Vapor Recompression

Recovering Low Pressure Waste Steam

By Everest Blowers

Increasing energy cost and pressures on improving process efficiency are forcing process engineers to minimize wasteful losses. Efforts are continually being made to minimize all such losses.

In many industrial processes low pressure spent steam is let off into atmosphere and goes off as waste heat. Thermal separation processes such as evaporation and distillation are energy intensive. The need for reducing energy costs led to multi- effect plants, then to thermal vapor compression and finally to use of mechanical vapor compression systems. Under steady state conditions, sum of all energy and enthalpy inputs must equal the sum of all energy and enthalpy outputs. It, therefore, becomes important to ensure that energy imparted to the vapors is recovered back/re- used. The following options are generally adopted in the industry for recovery of energy:

a) **Multi-effect Evaporation**
b) **Vapor Recompression**
    i) Thermal vapor recompression
    ii) Mechanical Vapor recompression

Multi-effect Evaporation

In a multi effect evaporation plant, the vapors produced in the first effect are utilized as the heating medium of the second effect and so on. This effectively reduces steam consumption in proportion to the number of effects. Ideally unit mass of vapor on condensation can evaporate unit mass of liquid. The vapors generated at the first effect are condensed in the second stage to further evaporate the liquid from the second stage and so on. A temperature gradient of about 7-10°C is maintained between stages for maximum efficiency. So a triple effect evaporator would consume only 35-36% of the energy in comparison to a single effect system.

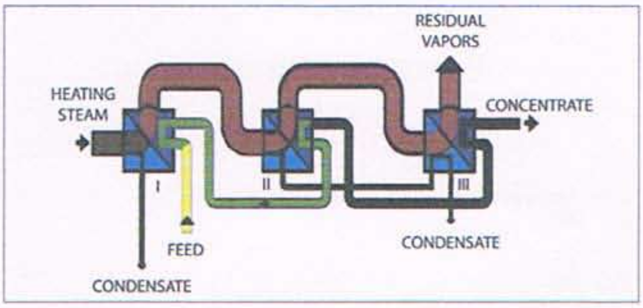

Fig. 1 Triple Effect Evaporator

Vapor Recompression

In vapor recompression arrangement the heat of condensation of the evaporated vapor is recovered in single effect only by raising the pressure and temperature of the generated vapor and then their condensation in the same evaporator. The vapor compression can be done by Thermal Vapor Compression or Mechanical Vapor Compression Process.

Thermal Vapor Compression

In thermal vapor recompression steam jet ejectors are used to raise the pressure and temperature of the generated vapors. The motive steam mixes with the vapor and to maintain the steady flow heat balance some of the vapor steam mixture has to be taken to second effect for full recovery of latent heat of vapor and, therefore, excess vapor is to be conveyed to next effect for recovery.

