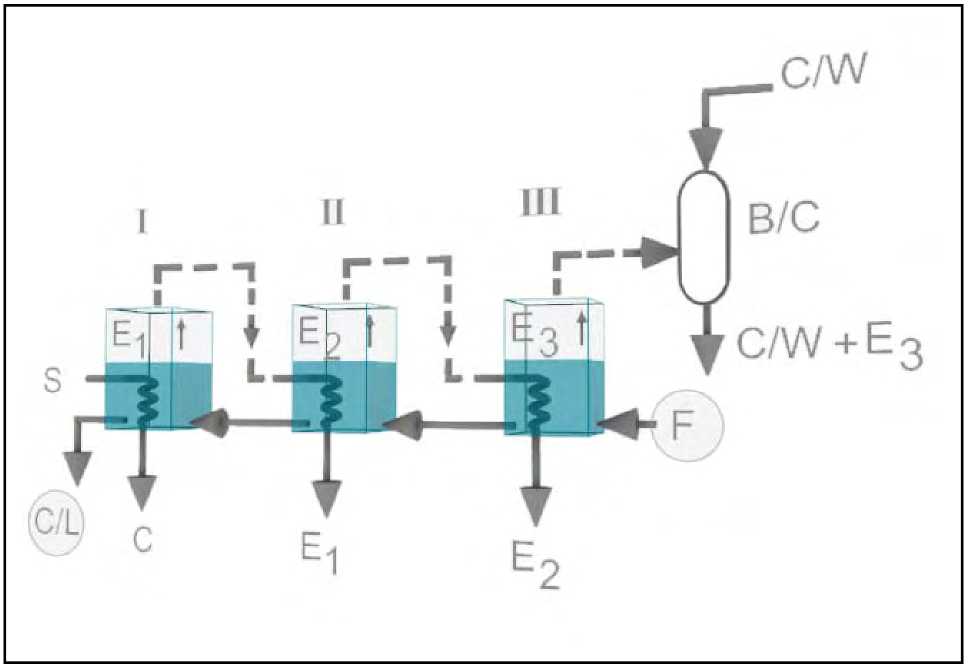

Figure 1. Backward-feed triple-effect evaporator

HEAT TRANSFER—

Recompression Evaporation

As the price of process steam rises, so will the necessity for using cost saving techniques such as mechanical recompression.

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Evaporation is one of the oldest unit operations and, with a few exceptions, is one of the most energy intensive. Industries that use this process extensively have traditionally depended on low-cost steam in the form of turbine exhaust or waste heat generated by the burning of byproduct materials. In most early chemical plants, where fuel was burned to generate both steam and power, a careful balance was maintained between power and exhaust steam requirements. Costs were somewhat arbitrarily assigned to steam and power, but only when purchased power was required was there any realistic value that could be assigned to one or the other.

In the early 1950s, when natural gas was more readily available, excess process steam requirements could often be met at almost any convenient pressure and the Btu cost was so low that there was no real incentive to consider the techniques for reducing energy consumption that had been practiced in other parts of the world for sometime. From the present time, and on into the foreseeable future, the cost of natural gas will be increasing, and in some cases may be unavailable as a source for process steam. A viable alternative for those industries that must use evaporation is purchased power from coal, nuclear, hydroelectric, or geothermal sources which may be converted into evaporation via the route of recompression.

