Part 5

INSTALLATION AND SERVICE

Section 24. INSTALLATION

Section 25. SERVICING COPELAND COMPRESSORS

Section 26. FUNDAMENTALS OF SERVICE OPERATIONS

Section 27. USEFUL ENGINEERING DATA

INDEX OF TABLES

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)

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 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.

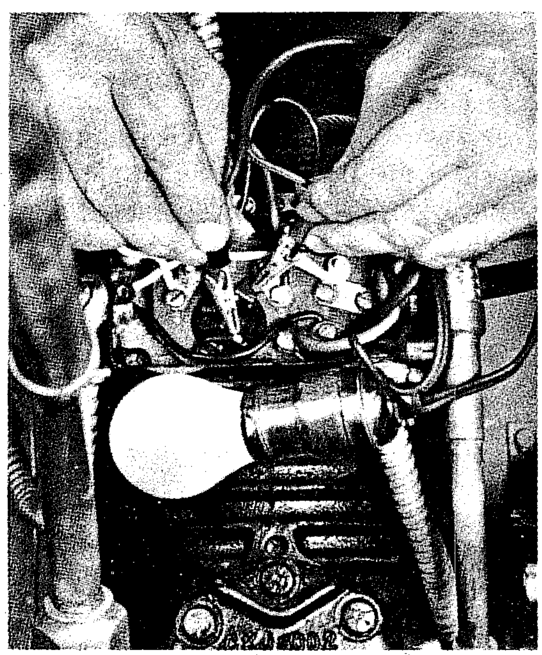


Figure 150

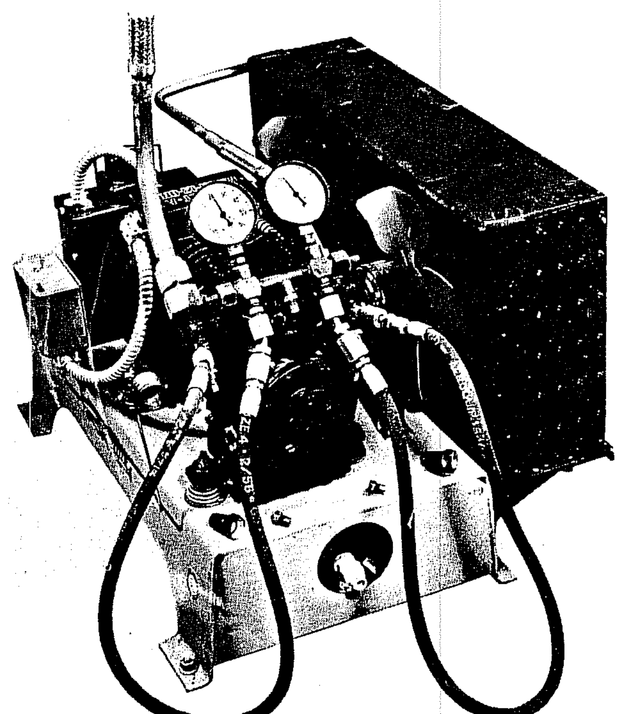


Figure 151

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.

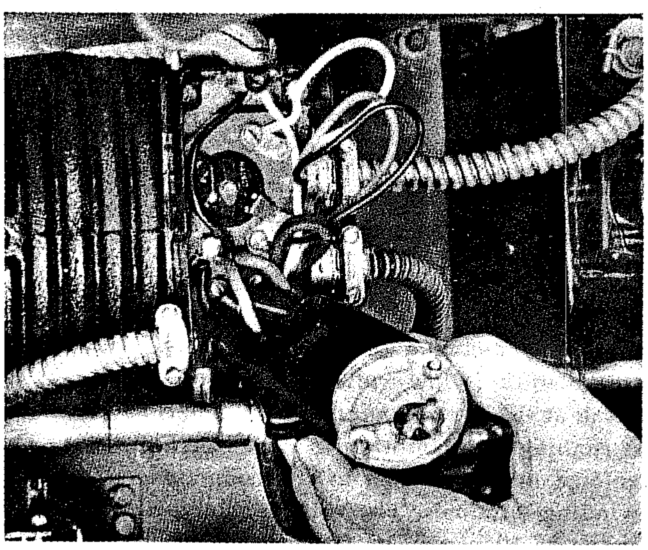


Figure 152

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.

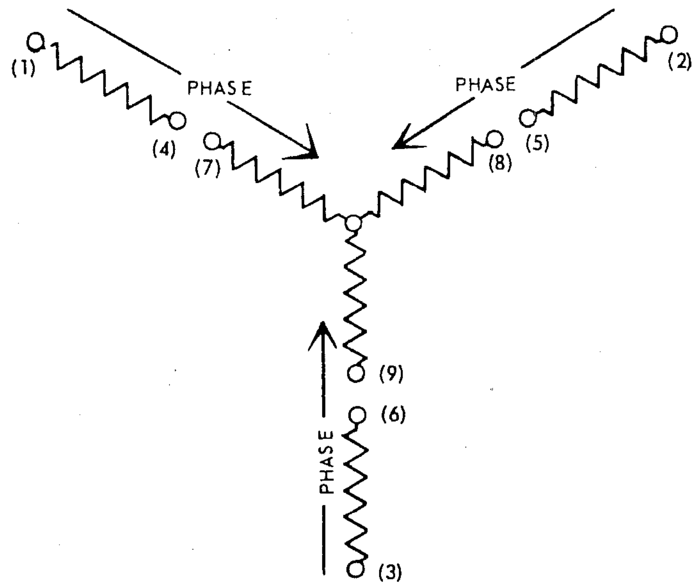
If the amperage is sufficiently unbalanced to cause a protector trip, and the voltage supply is unbalanced, check with the power company to see if the condition can be corrected. If the voltage supply is balanced, indicating a defective motor phase, the compressor should be replaced.

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

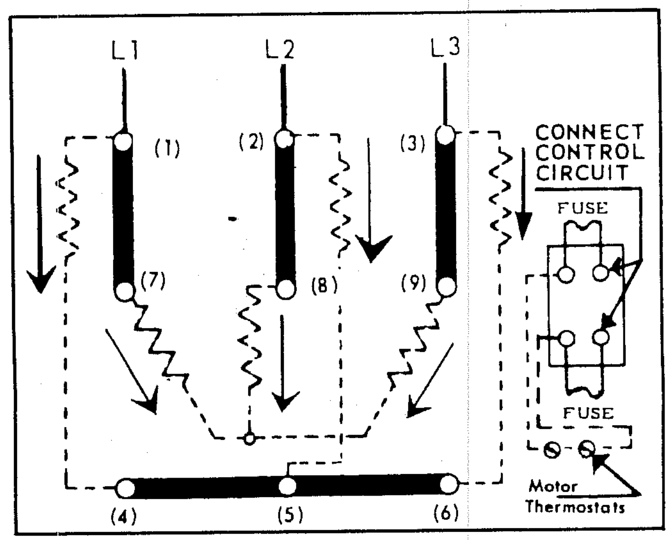
5. Check the wiring against the wiring diagram in the terminal box. On dual voltage motors, check the location of the terminal jumper bars to be sure phases are properly connected. (See Figure 153.)

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.)

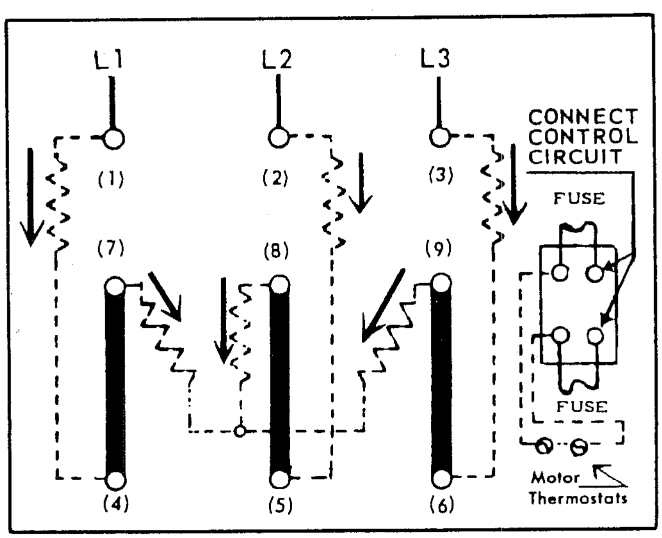
DUAL VOLTAGE (220V/440V) MOTOR WINDINGS



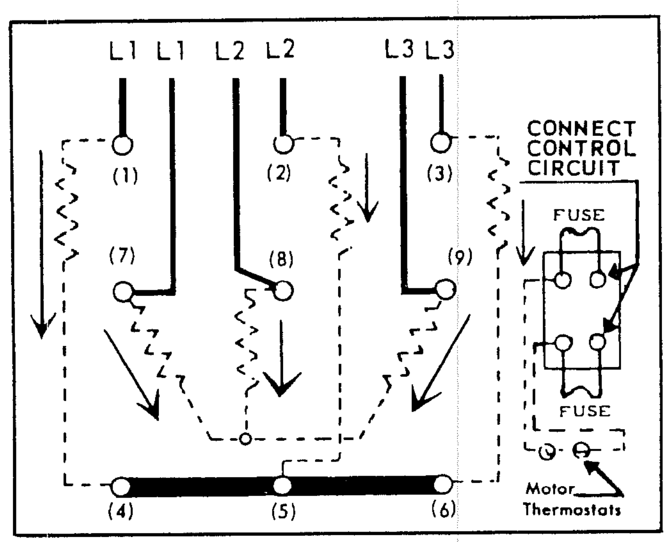
Schematic wiring diagram showing the terminal positions and phase relation.



