Flow of Fluids through Granular Beds and Packed Columns

1- INTRODUCTION

The flow of fluids through beds composed of stationary granular particles is a frequent occurrence in the chemical industry and therefore expressions are needed to predict pressure drop across beds due to the resistance caused by the presence of the particles .

For example :

1- fixed bed catalytic reactors, such as $SO_2 - SO_3$ converters ,
2- drying columns containing silica gel or molecular sieves , gases are passed through a bed of particles .
3- gas absorption into a liquid, the gas flows upwards against a falling liquid stream, the fluids being contained in a vertical column packed with shaped particles .
4- filtration of a suspension, liquid flows at a relatively low velocity through the spaces between the particles which have been retained by the filter medium and , as a result of the continuous deposition of solids .

2-Flow of a single fluid through a granular bed

2.1. Darcy's law and permeability

The average velocity, as measured over the whole area of the bed, was directly proportional to the driving pressure and inversely proportional to the thickness of the bed

$$U = K \frac{-\Delta P}{L} \qquad \text{Darcy's law} \text{ -----------(1)}$$

Where :

$-\Delta P$: is the pressure drop across the bed .

L : is the thickness of the bed,

U : is the average velocity of flow of the fluid, defined as $(1/A)(dV/dt)$,
A : is the total cross sectional area of the bed,
V : is the volume of fluid flowing in time t, and
K : is a constant depending on the physical properties of the bed and fluid.

Eq.(1) could be expressed as :

$$U = K\frac{\Delta P}{L} = B\frac{\Delta P}{\mu L}$$

Where :
μ : is the viscosity of the fluid
B : is termed the permeability coefficient for the bed, and depends only on the properties of the bed.

The value of the permeability coefficient is frequently used to give an indication of the ease with which a fluid will flow through a bed of particles or a filter medium. Some values of B for various packings , are shown in Table 4.1, (p193 , vol II) and it can be seen that B can vary over a wide range of values. It should be noted that these values of B apply only to the laminar flow region .

2.2. Specific surface and voidage

The specific surface area of the bed S_B : is the surface area presented to the fluid per unit volume of bed when the particles are packed in a bed. Its units are $(\text{length})^{-1}$.

$$S_B = \frac{Surface\ area\ presented\ to\ the\ fluid}{volume\ of\ bed}$$

voidage (porosity) of the bed (e) : is the fraction of the volume of the bed not occupied by solid material and is termed the fractional voidage, or porosity. It is dimensionless. Thus the fractional volume of the bed occupied by solid material is $(1 - e)$.

$$e \text{ or } (\varepsilon) = \frac{\text{total volume of column} - \text{volume of particles}}{\text{totoal volume of column}}$$

specific surface area of the particles (S) : is the surface area of a particle divided by its volume. Its units are again (length)$^{-1}$

$$S = \frac{surface\ area\ of\ particle}{volume\ of\ particle}$$

For a sphere, for example:

$$S = \frac{\pi\, d^2}{\frac{\pi}{6} d^3} = \frac{6}{d}$$

$S \neq S_B$
$S_B = S(1 - e)$

Notes :

- for a given shape of particles , (S) increases as the particle size is reduced .
- as (e) is increased , the flow through the bed becomes easier and so the permeability coefficient (B) increases .
- If the particles are randomly packed , then (e) should be approximately constant through the bed and the resistance to flow the same in all directions .

- Often near containing walls , (e) is higher , and corrections for this should be made if the particle size is a significant fraction of the size of the containing vessel .