EXPERIMENTAL MEASUREMENT OF MASS TRANSFER COEFFICIENTS

- **The mass transfer coefficient, k_c, can be studied in experimental devices in which the area of the contact between phases is known.**

- **The wetted-wall tower is one of the instruments used in practice.**

- **It can give valuable information on mass transfer to and from fluids in turbulent flow.**

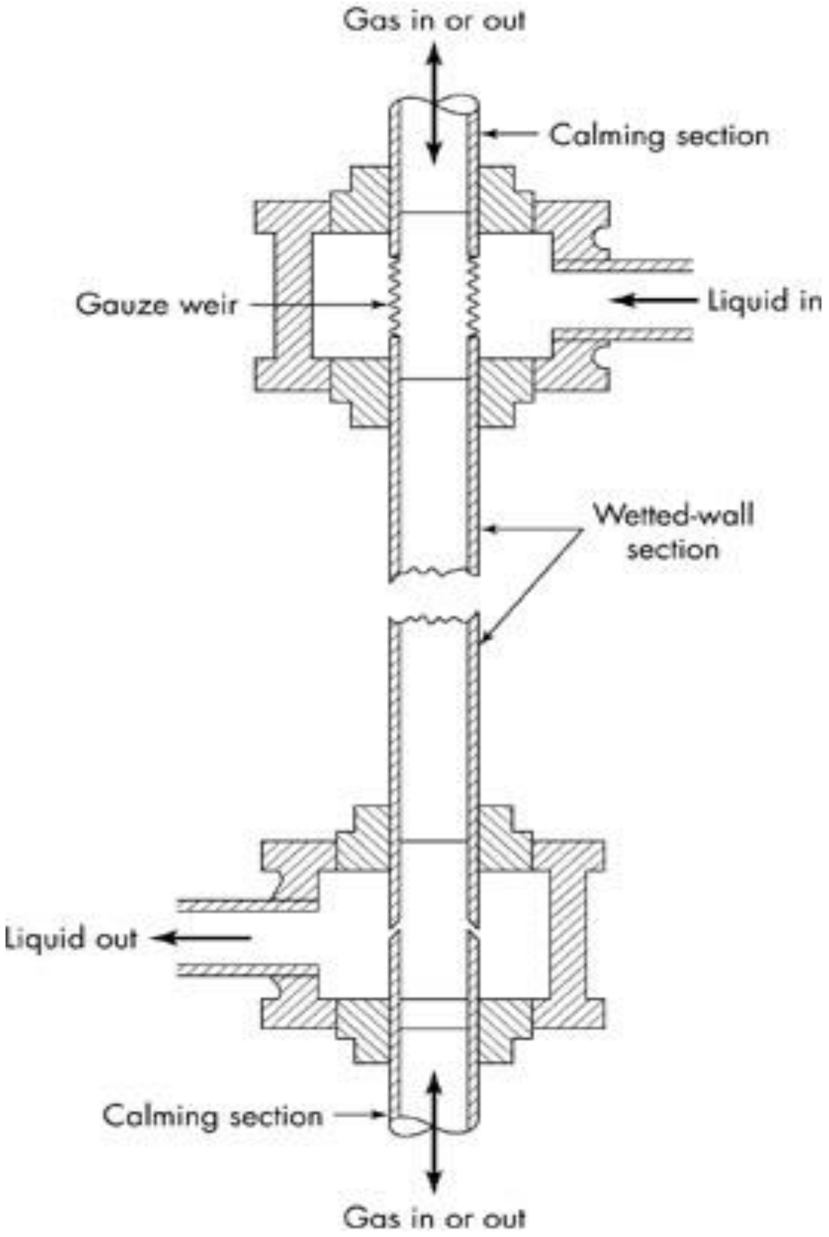

Figure 15 Wetted-wall tower

- Generally, the gas enters the bottom of the tower and flows <u>countercurrent</u> to the liquid, but parallel flow (concurrent) can also be used.

- Experiments were conducted for obtaining the numerical values of c_A or x_A. These values can then be used to calculate the mass transfer coefficient.

- Measurement of the rate of evaporation of the liquid into the gas stream over the known surface permits calculation of the mass transfer for the gas phase.

- The use of different gases and liquids provides variation of Schmidt number, Sc.

