Permeation dryer

The selective and continuous removal of water vapour is performed by leading the flue-gas through a tube. Water vapour is absorbed through the tubing walls and moves through it. Dry purge gas is flowing at the outside of the drying-tube in the opposite direction and carries the water vapour away. Virtually all elements of the flue-gas sample remain unchanged, only the water vapour is removed. The drying effect is relative to the difference in vapour pressure between the gas outside the tube and the wet gas inside.

Gas permeation is the term used to describe a membrane separation process using a non-porous semi-permeable membrane. In this type of process, a gaseous stream is separated into permeating and non-permeating streams. The non-permeating stream is generally called the non-permeate in gas separations terminology. Transport occurs by a solution diffusion mechanism, and membrane selectivity is based on the relative permeation rates of the components through the membrane. Each gaseous component transporting through the membrane has a characteristic permeation rate that is a function of the ability to diffuse through the membrane material. The mechanism for transport is based on solubility and diffusion. The two relationships upon which the equations are based are Fick's law for diffusion and Henry's law for solubility.

Diffusive flux through the membrane can be expressed by Fick's Law related to the membrane system as given by:

$$J_i = \frac{D_i}{L}\left(C_{im1} - C_{im2}\right) \qquad \text{(I)}$$

Where: J_i : flux of component i (mole/m^2/s)
D_i : diffusivity of component i (m^2/s)
L : thickness of the membrane (m)
C_{im1}: concentration of component i inside membrane on feed side (mole/m^3)
C_{im2}: concentration of component i inside membrane on permeate side (mole/m^3)

From Henry's Law:

$$C_{im} = S_i * p_i \qquad \text{(II)}$$

Where, S_i : solubility constant for component i in the membrane (mol/m^3.Pa)
p_i : partial pressure of component i in the gas phase (Pa)

Permeation through the membrane is a function of solubility and diffusivity:

$$P_i = D_i * S_i \qquad \text{(III)}$$

Separation efficiency a_{ij} is based on the different rates of permeation of the gas components, data that is not commonly available:

$$a_{ij} = \frac{P_i}{P_j} \qquad \text{(IV)}$$

An experimental separation factor a^*_{ij} is frequently used to quantify the separation of a binary system of components i (oxygen) and j (nitrogen), where C_p and C_r represent molar concentrations in the permeate and retentate (non-permeate) streams, respectively. The separation factor can also be defined in terms of C_p and C_f, i.e., concentrations in the permeate and feed streams, respectively [1, 4]. These relationships can be written in terms of mole fractions x_p, x_r and x_f, which is more convenient in this experiment since the oxygen analyzers measure concentrations in mole % .

$$a'_{ij} = \frac{C_{ip}/C_{jp}}{C_{ir}/C_{jr}} = \frac{x_{ip}/x_{jp}}{x_{ir}/x_{jr}} \qquad \text{(Va)}$$

$$a''_{ij} = \frac{C_{ip}/C_{jp}}{C_{if}/C_{jf}} = \frac{x_{ip}/x_{jp}}{x_{if}/x_{jf}} \qquad \text{(Vb)}$$

Recovery is defined by the equations below, where Q_p, Q_r and Q_f represent the volumetric flow rates of permeate (or non-permeate) and feed streams, respectively (m^3/s).

$$Recovery\ of\ O_2 = \frac{Q_p C_{O_2,p}}{Q_f C_{O_2,f}} \qquad \text{(VIa)}$$

$$Recovery\ of\ N_2 = \frac{Q_r * C_{N_2,r}}{Q_f * C_{N_2,f}} \qquad \text{(VIb)}$$

Stage cut defines the ratio of permeate flow rate to total feed flow rate. This assumes that both concentrations and volumetric flow rates are measured at atmospheric pressure in both the permeate and the non-permeate streams.

$$Stage\ Cut = \frac{Q_p}{Q_p + Q_r} \qquad \text{(VII)}$$

The total flux of a component, J_i may be calculated from the expression below:

$$J_i = \frac{Q_{i,p}\,\rho}{n\,A} \qquad \text{(VIII)}$$

Where, Q_{ip} : volumetric flow rate of species i in the permeate (m^3/sec).

ρ : density of permeate (mole/m^3).

A : area of membrane (m^3)

n : number of modules used.