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Darcy and Non-Darcy Flow Through Packing Particles

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Abstract—**Darcy and non-Darcy flow through packing particles is an important study to determine the flow rate and pressure drop through porous media. Darcy is formed with a low liquid flow rate while the non-Darcy flow is formed with a high flow rate. The objective of this experiment is to determine the flow performance through packing particles. In this study, a syringe piston pump is used to inject the water through various packing particles. The permeability of the material was calculated using Darcy's Equation. This study considered different variables such as: flow rate viscosity, the cross-sectional area of the sample, the pressure difference across the sample, and the length of the sample for the permeability calculation. The results showed high and low permeability rates of the specimens using in the experiment. Consequently, the results of this experiment can be used for selecting the best particle sizes for water treatments and hydraulic fracking in reservoir stimulation or enhanced oil recovery methods (EOR).**

Index Terms: **Darcy flow, non-Darcy, flow rate, permeability Packing Particles, fifth term.**

I. INTRODUCTION

Permeability refers to the degree to which pore spaces (voids that can be filled by a fluid) in a medium connect to each other, promoting the movement of fluid through that material whereas porosity is the measure of void spaces in a material (Dandekar 2006). Permeability and porosity are closely connected; however, a material may be highly porous but have few channels connecting these pores, leading to low permeability. Permeability of a material is governed by these 4 factors: shape and size of the grain, lamination, cementation, and fracturing and solution. The permeability of reservoir rocks may range from 0.1 to 1,000 or more millidarcies (Bai, B. 2013). A reservoir with a permeability of less than one millidarcy is considered poor to fluid flow whereas the permeability that is greater than 250 millidarcies reflects the efficiency of the porous media (Bai, B. 2013). In the oil and gas industries and well logging industries knowing the permeability of a rock or medium is the important factor to extract these fluids present in the voids of that rock (Economides 2013). The higher permeability of that rock the easier it is for that fluid to flow which makes it a lot more accessible for extraction. Stimulation techniques such as hydraulic fracturing and acidizing increases the permeability of such rocks (Elsharafi 2013). This project aims to find the permeability of the various packing materials as well as to identify the regions on the graph that experiences a Darcy and a Non-Darcy flow. A water solution was injected through various packing particles using the syringe piston pump. The solution contained a constant salt concentration mixed with desalinated water. A round tube was filled with various particles such as; gel particles, sand particles, limestone particles, poly-propylene plastic pellet particles, clay pellets alternatively. Also, the sieve tube was used to separate the different size particles in categories of Mesh size 5 and 10 and Mesh 35. These different particle sizes were used, and the flow rate was controlled from the syringe pump. The pressure was measured by using pressure gauges at either ends of the tube and a pressure change was calculated.

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II. METHODOLOGY

A model of the tube and pressure gauges were created using Solid Works software to get the required dimensions as showing in figure 2. The dimensions of the tube were cut out and the actual tube was set up along with its components. And then the tube was connected to the injection pipe in order for the apparatuses of the experiment to be ready to work.

- *Gel procedure*

The tube was firstly filled with the LiquiBlock 40F polymer. Valve 1 was then opened and allowed the syringe pump to fill with 1% brine solution. Valve 1 closed and valve 2 simultaneously opened. 1% brine solution injected through the sample using a constant flow rate. The pressure readings monitored and recorded. The core permeability was calculated. After that the flow rates was changed. Various flow rates were used in the permeability calculation.

- *Arkose sand and limetsone procedure*

Arkose sand placed in a sieve set and shaken vigorously. Mesh sizes were selected from 5 to 10 to fill the tube. 1% brine solution injected through the sample using a constant flow rate. The pressure in the core flooding system was monitored and recorded. The permeability of the core sample was determined by using different flow rates. After that the procedure was repeated for the other material.

- *Clay pellets procedure*

Clay pellets of various sizes ranging from 4 mm to 6 mm were placed into the tube and shaken vigorously to reduce the amount of pore spaces between each particle. 1% brine solution injected through the sample using a constant flow rate. The pressure readings monitored and recorded, and the permeability was calculated by using different flow rates.

- *Poly-propylene plastic pellets procedure*

Poly-propylene plastic pellets with a constant size of approximately 3 mm were placed into the tube and shaken to reduce the amount of pore spaces between each particle. 1% brine solution injected through the sample using a constant flow rate. The pressure readings monitored and recorded. The permeability was calculated by using different flow rates.

- *Equipment and materials*

As shown in figure 1 the picture appears the complete set up for the experiment:

- Deionized water.
- Pressure gauges (figure: 2 & 3).
- LiquiBlock 40F polymer.
- Limestone sample.
- Arkose sand sample.
- Clay Pebbles.
- Poly Pellets.
- Syringe Pump (figure: 4).
- Sieve tube (figure: 2 & 3).
- Bottle.
- Injection Pipe Line.
- Brine.

