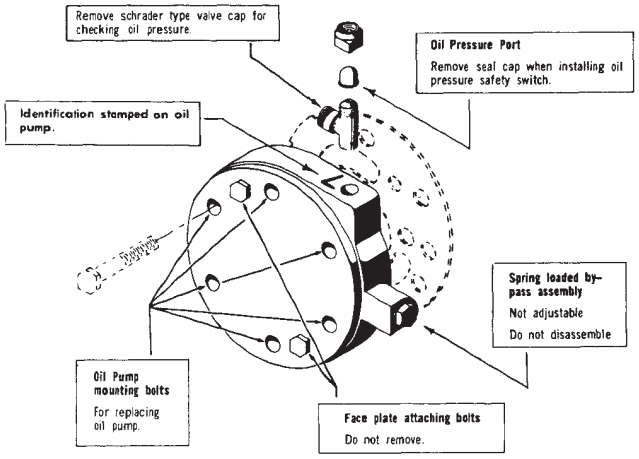
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lubrication will be maintained at pressures down to 10 psi. The bypass valve is set at the factory to prevent the net pump pressure from exceeding 60 psi.

Every oil pump is given a 100% operating inspection at the factory prior to shipment. The pump is installed in a test stand and must lift oil through unprimed oil lines to a height not less than 12 inches, pick up and develop a full flow of oil within 30 seconds, must not exceed an established maximum power requirement, must develop a minimum of 40 psi pressure with the main outlet closed, and must pump a specified quantity of oil at standard test conditions. Operating pressures and reversal of the pump are checked on the test stand, and on larger compressors are checked again after the pump is installed in a compressor.

The oil pump may be operated in either direction, the reversing action being accomplished by a friction plate which shifts the inlet and outlet ports. After prolonged operation in one direction, wear, corrosion, varnish formation, or burrs may develop on the reversing plate, and this can prevent the pump from reversing. Therefore, on installations where compressors have been in service for some time, care must be taken to maintain the original phasing of the motor if for any reason the electrical connections are disturbed. On transport refrigeration applications where power may be provided from both generators and dock power, both sources of power must be phased alike when connected to the unit in order to prevent reversing the compressor rotation.

The presence of liquid refrigerant in the crankcase can materially affect the operation of the oil pump. Violent foaming on start up can result in a loss of oil from the crankcase, and a resulting loss of oil pressure until oil returns to the crankcase. If liquid refrigerant or a refrigerant rich mixture of oil and refrigerant is drawn into the oil pump, the resulting flash gas may result in large variations and possibly a loss of oil pressure. Crankcase pressure may vary from suction pressure since liquid refrigerant in the crankcase can pressurize the crankcase for short intervals, and the oil pressure safety control low pressure connection should always be connected to the crankcase.



TYPICAL COPELAND® BRAND OIL PUMP

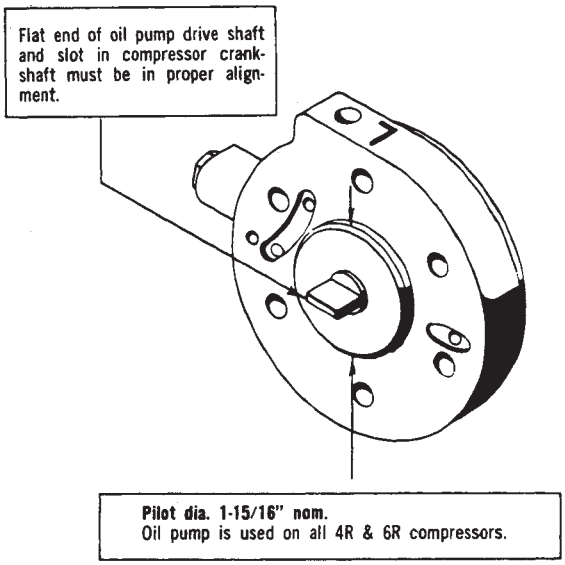
Figure 129

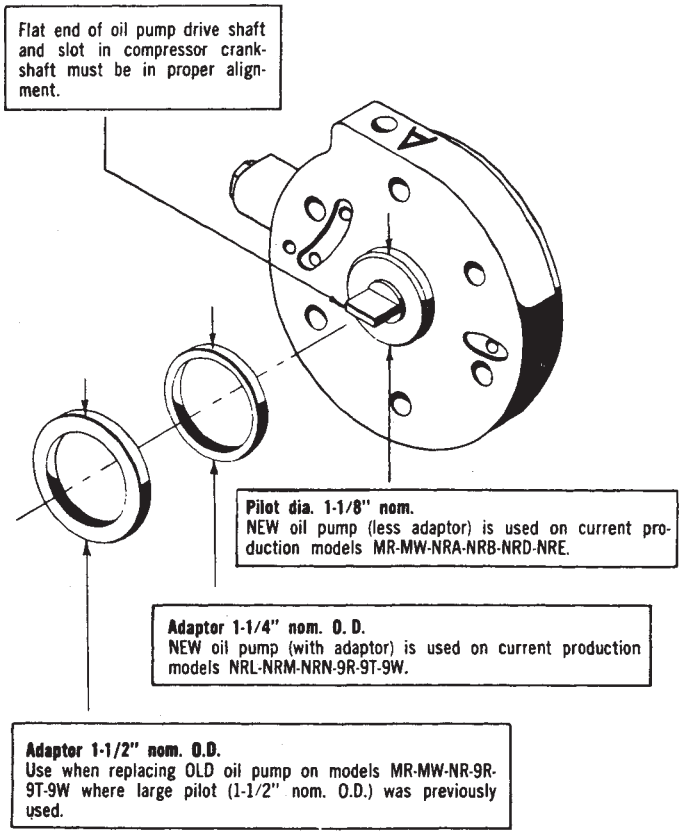
During a rapid pull-down of the refrigerant evaporating pressure, the amount of refrigerant in solution in the crankcase oil will be reduced, and may cause flash gas at the oil pump. During this period the oil pump must pump both the flash gas and oil, and as a result the oil pressure may decrease temporarily. This will merely cause the oil pump to bypass less oil, and so long as the oil pressure remains above 9 psi, adequate lubrication will be maintained. As soon as a stabilized condition is reached, and liquid refrigerant is no longer reaching the pump, the oil pressure will return to normal.

The oil pressure safety control high pressure connection should be made to the oil pressure port on the oil pump as shown. On the initial start-up of a system, or if at anytime abnormal noise causes any question regarding lubrication, it is recommended that a gauge be attached to the Schrader type valve so that the oil pressure can be observed while the compressor is in operation. The Schrader type valve is for pressure checking only, and is normally closed, so the oil pressure safety control must never be connected to this port.

The oil pump face plate is held in place by the two bolts shown in Figure 129. (Note that these are smaller than the six mounting bolts). The face plate seats on an “O” ring seal and should not be removed. Do not put a gasket between the face

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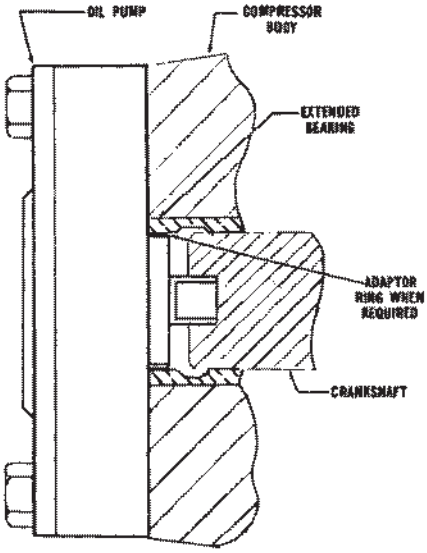


TYPICAL PRODUCTION OIL PUMPS

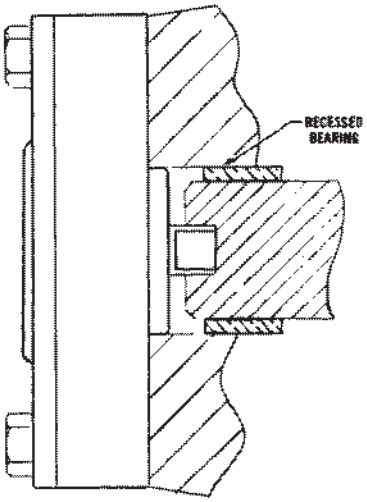
Figure 130

plate and the oil pump body, or the oil pump will be rendered inoperative.

The bolt holding the spring loaded bypass assembly in place should not be removed. The bypass pressure is not adjustable, and the bolt is provided for



"A" MODEL OIL PUMP ON N, M, OR 9 MODEL COMPRESSOR WITH EXTENDED LINE BORED BUSHING



"L" OR "S" MODEL OIL PUMP ON 4R, 6R, OR OLDER N, M, OR 9 MODEL COMPRESSOR WITH RECESSED BUSHING

Figure 131

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access during original assembly or factory maintenance, but it is not intended for field repairs. If the bolt is removed, the spring or other components are easily lost or damaged, rendering the oil pump inoperative.

Copeland® brand oil pumps are identified with a letter stamped into the casting as shown in Figure 129 and 130 and all are identical except for the pilot diameter.

Oil pumps identified with an "L" have a 1-15/16" O.D. pilot diameter, are designed for use on all 4R and 6R compressors, and will not fit any other compressor.

"S" oil pumps have a 1 °" O.D. pilot diameter, and were standard on all two and three cylinder compressors having oil pumps for many years. The "S" model oil pump is being replaced in current production with the "A" model oil pump, because of a change in bearing design on N, M, and 9 model compressors.

The "A" model oil pump has a 1 1/8" O.D. pilot diameter. It differs from the "S" and "L" oil pumps in that it is designed to register in the bearing rather than the bearing housing. This makes possible a new style line bored oil pump housing bearing providing accurate alignment of the oil pump.

A larger capacity oil pump with a double impeller has been developed for larger displacement compressors, but it is interchangeable with standard oil pumps with the exception that longer mounting bolts are required.

Field Replacement of Oil Pumps

If it is determined that an oil pump is not functioning properly, replace the oil pump and not the compressor.

The oil pump is mounted on the compressor bearing housing by means of the six bolts shown in Figure 129. Compressor bearing housings are not interchangeable on most compressor bodies and should not be removed.

Gaskets installed between the oil pump and the compressor body are shown in Figure 132. The tab on the gasket has been added solely for aid in identification and alignment. The gasket must be installed with the tab in the position shown (11 o'clock position) when viewed facing the compressor, and the slotted hole must always be to the installer's left in the 9 o'clock position. If the gasket is installed in any other position, the oil ports will be blocked. Gaskets for "L" oil pumps are not interchangeable with gaskets for "A" and "S" pumps.

Some older models of Copelametic® compressors are equipped with Tuthill oil pumps, and these may be furnished on service replacement compressors. The Copeland® brand oil pump is perfectly interchangeable with the Tuthill pump, and the same gaskets may be used.

WARNING

The oil pump pilot shoulder must register snugly in either the bearing housing or bearing (depending on compressor design) to insure centering the oil pump. See Figure 131. If not properly registered, the resulting misalignment can result in excessive wear and possible failure of the oil pump. Tolerances are very critical for proper operation and extreme care must be taken to insure that proper oil pump, and adaptor if required, is used. The following replacement procedures must be followed to insure trouble free operation.

1. Replacement of "L" oil pumps (4R and 6R compressors). Use only "L" oil pumps. Occasionally a serviceman will mount an "A" oil pump on a 4R or 6R compressor by mistake, and since the pilot shoulder will not register on the bearing housing, excessive play and misalignment of the shafts will develop resulting in failure of the oil pump. The pump should register in the bearing housing.

2. Replacement of "S" oil pumps with "A" replacement kit (M, N, 9 model compressors). Adaptors have been developed for the "A" oil pump so it can be used as a replacement on all two and three cylinder Copelametic® compressors having oil pumps, regardless of the compressor pilot diameter. The "A" replacement kit can be used to replace "S" oil pumps on all older model M, N, and 9 compressors which have bearing housing pilot diameters, by using the 1 ½" O.D. adaptor.

(continued on p. 25-20)

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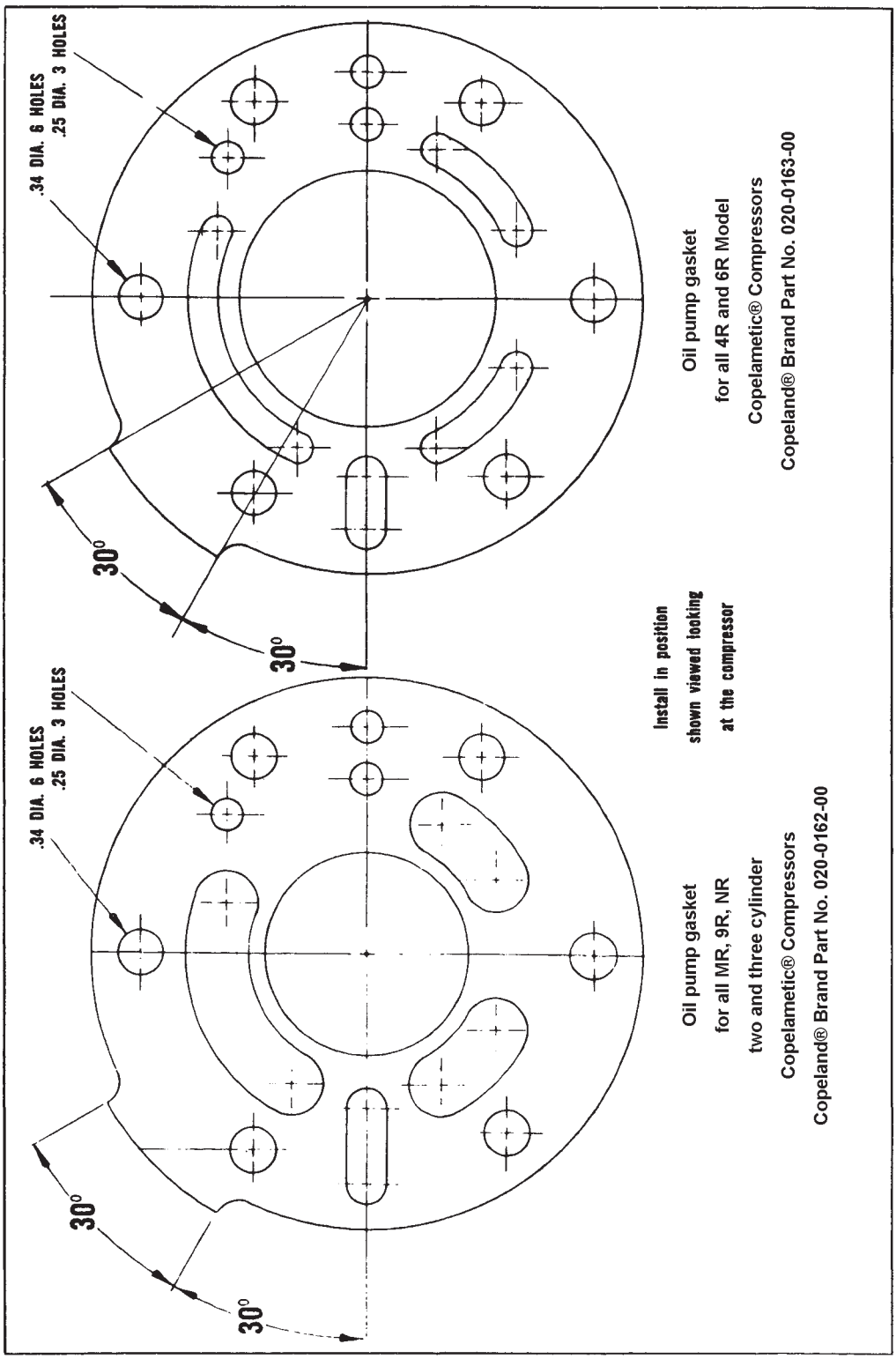
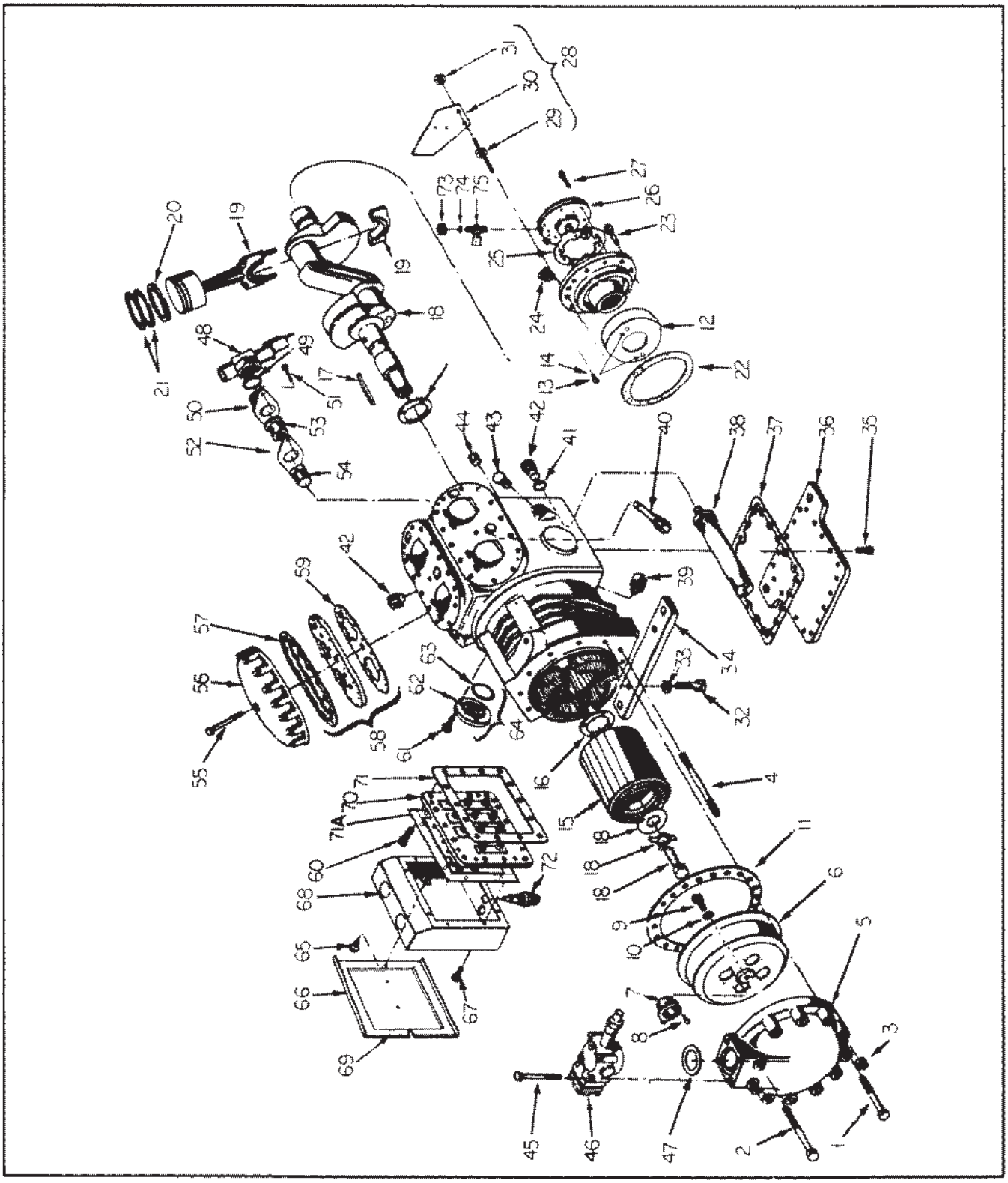


Figure 132

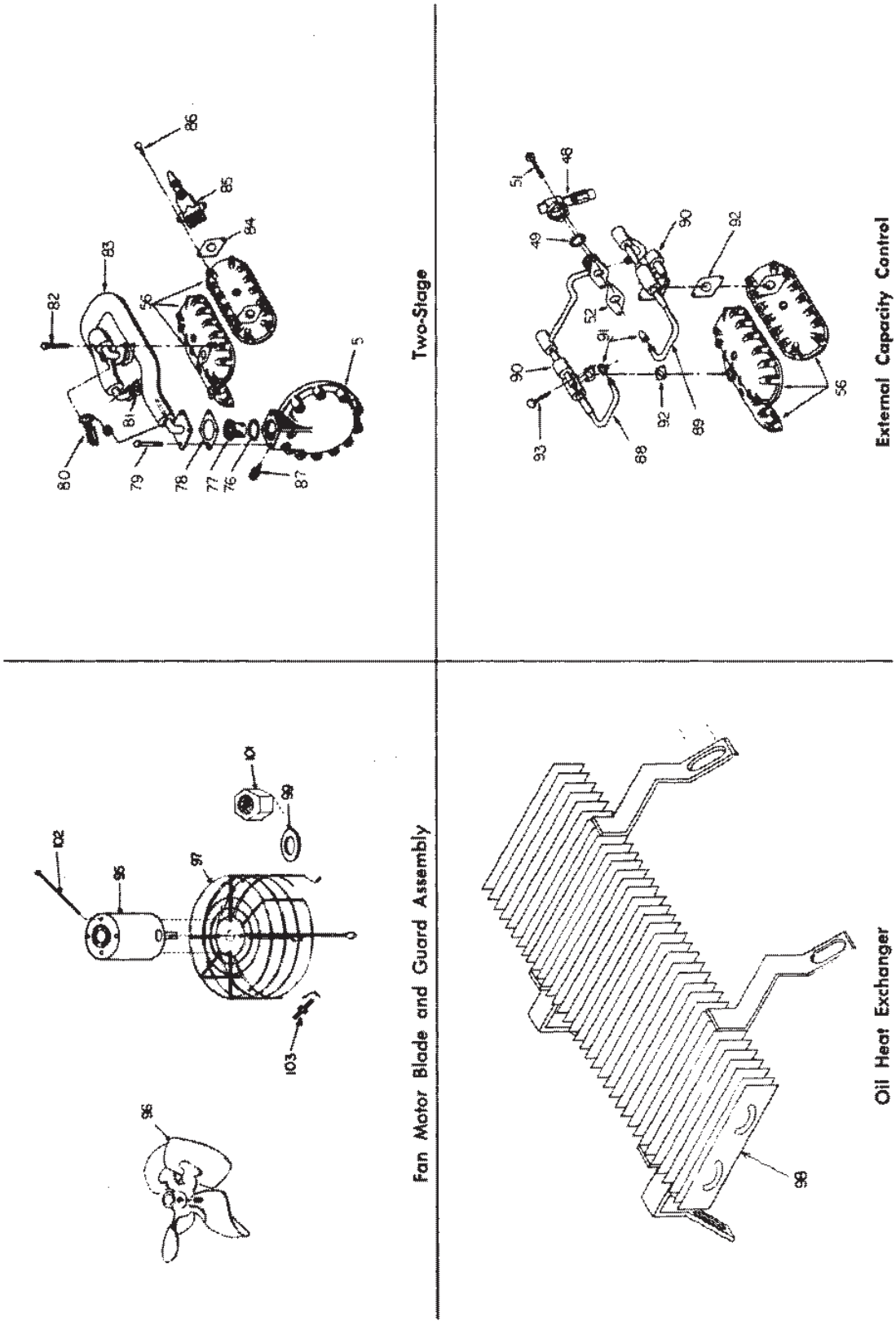
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EXPLODED VIEW - TYPICAL SIX CYLINDER COMPRESSOR

Figure 133

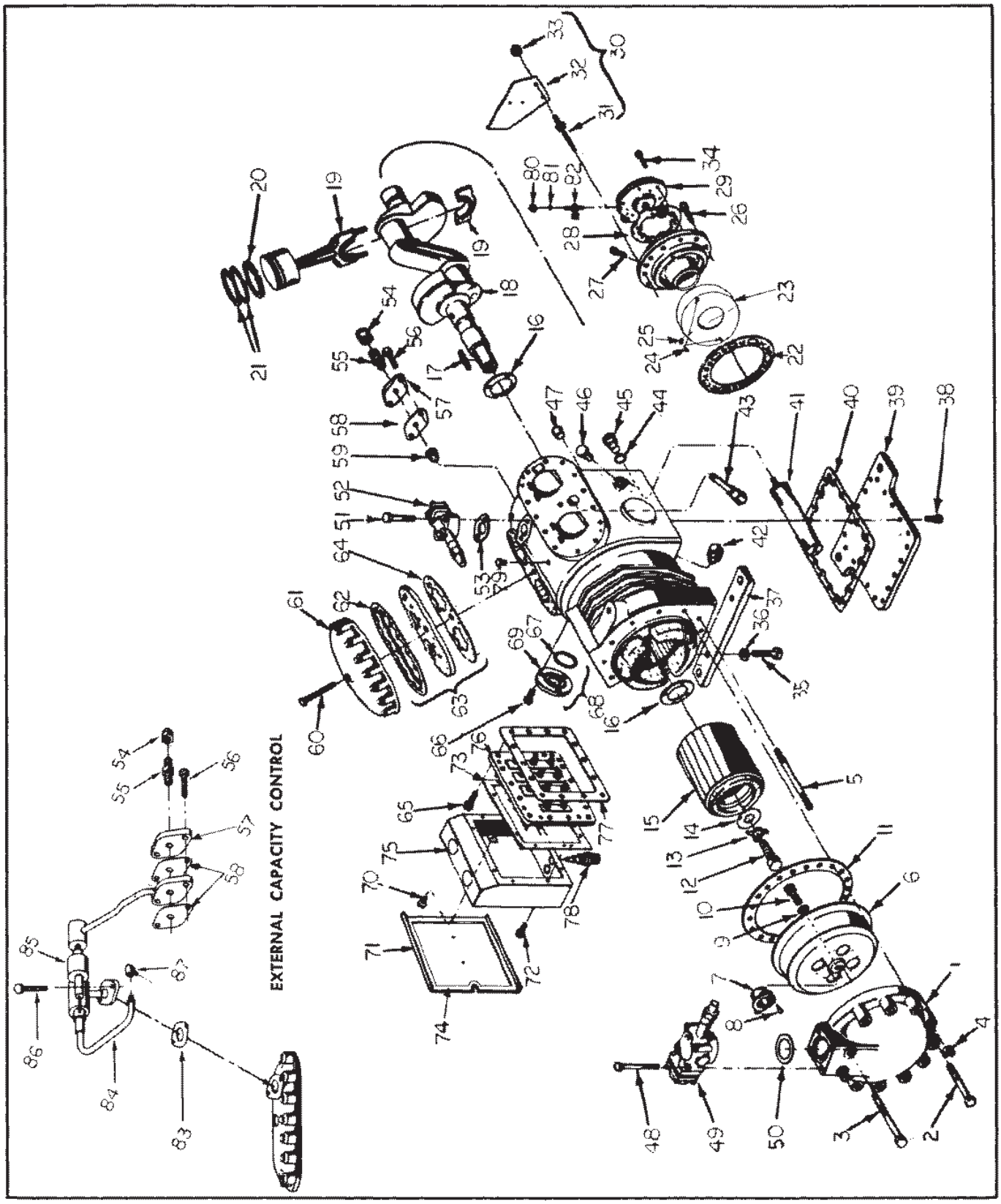
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TYPICAL ACCESSORIES AND MODIFICATIONS - SIX CYLINDER COMPRESSOR

Figure 134

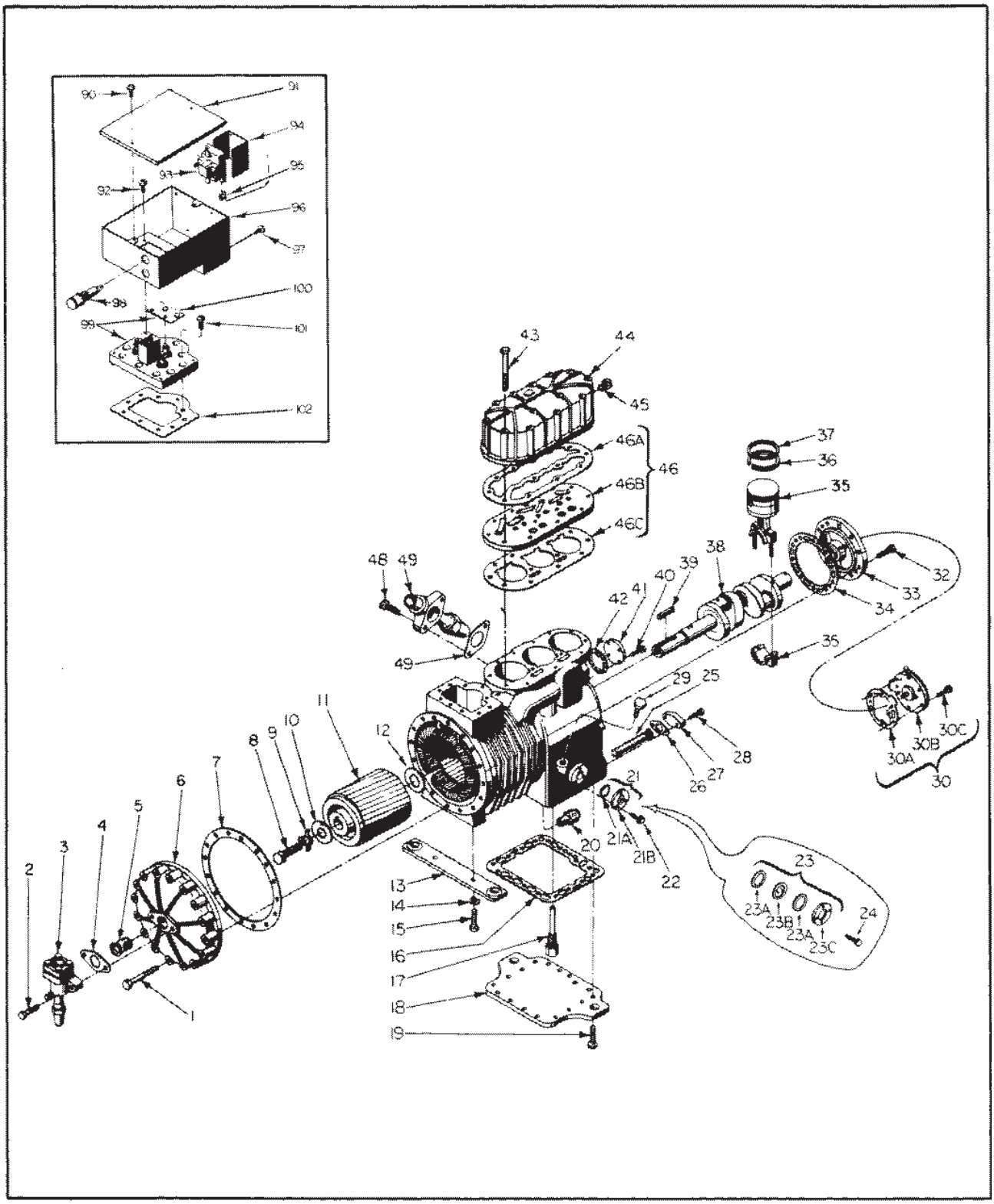
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EXPLODED VIEW - TYPICAL FOUR CYLINDER COMPRESSOR

Figure 135

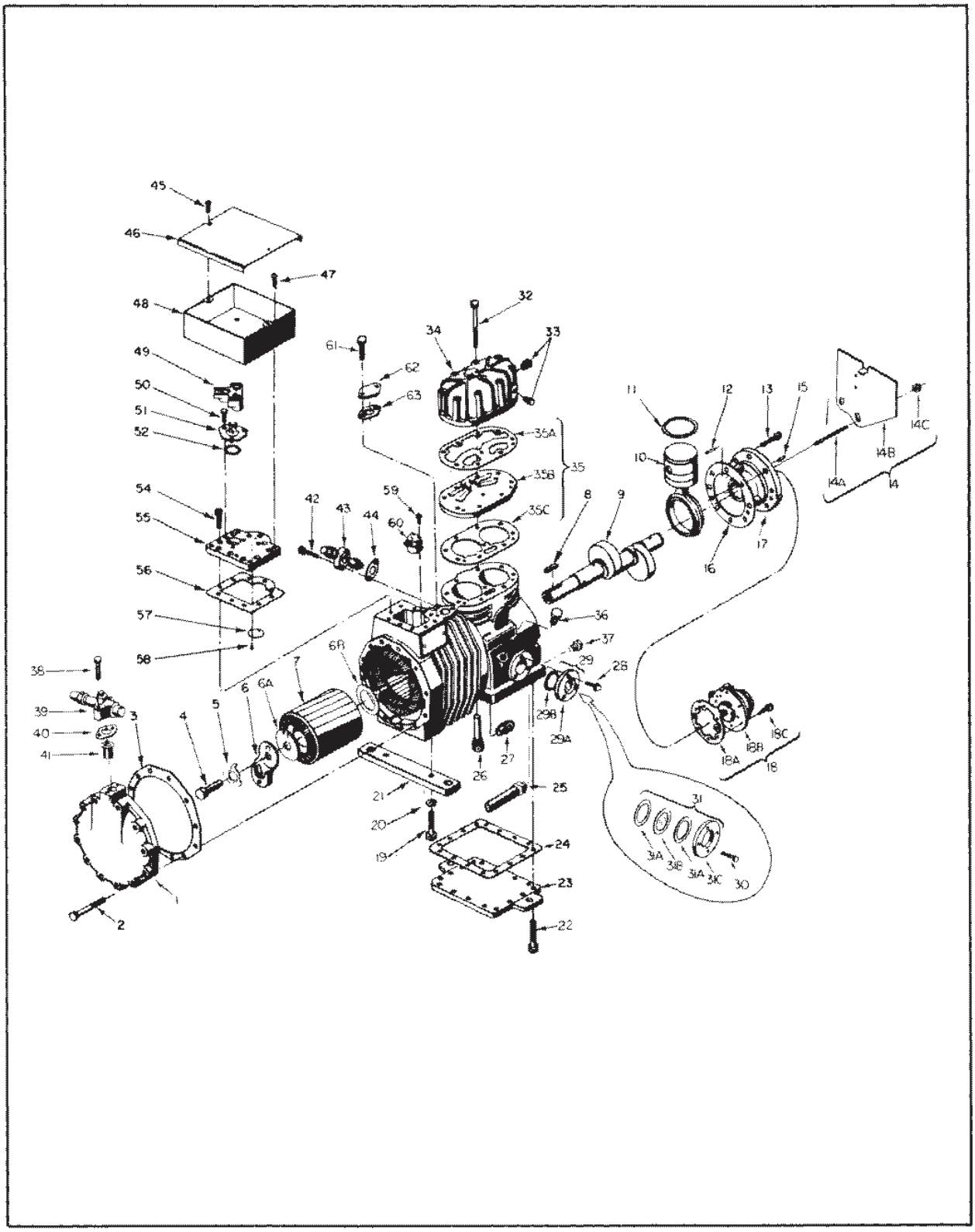
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EXPLODED VIEW - TYPICAL THREE CYLINDER COMPRESSOR

Figure 136

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EXPLODED VIEW - TYPICAL TWO CYLINDER COMPRESSOR

Figure 137

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3. Replacement of “A” oil pump on NRL, NRM, NRN, 9R, 9T, 9W model compressors. The above compressor models with “A” oil pumps have an extended bearing, with a 1 ¼” I.D. nominal register. The “A” replacement kit can be used to replace the original “A” pump by using the 1 ¼” O.D. adaptor.