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

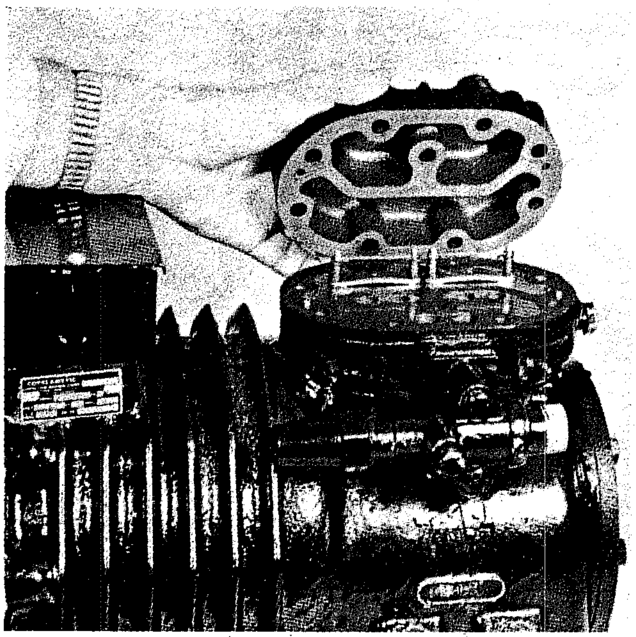


Figure 154

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.

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.

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

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

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.

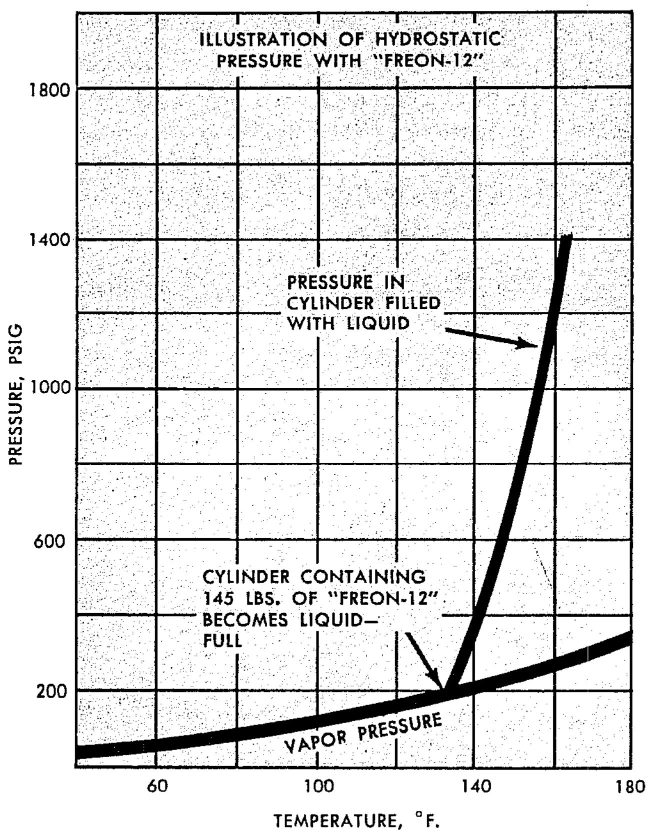
Reasonable care during installation and service can keep contamination in a system at a safe and acceptable level.

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. Any time the system is to be opened, introduce a slight positive refrigerant pressure to prevent air from rushing in to the open lines.
7. Install a new filter-drier in the liquid line each time the system is opened for service.

HANDLING OF REFRIGERANT CONTAINERS

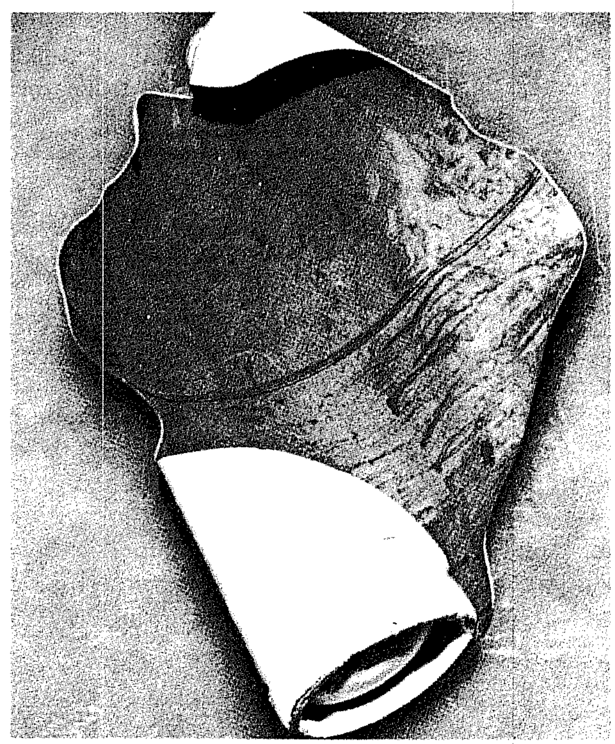
The pressure created by liquid refrigerant in a sealed storage container is equal to its saturation pressure at the liquid temperature so long as there is vapor space available. If however, the container is over-filled, or if in the case of gradual and uniform overheating the liquid expands until the 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 liquified 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 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 not 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, Copeland 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 Copelaweld 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 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.

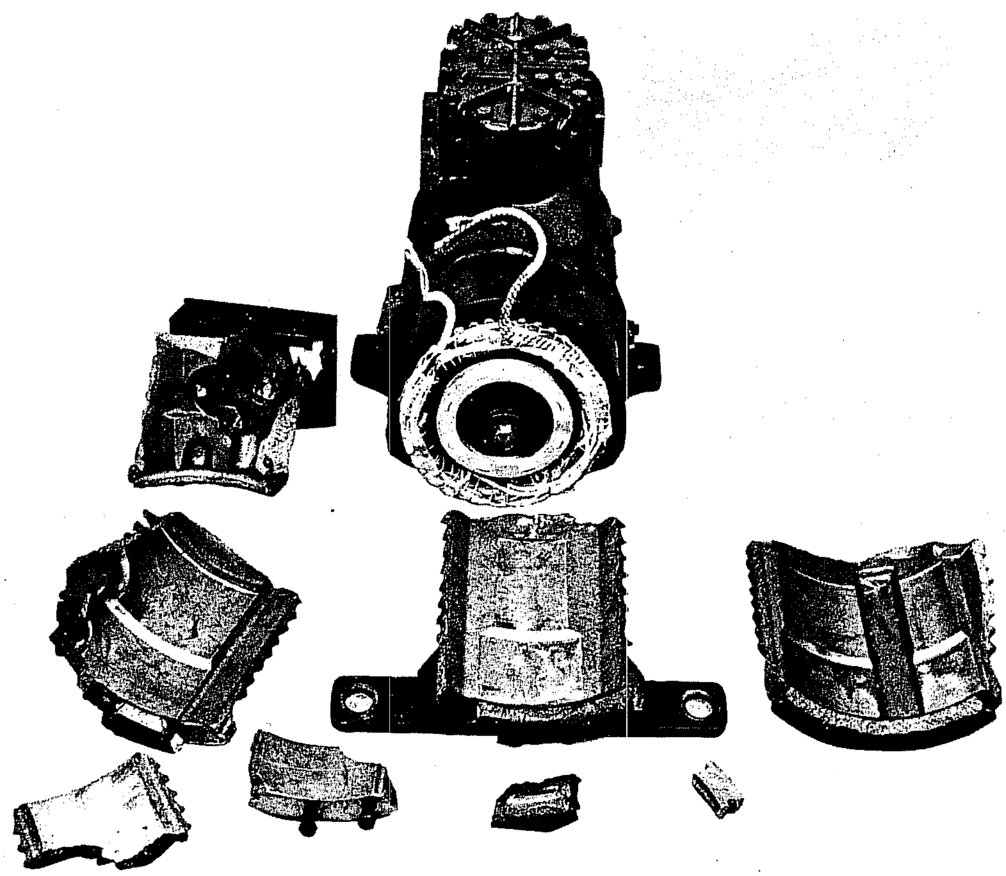
Every Copelametic compressor crankcase is subjected to a 300 psig pressure at the factory, and every Copeland compressor is leak tested at a minimum of 175 psig.

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 Copeland, it is recommended that all crankcase test pressures and all leak test pressures be limited to a maximum of 175 psig. U.L. safety standards 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. Copeland minimum high side test pressures for unit applications are as follows, but the maximum is not to exceed 500 psig.

Copeland Unit Application	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.

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.

