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The Effects of Porosity and Angle of Inclination on the Deflection of Fluid Flow in Porous Media

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Abstract: The movement of contaminated fluid from a solid waste landfill into a portable water aquifer located beneath is an example of unwanted underground flow. With the problem of limited portion of land available for building construction in the cities, coupled with the rise in price of good and accessible land, there is a need for quick and urgent solutions to environmental pollution that may be resulted from this problem. In this research, a laboratory set-up consisting of a big transparent cylindrical pipe 108.5 cm long with radius 2.23 cm was used as inlet pipe and five small equal transparent cylindrical pipes with radii 0.3 cm were used as outlets, which were joined to the circular plastic plate on the top of the inlet pipe at different angles ranged from 0-90° from a normal point. The inlet pipe and outlets pipes were filled with samples of soil of different porosities and titled at different angles of inclination. The volume of water discharged was measured directly with measuring cylinder from the set-up in each case. The volumetric flow rate and volume flux were computed from the values of volume discharged. These were done in order to determine how the arrangement of porous material of different porosities with a particular angle of inclination can influence the deflection of fluid flow from its linear direction. This is sequel to its practical applications in designing a construction with a cross-section of soils in deflecting contaminated fluid from septic tank to different directions from the source of water within the same small portion of land. It was observed that angle of inclination does not have a significant effect on the deflection of fluid but volume flux increases with increasing angle of inclination. Also, the greater the difference in the porosity of the cross-section of the media in which the fluid is flowing the greater the volume flux. However, the most suitable arrangement of cross-section of soils for deflection of fluid to higher angles from normal is when it flows through a medium of low porosity to that of higher porosity.

Key words: Porosity, inclination angle, volume flux, deflection, outlet angle

INTRODUCTION

The contamination of soil and underground water with mineral oils (hydrocarbon) or mineral oil-based product is among the common negative effects of industrial society (Seitinger and Schindlbauer, 1994). Contamination comes from a variety of source, ranging from underground petrol tank at filling stations to nuclear weapons facilities. Industrial plants and garbage dump can also, cause environmental problems (Breadhoeft, 1996).

Control of the water content, control of the movement of water and prevention of damaged caused by the movement of water in soils are vital aspects of soil engineering (Sowers and Sower, 1970). Soil mass through which seepage occur is man-made, like septic tank or sewage disposal facility. The permeability can be reduced by the proper selecting materials, for example, mixing a small amount of clay with the sand (Protective filter) used for construction can reduce the permeability greatly (Sowers and Sower, 1970). The study of seepage patterns in cross-section with soils of more than one permeability is one of the most worthwhile and rewarding applications especially in selecting a protective filter or seepage control in man-made constructions (Popoola *et al*., 2008).

The permeability is the most important physical property of a porous medium, which is a measure of the ability of a material to transmit fluid through it. The application of Darcy's law enables hydraulic conductivity to be determined, from which permeability can be computed by using Hubert King relation (Domenico and Schwartz, 2000). The flow of fluid in

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porous media is governed by Darcy' law. This law holds when, the water particles move in a smooth, orderly procession in the direction of flow that is laminar (Barer *et al.*, 1972). The porosity of a porous medium depends on grain size distribution, state of grain aggregate or arrangement, shape of the grains, continuity and tortuosity of the pores (Brain and Robert, 2002). The determination of seepage velocity of fluid in the porous media which is one of the major parameter in applications of Darcy's law in solving environmental problems depends strongly on the porosities of the media.

The purpose of this study is to improve the achievements made so far by Darcy. The objectives are to investigate how volume flow rate and volume flux of fluid are affected when it flows through porous media of different porosities of varying angles of inclination. These are important parameters in knowing the deflecting ability and flow rate to higher angles from normal direction when, it flows through cross-section of soil different porosities. These are necessary for designing a seepage control in such a way that septic tank can be constructed along with the borehole or well safely without the source of water being contaminated.

Theory: Hydraulic conductivity K is the specific discharge per unit hydraulic gradient. It expresses the ease with which a fluid is transported through void space. It depends on the solid matrix and fluid properties. The permeability k, of a porous medium is its fluid capacity for transmitting a fluid under the influence of a hydraulic gradient (Sherwani, 1980).

It depends solely on the geometrical structure of the material, that is porosity, grain size distribution, turtosity and connectivity.

Fluid flow through porous material of permeability k, by Darcy is generally written as:

$$V_s = -\frac{K}{\mu}(P - \rho g) \quad \text{(Frick and Tailor, 1978)} \qquad (1)$$

Which can be expressed as:

$$V_s = -\frac{K}{\mu}\left(\frac{dp}{ds} - \rho g\frac{dz}{ds}\right) \qquad (2)$$

Where:

S = Distance in the direction of flow, always positive

V_s = Volume flux across a unit area of the porous medium is unit time

Z = Vertical coordinate, considered downward

ρ = Density of the fluid

g = Acceleration of gravity

dp/ds = Pressure gradient along s at the point to point to what V_s refers

μ = Viscosity of the fluid

k = Permeability of the medium

dz/ds = Sin θ, where θ is the angle between and the horizontal V_s

Equation 2 can be expressed further as follows:

$$V_s = -\frac{K}{\mu}\left(\rho g\frac{dp}{ds} - \frac{dz}{ds}\right) \qquad (3)$$

$$\frac{V_s\mu}{k} = \left(\rho g\frac{dz}{ds} - \frac{dp}{ds}\right) \qquad (4)$$

$$\frac{dz}{ds} = \operatorname{Sin}\theta \qquad (5)$$

Then,

$$\frac{V_s\mu}{k} = \rho g\sin\theta - \frac{dp}{ds} \qquad (6)$$

$$\frac{V_s\mu}{k} - \rho g\sin\theta = -\frac{dp}{ds} \qquad (7)$$

Integrating both sides

$$\left\{\frac{V_s\mu}{k} - \rho g\sin\theta\right\}\frac{ds}{dp} = \frac{P_2}{P_1} \qquad (8)$$

$$\left\{\frac{V_s\mu}{k} - \rho g\sin\theta\right\} s = P_1 - P_2 = P \qquad (9)$$

$$\frac{V_s\mu}{k} = \frac{P}{S} + \rho g\sin\theta \qquad (10)$$

If a porous medium is completely saturated with an incompressible fluid and is vertical (Fig. 1 and 2) dz/ds = sin90° ($\theta = 90°$, $\sin 90° = 1$)

Then Eq. 10 reduces to

$$\frac{V_s\mu}{k} = \frac{P}{S} + \rho g \qquad (11)$$

$$V_s = \frac{k}{\mu}\left\{\frac{P}{S} + \rho g\right\} \qquad (12)$$

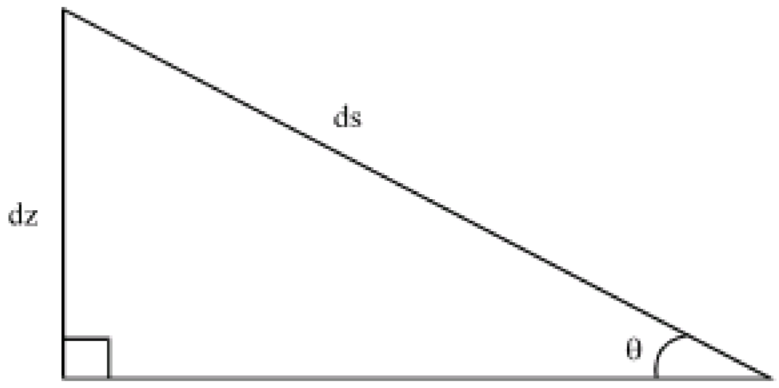

Fig. 1: Illustration of dz/ds

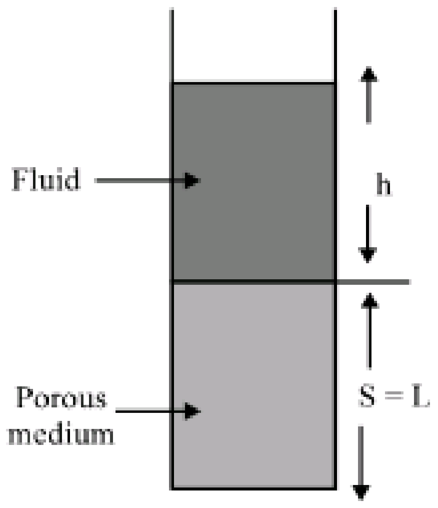

Fig. 2: When θ = 90° with horizontal (vertical flow)

$P = \rho g h$, $S = L$ (Fig. 2)

$$V_s = \frac{k}{\mu}\left\{\frac{\rho g h}{S} + \rho g\right\} \quad (13)$$

$$V_s = \frac{\rho g}{\mu} k\left\{\frac{h}{L} + \rho g\right\} \quad (14)$$

But,

$$K = \frac{\rho g}{\mu} k \quad (15)$$

(Domenico and Schwartz, 2000)

Where:

K = Hydraulic conduct (msec^{-1})
k = Permeability (m^2)
μ = Viscosity of fluid (Nsm^{-2})
ρ = Density of fluid (kgm^{-3})
μ/ρ = Kinematics viscosity (for water) = 1×10^{-6} m^{2}sec^{-1}

The hydraulic conductivity contains properties of both medium and fluid with units msec^{-1} and characterizes the capacity of a medium to transmit water, whereas the permeability with units m^2 characterizes the capacity of the medium to transmit any fluid. The two properties are related by Eq. 15.

By using Eq. 15 in Eq. 14 becomes

$$V_S = K\left\{\frac{h}{L} + 1\right\} \quad (16)$$

$$V_s = q = \frac{Q}{A} = K\left\{\frac{h}{L} + 1\right\} \text{(Jacob and Arnold, 1990)} \quad (17)$$

Where:

Q = Volumetric flow rate (m^3 sec^{-1})
A = Average cross-sectional area perpendicular to the line of flow (m^2)
q = Volume flux (msec^{-1})
h = Head constant (or hydraulic head) (m)
L = Flow path length of sample (m)

Thus, Eq. 17 can be written in simple form as:

$$q = K\left\{\frac{h}{L} + 1\right\} \text{(Ghildyal and Tripathi, 1987)} \quad (18)$$

or

$$q = K\,I \quad (19)$$

Where:

$$i = \left\{\frac{h}{L} + 1\right\} = \text{hydraulic gradient}$$

while the volume flux q, is the volume of water flowing across a unit area of the porous medium in a unit of time along the flow path. It has the units of velocity, but it is not the velocity of the water in the pores because the matrix takes up some of the flow area. The average pore water velocity is termed the seepage velocity, v and is given as:

$$V = \frac{Q}{A\phi} = \frac{q}{\phi} \text{(Jacob and Arnold, 1990)} \quad (20)$$

Where:

V = Seepage velocity (msec^{-1})
q = Volume flux (msec^{-1})
ϕ = Porosity of the media

The maximum pore velocity is a function of the pore geometry and cannot be easily predicted except for simple shapes. However, it can be determined in the laboratory by volumetric method.