4. Replacement of “A” oil pump on MR, MW, NRA, NRB, NRD, NRE model compressors. The above compressor models with “A” oil pumps have an extended bearing with a 1⅛” nominal I.D. register. The “A” replacement kit can be used to replace the original “A” pump without the use of any adaptor.

TYPICAL COPELAMETIC® COMPRESSOR CONSTRUCTION

The exploded views illustrate typical Copeland® brand compressor construction details. Individual components will vary with different compressor models, but the basic method of assembly is similar.

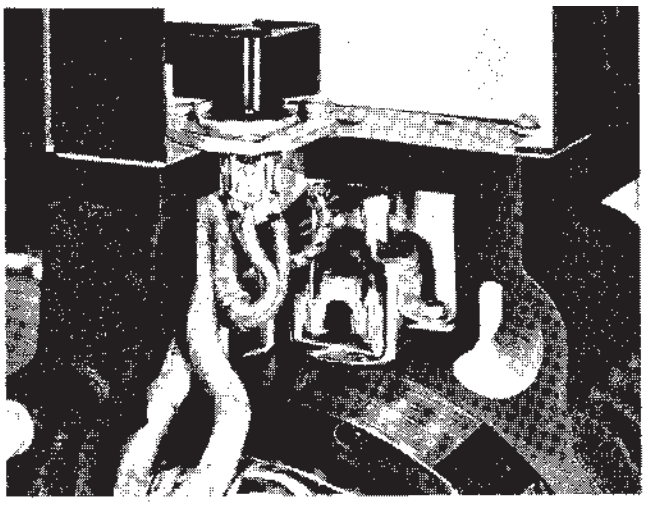
MAINTENANCE ACCESSIBILITY ON COPELAMETIC® COMPRESSORS

The heads may be removed on all Copelametic® compressors by removing the head bolts as shown in Figure 139.

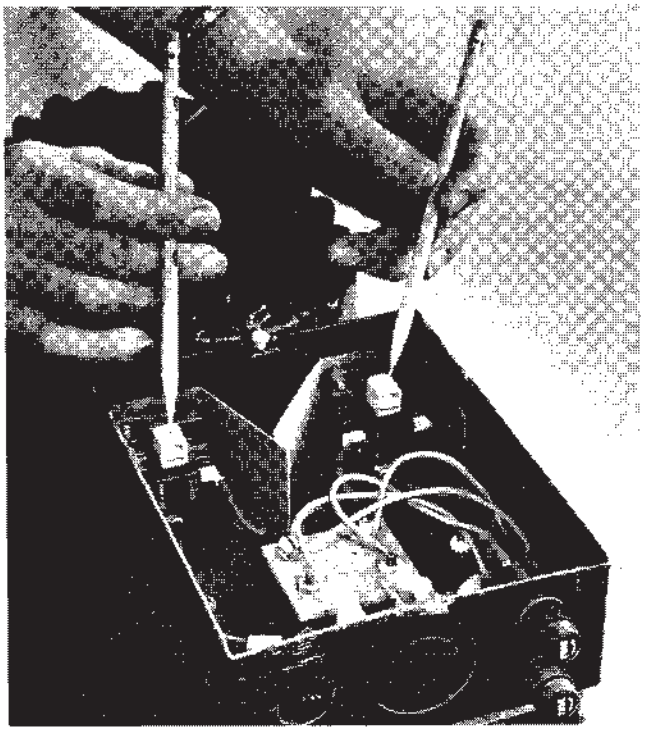
The valve plate is then accessible and may be removed as shown in Figure 140. Note that the suction valve reeds are retained in position by dowel pins in the body.

If the motor-compressor is not seized internally it is normally possible to move the pistons by exerting force on the top of the piston, as illustrated in Figure 141. In the event of a broken connecting rod, the piston may “float” in the cylinder during operation. The connecting rod is broken if the piston can be depressed with little or no pressure without affecting the position of the other piston or pistons.

TYPICAL DETAILS OF MOTOR PROTECTORS USED ON COPELAMETIC® MOTOR-COMPRESSORS



Internal Inherent Protector in intimate contact with stator iron provides compressor motor with instant line-break protection from temperature and current overloads.



External Protectors in terminal box supplement thermostat in motor windings to provide protection from excessive current in two legs of three phase electric power supply. Note: Third leg protector optional.

Figure 138

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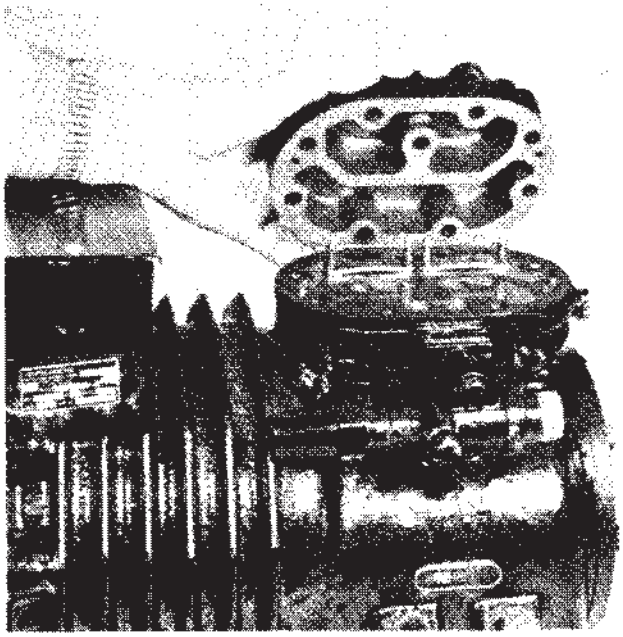


Figure 139

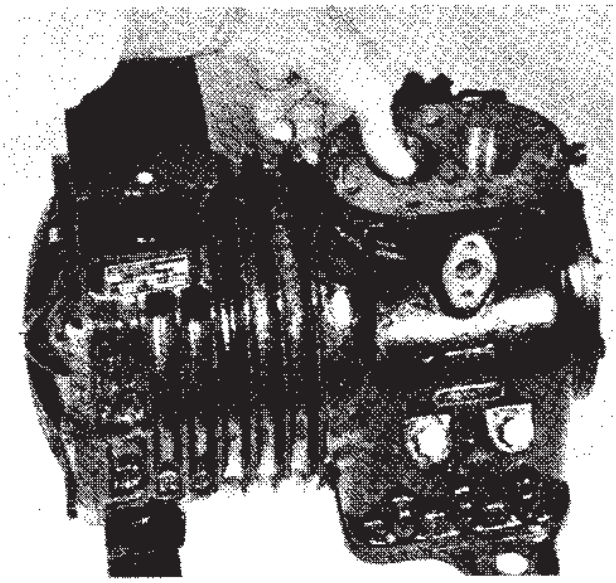


Figure 141

Figure 142 shows the location of the suction strainer screen on small Copelametic® compressors. If a restriction somewhere in the low pressure side of the system is indicated, it is advisable to check the strainer for restriction.

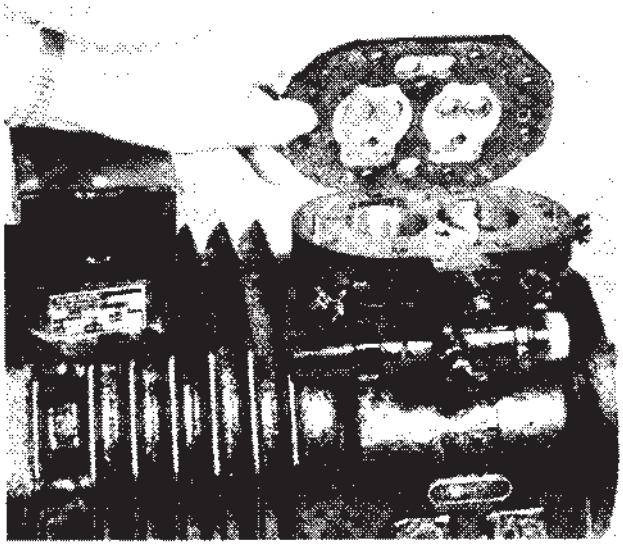


Figure 140

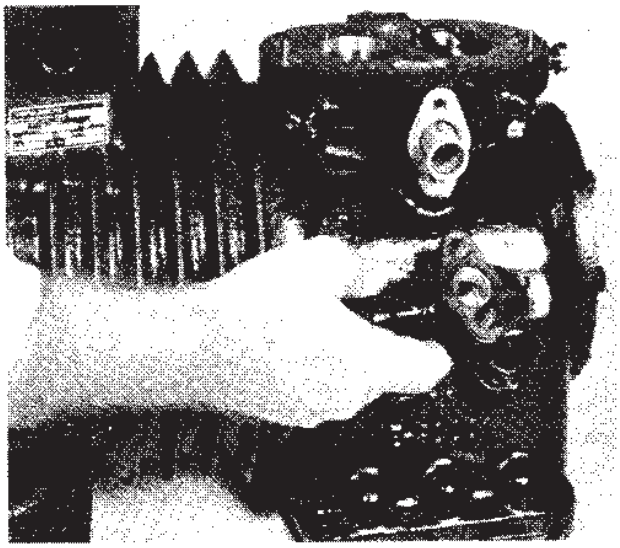


Figure 142

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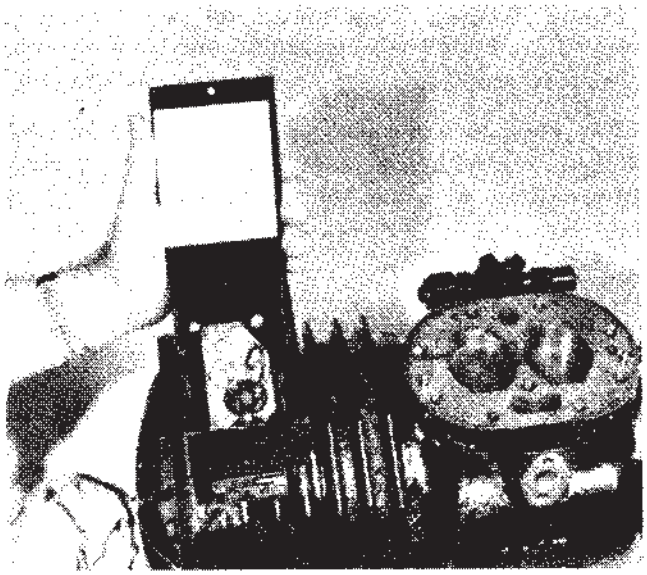


Figure 143

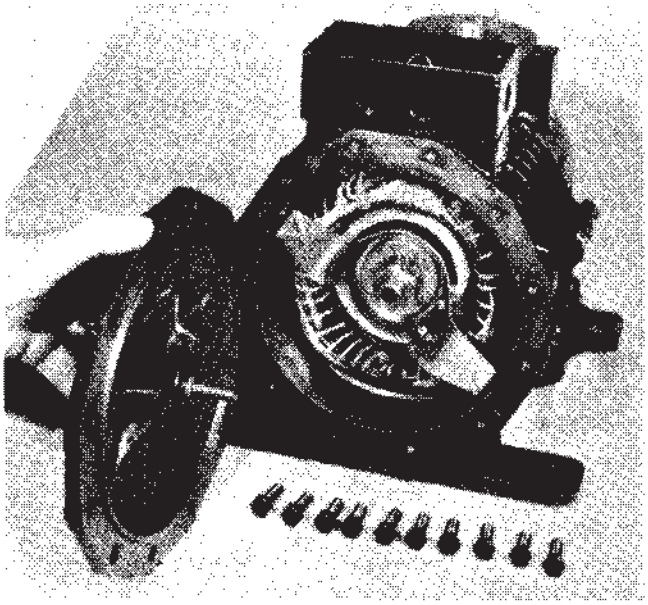


Figure 145

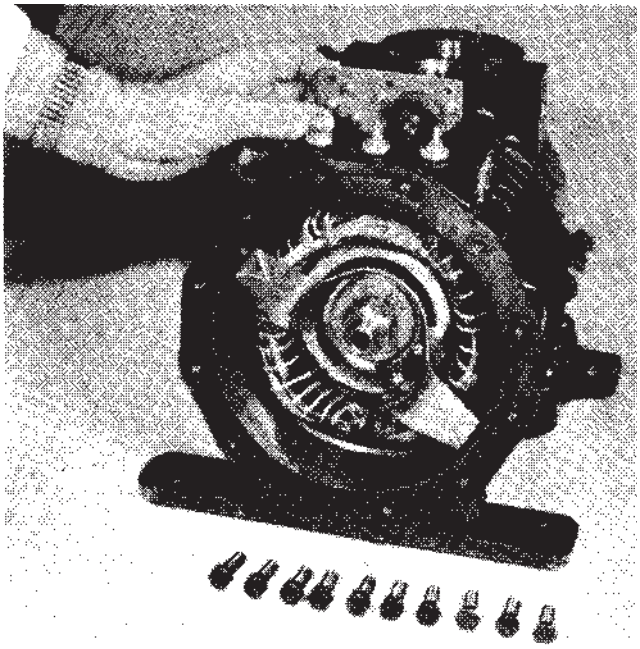


Figure 144

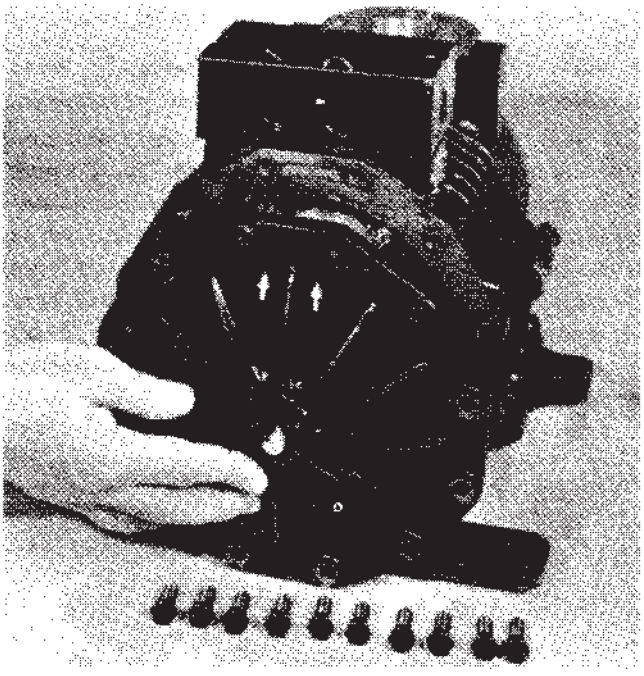


Figure 146

The compressor motor terminals and external protectors are accessible by removing the terminal box lid as shown in Figure 143. The terminal box can be removed by removing the attaching screws.

Figure 144 is a view of the motor end of a small compressor with the stator cover removed. Note that the external protector, on top of the body is held in position so that it has perfect contact with the compressor body when in the proper position.

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This particular model uses an oil flinger for lubrication. The ends of the oil flinger run through the oil, some of which is picked up by the "V" near the ends of the arms. The flinger deposits the oil at the top of the stator cover, which then drains into the oil well shown on the stator cover in Figure 145. Note that the oil tube which centers in the hollow crankshaft then permits oil to run from the well through the crankshaft to provide lubrication to the moving parts.

Figure 146 shows arrows on the motor housing cover which must point upward in order that the oil well will be in a proper position to trap the oil.

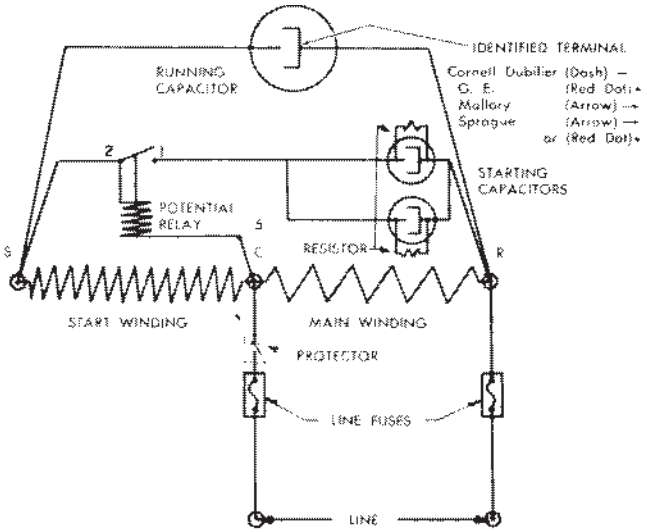
FIELD TROUBLESHOOTING

One of the basic difficulties in preventing compressor failures arises in determining the actual reason for the failure. The compressor is the functioning heart of the refrigeration system, and regardless of the nature of a system malfunction, the compressor must ultimately suffer the consequences. Since the compressor is the component that fails, there often is a tendency to blame any failure on the compressor without determining the actual cause of the malfunction. In far too many cases, the actual cause of failure has not been discovered and corrected and the result has been recurring failures that could have been prevented.

If the service engineer is to help in eliminating the causes of compressor failure, then he must thoroughly understand both the operation of the system and the possible causes of failure that might occur, and he must be on the alert for any signs of system malfunction.

If a motor compressor fails to start and run properly, it is important that the compressor be tested to determine its condition. It is possible that external electrical components may be defective, the protector may be open, a safety device may be tripped, or other conditions may be preventing compressor operation. If the motor compressor is not the source of the malfunction, replacing the compressor will only result in the unnecessary expenditure of time and money, while the basic problem remains.

If the service engineer closes his eyes to a basic system malfunction, or an improper control setting, or an operating condition he knows is not right, he is not fooling the system or the compressor; he is only fooling himself.



Capacitor-start, capacitor-run motor is shown. The PSC motor is the same but without starting capacitor and relay.

SCHEMATIC WIRING DIAGRAM, SINGLE PHASE MOTORS

Figure 147

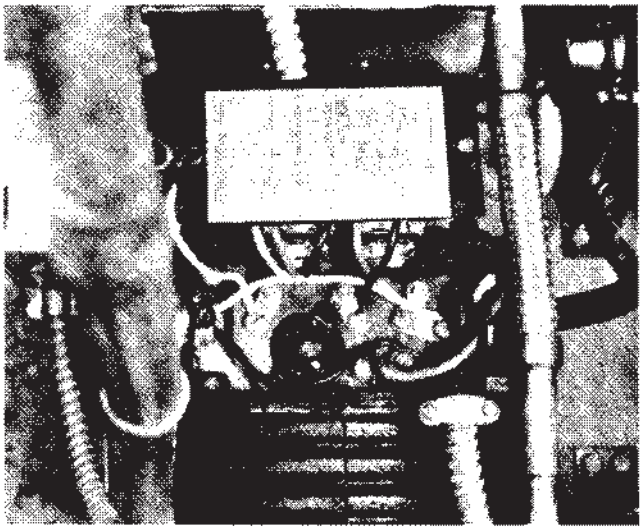


Figure 148

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Every service man should have this motto emblazoned in his mind “Do the job right the first time.” If you can’t find time to do it right, how can you find time to do it over again?

Schematic Wiring Diagram, Single Phase Motors

Actual field wiring diagrams may vary considerably in style or format, but Figure 147 is a simple schematic illustration of the basic wiring connections and compressor motor winding relationships in a single phase motor. The diagram as shown illustrates a capacitor start, capacitor run motor, but the same diagram can apply to a permanent split capacitor motor if the starting capacitors and relay are removed, and can apply to a capacitor start, induction run motor if the running capacitor is removed.

A thorough understanding of the basic wiring connections is essential to successfully diagnose field electrical problems on single phase compressors.

If the Compressor Will Not Run

1. If there is no voltage at the compressor terminals, follow the wiring diagram (Figure 148) and check back from the compressor to the power supply to find where the circuit is interrupted.

   Check the controls to see if the contact points are closed (low pressure control, high pressure control, thermostat, oil pressure safety control, etc.). If a contactor is used check to see if the contacts are closed. Check for a blown fuse, open disconnect switch, or loose connection.

2. If power is available at the compressor terminals, and the compressor does not run, check the voltage at the compressor terminals while attempting to start the compressor (see Figure 149).

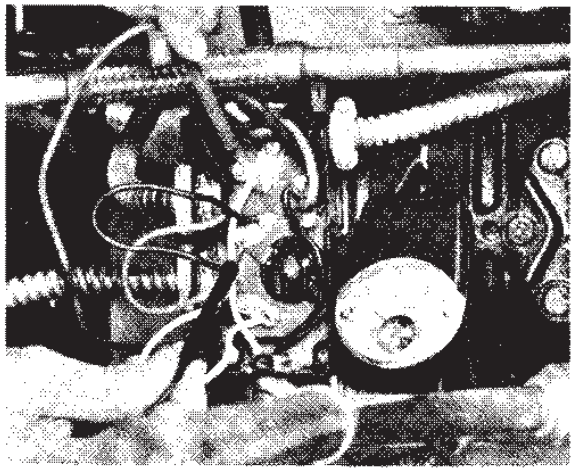


Figure 149

   If the voltage at the compressor terminals is below 90% of the nameplate voltage, it is possible the motor may not develop sufficient torque to start. Check to determine if wire sizes are adequate, electrical connections are loose, the circuit is overloaded, or if the power supply is adequate.

3. On units with single phase PSC motors, the suction and discharge pressures must be equalized before starting because of the low starting torque of the motor. Any change in the refrigerant metering device, the addition of a drier, or other changes in the system components may delay pressure equalization and create starting difficulties. If PSC motor starting problems are being encountered, the addition of a capacitor start kit is recommended.

4. On single phase compressors, a defective capacitor or relay may prevent the compressor starting. If the compressor attempts to start, but is unable to do so, or if there is a humming sound, check the relay to see if the relay contacts are damaged or fused. The relay points should be closed during the initial starting cycle, but should open as the compressor comes up to speed.

   Remove the wires from the starting relay and capacitors. Use a high voltage ohmmeter to check for continuity through the relay coil. Re-

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place the relay if there is no continuity. Use an ohmmeter to check across the relay contacts. Potential relay contacts are normally closed when the relay is not energized, current relay contacts are normally open. If either gives an incorrect reading, replace the relay.

Any capacitor found to be bulging, leaking, or damaged should be replaced.

Make sure capacitors are discharged before checking. Check for continuity between each capacitor terminal and the case. Continuity indicates a short, and the capacitor should be replaced.

Substitute “a known to be good” start capacitor if available. If compressor then starts and runs properly, replace the original start capacitor. On PSC motors, substitute “a known to be good” run capacitor if available. If compressor then starts and runs properly, replace the original run capacitor.

If a capacitor tester is not available, an ohmmeter may be used to check run and start capacitors for shorts or open circuits. Use an ohmmeter set to its highest resistance scale, and connect prods to capacitor terminals.

(a) With a good capacitor, the indicator should first move to zero, and then gradually increase to infinity.

(b) If there is no movement of the ohmmeter indicator, an open circuit is indicated.

(c) If the ohmmeter indicator moves to zero, and remains there or on a low resistance reading, a short circuit is indicated. Defective capacitors should be replaced.

5. If the correct voltage is available at the compressor terminals, and no current is drawn, remove all wires from the terminals and check for continuity through the motor windings. On single phase motor compressors, check for continuity from terminals C to R, and C to S. On three phase compressors, check for continuity between the terminals for connections to phases 1 and 2, 2 and 3, and 1 and 3. On compressors with line break inherent protectors, an open overload protector can cause a lack of continuity. If the compressor is warm, wait one hour for compressor to cool and recheck. If continuity cannot be established through all motor windings, the compressor should be replaced.

   Check the motor for ground by means of a continuity check between the common terminal and the compressor shell. If there is a ground, replace the compressor.

6. If the compressor has an external protector, check for continuity through the protector or protectors. (See Figure 150)

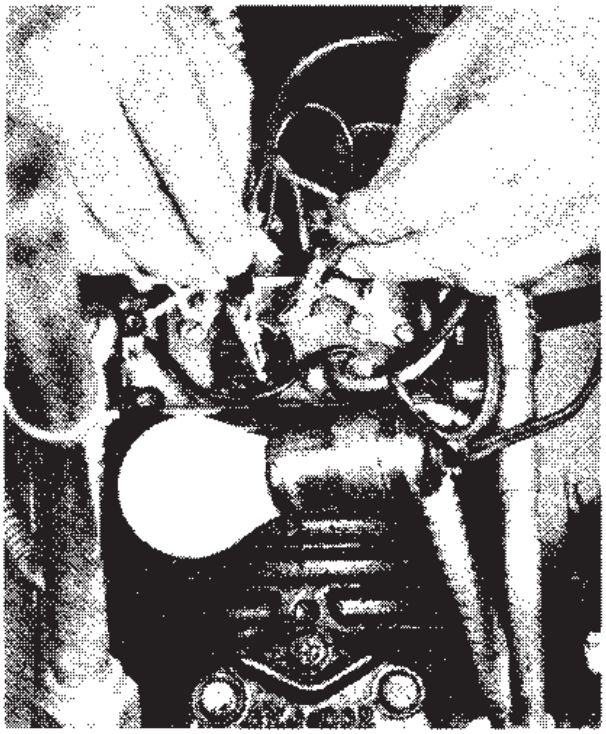


Figure 150

All external and internal inherent protectors on Copelametic® compressors can be replaced in the field. On larger compressors with thermostats, thermotectors, or solid state sensors, in the motor windings (D, H, M, S protection), the internal protective devices cannot be replaced

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and the stator or compressor must be changed if the internal protectors are defective or damaged.

If The Motor Compressor Starts But Trips Repeatedly On The Overload Protector

1. Check the compressor suction and discharge pressures while the compressor is operating. (See Figure 151.) Be sure the pressures are within the limitations of the compressor. If pressures are excessive, it may be necessary to clean the condenser, purge air from the system, add a crankcase pressure regulating valve, modify the system control, or take such other action as may be necessary to avoid excessive pressures.

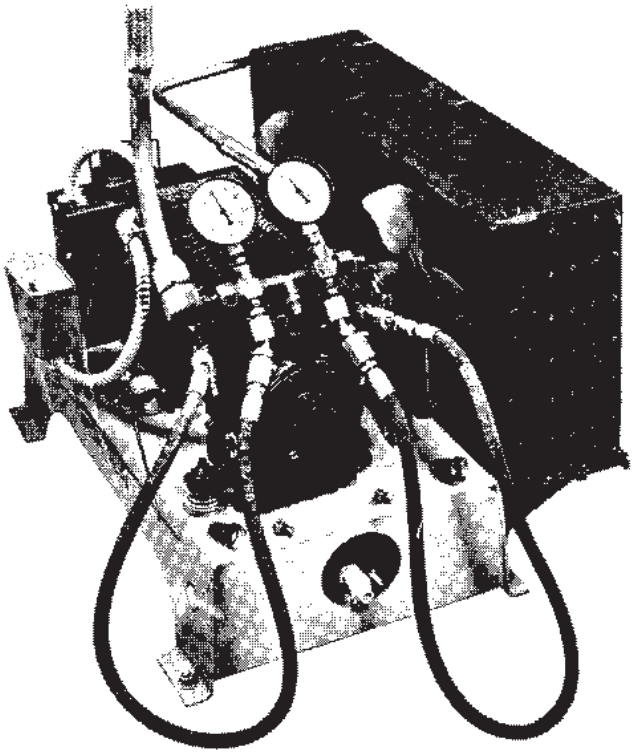


Figure 151

An excessively low suction pressure may indicate a loss of charge, and a suction cooled motor compressor may not be getting enough refrigerant vapor across the motor for proper cooling.

On units with no service gauge ports where pressures can be checked, check condenser to be sure it is clean and fan is running. Excessive temperatures on suction and discharge line may also indicate abnormal operating conditions.

2. Check the line voltage at the motor terminals while the compressor is operating. (See Figure 149.) The voltage should be within 10% of the nameplate voltage rating. If outside those limits, the voltage supply must be brought within the proper range, or a motor compressor with different electrical characteristics must be used.

3. Check the amperage drawn while the compressor is operating. (See Figure 152.) Under normal operating conditions, the amperage drawn will seldom exceed 110% of the nameplate amperage and should never exceed 120% of the nameplate amperage. High amperage can be caused by low voltage, high head pressure, high suction pressure, low oil level, compressor mechanical damage, defective running capacitors, or a defective starting relay.

