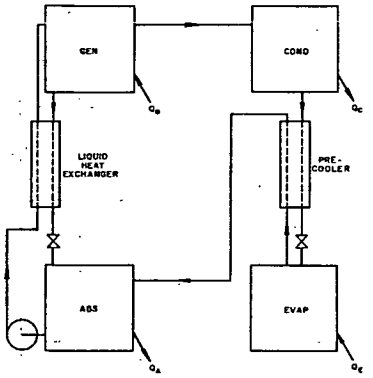


Fig. 26 .... Basic Absorption Refrigeration Cycle with Liquid Heat Exchanger and Refrigerant Precooler

absorber pressure, then the work required by the pump is:

$$\frac{(P_g - P_a)(144)(M+1)}{[\text{Sp Gr of Stream 6}]\ (62.4)} \text{ ft lbs/unit time} \qquad (27)$$

The heat equivalent is thus:

$$q_p = \frac{(P_g - P_a)(144)(M+1)}{(778)\ [\text{Sp Gr of Stream 6}]\ (62.4)} \text{ Btu/unit time} \qquad (28)$$

To determine the value of $M$, which is defined as the ratio of the weight of absorbing solution supplied to the absorber to the weight of refrigerant supplied to the evaporator (sometimes called *relative pumping* or *relative circulation*), a material balance can be made around either the absorber or generator. In the absorber material balance, note that stream 5 is one pound per unit time, stream 12 is $M$ pounds per unit time (by definition), and stream 6 must therefore be $(M+1)$ pounds per unit time, to maintain steady-state conditions. An absorbent balance may be set up as follows:

$$Mx_{12} = (M+1)x_6 \qquad (29)$$

*where*

$x_{12}$ = weight fraction of absorbent in stream 12.
$x_6$ = weight fraction of absorbent in stream 6.

Solving for $M$ yields the expression:

$$M = \frac{x_6}{x_{12} - x_6} \qquad (30)$$

Equation 30 can be used to determine the numerical value of $M$ if the values $x_6$ and $x_{12}$ are known.

The expansion device in the refrigerant stream located between points 2 and 3 is assumed to operate adiabatically. During the expansion process, a part of liquid refrigerant at condition 2 will be evaporated to cool the refrigerant to the condition 3, but the enthalpy will remain constant, i.e., $h_2 = h_3$. The same is true of the flow of absorbent solution through the flow control device between points 11 and 12, except that, in the latter case, there is no expansion and no change in temperature, assuming that the liquid heat exchanger is sufficiently large to cool the stream of absorbent solution to a temperature equal to or below its equilibrium temperature at the absorber pressure.

In the foregoing discussion, it was assumed that sufficient data are available to evaluate the enthalpy of all the streams of fluids in the cycle. In order to design the system, however, it is necessary to set up specifications and make certain assumptions regarding operating conditions and equipment effectiveness. Then the heat and material balances can be made; impossible or impractical assumptions will become obvious and subsequent assumptions must be modified accordingly.

*Example 10* illustrates the application of this procedure.

*Example 10*: Determine the conditions in a water-lithium bromide system that might be practical for a refrigeration machine to be used for air conditioning, if cooling water is available at 75 F and the required evaporator temperature is 40 F.

*Solution*: In order to be able to proceed with the calculations, certain assumptions are required. These assumptions are:

1. The absorbent solution leaves the absorber in equilibrium with the vapor and at a temperature of 80 F.
2. The absorbent solution enters the absorber at a concentration of 57 percent lithium bromide, and has been cooled in the liquid heat exchanger to within 10 F of the temperature of the solution leaving the absorber.
3. The condensing temperature is 100 F.
4. The vapor leaving the precooler is warmed to within 10 F of the temperature of the liquid refrigerant leaving the condenser.

From the $p$-$t$-$x$ chart for the water-lithium bromide system, Figure 20, determine that the evaporator pressure is 6.5 mm Hg at 40 F. Next, from assumption 1, determine that the concentration of the solution having a vapor pressure of 6.5 mm at 80 F is 50.8 percent lithium bromide. Then using Equation 20, calculate

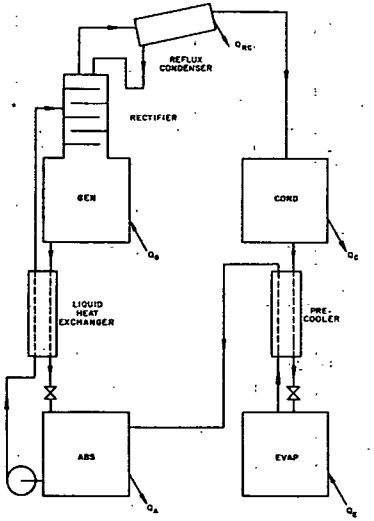


Fig. 27 .... Basic Absorption Refrigeration Cycle with Rectifier Added



Table 3 .... Conditions in Cycle of *Example 10*

| Point | Temp, F | Pressure mm Hg | Weight Fraction LiBr | Enthalpy h Btu/lb | Flow M, lb/ unit time | Heat Flow, Btu/unit time |
|---|---|---|---|---|---|---|
| 1 | 100 | 51 | 0.0 | 67.9 | 1.0 | 67.9 |
| 2 | 77 | 51 | 0.0 | 45.3 | 1.0 | 45.3 |
| 3 | 40 | 6.5 | 0.0 | 45.3 | 1.0 | 45.3 |
| 4 | 40 | 6.5 | 0.0 | 1077 | 1.0 | 1077 |
| 5 | 90 | 6.5 | 0.0 | 1100 | 1.0 | 1102 |
| 6 | 80 | 6.5 | 0.508 | −76 | 9.19 | −698 |
| 7 | 80 | 51 | 0.508 | −76 | 9.19 | −698 |
| 8 | 145 | 51 | 0.508 | −43 | 9.19 | −395 |
| 9 | 170 | 51 | 0.0 | 1135 | 1.0 | 1136 |
| 10 | 170 | 51 | 0.570 | −38 | 8.19 | −312 |
| 11 | 90 | 51 | 0.570 | −75 | 8.19 | −615 |
| 12 | 90 | 6.5 | 0.570 | −75 | 8.19 | −615 |

