Chapter – 20 Oil and Lubricants

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Refrigeration compressors need oil for lubrication to reduce friction and to reduce wear. Oil flow rate required for various compressors varies. Centrifugal compressor requires minimal amount of oil flow, reciprocating compressor requires more oil circulation and the amount of oil injection and oil recirculation for screw compressor is a lot. Oil carryover in refrigeration system is not avoidable except the oil free compressor; however, all the oil free compressors are not designed for refrigeration duty. Most refrigeration systems of modern design are with screw compressors, therefore, the refrigeration system is to be designed with features to handle and to manage the oil problems.

The Roles of Lubricant for Refrigeration Compressors:

- To prevent or minimize wear of moving parts.
- To provide mechanical cooling for the compressor.
- To reduce gas leakage, to improve compression ratio and efficiency.
- To reduce friction driving horsepower.
- Protecting metal from rust and corrosion.
- Washing away dirt and wear particles.

The Basic Terms for Compressor Oil:

Oil characteristics are defined by viscosity, solubility, pour point, floc point, flash point, stability, foaming, dielectric and cleanness; the details are as the following:

Viscosity:

Viscosity of the oil is the degree to which oil resists internal flow measured by SUS (Saybolt Universal Seconds), usually at one of three temperatures of 0°F, 100°F or 210°F. SUS is measured in Saybolt cup. It is the time in seconds for the oil to flow out from the cup at the temperature specified. If the oil takes 100 seconds 100°F, the oil is 100 SUS 100°F. Viscosity of oil must be high enough to provide a hydrodynamic film for compressor and yet thin enough to flow through the refrigeration system at low temperature application. SUS is the unit which is merely a measurement of viscosity, it has nothing to do with the quality of the oil.

Solubility (Miscibility):

Solubility or miscibility of the oil is the ability of the oil to mix and dissolve with the refrigerant. The oil return rate is good if the solubility of the oil with the refrigerant is good. The solubility is depending upon the oil characteristic, temperature and pressure.

Pour Point:

Pour point is that the lowest temperature which the oil still can flow by gravity. Pour Point is measured by putting oil in a beaker and measure the lowest temperature that it pours.

Floc Point:

Floc point is the temperature when refrigerant mixed with oil shows flocculent and waxy material. Floc Point also called cloud point. The Floc Point must be below the lowest system temperature of the system. Refrigeration oil must be exceptionally free of wax

Flash Point:

Flash point is the temperature the oil is breaking down. The flash point reflects the volatility of the oil.

Stability:

Stability of the oil is the quality of oil to minimize corrosion, gum, varnish, tar and sludge, protection against oxidation and thermal instability, particularly the quality of minimizing chemical reaction to metal due to moisture in the oil. Stability is a vital characteristic of good lubricant, which must resist the deterioration over prolonged period of service to minimize compressor wear and maintenance problem. Also, the oil should not easily carbonize when working at high temperatures or around hot spots such as oil heater.

Defoaming Characteristics:

Oil having low foaming character is preferred in refrigeration system. Most refrigeration oils contain with foam inhibitor ingredient.

Dielectric Strength:

Water content in oil is measured by the electric current that can pass through the oil. Refrigeration oil should have extremely good dielectric strength, particularly in hermetic compressor system. Refrigeration oil should be kept water free.

Cleanness:

Oil should be free of contamination.

Requirements of Compressor Oil:

Refrigeration system is a clean, sealed and enclosed environment. The lubrication oil selected should be compatible with the refrigerant and the compressor; the compressor oil shall be with the preferred features as listed below:

1.0 Lubricity at all operating temperature and pressure of the refrigerant.
2.0 Chemically stable at high and low temperatures.
3.0 Thermally resistant to high temperature breakdown.
4.0 High flash points.
5.0 Dirt and moisture free.
6.0 Low pour points to resist congealing in condensers and evaporators.
7.0 Exceptionally wax free.
8.0 Formulated to have proper viscosities for specific applications.

Influence of Oil Migration in Refrigeration System

Lubrication oil in refrigeration system is not avoidable. But, the oil is harmful to heat transfer in refrigeration system. The heat transfer efficiency is reduced if the oil film accumulated on the heat transfer surface is increased. Figure 20-1 is the typical diagram showing the relationship between the oil film and the heat transfer coefficient at various oil film accumulations on the tubes. For example: if a clean tubes heat exchanger is having heat transfer coefficient of 162 $Btu/Hr/Ft^2/^{\circ}F$, the heat transfer coefficient is reduced to 126.36 162 $Btu/Hr/Ft^2/^{\circ}F$ or 78% if the tubes surface is with 1.5 Mils oil film thickness; the heat transfer coefficient is further reduced to only 58% or to 93.96 $Btu/Hr/Ft^2/^{\circ}F$ at 4.0 Mils oil film accumulation on the tubes. The refrigeration capacity of the refrigeration system is greatly reduced if excess oil is remained in the evaporator; therefore, it is detrimental to refrigeration system if the oil is not removed from the evaporator. In view of this, therefore, the oil in refrigeration system should be managed in such way the oil carryover from compressor discharge is minimized and the oil is recovered and is returned to compressor or oil reservoir from the evaporator.

The Figure 20-2 is a typical lubrication oil migration diagram for a screw refrigeration system; the oil migration rates are as the following:

1.0 Oil Pumping Rate: This is the total flow of oil discharge from compressor together with refrigerant gas. The oil carry over from compressor discharge exists in two forms, one is the aerosols; the other form is the oil vapor. Aerosols are fine mists or droplets that can be separated and removed by mechanical filter; oil vapor is in gas form and cannot be removed by mechanical separation.

2.0 Oil Separation Rate: This is the amount of oil separated by an oil separator in discharge line and returned to the compressor for compressor cooling and lubrication. Most oil mists are separated by the oil separator, particularly if coalesce filter is used.

3.0 Oil Carryover Rate: The amount of oil that goes to condenser. Most of the oil is in the form of vapor after the oil separator. The flow of oil shall be equal to (1) if no oil separator is used.

4.0 Oil Return Rate: The oil returns from system to the compressor suction. This flow includes the oil return with the suction refrigerant gas (4a), if the oil is miscible with oil, plus the amount of oil return from oil still (4b).