Pumping heat

Evaporators that are to use electric energy as a driving source do not have to rely on resistance heating as a technique for producing the heat flux required for vaporization of water. A more economical alternative is to take the vapor boiled off in the evaporator and compress it to a higher pressure, here it may be used again as a source of

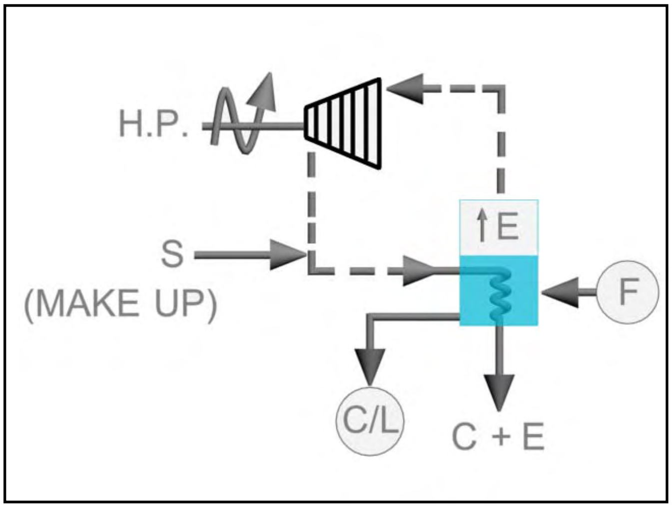

Figure 2. Mechanical recompression evaporator.

heating steam for the evaporator. From an energy conservation standpoint, it is far more attractive to “pump” the heat from one level to another where it can be reused rather than to make use of it in resistance heating elements directly.

In a sense, the evaporated water is pumped as a heat transfer medium in a manner similar to the pumping of refrigerants from one temperature level to another in refrigeration machinery. Use of the process fluid (rather than a refrigerant) introduces new complications in terms of corrosion and contamination. But aside from this the techniques employed are similar in principle to those used in refrigeration and have been known for a very long time.

The availability of electricity at a relatively lower cost than steam (i.e., generation from a separate or more economical source) makes this technique attractive in evaporation. In Europe, where hydroelectric power has long been available at a relatively low cost compared with fossil fuel-generated steam, the use of recompression evaporation has become more widespread in its use.

To appreciate the difference between conventional multiple-effect evaporation and recompression evaporation, it is helpful to review specifically the important features of a multiple-effect evaporator. Shown in simplified form in Figure 1 is a backward-feed, triple-effect evaporator. Steam entering the first effect boils off water from a process solution, which is discharged from the effect *(C/L);* and the water *(E_1)* passes through a pipe to the second effect evaporator where it enters the heating element and causes vaporization of water *(E_2)* as shown. Vapor from this second-effect evaporator passes in similar manner to the third effect, and vapor leaving the third effect is discharged to a barometric condenser and then to a cooling tower, or other heat sink.

If there were no sensible heat effects involved, then for each ‘pound of steam condensed there would be one pound of evaporation in each effect of a multiple-effect evaporator. In actual practice this cannot be true. As the feed temperature decreases and as the ratio of evaporation to feed decreases, the quantity of steam required becomes correspondingly greater. In practice it is common to assume that about 0.8 lb. of evaporation per lb. of steam per effect can be achieved. In other words, a triple-effect evaporator could be expected to have an economy of about 2.4.

The steam economy will improve for each effect that is added; however, the sump for the heat must be at a sufficiently low temperature so the vapors leaving the last effect (highest number) can be condensed. It is not uncommon to have triple, quadruple, or even sextuple, evaporators operating between a steam pressure in the first effect of 15 to 50 lb./sq. in., and with cooling water entering the barometric condenser at approximately 75 to 95°F.

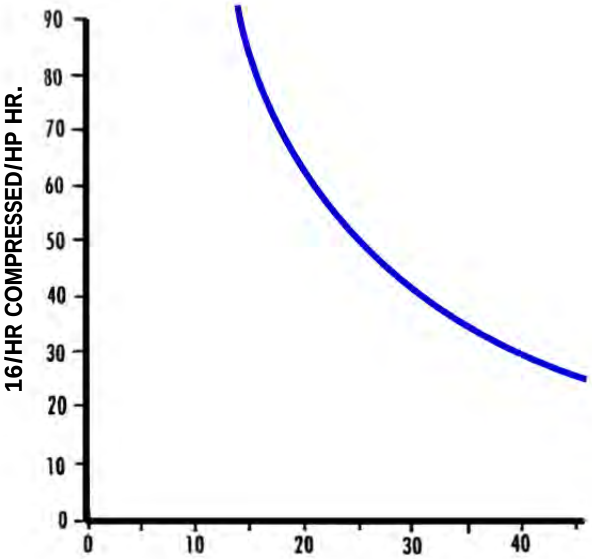

Figure 3. Effect of temperature difference on energy requirements of a mechanical compress-ion evaporator.