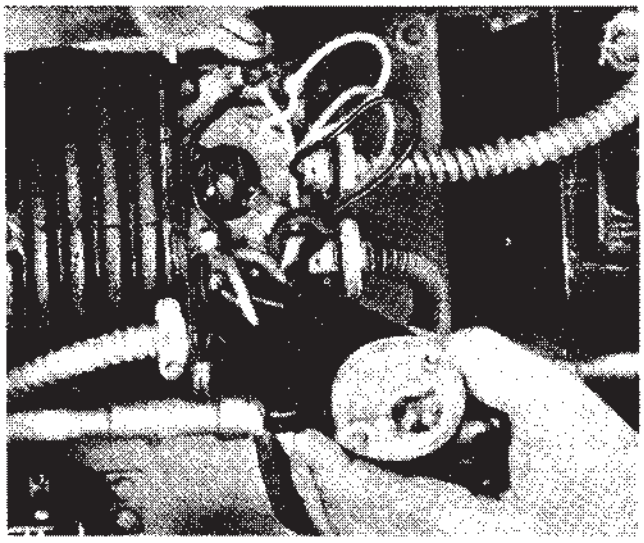
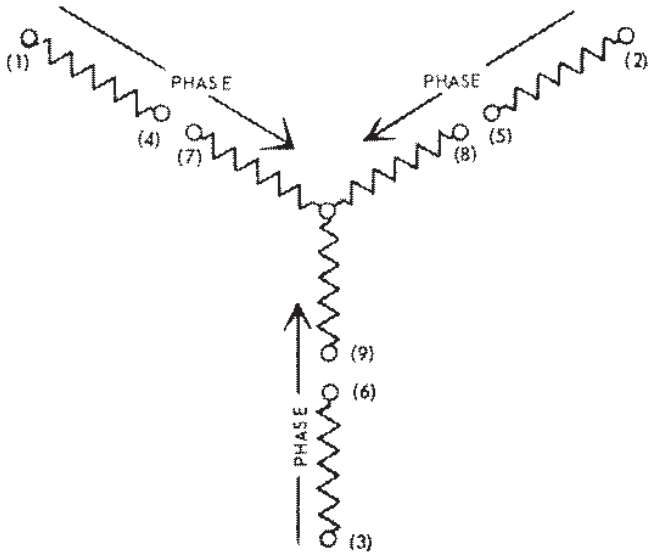


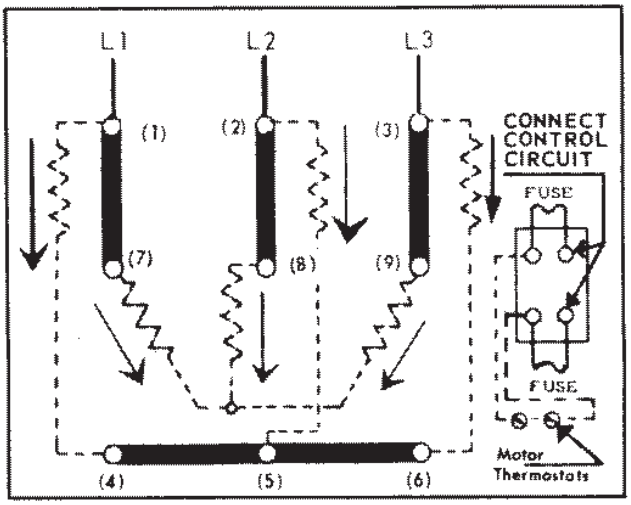
Figure 152

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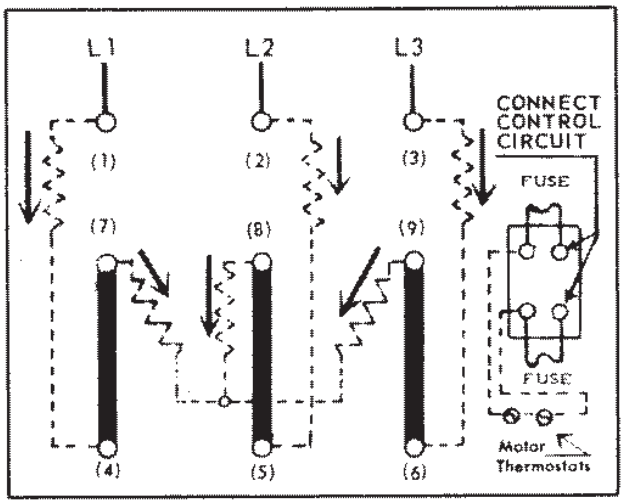
DUAL VOLTAGE (220V/440V) MOTOR WINDINGS



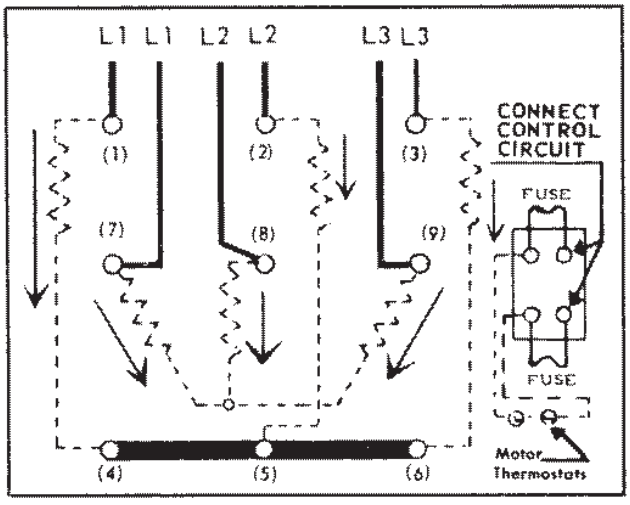
Schematic wiring diagram showing the terminal positions and phase relation.



Internal connection of the motor with terminal jumpers positioned for single contactor 208/220 volt across-the-line start.



Internal connection of the motor with terminal jumpers positioned for 440/480 volt across-the-line start.



Internal connection of the motor with terminal jumpers positioned for 208/220 volt across-the-line start with two contactors, or part-winding start.

Figure 153

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On three phase compressors, check amperage in each line. One or two high amperage legs on a three phase motor indicates an unbalanced voltage supply, or a winding imbalance. If all three legs are not drawing approximately equal amperage, temporarily switch the leads to the motor to determine if the high leg stays with the line or stays with the terminal. If the high amperage reading stays with the line, the problem is in the line voltage supply. If the high amperage reading stays with the terminal, the problem is in the motor.

If the amperage is sufficiently unbalanced to cause a protector trip, and the voltage supply is unbalanced, check with the power company to see if the condition can be corrected. If the voltage supply is balanced, indicating a defective motor phase, the compressor should be replaced.

4. Check for a defective running capacitor or starting relay in the same manner described in the previous section.

5. Check the wiring against the wiring diagram in the terminal box. On dual voltage motors, check the location of the terminal jumper bars to be sure phases are properly connected. (See Figure 153.)

6. Overheating of the cylinders and head can be caused by a leaking valve plate. To check, close the suction service valve and pump the compressor into a vacuum. Stop the compressor and crack the suction valve to allow the pressure on the suction gauge to build up to 0 psig. Again close the valve. If the pressure on the gauge continues to increase steadily, the valve plate is leaking. Remove the head and check the valve plate, replace if necessary. (See Figure 154.)

7. If all operating conditions are normal, the voltage supply at the compressor terminals balanced and within limits, the compressor crankcase temperature within normal limits, and the amperage drawn within the specified range, the motor protector may be defective, and should be replaced.

If the operating conditions are normal and the compressor is running excessively hot for no observable reason, or if the amperage drawn is above the normal range and sufficient to repeatedly trip the protector, the compressor has internal damage and should be replaced.

If The Compressor Runs But Will Not Refrigerate

1. Check the refrigerant charge. If sight glass is available, it should show clear liquid. Check the evaporator surface to determine if it is evenly cold throughout, or if partially starved. A lack of charge may be indicated by light, fluffy frost at the expansion valve and evaporator inlet. Add refrigerant if necessary.

2. Check the compressor suction pressure. An abnormally low pressure may indicate a loss of refrigerant charge, a malfunctioning expansion valve or capillary tube, a lack of evaporator capacity possibly due to icing or low air flow, or a restriction in the system.

(continued on p. 25-30)

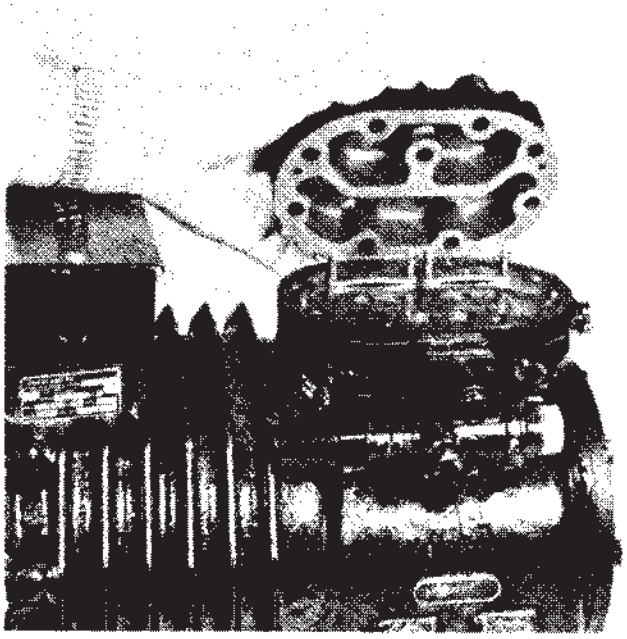


Figure 154

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Table 52

SERVICE DIAGNOSIS CHART

SYMPTOMS	POSSIBLE CAUSE
A. Compressor hums, but will not start	1. Improperly wired 2. Low line voltage 3. Defective run or start capacitor 4. Defective start relay 5. Unequalized pressures on PSC motor 6. Shorted or grounded motor windings 7. Internal compressor mechanical damage
B. Compressor will not run, does not try to start (no hum)	1. Power circuit open due to blown fuse, tripped circuit breaker, or open disconnect switch 2. Compressor motor protector open 3. Open thermostat or control 4. Burned motor windings - open circuit
C. Compressor starts, but trips on overload protector	1. Low line voltage 2. Improperly wired 3. Defective run or start capacitor 4. Defective start relay 5. Excessive suction or discharge pressure 6. Tight bearings or mechanical damage in compressor 7. Defective overload protector 8. Shorted or grounded motor windings
D. Unit short cycles	1. Control differential too small 2. Shortage of refrigerant 3. Discharge pressure too high 4. Discharge valve leaking
E. Starting relay burns out	1. Low or high line voltage 2. Short cycling 3. Improper mounting of relay 4. Incorrect running capacitor 5. Incorrect relay
F. Contacts stick on starting relay	1. Short running cycle 2. No bleed resistor on start capacitor
G. Starting capacitors burn out	1. Compressor short cycling 2. Relay contacts sticking 3. Incorrect capacitor 4. Start winding remaining in circuit for prolonged period
H. Running capacitors burn out	1. Excessively high line voltage 2. High line voltage, light compressor load 3. Capacitor voltage rating too low
I. Head pressure too high	1. Refrigerant overcharge 2. Air in system 3. Dirty condenser 4. Malfunction of condenser fan (air-cooled) 5. Restricted water flow (water-cooled) 6. Excessive air temperature entering condenser 7. Restriction in discharge line

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Table 52 (Cont'd)

SERVICE DIAGNOSIS CHART

SYMPTOMS	POSSIBLE CAUSE
J. Head pressure too low	1. Low ambient temperatures (air-cooled) 2. Refrigerant shortage 3. Damaged valves or rods in compressor
K. Refrigerated space temperature too high	1. Refrigerant shortage 2. Restricted strainer, drier, or expansion device 3. Improperly adjusted expansion valve 4. Iced or dirty evaporator coil 5. Compressor malfunctioning
L. Loss of oil pressure	1. Loss of oil from compressor due to: (a) oil trapping in system (b) Compressor short cycling (c) insufficient oil in system (d) operation at excessively low suction pressure 2. Excessive liquid refrigerant returning to compressor 3. Malfunctioning oil pump 4. Restriction in oil pump inlet screen

Often a restriction in a drier or strainer can be identified by frost or a decrease in temperature across the restriction due to the pressure drop in the line. This will be true only if liquid refrigerant is in the line at the restricted point, since any temperature change due to restriction would be caused by the flashing of liquid into vapor as the pressure changes.

Any abnormal restrictions in the system must be corrected.

3. Check the compressor discharge pressure. An abnormally high discharge pressure can cause loss of capacity, and can be caused by a dirty condenser, a malfunctioning condenser fan, or air in the system.

4. If the suction pressure is high, and the evaporator and condenser are functioning normally, check the compressor amperage draw. An amperage draw near or above the nameplate rating indicates normal compressor operation, and it is possible the compressor or unit may have damaged valves or does not have sufficient capacity for the application.

   An amperage draw considerably below the nameplate rating may indicate a broken suction reed or broken connecting rod in the compressor. Check the pistons and valve plate on an accessible compressor. If no other reason for lack of capacity can be found, replace a welded compressor.

Service Diagnosis Chart

Table 52 is a service diagnosis chart which can serve as a checklist of possible causes for various system malfunctions. While unusual conditions may occasionally occur, the chart covers the common types of malfunctions normally encountered.

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SECTION 26
FUNDAMENTALS OF SERVICE OPERATIONS

The installation and maintenance of refrigeration equipment is one of the most exacting and demanding tasks in the service field. In addition to the care necessary in working with equipment built with fine precision to the close tolerances required, refrigerants introduce an additional hazard. Servicemen often tend to underestimate how much care is required to properly protect a system.

So long as a refrigerant is tightly imprisoned and properly controlled, it can be made to perform useful work. But it doesn't do it willingly. Given the slightest opportunity, it will escape. If joined by such common substances as moisture or air, it combines with them to form acids and attack the system. And, if left uncontrolled for even a few hours, it can migrate through the system, often with fatal results to the compressor on start-up. When handling refrigerants, the serviceman can never relax, he must always be alert and on guard.

CONTAMINANTS

Absolute cleanliness is essential in a refrigeration system. In order to insure a reliable, trouble free unit, there are no compromises.

Unlike most other mechanical equipment, refrigeration systems are vulnerable to attack from two common contaminants, air and water, which cannot be seen. Yet if either or both are present in a system, they quickly join in a common attack on the refrigerant and oil, and can cause corrosion, copper plating, acid formation, sludging, and other harmful reactions.

Antifreeze solutions or other additives may create undesirable chemical reactions in a system. Additives of any type are not recommended and should not be used.

It is amazing, and sometimes almost unbelievable, to see the many foreign materials that have entered a refrigeration system and end up in the compressor. Filings, shavings, dirt, solder, flux, metal chips, bits of steel wool, mortar, sand from sandcloth, wires from cleaning brushes, lengths of copper tubing—all have been encountered. Examination of returned compressors indicates that many early failures could have been prevented if the contaminants had been removed from the system at the time of installation. This type of problem is encountered most often on field installed systems, and it seems inescapable that many of the contaminants found in systems could get there only from carelessness during installation.

When brazing copper tubing and fittings, copper oxide is invariably formed on the inside of the tube unless nitrogen or some other inert gas is circulated through the tubing during the brazing operation. That oxide can become a powdered abrasive, plugging oil passages, scoring bearings, plugging filters, and causing other injurious effects.

Reasonable care during installation and service can keep contamination in a system at a safe and acceptable level.

1. Take care to keep tubing clean and dry.

2. Pass an inert gas through the tubing when brazing refrigerant tubes.

3. Take extreme care to keep foreign materials out of the system when it is opened for service.

4. Suction line filters and liquid line filter-driers should be installed in all field installed systems.

5. Thoroughly evacuate the system at the time of original installation, or after exposure for long periods, during maintenance.

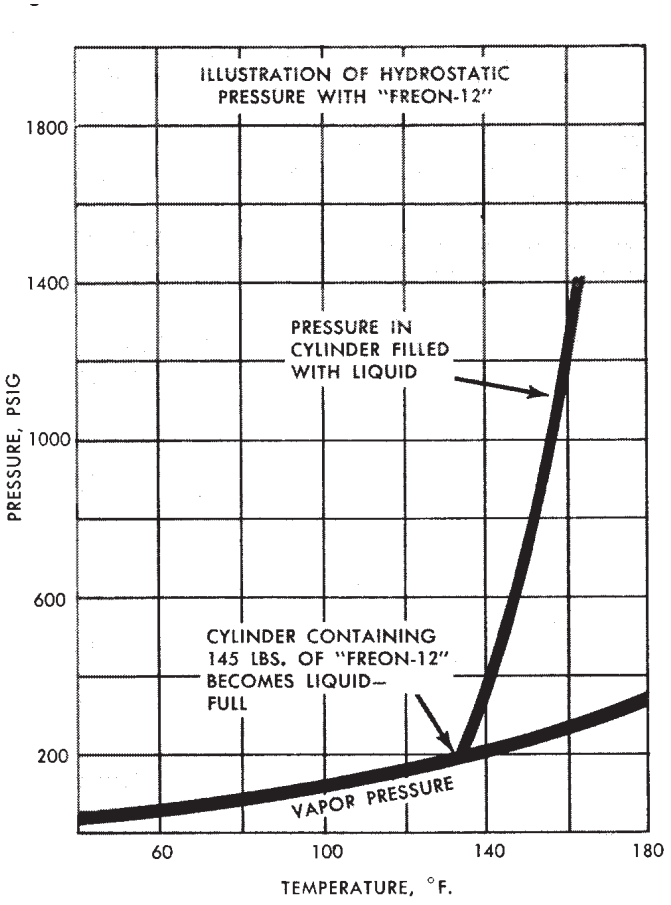
6. Install a new filter-drier in the liquid line each time the system is opened for service.

HANDLING OF REFRIGERANT CONTAINERS

The pressure created by liquid refrigerant in a sealed storage container is equal to its saturation pressure at the liquid temperature so long as there is vapor space available. If however, the container is over-filled, or if in the case of gradual and uniform overheating the liquid expands until

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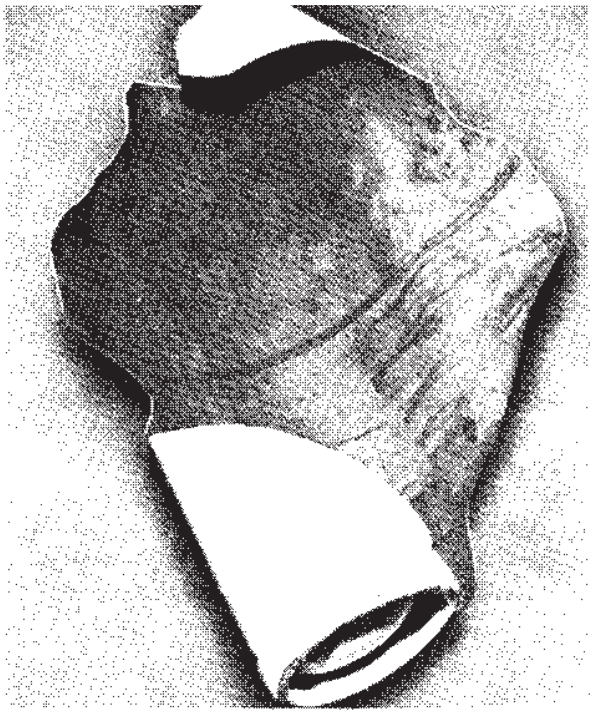
the container becomes liquid full, hydrostatic pressure builds up rapidly to pressures far in excess of saturation pressures. Figure 155 illustrates the dangerous pressures that can be created under such circumstances, which can result in possible rupture of the refrigerant container such as illustrated in Figure 156.



Courtesy E. I. DuPont de Nemours & Co.

Figure 155

The chart in Figure 155 illustrates the pressure-temperature relationship of liquid refrigerant before and after a cylinder becomes liquid-full under gradual and uniform heating. The true pressure-temperature relationship exists up to the point where expansion volume is no longer available within the cylinder.



Courtesy E. I. DuPont de Nemours & Co.

Figure 156

If a refrigerant cylinder becomes liquid-full, hydrostatic pressure builds up rapidly with only a small increase in temperature. Excessive pressure build-up can cause cylinder rupture as pictured. Under uniform conditions of heating, the cylinder illustrated ruptured at approximately 1,300 pounds per square inch gauge pressure. If heat is applied with a torch to a local area, cylinder wall may be weakened at this point and the danger of rupture would be increased. In a controlled test a cylinder such as the one pictured flew over 40 ft. in the air upon rupture—a dramatic demonstration of the danger of over-heating cylinders.

Interstate Commerce Commission regulations prescribe that a liquefied gas container shall not be liquid full when heated to 55°C. (131°F.). If cylinders are loaded in compliance with this regulation, at temperatures above 131°F. liquid refrigerant may completely fill a container because of expansion of the liquid at increasing temperatures. Fusible metal plugs are designed to protect the cylinder in case of fire, but will not protect the cylinder from

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gradual and uniform overheating. Fusible metal plugs begin to soften at 157°F., but hydrostatic pressure developed at 157°F. is far in excess of cylinder test pressure.

The following safety rules should be followed at all times when handling cylinders of compressed gas.

1. Never heat a cylinder above 125°F.
2. Never store refrigerant cylinders in the direct sunlight.
3. Never place an electric resistance heater in direct contact with a refrigerant cylinder.
4. Never apply a direct flame to a cylinder.
5. When refilling small cylinders, never exceed the weight stamped on the refrigerant cylinder.
6. Do no drop, dent, or otherwise abuse cylinders.
7. Always keep the valve cap and head cap in place when the cylinder is not in use.
8. Always open all cylinder valves slowly.
9. Secure all cylinders in an upright position to a stationary object with a strap or chain when they are not mounted in a suitable stand.

The common fluorocarbon refrigerants (R-12, R-22, R-502) were originally developed by Dupont as "Freon" refrigerants, but different manufacturers use different trade names for the same refrigerant. For example R-12 is the common industry designation for the refrigerant Dichlorodifluoromethane, but it may be marketed as Freon 12, Genetron 12, Isotron 12, Ucon 12, etc. Refrigerant containers are usually color coded as follows:

R-11	Orange
R-12	White
R-22	Green
R-502	Purple

SAFE HANDLING OF COMPRESSED GASES WHEN TESTING OR CLEANING REFRIGERATION SYSTEMS

When the use of an inert gas is required for high pressure test purposes or to flush a contaminated system, Emerson Climate Technologies, Inc. recommends the use of either dry nitrogen (N_2) or dry carbon dioxide (CO_2). At 70°F., dry nitrogen in "K" cylinders may be under a pressure of 2200 psig or more, and carbon dioxide at the same temperature may be under a pressure in excess of 830 psig. Extreme caution must be exercised in the use of highly compressed gases, since careless or improper handling can be very dangerous.

Oxygen or acetylene should never be used for pressure testing or cleanout of refrigeration systems, as the use of either may result in a violent explosion. Free oxygen will explode on contact with oil, and acetylene will explode spontaneously when put under pressure unless dissolved in a special holding agent such as used in acetylene tanks.

WARNING - HIGH PRESSURE COMPRESSED GASES SHOULD NEVER BE USED IN REFRIGERATION SYSTEMS WITHOUT A RELIABLE PRESSURE REGULATOR AND PRESSURE RELIEF VALVE IN THE LINES AS DESCRIBED HEREIN.

Recommended Test Pressures

All new Copelametic® and welded compressors are now designed with a crankcase ultimate bursting pressure in excess of 850 psig, and production samples are periodically checked hydrostatically to insure this standard being maintained. Many older models of Copeland® brand compressors and all belt driven compressor crankcases were designed for a minimum of 650 psig bursting pressure. However, the ultimate burst test is a strength test only, and both leaks and distortion can occur at high pressures even though the crankcase may not rupture.

Every Copelametic® compressor crankcase is subjected to a 300 psig pressure at the factory, and every Copeland® brand compressor is leak tested at a minimum of 175 psig.

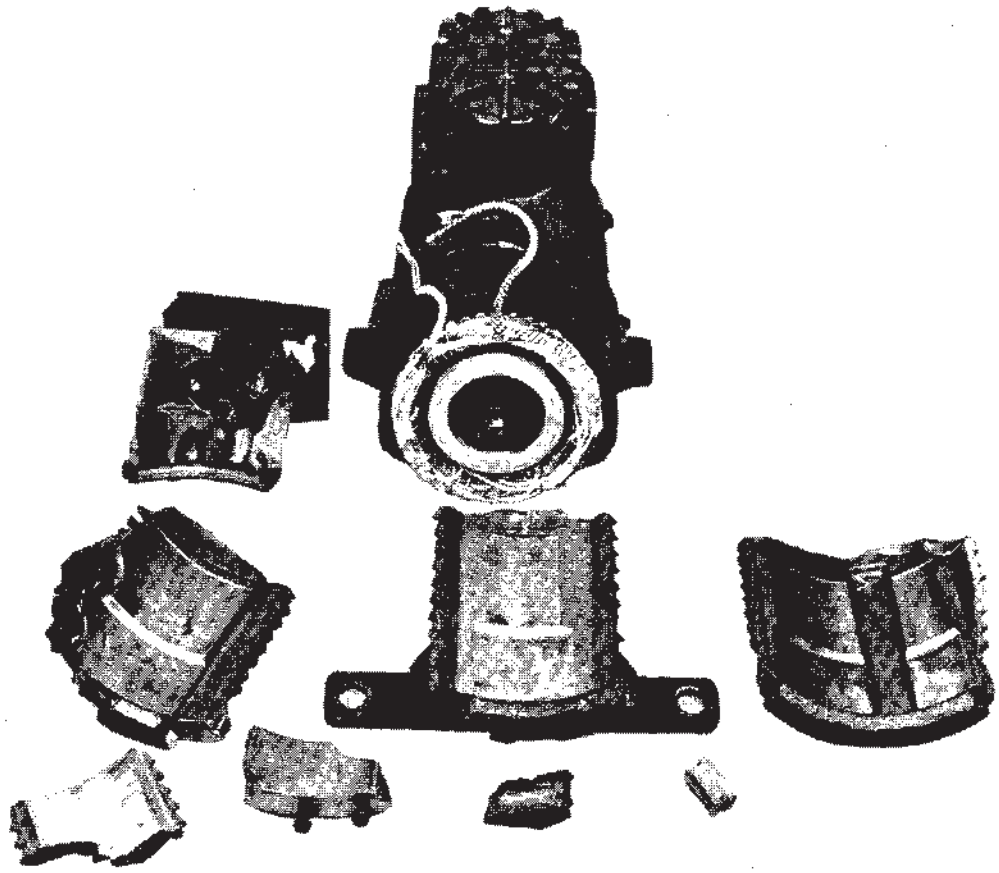
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Because of the possibility of damage in transit, and the hazard of rupture with compressed gas or air, plus the fact that many manufacturers do not design for crankcase pressures as high as those for Copeland® brand products, it is recommended that all crankcase test pressures and all leak test pressures be limited to a maximum of 175 psig. U. L. safety standard for condensing units normally can be met by testing the complete unit at the required low side pressure of 150 psig.

In the event high side test pressures are required, the crankcase must be protected from the high pressure, not only as a safety measure, but also to prevent possible distortion of the crankcase resulting in noise or mounting problems.

High side pressure conditions are dictated by the intended usage. Emerson Climate Technologies, Inc. minimum high side test pressures for unit applications are as follows, but the maximum is not to exceed 500 psig.

Copeland® Brand Application	Unit High Side Minimum Leak Test Pressure
R-12, Air or Water Cooled	335 psig
R-22 and R-502, Water Cooled	335 psig
R-22 and R-502, Air Cooled	450 psig



COMPRESSOR DAMAGE FROM EXCESSIVE INTERNAL PRESSURE

Figure 157

Figure 157 illustrates what can happen to a compressor if exposed to pressures in excess of the compressor's ultimate strength. This type of damage most frequently occurs when servicemen attempt to purge or pressurize a refrigeration system with high pressure compressed gases without a pressure regulator.

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Recommended Procedure for Leak or Pressure Tests

Figure 158 illustrates the gauges and valves that must be installed in the supply line for proper safety of personnel and equipment when testing with high pressure gases.

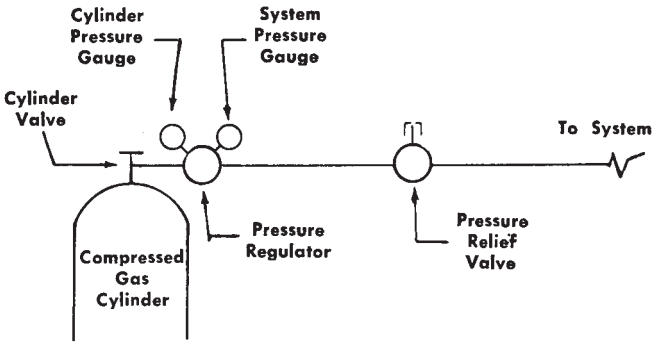


Figure 158

1. Separate relief valves for high and low side tests are required, one preset for 175 psig for low side tests, including the crankcase; the other preset at the required high side pressure.

2. When testing at pressures above 175 psig, the compressor and low pressure components must be disconnected from the system. Should it be impractical to disconnect the compressor during high side pressure test, an adequate means of pressure relief must be provided on the compressor crankcase to prevent damage in the event the high pressure gas should leak back into the crankcase. A bleed line, if provided, should be larger than the line from the gas cylinder.

3. With the compressed gas cylinder in the upright position, admit the dry nitrogen or dry carbon dioxide slowly until the desired system pressure is obtained.

4. Close the cylinder valve. Check the system pressure gauge, and adjust as necessary to obtain the proper pressure.

5. Proceed with test, and when complete, system pressure should be reduced to 0 psig, compressor reconnected, the system evacuated, and then charged with the proper kind and amount of refrigerant.

Recommended Procedure For Purging Contaminated Systems

Evacuation is the only dependable and effective means of removing air and moisture from a system to the required low level. If air is trapped in the compressor, it is practically impossible to remove from the compressor crankcase by purging. In case of a motor burn, Emerson Climate Technologies, Inc. recommends only the filter-drier system cleaning procedure.

However, in the event a system is badly contaminated (for example, if a water line ruptures in a water cooled condenser) it may be desirable to purge the system with dry compressed gas prior to starting the final cleaning process. This not only can speed the cleaning procedure, but can reduce the contaminants to a level that can be handled effectively by the necessary high vacuum equipment.

1. Disconnect the compressor and remove the low pressure components (expansion valves, capillary tubes, controls, etc.) from the system. Install suitable jumpers in place of expansion valves, capillary tubes, etc. and cap fittings from which controls were disconnected. A pressure relief device preset at 175 psig must be installed in the supply line. (See Figure 158).

2. Dry nitrogen, dry carbon dioxide may now be introduced into the system. The pressure regulator should be set to limit the pressure to 100 psig.

3. Purge gas through the system until all free contamination has been removed.

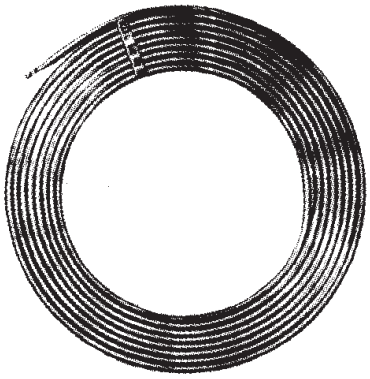
4. Close the cylinder gas valve, remove the pressure supply line, remove the jumpers, and reconnect the compressor and the low pressure components.

5. Install adequate filter-driers in the suction and liquid lines, pressure test, evacuate, and complete the system cleaning as necessary.

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HANDLING COPPER TUBING

Copper tubing is made for many types of usage, but tubing intended for plumbing or water pipe may contain waxes or oils on the interior surface that can be extremely detrimental in a refrigeration system.

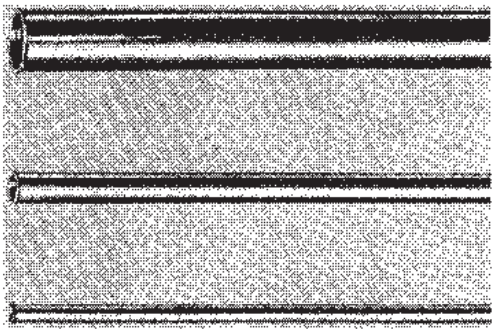


Courtesy Mueller Brass Company

Figure 159

Dehydrated and sealed coil of soft copper tubing as it comes from the manufacturer. Proper handling of tubing is necessary to obtain clean, dry systems.

Use only copper tubing especially cleaned and dehydrated for refrigeration usage. Soft copper tubing is available in rolls with the ends sealed, and hard drawn tubing is available capped and dehydrated. Keep the tubing capped or sealed until ready for installation, and reseal any tubing returned to storage.



Courtesy Mueller Brass Company

Figure 160

Examples of hard drawn copper tubing for refrigeration service. Note caps on ends to keep interior surfaces clean during storage.

In the event hard drawn tubing is left open and does get dirty, draw a rag soaked in refrigeration oil through the tubing prior to usage.