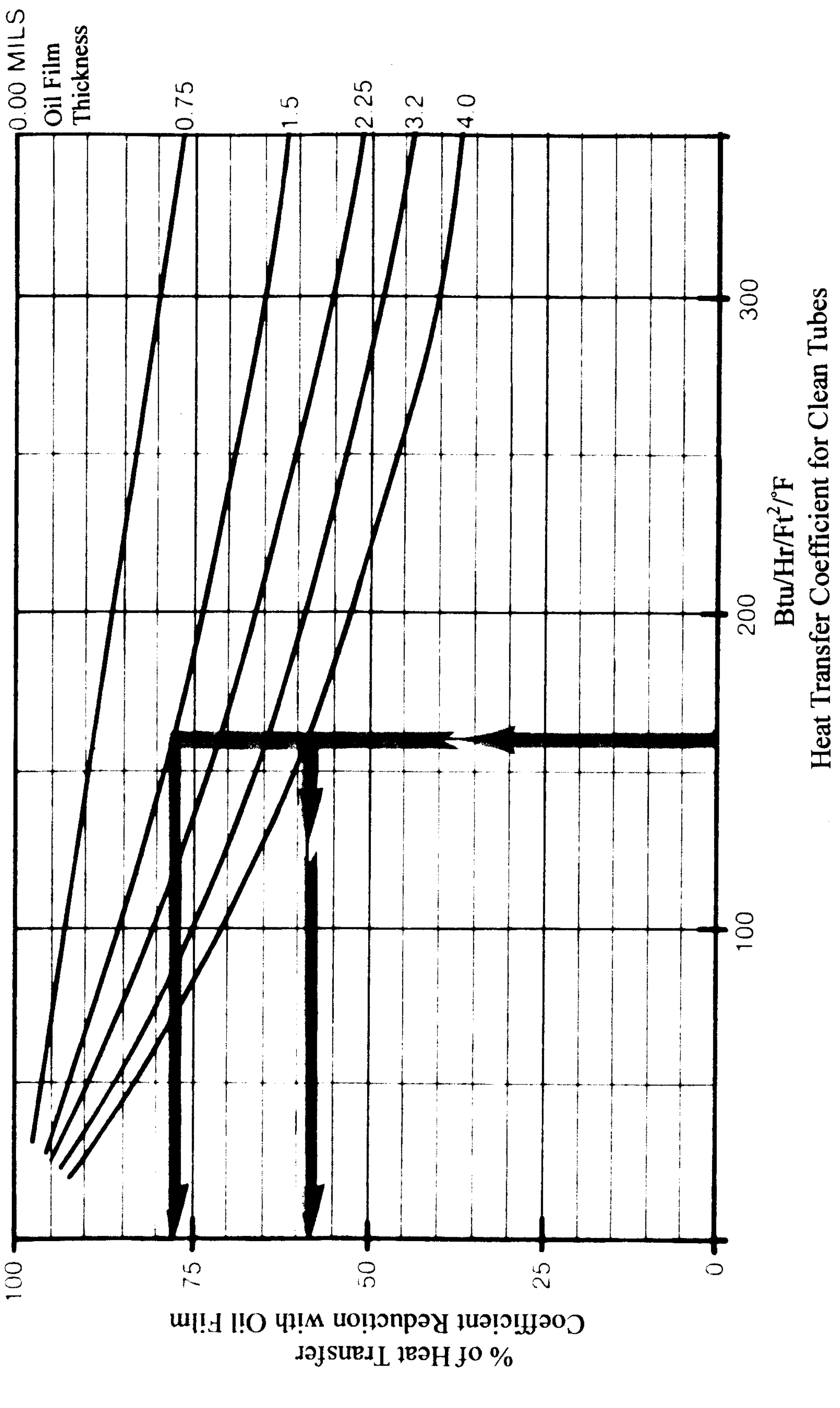
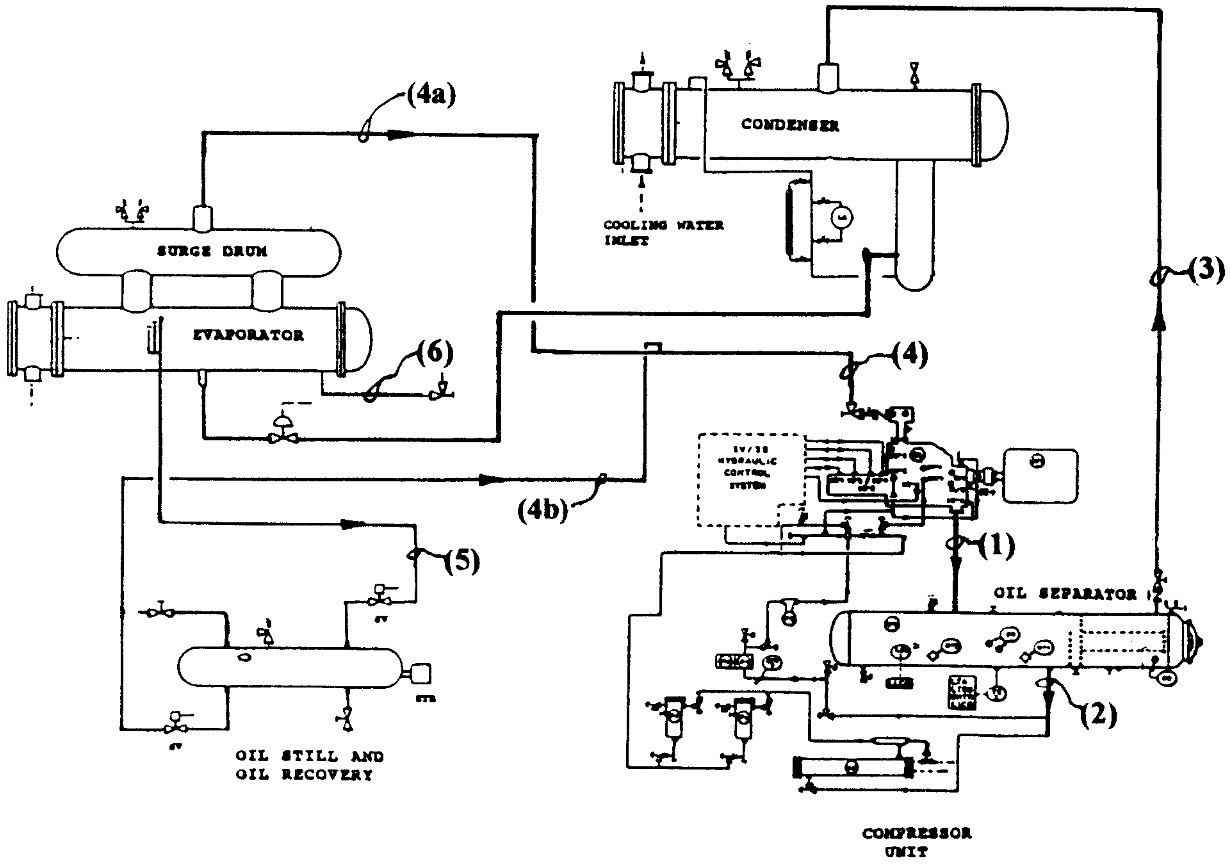


Figure 20-1 Influence of an Oil Film



(1) Oil Pumping Rate.
(2) Oil Separation Rate.
(3) Oil Carry Over Rate.
(4) Oil Return Rate.
(5) Oil Recovery Rate.
(6) Oil Draw-off Rate.