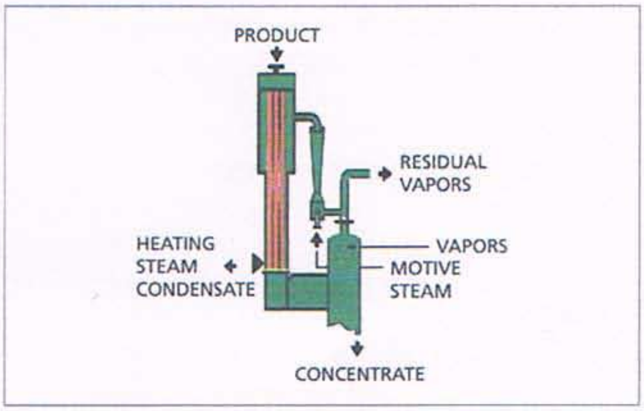

Fig. 2: Flow Diagram - Thermal Vapor Compression

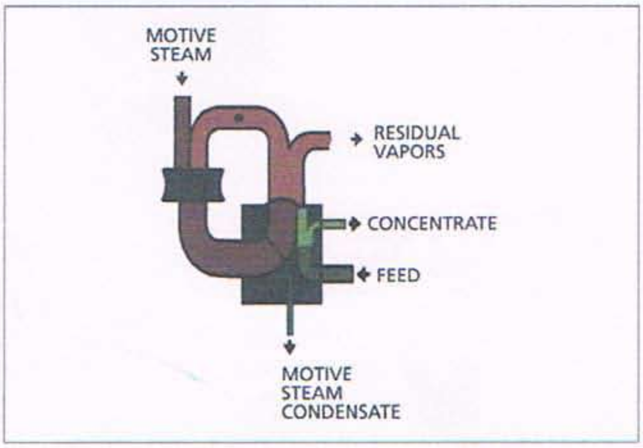

Fig. 3: Heat Flow Diagram – Thermal Vapor Compression

Initially, heating steam is used to initialize evaporation. The vapors evaporated are compressed to higher pressure and temperature by steam jet ejector, condensed back for heat recovery and the residual vapors are taken to second stage for condensation / heat recovery. The amount of surplus energy contained in the residual vapor corresponds to the amount of energy supplied for steam jet ejector operation. This is taken as additional heat input / work done for recovery of large heat content of the evaporated vapors.

Mechanical Vapor Compression

In mechanical vapor compression, positive displacement compressors or multi stage centrifugal compressors are generally used to raise the pressure and temperature of the generated vapors. Since mechanical compressors do not require any motive steam, all vapors can be compressed to elevated pressure and temperature eliminating the need for subsequent recovery system. The energy supplied to the compressor constitutes the additional energy input to vapors. After compression of vapor and subsequent condensation of the same, hot condensate leaves the system. A typical mechanical vapor recompression cycle would be as illustrated in figure below:

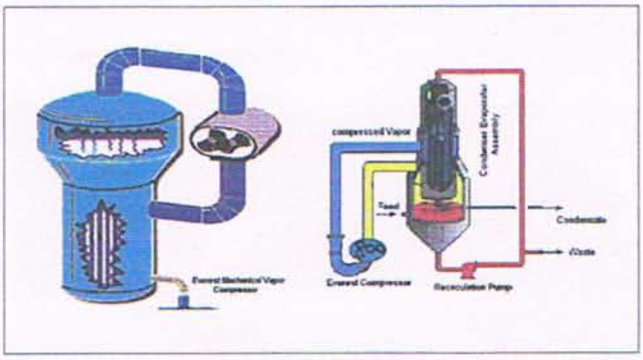

Fig. 4: Typical Mechanical Vapor Recompression Cycle

For mechanical vapor compressors, the specific energy input depends upon the compression ratio (ratio of input pressure to discharge pressure). Compression ratio, therefore, must be maintained to the lowest required.

The compression ratio is influenced by:

1. The boiling point elevation of the liquid to be evaporated. Higher the boiling point rise higher is the compression ratio required.
2. Minimum differential temperature gradient required for effective heat transfer. Indirect condensers require a minimum temperature gradient across the fluids exchanging heat. The condensers should be designed for least ΔT operation.
3. Total system pressure drop in the piping and valves. Adequate size of piping and valve selection should be done for minimum pressure drop during transfer of fluid through them.

The working cycle of Everest mechanical compressor for steam, as fluid handled, is explained under.

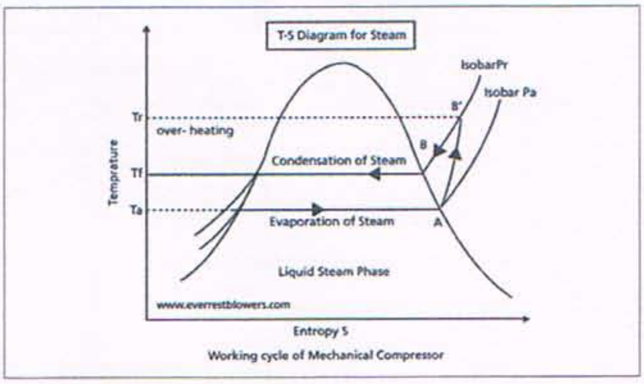

Fig 5: Working Cycle of Everest Mechanical Compressor

The vapor is sucked from the evaporator, at point A for P_a, T_a Pressure and Temperature conditions. It is adiabatically compressed to pressure P_r at point B'. The heat of compression raises the temperature of the steam to Tr. The super heated vapor at the discharge of the compressor are cooled, and brought to final saturation point B, (T_f, P_r). The compressed vapor is condensed in the indirect condenser to recover the latent heat. The condensate, at temperature T_f is discharged.

Steam Economy / MVR Process Efficiency

To estimate the Process Coefficient of Performance, a practical calculation is made for steam.

Latent heat of vaporization of water at 100°C, 1 bar is 2257 KJ/Kg. i.e. the quantity of heat input to evaporate 1 Kg of water at 100°C to saturated steam at 100°C is 2257 KJ.