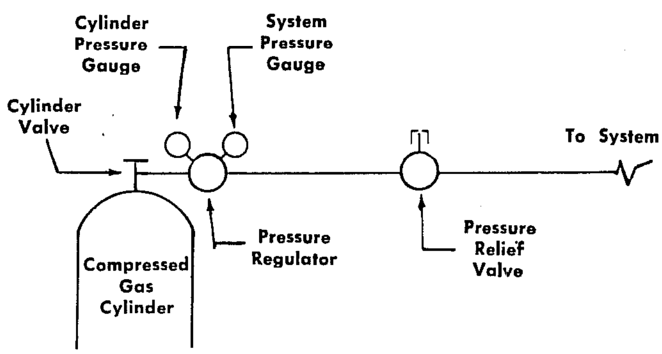


Figure 158

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, Copeland 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 or refrigerant 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, or refrigerant 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.

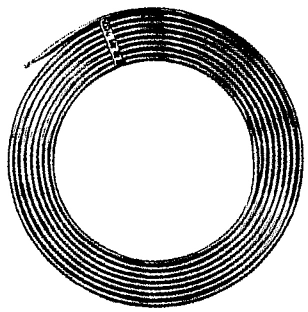
5. Install adequate filter-driers in the suction and liquid lines, pressure test, evacuate, and complete the system cleaning as necessary.

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.

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.

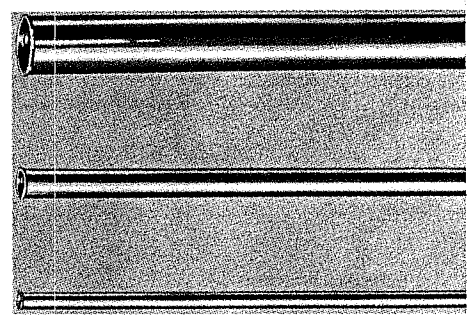
In the event hard drawn tubing is left open and does get dirty, draw a rag soaked in refrigeration oil through the tubing prior to usage.



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.



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.

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.

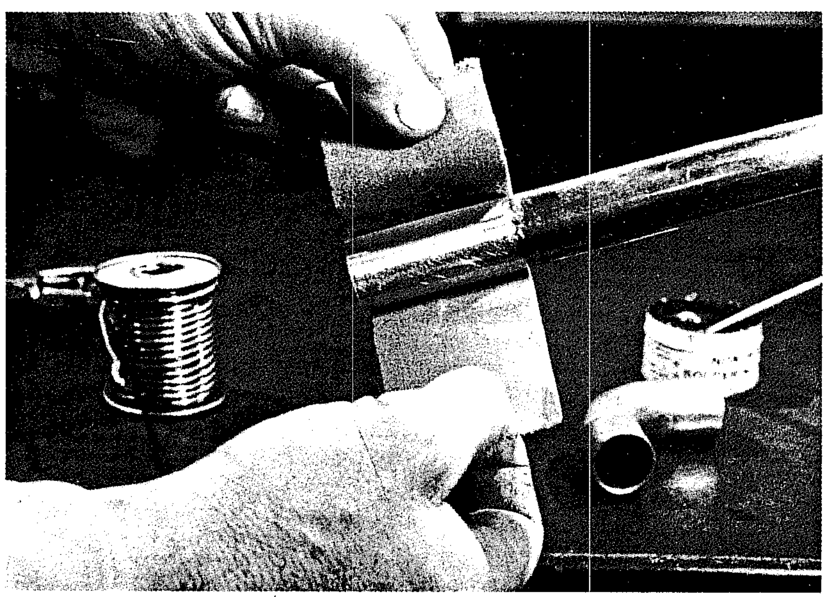
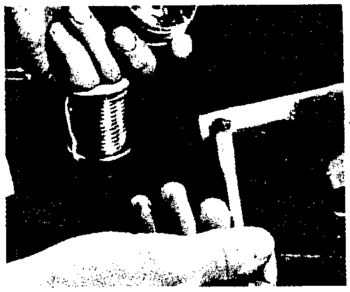


Figure 161

Courtesy E. I. DuPont de Nemours & Co.

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.

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 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.

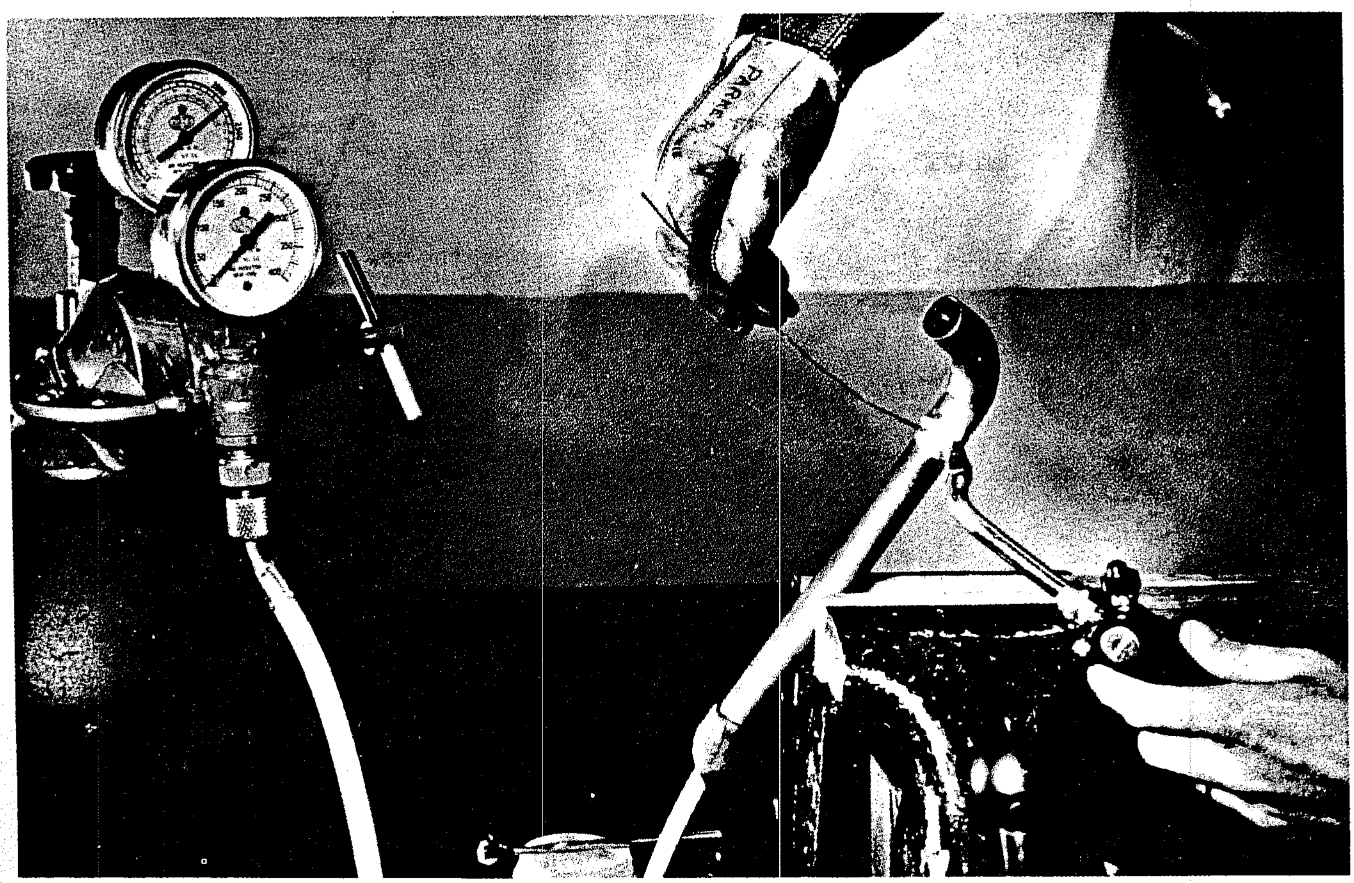


Figure 163 Courtesy E. I. DuPont de Nemours & Co.

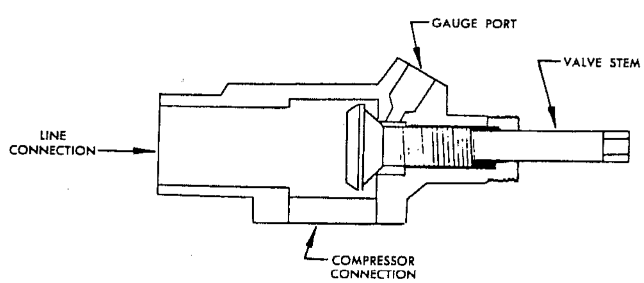
Making silver soldered joint with fitting looking down. Whenever possible, soldered joints should be made in this manner to keep flux and solder from getting inside. Note also that dry nitrogen is being swept through the tubing while soldering to prevent oxide formation.

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.

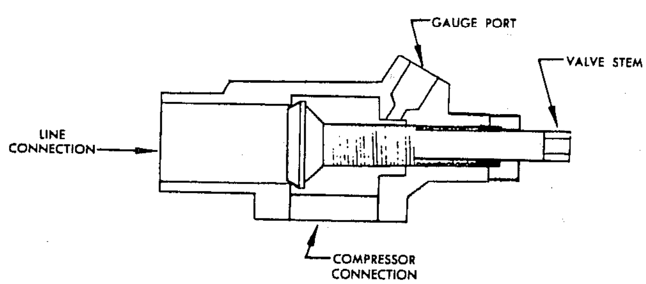
Immediately after the brazing alloy has set, apply a wet brush or cloth to the joint to wash off the flux. All flux must be removed for inspection and pressure testing.