- **Mass transfer coefficient, *k* would depend on:**
  1) **Diffusivity, D_{AB}**
  2) **Velocity, υ**
  3) **Viscosity, μ**
  4) **Density, ρ**
  5) **Linear dimension, *D***

or: $$k = \psi(D_{AB}, D, \upsilon, \mu, \rho)$$

- **Dimensional analysis gives:**

$$\frac{k_c D}{D_{AB}} = \psi_1\left(\frac{DG}{\mu}, \frac{\mu}{\rho D_{AB}}\right) = \text{Sherwood number, Sh} \qquad \textbf{.....(93)}$$

where: $G = \upsilon\rho$

Mass transfer with flow inside pipes

- **Correlations for mass transfer to the inside wall of a pipe is given by Sherwood number, Sh:**

a) <u>For laminar flow (Re < 2100)</u>:

$$\mathrm{Sh} = 1.76\,\mathrm{Gz'}^{1/3}$$ **…..(94)**

where:

$$\text{Graetz number, } \mathrm{Gz'} = \frac{\dot{m}}{D_{AB} L \rho} = \frac{\pi}{4}\,\mathrm{Re}\,\mathrm{Sc}\,\frac{D}{L}$$ **…..(95)**

*** Recall:** $\boxed{\mathrm{Sc} = \dfrac{\mu}{\rho D_{AB}}}$ $\boxed{\mathrm{Re} = \dfrac{D\upsilon\rho}{\mu}}$

b) For turbulent flow (Re > 2100):

$$\mathrm{Sh} = 0.023\mathrm{Re}^{0.8}\,\mathrm{Sc}^{1/3}\left(\frac{\mu}{\mu_w}\right)^{0.14} \qquad \text{.....(96)}$$

The term (μ /μ_w) is usually about 1.0 for mass transfer, hence can be omitted from Eq. (96).

c) For flow inside wetted-wall towers:

Data for evaporation of several liquids in wetted-wall towers were correlated with slightly higher exponents for both Re and Sc numbers:

$$\mathrm{Sh} = 0.023\mathrm{Re}^{0.81}\,\mathrm{Sc}^{0.44} \qquad \text{.....(97)}$$

A correlation for mass transfer at high Schmidt number (430 to 100000) was obtained by measuring the rate of solution of tubes of benzoic acid in water and viscous liquid:

$$\mathrm{Sh} = 0.0096\,\mathrm{Re}^{0.913}\,\mathrm{Sc}^{0.346} \qquad \text{…..(98)}$$

Example :

a) What is the effective thickness of the gas film for the evaporation of water into air in a 2-in.-diameter wetted-wall column at a Reynold's number of 10,000 and a temperature of 40°C?
b) Repeat the calculation for the evaporation of ethanol under the same conditions. At 1 atm, the diffusivities are 0.288 cm^2/s for water in air and 0.145 cm^2/s for ethanol in air.

Solution:

For air at 40°C,

From Appendix 8 (McCabe, Smith and Harriott):

$$\mu = 0.0186\,\mathrm{cP}$$

$$\frac{\mu}{\rho} = \frac{1.86 \times 10^{-4}\,\mathrm{g/cm\cdot s}}{1.129 \times 10^{-3}\,\mathrm{g/cm^3}} = 0.165\,\mathrm{cm^2/s}$$

a) For the air-water system:

$$\mathrm{Sc} = \frac{\mu}{\rho D_{AB}} = \frac{0.165}{0.288} = 0.573$$

From Eq. (97):

$$\mathrm{Sh} = 0.023(10000)^{0.81}(0.573)^{0.44} = 31.3$$

In the film theory, from Eq. (77):

$$k_c = \frac{D_{AB}}{z_T}$$ **and from Eq. (93)** $$\mathrm{Sh} = \frac{k_c D}{D_{AB}}$$

Therefore:

$$Sh = \frac{D}{z_T} \quad or \quad z_T = \frac{2.0\,in.}{31.3} = 0.064\,in.$$

b) For the air-ethanol system:

Similar to a), determine the Sc and Sh numbers:

$$Sc = \frac{0.165}{0.145} = 1.14$$

$$Sh = 0.023(10000)^{0.81}(1.14)^{0.44} = 42.3$$

Finally, calculate the effective thickness of the gas film:

$$z_T = \frac{2.0\,in.}{42.3} = 0.047\,in.$$

Note that thickness, z_T become smaller as the diffusivity decreases with mass transfer coefficient, k_c.