Determination of Transition Length in Flow Through Porous Sand Material.

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ABSTRACT

A transition length is normally observed when fluid flows through a conduit before laminar flow is accomplished. This work examined a situation whereby porous materials were filled into the conduit and fluid was made to flow through. An attempt was made to determine this transition length for flow of water through riverbed sand of varying porosities filled into a horizontal cylindrical pipe of diameter 0.345×10^{-2} m with piezometric water head, set at $0.06m$. The transition length was observed to be constant for the samples considered and it occurred at $0.60m$ from the point of entrance; nevertheless, values of pressure at this point increases with increase in porosity.

(Keywords: transition length, porosity, conduit, piezometric, laminar flow)

INTRODUCTION

According to Langhaar, 1942 [1], a transition length must be observed when fluid flow from a reservoir to a pipe. If the flow enters the pipe from a reservoir through a well-rounded entrance, the velocity at first is almost uniform over the cross-section. The action of wall shear stress (as the velocity must be zero at the wall) is to slow down the fluid near the wall [2, 3, 4]. As a consequence of continuity, the velocity must then increase in the central region. The transition length/entry length L' for the characteristic parabolic velocity distribution to develop is a function of the Reynolds number. Langhaar (1942) developed the theoretical formula:

$$\frac{L'}{D} = 0.058R$$

where R is Reynolds number and D is the diameter of the pipe. The flow regime within this region is not laminar, it is after this length/distance that laminar flow is attained and at which point Darcy law applies. By implication, when fluid flows into a pipe Darcy law only applies to the middle segment of the flow [9]; the first segment has the possibility of being turbulent and the last segment being affected by end factor.

MATERIALS AND METHODS

Basic Theory

Generally, the Darcy equation is given as [4]:

$$V_l = \frac{k}{\mu}\nabla(p - \rho g z) \qquad (1)$$

which can be re-expressed as;

$$V_l = \frac{k}{\mu}\left(\frac{dp}{dl} - \rho g\frac{dz}{dl}\right) \qquad (2)$$

where V_l is the volume flux across a unit area of the porous medium in unit time along flow path l; $\frac{dp}{dl}$ is the pressure gradient along l at the point to which V_l refers;

$$\frac{dp}{dl} = \sin\theta$$

where q is the angle between l and the horizontal. It can also be deduced from (2) that;

$$\frac{dp}{dl} = \rho g \sin\theta - V_l\frac{\mu}{k} \qquad (3)$$

For an horizontal flow:

$$\frac{dz}{dl} = 0$$

If a sample is completely saturated with an incompressible fluid, then;

$$\frac{dp}{dl} = -V_l \frac{\mu}{k} \qquad (4)$$

m is the viscosity, k permeability and V_l is the Volume flux across a unit area of the porous medium in unit time along flow paths [5].

Four samples of Riverbed sand were prepared having porosities *0.361, 0.375, 0.446* and *0.467*. A cylindrical plastic material of diameter 3.45×10^{-2} *m* and length *2.0m* was drilled at an interval of *0.2m* along a straight axis. Each drilled hole has a diameter of *4mm* and with the use of plasticine, the holes were blocked. One end of the pipe was screened and blocked. Placing it vertically, it was filled with water half way up. Prepared samples were soaked overnight to prevent 'swelling' which may be as a result of the possibility of the presence of microorganism [6, 7].

The samples were poured into the cylindrical tube half-filled with water so as to eliminate trapped air which will obviously affect free flow of water. This precaution is also very necessary so that uniform compaction may be ascertained in all the samples [8]. The other upper end is then screened so that we have a column of pipe that is completely filled with porous sand. With an elbow joint, a similar pipe drilled at *0.06m* from the axis of the *2.0 m* length pipe is joined and we have an L-shaped structure of piezometric height of *0.06m.*

There is inflow from a reservoir into the pipe and to maintain a constant water head (0.06m) a pipe is connected at the hole drilled at that point which drains off excess water. The waterhead was maintained, purposely because of the measuring range of the manometer used. The measuring range of the manometer used could not be exceeded by pressure measured at points close to the end of the pipe.

The values of pressure at each point were obtained from the waterhead read off from the manometer at that point.