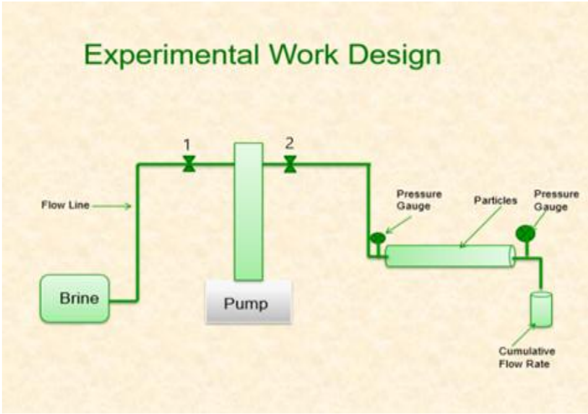


Figure 1. Showing the Complete Set up for the Experiment

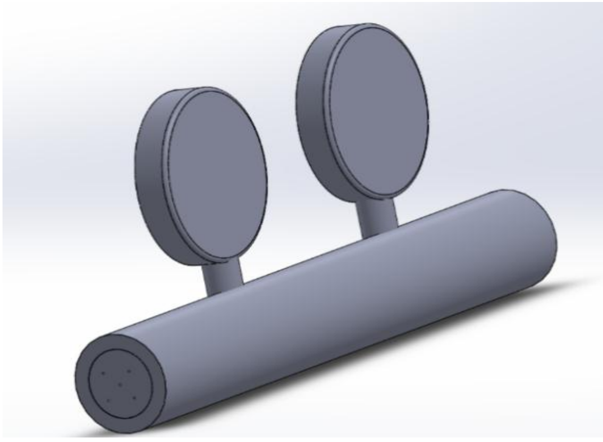


Figure 2. Showing the Solid Works Design of the Tube with Pressure Gauges

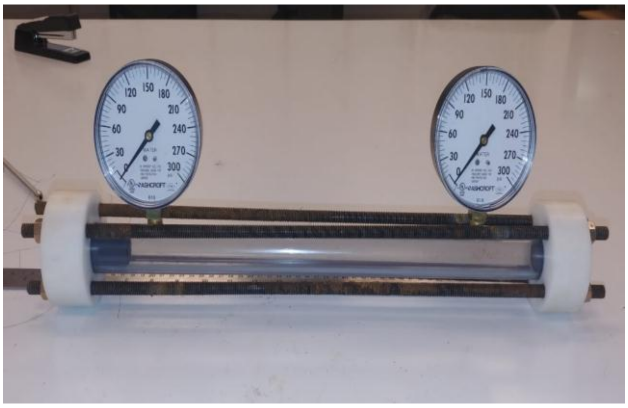


Figure 3. Showing the Actual set of the Tube with Pressure Gauges

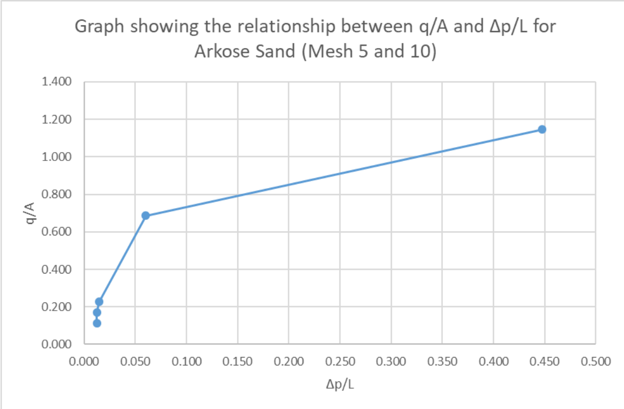
Figure 4. Showing the Syringe Pump

III. RESULTS AND DISCUSSION

Knowing the permeability of rocks can be crucial in searching for the best suited outcrop for drilling wells for aquifers. With these values one can have a general idea of what to expect from the soil type. In this experiment, the packing materials used were LiquiBlock 40F, arkose sand, limestone, clay pebbles and poly-pellets with varying particles sizes. Since the particles beneath the subsurface may come in all shapes and sizes, it was best to variate the particles with relation to their sizes to understand how much the particle size would affect the permeability of the medium.