Flow through sections of more than one permeability: In some instances, a great deal can be learned by studying seepage patterns in cross sections with soils of more than one permeability, such studies have revealed important shortcomings in some commonly accepted beliefs about seepage and drainage (Cedergreen, 1976).

When, water flows across a boundary between dissimilar soils, the flow line bend in such a way that light ray are refracted in passing from air into water or from air

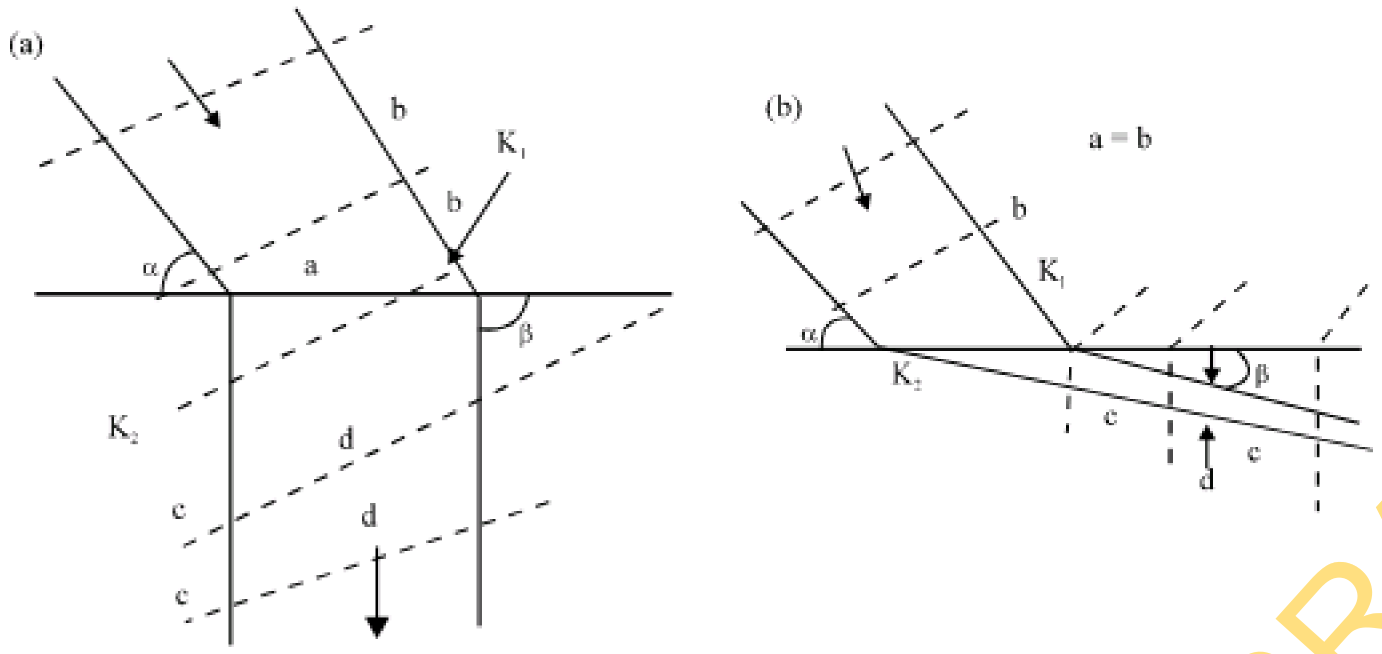

Fig. 3: Transfer conditions at boundaries between soils of different permeabilities (Casagrande, 1937)

into glass. (Cedergreen, 1976). The law of conservation of energy forces all natural phenomena to take the line of least resistance.

Thus, when water flows from a soil of high permeability into a material of lower permeability, the pattern develops in such a way that the flow remains in the more permeable material for the greatest possible distance. Likewise, if the flow is from a material of low permeability into one of higher permeability, it deflects as soon as possible into the material of higher permeability (Cedergreen, 1976). To conserve energy water seeks the easiest paths to travel.

Another way of looking at the behavior of seepage in sections with more than one permeability is the concept that other factors being equal, the higher the permeability, the smaller the area required to pass a given volume of water. Conversely, the lower the permeability, the greater the area required.

In relation to the amount of energy needed to force water through porous media, the higher the permeability, the lower the energy needed and vice versa. In seepage the rate of loss of energy is measured by the steepness of the hydraulic gradient, steep hydraulic gradient should be expected in the zones of low permeability and flats gradients, in zones of high permeability (Cedergreen, 1976).