RESULTS AND DISCUSSION

In Figures 1-4 pressure increases along the direction of flow from the entry point into the pipe. An optimum is reached at 0.6*m* down the flow line. This region may be described as a segment the fluid must flow before the parabolic curve is properly and completely built up. Within this region, the flow can be said to be fairly turbulent possibly because of the surge of the influx vis-à-vis the existing piezometric height. After this point of inflexion (Figures 1-4), pressure decreases with distance of flow. Figures 5-8 show the segment truncated and the result satisfies Darcy's law, using equation (4) V_l can be calculated from the gradient of the curves and its ratio to the porosity of the medium gives the seepage velocity. It is interesting to note that despite the constancy of this distance (Transition length) in all the samples, the value of pressure increases as the porosity increases. The pressure were found to be 446.2, 451.2, 468.8 and 475.6 Pa (Table 2) for samples A, B, C, and D respectively and this is represented in Figure 9.

The optimal or peak value of pressure (plotted from Table 1) were obtained as shown in Table 2; it revealed that the peak values of pressure occurred at constant distance of flow (0.6*m*) from the point of entrance to that point. Figure 10 shows a graph of this distance against porosity and it is clearly constant indicating that the transition length is independent of the porosity of the medium.

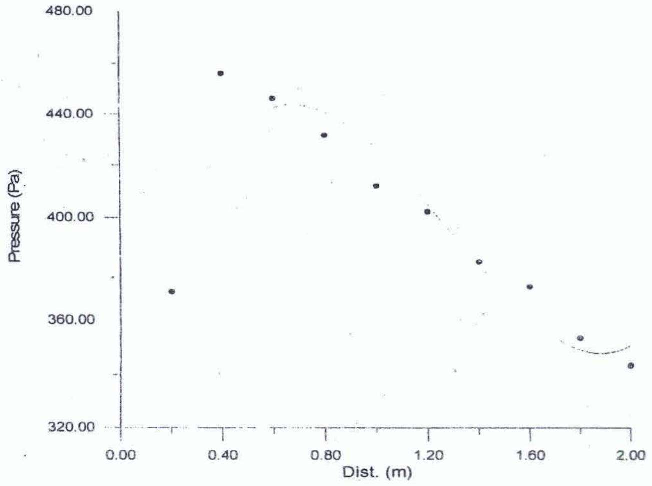

Figure 1: Graph of Pressure versus Distance Sample A.

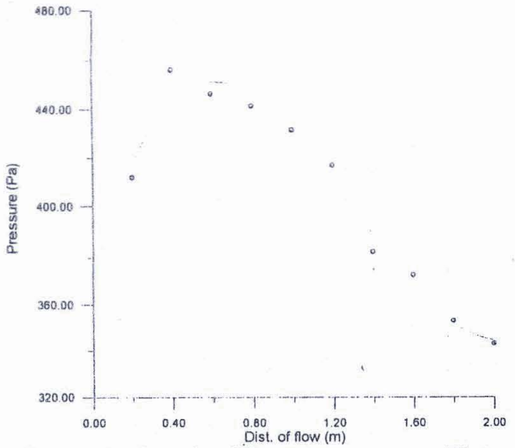

Figure 2: Graph of Pressure versus Distance for Sample B.

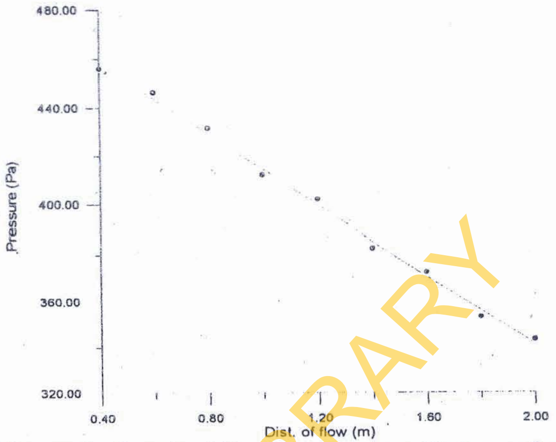

Figure 5: Graph of Pressure versus Distance for Sample A, Neglecting the Entry Length.