Equipment of this type is well suited to uses where low-temperature evaporation is required, or at least useful, and can use a wide variety of relatively low temperature sources of heat, such as waste steam or turbine exhaust. Even steam available at sub-atmospheric pressures can be used. There is almost no limit on the size to which such equipment can be built. But for almost all large-scale applications, multiple-effect evaporators are used. Typical heat input requirement is 250 to 500 Btu/lb. of evaporation.

A mechanical recompression evaporator is shown in simplified form in Figure 2. In this machine, all or part of the vapor evaporated is compressed (recompressed) to a higher pressure, where it can be used as a heat source in the heat exchanger. Although the compressor increases the pressure and temperature of the vapor discharged to the evaporator so it can be condensed in the heat exchanger, it is most convenient in dealing with evaporators to consider this change in pressure as the equivalent change in temperature based on saturated conditions for the vapor under consideration.

As shown in Figure 3, the ΔT referred to is all of the temperature difference from the surface of the liquid to the outside of the tube on which the vapor is condensed, which means that it includes the effects of boiling point elevation, vapor pipe friction loss, and ΔT for heat transfer. The main advantage of recompression is that to compress one pound of vapor through approximately 40°F temperature difference requires only 84 B.t.u. in the form of mechanical energy at the compressor shaft (24.6 waft-hr.)

Economic balance requires good judgement

In any given case under consideration, reducing the ΔT required for heat- transfer to reduce the power consumption will result in a larger heat transfer surface requirement and, therefore, a higher capital investment in heat exchange surface. An economic selection must always be made where the savings in energy for compression over

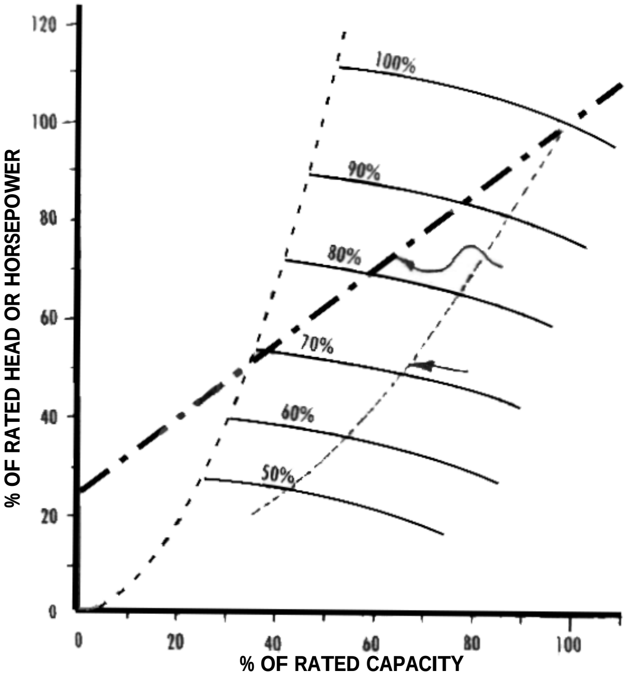

Figure 4. How the stability limit restricts the operating area of a mechanical recompression evaporation system.

a selected equipment life are offset by higher capital charges on the initial installation. Other costs that must be considered, but are less objectively defined, are the required investment in spare parts (which is much greater in recompression evaporators than in multiple-effect evaporators), the penalty for interrupted operation during repairs, and the part load response.