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.



Valve Backseated



Valve Frontseated

Courtesy Henry Valve Co.

COMPRESSOR SERVICE VALVE

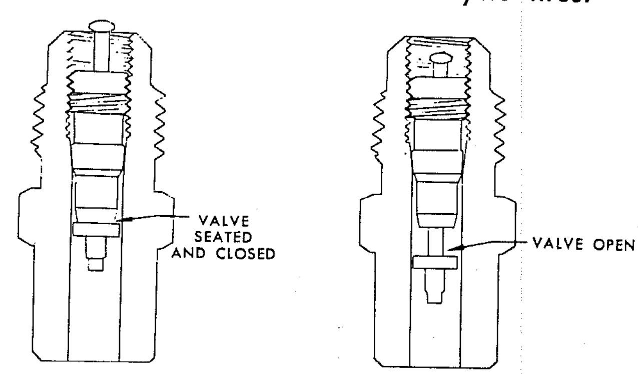
Figure 164

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.

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.



Valve In Closed Position   Valve In Open Position — Stem Depressed

SCHRADER TYPE VALVE

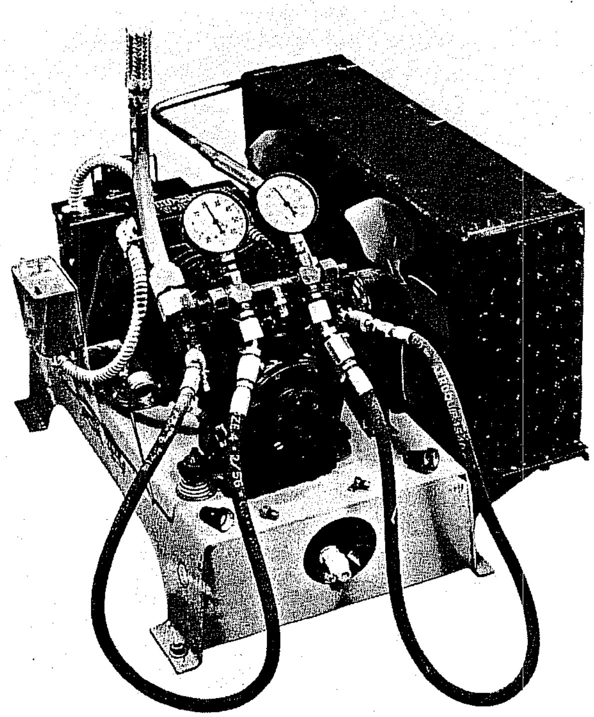
Figure 165

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.

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.

THE GAUGE MANIFOLD

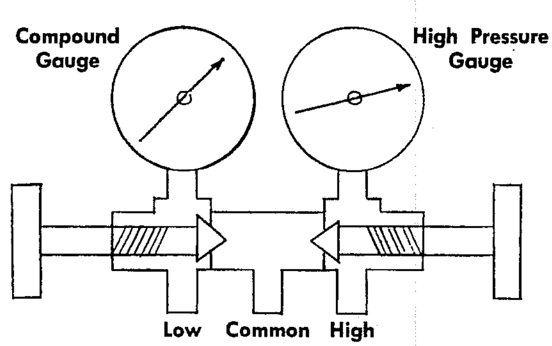
The most important tool of the refrigeration serviceman is the gauge manifold. It can be used for checking system pressures, charging refrigerant, evacuating the system, purging non-condensables, adding oil, and for many other purposes.



PRESSURE READING WITH GAUGE MANIFOLD

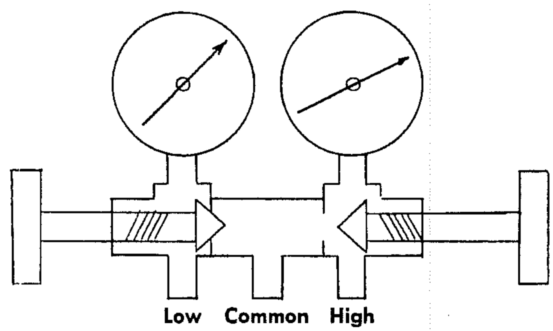
Figure 166

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.



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

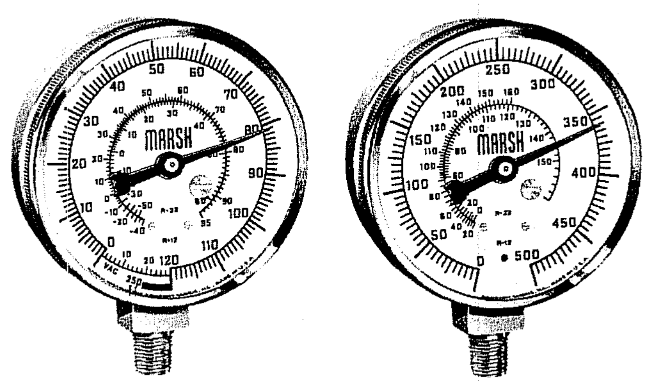
Figure 167



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

Figure 168

The 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.



Compound Gauge High Pressure Gauge

Courtesy Marsh Instrument Co.

REFRIGERATION SERVICEMAN'S GAUGES

Figure 169

Gauges are fine instruments and should be treated as such. Do not 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 systems 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. Then crack the high pressure service valve allowing refrigerant vapor to bleed through the loose hose connections. 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.

To purge non-condensables, stop the compressor but leave the condenser fan running on air cooled units, or block open the water valve on water cooled units. Allow 5 to 10 minutes for the non-condensables to rise to the top of the vapor space.

Some large systems have purge valves at the top of the condenser and/or receiver. If purge valves are not available, the service port on the compressor discharge valve may be used in an emergency for purging. Slowly open the purge valve. Limit the opening to restrict the flow of gas, since a rapid discharge will cause boiling of the liquid refrigerant and draw off excessive refrigerant vapor. Vent for a few seconds and close the valve.

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 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

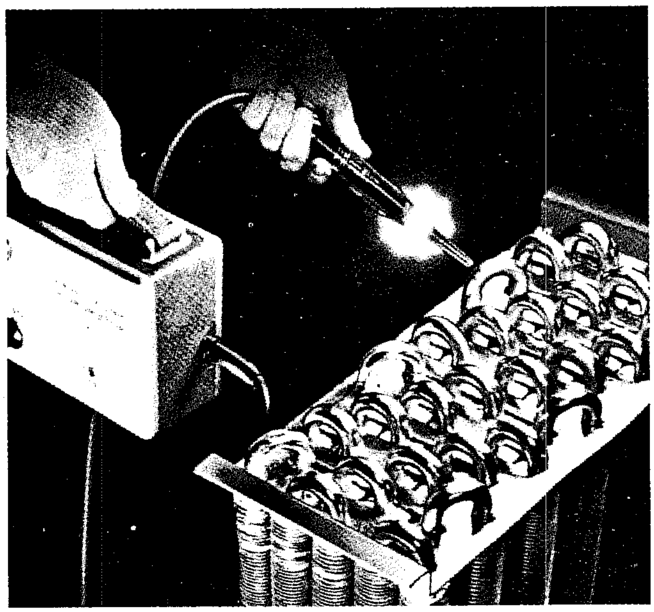
Refrigeration systems must be absolutely gas tight for two reasons. First, any leakage will result in loss of the refrigerant charge. Second, leaks allow air and moisture to enter the system.

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. Basically, the pressure test method involves pressurizing the system with refrigerant, and then checking for leakage outward. If the system is not already charged with refrigerant, it is more economical and just as effective to partially charge with refrigerant to a pressure of approximately 35 psig, and then use an inert gas such as dry nitrogen or dry carbon dioxide to build up pressure in the system to approximately 175 psig for testing purposes.

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 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 tetrochloride, or other solvents which may give a false reaction.



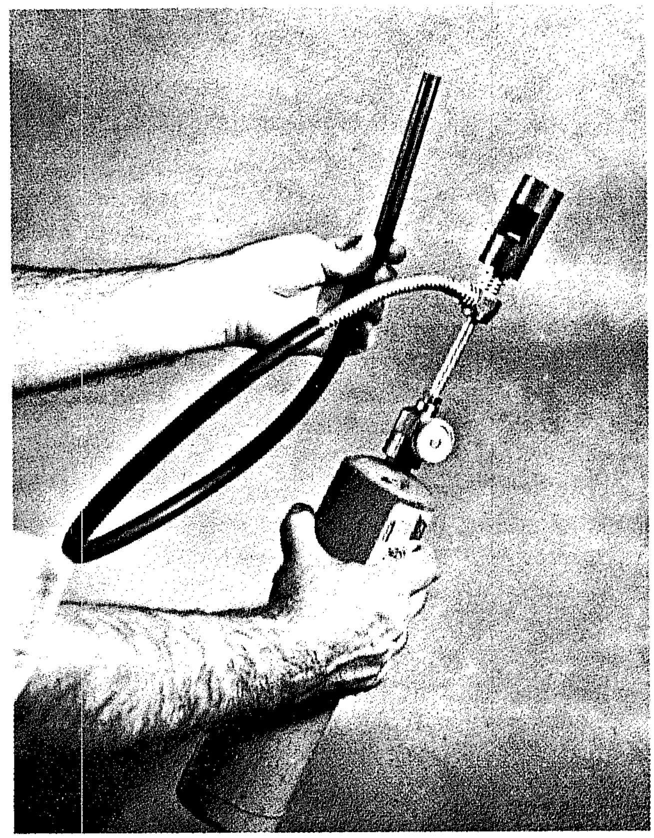
Courtesy E. I. DuPont de Nemours & Co.