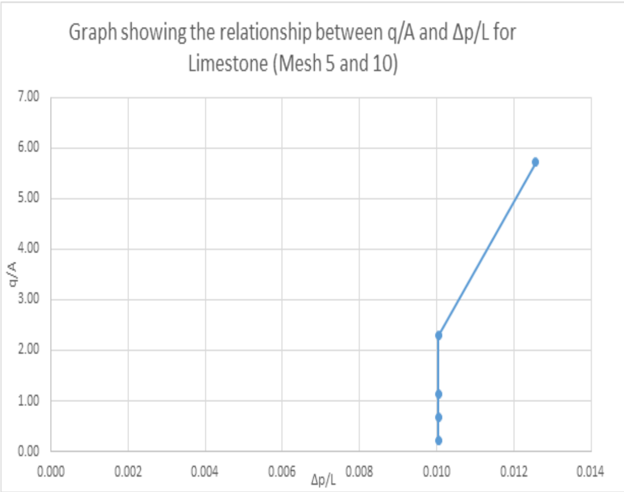
The particles were tested, each at multiple flow rates at linear time intervals. The results obtained were used to plot graphs highlighting the relationship between the dividends of the flow rate and cross-sectional area of the tube (q/A) and the pressure difference across the sample and length of the sample (ΔP/L). Using graphical representation, one can interpret on the graph which regions experienced a Darcy Flow, as well as, the regions which experienced a Non-Darcy Flow. Darcy flow usually occurs when the flow rates are small and Non-Darcy Flow occurs with larger flow rates.

Graph 1 shows the relationship between q/A and ΔP/L for Arkose Sand (Mesh 5 and 10). It can be seen that the first three points on the graph were somewhat clustered which was due to the small variations in pressure change across the medium when the flow rate was slightly increased. From point three to point four the pressure change that occurred in that region was significant enough to shift the graph up and right of the plot. This region of the graph exhibited the Darcy Flow. As we got in the realms of high flow rates the pressure in the system skyrocketed due to the arkose sand's ability to be compressed resulting in clumping of the particles. This clumping created a blockage in the tube. Evidence of this can be seen in the graph by looking at how far point five was distorted away from point four in terms of the X axis. This region is said to have experienced Non-Darcy Flow. The Arkose Sand at mesh size 35 experienced a similar outcome but the pressures at the high flow rates were a lot greater than that of the pressures of the mesh sizes 5 and 10. The smaller particles when compressed acted like concrete, leaving little to no room for the brine solution to flow through the medium.



Graph 1. Showing the Relationship between q/A and Δp/L for Arkose Sand (Mesh 5 and 10)

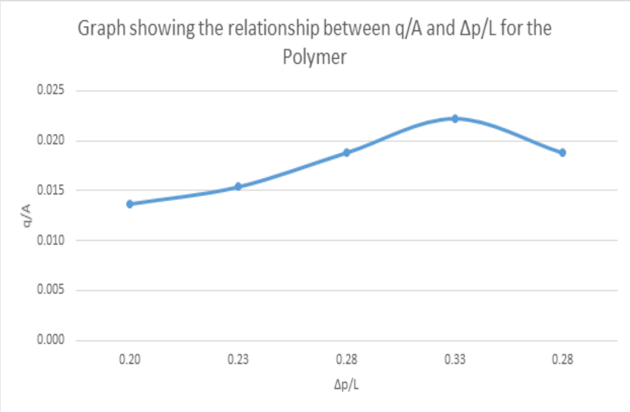
The second graph (graph 2) depicts the relationship between q/A and Δp/L for Limestone (Mesh 5 and 10). This packing particle did not show much change in pressure over the duration of the experiment. This was simply due to its inability to be compressed which can be seen clearly by the 0.002 scale used on the X axis. By observation, this medium was highly porous with lots of interconnecting spaces providing a pathway for the easy flow of the brine solution through the medium. Limestone at mesh size 35 had corresponding results to that of the mesh sizes 5 and 10 with a slightly greater variation in pressure change.



Graph 2. Showing the Relationship between q/A and Δp/L for Limestone (Mesh 5 and 10)

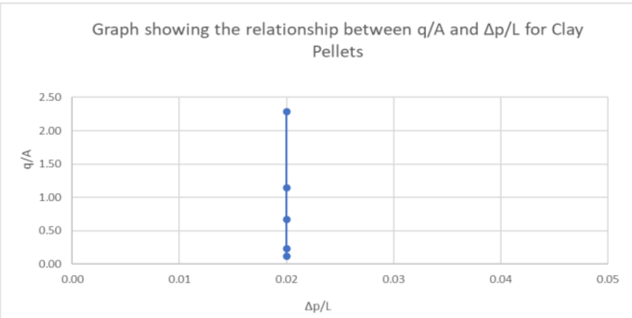
The Third graph (Graph 3) LiquiBlock 40F polymer was the most fascinating out of the five packing particles used throughout the research. Under pressure the particles of the polymer were subjected to being compressed. Unlike the Arkose Sand, whose particles were also subjected to being compressed, the particles of the polymer when compressed became small enough to pass through the five slit spaces at the end of the tube. A direct proportional relationship was observed as the flow rate increased the mass of the gel that exits the tube also increased.