Figure 20-2 Lubrication Oil Migration

5.0 Oil Recovery Rate: The amount of oil which is recovered from the evaporator by means of an oil still/recovery unit and returned to oil receiver. Some system, the oil is recovered from intercooler if compound system is used.

6.0 Oil Draw-off Rate: The amount of oil is drawn off from evaporator and discarded. Some ammonia system, the oil is drawn off from the condenser.

7.0 Oil Make-up Rate: Amount of oil is added to the oil reservoir in the oil separator.

In this oil migration diagram of Figure 20-2, the oil should be separated as much as possible from the compressor discharge and then the oil is recovered from the evaporator. A good automatic oil management system is that the oil flows of (4) and (5) should be equal to the oil flow of (3) at normal operation of the refrigeration system.

Wire Mesh or Demister Type Discharge Oil Separator

Wire mesh or demister type discharge oil separator is also referred to as Knitted wire fabric type discharge oil separator. The velocity is critical when this type of separator is used. Too high a velocity tends to apply too much force to the droplets on the wires, re-entraining some and carrying tem through. Too low a velocity permits some of the droplets to follow the gas stream without impingement.

Maximum allowable vapor velocity through the element V, ft/sec:

$$V = 0.35 \times \sqrt{\frac{\delta_L - \delta_V}{\delta_V}}$$

V = Velocity, Ft/Sec.
δ_L = Density of the entrained liquid. Lbs/Ft^3
δ_V = Density of the gas. Lbs/Ft^3

The minimum velocity for maintained separator efficiency of approximately 25% of the design value may be used.

The separation efficiency depends to some extend on the thickness of pad or pads and also on the vessel arrangement, but it is usually in the region of 30 to 50 ppm. Some application might be 15 to 25 ppm.

Oil Vapor Carry Over by Compression

Assuming an oil separator is 100% efficiency to eliminate all the mists and droplets from the discharge from compressor, but, oil carryover still exists in the form of oil vapor. Oil vapor is a gas and it carries over through the mechanical filter. The amount of oil vapor in the discharge line of the compressor depends on the type or brand of oil, type of refrigerant, discharge pressure and discharge temperature. The oil carryover in vapor form can be calculated as the following:

Gas Law:

$$P \times V = W \times R \times T$$

P = Gas pressure, Psia
W= Weight of Gas, Lbs
R = Gas Constant
V = Volume, ft^3
T = Temperature, (460 + °F)

$$P_o \times V = W_o \times R_o \times T$$

$$P_g \times V = W_g \times R_g \times T$$

P_o = Oil vapor pressure, Psia
W_o = Weight, Oil, Lbs
R_o = Gas Constant of Oil
P_g = Refrigerant vapor pressure, Psia
W_g = Weight, Refrigerant, Lbs
R_g = Gas Constant of Refrigerant
V = Volume, **f**^{3}
T = Temperature, (460 + °F)

$$\frac{P_o \times V}{P_g \times V} = \frac{W_o \times R_o \times T}{W_g \times R_g \times T}$$

$$R = \frac{1545}{MW}$$

R = Gas Constant
MW = Molecular Weight

$$R_o = \frac{1545}{MW_o}$$

$$R_g = \frac{1545}{MW_g}$$

MW_g = Molecular Weight of the Refrigerant Vapor
MW_o = Molecular Weight of the Oil Vapor

$$\frac{P_o \times V}{P_g \times V} = \frac{W_o \times R_o \times T}{W_g \times R_g \times T} = \frac{W_o \times MW_g \times T}{W_g \times MW_o \times T}$$

$$\frac{P_o}{P_g} = \frac{W_o}{W_g} \times \frac{MW_g}{MW_o}$$

$$\frac{W_o}{W_g} = \frac{P_o}{P_g} \times \frac{MW_o}{MW_g}$$

$$\text{Oil Vapor Carry Over In PPM} = \frac{P_o}{P_g} \times \frac{MW_o}{MW_g} \times 10^6$$

Gas pressure is the system pressure, therefore:

$$P_g \cong P_s$$

$$\text{Oil Vapor Carry Over In PPM} = \frac{P_o}{Ps} \times \frac{MW_o}{MW_g} \times 10^6$$

If the oil vapor pressure is in mm Hg instead of Psia, the formula is as the following:

$$\text{Oil Vapor Carry Over In PPM} = \frac{VP_o}{Ps} \times \frac{14.7}{760} \times \frac{MW_o}{MW_g} \times 10^6$$

VP_o = Oil vapor pressure, mm Hg

Figure 20-3 shows the relationship of oil vapor carryover rate at various condensing temperature, evaporative temperature and percent of refrigeration load at 50 Hz or 60 Hz compressor speed.

Refrigerant Gas Molecular Weight:

The gas molecular weight for various commonly use refrigerant as listed in Table 20.1.

Table 20.1 Molecular Weight of Refrigerants

Refrigerant	Molecular Weight
Ammonia, R-717	17.03
R-12	120.93
R-13	104.47
R-13B1	148.93
R-22	86.48
R-134a	102.03
R-290	44.10
R-1270	42.09
R-503	87.50

Molecular Weight of Common Use Refrigeration Oil:

The molecular weights of various refrigeration oil is listed in Table 20.2

Table 20.2 Molecular Weight of Oil

Refrigeration Oil	Molecular Weight
Capella D	300 – 310
Suniso 4G	261 – 265
Capella D	240 – 243

Vapor Pressure of Various Oils:

The oil vapor pressures for various refrigeration oil is shown in Table 20.3,

Table 20.3 Oil Vapor Pressure

Refrigeration Oil	100°F	150°F	200°F	250°F	300°F
	Vapor Pressure in mm Hg				
Capella D	0.0001	0.0013	0.013	0.085	
Terristic 52	0.000011	0.00014	0.0012		
Zerice S-41	0.00065	0.0074	0.055	0.31	1.3
Suniso 3GS	0.0003	0.004	0.031	0.2	0.9
Suniso 5G	0.000075	0.0011	0.0099	0.061	0.3