ELECTRIC LEAK DETECTOR

Figure 170

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

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.

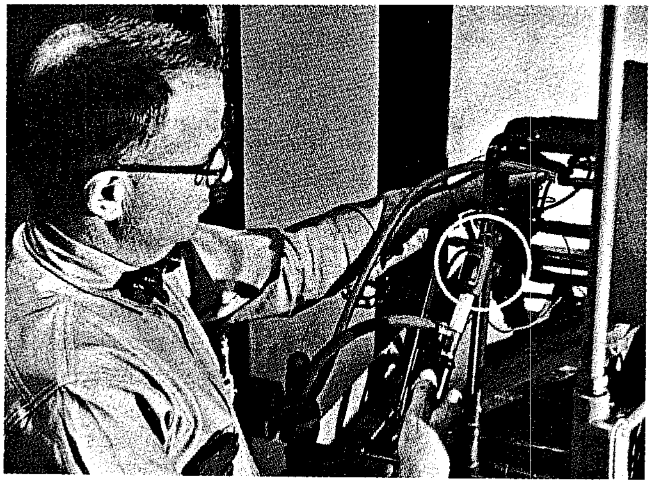
HALIDE TYPE LEAK DETECTOR

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.

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.

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.

Blowing out lines with refrigerant or purging from the top of the condenser will remove a major part of the air from the system, but it will not remove air from trapped areas. 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 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″ I.D. minimum size are recommended for high vacuum work.

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

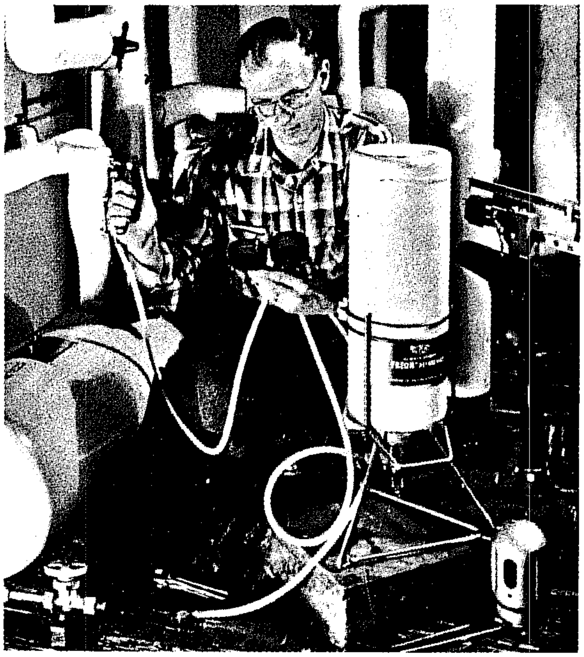
Each system must be considered separately, since systems with the same capacity or horsepower rating may not necessarily require the same refrigerant or the same amount of charge. Therefore it is important to first determine the type of refrigerant required for the system, the unit nameplate normally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



Courtesy E. I. DuPont de Nemours & Co.

Figure 173

Liquid-charging "Freon" 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.

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.

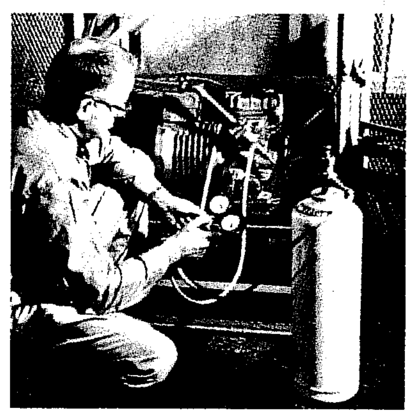
To determine if the charge is approaching the system requirement, open the receiver outlet valve, close the charging valve, and observe the system operation. Continue charging until the proper charge has been introduced into the system. Again weigh the refrigerant drum, and make a record of the weight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

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 manifold permits throttling of the vapor from 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, 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.

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 between 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 overcharged 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 the refrigerant from a system. This may be required in order to repair leaks or make other repairs, or if a system has been overcharged, it may be necessary to remove the excess to insure proper system operation. The weight of refrigerant involved will largely determine whether it is worthwhile to salvage the refrigerant. With systems containing less than 10 pounds of refrigerant, it is usually more economical to vent the charge rather than to attempt salvage.

When pumping discharge gas directly into a refrigerant container for transfer purposes, care must be taken to properly cool the container so that the fusible plug does not overheat. Even though the container may not be subjected to excessive pressures, fusible plugs melt at approximately 165° F. and may be blown from the container if temperatures reach that level.

On systems with water chillers or water cooled condensers, either drain the water completely or circulate water at all times to prevent a freeze-up while removing refrigerant. If excess refrigerant is to be vented, and water cannot be drained, do not release refrigerant pressure rapidly, since the decreased refrigerant pressure in the system will result in the refrigerant boiling off at its saturated temperature, and this can cause freeze-ups.

Obtain a sufficient number of clean, dry, empty refrigerant containers for the refrigerant to be removed, together with an accurate scale for weighing.

1. Venting to Atmosphere

The simplest method of removing refrigerant is by venting to the atmosphere (outdoors if possible) as a vapor. This can be easily accomplished through the gauge manifold, with the valve on the gauge manifold serving as a metering and control device. If discharged through a hose, the hose must be secured to prevent whipping.

If the system has been overcharged, and only a part of the refrigerant is to be vented, alternately vent for a few seconds and check the system operation until the proper charge level is reached. If the entire charge is to be vented, continue until pressure is dissipated.

The escaping refrigerant will carry a considerable quantity of oil with it, and care must be taken to avoid spraying oil over the surrounding area. Any oil lost must be replaced when the system is put back in operation.

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 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. To remove the remainder of the refrigerant, disconnect the refrigerant cylinder and vent the remaining refrigerant to the atmosphere.

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 not 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 refrigerant is 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 to 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 Copeland 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 Copeland 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 compressors equipped with crankcase sightglasses, the oil level should be maintained at or slightly above the center of the sightglass while operating. An abnormally low oil 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. Closed System Method
In an emergency where an oil pump is not available and 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. Crack the gauge valve and vent a small amount of refrigerant through the common connection and the oil to purge the lines of air.

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.

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.

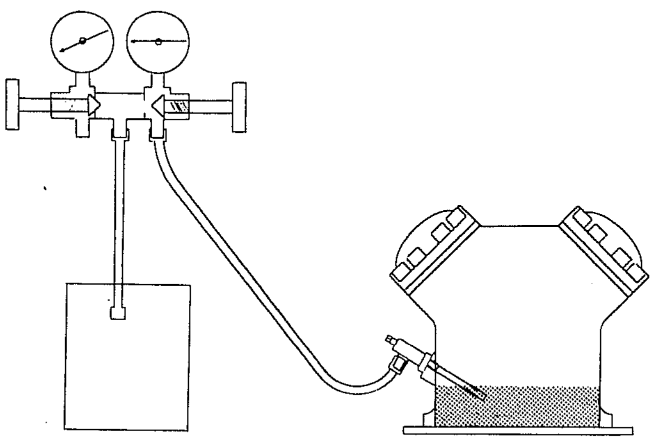
Close the suction service valve, and operate the compressor until the crankcase pressure is reduced to approximately 1 to 2 psig. Stop the compressor and isolate the crankcase by closing the discharge service valve. Carefully loosen the oil drain plug, allowing any pressure to bleed off before the threads 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" 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 reclose the valve.



FIELD CONNECTION FOR REMOVING LARGE AMOUNTS OF OIL

Figure 175

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 will prevent the entrance of any serious amounts of moisture or air into the system. Purge the crankcase by cracking the suction service valve off its seat for 1 or 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 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 or 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, Application Engineering, Copeland Refrigeration Corporation)

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

If the problem is detected and corrected in 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 component, 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 a decreasing period of operation. It was recognized at an early stage that contamination resulting from the 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.

The refrigerant flush-out system was developed and introduced as a dependable system cleaning procedure. Applied properly, it will restore a system to first class operating condition. But many problems are involved with the flushing procedure.

It is a complicated, time consuming process, requiring a serviceman with skill, knowledge, and experience. It is very expensive in that it necessitates the loss of great quantities of refrigerant. Damage to roofs and floors is frequently caused by spilled refrigerant. A system having only a mild burn might smell as though a bad burn has occurred, leading to a major cleaning that might not be necessary. And, it is not always dependable—few servicemen have the equipment or will take the time to wash large multiple systems completely. In many instances, badly contaminated systems have been improperly flushed with R-11, and the contaminants were merely moved into low velocity areas, later returning to the compressor after the system was put into operation.