Deflection of flow lines across boundaries between soils of different permeabilities: The way flow lines deflect when they cross the boundaries between soil of different permeabilities is shown in Fig. 3a and b. The flow lines bend to confirm to the following relationship.

$$\frac{\text{Tan}\,\beta}{\text{Tan}\,\alpha} = \frac{k_1}{k_2} \text{ (Cedergreen, 1976)} \qquad (21)$$

Simultaneously, the areas formed by the intersecting line either elongate or shorten, depending on the ratio of the 2 permeabilities, according to the following relationship,

$$\frac{c}{d} = \frac{k_2}{k_1} \qquad (22)$$

In Fig. 3a the second permeability is lower than the first hence, shortened rectangles are formed in the second.

In Fig. 3b second permeability is greater than the first, so elongated rectangles form in the second materials. The deflection relationship expressed by Eq. 21 should be in mind, however the change is the shapes of areas as expressed by Eq. 22 is extremely useful, as it provides an exact check of the accuracy of flow nets for sections with more than one permeability.

A similar explanation was given by Eagleman and Jamison (1962) for soil layers of different texture. It was observed that if a finer textured soil layer overlying a coarser-textured layer (Fig. 4a), particularly if the boundary between the two layer is fairly sharp, will hold more water against drainage than if its underlain by material of its own texture (Fig. 4b), or a finer-textured layer (Fig. 4c).

This is very noticeable if the coarser-textured layer is a sand, for there will be a sudden change of capillary conductivity at this junction. When, the water lost its interstitial water, so water will only be able to leak out from the finer-texture soil very slowly because of the low capillary conductivity of the sand. It is evident form above explanation that the volume of water discharge can be affected by changes of texture vis-à-vis porosity in the profile (Popoola *et al*., 2008).

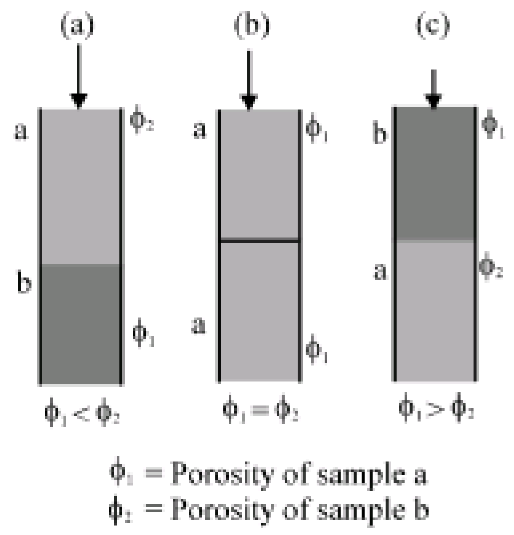

Fig. 4: Change of texture vis-a-vis porosity

MATERIALS AND METHODS

Sample preparation: Sand samples were collected from the riverbed of two different river within the University of Ibadan. Sizeable quantities of these samples were washed and rinsed in order to remove organic particles and unwanted grams are brought to the laboratory. Thereafter, the sand samples sun dried and later placed in an oven. After, the samples were allowed to cool down, the stony particles and peoples were removed. Five different sieves were used to sieve the available sand samples in order to obtain samples of different grain sizes.

Determination of porosity: The porosity of each sample was determined by volumetric approach. In the laboratory measurement of porosity, it is necessary to determine only two basic parameters (bulk volume and grain volume).

$$\text{Bulk volume} = \text{grain volume} + \text{pure volume} \tag{23}$$

$$\text{Total porosity } (\phi) = \frac{\text{Bulk volume - Grain volume}}{\text{Bulk volume}} \tag{24}$$

$$\phi = \frac{\text{Pure volume}}{\text{Bulk volume}} \tag{25}$$

In this research, bulk and grain or matrix volume were determined volumetrically by measured 3 mL of dried sand sample using a 10 mL measuring cylinder. It was ensured that the measuring cylinder was tapped with a solid object and the sand inside get re-arranged and compacted before the value of the volume was recorded. This is necessary in order to maintain steady volume. A similar measuring cylinder was half-filled with water and the volume was noted. The sand was then poured into the water and the final volume of the components of the cylinder (water and sand) is recorded.

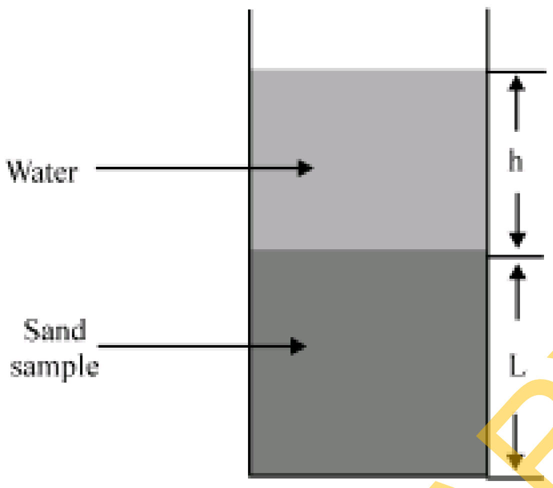

Fig. 5: Sand model for vertical flow head h (Jacob, 2001)

Porosity can be determined as follows:

Volume of sand (bulk volume)	=	A (mL)
Volume of water	=	B (mL)
Volume of mixture of water and sand	=	C (mL)

$$\text{Therefore, total porosity } (\phi) = \frac{\text{Pure volume}}{\text{Bulk volume}} \tag{26}$$

$$= \phi = \frac{(A+B)-C}{A} \text{ (mL)} \tag{27}$$

Determination of hydraulic conductivity and permeability: In an experimental set up in the laboratory, volume flux q, for each sample at different hydraulic gradients was determined. A saturated sand sample was transferred to the transparent cylindrical tube of cross-sectional area $2.69\times10^{-4}\text{m}^2$ (Fig. 5). To ascertain uniform compaction throughout the sample, the screened end was blocked so as to prevent the water passing through when the sample was being transferred. A continuous steady supply of water was fed through, the sand sample samples of length L and at height h a hole was drilled, this enabled the height to be maintained, as excess water got drained through on overflow arrangement. The volume of water discharged Q, through the sample for a period of 60 sec after steady state has been attained at constant head was measured by measuring cylinder. It must be noted that the length L was varied in order to obtain different hydraulic gradients. Measurements were made at hydraulic gradients of i = 1.875, 3.750, 7.500, 15.000 and 30.000, for each sample. The results of their experiment were used to prepare plots of volume flux against hydraulic gradient and the slope of the graph is hydraulic conductivity. The permeability was then computed by using Eq. 15.

Determination of volume flux at different angles of inclination: The experimental set-up consisted of a big transparent cylindrical pipe 108.5 cm long with radius

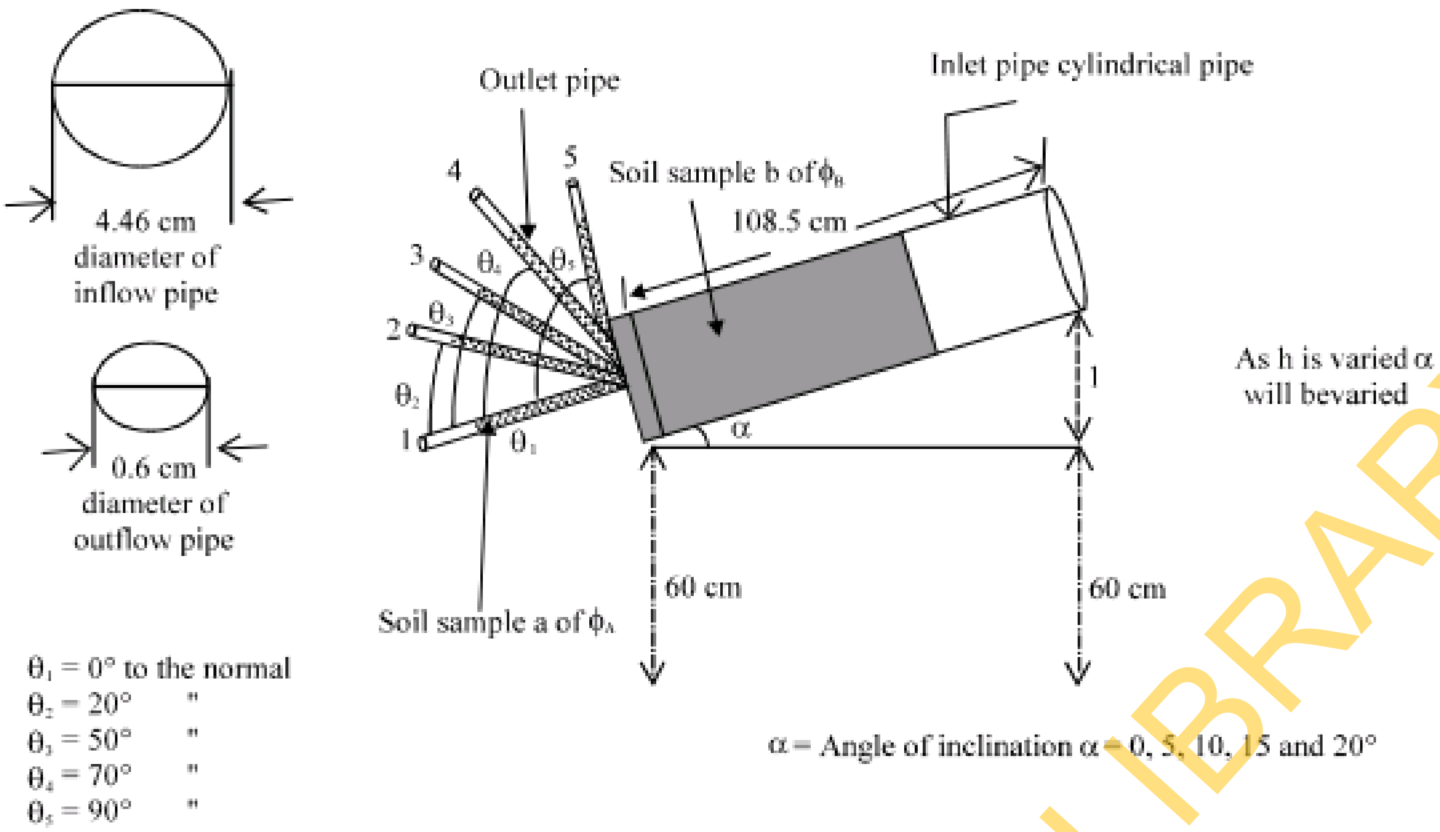

Fig. 6: Experimental set up to determine volume flux at different angles of inclination