the ratio of entering absorbent liquid to refrigerant as follows:

$$M = \frac{0.508}{0.570 - 0.508} = 8.19$$

On the basis of assumption 3, determine from Fig. 20, that the condenser pressure, and hence the generator pressure, is 51 mm Hg. Then determine that the generator temperature (the temperature at which the 57 percent lithium bromide solution exerts a vapor pressure of 51 mm Hg) is 170 F.

As these values are obtained, they can be placed in a table such as Table 3.

Next find the enthalpy of stream 1 to be 67.9 Btu/lb (Steam Tables).[3] Also find enthalpy of saturated water vapor at 40 F to be 1077 Btu/lb, point 4. Determine that the enthalpy of vapor of stream 9, at a pressure of 51 mm and superheated to 170 F, is 1136 Btu/lb.

Through the precooler, the water vapor from the evaporator is heated from 40 to 90 F (assumption 4). At this low pressure the value of $c_p$ for the water vapor is essentially constant at 0.453. Therefore, the increase of vapor enthalpy is $0.453\ (90 - 40) = 22.6$ Btu/lb. Thus, the enthalpy of the vapor at point 5 is 1100 Btu/lb and the enthalpy of the liquid refrigerant stream at points 2 and 3 is 45.3. Btu/lb. From the Steam Tables, determine that the temperature of stream 2 is approximately 77 F.

From the enthalpy chart for lithium bromide solutions, Fig. 22, determine the enthalpy of stream 6 to be − 76 Btu/lb. Also determine enthalpy of stream 10 to be. − 38 Btu/lb. Then determine the enthalpy of stream 11 at 90 F (assumption 2) to be − 75 Btu/lb. Then by Equation 25, calculate the enthalpy of stream 8:

$$q_{LHE} = 8.19\ (h_{10} - h_{11}) = 9.19\ (h_8 - h_7)$$
$$9.19\ h_8 = -395$$
$$h_8 = -43$$

Then, from Fig. 22, determine the approximate temperature of stream 8 to be 145 F. Complete Table 3 by filling in the last column.

Applying Equations 21, 22, 23, and 24

$q_r = 1077 - 45 = 1032$ Btu
$-q_a = -698 - 1102 + 615 = -1185$ Btu
$q_g = 395 - 312 + 1136 = 1219$ Btu
$-q_e = 67.9 - 1136 = -1068$

From Equation 28, evaluate $q_p = 0.016$ Btu/unit time; the heat energy required to pump the solution is so small that it can be neglected. Therefore, the overall heat balance can be made as follows:

$$q_r + q_g = 1032 + 1219 = 2251 \text{ Btu}$$
$$-q_a - q_c = -1185 - 1068 = -2253 \text{ Btu}$$

The coefficient of performance for the assumed system can be evaluated thus:

$$(CP) = \frac{q_r}{q_g} = \frac{1032}{1219} = 0.847$$

The foregoing analysis has ignored heat losses from the system and heat leakages between various parts of the system in order to keep the presentation relatively simple and straightforward. Such heat losses would, of course, tend to lower the value of the CP. However, in a well designed piece of equipment, the effect of heat losses is a minor one.

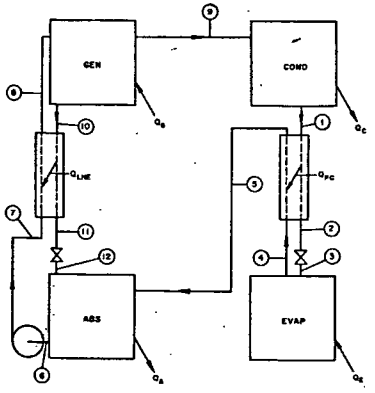


Fig. 28 .... Basic Absorption Refrigeration Cycle for Cycle Analysis

## Additional Reading

For those desiring more detailed information on absorption refrigeration, Reference 33 provides a thermodynamic description of the absorption cooling process, an evaluation of the properties and requirements of the absorbent-refrigerant combinations, a compilation of pertinent data, and a good reference list.

A more extensive coverage of the subject can be found in Reference 40.

## REFERENCES

[1] S. R. DeGroot: *Thermodynamics of Irreversible Processes* (Interscience Publishers, New York, 1951).
[2] G. J. VanWylen: *Thermodynamics* (John Wiley & Sons, New York, 1959).
[3] O. A. Hougen, K. M. Watson, and R. A. Ragats: *Chemical Process Principles* (John Wiley & Sons, New York, 1959).
[4] F. W. Sears: *Thermodynamics* (Addison-Wesley Publishing Co., Inc., Reading, Mass., 1956).
[5] J. F. Lee and F. W. Sears: *Thermodynamics* (Addison-Wesley Publishing Co., Inc., Reading, Mass., 1963).