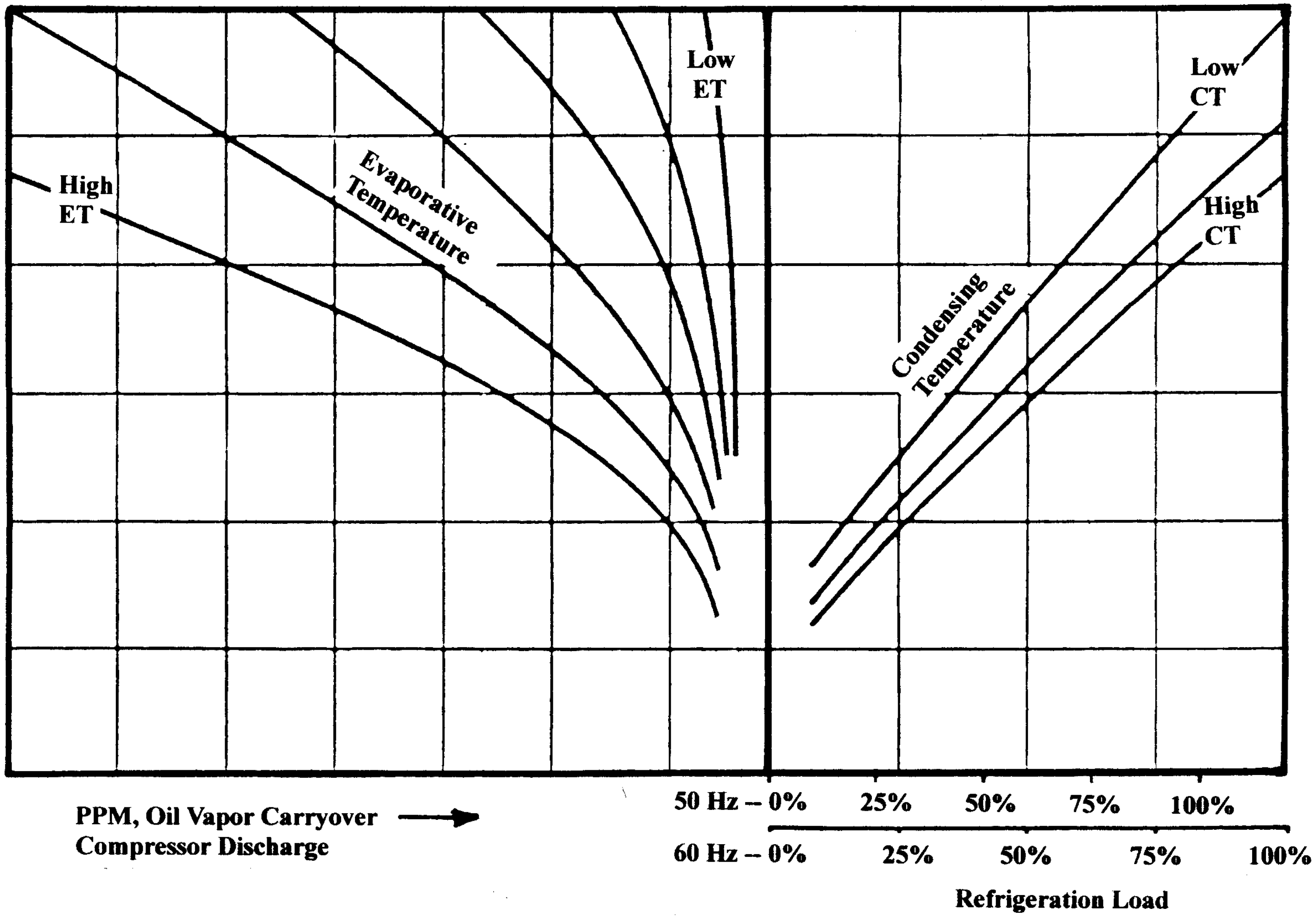


Figure 20-3 Oil Vapor Carryover – Screw Compressor

Theoretical Oil Vapor Carryover Rates

Oil vapor carryover rate varies at various discharge temperature even with same condensing temperature based on the oil separator is with 100% separation efficiency, all droplets and mists are removed. The oil vapor carryover rate is lower if the discharge temperature is lower.

Ammonia (R-717), propylene (R-1270) and R-22 are the most commonly used refrigerant for industrial process refrigeration application. The oil vapor carryover amount is shown for these refrigerants at various discharge temperatures in Table 20.4.

Table 20.4 Oil Vapor Carryover Rates

Refrigerant	Ammonia (R-717)	Propylene (R-1270)	R-22
Molecular weight, gas	17.03	42.09	86.68
Molecular weight, oil	305	305	305
System pressure, 105˚F CT	228.9 Psia	242.41 Psia	225.45 Psia
At discharge temperature 250˚F	128.6 PPM	49.15 PPM	25.72 PPM
At discharge temperature 200˚F	19.6 PPM	7.52 PPM	3.03 PPM
At discharge temperature 150˚F	2.0 PPM	0.75 PPM	0.39 PPM
At discharge temperature 100˚F	0.2 PPM	0.06 PPM	0.03 PPM

Amount of Vaporized Oil Carryover to Evaporator

The example is made for R-22 and R-717, based on a single stage screw compressor flooded refrigeration system, 100°F condensing temperature, 10°F evaporative temperature; the refrigeration full load is 50 TR. Assuming the oil separator is with 100% separation efficiency, all droplets and mists are removed. The oil vapor carryover rates which are for 30 days operation for this refrigeration system are shown in Table 20.5.

Table 20.5 Approximate Oil Carryover Rates

Refrigerant	Refrigerant Flow, Lbs/Hr	Oil Vapor Carryover, Lbs/Hr	If for 30 days, 24 hours per day. Oil Vapor carryover, Lbs	Approximate Oil Carryover in Gal of Oil at Sp.Gr 0.93
R-22	9,066.87	0.04633	33.36	3.55
R-717	1,305.20	0.01779	12.81	2.58

A lot of oil will be accumulated in the evaporator after long period of operation. The refrigeration capacity of the evaporator will be reduced if the oil is not removed from low side.