BRAZING REFRIGERANT LINES

Refrigeration systems must be leak free, and the ability to properly braze joints in tubing is an essential skill of the refrigeration serviceman.

Tubing should be cleaned and burnished bright before brazing. Care in cleaning is essential for good gas-tight connections. Particular attention should be given to preventing metal particles or abrasive material from entering the tubing.

A suitable low temperature brazing flux that is fully liquid and active below the flow point of the brazing alloy is required. Because of their nature, brazing fluxes are quite active chemically, and must be kept out of the system. Only the male connection should be fluxed, and only enough flux should be used to adequately cover the surface.



Courtesy E. I. DuPont de Nemours & Co.

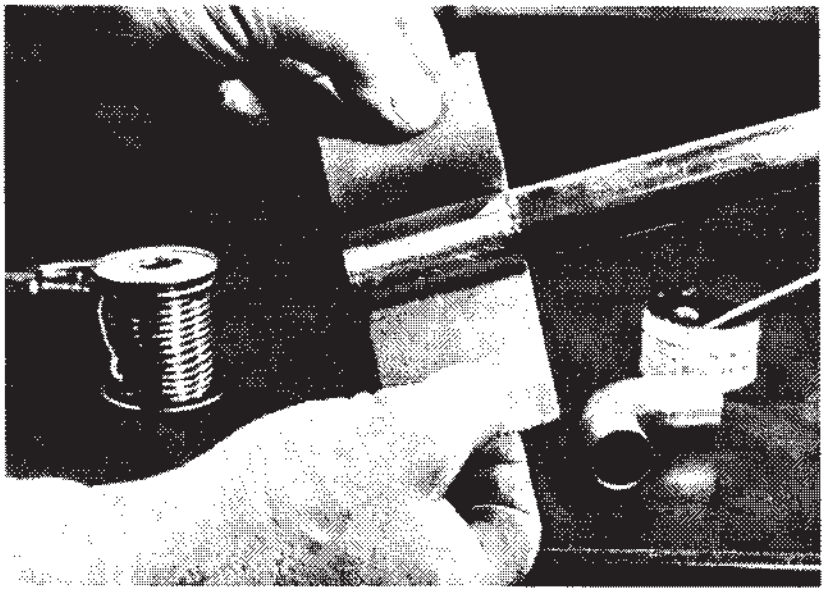
Figure 162

Applying flux to cleaned tubing before soldering. Flux should be applied sparingly and kept away from tube end.

When heat is applied to copper in the presence of air, copper oxide is formed. This oxide can be extremely harmful to a refrigeration system. To prevent its formation, an inert gas such as dry

(continued on p. 26-8)

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Courtesy E. I. DuPont de Nemours & Co.

Figure 161

Copper tube and fittings should be thoroughly cleaned down to bare metal before making soldered or brazed joint. Care in cleaning will largely insure good, gas-tight connections. Note tubing is pitched downward to prevent entry of abrasive particles.

Making silver soldered joint with fitting looking down. Whenever possible, soldered joints should be made in this manner to keep flux and solder from getting inside. Note also that dry nitrogen is being swept through the tubing while soldering to prevent oxide formation.

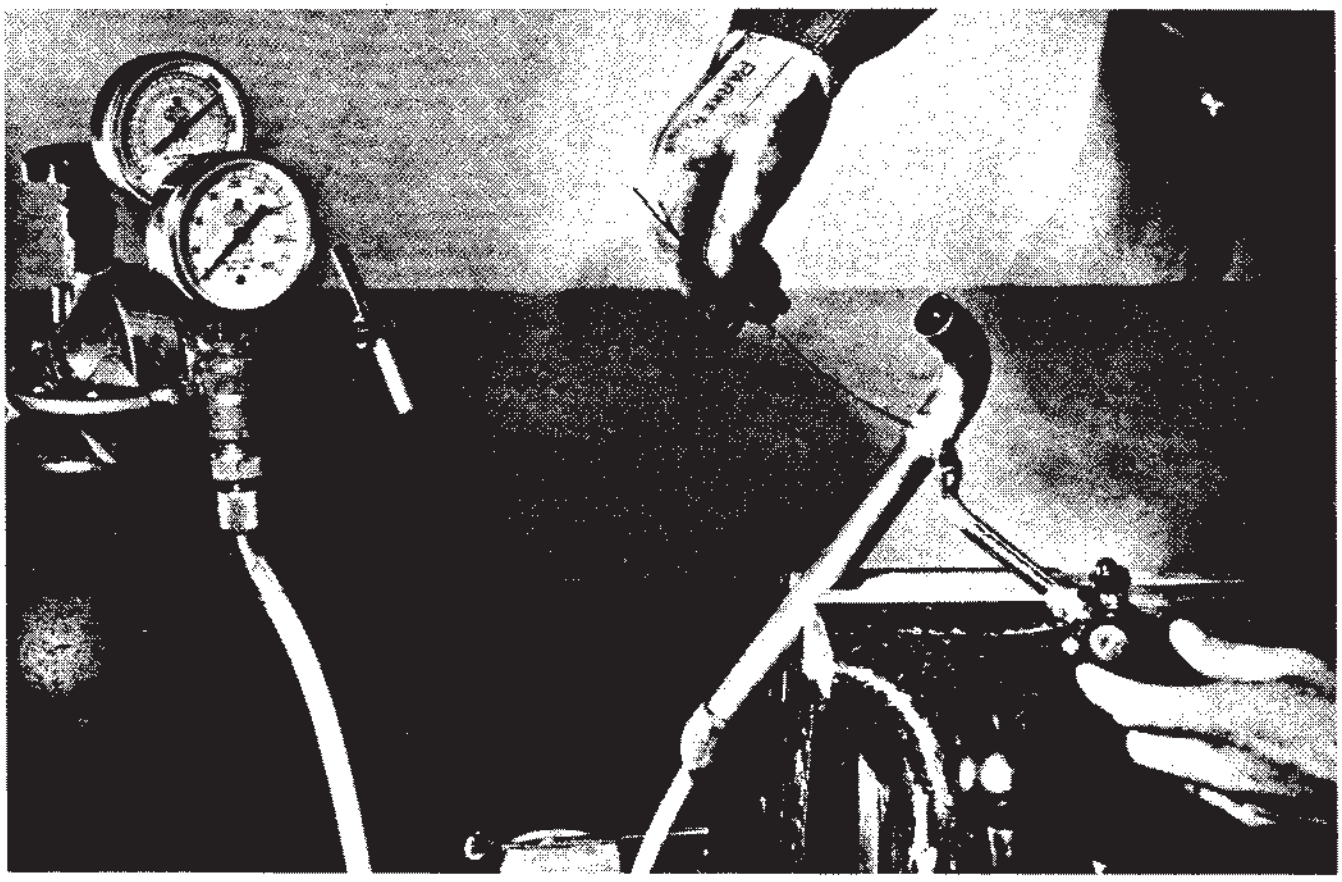


Figure 163

Courtesy E. I. DuPont de Nemours & Co.

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nitrogen should be swept through the line at low pressure during the brazing operation. Always use a pressure regulating valve in the line connecting the nitrogen cylinder to the system.

The tubing should be properly supported so that no strain is placed on the joints during brazing and cooling, and so that expansion and contraction will not be restricted.

Apply heat evenly to the tube and fitting until the flux begins to melt. The way heat is applied can either draw flux into the joint or prevent its entry. Apply heat around the circumference of the fitting to draw the brazing alloy into the joint to make a mechanically strong and tight joint.

Never apply heat to a line under refrigerant pressure. The line may rupture, and the escaping refrigerant pressure may throw blazing oil or molten solder through the air. Refrigerants when exposed to an open flame may break down into irritating or poisonous gases.

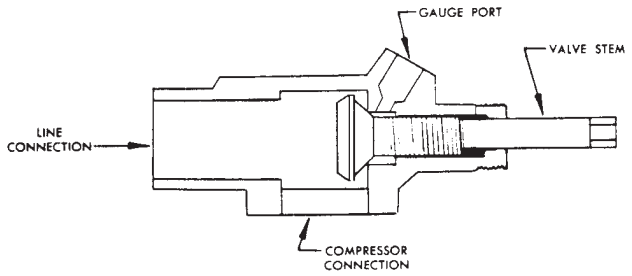
Immediately after the brazing alloy has set, apply a wet brush or cloth to the joint to wash off the flux. All flux must be removed for inspection and pressure testing.

SERVICE VALVES

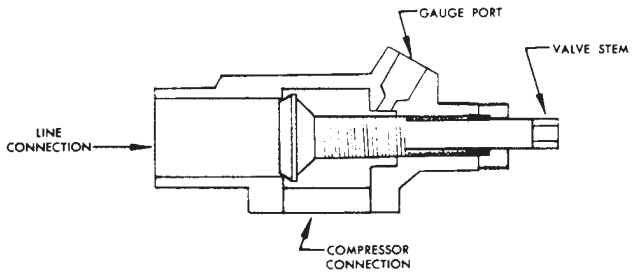
With the exception of small, unitary, sealed systems utilizing welded compressors, almost all refrigeration and air conditioning systems have service valves for operational checking and maintenance access. Normally on accessible-hermetic compressors, the compressor is equipped with suction and discharge valves having service ports. Some systems may have service valves on line connections, receiver valves, or charging valves.

Figure 164 illustrates a typical compressor service valve, but valves of similar construction may be used for base valves, receiver valves, or charging valves. Note that there is a common connection that is always open, a line connection, and a gauge port.

When the valve is back-seated (the stem turned all the way out) the gauge port is closed and the valve is open. If the valve is front-seated (the stem turned all the way in) the gauge port is open to the common connection and the line connection is closed. In order to read the pressure while the valve is open, the valve should be back-seated, and then turned in one or two turns in order to slightly open the connection to the gauge port.



Valve Backseated



Valve Frontseated

Courtesy Henry Valve Co.

COMPRESSOR SERVICE VALVE

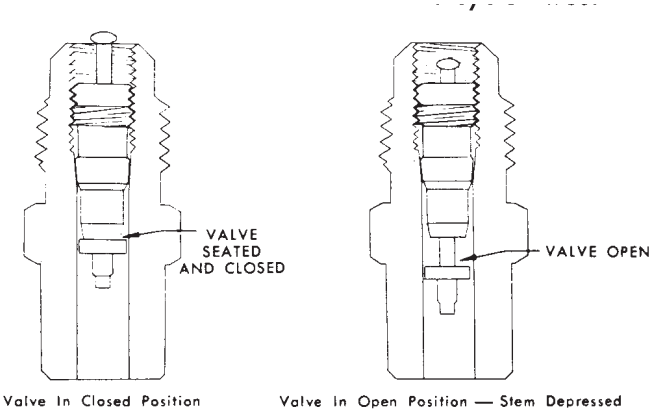
Figure 164

Some valves of the same general type intended for process access only may have only the line and gauge connections with the common port omitted. The action of the valve seat is unchanged. The line connection is closed when the valve is front-seated, the gauge connection is closed when the valve is back-seated.

Figure 165 illustrates a Schrader type valve similar in appearance and principle to the air valve used on automobile or bicycle tires.

The Schrader type valve is a recent development for convenient checking of system pressures where it is not economical, convenient, or possible to use the compressor valves with gauge ports.

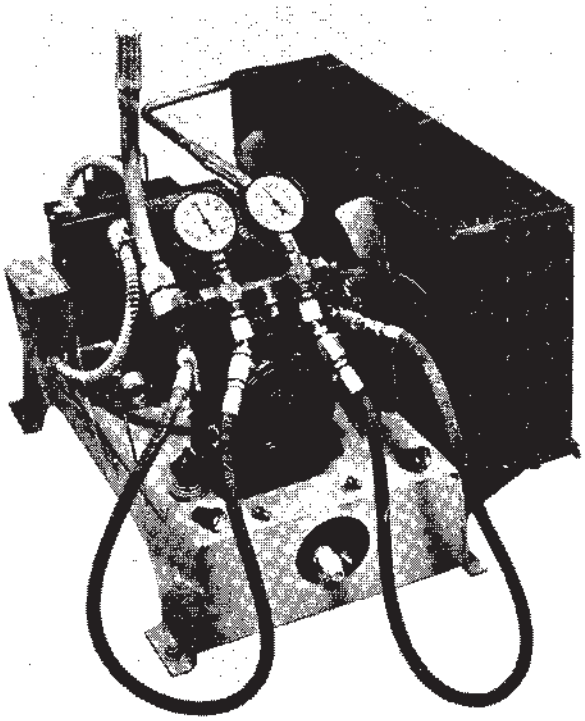
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SCHRADER TYPE VALVE

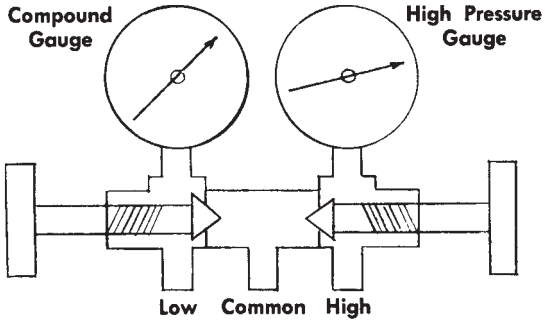
Figure 165

This type of valve enables checking of the system pressure, or charging refrigerant without disturbing the unit operation. An adaptor is necessary for the standard serviceman's gauge or hose connection to fit the Schrader type valve.



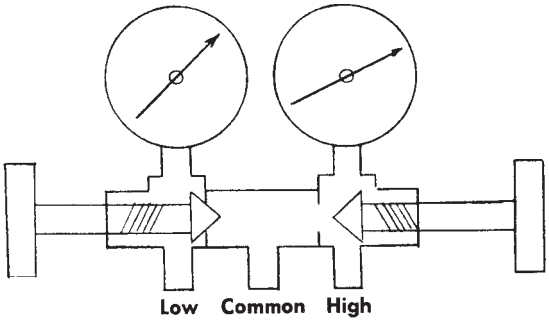
PRESSURE READING WITH GAUGE MANIFOLD

Figure 166



GAUGE MANIFOLD SHOWING REFRIGERANT PRESSURE CONNECTIONS WITH BOTH VALVES CLOSED AND THE COMMON CONNECTION ISOLATED

Figure 167



GAUGE MANIFOLD SHOWING REFRIGERANT PRESSURE CONNECTIONS WITH HIGH PRESSURE VALVE OPEN TO COMMON CONNECTION

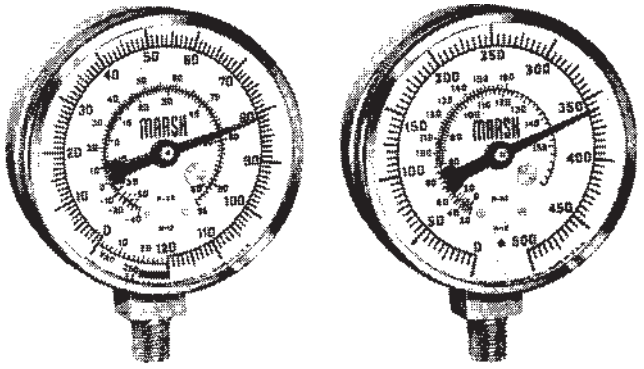
Figure 168

THE GAUGE MANIFOLD

The most important tool of the refrigeration serviceman is the gauge manifold. It can be used for checking system pressures, charging refrigerant, evacuating the system, purging non-condensables, adding oil, and for many other purposes.

Basically the gauge manifold consists of compound and high pressure gauges mounted on a manifold with hand valves to isolate the common connection, or open it to either side as desired. Figure 167 shows a schematic view of a gauge manifold with both valves closed. Figure 168 illustrates the same manifold with the common connection open to the high pressure connection. The ports above and below each valve are interconnected so the gauges will always register when connected to a pressure source.

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Compound Gauge High Pressure Gauge

Courtesy Marsh Instrument Co.

REFRIGERATION SERVICEMAN'S GAUGES

Figure 169

The left hand gauge is normally a compound or suction pressure gauge. The right hand gauge is the high or discharge pressure gauge. Flexible hoses are used to make connections from the manifold to the system.

Gauges are fine instruments and should be treated as such. Do no drop, keep in adjustment, and do not subject gauges to pressures higher than the maximum pressure shown on the scale.

Connecting the gauge manifold to a system is one of the most common service functions. To avoid introducing contaminants into the system, the hose connections must always be purged with refrigerant before connecting the manifold. A consistent procedure should always be followed by the serviceman in making the connections. For an operating system containing refrigerant, proceed as follows:

First, back-seat the service valves to which the gauges are to be connected so that the gauge ports are isolated. Be sure both manifold valves are closed (front-seated).

If operating conditions are such that the suction pressure is certain to be above 0 psig, tighten hose connections to both service valves. Be sure common hose connection on manifold is open.

Crack (open slightly) the high pressure manifold valve. Then crack the high pressure service valve thus allowing refrigerant to bleed through the discharge and common hoses. Allow refrigerant to bleed for a few seconds, and then close the high pressure valve on the manifold. Repeat the same procedure with the low pressure valves. The manifold is then connected to the system ready for use.

In the case of system where the low side pressure might be in a vacuum, all purging must be done from the high pressure service valve. Back-seat the service valves and tighten the hose connection to the high pressure service valve. Leave hose connection at low side service valve loose and cap or plug loosely the common hose connection. Crack both high and low pressure valves on the manifold. After a few seconds, tighten the hose connection at the low pressure service valve, and then tighten the cap or plug in the common connection. Close the valves on the manifold, crack the low pressure service valve, and the manifold is then connected to the system ready for use.

PURGING NON-CONDENSABLES

A leak in the low pressure side of an operating system frequently results in the entrance of air. In some cases it may be impractical to remove the refrigerant charge and evacuate the system, yet the air must be removed to prevent damaging chemical reactions.

Air is non-condensable under the temperatures and pressures encountered in an air conditioning or commercial refrigeration system. The liquid seal at the outlet of the receiver and condenser will normally trap the air in the top of the receiver and condenser. The system condensing pressure will be increased by the pressure exerted by the trapped air, the amount of the increase in pressure being dependent on the quantity of air trapped. Before starting to purge, note the compressor operating discharge pressure, and compare with the temperature of the condensing medium.

Restart the compressor and check to see if the discharge pressure is still abnormally high. If so, operate the system for a few minutes and repeat the purging procedure. Normally purging 3 or 4 times will remove most of the non-condensables trapped in the top of the condenser and restore

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normal operating pressures. However, purging should be used only as a short term emergency measure. In order to insure satisfactory compressor operation the system should be evacuated as soon as practical.

SYSTEM PUMPDOWN

For any service work requiring access to the compressor or the sealed part of the system, the refrigerant must first be removed. On small systems without service valves, it may be necessary to remove the refrigerant charge prior to servicing the equipment, and then recharge the system when put back in service.

On any system with service valves, the refrigerant can be pumped into the condenser and receiver (if used) and isolated there. This operation is termed pumping the system down, and is accomplished by closing the valve at the outlet of the receiver or condenser while the compressor is operating. Since no further refrigerant can flow to the evaporator, the refrigerant is pumped out of the evaporator and into the condenser.

Check the operating pressures by means of a gauge manifold, (see Figure 166) and when the suction pressure reaches 1 to 2 inches of vacuum, stop the compressor. (Note: If the unit is equipped with a low pressure control having a higher setting, it will be necessary to bypass the low pressure control in order to keep the compressor operating while pumping the system down.) If the pressure rises rapidly, this is an indication that there is still residual refrigerant in the compressor crankcase. Start the compressor and again pump the suction pressure down to 1 to 2 inches of vacuum. If the pressure remains at that point or rises very slowly, close the compressor discharge service valve. In the event the pressure should remain in a vacuum, disconnect power from the compressor, and crack the receiver valve momentarily to introduce sufficient refrigerant to obtain a slight positive pressure.

The liquid line, the low pressure side of the system, and the compressor should now be at a slight positive pressure, (approximately 1 psig) and that part of the system can be opened for service. The refrigerant pressure prevents the inrush of air into the open system, and reduces contamination to a minimum.

Note that if it is necessary to remove or gain access to the discharge line, condenser, or receiver, pumping the system down is of no benefit, and the refrigerant charge must be removed unless there are valves to isolate the defective component.

Pumpdown control is also used as a means of isolating the refrigerant and preventing migration to the compressor crankcase during periods of shipment, storage, or long non-operating off cycles.

REFRIGERANT LEAKS

Refrigeration systems must be absolutely gas tight for two reasons. First, any leakage will result in loss of the refrigerant charge. Second, leaks allow air and moisture to enter the system.

Leaks can occur not only from joints or fittings not properly made at the time of the original installation, but from line breakage due to vibration, gasket failure, or other operating malfunctions. A recent study by a major user of commercial equipment revealed that of approximately 3,000 service calls made during a typical year's operation, 1 out of 6 were required because of refrigerant leaks. Since leak detection is such a common service complaint, it is essential that the service engineer check the system carefully to insure that it is leak tight before charging with refrigerant.

There are three common means of pressure testing a system for leaks. The pressure text method involves pressurizing the system and checking for leakage outward.

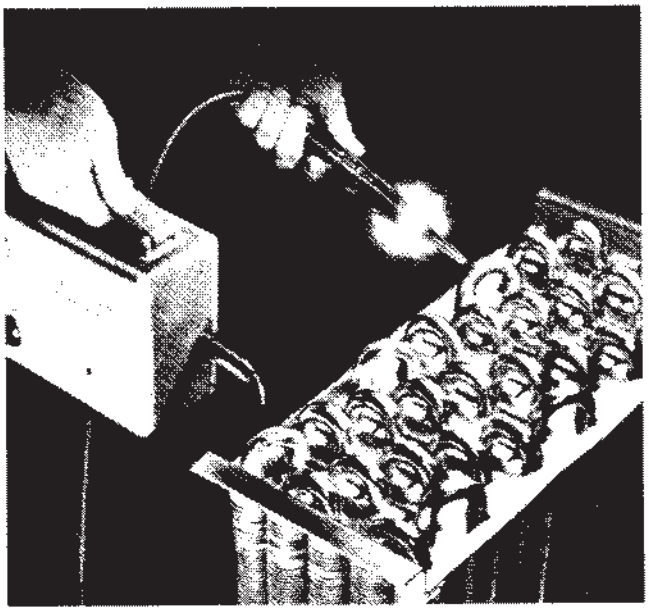
WARNING — Never use oxygen for pressurizing a system; an explosion may occur if oil is present in the system. Always use a gauge equipped pressure regulator on the high pressure back-up gas, and never interconnect the refrigerant cylinder and the inert gas cylinder through a gauge manifold. Nitrogen and carbon dioxide cylinder pressures can rupture a refrigerant cylinder.

The electronic leak detector is the most sensitive

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type available. These are available at reasonable cost, and can detect small leaks of a fraction of an ounce per year, often missed when using other testing methods. Because of their extreme sensitivity, electronic detectors can only be used in a clean atmosphere not contaminated by refrigerant vapor, smoke, vapor from carbon tetrachloride, or other solvents which may give a false reaction.

The leak detector most widely used for field service is the halide torch. It consists of a small portable propane or L. P. gas tank, a sniffer hose, and a special burner which contains a copper element. The gas feeds a small flame in the burner, pulling a slight vacuum on the sniffer hose. When the probe is passed near a leak, the refrigerant is drawn into the hose and injected into the burner below the copper element. A small amount of refrigerant burning in the presence of copper has a bright green color. A larger amount will burn with a violet colored flame. When testing for leaks with a torch, always watch the flame for the slightest changes in color. With experience, very small leaks can be detected.



Courtesy E. I. DuPont de Nemours & Co.

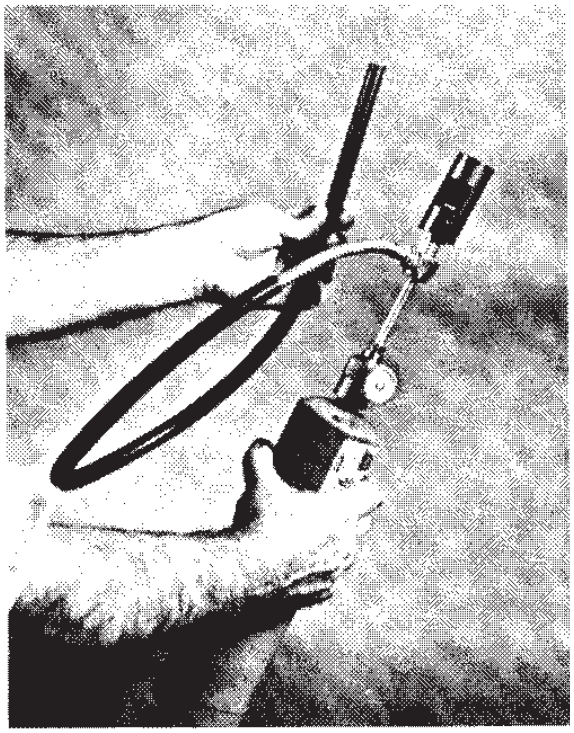
ELECTRIC LEAK DETECTOR

Figure 170

This type of detector is ideally suited for field service of air conditioning and refrigeration equipment.

To use the halide torch to find a leak, explore each joint and fitting in the system. Check all gasketed joints at the compressor. Some manufacturers use the halide torch as a final check on packaged systems which are shipped in cartons, by punching a hole in the carton and checking inside the carton several hours after the unit is packaged. A very small leak will tend to build up in strength in an enclosed area, and can thus be detected.

The simplest and oldest method of leak detection is by means of soap bubbles. Swab a suspected leak with liquid soap or detergent, and bubbles will appear if a leak exists. Despite its simplicity, the soap bubble method can be extremely helpful in pinpointing a leak which is difficult to locate.



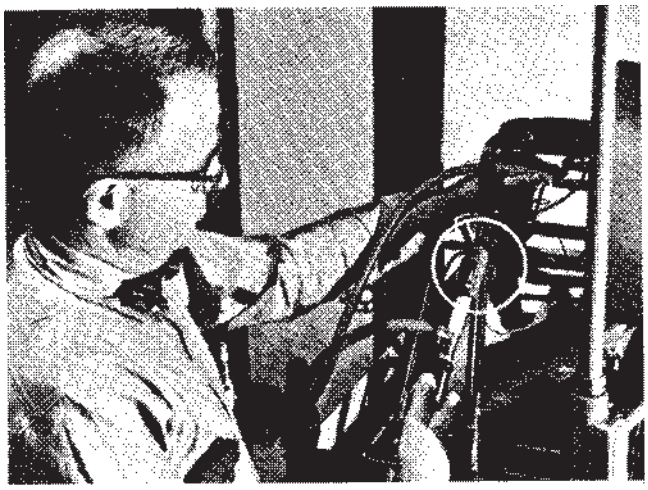
Courtesy E. I. DuPont de Nemours & Co.

HALIDE TYPE LEAK DETECTOR

Figure 171

The oldest and probably most widely used leak detector for fluorinated refrigerants is the halide type. The one illustrated is made to attach to a small, portable gas cylinder. This makes a very compact, easy to use, leak detection device.

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Courtesy E. I. DuPont de Nemours & Co.

Figure 172

Checking for refrigerant leaks with halide torch. Note sampling tube held adjacent to point of possible leak. Eye should be kept on flame to observe any color change.

When a leak is located, it should be marked. When leak testing is completed and all leaks have been located and marked, vent the test pressure gas. If a leak requiring brazing is found in the high pressure side of a system containing a refrigerant charge, in a location that cannot be isolated, it will be necessary to remove the refrigerant in order to make repairs.

When pressure has been removed from the area where the leak is located, the leak can be repaired as necessary. It may be necessary to re-braze fittings, replace gaskets, repair flare connections, or merely tighten connections. When all leaks have been repaired, the system should again be pressurized and the leak testing process repeated.

Pressure leak testing is necessary to locate individual leaks. In order to determine if the system is free of all leaks, a vacuum test is helpful. After repairing all known leaks, draw a deep vacuum on the system with a good vacuum pump. The pressure should be reduced to 1 psia or less (the vacuum registered on the test gauge will vary with atmospheric pressure) and the system should be sealed and left for at least 12 hours. Any leakage of air into the system will cause the vacuum reading to decrease. (Some slight change in pressure may be caused by changes in ambient temperature). If an air leak is indicated, the system should again be pressure leak tested, and the leaks located and repaired.

When all leaks have been repaired and the system satisfactorily passes the leak tests, it is ready for evacuation and charging.

EVACUATION

Any time the compressor or system is exposed for prolonged periods to atmospheric air, or if the system becomes contaminated and removal of the refrigerant charge is necessary, the system should be evacuated in the same manner as at the original installation.

Liquid line filter-driers will effectively remove small amounts of moisture from a system, but the amount of moisture in an open system may be greater than a drier's capacity. In both cases, evacuation is the only means of insuring a contaminant free system.

Under no conditions is the motor-compressor to be started or operated while the system is under a high vacuum. To do so may cause serious damage to the motor windings.

A small portable vacuum pump specifically built for refrigeration evacuation should be used. Do not use the refrigeration compressor as a vacuum pump. The serviceman who uses some discarded refrigeration compressor as a vacuum pump is fooling himself and endangering the system.

The gauge manifold provides a convenient means of connecting the vacuum pump to a service valves on the compressor or in the system, and is adequate for field evacuation of relatively small systems with small displacement vacuum pumps. For larger systems and larger vacuum pumps, however, the pressure drop through the hose connections on the normal service gauge manifold is so high that evacuation is very slow, and gauge readings may be misleading. Copper tubing or high vacuum hoses of ¼ in. I.D. minimum size are recommended for high vacuum work.

Triple evacuation is strongly recommended for all field installed systems because of the greater

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degree of contamination that must be expected under actual operating conditions as opposed to laboratory or production line processing.

To evacuate a system with a small vacuum pump and a gauge manifold, attach the common connection on the gauge manifold to the suction connection on the vacuum pump. The high and low pressure connections on the gauge manifold should be securely connected to gauge ports on service valves on the high and low pressure sides of the system respectively.

With the valves on the gauge manifold closed (front-seated) open the service valves and adjust to a point approximately midway between the front-seat and back-seat position.

Start the vacuum pump and gradually open the gauge manifold valves. It may be necessary to restrict the vacuum pump suction pressure by means of the gauge manifold valves to avoid overloading the pump motor. Continue evacuation until the desired vacuum reading is obtained on both gauges.

When evacuation is complete, close the gauge manifold valves tightly, remove the line from the vacuum pump, and connect to a refrigerant cylinder of the same type refrigerant used in the system. Loosen the common hose connection at the gauge manifold, crack the refrigerant drum valve to purge the hose, and retighten the hose connection. Crack the valves on the gauge manifold until the system pressure rises to 2 psig. Close the refrigerant drum valve and the gauge manifold valves.

For triple evacuation, the above procedure should be repeated three times, evacuating twice to 1500 microns, and the last time to 500 microns, or to the limit of the vacuum pump's ability.

When complete, the system is ready for charging. If it is not to be charged immediately, the system may be sealed by back-seating the service access valves, and plugging or capping all open gauge ports or connections.

CHARGING REFRIGERANT INTO A SYSTEM

The proper performance of a refrigeration or air conditioning system is dependent on the proper refrigerant charge. An under-charged system will starve the evaporator, resulting in excessively low compressor suction pressures, loss of capacity, and possible compressor overheating. Overcharging can flood the condenser resulting in high discharge pressures, liquid refrigerant flooding, and potential compressor damage. Most systems have a reasonable area of tolerance for some variation in charge, although some small systems may actually have a critical charge which is essential for proper operation.

Each system must be considered separately, since systems with the same capacity or horsepower rating may not necessarily require the same refrigerant or the same amount of charge. Therefore it is important to first determine the type of refrigerant required for the system, the unit nameplate normally identifying both the type of refrigerant and the weight of refrigerant required.

Liquid Charging

Charging with liquid refrigerant is much faster than vapor charging, and because of this factor is almost always used on large field installed systems. Liquid charging requires either a charging valve in the liquid line, a process fitting in the high pressure side of the system, or a receiver outlet valve with a charging port. It is recommended that liquid charging be done through a filter-drier to prevent any contaminants from being inadvertently introduced into the system. Never charge liquid into the compressor suction or discharge service valve ports, since this can damage the compressor valves.

