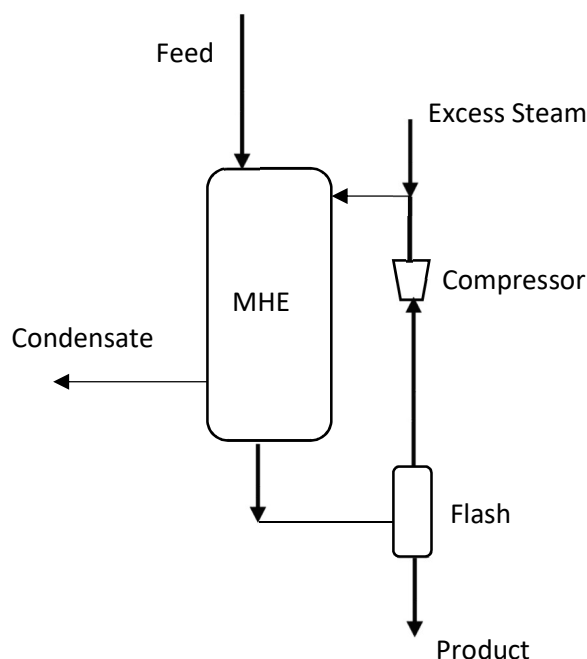


What is MVR System?

Mechanical Vapor Recompression (MVR) System is a new technique used to concentrate a mixture containing one volatile solvent and multiple non-volatile solutes, similar to MEE. Main application of MVR is in Effluent Treatment Plants (ETP) to recover pure water from effluent and concentrating the effluent before sending waste to RO plant. MVR has much higher steam economy than MEE system because of the fact that MVR recycles all of the vapor generated from feed, which is not possible in MEE system. As a result, it is more energy efficient process than MEE, if designed properly.

Diagram:



(MHE: Main Heat Exchanger)

Assumptions:

- 1) Constant value of specific heat capacities is assumed of solid components
- 2) Only one volatile component present in feed. All other components are solids and non-volatile. Water is present as the volatile component.
- 3) Feed entering in the tube side of main heat exchanger.
- 4) Additional steam enters at the same pressure as steam at the exit of compressor.

Simulation:

- 1) It is assumed that the steam entering from compressor gets completely condensed i.e. the area of main heat exchanger is large enough to not lose any steam.

Note:

- 1) One might encounter the following error:

| Type | Message |
|-------|---|
| Error | Traceback (most recent call last): File "<string>", line 187, in <module> File "<string>", line 142, in FindH SystemError: Object reference not set to an instance of an object. |
| Error | Errors occurred during the calculation of the flowsheet, please read the following messages for more details. |

This is a problem in DWSIM when using database of other property data bank other than the one using (in this case Peng Robinson (main) and Steam Tables (secondary)). In order to resolve the error, change the property package to Steam Tables from Peng Robinson and then back to Peng Robinson. Code would function on doing so.

Equations Used:**For finding Elevation in Boiling Point:**

1. Elevation in Boiling Point Calculation:

Rise in boiling point = (Ebullioscopy constant) * (Molality)

$$\text{Molality} = \frac{\text{Moles of Solute} \times \text{Von't Hoff factor}}{\text{Mass of solvent}}$$

For multiple components, numerator of molality will be summed over moles of solute x Von't Hoff Factor over every component.

$$\text{Ebullioscopy constant} = \frac{R \times T_b^2 \times M}{\Delta H_{vap}}$$

Where R = 8.314 J/mole-K (Universal gas constant)

T_b = Boiling point of pure solvent in K

M = Molar mass of solvent in Kg/mole

ΔH_{vap} = Latent heat of Vaporization in J/mole

Mass Balance in Main Heat Exchanger:

1. Conservation of total mass:

Total Mass in = Total Mass out

$$M_F + M_S + M_{V2} = M_P + M_C$$

2. Since no amount of solute will be vaporized, amount of solute in feed = amount of solute in product stream.

Energy Balance in Main Heat Exchanger:

1. Energy released by condensation of steam = Energy absorbed by feed for pre-heating and vaporization

$$m_1 \lambda(P_c) = f C_p (T_{fsat} - T_f) + m_2 \lambda(P_f) = E_1,$$

where m_1 is the mass flow rate of steam; $\lambda(P)$ corresponds to latent heat of vaporization at Pressure P; P_c is the pressure of steam leaving compressor; f is mass flowrate of feed; C_p is the specific heat capacity of feed; T_{fsat} is the saturation temperature of feed; T_f is the inlet temperature of feed; m_2 is the mass flow rate of steam produced from vaporization of feed; P_f is the pressure of feed leaving main heat exchanger

