equivalent to the interstage pressure. Its disadvantages are that the pressure of the subcooled liquid is reduced to interstage pressure, leaving less pressure difference available for the liquid line and expansion valve. Also the valve controlling the liquid flow to the subcooler must be large enough to pass all of the liquid refrigerant flow. The failure of this valve could result in a large flow of liquid to the upper stage compressor suction, a condition which could cause serious damage to the compressor.

Fig. 7 shows the closed or heat exchanger type of subcooler. It should be designed with sufficient heat transfer surface to transmit the heat from the liquid to the evaporating refrigerant with a reasonably small final temperature difference. The pressure of the liquid leaving this subcooler is very nearly that of the liquid entering so that practically full pressure is available for the expansion valve at the low temperature evaporator. The liquid flow control valve need

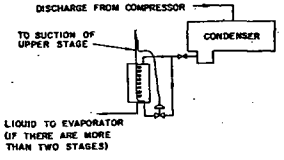



Fig. 7 .... Exchanger-Type Subcooler

be sized only sufficiently large to pass the amount of refrigerant required to do the subcooling and, therefore, its failure could not result in such a tremendous quantity of liquid flowing to the upper stage suction as is possible with the flash type subcooler.

## Gas Intercooler (Desuperheater)

The discharge gas from a low-stage compressor is normally very highly superheated and is too hot for the suction of the high-stage compressor. It is, therefore, desirable to remove this superheat to within 10 to 25 F deg of the temperature corresponding to the interstage pressure.

It is thermodynamically most desirable to cool the low-stage discharge gas by means of a coolant such as water or air which can remove the excess heat from the discharge gas. When a water-cooled intercooler is used, however, there is always the possibility that if compression does not take place in the machine preceding the intercooler (suction gas from evaporator being drawn through or bypassing an idle booster machine), the gas may reach the intercooler at temperatures below 32 F with the possibility of freezing water in the intercooler and resultant damage. This would not be a possibility with an air-cooled intercooler. In addition, if the temperature of the fluid which is removing heat from the refrigerant gas is below that corresponding to the saturation pressure of the gas some condensation of the refrigerant might occur. If this is a possibility, a means of separating the liquid from the gas before it enters the higher stage of compression is required. Normally if water is used as a coolant and is available at low enough temperatures to cause condensation at the interstage pressure, it would be used as a final condensing medium. It should be pointed out, however, that where water is normally at temperatures which would not cause condensation, seasonal variations in cooling water temperatures may be such as to present this as a problem.

Although not the most effective from a thermodynamic cycle standpoint, direct injection of refrigerant liquid into the interstage gas is probably the most common method of intercooling. One type of injection desuperheater is illustrated in Fig. 8. Since the intention is that all of the liquid injected should be evaporated, it must be sprayed into the gas in a very fine mist. Large droplets are very likely to collect on the bottom of the desuperheater from which point evaporation will be quite slow. There are individual preferences as to whether the spray should be directed with or against the gas flow. Successful units have been built both ways. Good operation requires a low gas velocity, some space for evaporation of the droplets between the nozzles and the point where the desuperheated gas leaves the apparatus and some means for separating possible excess liquid from the gas and draining it from the desuperheater. Excess liquid which is carried off, should be heated and evaporated with warm liquid, or other heat source, and the resulting gas and oil returned to the suction line at a point after the desuperheater.

Desuperheating accomplished by evaporation of injected liquid, does not result in thermodynamic cycle gain for most refrigerants. Its purpose is only to reduce the gas temperature so that the discharge from the high-stage compressor does not become excessively hot. The characteristics of the particular refrigerant should be considered before providing an injection type desuperheater. From a thermodynamic standpoint there is a slight loss in cycle efficiency if Refrigerant 12 is desuperheated by the evaporation of the refrigerant. There is, however, some slight thermodynamic gain when using Refrigerant 717.

## Heat Exchangers (Liquid-to-Suction)

There is considerable discussion of liquid-suction heat exchangers in Chapter 70 to which the reader is referred. What is said here pertains especially to low temperature applications.

For some types of compressors it may be necessary to raise the temperature of the low-stage suction gas to above some predetermined point to maintain the lubricating ability of the oil in the compressor. This is not always the case because one of the most common problems in low temperature compressors is, ironically, the overheating of the compressors.

With respect to compressor performance, heating of the suction gas by subcooling the liquid refrigerant may help to reduce the heat pickup by the gas as it enters the compressor cylinder through the relatively warm valve ports. This apparent advantage, however, must be balanced against the pressure drop in the gas which will occur as it passes through the heat exchanger. Careful consideration in the selection of, or the sizing of suction liquid heat exchangers, should be given to these factors.

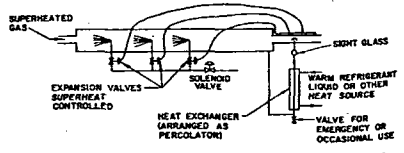



Fig. 8 .... One Type of Desuperheater for Interstage Gas



## Oil Return Equipment

One of the most difficult problems in low temperature refrigeration is that of effecting the return of lubrication oil from the evaporator to the compressors. With the exception of most centrifugal compressors and the rather infrequent application of nonlubricated or diaphragm type of compressors, lubricating oil is continuously injected into the discharge line along with the refrigerant. Some of this oil may be removed with an oil separator and returned directly to the compressor. However, even the best oil separator does not remove 100 percent of the oil and, therefore, some continues on to the condenser and will find its way to the low side of the refrigeration system.