General Classification of Oils

There are three groups of compressor lubricant, i.e. mineral oils, synthetic oils and semisynthetic oils. Many selections are available, but, it shall be always follow the recommendation of the compressor maker as which type of oil is recommended. Some of the oil is miscible in the refrigerant and some is immiscible with the lubricant. The oil recovery rate is better if the oil use is miscible with oil.

Synthetic oil is specially designed for refrigeration use and it has many advantages as the following:

- Extending oil change period.
- Reduce oil carry over.
- Reduce oil consumption.
- Lower operating oil temperature.
- Higher flash point.
- Higher film strength.
- Reduce compressor wear and longer compressor operating life.
- Non-foaming character.
- Low toxicity.
- Good for wide operating temperature range.

The disadvantage of Synthetic oil is the higher initial cost and lesser compatibility with seal materials.

Oil in refrigeration system should be checked and analysis periodically for water content, viscosity, alkalinity/acidic level and chemical element content.

Discharge Oil Separator, Oil Still and Oil Return

The main purpose of using compressor discharge oil separator is to eliminate most of the oil mists and droplets from the discharge line before it is carried over to the refrigeration system. The amount of oil carryover from centrifugal compressor discharge is smallest and therefore, discharge oil separator is not usually used for centrifugal systems. Discharge oil separator is commonly used for reciprocating and discharge oil separator is part of the screw compressor standard accessories.

Oil Separator for Reciprocating Compressors

Most discharge oil separators designed for reciprocating compressor are wire mesh or demister type because of initial cost concern. The efficiency of wire mesh or demister oil separator is usually can be as good as 99.99%; the oil carryover is about 30 to 400 PPM by weight. Figure 20-4 shows a typical horizontal design of the mesh type oil separator; the Figure 20-5 is the typical arrangement of a vertical mesh type oil separator. Both figures show that the separated oil drains to an oil float valve from the oil separator and then returned to oil receiver of back to the crankcase of the compressor.

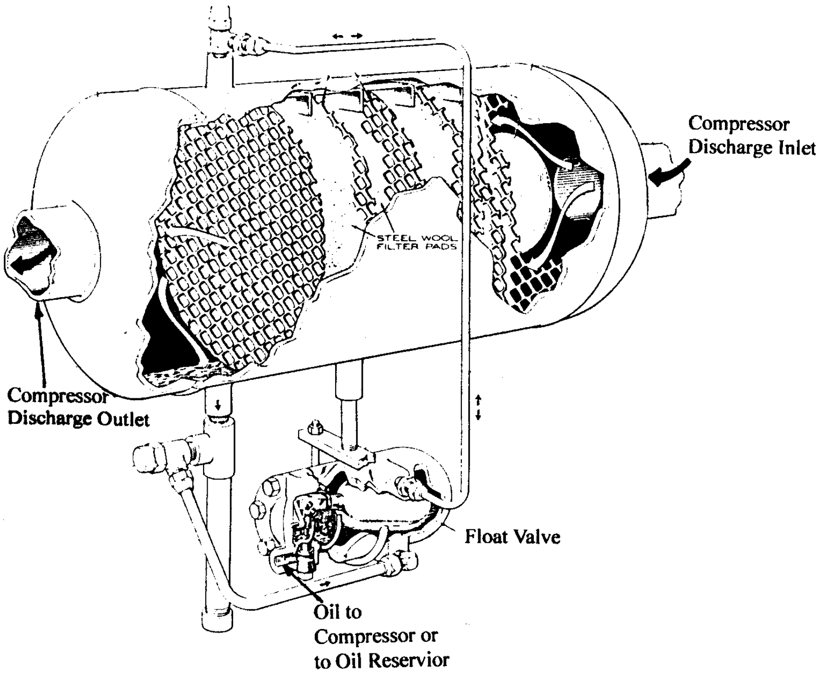


Figure 20-4 Oil Separator
Typical Horizontal Design

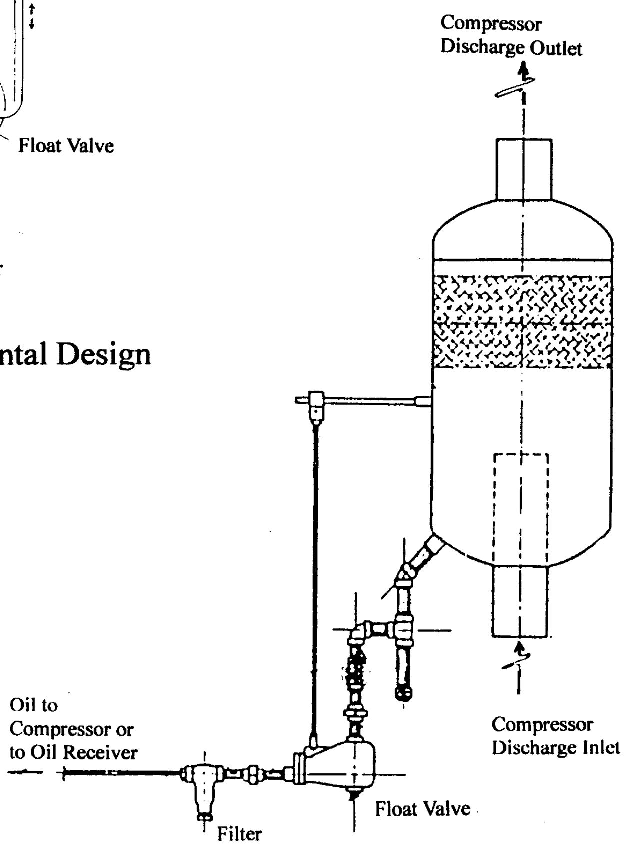


Figure 20-5 Oil Separator
Typical Vertical Design

Figure 20-6 is the typical piping arrangement for equal size reciprocating compressor in parallel operation with a common oil separator. Figure 20-7 is the typical piping arrangement for mix sizes of parallel reciprocating compressors with a common oil separator. In either case, the oil inlet connection to the crankcase oil float vale of the both compressors should be same level to the bottom of the common oil receiver.

Oil Separator for Screw Compressors

Screw compressor circulates lots of oil during operation; an oil separator must be used for the screw compressor, otherwise, the compressor is unsuitable for refrigeration application. This is the reason why an oil separator is part of a standard equipment of a screw compressor unit (See Figure 6-4). Almost all the oil separators for screw compressor are designed with multiple stages of oil separation and are equipped with coalescent filters; some designs can eliminate 100% of all mists and droplets of the oil, the remaining oil carryover from the discharge line in this case is the oil vapor.

