`Steps to convert Eov from Oldershaw column to EMV for industrial column.

The point efficiency, Eov, is defined by equation 6-30 in Seader’s book, where the mole fractions y and x are evaluated at a point along the tray. The Murphree vapor efficiency, EMV, is defined by the same equation averaged over the tray. Because the Oldershaw column is small and well mixed, Eov and Emv are equal. You will obtain Eov using the Oldershaw column and a process simulator. The value of Emv for the industrial column is found using the steps below.

1. Find Uaold (Uaold is velocity of the vapor based on active area of tray) for the Oldershaw column for a stage in the middle of the rectifying section. This is found by  where Vold is the molar flow rate of the vapor in the Oldershaw column in the rectifying section, Mvap is the molecular weight of the vapor,  is the density of the vapor (Use ideal gas calculation), and Aaold is the active area of a stage in the Oldershaw column. Aaold must be estimated, but it is the area where the holes for the vapor occur on the tray.
2. Find Ufold (Ufold is the flooding velocity for the Oldershaw column). This is found using (p. 226, (6-40)) where liq and vap are the densities of the liquid and vapor, respectively, on the same stage as used in step 1. The value of Cold is found by Cold = FSTFFFHACFold ((6-42) p. 226) where FST = (/20)0.2 ( is the surface tension of the liquid in dyne/cm), FF is a foaming factor and is 1 if the liquid is non-foaming, FHA = 1.0 for Ahold/Aaold  0.1 and 5(Ahold/Aaold) + 0.5 for 0.06  Ahold/Aaold  0.1 where Ahold is the total area of the sieve holes on a stage and Aaold is total active area as defined in step 1 (You can safely assume Ahold/Aaold  0.1) (p. 226), and CFold is found using Figure 6.23 on page 226. The x axis of the figure is found by where Lold is the molar flow of the liquid and Mliq is the molecular weight of the liquid on the stage chosen above. (Flv will be same in both the Oldershaw and the industrial column since will want to operate at the same conditions with the same L/V).
3. Find Ufind (Ufind is flooding velocity of the vapor based on active area of tray) for a tray in the industrial tower. Use the same FLV found in step 2 and find CFind for the industrial tower using Figure 6.23 page 226. The factors FST, FF, and FHA will be the same as found in step 2. Now .
4. Find Uaind (The vapor velocity based on the active area of the industrial column). To get the same Eov in the industrial tower as you found in the Oldershaw column you must have same fraction of flooding (Uaind/Ufind = Uaold/Ufold) and the same L/V as in the Oldershaw column. This leads to the equation To get the same L/V, you must have the same reflux ratio.
5. Find Aaind, the active tray area of the industrial column. Remember that at the same reflux ratio, the distillate flow rate is the proportional to the feed. You will get the area of the industrial column by the equation:



6. Find Ad/Aind, where Ad is the area of the downcomer (one of the shaded area in figure below) and Aind is the total tower cross-sectional area, by:

Ad/Aind = 0.1, if FLV 0.1

Ad/Aind = 0.1 + (FLV – 0.1)/9, if 0.1  FLV  1.0 (p. 227 below Eq. 6-44)

Ad/Aind = 0.2 , FLV  1.0

7. Find diameter (Dtower) of industrial tower  

8. Calculate  from 

9. Calculate 

10. Find the volumetric liquid flow rate (qL): , where Lind is the liquid molar flow rate in the industrial tower.

11. Find a value for the eddy diffusivity De for bubble caps by:

$D\_{e}=\left(0.0038+0.017U\_{a}+3.86\frac{q\_{L}}{\bar{W}}+1.8×10^{-4}h\_{w}\right)^{2}$ (Towler & Sinnott (17.45))

where Ua is vapor velocity in m/s,  is liquid rate in m3/s,  is the average flow width in meters , and hw is the weir height in mm. De has units of m2/s. Multiply the value of DE obtained above by 1.25 if you have sieve trays instead of bubble caps. (King, 12-47)

12. Find the Peclet number (NPe) using:  (6-36)

Where u = mean liquid velocity across the tray and is found by
$$u=\frac{Z\_{L}}{θ\_{L}}$$

13. Find  using: (6-33), where m is the slope, dy/dx, of the vapor-liquid equilibrium line. This slope changes with x (the liquid mole fraction). Evaluate the slope at the midpoint between the feed and the distillate composition for the rectifying section, and at the midpoint between the feed and the bottoms composition for the stripping section. One good way to estimate this for binary mixtures is to use the equations:

 and 

where:

xdist is the mole fraction of the distillate

yeq,dist is the vapor mole fraction in equilibrium with xdist

yfeedline is the vapor mole fraction at the intersection of the feedline
(i.e., the q line, eq. 7-26) with the equilibrium line

xfeedline is the corresponding liquid mole fraction

xbottoms is the mole fraction of the bottoms product

yeq,bottoms is the vapor mole fraction in equilibrium with xbottoms.

All mole fractions here are in terms of the light component.

14. Find  by:  (6-35)

15. Find EMV/EOV by: 

 (6-34)

16. Find fractional entrainment  using Figure 6.27 p. 231.

17. Now get EMV,wet (this includes the effect of entrainment and is the value you will use in a process simulator to find the number of actual stages in the industrial column) by: . This is final answer. (6-69)

Note: For large columns, EMV,wet can be greater than 1.0 since it is an average across the tray and cross-flow increases the effective efficiency. However, Eov can never be larger than 1.0.

# References

Seader, J. D., Henley, E. J., & Roper, D. K. (2011). *Separation Process Principles: Chemical and Biochemical Operations; Third Edition.* Hoboken, NJ: John Wiley & Sons, Inc.

Towler, G., & Sinnott, R. (2013). *Chemical Engineering Design: Principles, Practice and Economics of Plant and Process Design; Second Edition.* Oxford: Butterworth-Heinemann.