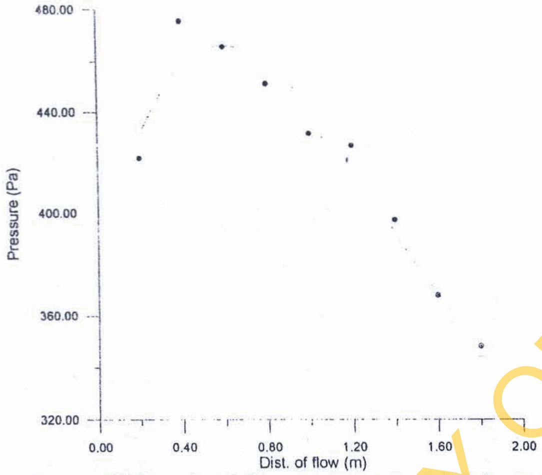

Figure 3: Graph of Pressure versus Distance for Sample C.

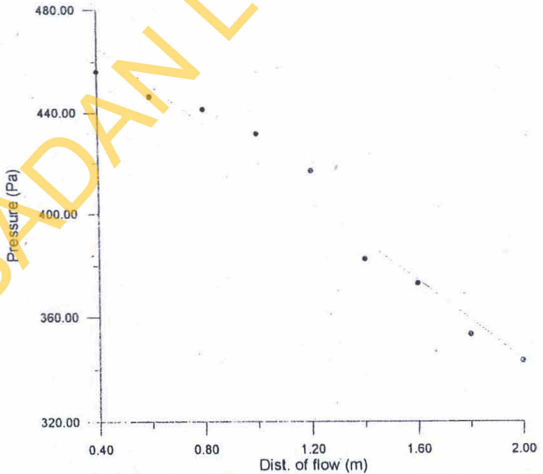

Figure 6: Graph of Pressure versus Distance for Sample B, Neglecting the Entry Length.

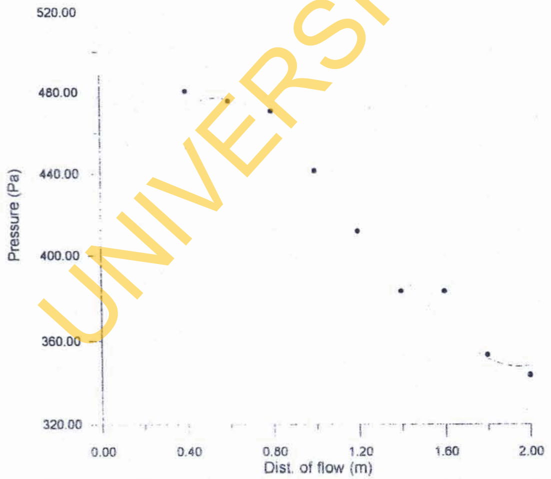

Figure 4: Graph of Pressure versus Distance for Sample D.

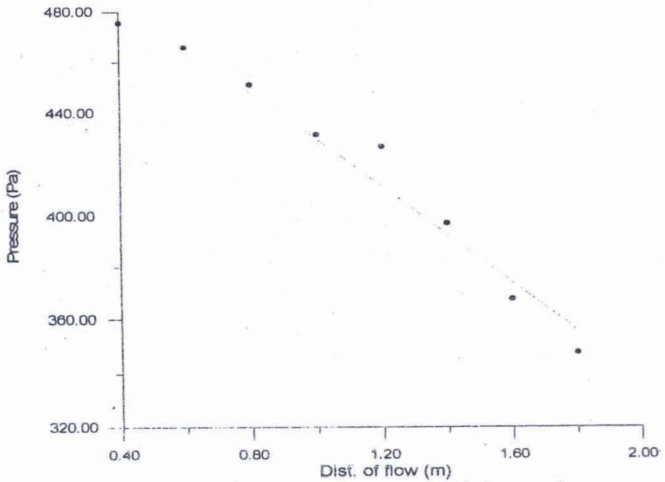

Figure 7: Graph of Pressure versus Distance for Sample C, Neglecting the Entry Length.