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 1960's 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 dessicant 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 worth while. 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 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 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.

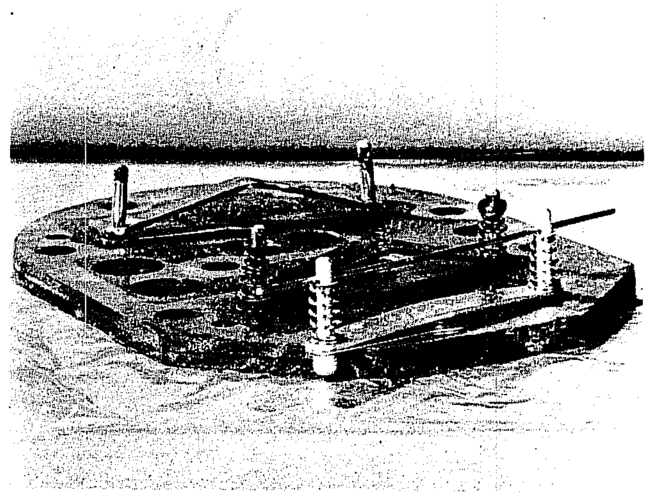


Figure 176

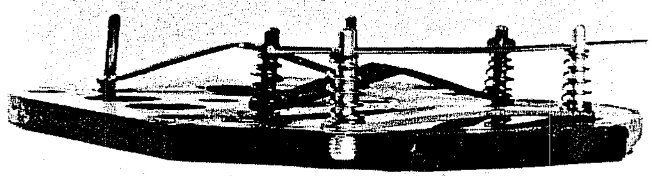


Figure 177

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.

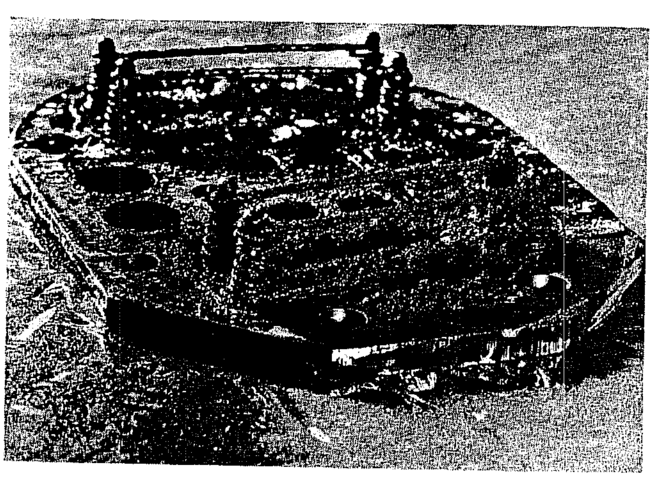


Figure 178

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 pressures of this magnitude to build up it is probable that either a restriction in the discharge line or liquid line — possibly in the refrigerant control device — may have created a hydraulic pressure condition in the compressor discharge chamber.

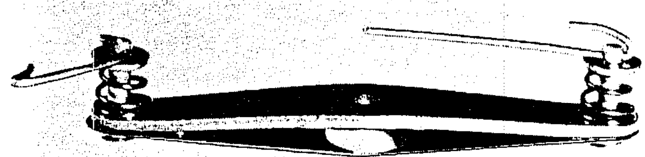


Figure 179

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.

Ruptured Discharge Chamber

A discharge chamber from a Copelaweld 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 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.

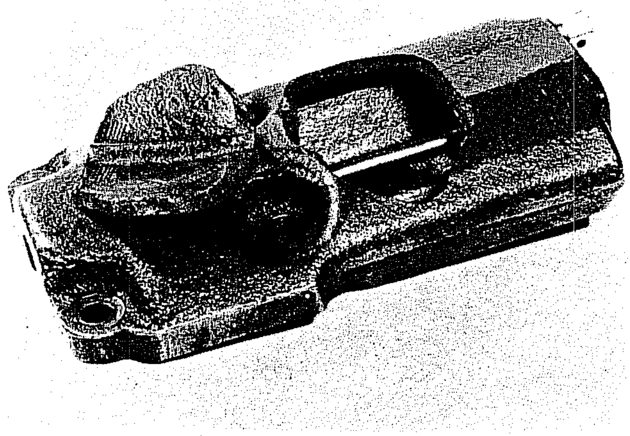


Figure 180

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 the 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.

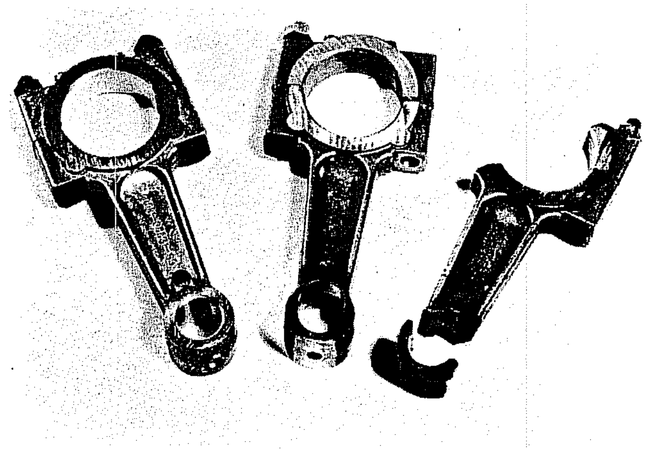


Figure 181

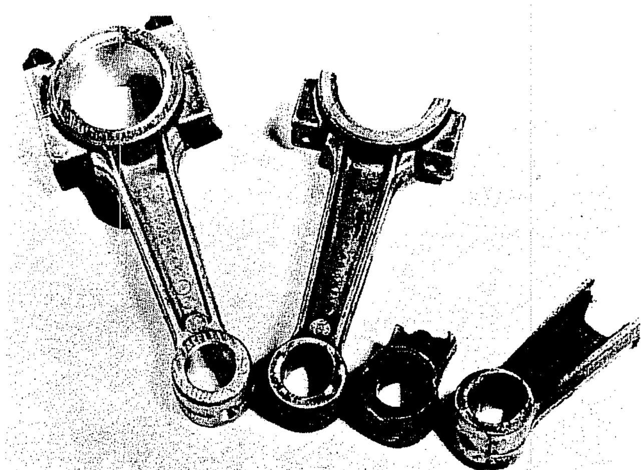


Figure 182

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.

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.

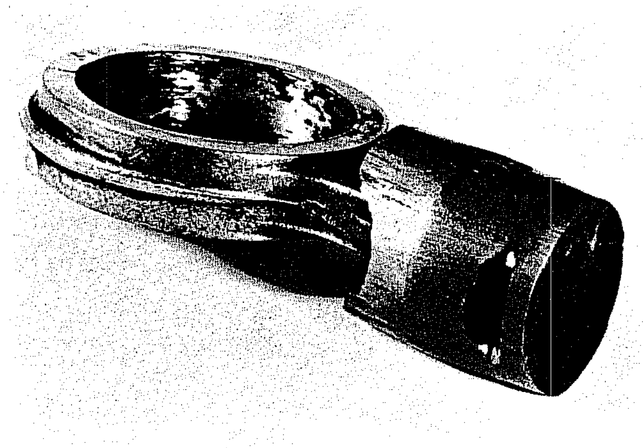


Figure 183

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.

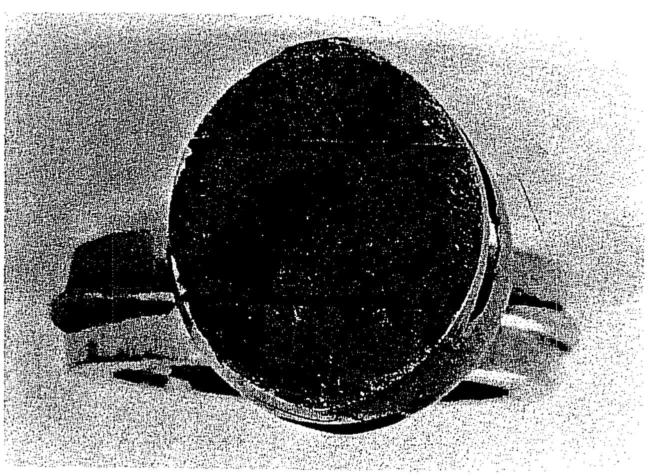


Figure 184

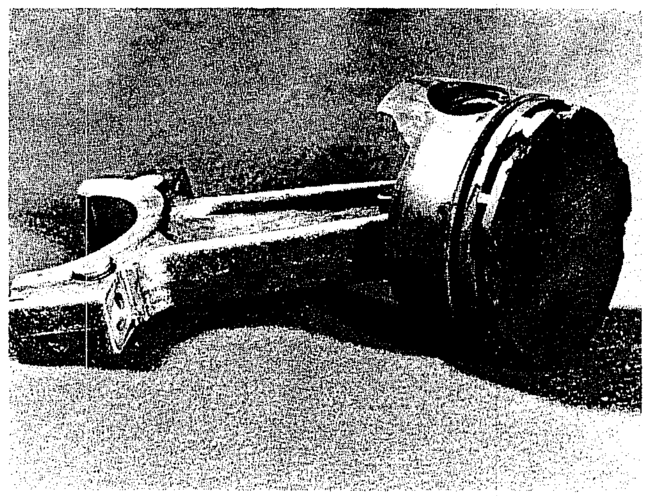


Figure 185

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.

