Ex : A gas of density p = 1.25 kg/m^3 and dynamic viscosity of 1.5 * 10^{-5} Pa s(kg/m.s) flows steadily through a bed of spherical particles 5mm in diameter . The bed has a height of 3.00 m and a voidage of 0.33 . The linear approach velocity is 3*10^{-2} m/s . Calculate the pressure drop through the bed using :

a) Kozeny's Eq.
b) Carman's Eq.
c) Ergun Eq.

a) $$U = \frac{e^3}{k\,s^2(1-e)^2} \cdot \frac{\Delta p}{\mu L}$$

$$3 * 10^{-2} = \frac{0.33^3}{5(\frac{6}{d})^2(1-.33)^2} \cdot \frac{\Delta p}{3*1.5*10^{-5}} \rightarrow \Delta p = 116.64 \ {}^{N}/_{m^2}$$

b)

$$\frac{R_1}{\rho U_1^2} = \frac{e^3}{S(1-e)} \cdot \frac{\Delta p}{\rho U_1^2 L}$$ carman's Eq. to determine Δp

$$\frac{R_1}{\rho U_1^2} = 5Re_1^{-1} + 0.4Re_1^{-0.1}$$

$$\frac{R_1}{\rho U_1^2} = 5(\frac{\rho U}{s(1-e)\mu})^{-1} + 0.4(\frac{\rho U}{s(1-e)\mu})^{-0.1}$$

$$= 5(\frac{1.25*3*10^{-2}}{\frac{6}{.005}*(1-.33)*1.5*10^{-5}})^{-1} + 0.4(\frac{1.25*3*10^{-2}}{\frac{6}{0.005}*(1-0.33)*1.5*10^{-5}})^{-0.1}$$

=1.9569

Sub. In $\frac{R_1}{\rho U_1^2} = \frac{e^3}{S(1-e)} \cdot \frac{\Delta p}{\rho U_1^2 L}$

$$\Delta p = 142.658 \ N/m^2$$

c) $$\frac{R_1}{\rho U_1^2} = 4.17Re_1^{-1} + 0.29$$

Sub. In : $\frac{R_1}{\rho U_1^2} = \frac{e^3}{S(1-e)} \cdot \frac{\Delta p}{\rho U_1^2 L}$

$\Delta p = 118.42 \ N/m^2$

Dependence of (K") on structure of bed

1-**Tortuosity** : Carman has shown that:

$$k" = (\frac{L'}{L})^2 * k_0$$

Where :

(L'/L) : is the tortuosity and is a measure of the fluid path length through the bed compared with the actual depth of the bed,

K_0 : is a factor which depends on the shape of the cross-section of a channel through which fluid is passing.

K_0 =2.0 for streamline flow through circular pipe .

K_0 = 2.65 for streamline flow through a rectangle where the ratio of the lengths of the sides is 10 : 1. Carman has listed values of K_0 for other cross-sections .

2-Wall effect : In a packed bed , the particles will not pack as closely in the region near the wall as in the centre of the bed, so that the actual resistance to flow in a bed of small diameter is less than it would be in an infinite container for the same flowrate per unit area of bed cross-section. A correction factor (f_w) for this effect has been determined experimentally by Coulson . This takes the form :

$$f_w = \left[1 + \frac{1}{2}\left(\frac{S_c}{S}\right)\right]^2$$

Where :

S_c : is the surface of the container per unit volume of bed.

Equation (5) then becomes :

$$U = \frac{1}{k''} \cdot \frac{e^3}{s^2(1-e)^2} \cdot \frac{\Delta p}{\mu L} \cdot f_w \qquad \text{-------------------(6)}$$

The values of (K") shown on Figure 4.2 ,vol.II

packed columns

1- Fluid flow in packed columns

a) Pressure drop:

It is important to be able to predict the drop in pressure for the flow of the two fluid streams through a packed column . Fig.(4.16 , p223 , vol. II)

- The point X is known as the loading point, and point Y as the flooding point for the given liquid flow
- Over this section XY the liquid flow is interfering with the gas flow and the hold-up of liquid is progressively increasing

- It is not practicable to operate under flooding conditions, and columns are best operated over the section XY. Since this is a section with a relatively short range in gas flow, the safe practice is to design for operation at the loading point X.

Rose and Young correlated their experimental pressure drop data for Raschig rings by the following equation:

$$\Delta p_w = \Delta p_d \left(1 + \frac{3.3}{d_n}\right)$$

Where:

Δp_w : is the pressure drop across the wet drained column.

Δp_d : is the pressure drop across the dry column, and

d_n : is the nominal size of the Raschig rings in (mm) .

This effect will thus be most significant for small packings.

There are several ways of calculating the pressure drop across a packed column when gas and liquid are flowing simultaneously and the column is operating below the loading point.
One approach is to calculate the pressure drop for gas flow only and then multiply this pressure drop by a factor which accounts for the effect of the liquid flow. Equation:

$$\frac{R_1}{\rho U_1^2} = 5Re_1^{-1} + Re_1^{-0.1}$$

may be used for predicting the pressure drop for the gas only, and then the pressure drop with gas and liquid flowing is obtained by using the correction factors for the liquid flow rate given by SHERWOOD and PIGFORD.

Another approach is that of MORRIS and JACKSON who arranged experimental data for a wide range of ring and grid packing's in a graphical form convenient for the calculation of the number of velocity heads N lost per unit height of packing. N is substituted in the equation:

$$-\Delta p = \frac{1}{2}.N.\rho_G.U_G^2.L$$

Where:
$-\Delta p$ = pressure drop .
ρ_G = gas density.
U_G^2 = gas velocity, based on the empty column cross-sectional area .
L= height of packing .