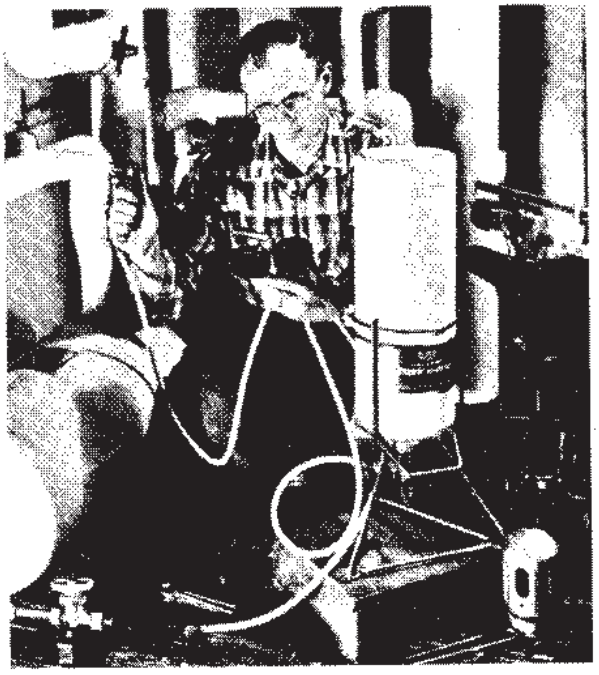
For original installations, the entire system should be pulled to a deep vacuum. Weigh the refrigerant drum, and attach the charging line from the refrigerant drum to the charging valve. If the approximate weight of refrigerant required is known, or if the charge must be limited, the refrigerant drum should be placed on a scale so that the weight of refrigerant can be checked frequently.

Purge the charging line and open the cylinder liquid valve and the charging valve. The vacuum in the system will cause liquid to flow through the charging connection until the system pressure is equalized with the pressure in the refrigerant cylinder.

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Close the receiver outlet valve and start the compressor. Liquid refrigerant will now feed from the refrigerant cylinder to the liquid line, and after passing through the evaporator will be collected in the condenser and receiver.

To determine if the charge is approaching the system requirement, open the receiver outlet valve, close the charging valve, and observe the system operation. Continue charging until the proper charge has been introduced into the system. Again weigh the refrigerant drum, and make a record of the weight charged into the system.



Courtesy E. I. DuPont de Nemours & Co.

Figure 173

Liquid-charging refrigerant through the charging valve on main liquid supply line. Note that cylinder is safely held in inverted position on weighing scale. Liquid shut off valve on receiver would also be throttled to facilitate flow from cylinder.

Watch the discharge pressure gauge closely. A rapid rise in pressure indicates the condenser is filling with liquid, and the system pumpdown capacity has been exceeded. Stop charging from the cylinder immediately if this occurs, and open the receiver outlet valve.

On factory assembled package units utilizing welded compressors, charging is normally accomplished by drawing a deep vacuum on the system, and introducing the proper charge by weight into the high pressure side of the system by means of a process connection which is later sealed and brazed closed. To field charge such systems, it may be necessary to install a special process fitting or charging valve, and weigh in the exact charge required.

Vapor Charging

Vapor charging is normally used when only small amounts of refrigerant are to be added to a system, possibly up to 25 pounds, although it can be more precisely controlled than liquid charging. Vapor charging is usually accomplished by means of a gauge manifold into the compressor suction service valve port. If no valve port is available—for example on welded compressors—it may be necessary to install a piercing valve or fitting in the suction line.



Courtesy E. I. DuPont de Nemours & Co.

Figure 174

Vapor-charging refrigerant through compressor suction service valve. Gauges are connected to read both suction and discharge pressure. When adding refrigerant, discharge pressure should be observed to be sure system is not over-charged and refrigerant is not being added too rapidly. Higher than normal discharge pressure indicates either that condenser is filling with liquid or compressor is being over-loaded by too rapid charging. Charging

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manifold permits throttling of the vapor from the cylinder. Cylinder is mounted on scale to measure amount of refrigerant charged. Approved valve wrench is being used to operate cylinder valve.

Weigh the refrigerant cylinder prior to charging. Connect the gauge manifold to both suction and discharge service valves, with the common connection to the refrigerant cylinder. Purge the lines, open the refrigerant cylinder vapor valve, start the compressor, and open the suction connection on the gauge manifold. Modulate the rate of charging with the gauge manifold valve.

The refrigerant cylinder must remain upright with refrigerant withdrawn only through the vapor valve to insure vapor only reaching the compressor. The vaporizing of the liquid refrigerant in the cylinder will chill the liquid remaining and reduce the cylinder pressure. To maintain cylinder pressure and expedite charging, warm the cylinder by placing it in warm water or by using a heat lamp. **Do not** apply heat with a torch.

To determine if sufficient charge has been introduced, close the refrigerant cylinder valve and observe the system operation. Continue charging until the proper charge has been added. Again weigh the refrigerant drum and make a record of the weight charged into the system.

Watch the discharge pressure closely during the charging operation to be certain that the system is not overcharged.

How To Determine The Proper Charge

1. Weighing the Charge.

The most accurate charging procedure is to actually weigh the refrigerant charged into the system. This can only be done when the system requires a full charge and the amount of charge is known. Normally such data is available on packaged unitary equipment. If the charge is small, it is common practice to vent the system charge to the atmosphere if repairs are required, and add a complete new charge after repairs are complete.

2. Using A Sight Glass

The most common method of determining the proper system charge is by means of a sight glass in the liquid line. Since a solid head of liquid refrigerant is essential for proper expansion valve control, the system can be considered properly charged when a clear stream of liquid refrigerant is visible. Bubbles or flashing usually indicate a shortage of refrigerant. Bear in mind that if there is vapor and no liquid in the sight glass, it will also appear clear.

However, if the service engineer should be aware of the fact that at times the sight glass may show bubbles or flash gas even when the system is fully charged. A restriction in the liquid line ahead of the sight glass may cause sufficient pressure drop to cause flashing of the refrigerant. If the expansion valve feed is erratic or surging, the increased flow when the expansion valve is wide open can create sufficient pressure drop to create flashing at the receiver outlet. Rapid fluctuations in condensing pressure can be a source of flashing. For example, in a temperature controlled room, the sudden opening of shutters or the cycling of a fan can easily cause a change in condensing temperature of 10°F. to 15°F. Any liquid in the receiver may then be at a temperature higher than the saturated temperature equivalent to the changed condensing pressure, and flashing will occur until the liquid temperature is again below the saturation temperature.

Some systems may have different charge requirements under different operating conditions. Low ambient head pressure control systems for air cooled applications normally depend on partial flooding of the condenser to reduce the effective surface area. Under such conditions a system operating with a clear sight glass under summer conditions may require a refrigerant charge twice as large for proper operation under low ambient conditions.

While the sight glass can be a valuable aid in determining the proper charge, the system performance must be carefully analyzed before placing full reliance on it as a positive indicator of the system charge.

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3. Using A Liquid Level Indicator

On some systems, a liquid level test port may be provided on the receiver. The proper charge can then be determined by charging until liquid refrigerant is available when the test port is cracked. With less than a full charge, only vapor will be available at the test port.

Larger receiver tanks may be equipped with a float indicator to show the level of liquid in the receiver much in the same manner as a gasoline tank gauge on an automobile.

4. Checking Liquid Subcooling

On small systems, if no other easy means of checking the refrigerant charge is available, a determination of the liquid subcooling at the condenser outlet can be used. With the unit running under stabilized conditions, compare the temperature of the liquid line leaving the condenser with the saturation temperature equivalent to the condensing pressure. This provides an approximate comparison of the condensing temperature and the liquid temperature leaving the condenser. Continue charging until the liquid line temperature is approximately 5°F. below the condensing temperature under maximum load conditions. This type of charging is normally used only on factory packaged systems, but it does provide a means of emergency field checking which should indicate proper system operation.

5. Charging By Superheat.

On small unitary systems equipped with capillary tubes, the operating superheat may be used to determine the proper charge.

If a service port is available so that the suction pressure can be determined, the superheat may be calculated by determining the difference be tween the temperature of the suction line approximately 6 inches from the compressor and the saturation temperature equivalent of the suction pressure. If no means of determining pressure is available, then the superheat can be taken as the difference between the suction line temperature 6 inches from the compressor and a temperature reading on an evaporator tube (not a fin) at the midpoint of the evaporator.

With the unit running at its normal operating condition, continue charging until the superheat as determined above is approximately 20° to 30°. A superheat approaching 10° indicates an over charged condition, a superheat approaching 40° indicates an undercharge.

6. Charging by Manufacturer's Charging Charts.

Some manufacturers of unitary equipment have charging charts available so that the proper charge may be determined by observing the system operating pressures. Follow the manufacturer's directions for determining proper charge if the unit is to be charged in this fashion.

REMOVING REFRIGERANT FROM A SYSTEM

Occasionally it will be necessary to remove refrigerant from a system. To properly remove the refrigerant, the individual servicing the unit must abide by the following guidelines.

1. Complying with Law and Regulation

During the recovery, recycle and reuse of any and all refrigerants it is imperative that one complies with current laws and regulations. It is the responsibility of the individual servicing the refrigeration unit to follow all current local, state, and federal laws, regulations, and ordinances. It is also their responsibility to follow any directions or guidelines that are set forth by the recovery unit equipment manufacturer.

2. Using the System Compressor

Connect the gauge manifold from the compressor discharge valve service port to the refrigerant container and purge the lines. Note the maximum allowable refrigerant container weight.

Place the refrigerant container in ice. Place the compressor in normal system operation. Turn the discharge service valve in a few turns to open the service port, open the refrigerant container valve and the gauge manifold so that discharge gas can enter the cold container, with the discharge pressure registering on the manifold high pressure gauge. **WARNING.** Do not close off the discharge valve to the condenser. A portion of the discharge

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gas will now enter the container and condense. Weigh the container frequently to check the progress in filling. Continue bypassing a portion of the discharge gas into the refrigerant container until it is filled to its weight capacity. **Do Not Overfill**. Use additional containers as necessary.

When a major portion of the refrigerant has been removed, system pressures may fall so low that refrigerant can no longer be efficiently transferred.

3. Using a Transfer Condensing Unit

A small, air cooled condensing unit equipped with an oil separator may be used as a scavenging or transfer pump to transfer refrigerant to storage containers. By means of a gauge manifold connect system discharge and suction service ports to the transfer pump, and connect the transfer unit liquid outlet connection to the refrigerant container.

Purge lines as previously outlined, start the transfer pump, and modulate the suction pressure as necessary with the gauge manifold to prevent overloading.

WARNING. Watch refrigerant cylinder weight closely. Do no overfill.

4. Charge Migration.

In the absence of a transfer condensing unit, and when the system compressor is inoperative, refrigerant may be transferred to a storage container by migration. Evacuate the container if possible, and connect to the system by means of the gauge manifold.

Chill the refrigerant container to the lowest possible temperature. Pack in ice or dry ice if available. Open the valves so that the refrigerant can migrate from the warm and therefore higher pressure system to the cold and lower pressure cylinder. **Do Not overfill**.

Migration will continue until the system pressure is the equivalent of the saturated pressure of the refrigerant at the cylinder temperature. For example, if the cylinder is 40°F. and the refrigerants R-12, migration will continue until the system pressure is approximately 37 psig.

A disadvantage of this system is the length of time required for the transfer.

HANDLING REFRIGERATION OIL

Oil processed for use in refrigeration compressors is highly refined, dewaxed, and dehydrated. In order top protect its quality, refrigeration oil is shipped in tightly sealed containers. Exposure to air and moisture for extended periods will result in contamination of the oil, and can cause harmful reactions in the compressor.

Refrigeration oils are available in sealed containers in various sizes, but should be purchased only in the sized container needed for the immediate application. It is highly recommended that oil added to a compressor be taken only from sealed containers opened at the time of use. Do not transfer oil from one container to another, and do not store in open containers. Buying oil in large containers to obtain a better price is false economy. In the long run, it will be far more costly in terms of compressor damage and customer ill will.

Compressors leaving the Emerson Climate Technologies, Inc. factory are charged with Suniso 3G or 3GS, 150 SUS viscosity refrigeration oil, and the use of any other oil must be specifically cleared with the Emerson Climate Technologies, Inc. Application Engineering Department.

DETERMINING THE OIL LEVEL

All service compressors are shipped with a charge of the proper refrigeration oil. Normally the factory oil charge in the compressor is somewhat greater than the normal oil level required for adequate lubrication, in order to provide some allowance for oil which will be circulating in the system during operation. Depending on the system design, the amount of oil in the system at the time of compressor installation, oil lost due to leakage, etc., it may be necessary either to add or remove oil from a system any time it is first placed in operation with a different compressor.

On Copeland® brand compressors equipped with crankcase sightglasses, the oil level should be maintained at or slightly above the center of the sight glass while operating. An abnormally low oil

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level may result in a loss of lubrication; while an excessively high oil level may result in oil slugging and possible damage to the compressor valves or excessive oil circulation. The oil level may vary considerably on initial start-up if liquid refrigerant is present in the crankcase, and the oil level should be checked with the compressor running after having reached a stabilized condition.

Most welded hermetic compressors have no means of determining the oil level. This type of compressor is primarily designed for installation in factory designed, assembled, and charged systems where the oil charge can be accurately measured into the system at the time of original assembly. In the case of a leak, if the amount of oil lost is small and can be reasonably calculated, this amount should be added to the compressor. If however, there is a major loss of oil, the serviceman must remove the compressor, drain the oil, and add the correct measured charge before placing the compressor in operation.

ADDING OIL TO A COMPRESSOR

1. Open System Method

If the compressor is equipped with an oil fill hole in the crankcase, the simplest means of adding oil is to isolate the compressor crankcase, and pour or pump the necessary oil in. If the system contains no refrigerant, or the compressor is open for repairs, no special precautions are necessary other than the normal measures of keeping the oil clean and dry, since the system should be evacuated prior to start-up.

If the system contains a charge of refrigerant, close the compressor suction valve and reduce the crankcase pressure to approximately 1 to 2 psig. Stop the compressor and close the compressor discharge valve.

Remove the oil fill plug and add the required amount of oil. The residual refrigerant in the crankcase will generate a slight continuing pressure and outflow of refrigerant vapor during the period when the compressor is exposed to the atmosphere, preventing the entrance of serious amounts of either air or moisture. Purge the crankcase by cracking the suction service valve off its seat for 1 or 2 seconds. Replace the oil fill plug, open the compressor valves, and restore the system to operation.

In the case of welded compressors installed in systems without service fittings, the only means of adding oil to the compressor may be by cutting the refrigerant lines so that oil can be poured directly into the suction line since the suction connection on a welded compressor opens directly into the shell.

2. Oil Pump Method

Many servicemen have either fabricated or purchased a small oil pump for adding oil to compressors. The pump is quite similar to a small bicycle tire pump, and allows the addition of oil to an operating compressor through the service port if necessary, or can be used to add oil directly to the crankcase where space may not permit a gravity feed. When the compressor is in operation, the pump check valve prevents the loss of refrigerant, while allowing the serviceman to develop sufficient pressure to overcome the operating suction pressure and add oil as necessary.

3. Close System Method

In an emergency where an oil pump is not available to the compressor is inaccessible, oil may be drawn into the compressor through the suction service valve.

Connect the suction connection of the gauge manifold to the compressor suction service valve, and immerse the common connection of the gauge manifold in an open container of refrigeration oil. Close the manifold valve and the compressor suction service valve and pull a vacuum in the compressor crankcase. Then open the manifold valve, drawing oil into the compressor through the suction service valve.

WARNING. Extreme care must be taken to insure the manifold common connection remains immersed in oil at all times. Otherwise air will be drawn into the compressor. On smaller horsepower or older style compressors where the suction vapor and oil are returned directly into the suction chamber, oil must be added very slowly since drainage to the crankcase may be quite slow.

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Continue as necessary until the proper amount of oil has been drawn into the compressor.

REMOVING OIL FROM A COMPRESSOR

Occasionally problems in line sizing or system operation may cause oil to trap in the evaporator or suction line, and large amounts of oil may be added to the system in an effort to maintain a satisfactory oil level in the compressor. When the basic oil logging problem is corrected, the excess oil will return to the compressor crankcase, and unless removed from the system, can cause oil slugging, excessive oil pumping, and possible compressor damage. Also in cases where the system has been contaminated, for example by a broken water tube in a water cooled condenser, or in cleaning a system after a bad motor burn, it may be necessary to completely remove the oil from the compressor crankcase.

To some extent the choice of a method for removing oil depends on the degree of system contamination. For removing excess oil or on systems with only slight contamination, almost any method is acceptable. However if the system is badly contaminated, it may be advisable to remove the compressor bottom plate and thoroughly clean the interior of the crankcase.

1. Removing by Oil Drain Plug

Some compressors are equipped with oil drain plugs. If so, this provides an easy method for removing oil.

Close the suction service valve, and operate the compressor until the crankcase pressure is reduced to approximately 1 to 2 psig. Stop the compressor and isolate the crankcase by closing the discharge service valve. Carefully loosen the oil drain plug, allowing any pressure to bleed off before the threads are completely disengaged. Drain oil to the desired level by seepage around the threads without removing the plug.

When draining is complete, tighten the drain plug, open the compressor valves, and restore the compressor to operation. The oil seal at the drain hole and the residual refrigerant pressure in the crankcase will effectively block the entrance of any measurable quantities of air or moisture into the system.

2. Removing by Oil Fill Hole

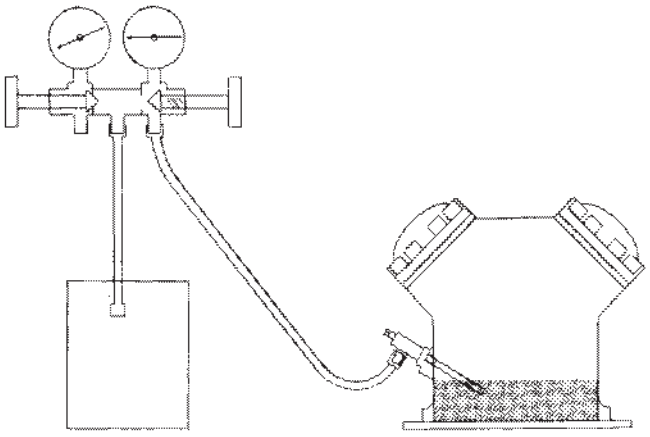
If a drain plug is not convenient or is not furnished on the compressor, oil may be removed by means of the oil fill hole.

Close the compressor suction service valve, reduce the crankcase pressure to 1 to 2 psig, and isolate by closing the discharge service valve.

Carefully loosen the oil fill plug, allowing any pressure to bleed off before the threads are completely disengaged. Remove the oil fill plug, and insert a ¼ in. O. D. copper tube so that the end is at or near the bottom of the crankcase. If possible use a tube of sufficient length so that the external end can be bent down below the crankcase, thus forming a syphon arrangement. Wrap a waste rag tightly around the oil fill opening, and crack the suction service valve, pressurizing the crankcase to approximately 5 psig, and then close the valve.

Oil will be forced out the drain line, and will continue to drain by the syphon effect until the crankcase is emptied. If the syphon arrangement is not possible, repressurize the crankcase as necessary to remove the desired amount of oil.

The residual refrigerant pressure in the crankcase



FIELD CONNECTION FOR REMOVING LARGE AMOUNTS OF OIL

Figure 175

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will prevent the entrance of any serious amounts o of moisture or air into the system. Purge the crankcase by cracking the suction service valve off its seat for 1 to 2 seconds. Reinstall the fill plug, tighten, open the compressor valves, and restore the compressor to operation.

In large systems where a large amount of excess oil must be removed, or where oil must be removed at intervals over a prolonged period, considerable time can be saved by brazing a dip tube in a valve so that oil can be removed as desired as long as the crankcase pressure is above 0 psig. (See Figure 175.) To speed up separation, the oil should be removed to a ¼ in. sight glass level. After oil removal is complete, the oil level may then be raised to the normal operating level.

3. Removal by Means of Baseplate

On accessible compressors, it may be necessary to remove the base plate if complete crankcase cleaning is necessary.

Pump the system down to isolate the compressor, remove the base plate, clean as necessary, and reinstall with new gasket. Since both air and moisture can enter the crankcase during this operation, the crankcase should be evacuated with a vacuum pump before restoring to operation. In an emergency, the crankcase may be purged by cracking the suction service valve and venting through the oil fill hole and the discharge service port. Replace the plug in the oil fill hole and jog the compressor a few times by starting and stopping, discharging through the discharge service port. Cap the discharge service port, open the discharge valve, and the compressor can be restored to operation.

4. Removing Oil From Welded Compressors

If the oil must be removed from a welded compressor, for example to recharge with a measured amount of oil, the compressor must be removed from the system, and the oil drained out the suction line stub by tilting the compressor.

After the compressor is reinstalled the system must then be evacuated by means of an access valve or the process tube before recharging with refrigerant and restoring to operation.

HANDLING FILTER-DRIERS

Regardless of the precautions of care taken, any time a system is opened for repair or maintenance, some amount of moisture and air enters. In order to avoid freezing of the moisture at the expansion valve or capillary tube, and to prevent acid formation and other detrimental system effects, the moisture level in the system must be kept at a minimum. Therefore every system opened for repair or installed in the field must have a liquid line filter-drier.

Self-contained filter-driers or replaceable drier elements are factory sealed for protection. If the seal is broken and the drier is exposed to the atmosphere for more than a few minutes, the drier will pick up moisture from the atmosphere and will quickly lose much of its moisture removal ability.

The system must be sealed and evacuated within a few minutes of the installation of the drier. Leaving a system open overnight after installation of a drier may completely destroy the drier's value.

COMPRESSOR BURNOUTS - WHAT TO DO

(Excerpts from a speech by Raymond G. Mozley, Vice President, Emerson Climate Technologies, Inc. Application Engineering)

Sometimes we get so involved in the technical details of how to solve a problem that we lose sight of the ultimate objective—how to get rid of the problem. As the old saying goes, "We can't see the forest for the trees."

Our objective in any refrigeration or air conditioning application is a satisfactory trouble free system. And, viewed from that standpoint, our answer to the question of compressor burnouts is at once simple and logical—prevent them before they occur. Our ultimate objective is to prevent the occurrence of a burnout, and this can only be done before a burnout occurs, not afterward.

It is true that occasionally a fault in the motor insulation may result in a motor burn, but in a system with proper design, manufacture, application, and installation, burnouts rarely occur. Of those that do occur, most are the result of mechanical or

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lubrication failures, resulting in the burnout as a secondary result.

If the problem is detected and corrected I time, a large percentage of compressor failures can be prevented. Periodic maintenance inspections by an alert serviceman on the lookout for abnormal operation can be a major factor in maintenance cost reduction. It is far easier, far less costly, and far more satisfactory to all parties concerned to take the few simple steps necessary to insure proper system operation than it is to allow a compressor failure to occur that could have been prevented, and then have to restore the system to satisfactory condition.

Probably no single type of failure has been more publicized, more studied, more debated, and more blamed for compressor failures than burnouts. As a result of this widespread publicity, the burnout problem has been the whipping boy for other system problems of far more serious proportions, and in many cases has been blown up out of proper perspective for competitive reasons. At one time several years ago, motor burnouts were a serious problem in hermetic compressors, and even today, many service engineers feel that burnouts are a major source of compressor failures. Our experience certainly indicates that due to the tremendous improvements in compressor design and system practices over the past years, burnouts as a cause of system failures ceased to be a major factor several years ago.

Motor failures do occasionally occur as a result of other malfunctions in the system, most often as an after effect of a lubrication failure. This is one of the major factors which contribute to frequent field misunderstanding of the type of compressor failure which may have actually occurred. As a result many service personnel mistakenly attribute the cause of recurring failures to motor burns, whereas in reality the motor failure has been an after effect of other system difficulties.

If the service engineer is to help in eliminating unnecessary compressor failures, he must thoroughly understand both the operation of the system and possible causes of failure that might occur, and he must be on the alert for any signs of system malfunction. On the return material cards which are attached to the compressors returned to our factory, a space is provided to note the cause of failure if known. On a great majority of the cards, there is a notation of bad compressor, compressor won't run, motor burn, or compressor locked up, and we suspect that the majority of these are classified in the service engineer's mind as compressor burnouts. The truth of the matter is that of the compressors returned to our factory during the warranty period, probably 65% to 75% have failed due to lack of lubrication or damage from liquid refrigerant. Seldom do we see any notation to this effect on a return material card. We suspect that in the great majority of cases the serviceman did not know what the cause of failure was, and installed a replacement compressor without determining whether he had corrected the basic cause of failure.

System malfunctions rarely originate from normal operation. They may be caused by some quirk in system design, by contaminants left in the system at the time of installation, by refrigerant leaks, by the improper operation of some electrical or refrigerant control components, or from a dozen other possible causes. In many cases, it may be a long period of time before the effects of some system fault begin to affect the compressor operation. In practically every case, indications of a system malfunction are clearly evident prior to the compressor failure.

When A Burnout Occurs

But suppose, despite your best precautions, a motor burn does occur. What can you do? Happily, today as a result of many years' experience, techniques are available which make system cleaning simple, effective, relatively inexpensive, and dependable.

The type of failure which has created the most hardship on the user, and the one which has received the most publicity in recent years has been the repeat burnout type of failure, where the initial burnout has triggered a series of failures on the same system—each after decreasing period of operation. It was recognized at an early stage that contamination resulting from previous burnout, remaining in the system, was the source of the succeeding failure, but developing a dependable cure for the system was not an easy task.

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Our company has been interested in cleaning methods for a long time, and because of the problems involved in the flushing process, we felt a simpler, less expensive procedure was badly needed. Field experience in removing moisture from systems had indicated that filter-driers might be the answer.

In the early 1960s in cooperation with major air conditioning and filter-drier manufacturers, we launched an intensive field trial of the filter-drier cleanout method. Basically this involved the use of approved filter-driers, incorporating an adequate desiccant in both the liquid and suction lines.

A great deal of corporate money and prestige was risked in early field tests, but it paid off not only in successfully cleaned systems, but in developing a background of test data so that we could safely recommend field proven components and know they would do the job. Several manufacturers are now producing suitable filter-driers, and many of these have been proven by field experience to be of equal value in successfully cleaning systems.

Due to its simplicity, the cost of the filter-drier cleanout system is quite inexpensive. There is no need for large quantities of refrigerant for flushing the system, no waste of man hours in laboriously cleaning each circuit, no long periods of down time. In most cases even the refrigerant in the system can be saved. This is the only practical method which can assure proper cleaning especially where long lines and multiple evaporators and circuits are involved.

This procedure has been used in thousands of installations during the past few years, and where properly used we do not know of a single instance of a second burnout due to improper cleaning. We do not feel there is any excuse today for repeat failures due to improperly cleaned systems.

We do still get occasional reports of repeat failures on systems which have experienced a motor burn. In practically every case we find the system has been improperly cleaned, in many instances because the serviceman felt the system could be cleaned merely by purging with refrigerant or by failure to use the recommended suction line filter-drier.

We feel there is no such thing as a mild burnout. The only safe procedure is to treat every motor burn as a serious one. We do not agree with those people in the industry who feel a system which has experienced a so-called mild burn can be safely cleaned by use of filters only in the suction line in conjunction with a liquid line filter-drier. In our opinion the risks are far too great to gamble on a half-way cleaning job when the stakes are possible future costly trouble on the system, and the possible savings are nominal at best.

Cleanout Procedure

The actual cleanout procedure with the filter-drier system is quite simple.

A. **Save Refrigerant**

On any system the refrigerant charge should be saved if the volume is large enough to be worthwhile. If the compressor has service valves, there may be no need to even remove the refrigerant charge. If a separate condensing unit or transfer pump is available, flange adapters may be used to pump the system down or pump the system charge into an empty drum. If a separate condensing unit is not available, in an emergency the replacement compressor can be installed to pump the system down prior to the cleanout. Although some contaminants will be returned to the compressor during the pumpdown procedure, the compressor will not be harmed by the short period of operation required, and the contaminants will be safely removed as they are circulated through the system after installation of the system cleaner.

B. **Remove Old Driers**

All filter-driers previously installed in the system must be replaced, all filters or strainers cleaned or replaced, and in the event of a bad burn, refrigerant control devices such as expansion valves and solenoid valves should be checked and cleaned if necessary.

C. **Install New Filter-Driers**

Adequate filter-driers of the proper size must be installed in both the liquid and suction lines. The suction line filter-drier is most important, since contaminants may not be effectively removed by a

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liquid line filter-drier alone. A pressure fitting should be provided ahead of the suction line filter-drier, preferably in the shell, to facilitate checking the pressure drop across the filter-drier.

D. **Check Electrical Circuits**

All electrical connections should be checked to be sure they are tight and properly made. The contactor should be examined, and any worn or pitted contacts should be cleaned or replaced. On externally protected motors standard service replacement compressors are normally supplied with motor protectors mounted in the terminal box. No attempt should be made to salvage the external inherent protector or external supplementary protectors mounted in the terminal box of the compressor being replaced, as these might have been damaged and could contribute to another failure.

If an electrical problem was responsible for the original motor burn, and is not corrected, it can result in the loss of the replacement compressor.

E. **Place In Operation**

The system may then be placed in operation, but should be closely watched for at least two hours after start-up. As the contaminants in the system are filtered out, the pressure drop across filter-driers will increase. Check the pressure drop across the suction line filter-drier frequently. If the pressure drop increases to the point where it exceeds the manufacturer's recommended maximum limit, the filter-drier should be replaced.

F. **48 Hour Check**

The system may then be allowed to operate for 48 hours, at which time the color and odor of the oil should be checked. Normally the system will be adequately cleaned by this time. However, if an acid content is present, if the oil is still discolored, or has an acid odor, the filter-driers should be changed, and in the case of bad burns, the compressor oil should be changed. After an additional 48 hours of operation, the oil should be checked again, and the filter-drier change repeated until the oil remains clean, odor free, and the color approaches that of new oil. The suction line filter-drier may then be removed, preferably replaced with a permanent suction line filter, the liquid line filter-drier should be changed, and the system can be returned to normal operation.

Acid Check

Acid test kits are available from several manufacturers for measuring the acid level in the oil. These are capable of making quite accurate acid measurements, but if they are not available, a check of the oil by sight and smell can give a quick indication if contamination remains in the system. Since refrigeration oil varies in color, a sample of the new oil in the replacement compressor should be removed prior to installation and sealed in a small glass bottle for comparison purposes. Suitable 2 ounce bottles are obtainable at any drug store. If the oil has been exposed to refrigerant, the bottle should not be tightly capped, since the residual refrigerant may create a high pressure if tightly sealed and exposed to high temperature.

Conclusion

In conclusion, let me stress again our answer to the question of compressor burnouts. Prevent them before they occur. It is impossible to view burnouts as a separate item, apart from the rest of the system. If you follow good refrigeration practice, apply the compressor properly, keep the system free of contamination, and stay on the alert for any system malfunctions, the burnout problem will take care of itself.

COMPRESSOR FAILURES THAT COULD HAVE BEEN PREVENTED

To enable the user and service engineer to better understand the type of damage that can occur in the compressor from improper system control or external system malfunctions, the following typical examples illustrate mechanical damage from compressor failures that could have been prevented.

Liquid Refrigerant or Oil Slugging

Figures 176 and 177 are different views of a typical valve plate from a smaller horsepower compressor. A discharge valve and discharge valve backer assembly are shown in the foreground in new condition for comparison. Note how the valve backers on both

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discharge valves have been bent from the original shape. The backers are made of steel, and only the force generated by a slug of liquid refrigerant or oil would have sufficient impact to cause this distortion. Once the valve backer is bent, it is only a matter of time before the reed is broken, since the reed is then subjected to stresses beyond its designed strength.