In case of Everest Mechanical Vapor Compressor the latent heat of evaporation of steam can be recovered back by spending much smaller quantity of electrical energy. The input electrical energy to compressor (Twin Lobe Type) is estimated by the PV curve.

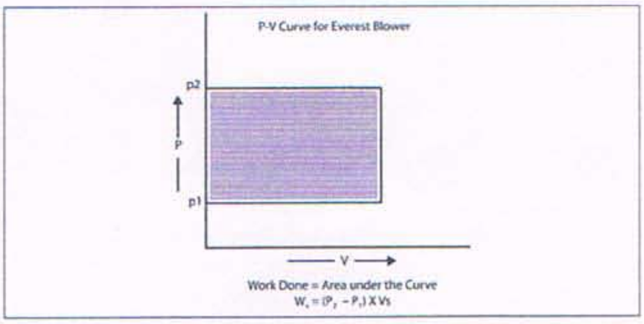

Fig 6: P-V Curve for Everest Mechanical Vapor Compressor

Everest Everest compressors consist of two lobes in the shape of figure eight rotating in opposite directions through a pair of timing gears. As the rotors move past the inlet they draw vapors at inlet condition P_1. As the rotor rotates the vapors are pushed out to discharge against the pressure P_2.

Fig 7: Everest Mechanical Vapor Compressor

The work done is the area under the curve, given as W_s.

$W_s = (P_2 - P_1) X Vs$

W_s = Specific work done KJ/kg.

P_2 , P_1 = final and initial pressure (KPa)

V_s = Specific Inlet volume (m^3).

Case Study

Taking a practical installation at one of the chemical units in Maharashtra where Everest Mechanical Compressor is installed to compress 1800 Kg/hr of steam from sodium chloride aqueous solution. The inlet design pressure P1 is 101.3 KPa, Vapor temperature T1 is 102°C and the compression ratio is 1.5

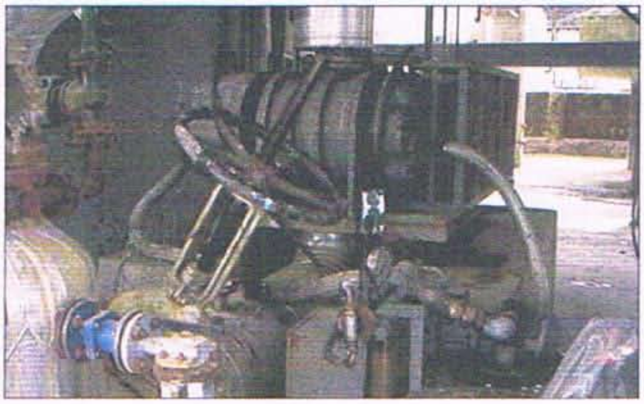

Fig 8: Typical Everest Mechanical Vapor Compressor Installation

Ideal Specific Input work, $W_s = (152 - 101.3) \times 1.6729$
$= 84.8$ KJ/kg.

Taking compressor overall efficiency 65%

Specific Energy input = Ws / 0.65

Specific Energy input = **130 KJ/kg** .... (1)

Latent heat of evaporation of Water at 100°C and 1 bar (as per steam tables) is 2257 KJ/kg. It implies so by compressing the vapors through electrical input energy of 130 KJ/Kg, the process is able to recover 2257 KJ/Kg of energy.

Heat energy recovered on condensation = 2257 KJ/Kg ... (2)

Performance Ratio = 2257 / 130 = 17.36

This ratio of 17.36 indicates that the process of Mechanical Vapor Recompression is similar to a 17 stage evaporator, making it highly energy efficient.

Cost Advantage & Economy

As per the current fuel prices the cost of generation of steam is lower than the cost of equivalent electrical energy. Taking the ratio of cost of steam generation to equivalent cost of electrical energy as 1:3, the mechanical vapor recompression process gives the economic effect of 17/3 = 5.66 pass evaporator. The capital cost, installation and operation costs are much lower making it an ideal process choice. Increasing fuel energy costs are also tilting the process engineer's choice to MVR.

Advantages of Mechanical Vapor Compression:

1. Low specific energy consumption
2. Higher Performance co-efficient
3. Gentle evaporation of the product due to low temperature differences
4. Reduced load on cooling towers since no residual vapor
5. Simplicity of process, operation & maintenance.