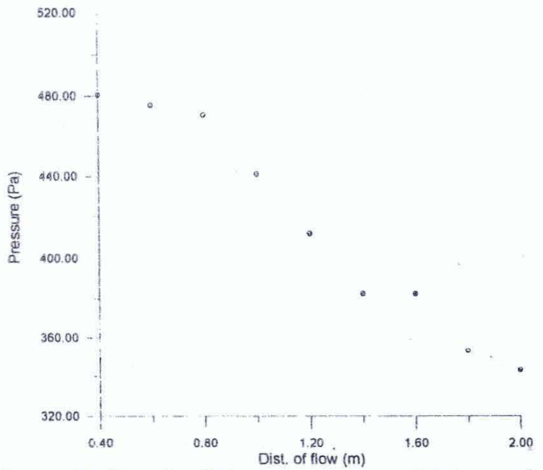

Figure 8: Graph of Pressure versus Distance for Horizontal Flow for Sample D, Neglecting the Entry Length.

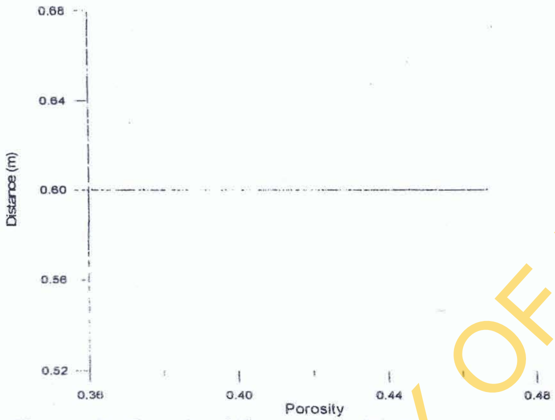

Figure 9: Graph of Transition Distance versus Porosity.

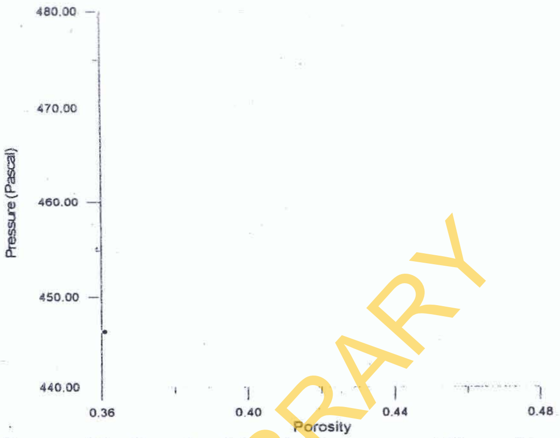

Figure 10: Graph of Peak Pressure at Transition Length/Distance versus Porosity.

CONCLUSION

Transition length exists in flows in porous media as it had been confirmed in flows through conduit. It was observed that Darcy law does not apply in the early segment of the flow and after this segment, pressure decreases along the line of flow and the corresponding value of pressure from one point to the other increases as porosity increases. The transition length is independent of the porosity of the medium but the peak pressure varies linearly, that is, increases with increase in porosity. The entry/transition length was obtained to be 0.60m and the diameter of the pipe was 3.45 x 10^{-2}*m* with piezometric height of 0.060*m*.

Table 1: Values of Pressure and their Corresponding Distances for samples A-D at angle $\theta = 0^c$.

Distance; L (m)	Pre.(Pa);A_0	Pre. (Pa);B_0	Pre. (Pa) -C_0	Pre. (Pa);D_0
0.20	370.6914	411.8793	421.6859	444.2412
0.40	456.0092	456.0092	475.6225	480.5258
0.60	446.2026	446.2026	465.8159	475.6225
0.80	431.4926	441.2993	451.1059	470.7192
1.00	411.8793	431.4926	431.4926	441.2993
1.20	402.0727	416.7826	426.5893	411.8793
1.40	382.4594	382.4594	397.1693	382.4594
1.60	372.6527	372.6527	367.7494	382.4594
1.80	353.0394	353.0394	348.1361	353.0394
2.00	343.2328	343.2328		343.2328

* $A_0, B_0, C_0, D_0,$ represents samples at angle $\theta = 0^c$

Table 2: Peak Value of Pressure at Constant Distance of Flow and the Porosity of Each Sample.

Sample	Porosity	Distance of flow at peak value (m)	Pressure (Pa) at peak value
A	0.361	0.6	446.2
B	0.375	0.6	451.2
C	0.446	0.6	465.8
D	0.467	0.6	475.6

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