2. The above energy transfer is equal to the heat transfer from shell side to tube side:

$$E_1 = UA \left(\frac{(T_{fsat} - T_f)}{\ln \frac{(T_s - T_f)}{(T_s - T_{fsat})}} \right),$$

where U is overall heat transfer coefficient; A is surface area of tubes in contact with steam;
 T_s is the entering steam temperature

Compressor:

1. The work done in isentropic compressor is: $W_1 = m_3(H_2 - H_1)$,
 where m_3 is the mass flowrate of steam through compressor; H_1 is the enthalpy of steam vaporized from feed; H_2 is the enthalpy of steam calculated at same entropy as steam inlet to compressor and pressure = inlet pressure to compressor*compression ratio
2. The work done by real compressor is given by: $W_2 = \frac{W_1}{\eta}$,
 where η is the compressor efficiency

Steps to use the model:

- 1) One may select multiple property packages, but the 2nd property package should be Steam Tables (IAPWS-IF97).
- 2) One of the components selected should be water, which should be the only volatile specie.
- 3) If the model is to be operated in design mode, specify the value of design in input box as 1. If the model is to be operated in simulation mode, specify the value of design in input box as 0.

Specifications required:

- 1) Specify the desired outlet product wt% in input box ProdConc.
- 2) Specify the shell side pressure drop in main heat exchanger against the input PresDropHEShell in units bar.
- 3) Specify the compression ratio of compressor against CompRat.
- 4) Specify the tube side pressure drop in main heat exchanger against the input PresDropHETube in units bar.
- 5) Specify the overall heat transfer coefficient against OverallHTCoeff in units W/m²K.
- 6) Specify the compressor efficiency against CompEff.
- 7) Specify average specific heat capacity of feed against CpFeed in units J/Kg-K.
- 8) Specify the Von't Hoff Factor for every non-volatile specie against VontHoffFac.

Calculation Procedure:

For Design:

- 1) Find out amount of water to be vaporized from feed through mass balance using given product data.
- 2) Find out composition and flowrate of the streams leaving main heat exchanger.
- 3) Find the elevation in Boiling point of feed stream.
- 4) Find the energy required to cause heating from feed temperature to boiling point and then vaporization of required amount of water using entered specific heat capacity data and steam table property package.
- 5) Find out the true work done by compressor and final state of vapor leaving compressor using given compressor data.

- 6) Find out the heat required to be removed from compressed steam to achieve saturated steam.
- 7) Find the enthalpy of condensate stream leaving main heat exchanger.
- 8) Verify whether sufficient amount of excess steam is supplied to the main heat exchanger or not by finding heat released from complete condensation of vapor stream and comparing it with the heat required to vaporize feed.
- 9) Find the area by equation amount of heat exchanged with $UA\Delta T_{LMTD}$.

For Simulation:

- 1) Find the boiling point of feed by doing elevation in boiling point calculations.
- 2) Break the vapor stream entering main heat exchanger and run iterations to make the mass of steam entering in the two ends converge. Use energy balance equation on main heat exchanger to find amount of feed vaporized using an initial value of entering steam. Change the value of entering steam to excess steam + feed vaporized until the two ends of vapor stream entering main heat exchanger converge.
- 3) Complete mass balance using the amount of feed vaporized for all streams.
- 4) Using the data of feed vaporized, find the true work done by compressor and also calculate the amount of heat to be removed from compressor to make steam saturated.

After all these steps, export these values to the corresponding streams and run the program.