2.23 cm as inlet pipe and five small equal transparent cylindrical pipes of length with radii 0.3 cm as outlets (Fig. 6). Each of the outlet pipes was joined to the centre of the circular plastic plate on the top of the inlet pipe at different angles θ of 0, 20, 50, 70 and 90° from the normal point or line. To serve as control experiment, water was allowed to flow through the empty inlet pipe and outlet pipe for a period of 60 sec and the discharged volume of water at each outlet was collected and measured with measuring cylinder. This was done at different tilting angle or angle of inclinationα of 0, 5, 10, 15 and 20°. Thereafter, the inlet pipe and outlet pipes were filled with the same sample at a time and the volume of water discharged through this sample in each outlet was measured for different angle of inclination α. This was repeated for all the samples. Then, all the five outlets were filled with the sample A, which has the lowest porosity, while the inlet pipe was filled with another sample of different porosity. The volume of water discharge from each outlet was measured. This was done at different angle of inclination α in order to know effect of angle of inclination on fluid flow rate for each sample. The sample in the inlet pipe was later changed in turn and the volume of water discharged from the outlets in different cases were collected and measured directly with measuring cylinder. The volume flux q ($\mathrm{msec^{-1}}$) (or specific discharge) was then computed from the volumetric flow rate Q ($\mathrm{m^3sec^{-1}}$) by dividing it with the cross-sectional area 2.83×10^{-5} $\mathrm{m^2}$ of the outlet pipe.

RESULTS AND DISCUSSION

Table 1 shows the porosities, hydraulic conductivities and permeabilities for samples A-E. The samples porosities ranged from 0.250-0.420. The sample E has the highest value, while the sample A has the lowest value. The hydraulic conductivity ranged from 0.46×10^{-4} $\mathrm{msec^{-1}}$ for sample A to 3.29×10^{-4} $\mathrm{msec^{-1}}$ for sample E. The permeability determined from the hydraulic conductivity by using Hubert King relation ranged from 0.47×10^{-11} $\mathrm{m^2}$ for sample A to 3.36×10^{-11} $\mathrm{m^2}$ for sample E. It shows that both hydraulic conductivity and permeability increase with increasing porosity.

Table 1: Values of porosities, hydraulic conductivity and permeability for samples A-E

Sample	Porosity	Hydraulic conductivity $K\times10^{-4}$ ($\mathrm{ms^{-1}}$)	Permeability $k\times10^{-11}$ ($\mathrm{m^2}$)
A	0.250±0.010	0.46	0.47
B	0.333±0.002	1.01	1.06
C	0.364±0.001	1.14	1.16
D	0.400±0.001	1.63	1.67
E	0.420±0.010	3.29	3.36

Table 2 and 3 shows the volume flux at various outlet angles at varying porosity difference for maximum inclination angle used in the experiment. This was done in order to show the effect of porosity difference on the volume flux at various outlet angles, when fluid flow from a lower porous medium to a higher porous medium and vice-versa, respectively. In addition, this will be of help in establishing the relationship that exist between the porosity difference and the total volume flux in each case.

Furthermore, in order to verify the relationship that exist between maximum or optimum volume flux, the highest volume flux in each case was extracted from Table 2 and 3 and shown in Table 4.

The results show that the total volume of water discharged at an angle of inclination 0° was zero for all the cases including the control experiment (when both inlet and outlet pipes were free of porous material). This is in

Table 2: Volume flux at various angles of outlet and porosity difference when fluid flows through A to either B, C, D or E ($\alpha = 20°$)

Angle of outlet θ (degrees)	$\overrightarrow{AB}$, $\phi_d = 0.083$ $q\times10^{-3}$ (msec^{-1})	$\overrightarrow{AC}$, $\phi_d = 0.114$ $q\times10^{-3}$ (msec^{-1})	$\overrightarrow{AD}$, $\phi_d = 0.150$ $q\times10^{-3}$ (msec^{-1})	$\overrightarrow{AE}$, $\phi_d = 0.170$ $q\times10^{-3}$ (msec^{-1})
0	0.47	0.62	0.75	1.46
20	1.61	1.93	0.75	1.65
50	4.60*	4.01	4.95	1.30
70	3.14	4.91*	5.47*	6.27
90	0.75	1.30	1.43	6.62*
Total	10.57	12.77	13.35	17.30

Table 3: Volume flux at various angles of outlet and porosity difference when fluid flows through either B, C, D or E to A ($\alpha = 20°$)

Angle of outlet θ (degrees)	$\overline{BA}$, $\phi_d = 0.083$ $q\times10^{-3}$ (msec^{-1})	$\overline{CA}$, $\phi_d = 0.114$ $q\times10^{-3}$ (msec^{-1})	$\overline{DA}$, $\phi_d = 0.150$ $q\times10^{-3}$ (msec^{-1})	$\overline{EA}$, $\phi_d = 0.170$ $q\times10^{-3}$ (msec^{-1})
0	11.43	11.99	15.52	17.80
20	10.96*	10.89*	12.65*	8.41*
50	4.56	5.70	7.33	8.31
70	2.59	2.64	3.07	6.01
90	0.00	0.00	0.00	0.00
Total	29.54	31.21	38.57	40.53

*Relatively higher volume flux in higher angle outlet pipe

Table 4: Optimum volume flux q_{max} at various porosity difference for the two different cases