Figure 20-8 shows the screw compressor with a horizontal oil separator. Most screw compressor units, the compressor is mounted on top of the horizontal oil separator, except that the motor is too heavy or over 1,000 HP. Figure 20-9 shows a typical screw compressor with vertical oil separator; the screw compressor-motor drive line is floor mounted on a steel base in this case.

Oil Still and Oil Recovery

If the oil is miscible with oil, oil is returned with refrigerant to compressor suction automatically, no forced oil return system is required. However, if the oil is not miscible with the refrigerant, oil still with forced oil return as shown in Figure 20-10 should be provided for the refrigeration system.

The oil still and oil recovery system consists of an oil receiver with heater and operating valves. This set up provides oil return function as the following:

Refrigerant liquid and oil sample flow through SV3 to the oil receiver. Equalizing line SV2 is open; SV1 and SV2 are closed. The refrigerant liquid in the oil receiver is boiled off by the oil heater, the gas is returned to compressor suction via SV2. Oil return is achieved by closing the SV2 and SV3; open SV1 and SV4; high pressure gas enters into the oil receiver through SV1, presses the oil in the oil receiver and oil is returned to compressor suction through SV4. This oil return system can be automatically operated by a timer or by level switches.

Screw compressor is able to take a steady small flow of oil in the suction. For reciprocating compressor or large amount of oil flow, it is suggested that the oil is to be returned to oil reservoir instead of compressor suction.

Figure 20-11 is a typical oil still and oil receiver with an oil pump; the oil is returned to oil reservoir by the oil pump.