Case Study I:

Consider the following data:

Feed Stream:

Flowrate: 0.806 Kg/s; Composition (wt%): 81% water, 9.5% NaCl, 9.5% KCl; Temperature: 352.5K; Pressure: 1 bar; Specific Heat Capacity (KJ/Kg-K) = 4; Von't Hoff Factor of solids: [2, 2]

Excess Steam stream:

flow rate = 0.05 Kg/s; Temperature: 1.81 bar; Saturated state of water

Compressor:

Compression Ratio: 1.8; Efficiency: 0.7

Property Packages: Peng-Robinson; Steam Tables (for water properties)

Assume 0 Pressure drop across main Heat exchanger

Find the composition of product stream assuming sufficient area of main heat exchanger for heat exchange.

| Component | Weight % in Product Stream | Mass flow rate (in Kg/s) |
|-----------|----------------------------|--------------------------|
| Water | 64.6 | 0.279 |
| NaCl | 17.7 | 0.076 |
| KCl | 17.7 | 0.076 |

Verification:

Amount of water vaporized: $0.806 \times 0.81 - 0.279 = 0.374$ Kg/s

Total steam entering Main Heat Exchanger: $0.374 + 0.05 = 0.424$ Kg/s

From steam table, latent heat of vaporization of compressed steam is: 2210 KJ/Kg

latent heat of vaporization of feed is: 2228.7 KJ/Kg

sum (Molality*Von't Hoff Factor) of product stream is:

$$(76/58.5*2/0.279+76/74.5*2/0.279) = 16.64$$

Boiling point of aqueous mixture corresponding to above compositions would be:

$$373.15 + 16.64*0.513 = 381.68 \text{ K (Simulation result} = 381.69 \text{ K)}$$

Heat liberated by condensation of steam: $2210*0.424 = 937.04 \text{ KW}$

Heat absorbed for vaporization of feed: $2228.7*0.374 = 833.5 \text{ KW}$

Heat absorbed for temperature increase from 352.4 K to 384.4 K: $0.806*4*(384.4-352.4) = 103.1 \text{ KW}$

Total Heat absorbed: $833.5 + 103.1 = 936.6 \text{ KW}$

The heat absorbed value approximately matches heat liberated value. This implies that the amount of vapor vaporized value given by simulator is in fact correct.

This verifies the operation of MVR model in simulation mode (assuming enough area is available in Main Heat Exchanger)

Case Study 2: Find the area of Main Heat Exchanger given above feed specifications and desired product concentration to be 40 wt%.

The corresponding product stream will be:

| Component | Weight % in Product Stream | Mass flow rate (in Kg/s) |
|-----------|----------------------------|--------------------------|
| Water | 60 | 0.229 |
| NaCl | 20 | 0.076 |
| KCl | 20 | 0.076 |

Verification:

Amount of water vaporized: $0.806*0.81-0.229 = 0.424 \text{ Kg/s}$

Total steam entering Main Heat Exchanger: $0.424 + 0.05 = 0.474 \text{ Kg/s}$

From steam table, latent heat of vaporization of compressed steam is: 2210 KJ/Kg

sum (Molality*Von't Hoff Factor) of product stream is:

$$(76/58.5*2/0.229+76/74.5*2/0.229) = 20.26$$

Boiling point of aqueous mixture corresponding to above compositions would be:

$$373.15 + 20.26*0.513 = 383.54 \text{ K (Simulation result} = 383.54 \text{ K)}$$

Temperature of steam entering Main Heat Exchanger = 390.5 K

Heat required for vaporization of feed:

$$0.806*4*(383.54-352.5) + 2228.7*0.424 = 1045.04 \text{ KW} = \text{Amount of Heat Exchanged}$$

Amount of heat exchanged is also given by: $Q = UA(\Delta T_{LMTD})$

$$\text{Thus, } 1045.04*1000 = 1000*A*(\Delta T_1 - \Delta T_2)/\ln(\Delta T_1/\Delta T_2)$$

$$\Delta T_1 = 390.5 - 352.5 = 38 \text{ K}$$

$$\Delta T_2 = 390.5 - 383.54 = 6.46 \text{ K}$$

On substituting above values in above equation, we get:

$$A = 1045.04 \times \frac{\ln \frac{38}{6.46}}{38 - 6.46} = 58.7 \text{ m}^2$$

The simulation result is 65 m^2 , which has 9.7% deviation from the calculated value. This is probably because of the assumption of constant specific heat capacity in above solution. In DWSIM code, specific heat capacity*dT has been summed over 100 times where dT is $(383.54 - 352.5)/100$.

On using same values of parameters is DWSIM as in above solution with more simplifying assumptions, we would reach the same solution. This verifies the code.

Bibliography/Web sites referred:

- 1) https://en.wikipedia.org/wiki/Mechanical_vapor_recompression
- 2) <https://www.aiche.org/resources/publications/cep/2018/may/essentials-continuous-evaporation>