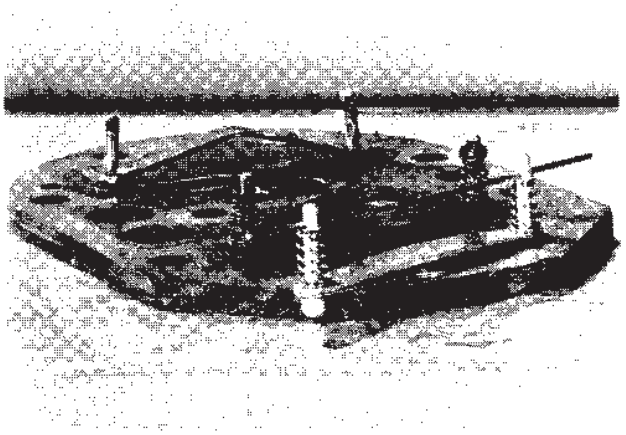


Figure 176

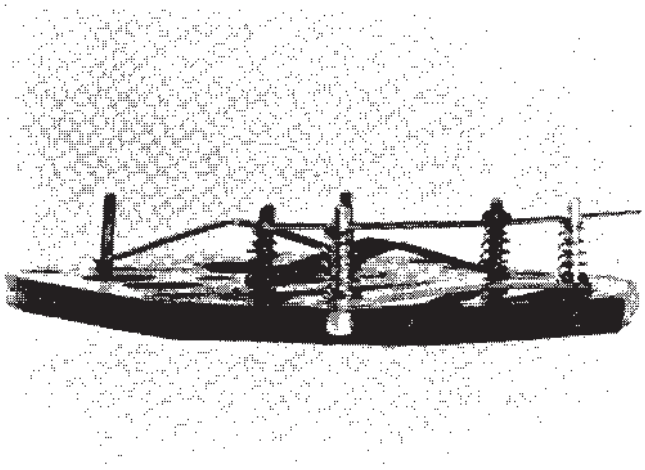


Figure 177

The solution to this problem lies in proper control of liquid refrigerant, and may require the use of a suction accumulator, crankcase heaters, or a pumpdown cycle in a system with an excessively large refrigerant charge.

Carbon Formation From Heat and Contaminants

Figure 178 is a similar type valve plate showing extreme carbon formation. This occurs due to oil breakdown, and can be caused by contaminants such as moisture and air in the system, or by excessively high discharge temperatures. Contrary to popular belief, carbon formation such as this can occur without a motor failure.

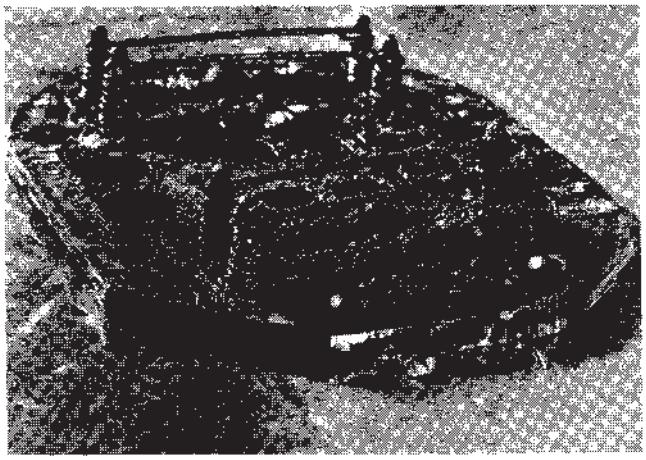


Figure 178

This will not occur in a system that is properly cleaned, dehydrated, and evacuated, with motor and discharge temperatures maintained within recommended operating limits.

Broken Discharge Reed

Figure 179 shows a discharge reed which has been damaged by excessively high head pressures. Note the round hole which has been broken out of the reed, and which actually has been forced down into the discharge port. This occurs when the discharge pressure builds up to a point at which there is sufficient pressure to actually shear the steel discharge reed against the sides of the discharge port in the valve plate on the piston suction stroke. Slugging is not necessarily connected with this type of damage, and the valve backer shows no signs of distortion. In order for pressure of this magnitude to build up it is probable that either a restriction in the discharge line or liquid line—possibly in the

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refrigerant control device—may have created a hydraulic pressure condition in the compressor discharge chamber.

Head pressures must be kept under proper control for the proper operation of any system. The pressures required to shear a reed in this manner are far in excess of established compressor limits.

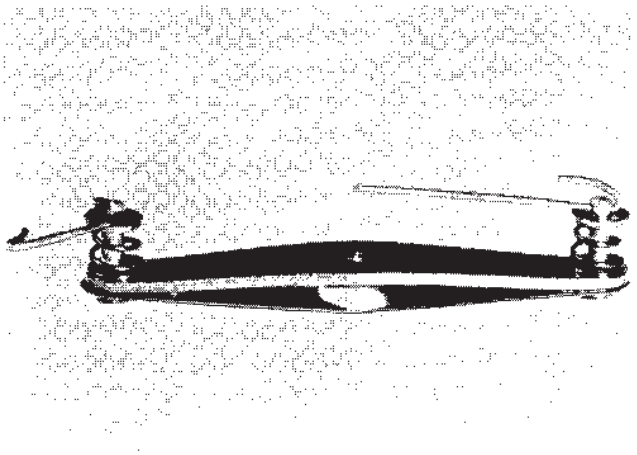


Figure 179

Ruptured Discharge Chamber

A discharge chamber from a welded compressor which has been ruptured by excessive liquid pressure is shown in Figure 180. Note the relief valve on the end of the discharge chamber which will relieve pressures between discharge and suction pressures to the compressor crankcase when the difference between discharge and suction pressures exceeds 550 ± 50 psig. This will effectively prevent gas pressures from exceeding the relief valve setting, but liquid cannot be forced through the valve quickly enough to prevent excessive pressures. This type of damage will occur only when excessive liquid slugging is taking place, or when excessive liquid in some way enters the discharge chamber, and is normally encountered only when the system refrigerant charge exceeds the compressor charge limitation. Peak pressures in excess of 2500 psig must have been experienced to cause this failure.

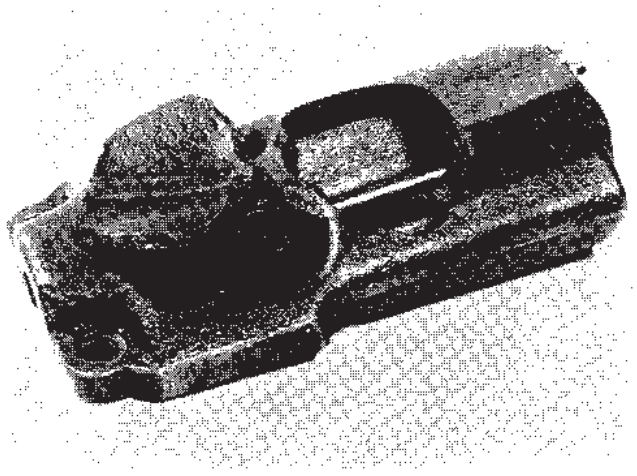


Figure 180

To avoid this type of damage, either the compressor charge must be kept within allowable limitations, or adequate safety provisions must be provided in system design. Automatic pumpdown system control, suction line accumulators, or crankcase heaters may be required.

Connecting Rod Pinhole Wear

Figures 181 and 182 illustrate progressive stages of connecting rod damage from wear of the connecting rod pinhole. This condition occurs when the discharge valve is broken, and this piston is subjected to discharge pressure on both discharge and suction strokes. As a result, the bottom side of the pinhole is always under pressure and receives no lubrication. As the pinhole elongates, excessive play develops, and the connecting rod starts hitting the underside of the piston. Eventual rod breakage results, either at the pinhole, or at the connecting rod shaft.

This type of failure normally is caused by discharge valve breakage. Usually it originates in liquid slugging or excessively high discharge pressures or temperatures causing the original valve damage.

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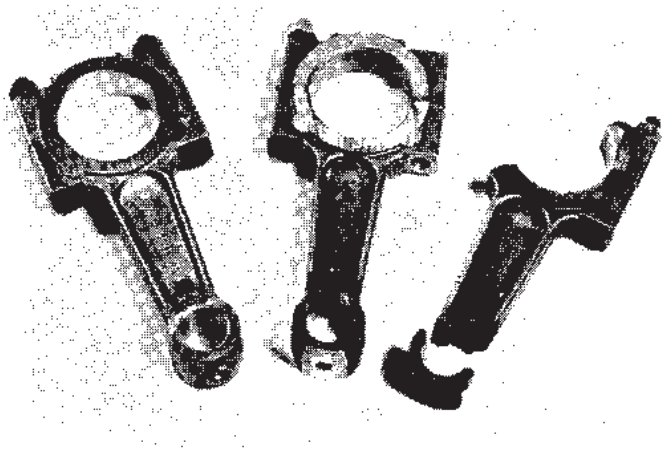


Figure 181

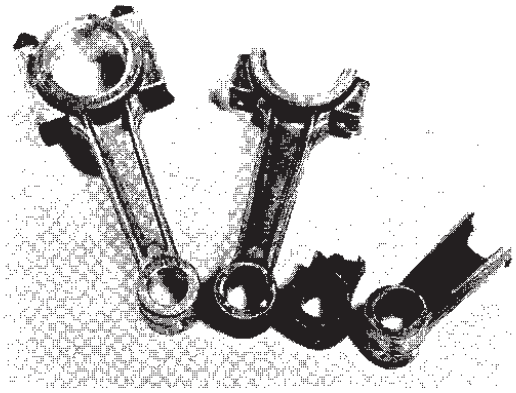


Figure 182

Piston Damage Due To Lack of Lubrication

Figure 183 illustrates the condition of a piston after operating without adequate lubrication for prolonged periods. This is most frequently encountered on low temperature applications. This can occur from excessive cylinder wall temperatures resulting from high compression ratios and low suction pressures, or from inadequate air flow over the compressor head and body. This same condition can also result in any air conditioning or refrigeration application from the continuous return of liquid refrigerant, or an excessively wet mixture of liquid and vapor returning to the crankcase, which can wash lubricant from the cylinder walls.

The oval shape resulting from piston wear is shown in Figure 184 and the eventual condition of the piston after failure due to contact with metal fragments is shown in Figure 185.

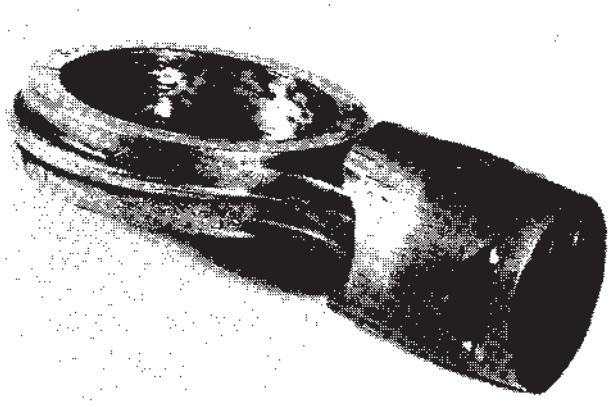


Figure 183

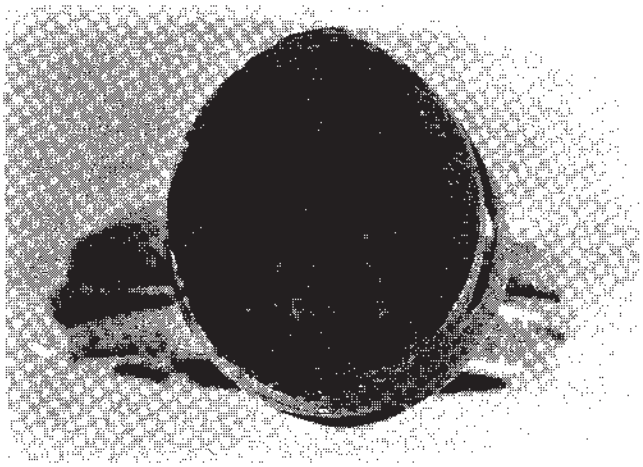


Figure 184

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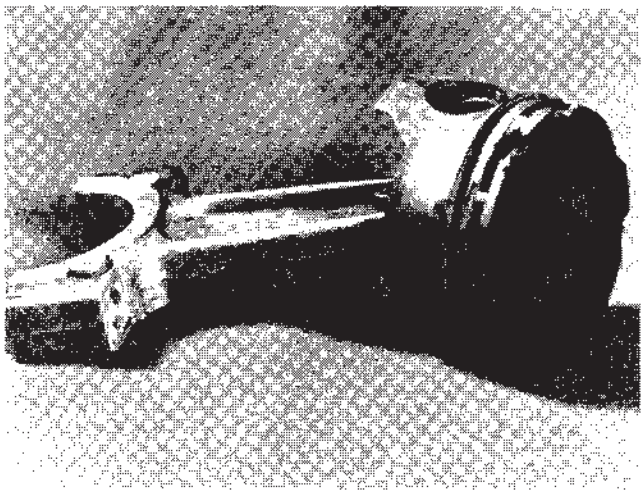


Figure 185

Crankshaft Damage Due To Lack of Lubrication

Scoring and wear of a crankshaft due to lack of adequate lubrication is shown in Figure 186. The ridge on the one throw is due to wear from a grooved connecting rod. The heat generated in the rods and bearings can cause eventual seizure of either rods or bearings, and possible connecting rod breakage.

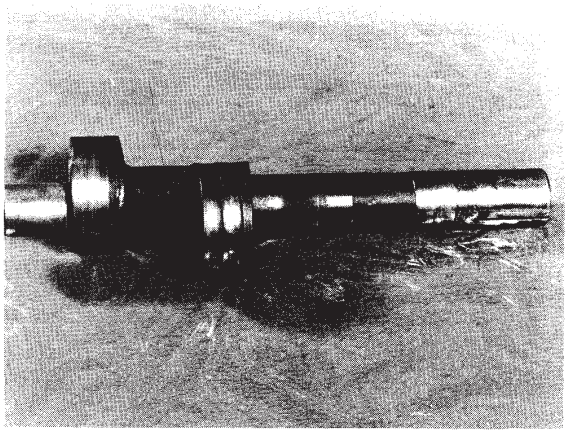


Figure 186

To avoid damage to bearings, crankshaft, pistons, and connecting rods, continuous lubrication must be maintained at all times. Repeated short periods of operation or prolonged periods of operation without adequate lubrication are almost certain to result in compressor failure.

Connecting Rod Damage Due To Liquid Slugging

While most Copeland® brand compressors have aluminum connecting rods which usually will break rather than bend when subjected to excessive stress, some rods in older models of belt-drive compressors are made with forged steel. Figures

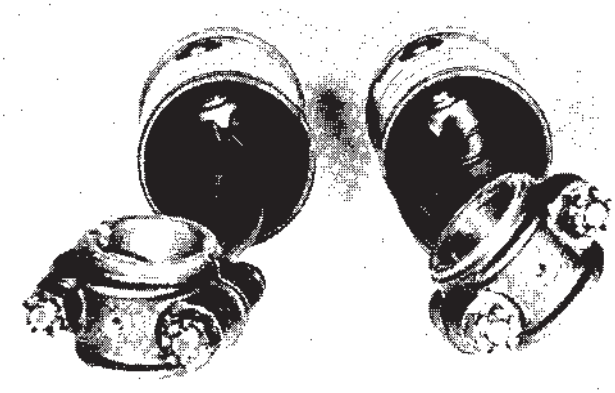


Figure 187

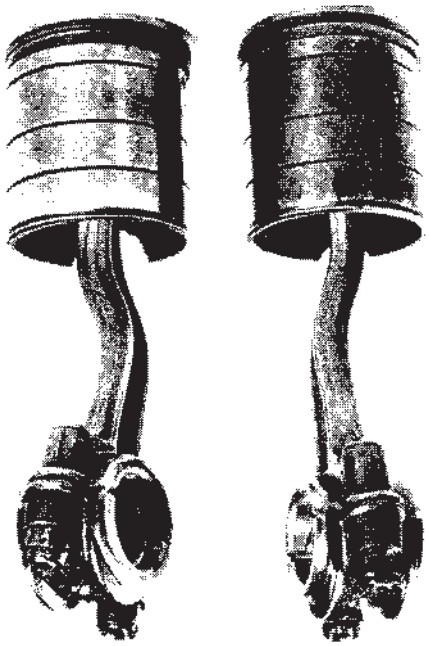


Figure 188

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187 and 188 illustrate the distortion and bending of the steel rods caused by liquid slugging. This is an excellent example of the tremendous force generated by hydraulic compression when liquid refrigerant enters the cylinders.

A refrigeration compressor is designed to pump vapor only. While small amounts of liquid can be tolerated, large amounts of liquid returning to the compressor crankcase can cause major damage. Systems must be designed and applied so the compressor is not subjected to such abuse.

System Cleaning with Filer-Drier

Emerson Climate Technologies, Inc. recommends only the filter-drier cleaning procedure in the case of a motor burn. Basically this involves the use of approved filter-driers incorporating an adequate desiccant (not a filter only) in both the liquid and suction lines.

To illustrate the effectiveness of a suction line filter-drier, 26 ounces of badly contaminated oil were put in an operating system with a 10 H. P. compressor. Bottle #1 shows a sample of oil removed from the system prior to the test. Bottle #2 is a sample of the contaminated oil introduced into the system, which was then allowed to operate for 24 hours without a filter-drier. The system was then equipped with a suction line filter-drier, and a sample of the oil taken from the compressor at this time is shown in Bottle #3. Sample #4 was taken from the crankcase one hour after the filter-drier was installed, and Sample #5 was taken from the crankcase 72 hours after the filter-drier was installed. The oil has been effectively cleaned so that the color and appearance are equal to the original oil.

This system cleaning procedure has been used in thousands of installations during the past few years, and when this procedure has been properly followed, we do not know of a single instance where a second failure has resulted because of improper cleaning.

Discharge Valves Damaged From Slugging

Figure 190 shows a comparison of a new valve plate of the type used on larger compressors with a valve plate on which the discharge reeds and discharge reed backstops have been damaged from liquid refrigerant or oil slugging. The backstops are made of ⅛" hardened steel, and the distortion clearly illustrates the tremendous force exerted by the liquid or oil slug.

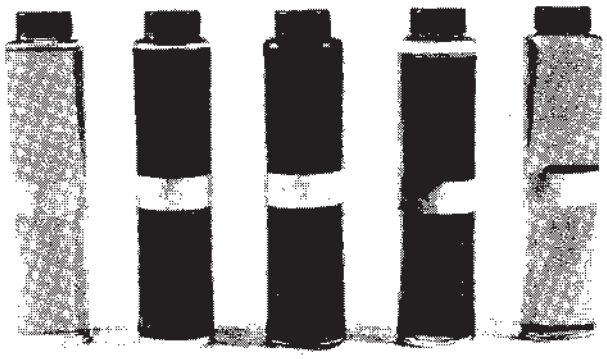


Figure 189

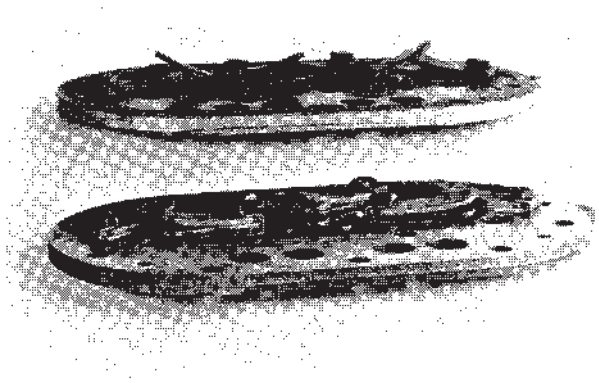


Figure 190

Note that on the valves on which the backstops have been badly bent, the discharge reed has been broken, due to the resulting excessive stress on the reed.

PREVENTIVE MAINTENANCE

The question is frequently asked as to how long it takes a compressor to wear out. It is almost impossible to answer that question because seldom if ever does a compressor fail from wear due to

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normal operation. Almost invariably a compressor failure results from malfunctions in either the refrigerant or electrical system, or from system operating conditions beyond the limitations of the system design.

Just what does this mean in terms of preventive maintenance? In practically every case, indications of a system malfunction are clearly evident prior to the compressor failure. If the problem is detected and corrected in time, a large percentage of compressor failures can be prevented. If the inspector is alert and on the lookout for any indication that operation of the system is in any way abnormal, a periodic maintenance inspection can be a major factor in maintenance cost reduction. Inspections should be made at least three times per year, and more frequent inspection is recommended during heavy usage periods.

Following is a summary of the major items to be checked.

Check With Operating Personnel

Always check with the operating personnel who are using the equipment to see if there have been any reports of abnormal or erratic operation. Frequently indications of abnormal operation may be observed by operating people who do not realize their significance, and this information may never be given to the service personnel unless brought out by specific questions concerning system operation. Ask particularly about trips of the oil pressure safety control, or other safety devices.

Operating Pressures and Temperatures

If permanent gauges are available, check the compressor suction and discharge pressures to be sure they are within the normal range for the application and the temperature of the condensing medium. If there are any indications of abnormal operation such as short cycling on pressure controls or excessive compressor temperatures, use a gauge manifold to check the operating pressures on systems without permanently installed gauges.

If abnormal operating pressures are found, the cause must be found and the malfunction corrected.

Check the compressor head temperature by touch. An abnormally cool head can indicate a broken valve, a broken connecting rod, or excessive liquid refrigerant flood back. An abnormally hot head can indicate a broken discharge valve, a blown or improper head gasket, or inadequate compressor cooling.

Oil Level and Condition

On Copeland® brand compressors, the oil level should be at or slightly above the center of the sight glass. It should be kept in mind that some slight fluctuation in oil level may occur during an operating cycle—particularly before and after defrost periods. So long as the oil level is maintained well within the sight glass such fluctuations are not harmful.

If the oil is black in color, the crankcase should be drained and the oil replaced. If there has been a recent compressor failure on the system and the oil has an acid odor, a fresh filter-drier should be installed in the suction line and left in the line for a period of 48 hours. If the oil is still discolored, the suction line filter-drier is still discolored, the suction line filter-drier element should again be changed. This procedure should be continued until the oil remains clean, odor free, and the color approaches that of new oil. The filter-drier element may then be replaced with a permanent type suction line filter.

It is recommended that only Suniso 3G or 3GS oil be used in Copeland® brand compressors. Unless there are reasons as outlined above for changing the oil, the refrigeration oil should not be changed. It does not deteriorate or wear out with normal usage.

System Refrigerant Charge

All systems must have a full head of liquid refrigerant at the expansion valve to insure proper operation. A clear sight glass indicates an adequate charge. Bubbles or flashing in the sight glass may indicate a shortage of refrigerant, but flashing can also be caused by a liquid line restriction, hunting expansion valves, sudden changes in condensing pressure, and rapid changes in the refrigeration load. If there is a doubt as to the refrigerant charge, check the liquid level in the receiver. If no test cock is available, pass a torch flame momentarily back and forth on

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the receiver. If the metal remains relatively cool, a liquid level is indicated, but if the metal heats up rapidly, vapor is indicated. The liquid level can be determined by the point where the temperature change occurs.

Units with roof mounted condensers equipped with low ambient head pressure controls will require a great deal more refrigerant for low ambient conditions, since the head pressure is normally maintained by partially flooding the condenser.

Too little refrigerant can result in lack of refrigeration, loss of oil in the evaporator, and overheating of the compressor. Too much refrigerant can contribute to high discharge pressures, liquid refrigerant flooding, liquid slugging, with resulting compressor lubrication problems.

Special care should be taken in finding and repairing any leaks if a loss of refrigerant occurs.

System Control Settings

If there is any question as to the proper operation of the low pressure control, high pressure control, or oil pressure safety control, the pressure setting should be checked. The accuracy of indicating scales on refrigeration pressure controls is not dependable, and if operation is questionable, the control should be checked with serviceman's gauges.

Do not set the low pressure control below the recommended operating limits of the compressor.

The cause of any short cycling condition must be corrected.

If the operation of an oil pressure safety controls is questionable, it should be checked by running a jumper connection across the pressure contacts to determine if the control will trip.

Liquid Line Filter-Drier

Check the color code of the moisture indicator. A positive moisture indication indicates the filter-drier should be replaced.

If the drier is frosted or if there is a perceptible temperature change between the liquid line entering and leaving the drier, an excessive pressure drop in the drier is indicated, and the drier or drier element should be replaced.

Vibration Eliminators

If the wire braid cover on a metal vibration eliminator is starting to pull out of the brazed end connectors, the vibration eliminator should be replaced to prevent possible rupture, loss of the refrigerant charge, and potential personal injury.

Capillary Tubes and Refrigerant Lines

Check all capillary lines for wear and vibration. Tape or support as necessary. Check refrigerant line supports and braces to make certain they are not wearing or cutting the refrigerant lines.

Oil traces at flare nuts or valve connections indicate the possibility of a refrigerant leak. Wipe clean and tighten the flare nut.

Liquid Refrigerant Control

Check for any indications of liquid refrigerant flooding such as sweating or frosting of the compressor, rust on the suction service valve or compressor body, tripping of the oil pressure safety control, audible slugging, or excessive foaming in the crankcase. If there is any question as to liquid control, the operation of the system immediately after a defrost cycle should be observed. Excessive sweating or frosting of the suction line and/or compressor body must be corrected.

If the refrigerant cannot be properly controlled with the existing system controls, a suction line accumulator may be required.

Suction Line Filter

Check pressure drop across suction line filter, and replace element if pressure drop exceeds manufacturer's recommended maximum.

Electrical Control Panel

Check the electrical control panel to see that heaters or motor protectors are not jumpered. Look for burn marks on the cabinet that might indicate possible

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shorts, and check the contacts on any contactor on which there is any question.

Air Cooled Machine Room

Check the exhaust fan and fan motor, and lubricate if necessary. Check operation of dampers and louvers, and lubricate as necessary. Run fan through on and off cycle by means of thermostat.

Remote Air Cooled Condenser

Check belt condition, and lubricate motor and shaft bearings. Clean condenser face if necessary. Inspect all line supports for vibration and line wear.

Walk-in Coolers, Freezers, Refrigerated Fixtures

Check coils for ice build-up and cleanliness. Check temperatures being maintained in refrigerated space. Inspect door latches, gaskets, moulding, etc.

Air Conditioning Air Handlers

Check filters and change if necessary. Check belt condition and lubricate motor and shaft bearings.

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SECTION 27
USEFUL ENGINEERING DATA

The following reference tables and charges cover miscellaneous data and conversion factors frequently required in engineering calculations. Data specifically pertaining to refrigeration has been included where appropriate in previous sections.

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Table 53

TEMPERATURE SCALES

Absolute temperature Rankin	= °F. + 459.6°
Absolute temperature Kelvin	= °C. + 273.2°
Rankin	= 1.8 Kelvin
Centigrade (Celsius)	= 5/9 (°F. — 32°)
Fahrenheit	= 9/5 °C. + 32°

Table 54

INTERNATIONAL RATING CONDITIONS

CENTIGRADE - FAHRENHEIT

Evaporating Temperature		Condensing Temperature		Ambient Temperature	
°C.	°F.	°C.	°F.	°C.	°F.
12.5	55	30	86	21	69.8
10	50	32	90	27	80.6
7	45	35	95	32	89.6
5	41	40	104	38	100.4
0	32	45	113	43	109.4
- 5	23	50	122		
-10	14	55	131		
-15	5	60	140		
-20	- 4				
-25	-13				
-30	-22				
-40	-40				

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Table 55

THERMAL UNITS

Latent heat of ice	= 144 BTU/lb	= 288,000 BTU/ton
1 ton refrigeration	= 12,000 BTU/hr	= 288,000/24 hours
1 British Thermal Unit (BTU)		= .252 kcal
1 kilo - calorie (kcal)		= 3.97 BTU
1 BTU/lb		= 0.555 kcal/kg
1 kcal/kg		= 1.8 BTU/lb
1 BTU/lb/°F.		= 1 kcal/kg/°C.
1 watt		= 3.413 BTU/hr

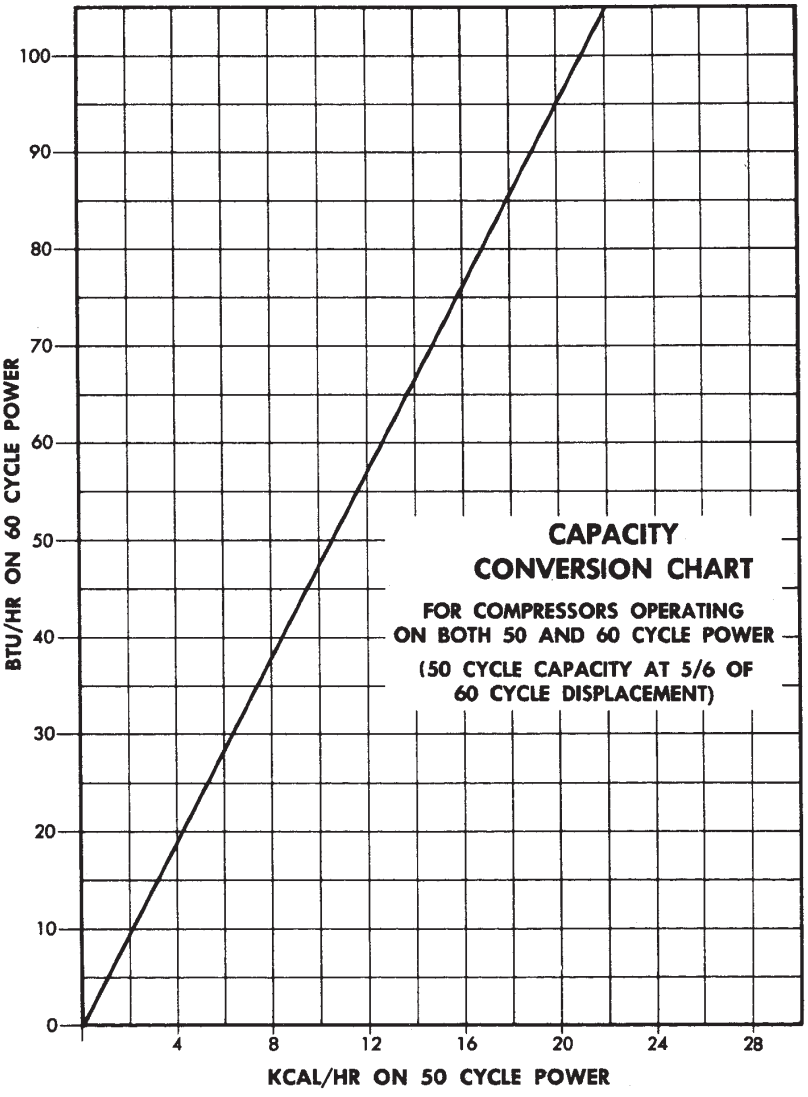


Figure 191

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Table 56

FAHRENHEIT - CENTIGRADE TEMPERATURE CONVERSION CHART

The numbers in bold-face type in the center column refer to the temperature, either in Centigrade or Fahrenheit, which is to be converted to the other scale. If converting Fahrenheit to Centigrade, the equivalent temperature will be found in the left column. If converting Centigrade to Fahrenheit, the equivalent temperature will be found in the column on the right.

