between the vapor in the cylinder and the cylinder wall, and also because of intentional heat dissipation from the outside of the cylinder walls to the surroundings, or to a cooling fluid passing through a water jacket around the cylinder. Compressor cooling is highly desirable as a method of reducing power consumption.

### Influence of Superheating and Subcooling

The most common departure from conditions of the simple saturation cycle is that resulting from admission of superheated vapor to the compressor. Thermodynamically, superheat is undesirable because the enthalpy increase required to compress a vapor through a given pressure range increases with superheat. Further, superheated vapor leaving an evaporator is usually an indication that the suction pressure is lower than necessary. Under practical operating conditions, however, superheat is almost universally used as a means of assuring complete vaporization of the refrigerant going to the compressor. With modern compressors operating at high speed, and with relatively small clearance space, it is particularly necessary to avoid admission through the suction valves of liquid refrigerant.

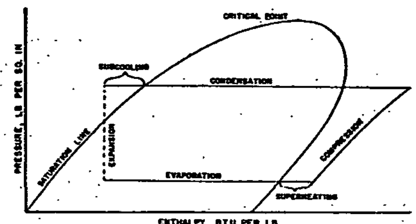


FIG. 4. PRESSURE-ENTHALPY DIAGRAM FOR REFRIGERATION CYCLE WITH SUBCOOLING AND SUPERHEATING

Another common departure of actual systems from the simple saturation cycle occurs because of subcooling of refrigerant in the condenser. Thermodynamically, such subcooling is advantageous since it increases the refrigerating effect without affecting the unit energy requirements of the compressor. Further, it can be shown that for a fixed ratio of condenser cooling water to refrigerant circulating rate, the total compressor power requirements will be greater when operating at simple saturation than when operating with maximum sub-cooling. What is even more surprising is that condenser pressure may be lower for the sub-cooling cycle than for the saturation cycle. This condition results from the fact that, for the same capacity on a heavily loaded condenser, the refrigerant flow rate is less when there is sub-cooling.

Because of the advantages attendant upon the use of sub-cooling, many methods are in use for obtaining some sub-cooling effect outside of the condenser. One common procedure is to use the cold vapor leaving the evaporator to cool the liquid flowing from condenser to expansion valve.

Another somewhat unusual sub-cooling cycle allows cold refrigerant from the downstream side of the expansion valve to cool liquid refrigerant from the condenser down to the evaporator temperature. Fig. 4 shows the pressure-enthalpy diagram for a typical refrigeration cycle operating with both sub-cooling of the refrigerant from the condenser and superheating of the refrigerant leaving the evaporator.



### Clearance and Volumetric Efficiency

*Clearance*, like displacement, is a characteristic—usually fixed—of a given compressor. In some cases clearance pockets are provided which place within the operator's control the ability to alter the clearance of the machine, but most moderate size compressors are built with fixed clearance. By definition, the clearance is the percentage of the volume swept by the piston, which is represented by spaces in the end of the cylinder (including valve spaces, etc.) when the piston is at the end of its stroke.

Because of the trapping of high pressure vapor in the clearance space, and its subsequent re-expansion, the suction valves of the compressor do not open until the piston has completed part of its stroke. Hence, the volume of fresh vapor introduced into the compressor per stroke is less than the volume swept by the piston. The ratio of actual volume of fresh gas to swept volume is, by definition, the clearance volumetric efficiency, CVE. In equation form,

$$(\mathrm{CVE}) = 100 - V_c\left[\frac{v_s}{v_d} - 1\right] \tag{8}$$

*where*

CVE = clearance volumetric efficiency.
$V_c$ = clearance, percent of volume swept by piston, which is contained in spaces at end of cylinder when piston is at end of stroke (clearance includes valve spaces, etc.).
$v_s$ = specific volume of gas at compressor inlet.
$v_d$ = specific volume of gas at compressor discharge.

Values of $v_s$ and $v_d$ can be obtained directly or by calculation from the tables of properties of refrigerants.

In addition to clearance, there are several other factors which tend to reduce the volumetric efficiency. The suction gases from the evaporator are heated and expanded upon contact with the hot cylinder walls during the suction stroke. This results in a reduction of the actual charge drawn into the cylinder. Wire-drawing through the suction and discharge valves reduces the suction pressure in the cylinder below that in the evaporator, and increases the discharge pressure above that in the condenser. Leakage of gases around the pistons also decreases the volumetric efficiency. The total volumetric efficiency (TVE) includes all of these factors and is reliably obtained only by laboratory measurements. It is too difficult to predict the effects of these factors to any degree of accuracy comparable to actual tests.

### Complex Refrigeration Cycles

The preceding sections have dealt only with refrigeration systems in which there is but one evaporator; compression is accomplished through but a single stage, and expansion proceeds through a single expansion valve. In large systems or in low temperature systems in which the compression ratio is high, the compression process can be carried out in stages, with the refrigerant passing through several cylinders arranged for operation in series. The thermodynamic advantage of such compound compression arises from the fact that intercoolers can be placed between the stages of