The choice of the drive and the ΔT in the heat exchanger lead to logical engineering choices, but the part load response is the more complex question because the efficiency of the compressor chosen decreases as the capacity is reduced. Depending on the initial heat transfer area selection, the effect of excess heating surface at part load conditions tends to reduce the relative compression range required, and thereby leads to lower power requirements per pound of vapor handled.

Another important consideration with centrifugal and axial flow compressors is that there is a stability limit at approximately 55% of design flow at design speed, below which the system becomes mechanically inoperable. As shown in Figure 4, this stability limit restricts the operating area of the system considerably. The major head against which the compressor pumps are proportional to the boiling point elevation plus the ΔT for heat transfer.

This heat transfer ΔT, in forced circulation evaporators, is directly proportional to the evaporation rate. This means that the system response (neglecting pipe friction loss) is essentially a straight line intersecting the compressor at some finite Level equivalent to the boiling point elevation.

To operate at loads other than the design Load therefore, it is either necessary to reduce the compressor speed or to change the operating pressure so that the compressor sees an increase in specific volume of the vapor and hence a lower operating temperature. Depending on the choice of the compressor driver and conditions, this may impose rather restrictive limits of operation.

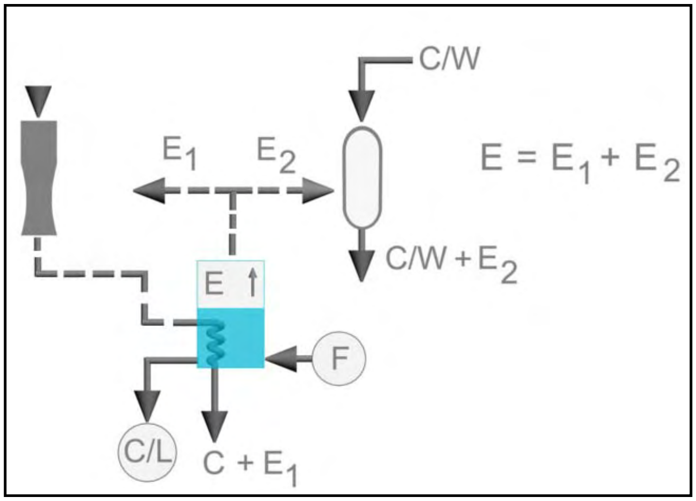

Figure 5. A thermo-compressor.

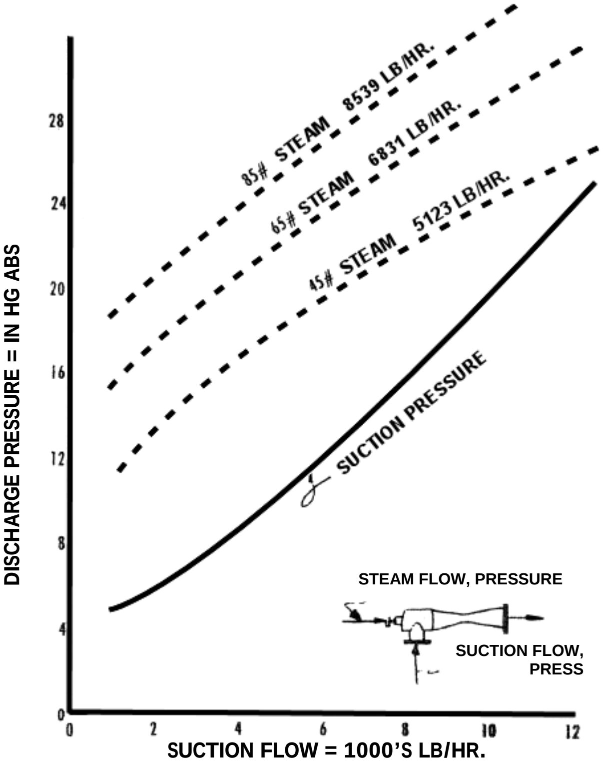

Figure 6. Characteristic curve of a thermo-compressor.