Oil is miscible with Refrigerant 717 (ammonia) in only an extremely small proportion and, therefore, some can be separated from the refrigerant in the high side receiver. The ammonia floats on top of the oil. The special considerations for this refrigerant are treated in Chapter 71.

For the halocarbon refrigerants, oil is reasonably miscible at the higher temperatures. However, at the lower temperatures the proportion of oil to the refrigerant which is miscible is decreased with many refrigerants. If the proportion of oil in the evaporator exceeds the miscible percentage, it will separate and (with most refrigerants) go to the top in a flooded system. If evaporation of the refrigerant is occurring at a very low temperature it is likely to be below the pour point of the oil so that the floating mass becomes rather solid and will not properly flow. This separation has resulted in sticking of controls and blocking of refrigerant passages, especially at return bends on the coils in addition to fouling of the heat transfer surface.

There are many factors to consider in the design of a satisfactory oil return system, and each individual application should be carefully analyzed to assure that the system is suitable for the actual equipment being used.

Oil separators are usually installed only after the high-stage compressor in compound systems. If the separator is very good and properly sized for the application it will remove practically all of the oil that is in fog or droplet form. An impingement type of separator cannot remove the oil which is in vapor form. Oil separators with heat transfer surface and cooling fluids which may be effective in condensing oil vapors are sometimes used, but result in the additional possibility of condensing some of the liquid refrigerant which then must be distilled off from the oil before it is returned to the system. Even though oil separators do not remove all of the oil from the discharge, there is good reason for using them on low temperature jobs because a reduction in the percentage of oil with the refrigerant in the evaporator may be helpful in permitting the oil return apparatus at the evaporator to return oil at a rate equal to that at which it is entering the evaporator.

In general, the direct-expansion type of evaporator is likely to give the least oil problems since there is a continuous flow from one end to the other and all of the fluid, refrigerant and oil, which comes in one end should go out the other. Unless the flow rate is extremely small or the concentration of oil is sufficiently high to permit it to thicken and stick to the walls of the evaporator, there is little possibility of any oil remaining behind.

With a flooded evaporator, although refrigerant and oil may enter, practically nothing but refrigerant will leave with suction gas. Unless other means are provided, there will be a continual increase in the proportion of oil to refrigerant in the evaporator. Some means of separation of this oil from the evaporator refrigerant and return to the compressor, therefore, must be provided.

The simplest and most effective method is to bleed off a sample of the refrigerant oil mixture continuously and boil off the refrigerant, leaving only the oil to be returned to the compressor. The source of heat for this distillation process may be from an outside supply, but probably the most common, and certainly the most efficient, is to provide heat from the warm liquid. Because even subcooled liquid is always at a temperature higher than the evaporating refrigerant, it is an effective heat source. Since the heat used to evaporate the refrigerant from the mixture is equal to the heat removed from the liquid, there is no thermodynamic loss to the cycle.

With some refrigerants at the lower evaporator temperatures, there is likely to be separation of oil from the refrigerants, and the designer must determine the proper level for removal of the mixture of oil and refrigerant to provide the most effective oil return. Fig. 9 illustrates one arrangement of the evaporator, a surge drum and oil recovery system, which automatically takes care of this problem. In this system the level in the flooded evaporator is maintained sufficiently high to guarantee a continuous return of liquid to the surge drum along with the evaporated refrigerant. Since the refrigerant in the evaporator is thoroughly agitated by the effect of boiling, it will carry over into the surge drum a mixture which will be at least of average oil concentration as it exists in the evaporator. If the conditions are such that the oil and refrigerant are somewhat separated, the oil will tend to rise to the top and the return to the surge drum will be of higher than average concentration. Thus, with this system, whatever goes to the surge drum is of either average, or higher than average, oil concentration.

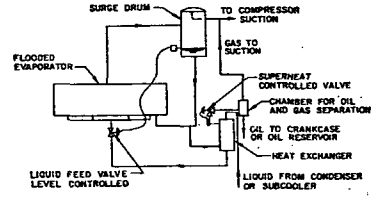



Fig. 9 .... Flooded Evaporator with Oil Recovery Arrangement for Refrigerants of Greater Density Than the Oil

The mixture of liquid refrigerant and oil which enters the surge drum is separated from the gas which goes off to the compressor suction. As this liquid is returned to the flooded evaporator a portion of it is bled off into a heat exchanger which acts as an oil recovery device. Heat from warm condenser liquid causes the refrigerant in the refrigerant oil mixture to evaporate. It then leaves the heat exchanger and enters a separation chamber where the vapor goes off to the compressor suction line and the oil back to an oil reservoir or to the compressor crankcase.

It is normal when the flooded evaporator has a surge drum to feed the liquid refrigerant into the surge drum so that the flash gas generated from the expansion of the high pressure liquid need not go through the evaporator. However, when an oil recovery system such as is illustrated in Fig. 9 is