Temperature			Temperature			Temperature			Temperature		
Cent.	C or F	Fahr	Cent.	C or F	Fahr	Cent.	C or F	Fahr	Cent.	C or F	Fahr
−40.0	**−40**	−40.0	−6.7	**+20**	+68.0	+26.7	**+80**	+176.0	+60.0	**+140**	+284.0
−39.4	**−39**	−38.2	−6.1	**+21**	+69.8	+27.2	**+81**	+177.8	+60.6	**+141**	+285.8
−38.9	**−38**	−36.4	−5.5	**+22**	+71.6	+27.8	**+82**	+179.6	+61.1	**+142**	+287.6
−38.3	**−37**	−34.6	−5.0	**+23**	+73.4	+28.3	**+83**	+181.4	+61.7	**+143**	+289.4
−37.8	**−36**	−32.8	−4.4	**+24**	+75.2	+28.9	**+84**	+183.2	+62.2	**+144**	+291.2
−37.2	**−35**	−31.0	−3.9	**+25**	+77.0	+29.4	**+85**	+185.0	+62.8	**+145**	+293.0
−36.7	**−34**	−29.2	−3.3	**+26**	+78.8	+30.0	**+86**	+186.8	+63.3	**+146**	+294.8
−36.1	**−33**	−27.4	−2.8	**+27**	+80.6	+30.6	**+87**	+188.6	+63.9	**+147**	+296.6
−35.6	**−32**	−25.6	−2.2	**+28**	+82.4	+31.1	**+88**	+190.4	+64.4	**+148**	+298.4
−35.0	**−31**	−23.8	−1.7	**+29**	+84.2	+31.7	**+89**	+192.2	+65.0	**+149**	+300.2
−34.4	**−30**	−22.0	−1.1	**+30**	+86.0	+32.2	**+90**	+194.0	+65.6	**+150**	+302.0
−33.9	**−29**	−20.2	−0.6	**+31**	+87.8	+32.8	**+91**	+195.8	+66.1	**+151**	+303.8
−33.3	**−28**	−18.4	.0	**+32**	+89.6	+33.3	**+92**	+197.6	+66.7	**+152**	+305.6
−32.8	**−27**	−16.6	+0.6	**+33**	+91.4	+33.9	**+93**	+199.4	+67.2	**+153**	+307.4
−32.2	**−26**	−14.8	+1.1	**+34**	+93.2	+34.4	**+94**	+201.2	+67.8	**+154**	+309.2
−31.7	**−25**	−13.0	+1.7	**+35**	+95.0	+35.0	**+95**	+203.0	+68.3	**+155**	+311.0
−31.1	**−24**	−11.2	+2.2	**+36**	+96.8	+35.6	**+96**	+204.8	+68.9	**+156**	+312.8
−30.6	**−23**	−9.4	+2.8	**+37**	+98.6	+36.1	**+97**	+206.6	+69.4	**+157**	+314.6
−30.0	**−22**	−7.6	+3.3	**+38**	+100.4	+36.7	**+98**	+208.4	+70.0	**+158**	+316.4
−29.4	**−21**	−5.8	+3.9	**+39**	+102.2	+37.2	**+99**	+210.2	+70.6	**+159**	+318.2
−28.9	**−20**	−4.0	+4.4	**+40**	+104.0	+37.8	**+100**	+212.0	+71.1	**+160**	+320.0
−28.3	**−19**	−2.2	+5.0	**+41**	+105.8	+38.3	**+101**	+213.8	+71.7	**+161**	+321.8
−27.8	**−18**	−0.4	+5.5	**+42**	+107.6	+38.9	**+102**	+215.6	+72.2	**+162**	+323.6
−27.2	**−17**	+1.4	+6.1	**+43**	+109.4	+39.4	**+103**	+217.4	+72.8	**+163**	+325.4
−26.7	**−16**	+3.2	+6.7	**+44**	+111.2	+40.0	**+104**	+219.2	+73.3	**+164**	+327.2
−26.1	**−15**	+5.0	+7.2	**+45**	+113.0	+40.6	**+105**	+221.0	+73.9	**+165**	+329.0
−25.6	**−14**	+6.8	+7.8	**+46**	+114.8	+41.1	**+106**	+222.8	+74.4	**+166**	+330.8
−25.0	**−13**	+8.6	+8.3	**+47**	+116.6	+41.7	**+107**	+224.6	+75.0	**+167**	+332.6
−24.4	**−12**	+10.4	+8.9	**+48**	+118.4	+42.2	**+108**	+226.4	+75.6	**+168**	+334.4
−23.9	**−11**	+12.2	+9.4	**+49**	+120.2	+42.8	**+109**	+228.2	+76.1	**+169**	+336.2
−23.3	**−10**	+14.0	+10.0	**+50**	+122.0	+43.3	**+110**	+230.0	+76.7	**+170**	+338.0
−22.8	**−9**	+15.8	+10.6	**+51**	+123.8	+43.9	**+111**	+231.8	+77.2	**+171**	+339.8
−22.2	**−8**	+17.6	+11.1	**+52**	+125.6	+44.4	**+112**	+233.6	+77.8	**+172**	+341.6
−21.7	**−7**	+19.4	+11.7	**+53**	+127.4	+45.0	**+113**	+235.4	+78.3	**+173**	+343.4
−21.1	**−6**	+21.2	+12.2	**+54**	+129.2	+45.6	**+114**	+237.2	+78.9	**+174**	+345.2
−20.6	**−5**	+23.0	+12.8	**+55**	+131.0	+46.1	**+115**	+239.0	+79.4	**+175**	+347.0
−20.0	**−4**	+24.8	+13.3	**+56**	+132.8	+46.7	**+116**	+240.8	+80.0	**+176**	+348.8
−19.4	**−3**	+26.6	+13.9	**+57**	+134.6	+47.2	**+117**	+242.6	+80.6	**+177**	+350.6
−18.9	**−2**	+28.4	+14.4	**+58**	+136.4	+47.8	**+118**	+244.4	+81.1	**+178**	+352.4
−18.3	**−1**	+30.2	+15.0	**+59**	+138.2	+48.3	**+119**	+246.2	+81.7	**+179**	+354.2
−17.8	**0**	+32.0	+15.6	**+60**	+140.0	+48.9	**+120**	+248.0	+82.2	**+180**	+356.0
−17.2	**+1**	+33.8	+16.1	**+61**	+141.8	+49.4	**+121**	+249.8	+82.8	**+181**	+357.8
−16.7	**+2**	+35.6	+16.7	**+62**	+143.6	+50.0	**+122**	+251.6	+83.3	**+182**	+359.6
−16.1	**+3**	+37.4	+17.2	**+63**	+145.4	+50.6	**+123**	+253.4	+83.9	**+183**	+361.4
−15.6	**+4**	+39.2	+17.8	**+64**	+147.2	+51.1	**+124**	+255.2	+84.4	**+184**	+363.2
−15.0	**+5**	+41.0	+18.3	**+65**	+149.0	+51.7	**+125**	+257.0	+85.0	**+185**	+365.0
−14.4	**+6**	+42.8	+18.9	**+66**	+150.8	+52.2	**+126**	+258.8	+85.6	**+186**	+366.8
−13.9	**+7**	+44.6	+19.4	**+67**	+152.6	+52.8	**+127**	+260.6	+86.1	**+187**	+368.6
−13.3	**+8**	+46.4	+20.0	**+68**	+154.4	+53.3	**+128**	+262.4	+86.7	**+188**	+370.4
−12.8	**+9**	+48.2	+20.6	**+69**	+156.2	+53.9	**+129**	+264.2	+87.2	**+189**	+372.2
−12.2	**+10**	+50.0	+21.1	**+70**	+158.0	+54.4	**+130**	+266.0	+87.8	**+190**	+374.0
−11.7	**+11**	+51.8	+21.7	**+71**	+159.8	+55.0	**+131**	+267.8	+88.3	**+191**	+375.8
−11.1	**+12**	+53.6	+22.2	**+72**	+161.6	+55.6	**+132**	+269.6	+88.9	**+192**	+377.6
−10.6	**+13**	+55.4	+22.8	**+73**	+163.4	+56.1	**+133**	+271.4	+89.4	**+193**	+379.4
−10.0	**+14**	+57.2	+23.3	**+74**	+165.2	+56.7	**+134**	+273.2	+90.0	**+194**	+381.2
−9.4	**+15**	+59.0	+23.9	**+75**	+167.0	+57.2	**+135**	+275.0	+90.6	**+195**	+383.0
−8.9	**+16**	+60.8	+24.4	**+76**	+168.8	+57.8	**+136**	+276.8	+91.1	**+196**	+384.8
−8.3	**+17**	+62.6	+25.0	**+77**	+170.6	+58.3	**+137**	+278.6	+91.7	**+197**	+386.6
−7.8	**+18**	+64.4	+25.6	**+78**	+172.4	+58.9	**+138**	+280.4	+92.2	**+198**	+388.4
−7.2	**+19**	+66.2	+26.1	**+79**	+174.2	+59.4	**+139**	+282.2	+92.8	**+199**	+390.2

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Table 57

PROPERTIES OF SATURATED STEAM: TEMPERATURE TABLE

Temp F t	Abs. Press. Lb/Sq In. p	Specific Volume		Enthalpy			Entropy			Temp. F t
		Sat. Liquid v_f	Sat. Vapor v_g	Sat. Liquid h_f	Evap. h_{fg}	Sat. Vapor h_g	Sat. Liquid s_f	Evap. s_{fg}	Sat. Vapor s_g	
212	14.696	0.01672	26.80	180.07	970.3	1150.4	0.3120	1.4446	1.7566	212
214	15.289	0.01673	25.83	182.08	969.0	1151.1	0.3149	1.4385	1.7534	214
216	15.901	0.01674	24.90	184.10	967.8	1151.9	0.3179	1.4323	1.7502	216
218	16.533	0.01676	24.01	186.11	966.5	1152.6	0.3209	1.4262	1.7471	218
220	17.186	0.01677	23.15	188.13	965.2	1153.4	0.3239	1.4201	1.7440	220
222	17.861	0.01679	22.33	190.15	963.9	1154.1	0.3268	1.4141	1.7409	222
224	18.557	0.01680	21.55	192.17	962.6	1154.8	0.3298	1.4080	1.7378	224
226	19.275	0.01682	20.79	194.18	961.3	1155.5	0.3328	1.4020	1.7348	226
228	20.016	0.01683	20.07	196.20	960.1	1156.3	0.3357	1.3961	1.7318	228
230	20.780	0.01684	19.382	198.23	958.8	1157.0	0.3387	1.3901	1.7288	230
232	21.567	0.01686	18.720	200.25	957.4	1157.7	0.3416	1.3842	1.7258	232
234	22.379	0.01688	18.084	202.27	956.1	1158.4	0.3444	1.3784	1.7228	234
236	23.217	0.01689	17.473	204.29	954.8	1159.1	0.3473	1.3725	1.7199	236
238	24.080	0.01691	16.886	206.32	953.5	1159.8	0.3502	1.3667	1.7169	238
240	24.969	0.01692	16.323	208.34	952.2	1160.5	0.3531	1.3609	1.7140	240
242	25.884	0.01694	15.782	210.37	950.8	1161.2	0.3560	1.3551	1.7111	242
244	26.827	0.01696	15.262	212.39	949.5	1161.9	0.3589	1.3494	1.7083	244
246	27.798	0.01697	14.762	214.42	948.2	1162.6	0.3618	1.3436	1.7054	246
248	28.797	0.01699	14.282	216.45	946.8	1163.3	0.3647	1.3379	1.7026	248
250	29.825	0.01700	13.821	218.48	945.5	1164.0	0.3675	1.3323	1.6998	250
252	30.884	0.01702	13.377	220.51	944.2	1164.7	0.3704	1.3266	1.6970	252
254	31.973	0.01704	12.950	222.54	942.8	1165.3	0.3732	1.3210	1.6942	254
256	33.093	0.01705	12.539	224.58	941.4	1166.0	0.3761	1.3154	1.6915	256
258	34.245	0.01707	12.144	226.61	940.1	1166.7	0.3789	1.3099	1.6888	258
260	35.429	0.01709	11.763	228.64	938.7	1167.3	0.3817	1.3043	1.6860	260
262	36.646	0.01710	11.396	230.68	937.3	1168.0	0.3845	1.2988	1.6833	262
264	37.897	0.01712	11.043	232.72	936.0	1168.7	0.3874	1.2933	1.6807	264
266	39.182	0.01714	10.704	234.76	934.5	1169.3	0.3902	1.2878	1.6780	266
268	40.502	0.01715	10.376	236.80	933.2	1170.0	0.3930	1.2824	1.6753	268
270	41.858	0.01717	10.061	238.84	931.8	1170.6	0.3958	1.2769	1.6727	270
272	43.252	0.01719	9.756	240.88	930.3	1171.2	0.3986	1.2715	1.6701	272
274	44.682	0.01721	9.463	242.92	929.0	1171.9	0.4014	1.2661	1.6675	274
276	46.150	0.01722	9.181	244.96	927.5	1172.5	0.4041	1.2608	1.6649	276
278	47.657	0.01724	8.908	247.01	926.1	1173.1	0.4069	1.2554	1.6623	278
280	49.203	0.01726	8.645	249.06	924.7	1173.8	0.4096	1.2501	1.6597	280
282	50.790	0.01728	8.391	251.10	923.3	1174.4	0.4124	1.2448	1.6572	282
284	52.418	0.01730	8.146	253.15	921.8	1175.0	0.4152	1.2395	1.6547	284
286	54.088	0.01732	7.910	255.20	920.4	1175.6	0.4179	1.2343	1.6522	286
288	55.800	0.01733	7.682	257.26	918.9	1176.2	0.4207	1.2290	1.6497	288
290	57.556	0.01735	7.461	259.31	917.5	1176.8	0.4234	1.2238	1.6472	290
292	59.356	0.01737	7.248	261.36	916.0	1177.4	0.4261	1.2186	1.6447	292
294	61.201	0.01739	7.043	263.42	914.6	1178.0	0.4288	1.2134	1.6422	294
296	63.091	0.01741	6.844	265.48	913.1	1178.6	0.4315	1.2083	1.6398	296
298	65.028	0.01743	6.652	267.53	911.6	1179.1	0.4343	1.2031	1.6374	298
300	67.013	0.01745	6.466	269.59	910.1	1179.7	0.4369	1.1980	1.6350	300
310	77.68	0.01755	5.626	279.92	902.6	1182.5	0.4504	1.1727	1.6231	310
320	89.66	0.01765	4.914	290.28	894.9	1185.2	0.4637	1.1478	1.6115	320
330	103.06	0.01776	4.307	300.68	887.0	1187.7	0.4769	1.1233	1.6002	330
340	118.01	0.01787	3.788	311.13	879.0	1190.1	0.4900	1.0992	1.5891	340
350	134.63	0.01799	3.342	321.63	870.7	1192.3	0.5029	1.0754	1.5783	350
360	153.04	0.01811	2.957	332.18	862.2	1194.4	0.5158	1.0519	1.5677	360
370	173.37	0.01823	2.625	342.79	853.5	1196.3	0.5286	1.0287	1.5573	370
380	195.77	0.01836	2.335	353.45	844.6	1198.1	0.5413	1.0059	1.5471	380
390	220.37	0.01850	2.0836	364.17	835.4	1199.6	0.5539	0.9832	1.5371	390
400	247.31	0.01864	1.8633	374.97	826.0	1201.0	0.5664	0.9608	1.5272	400
410	276.75	0.01878	1.6700	385.83	816.3	1202.1	0.5788	0.9386	1.5174	410
420	308.83	0.01894	1.5000	396.77	806.3	1203.1	0.5912	0.9166	1.5078	420
430	343.72	0.01910	1.3499	407.79	796.0	1203.8	0.6035	0.8947	1.4982	430
440	381.59	0.01926	1.2171	418.90	785.4	1204.3	0.6158	0.8730	1.4887	440
450	422.6	0.0194	1.0993	430.1	774.5	1204.6	0.6280	0.8513	1.4793	450
460	466.9	0.0196	0.9944	441.4	763.2	1204.6	0.6402	0.8298	1.4700	460
470	514.7	0.0198	0.9009	452.8	751.5	1204.3	0.6523	0.8083	1.4606	470
480	566.1	0.0200	0.8172	464.4	739.4	1203.7	0.6645	0.7868	1.4513	480
490	621.4	0.0202	0.7423	476.0	726.8	1202.8	0.6766	0.7653	1.4419	490
500	680.8	0.0204	0.6749	487.8	713.9	1201.7	0.6887	0.7438	1.4325	500

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Table 58

DECIMAL EQUIVALENTS, AREAS AND CIRCUMFERENCES OF CIRCLES

Diameter	Decimal Equivalent	Circumference	Area	Diameter	Decimal Equivalent	Circumference	Area	Diameter	Decimal Equivalent	Circumference	Area
				3/4	.7500	2.356	.4418	3	3.000	9.425	7.069
1/64	.0156	.04909	.00019	49/64	.7656	2.405	.4604	3 1/16	3.0625	9.621	7.366
1/32	.0312	.09817	.00077	25/32	.7812	2.454	.4794	3 1/8	3.1250	9.817	7.670
3/64	.0468	.1473	.00173	51/64	.7969	2.503	.4987	3 3/16	3.1875	10.01	7.980
1/16	.0625	.1963	.00307	13/16	.8125	2.553	.5185	3 1/4	3.2500	10.21	8.296
5/64	.0781	.2454	.00479	53/64	.8281	2.602	.5386	3 5/16	3.3125	10.41	8.618
3/32	.0937	.2945	.00690	27/32	.8437	2.651	.5591	3 3/8	3.3750	10.60	8.946
7/64	.1093	.3436	.00940	55/64	.8594	2.700	.5800	3 7/16	3.4375	10.80	9.281
1/8	.1250	.3927	.01227	7/8	.8750	2.749	.6013	3 1/2	3.5000	11.00	9.621
9/64	.1406	.4418	.01553	57/64	.8906	2.798	.6230	3 9/16	3.5625	11.19	9.968
5/32	.1562	.4909	.01917	29/32	.9062	2.847	.6450	3 5/8	3.6250	11.39	10.32
11/64	.1718	.5400	.02320	59/64	.9219	2.896	.6675	3 11/16	3.6875	11.58	10.68
3/16	.1875	.5890	.02761	15/16	.9375	2.945	.6903	3 3/4	3.7500	11.78	11.04
13/64	.2031	.6381	.03241	61/64	.9531	2.994	.7135	3 13/16	3.8125	11.98	11.42
7/32	.2187	.6872	.03758	31/32	.9687	3.043	.7371	3 7/8	3.8750	12.17	11.79
15/64	.2343	.7363	.04314	63/64	.9844	3.093	.7610	3 15/16	3.9375	12.37	12.18
1/4	.2500	.7854	.04909	1	1.000	3.142	.7854	4	4.000	12.57	12.57
17/64	.2656	.8345	.05542	1 1/16	1.0625	3.338	.8866	4 1/16	4.0625	12.76	12.96
9/32	.2812	.8836	.06213	1 1/8	1.1250	3.534	.9940	4 1/8	4.1250	12.96	13.36
19/64	.2968	.9327	.06920	1 3/16	1.1875	3.731	1.108	4 3/16	4.1875	13.16	13.77
5/16	.3125	.9817	.07670	1 1/4	1.2500	3.927	1.227	4 1/4	4.2500	13.35	14.19
21/64	.3281	1.031	.08456	1 5/16	1.3125	4.123	1.353	4 5/16	4.3125	13.55	14.61
11/32	.3437	1.080	.09281	1 3/8	1.3750	4.320	1.485	4 3/8	4.3750	13.74	15.03
23/64	.3593	1.129	.1014	1 7/16	1.4375	4.516	1.623	4 7/16	4.4375	13.94	15.47
3/8	.3750	1.178	.1104	1 1/2	1.5000	4.712	1.767	4 1/2	4.5000	14.14	15.90
25/64	.3906	1.227	.1198	1 9/16	1.5625	4.909	1.917	4 9/16	4.5625	14.33	16.35
13/32	.4062	1.276	.1296	1 5/8	1.6250	5.105	2.074	4 5/8	4.6250	14.53	16.80
27/64	.4218	1.325	.1398	1 11/16	1.6875	5.301	2.237	4 11/16	4.6875	14.73	17.26
7/16	.4375	1.374	.1503	1 3/4	1.7500	5.498	2.405	4 3/4	4.750	14.92	17.72
29/64	.4531	1.424	.1613	1 13/16	1.8125	5.694	2.580	4 13/16	4.8125	15.12	18.19
15/32	.4687	1.473	.1726	1 7/8	1.8750	5.890	2.761	4 7/8	4.8750	15.32	18.67
31/64	.4844	1.522	.1843	1 15/16	1.9375	6.087	2.948	4 15/16	4.9375	15.51	19.51
1/2	.5000	1.571	.1963	2	2.000	6.238	3.142	5	5.000	15.71	19.63
33/64	.5156	1.620	.2088	2 1/16	2.0625	6.480	3.341	5 1/16	5.0625	15.90	20.13
17/32	.5312	1.669	.2217	2 1/8	2.1250	6.676	3.547	5 1/8	5.1250	16.10	20.63
35/64	.5468	1.718	.2349	2 3/16	2.1875	6.872	3.758	5 3/16	5.1875	16.30	21.14
9/16	.5625	1.767	.2485	2 1/4	2.2500	7.069	3.976	5 1/4	5.2500	16.49	21.65
37/64	.5781	1.816	.2626	2 5/16	2.3125	7.265	4.200	5 5/16	5.3125	16.69	22.17
19/32	.5937	1.865	.2769	2 3/8	2.3750	7.461	4.430	5 3/8	5.3750	16.89	22.69
39/64	.6094	1.914	.2916	2 7/16	2.4375	7.658	4.666	5 7/16	5.4375	17.08	23.22
5/8	.6250	1.963	.3068	2 1/2	2.5000	7.854	4.909	5 1/2	5.5000	17.28	23.76
41/64	.6406	2.013	.3223	2 9/16	2.5625	8.050	5.157	5 9/16	5.5625	17.48	24.30
21/32	.6562	2.062	.3382	2 5/8	2.6250	8.247	5.412	5 5/8	5.6250	17.67	24.85
43/64	.6719	2.111	.3545	2 11/16	2.6875	8.443	5.673	5 11/16	5.6875	17.87	25.41
11/16	.6875	2.160	.3712	2 3/4	2.7500	8.639	5.940	5 3/4	5.7500	18.06	25.97
45/64	.7031	2.209	.3883	2 13/16	2.8125	8.836	6.213	5 13/16	5.8125	18.26	26.53
23/32	.7187	2.258	.4057	2 7/8	2.8750	9.032	6.492	5 7/8	5.8750	18.46	27.11
47/64	.7344	2.307	.4236	2 15/16	2.9375	9.228	6.777	5 15/16	5.9375	18.65	27.69

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Table 59

CONVERSION TABLE
INCHES INTO MILLIMETERS

Inches	Milli-meters	Inches	Milli-meters	Inches	Milli-meters	Inches	Milli-meters	Inches	Milli-meters	Inches	Milli-meters
1/64	0.3969	55/64	21.8281	2 13/32	61.1189	4 3/32	103.981	5 25/32	146.844	8 15/16	227.013
1/32	0.7937	7/8	22.2250	2 7/16	61.9126	4 1/8	104.775	5 13/16	147.638	9	228.600
3/64	1.1906	57/64	22.6219	2 15/32	62.7064	4 5/32	105.569	5 27/32	148.432	9 1/16	230.188
1/16	1.5875	29/32	23.0187	2 1/2	63.5001	4 3/16	106.363	5 7/8	149.225	9 1/8	231.775
5/64	1.9844	59/64	23.4156	2 17/32	64.2939	4 7/32	107.156	5 29/32	150.019	9 3/16	233.363
3/32	2.3812	15/16	23.8125	2 9/16	65.0876	4 1/4	107.950	5 15/16	150.813	9 1/4	234.950
7/64	2.7781	61/64	24.2094	2 19/32	65.8814	4 9/32	108.744	5 31/32	151.607	9 5/16	236.538
1/8	3.1750	31/32	24.6062	2 5/8	66.6751	4 5/16	109.538	6	152.400	9 3/8	238.125
9/64	3.5719	63/64	25.0031	2 21/32	67.4689	4 11/32	110.331	6 1/16	153.988	9 7/16	239.713
5/32	3.9687	1	25.4001	2 11/16	68.2626	4 3/8	111.125	6 1/8	155.575	9 1/2	241.300
11/64	4.3656	1 1/32	26.1938	2 23/32	69.0564	4 13/32	111.919	6 3/16	157.163	9 9/16	242.888
3/16	4.7625	1 1/16	26.9876	2 3/4	69.8501	4 7/16	112.713	6 1/4	158.750	9 5/8	244.475
13/64	5.1594	1 3/32	27.7813	2 25/32	70.6439	4 15/32	113.506	6 5/16	160.338	9 11/16	246.063
7/32	5.5562	1 1/8	28.5751	2 13/16	71.4376	4 1/2	114.300	6 3/8	161.925	9 3/4	247.650
15/64	5.9531	1 5/32	29.3688	2 27/32	72.2314	4 17/32	115.094	6 7/16	163.513	9 13/16	249.238
1/4	6.3500	1 3/16	30.1626	2 7/8	73.0251	4 9/16	115.888	6 1/2	165.100	9 7/8	250.825
17/64	6.7469	1 7/32	30.9563	2 29/32	73.8189	4 19/32	116.681	6 9/16	166.688	9 15/16	252.413
9/32	7.1437	1 1/4	31.7501	2 15/16	74.6126	4 5/8	117.475	6 5/8	168.275	10	254.001
19/64	7.5406	1 9/32	32.5438	2 31/32	75.4064	4 21/32	118.269	6 11/16	169.863	10 1/16	255.588
5/16	7.9375	1 5/16	33.3376	3	76.2002	4 11/16	119.063	6 3/4	171.450	10 1/8	257.176
21/64	8.3344	1 11/32	34.1313	3 1/32	76.9939	4 23/32	119.856	6 13/16	173.038	10 3/16	258.763
11/32	8.7312	1 3/8	34.9251	3 1/16	77.7877	4 3/4	120.650	6 7/8	174.625	10 1/4	260.351
23/64	9.1281	1 13/32	35.7188	3 3/32	78.5814	4 25/32	121.444	6 15/16	176.213	10 5/16	261.938
3/8	9.5250	1 7/16	36.5126	3 1/8	79.3752	4 13/16	122.238	7	177.800	10 3/8	263.526
25/64	9.9219	1 15/32	37.3063	3 5/32	80.1689	4 27/32	123.031	7 1/16	179.388	10 7/16	265.113
13/32	10.3187	1 1/2	38.1001	3 3/16	80.9627	4 7/8	123.825	7 1/8	180.975	10 1/2	266.701
27/64	10.7156	1 17/32	38.8938	3 7/32	81.7564	4 29/32	124.619	7 3/16	182.563	10 9/16	268.288
7/16	11.1125	1 9/16	39.6876	3 1/4	82.5502	4 15/16	125.413	7 1/4	184.150	10 5/8	269.876
29/64	11.5094	1 19/32	40.4813	3 9/32	83.3439	4 31/32	126.206	7 5/16	185.738	10 11/16	271.463
15/32	11.9062	1 5/8	41.2751	3 5/16	84.1377	5	127.000	7 3/8	187.325	10 3/4	273.051
31/64	12.3031	1 21/32	42.0688	3 11/32	84.9314	5 1/32	127.794	7 7/16	188.913	10 13/16	274.638
1/2	12.7000	1 11/16	42.8626	3 3/8	85.7252	5 1/16	128.588	7 1/2	190.500	10 7/8	276.226
33/64	13.0969	1 23/32	43.6563	3 13/32	86.5189	5 3/32	129.382	7 9/16	192.088	10 15/16	277.813
17/32	13.4937	1 3/4	44.4501	3 7/16	87.3127	5 1/8	130.175	7 5/8	193.675	11	279.401
35/64	13.8906	1 25/32	45.2438	3 15/32	88.1064	5 5/32	130.969	7 11/16	195.263	11 1/16	280.988
9/16	14.2875	1 13/16	46.0376	3 1/2	88.9002	5 3/16	131.763	7 3/4	196.850	11 1/8	282.576
37/64	14.6844	1 27/32	46.8313	3 17/32	89.6939	5 7/32	132.557	7 13/16	198.438	11 3/16	284.163
19/32	15.0812	1 7/8	47.6251	3 9/16	90.4877	5 1/4	133.350	7 7/8	200.025	11 1/4	285.751
39/64	15.4781	1 29/32	48.4188	3 19/32	91.2814	5 9/32	134.144	7 15/16	201.613	11 5/16	287.338
5/8	15.8750	1 15/16	49.2126	3 5/8	92.0752	5 5/16	134.938	8	203.200	11 3/8	288.926
41/64	16.2719	1 31/32	50.0063	3 21/32	92.8689	5 11/32	135.732	8 1/16	204.788	11 7/16	290.513
21/32	16.6687	2	50.8001	3 11/16	93.6627	5 3/8	136.525	8 1/8	206.375	11 1/2	292.101
43/64	17.0656	2 1/32	51.5939	3 23/32	94.4564	5 13/32	137.319	8 3/16	207.963	11 9/16	293.688
11/16	17.4625	2 1/16	52.3876	3 3/4	95.2502	5 7/16	138.113	8 1/4	209.550	11 5/8	295.276
45/64	17.8594	2 3/32	53.1814	3 25/32	96.0439	5 15/32	138.907	8 5/16	211.138	11 11/16	296.863
23/32	18,2562	2 1/8	53.9751	3 13/16	96.8377	5 1/2	139.700	8 3/8	212.725	11 3/4	298.451
47/64	18,6531	2 5/32	54.7688	3 27/32	97.6314	5 17/32	140.494	8 7/16	214.313	11 13/16	300.038
3/4	19.0500	2 3/16	55.5626	3 7/8	98.4252	5 9/16	141.288	8 1/2	215.900	11 7/8	301.626
49/64	19.4469	2 7/32	56.3564	3 29/32	99.2189	5 19/32	142.082	8 9/16	217.488	11 15/16	303.213
25/32	19.8437	2 1/4	57.1501	3 15/16	100.013	5 5/8	142.875	8 5/8	219.075	12	304.801
51/64	20.2406	2 9/32	57.9439	3 31/32	100.806	5 21/32	143.669	8 11/16	220.663		
13/16	20.6375	2 5/16	58.7376	4	101.600	5 11/16	144.463	8 3/4	222.250		
53/64	21.0344	2 11/32	59.5314	4 1/32	102.394	5 23/32	145.257	8 13/16	223.838		
27/32	21.4312	2 3/8	60.3251	4 1/16	103.188	5 3/4	146.050	8 7/8	225.425		

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Table 60

CONVERSION TABLE
DECIMALS OF AN INCH INTO MILLIMETERS

Inches	Milli-meters	Inches	Milli-meters	Inches	Milli-meters	Inches	Milli-meters	Inches	Milli-meters
0.001	0.025	0.140	3.56	0.360	9.14	0.580	14.73	0.800	20.32
0.002	0.051	0.150	3.81	0.370	9.40	0.590	14.99	0.810	20.57
0.003	0.076	0.160	4.06	0.380	9.65	0.600	15.24	0.820	20.83
0.004	0.102	0.170	4.32	0.390	9.91	0.610	15.49	0.830	21.08
0.005	0.127	0.180	4.57	0.400	10.16	0.620	15.75	0.840	21.34
0.006	0.152	0.190	4.83	0.410	10.41	0.630	16.00	0.850	21.59
0.007	0.178	0.200	5.08	0.420	10.67	0.640	16.26	0.860	21.84
0.008	0.203	0.210	5.33	0.430	10.92	0.650	16.51	0.870	22.10
0.009	0.229	0.220	5.59	0.440	11.18	0.660	16.76	0.880	22.35
0.010	0.254	0.230	5.84	0.450	11.43	0.670	17.02	0.890	22.61
0.020	0.508	0.240	6.10	0.460	11.68	0.680	17.27	0.900	22.86
0.030	0.762	0.250	6.35	0.470	11.94	0.690	17.53	0.910	23.11
0.040	1.016	0.260	6.60	0.480	12.19	0.700	17.78	0.920	23.37
0.050	1.270	0.270	6.86	0.490	12.45	0.710	18.03	0.930	23.62
0.060	1.524	0.280	7.11	0.500	12.70	0.720	18.29	0.940	23.88
0.070	1.778	0.290	7.37	0.510	12.95	0.730	18.54	0.950	24.13
0.080	2.032	0.300	7.62	0.520	13.21	0.740	18.80	0.960	24.38
0.090	2.286	0.310	7.87	0.530	13.46	0.750	19.05	0.970	24.64
0.100	2.540	0.320	8.13	0.540	13.72	0.760	19.30	0.980	24.89
0.110	2.794	0.330	8.38	0.550	13.97	0.770	19.56	0.990	25.15
0.120	3.048	0.340	8.64	0.560	14.22	0.780	19.81	1.000	25.40
0.130	3.302	0.350	8.89	0.570	14.48	0.790	20.07		