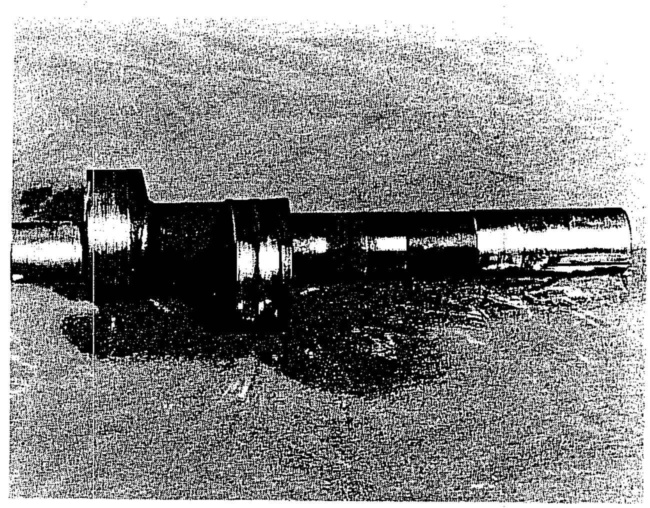


Figure 186

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 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 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.

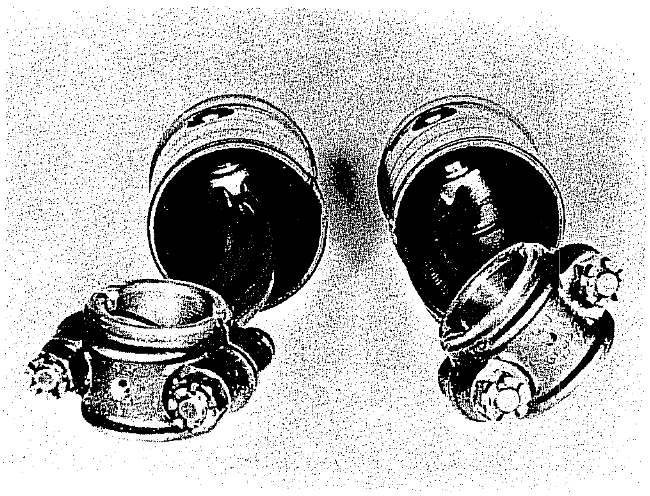


Figure 187

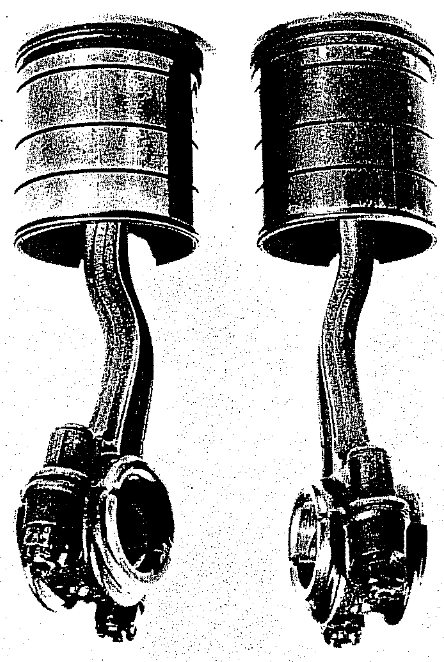


Figure 188

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 Filter-Drier

Copeland 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 dessicant (not a filter only) in both the liquid and suction lines.

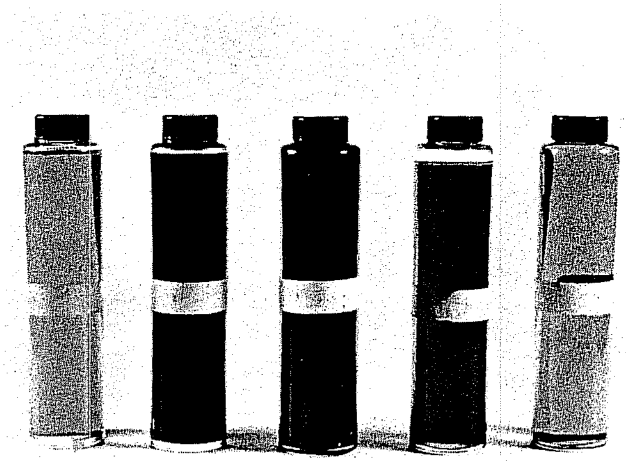


Figure 189

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.

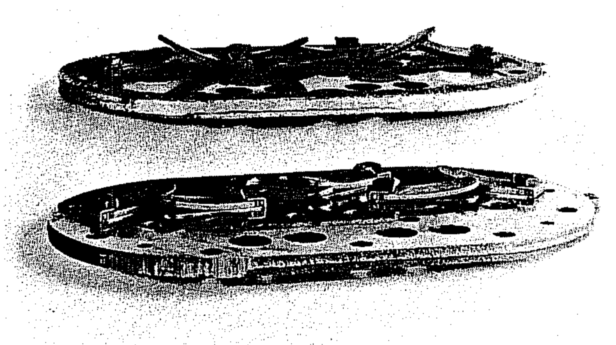


Figure 190

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 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 indicaate a broken discharge valve, a blown or improper head gasket, or inadequate compressor cooling.

Oil Level and Condition

On Copeland 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 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 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 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 control 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 line.

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 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 Condensers

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.

Section 27

USEFUL ENGINEERING DATA

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

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				

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

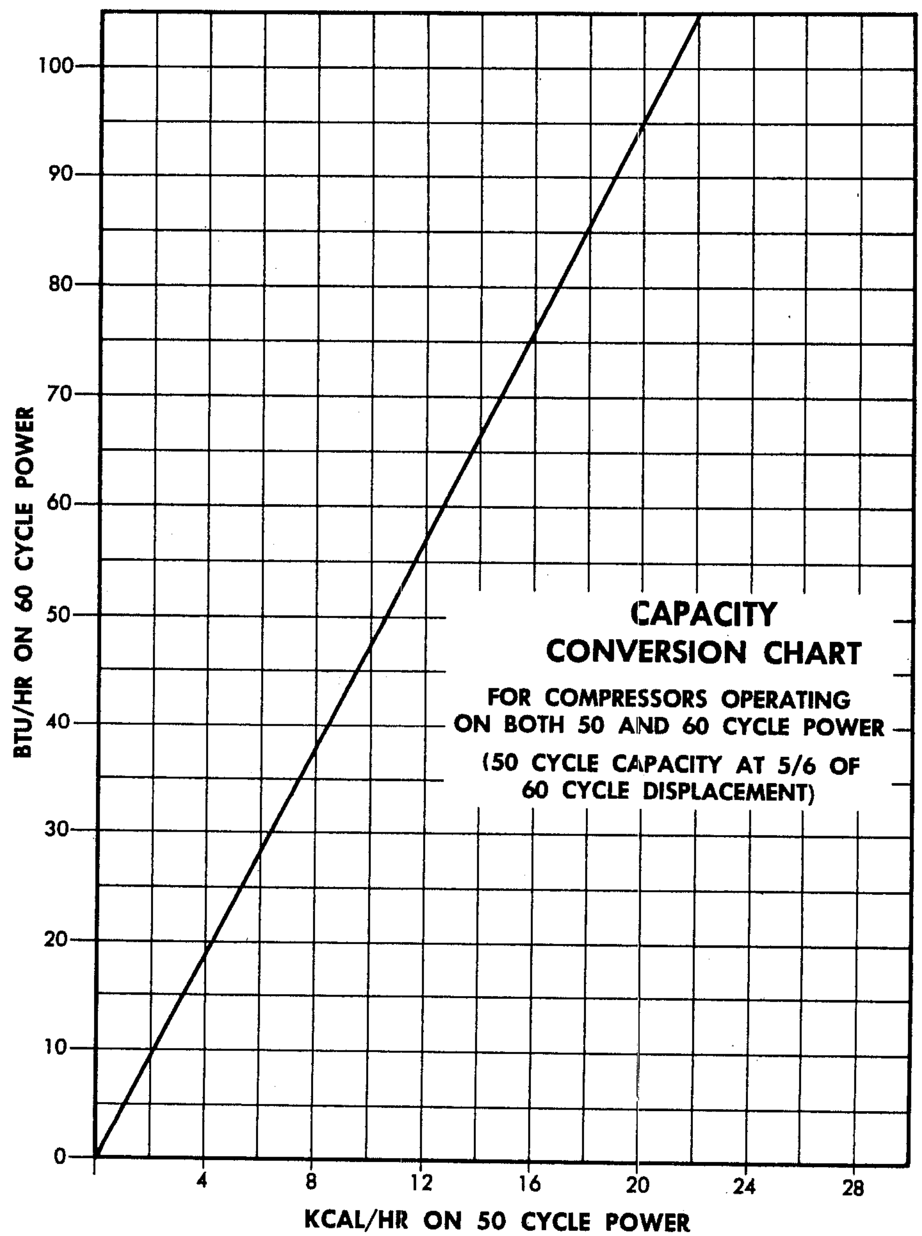


Figure 191

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

From 1967 ASHRAE Handbook of Fundamentals, Reprinted by Permission

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

From 1967 ASHRAE Handbook of Fundamentals, Reprinted by Permission

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

Table 59

CONVERSION TABLE
INCHES INTO MILLIMETERS

Inches	Millimeters	Inches	Millimeters	Inches	Millimeters	Inches	Millimeters	Inches	Millimeters	Inches	Millimeters
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		