This also illustrates the advantages of operating such a compressor with a variable-speed drive, but this type of drive is not easily achieved with electric power. For constant-speed compressors, a reduction in capacity may be achieved by adjustable suction vanes that lower the head curve and reduce the power consumption. A less

The Engineer

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attractive alternative is suction throttling, or recycle of discharge vapor.

Another useful way of decreasing steam consumption in recompression evaporators is to make use of thermo-compressors, as shown in Figure 5. A thermocompressor is a large ejector in which high-pressure steam is mixed with lower pressure steam so that energy from the high-pressure steam is imparted to the lower pressure steam, thereby increasing its pressure to some intermediate point. Typically, such devices operating at moderate pressure increases can entrain steam in ratios ranging from 0.5 to approximately 1.5.

Using this technique it is always necessary to bleed some of the evaporated vapors to either a condenser as shown in Figure 5 or to the successive bodies of a multiple-effect evaporator. It often works out that such a thermocompressor will be the equivalent of adding one additional effect, and from that standpoint in terms of overall energy requirements a thermo-recompression evaporator (ahead of a regular evaporator) will have an overall economy approximately the same as adding one additional effect.

The main advantage (other than low initial cost) of the thermo-recompression evaporator system is that it can operate over a much wider range of pressures than a typical mechanical recompression unit. Also, it can be conveniently made of alloys, which are more corrosion-resistant to the process vapors handled. It relies upon a source of high-pressure steam (generally 75 to 200 lb./sq. in. gauge) being available at a cost a little greater than low-pressure steam.

As in the case of the mechanical recompression evaporator, the thermo-compressor has a characteristic curve, which is shown in Figure 6. The capacity at the suction conditions and at the discharge pressure for a given steam pressure is shown in the graph. By throttling the steam to the thermo-compressor, the steam usage is reduced but the compression range is also reduced. In addition, the characteristic curve is altered slightly in that at the lower pressures the capacity is reduced more sharply as a function of absolute pressure than at higher pressures.

Nevertheless, these devices find wide usage, particularly when operating at low absolute pressures where it would be totally impractical to use a mechanical compressor. An additional disadvantage of this scheme is that the high-pressure steam entering the thermo-compressor is mixed with evaporated water vapor so that the condensed mixture is contaminated by small amounts of entrained liquid. This is a distinct difference from a multiple-effect evaporator, where the condensate from the first effect is kept separate from liquid processed in the system.

Criteria for evaluation

In both the case of the thermal recompression evaporator and the mechanical recompression evaporator, as the ΔT in the heat exchanger is reduced the amount of heat transfer surface increases. Hence, the cost increases but the savings in energy also become greater. In each case, a detailed study must be made to determine whether the increased cost for capital investment is offset attractively by the increased savings by reducing energy consumption.

As mentioned earlier, the recompression evaporator is very sensitive to boiling point elevation, feed temperature, and feed to evaporation ratio. To analyze a given application, it is necessary to make a detailed study of the flowsheet and to prepare alternate designs for different compression ratios so that a comparison of the utility and capital cost over an anticipated life can be made.

In addition to the power required for the compressor, many recompression evaporators require some make-up steam as well. It is convenient in evaluating such systems to use the energy use ratio (EUR) defined as follows:

$$\text{EUR} = \frac{\text{lb./hr. evaporation} \times \text{(LHV)}}{\text{Mech. Energy (Btu./hr.)} + \text{Makeup (Btu./hr.)}}$$

As the cost of steam rises, particularly process steam generated solely to be used as a source of heat, the necessity of using cost-saving techniques will continue to be felt. The use of mechanical compression particularly should be considered in all cases where 1) the boiling point elevation of the vapor being processed is low, or at least is low throughout part of the concentration range, 2) the vapor is only mildly corrosive or non-corrosive, and 3) the cost of electricity or at least its availability is favourable.