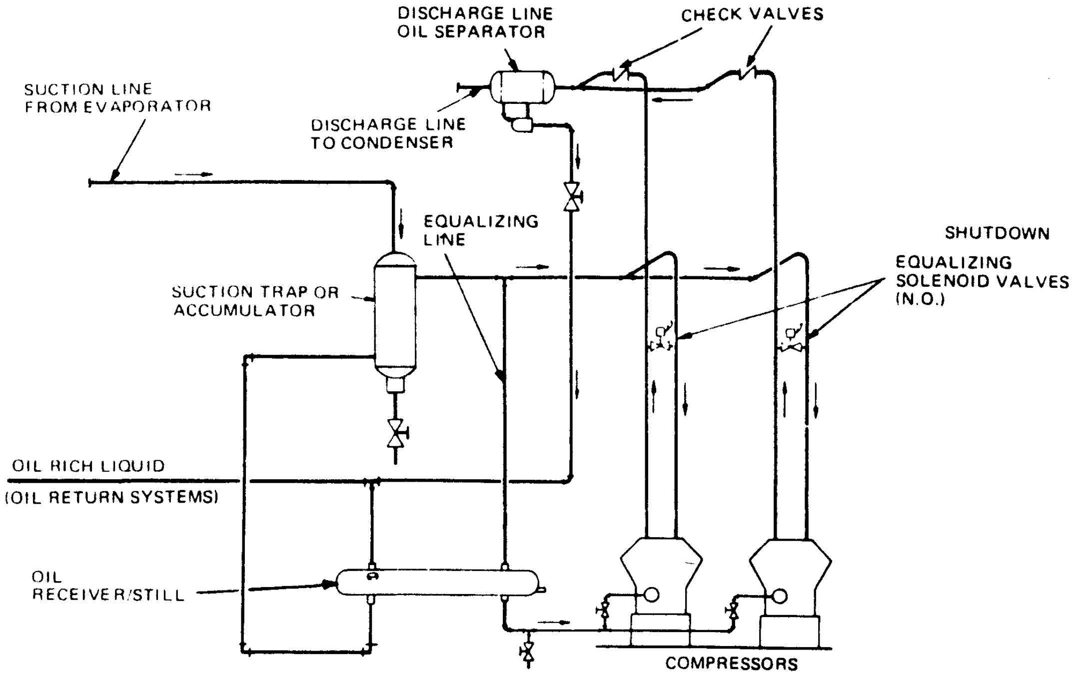


Figure 20-6 Oil Separation and Oil Return
Equal Size Reciprocating Compressors

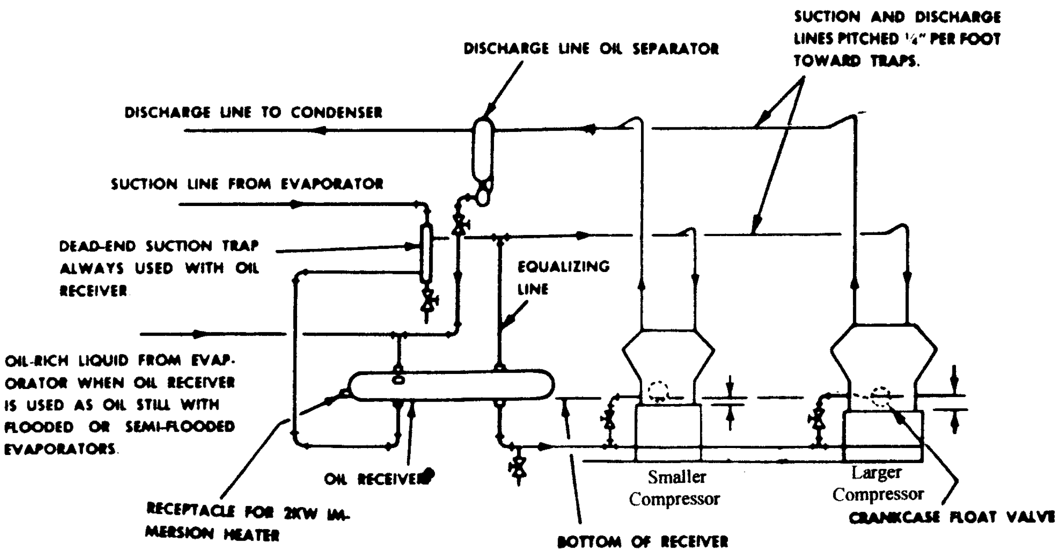


Figure 20-7 Oil Separation and Oil Return
Mix Size Reciprocating Compressors

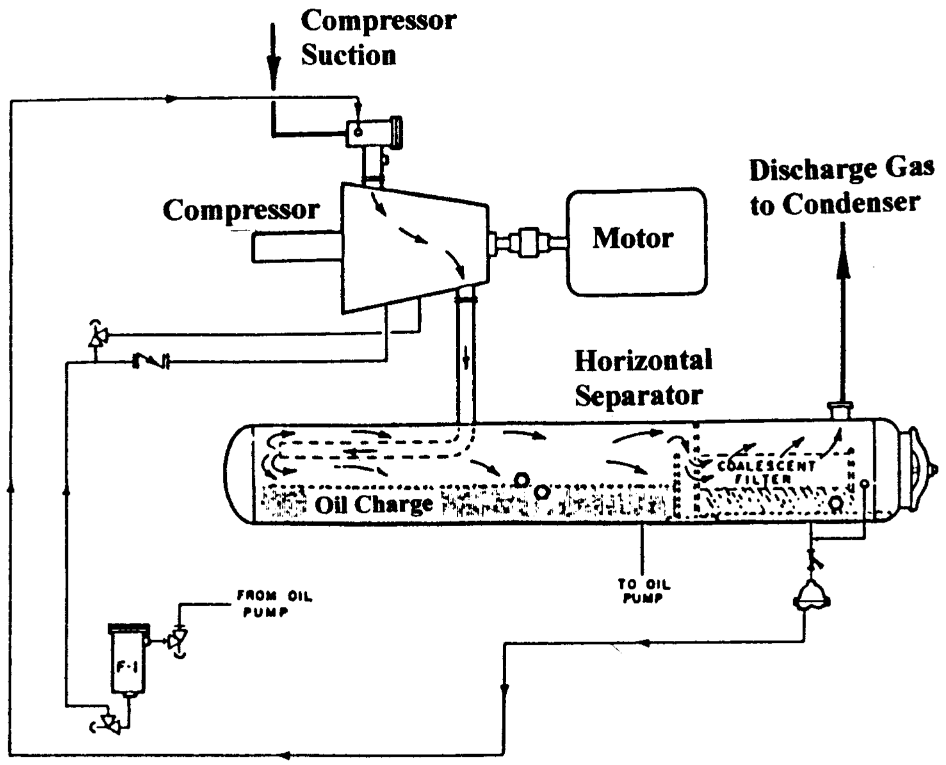


Figure 20-8 Horizontal Oil Separator – Screw Compressor

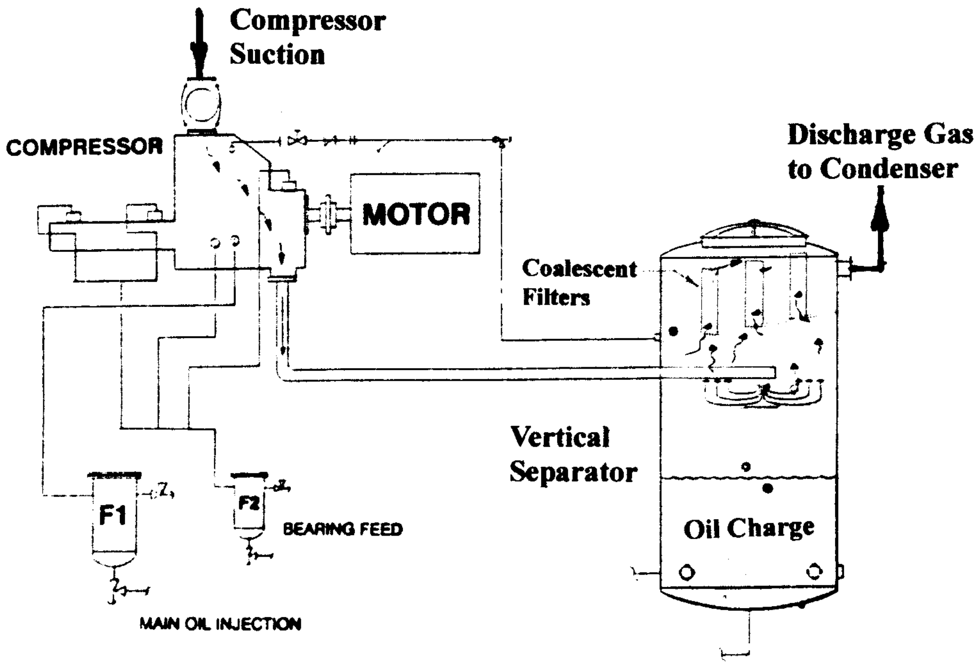


Figure 20-9 Vertical Oil Separator – Screw Compressor

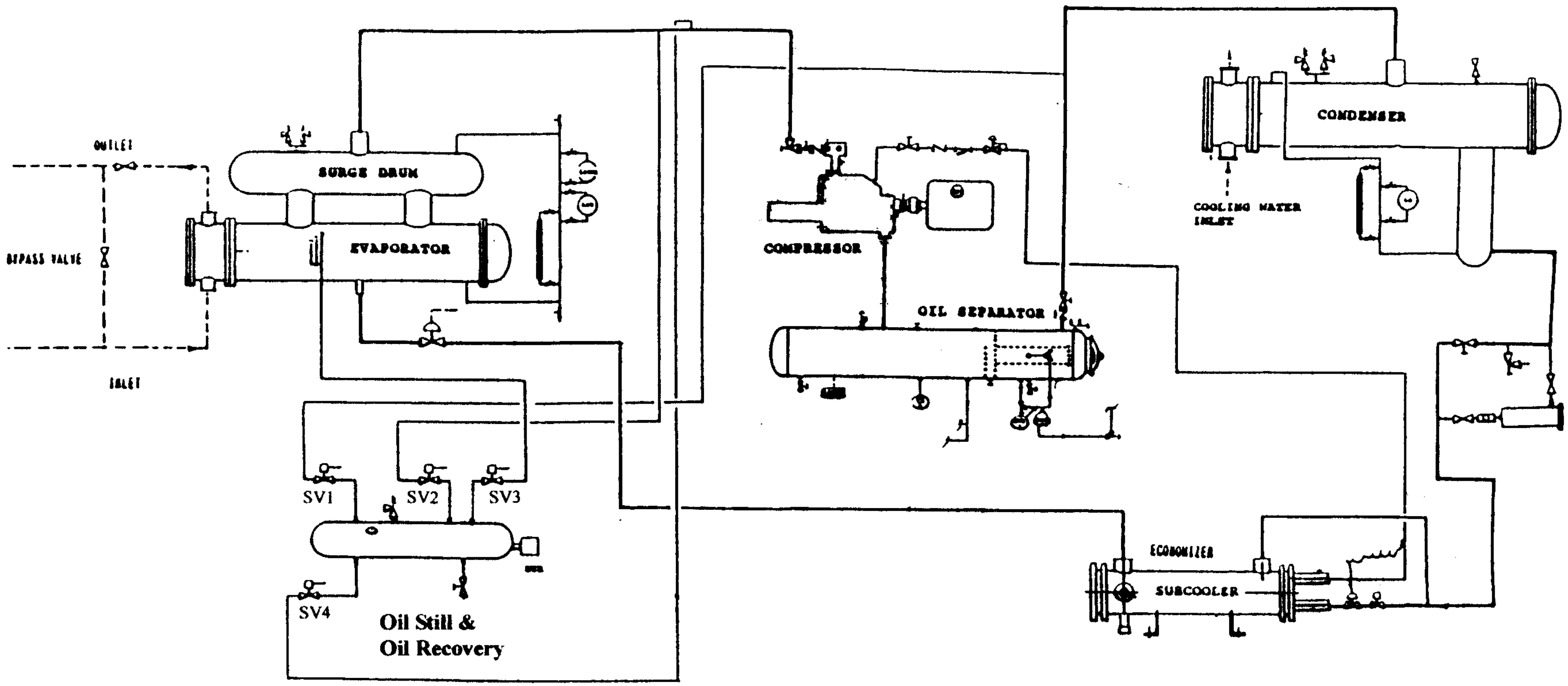


Figure 20-10 Refrigeration System with Oil Still & Oil Recovery

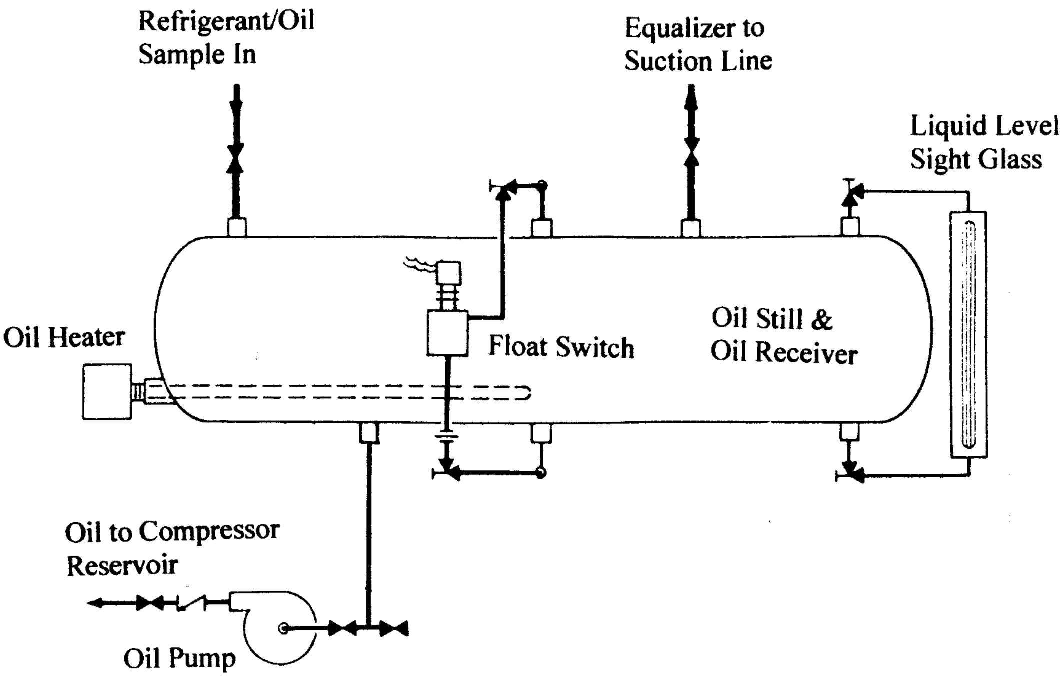


Figure 20-11 Oil Still with Pump Oil Return

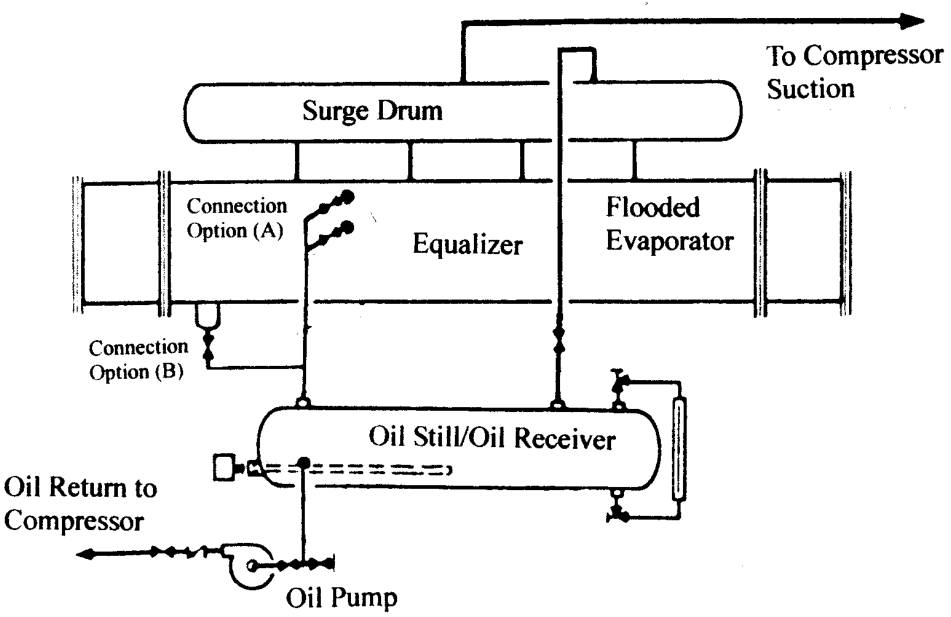


Figure 20-12 Evaporator with Possible Oil Return Connections

Figure 20-12 shows two possible oil tapping connections for oil return; the Connection Option (A) is for oil gravity which is lighter than the refrigerant, the oil is floating at the top layer of the liquid level in the evaporator, so the oil/liquid sample is taken out from the upper layer of the liquid level in the evaporator; connection Option (B) is for oil gravity which is heavier then the refrigerant, the oil is accumulated at the bottom of the evaporator in this case, so the oil/liquid sample is taken out from the lower point of the evaporator.

Oil Return by Ejector (Eductor)

The principal of operation of the ejector is to use high pressure gas to induce the oil and liquid sample from the evaporator, returning the oil/liquid mixture back to compressor suction. The cost of this type of oil return is the least expensive and it is only about 20% of the normal oil still and oil recovery system. However, the refrigeration capacity penalty is about 4% for this type of oil return because the hot gas is bypassed back to the suction.