Table 60

CONVERSION TABLE
DECIMALS OF AN INCH INTO MILLIMETERS

Inches	Millimeters	Inches	Millimeters	Inches	Millimeters	Inches	Millimeters	Inches	Millimeters
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

Millimeters	Inches	Millimeters	Inches	Millimeters	Inches	Millimeters	Inches	Millimeters	Inches	Millimeters	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	5.8861	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

Table 61 (Cont'd)

CONVERSION TABLE
MILLIMETERS INTO INCHES

Milli-meters	Inches	Milli-meters	Inches	Milli-meters	Inches	Milli-meters	Inches	Milli-meters	Inches	Milli-meters	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	9.3397	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

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

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

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		

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

PRESSURE CONVERSION CHART

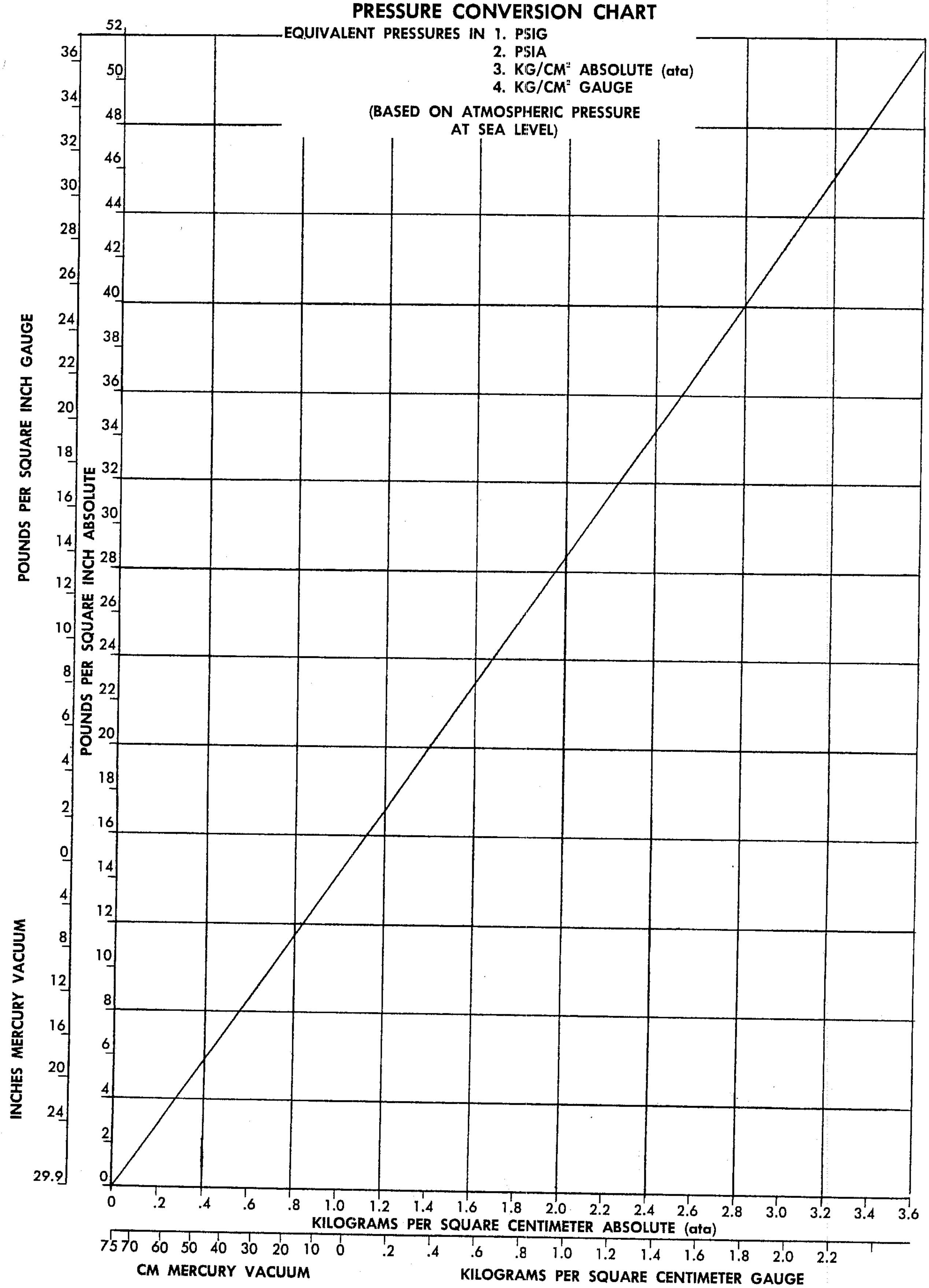


Figure 191

PRESSURE CONVERSION CHART

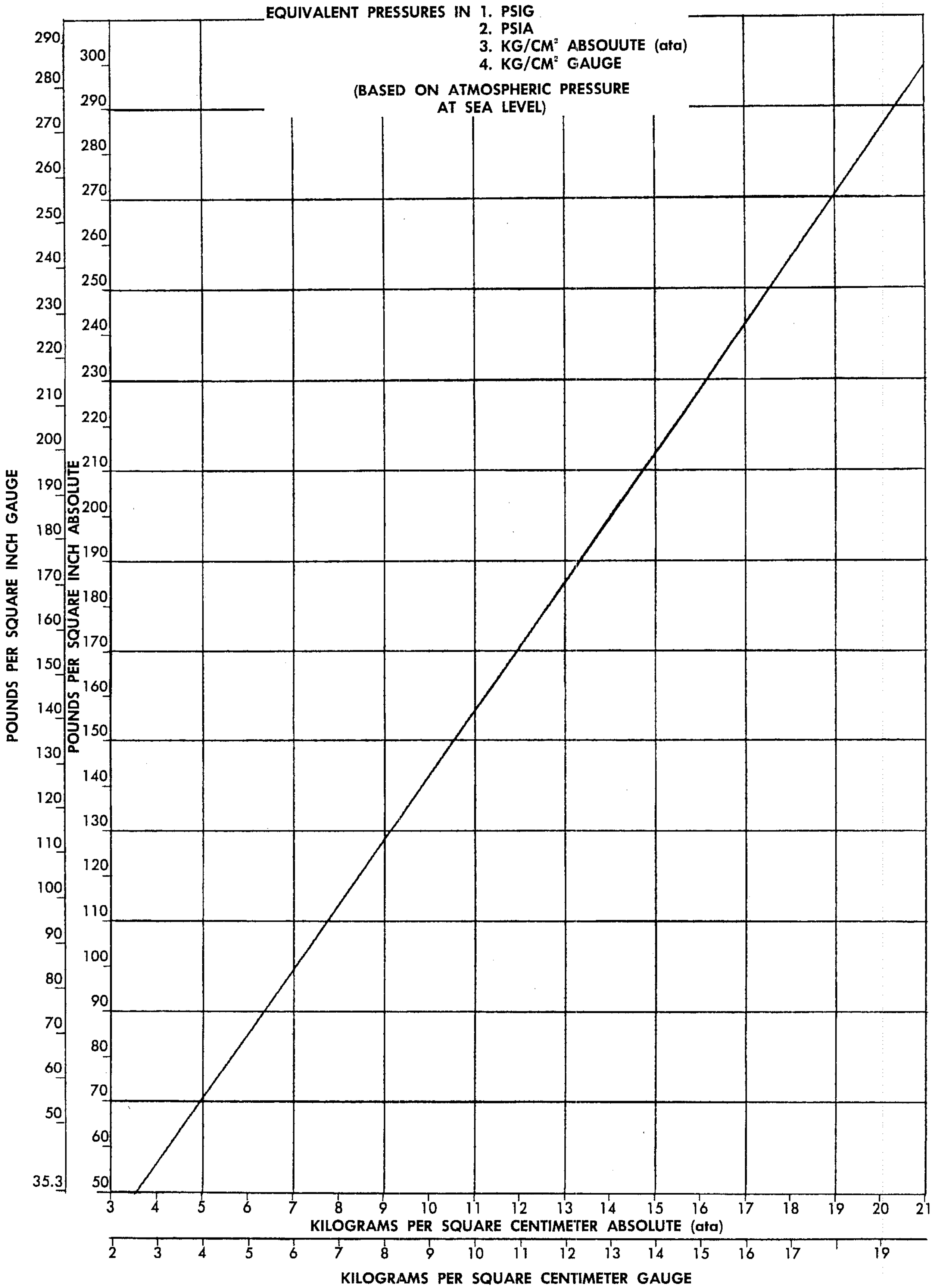


Figure 192