Table 61

CONVERSION TABLE
MILLIMETERS INTO INCHES

Milli-meters	Inches	Milli-meters	Inches	Milli-meters	Inches	Milli-meters	Inches	Milli-meters	Inches	Milli-meters	Inches
1	0.0394	33	1.2992	65	2.5590	97	3.8189	129	5.0787	161	6.3386
2	0.0787	34	1.3386	66	2.5984	98	3.8583	130	5.1181	162	6.3779
3	0.1181	35	1.3779	67	2.6378	99	3.8976	131	5.1575	163	6.4173
4	0.1575	36	1.4173	68	2.6772	100	3.9370	132	5.1968	164	6.4567
5	0.1968	37	1.4567	69	2.7165	101	3.9764	133	5.2362	165	6.4960
6	0.2362	38	1.4961	70	2.7559	102	4.0157	134	5.2756	166	6.5354
7	0.2756	39	1.5354	71	2.7953	103	4.0551	135	5.3149	167	6.5748
8	0.3150	40	1.5748	72	2.8346	104	4.0945	136	5.3543	168	6.6142
9	0.3543	41	1.6142	73	2.8740	105	4.1338	137	5.3937	169	6.6535
10	0.3937	42	1.6535	74	2.9134	106	4.1732	138	5.4331	170	6.6929
11	0.4331	43	1.6929	75	2.9527	107	4.2126	139	5.4724	171	6.7323
12	0.4724	44	1.7323	76	2.9921	108	4.2520	140	5.5118	172	6.7716
13	0.5118	45	1.7716	77	3.0315	109	4.2913	141	5.5512	173	6.8110
14	0.5512	46	1.8110	78	3.0709	110	4.3307	142	5.5905	174	6.8504
15	0.5905	47	1.8504	79	3.1102	111	4.3701	143	5.6299	175	6.8897
16	0.6299	48	1.8898	80	3.1496	112	4.4094	144	5.6693	176	6.9291
17	0.6693	49	1.9291	81	3.1890	113	4.4488	145	5.7086	177	6.9685
18	0.7087	50	1.9685	82	3.2283	114	4.4882	146	5.7480	178	7.0079
19	0.7480	51	2.0079	83	3.2677	115	4.5275	147	5.7874	179	7.0472
20	0.7874	52	2.0472	84	3.3071	116	4.5669	148	5.8268	180	7.0866
21	0.8268	53	2.0866	85	3.3464	117	4.6063	149	5.8661	181	7.1260
22	0.8661	54	2.1260	86	3.3858	118	4.6457	150	5.9055	182	7.1653
23	0.9055	55	2.1653	87	3.4252	119	4.6850	151	5.9449	183	7.2047
24	0.9449	56	2.2047	88	3.4646	120	4.7244	152	5.9842	184	7.2441
25	0.9842	57	2.2441	89	3.5039	121	4.7638	153	6.0236	185	7.2834
26	1.0236	58	2.2835	90	3.5433	122	4.8031	154	6.0630	186	7.3228
27	1.0630	59	2.3228	91	3.5827	123	4.8425	155	6.1023	187	7.3622
28	1.1024	60	2.3622	92	3.6220	124	4.8819	156	6.1417	188	7.4016
29	1.1417	61	2.4016	93	3.6614	125	4.9212	157	6.1811	189	7.4409
30	1.1811	62	2.4409	94	3.7008	126	4.9606	158	6.2205	190	7.4803
31	1.2205	63	2.4803	95	3.7401	127	5.0000	159	6.2598	191	7.5197
32	1.2598	64	2.5197	96	3.7795	128	5.0394	160	6.2992	192	7.5590

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Table 61 (Cont'd)

CONVERSION TABLE
MILLIMETERS INTO INCHES

Millimeters	Inches	Millimeters	Inches	Millimeters	Inches	Millimeters	Inches	Millimeters	Inches	Millimeters	Inches
193	7.5984	261	10.2756	329	12.9527	397	15.6299	465	18.3070	533	20.9842
194	7.6378	262	10.3149	330	12.9921	398	15.6693	466	18.3464	534	21.0236
195	7.6771	263	10.3543	331	13.0315	399	15.7086	467	18.3858	535	21.0629
196	7.7165	264	10.3937	332	13.0708	400	15.7480	468	18.4252	536	21.1023
197	7.7559	265	10.4330	333	13.1102	401	15.7874	469	18.4645	537	21.1417
198	7.7953	266	10.4724	334	13.1496	402	15.8267	470	18.5039	538	21.1811
199	7.8346	267	10.5118	335	13.1889	403	15.8661	471	18.5433	539	21.2204
200	7.8740	268	10.5512	336	13.2283	404	15.9055	472	18.5826	540	21.2598
201	7.9134	269	10.5905	337	13.2677	405	15.9448	473	18.6220	541	21.2992
202	7.9527	270	10.6299	338	13.3071	406	15.9842	474	18.6614	542	21.3385
203	7.9921	271	10.6693	339	13.3464	407	16.0236	475	18.7007	543	21.3779
204	8.0315	272	10.7086	340	13.3858	408	16.0630	476	18.7401	544	21.4173
205	8.0708	273	10.7480	341	13.4252	409	16.1023	477	18.7795	545	21.4566
206	8.1102	274	10.7874	342	13.4645	410	16.1417	478	18.8189	546	21.4960
207	8.1496	275	10.8267	343	13.5039	411	16.1811	479	18.8582	547	21.5354
208	8.1890	276	10.8661	344	13.5433	412	16.2204	480	18.8976	548	21.5748
209	8.2283	277	10.9055	345	13.5826	413	16.2598	481	18.9370	549	21.6141
210	8.2677	278	10.9449	346	13.6220	414	16.2992	482	18.9763	550	21.6535
211	8.3071	279	10.9842	347	13.6614	415	16.3385	483	19.0157	551	21.6929
212	8.3464	280	11.0236	348	13.7008	416	16.3779	484	19.0551	552	21.7322
213	8.3858	281	11.0630	349	13.7401	417	16.4173	485	19.0944	553	21.7716
214	8.4252	282	11.1023	350	13.7795	418	16.4567	486	19.1338	554	21.8110
215	8.4645	283	11.1417	351	13.8189	419	16.4960	487	19.1732	555	21.8503
216	8.5039	284	11.1811	352	13.8582	420	16.5354	488	19.2126	556	21.8897
217	8.5433	285	11.2204	353	13.8976	421	16.5748	489	19.2519	557	21.9291
218	8.5827	286	11.2598	354	13.9370	422	16.6141	490	19.2913	558	21.9685
219	8.6220	287	11.2992	355	13.9763	423	16.6535	491	19.3307	559	22.0078
220	8.6614	288	11.3386	356	14.0157	424	16.6929	492	19.3700	560	22.0472
221	8.7008	289	11.3779	357	14.0551	425	16.7322	493	19.4094	561	22.0866
222	8.7401	290	11.4173	358	14.0945	426	16.7716	494	19.4488	562	22.1259
223	8.7795	291	11.4567	359	14.1338	427	16.8110	495	19.4881	563	22.1653
224	8.8189	292	11.4960	360	14.1732	428	16.8504	496	19.5275	564	22.2047
225	8.8582	293	11.5354	361	14.2126	429	16.8897	497	19.5669	565	22.2440
226	8.8976	294	11.5748	362	14.2519	430	16.9291	498	19.6063	566	22.2834
227	8.9370	295	11.6141	363	14.2913	431	16.9685	499	19.6456	567	22.3228
228	8.9764	296	11.6335	364	14.3307	432	17.0078	500	19.6850	568	22.3622
229	9.0157	297	11.6929	365	14.3700	433	17.0472	501	19.7244	569	22.4015
230	9.0551	298	11.7323	366	14.4094	434	17.0866	502	19.7637	570	22.4409
231	9.0945	299	11.7716	367	14.4488	435	17.1259	503	19.8031	571	22.4803
232	9.1338	300	11.8110	368	14.4882	436	17.1653	504	19.8425	572	22.5196
233	9.1732	301	11.8504	369	14.5275	437	17.2047	505	19.8818	573	22.5590
234	9.2126	302	11.8897	370	14.5669	438	17.2441	506	19.9212	574	22.5984
235	9.2519	303	11.9291	371	14.6063	439	17.2834	507	19.9606	575	22.6377
236	9.2913	304	11.9685	372	14.6456	440	17.3228	508	20.0000	576	22.6771
237	9.3307	305	12.0078	373	14.6850	441	17.3622	509	20.0393	577	22.7165
238	9.3701	306	12.0472	374	14.7244	442	17.4015	510	20.0787	578	22.7559
239	9.4094	307	12.0866	375	14.7637	443	17.4409	511	20.1181	579	22.7952
240	9.4488	308	12.1260	376	14.8031	444	17.4803	512	20.1574	580	22.8346
241	9.4882	309	12.1653	377	14.8425	445	17.5196	513	20.1968	581	22.8740
242	9.5275	310	12.2047	378	14.8819	446	17.5590	514	20.2362	582	22.9133
243	9.5669	311	12.2441	379	14.9212	447	17.5984	515	20.2755	583	22.9527
244	9.6063	312	12.2834	380	14.9606	448	17.6378	516	20.3149	584	22.9921
245	9.6456	313	12.3228	381	15.0000	449	17.6771	517	20.3543	585	23.0314
246	9.6850	314	12.3622	382	15.0393	450	17.7165	518	20.3937	586	23.0708
247	9.7244	315	12.4015	383	15.0787	451	17.7559	519	20.4330	587	23.1102
248	9.7638	316	12.4409	384	15.1181	452	17.7952	520	20.4724	588	23.1496
249	9.8031	317	12.4803	385	15.1574	453	17.8346	521	20.5118	589	23.1889
250	9.8425	318	12.5197	386	15.1968	454	17.8740	522	20.5511	590	23.2283
251	9.8819	319	12.5590	387	15.2362	455	17.9133	523	20.5905	591	23.2677
252	9.9212	320	12.5984	388	15.2756	456	17.9527	524	20.6299	592	23.3070
253	9.9606	321	12.6378	389	15.3149	457	17.9921	525	20.6692	593	23.3464
254	10.0000	322	12.6771	390	15.3543	458	18.0315	526	20.7086	594	23.3858
255	10.0393	323	12.7165	391	15.3937	459	18.0708	527	20.7480	595	23.4251
256	10.0787	324	12.7559	392	15.4330	460	18.1102	528	20.7874	596	23.4645
257	10.1181	325	12.7952	393	15.4724	461	18.1496	529	20.8267	597	23.5039
258	10.1575	326	12.8346	394	15.5118	462	18.1889	530	20.8661	598	23.5433
259	10.1968	327	12.8740	395	15.5511	463	18.2283	531	20.9055	599	23.5826
260	10.2362	328	12.9134	396	15.5905	464	18.2677	532	20.9448	600	23.6220

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Table 62

CONVERSION TABLE
HUNDREDTHS OF A MILLIMETER INTO INCHES

Milli-meters	Inches	Milli-meters	Inches	Milli-meters	Inches	Milli-meters	Inches	Milli-meters	Inches	Milli-meters	Inches
0.01	0.0004	0.18	0.0071	0.35	0.0138	0.52	0.0205	0.69	0.0272	0.86	0.0339
0.02	0.0008	0.19	0.0075	0.36	0.0142	0.53	0.0209	0.70	0.0276	0.87	0.0343
0.03	0.0012	0.20	0.0079	0.37	0.0146	0.54	0.0213	0.71	0.0280	0.88	0.0346
0.04	0.0016	0.21	0.0083	0.38	0.0150	0.55	0.0217	0.72	0.0283	0.89	0.0350
0.05	0.0020	0.22	0.0087	0.39	0.0154	0.56	0.0220	0.73	0.0287	0.90	0.0354
0.06	0.0024	0.23	0.0091	0.40	0.0157	0.57	0.0224	0.74	0.0291	0.91	0.0358
0.07	0.0028	0.24	0.0094	0.41	0.0161	0.58	0.0228	0.75	0.0295	0.92	0.0362
0.08	0.0031	0.25	0.0098	0.42	0.0165	0.59	0.0232	0.76	0.0299	0.93	0.0366
0.09	0.0035	0.26	0.0102	0.43	0.0169	0.60	0.0236	0.77	0.0303	0.94	0.0370
0.10	0.0039	0.27	0.0106	0.44	0.0173	0.61	0.0240	0.78	0.0307	0.95	0.0374
0.11	0.0043	0.28	0.0110	0.45	0.0177	0.62	0.0244	0.79	0.0311	0.96	0.0378
0.12	0.0047	0.29	0.0114	0.46	0.0181	0.63	0.0248	0.80	0.0315	0.97	0.0382
0.13	0.0051	0.30	0.0118	0.47	0.0185	0.64	0.0252	0.81	0.0319	0.98	0.0386
0.14	0.0055	0.31	0.0122	0.48	0.0189	0.65	0.0256	0.82	0.0323	0.99	0.0390
0.15	0.0059	0.32	0.0126	0.49	0.0193	0.66	0.0260	0.83	0.0327	1.00	0.0394
0.16	0.0063	0.33	0.0130	0.50	0.0197	0.67	0.0264	0.84	0.0331		
0.17	0.0067	0.34	0.0134	0.51	0.0201	0.68	0.0268	0.85	0.0335		

Table 63

METRIC PREFIXES

micro	$= 10^{-6}$	(example)	micron
milli	$= 10^{-3}$		millimeter
centi	$= 10^{-2}$		centimeter
deci	$= 10^{-1}$		decimeter
deka	$= 10$		decaliter
hecto	$= 10^{2}$		hectoliter
kilo	$= 10^{3}$		kilometer
mega	$= 10^{6}$		megaton

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Table 64

LENGTH

1 inch (in.)	=	2.54 centimeters	=	25400 microns
1 foot (ft)	=	12 inches	=	.3048 meter
1 yard (yd)	=	3 feet	=	.9144 meter
1 mile	=	5280 feet	=	1.609 kilometers
1 nautical mile	=	6080 feet	=	1.853 kilometers
1 millimeter (mm)	=	1000 microns	=	.0394 inch
1 centimeter (cm)	=	10 millimeters	=	.3937 inch
1 decimeter	=	10 centimeters	=	3.937 inches
1 meter (m)	=	100 centimeters	=	3.281 feet
1 kilometer	=	1000 meters	=	.6214 mile

Table 65

AREA

1 sq in.	=		=	6.45 sq cm
1 sq ft	=	144 sq in.	=	.0929 sq meter
1 sq. yard	=	9 sq ft	=	.836 sq meter
1 acre	=	43560 sq ft	=	.4047 hectare
1 sq mile	=	640 acres	=	259 hectares
1 sq cm	=	100 sq mm	=	.155 sq in.
1 sq. meter	=	10,000 sq cm	=	10.764 sq ft
1 hectare	=	10,000 sq meters	=	2.471 acres
1 sq km	=	100 hectares	=	.3861 sq mile

Table 66

WEIGHT, AVOIRDUPOIS

1 ounce (oz)	=	473.5 grains	=	28.35 grams
1 pound (lb)	=	16 ounces	=	453.59 grams
1 pound	=	7000 grains	=	.454 kilograms
1 short ton	=	2000 pounds	=	907 kilograms
1 cu ft water @ 4° C.	=	62.42 lb	=	28.31 kilograms
1 gallon water @ 4° C.	=	8.34 lb	=	3.78 kilograms
1 gram (g)	=	1000 milligrams	=	15.43 grains
1 kilogram (kg)	=	1000 grams	=	2.205 pounds
1 metric ton	=	1000 kilograms	=	2204.6 pounds
1 cu cm water @ 4° C.	=	1 gram	=	.035 ounces
1 liter water @ 4° C.	=	1 kilogram	=	2.205 pounds

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Table 67

VOLUME, DRY

1 cu in.	=		=	16.39 cu cm
1 cu ft	=	1728 cu in.	=	.0238 cu meter
1 cu yard	=	27 cu ft	=	.7646 cu meter
1 quart, U.S.	=	.0389 cu ft	=	1101 cu cm
1 gallon, U.S.	=	4 quarts	=	4.405 cu decimeters
1 peck	=	2 gallons	=	8.810 cu decimeters
1 bushel, U.S.	=	4 pecks	=	35.239 cu decimeters
1 bushel, U.S.	=	1.244 cu ft		
1 bushel, Imperial	=	1.032 U.S. bushels		
1 cord	=	128 cu ft		
1 cu cm	=		=	.061 cu in.
1 cu. decimeter	=	1000 cu cm	=	61.02 cu in.
1 cu meter	=	1000 cu decimeters	=	1.308 cu yd
1 cu meter			=	35.314 cu ft

Table 68

VOLUME, LIQUID

1 pint	=	16 fluid ounces	=	.473 liters
1 quart	=	2 pints	=	.946 liter
1 gallon, U.S.	=	4 quarts	=	3.785 liters
1 gallon, U.S.	=	231 cu in.	=	3.785 cu decimeters
1 cu ft	=	7.48 gallon, U.S.	=	28.32 cu decimeters
1 gallon, Imperial	=	1.201 gallon, U.S.	=	
1 liter	=	1000 cu cm	=	1.057 quarts
1 liter	=	1 cu decimeter	=	.0353 cu ft
1 decaliter	=	10 liters	=	2.64 gallon, U.S.
1 cu meter	=	1000 liters	=	264.18 gallon, U.S.

Table 69

DENSITY

1 lb/cu in.	=	1728 lb/cu ft	=	27.68 gram/cu cm
1 lb/cu ft	=	27 lb/cu yd	=	16.018 kg/cu m
1 gram/cu cm	=	1000 kg/cu m	=	62.43 lb/cu ft

Table 70

PRESSURE

1 lb/sq in.	=	144 lb/sq ft	=	.0703 kg/sq cm
1 lb/sq in.	=	2.036 in. Hg	=	2.307 ft water @ 4° C.
1 kg/sq cm	=	735.51 mm Hg	=	14.22 lb/sq in.
1 kg/sq cm	=	10 m water @ 4° C.	=	.968 standard atmospheres
1 kg/sq cm	=	1 at		
1 in. Hg	=	.491 lb/sq in.	=	1.133 ft water at 4° C.
1 in. water	=	5.20 lb/sq ft	=	.0361 lb/sq in.
1 ft water @ 4° C.	=	62.43 lb/sq ft	=	.0305 kg/sq cm
1 ft water @ 4° C.	=	.433 lb/sq in.	=	.883 in. Hg
1 standard atmosphere (Atm)	=	14.7 lb/sq in.	=	29.92 in. Hg
1 standard atmosphere	=	33.9 ft water @ 4° C.	=	760 mm Hg
1 standard atmosphere	=	1.033 kg/sq cm	=	1.0133 bars
1 cm Hg	=	.0136 kg/sq cm	=	.1934 lb/sq in.
1 Bar	=	750 mm Hg	=	14.5 lb/sq in.
1 ata	=	1 kg/sq cm absolute		

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Table 71

VELOCITY

1 ft/sec	=	.682 miles/hr	=	.3048 m/sec
1 mile/hr	=	1.467 ft/sec	=	.447 m/sec
1 mile/hr	=	.868 knots	=	1.609 km/hr
1 m/sec	=	3.6 km/hr	=	3.28 ft/sec
1 km/hr	=	.2778 m/sec	=	.621 miles/hr
1 knot	=	1.152 miles/hr	=	1 nautical mile/hr

Table 72

HEAT, ENERGY, WORK

1 ft lb	=	.001285 BTU	=	0.13826 kg-meter
1 joule	=	1 watt - second	=	.000948 BTU
1 BTU	=	778.1 ft lb	=	.252 kcal
1 KCAL	=	3.968 BTU	=	1000 cal
1 hp-hr	=	.746 kw-hr	=	2544.7 BTU
1 kw-hr	=	1.341 hp-hr	=	3413 BTU
1 boiler horsepower	=	33479 BTU/hr	=	Evaporation of 34.5 water/hr at 212° F.

Table 73

SOLID AND LIQUID EXPENDABLE REFRIGERANTS

Evaporating Temperature of dry ice (solid CO_2) at 1 atmosphere	=	-109° F.
Heat of sublimation of dry ice at -109° F.	=	246.3 BTU/lb
Specific heat of CO_2 gas	=	.2 BTU/lb/°F.
Refrigerating effect of solid CO_2 to gas at 32° F. (246.3 + .2 [109 + 32])	=	274.5 BTU/lb
Evaporating Temperature of liquid carbon dioxide (CO_2) at 1 atmosphere	=	-70° F.
Heat of vaporization of liquid CO_2 at -70° F.	=	149.7 BTU/lb
Specific heat of CO_2 gas	=	.2 BTU/lb/°F.
Refrigerating effect of liquid CO_2 to gas at 32° F. (149.7 + .2 [70 + 32])	=	170.1 BTU/lb
Evaporating Temperature of liquid nitrogen (N_2) at 1 atmosphere	=	-320° F.
Heat of vaporization of liquid N_2 at -320° F.	=	85.67 BTU/lb
Specific heat of N_2 gas	=	.248 BTU/lb/°F.
Refrigerating effect of liquid nitrogen to gas at 32° F. (85.67 + .248 [320 + 32])	=	172.97 BTU/lb

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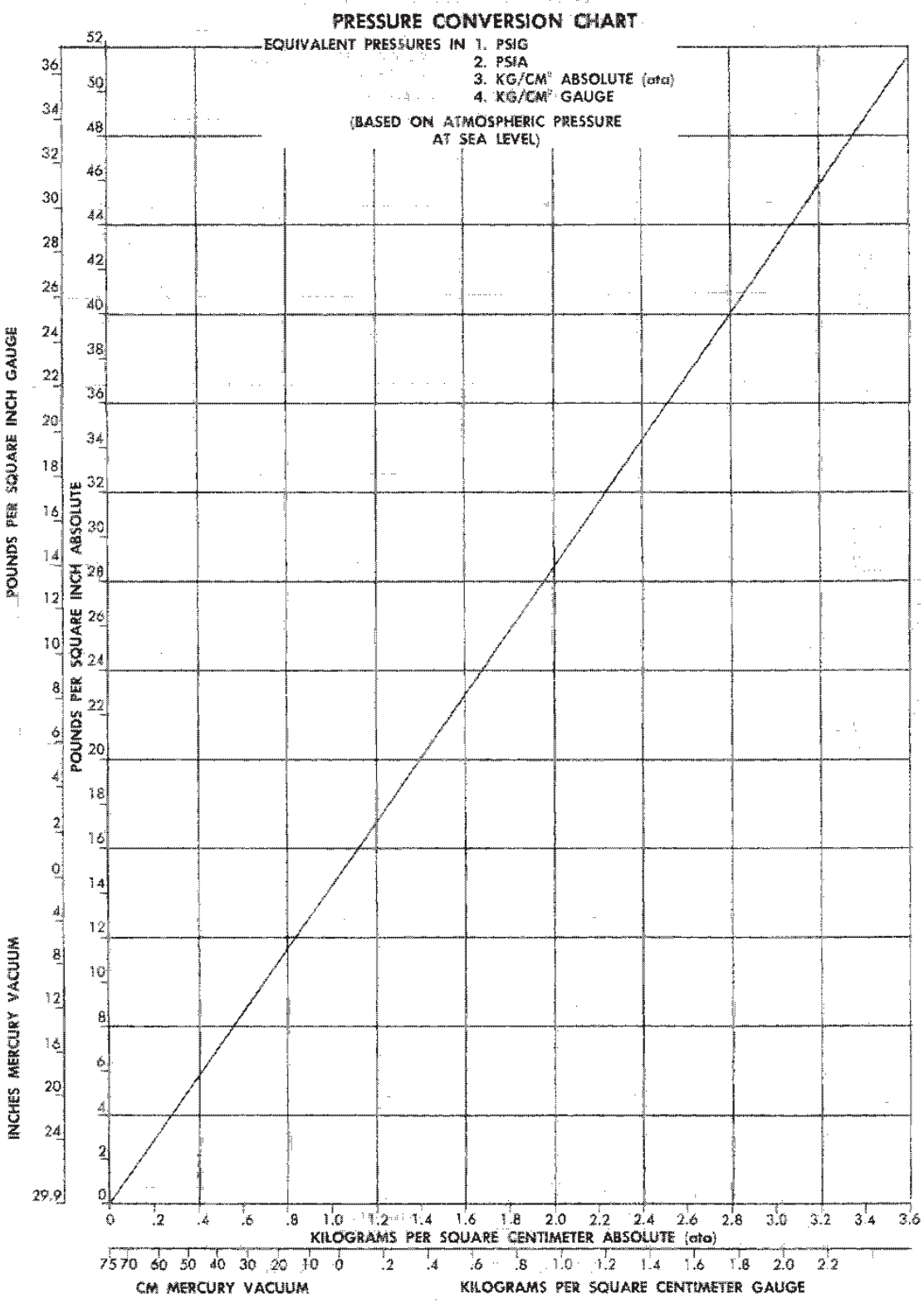


Figure 191

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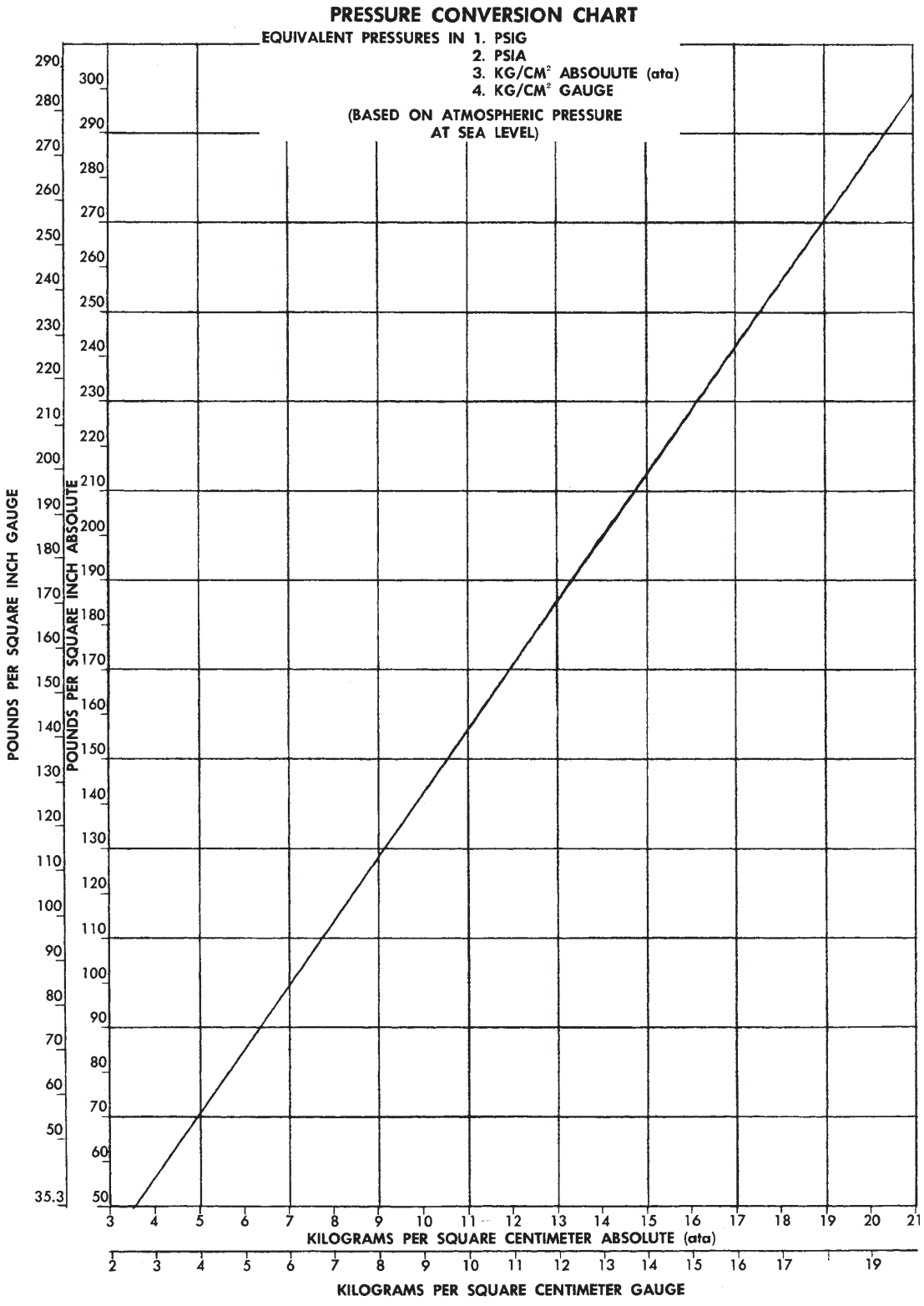


Figure 192

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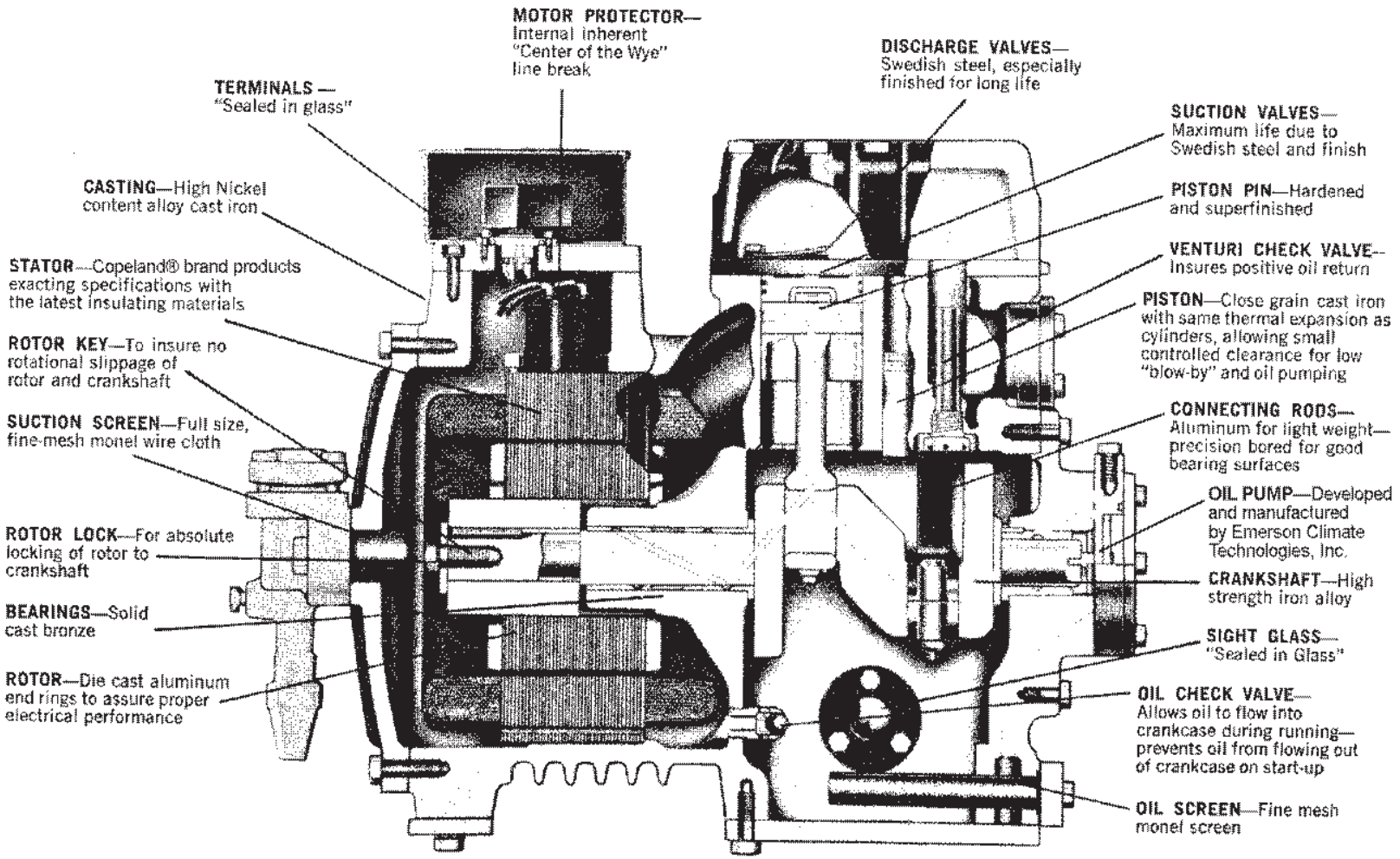
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