Case	Porosity difference ϕ_d	q_{max} $q\times10^{-3}$ (msec^{-1})	Deflection factor (f)
AB	0.083	4.60	9.79
AC	0.114	4.91	7.92
AD	0.150	5.47	7.29
AE	0.170	6.62	4.53
BA	0.083	11.43	0.96
CA	0.114	11.98	0.91
DA	0.150	12.65	0.82
EA	0.170	17.80	0.47

order because O° angle of inclination indicates hydrostatic angle or zero hydraulic gradient at which no flow is expected through the medium. Also, the highest volume flux and volumetric flow rate were obtained at an angle of inclination 20° for all the cases. This was so because angle of inclination can be likened to hydraulic gradient, which influences the rate of fluid flow. According to Darcy's law, the velocity of flow (or volumetric flow rate) is proportional to the hydraulic gradient, therefore it is expected that volume discharged, volumetric flow rate and volume flux should be increased whenever angle of inclination is increased. Generally, the volume flux increases with increasing angle of inclination.

It was observed that at a given angle of inclination, the volume flux decreases with increasing angle of outlet from the normal when both inlet and outlet pipes were filled with the same sample or medium of a given porosity. When, the inlet pipe was filled with sample of lower porosity and outlet pipes were filled with a sample of more higher porosity, at a given angle of inclination, volume flux decreases with increasing angle of outlet from the normal. However, when the inlet pipe was filled with a sample of higher porosity than that of the outlet pipe.

The above results revealed that higher volume flux vis-à-vis volumetric flow rate can be obtained at higher angles relatively to normal direction (or 0° outlet). Whenever, fluid flows from a lower porous medium to a higher porous medium. This is in line with Cedergreen (1976) result, which states that when fluid flows from a material of low permeability into one of higher permeability, it deflects as soon as possible into the material of higher permeability. In another research done by Eagleman and Jamison (1962) it was stated that for an arrangement of soil layers, when soil of low permeability overlaying a more permeable soil, the volumetric flow rate as well as volume discharge will be lower than when it is arranged otherwise. In this research it was found that for a given angle of inclination, the total volume of water discharged obtained when fluid flows from sample A to either B-E was lower than when fluid flows from either sample B, C, D or E to A.

In order to measure the degree of deflection of fluid to a particular higher angle from the normal, a dimensionless parameter called deflection factor was chosen. It is defined as the factor of increase of volume flux (or specific discharge) at higher angle of outlet relatively to that of normal direction (0° outlet). It can also be defined as the ratio of volume flux at higher angle outlet 0 to the volume flux at normal direction ($\theta = 0°$). Mathematically, it can be written as $f = q_\theta/q_0$ where, q_θ is the relatively higher volume flux or specific discharge (msec^{-1}), while q_0 is the volume flux or specific discharge at normal direction (msec^{-1}).

When the value of f>1, there is deflection and when f<1, there is no deflection. The greater the value of deflection of factor f, the higher the deflection of fluid at a particular higher angle outlet pipe.

The deflection factor f were determined to be 9.79, 7.92, 7.29 and 4.53 for porosities differences 0.083, 0.114, 0.150 and 0.170, respectively when water flows through sample A-E (Table 4). This implies that the closer the

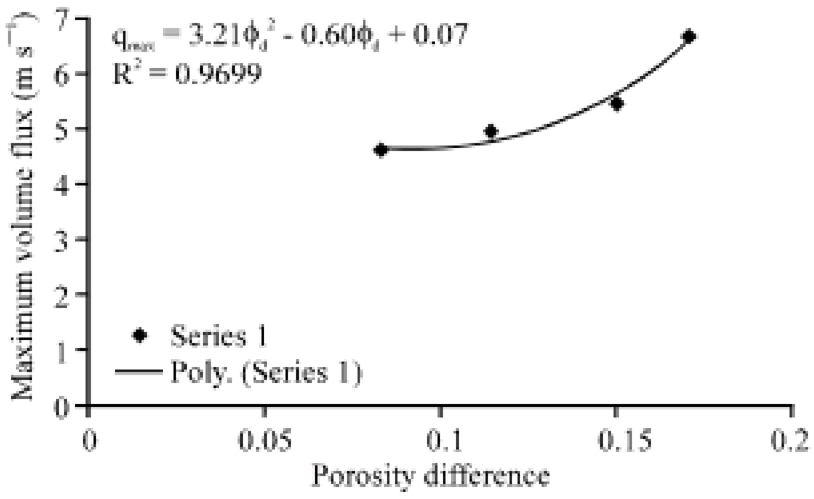

Fig. 7: Plot of max. Vol. Flux against porosity difference of fluid flow through low porous medium to higher porous medium

porosities of the media in the inlet pipe and outlet pipes, the greater the deflection. When water flows through inlet pipe filled with either sample B, C, D or E to outlet pipe filled with sample A, the deflection factor f were determined to be 0.96, 0.91, 0.82 and 0.47 for porosities differences 0.083, 0.114, 0.150 and 0.170, respectively. This implies that there is no deflection of fluid in this case (Table 4).

By considering the highest angle of inclination 20° used in this research, it was observed that optimum (maximum) volume flux q_{max} increase with increasing porosities difference in both cases. However, for a given porosity difference, the optimum volume flux was observed to be higher when fluid flow through the inlet pipe filled with either samples B, C, D or E to outlet pipes filled with sample A than when the inlet pipe was filled with A and outlet pipes were filled with either Sample B, C, D or E.

At an angle of inclination 20°, when fluid flows through the inlet pipe filled with sample A to outlet pipes filled with either sample B, C, D or E, the optimum volume flux and porosities difference are related with equation $q_{max} = 3.21\phi_d^2 - 0.60\phi_d + 0.07$ (Fig. 7) while, when fluid flows through either the inlet pipe filled with either sample B, C, D or E to outlet pipe A, the optimum volume flux and porosities difference are related with equation $q_{max} = 15.36\phi_d^2 - 3.26\phi_d + 0.28$ (Fig. 8). This shows that in both cases the optimum volume flux q_{max} and porosity difference are not linearly related, but they are found to be related with polynomial equation of degree two. In addition, these relations will be of help in predicting the maximum or optimum volume flux of a known porosity difference; whenever this kind of set-up is used in contaminated fluid seepage control. It also reveals that optimum volume flux is always higher or more in the latter set up (arrangement) than the former set-up for any given porosity difference.

The main purpose of this research is to seek for the best or the most suitable arrangement of porous materials of different porosity in designing a set-up to deflect contaminated fluid to a higher angle from normal from the direction of source of water (normal direction). Therefore, a case when volume flux should be lower at the normal direction, greater at the higher angle from the normal and generally low in all direction is required. Then from the above results and discussion, the most suitable arrangement required is when fluid flows through a medium of a low porosity to that of a higher porosity with a closer porosity difference. In such an arrangement, the volume flux will be greater at a higher outlet angle than in the normal direction and generally low in all direction.

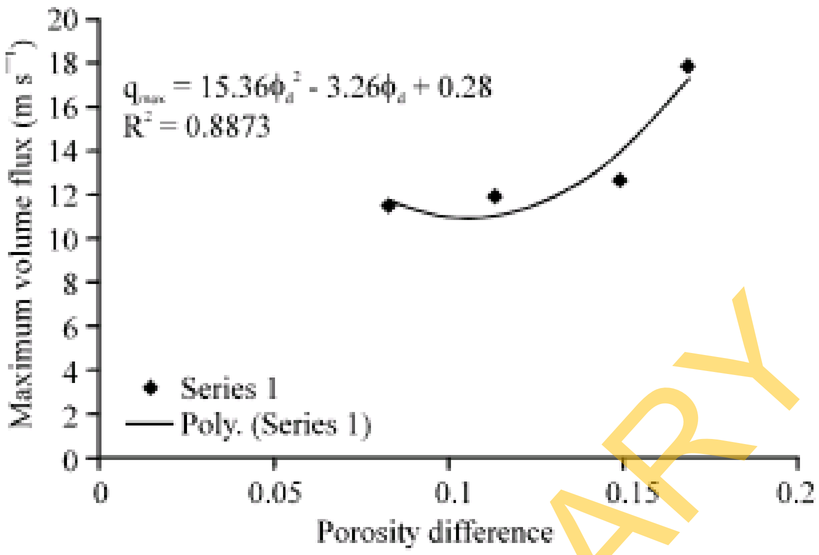

Fig. 8: Plot of max. Vol. Flux against porosity difference of fluid flow through high porous medium to lower porous medium

CONCLUSION

In this study riverbed sands samples of different porosities were used as porous media to investigate how porosities difference of porous media affect the volume flux and ability of the media to deflect the fluid flow, determine the relationship between porosities difference and optimum volume flux in different arrangement and suggest the most suitable arrangements for deflecting fluid flow to higher angles from the normal direction or line. This is sequel to the application in controlling the contaminated fluid seepage from the direction of source of water (aquifer) in homes. At the end of the study, it was found that:

- The volume discharged, volumetric flow rate and volume flux do not decrease with increasing angle of outlets from the normal in all cases, especially when fluid flows through a lower porous medium to a higher porous medium
- The angle of inclination does not have a significant effect on the deflection of fluid from the normal or linear direction, but volume discharged increases with increasing in angle of inclination with polynomial equation of order two. The equation is $V = 0.02\alpha^2 + 3.81\alpha - 0.29$ with correlation coefficient 0.99

- The closer the porosities of the medium in the inlet pipe and outlet pipes, the greater the deflection and the closer the porosities of the medium in the inlet pipe and outlet pipes, the lower the total volume flux (specific discharge). This could not be attributed to random error because it followed a definite pattern for all media
- When, fluid flows through a low porous medium to a higher porous medium with equation $q_{max}=3.21\phi_d^2-0.60\phi_d + 0.07$ while, they are related with equation $q_{max} = 15.36\phi_d^2-3.26\phi_d + 0.28$ when fluid flows through a high porous medium to a lower porous medium

RECOMMENDATIONS

It is expedient from the results and discussion above that the most suitable arrangement for deflecting contaminated fluid to higher angles from normal direction is when fluid flows through a medium of a lower porosity to that of a higher porosity. If the distance between the sewage or septic tank and source of water and porosity of the soil in which its constructed are known, a suitable porous material of a known porosity can be used to reduce the volume flux in normal direction and deflect the contaminated fluid to other direction from the source of water.

The angle of inclination is a very significant factor on the rate of fluid flow. Therefore, in further study, the angle of inclination may be increased more than 20° and re-investigate its effect on the deflection of fluid flow.

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