This relationship explained the relatively straight line from point one to point 4. As the gel exited the tube this may have caused slight variation in the pressure on the inside of the tube. This region of the graph illustrated Darcy Flow where the remaining portion of the graph represented the Non-Darry Flow. As the one percent brine solution entered the tube with varying flow rates it created channels through the gel allowing the flow of the solution through the medium. The greater the flow rates the greater the pressure inside the tube which shifted the equilibrium further away from the polymers threshold of compressibility. As a result, a lot more of the polymer was being deposited out of the tube. The decrease in the pressure across the tube from point four to point five was as a result of the majority of the gel leaving the tube.



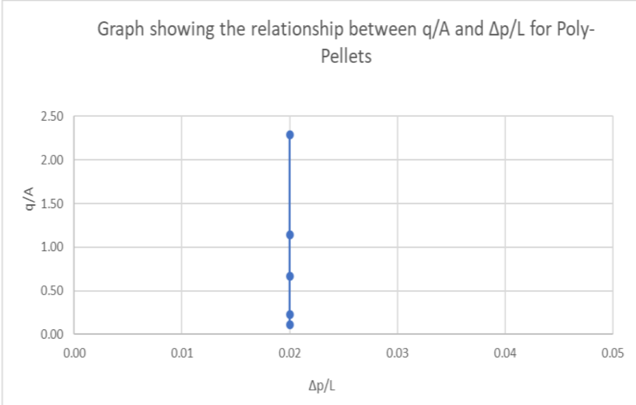
Graph 3.Showing the Relationship between q/A and Δp/L for LiquiBlock 40F polymer

Clay pebbles; 100% natural clay in pebble form used for different reasons such as a substitute for soil in plant pots. This medium was chosen because of its strong structural integrity and its ability to drain excess water freely. It also varied in size ranging from 4mm-6mm. The results in the fourth graph (Graph 4) depicts the relationship between q/A and Δp/L for clay pebbles. As seen, the graph line remained straight as there were no pressure change with this medium. The permeability level was high and remained consistent throughout the entire experiment.



Graph 4. Showing the Relationship between q/A and Δp/L for Clay Pebbles

The fifth graph (Graph 5) depicts the relationship between q/A and Δp/L for the poly-propylene plastic pellets. This particle was chosen based on the type of material and the size consistency which was approximately 3mm in size. The poly-pellets did not show much change in pressure over the duration of the experiment. This was simply due to the high level of permeability displayed as the brine entered the tube and through the plastic particles. This resulted in a high level of porosity inside the tube.



Graph 5. Showing the Relationship between q/A and Δp/L for Poly-Pellets

The permeabilities of the packing particles were calculated by transposing the formula

$$Q = \frac{k \times \Delta P \times A}{\mu \times L}$$

in terms of k. Where Q is the flow rate (cm3/sec), μ is the viscosity (cP), A is the cross-sectional area of the sample (cm2), ΔP the pressure difference across the sample (atm), L is the length of the sample (cm) and k is the permeability (Darcy). The permeabilities in respect to the difference packing particles can be seen in (Table 1) with the LiquiBlock 40F having the highest permeability of 1281 mD due its ability to facilitate the formation of interconnecting channels through the medium. Though the polymer may have the highest permeability it would be inappropriate for use in hydraulic fracturing and water treatment due to its ability to be easily compressed under high pressures which may result in the polymer becoming a contaminant. The permeabilities obtained for limestone with Mesh size 5 and 10 and Mesh size 35 were 489mD and 442mD respectively. Mesh size 5 and 10 had a slightly higher permeability due to the bigger sized particles present in the medium which accommodated a highly porosity. The Arkose sands permeability was more than a fifth times smaller than that of the polymer. The values obtained for the Arkose Sands with Mesh size 5 and 10 and Mesh size 35 were found to be 241mD and 190mD respectively. Under high pressures the Arkose Sands were compressed which caused the formation to clump creating a blockage inside the tube prohibiting the flow of the solution. Again, a higher permeability was observed in the sands with the bigger sized particles due to the larger void spaces created amongst them.

Table 1. Showing the Permeability of the Different Packing Materials in Descending Order

Permeability of the different Particles	
Materials	**Permeability**
Polymer (LiquiBlock40F)	1281
Poly Pellets	556
Clay Pebbles	543
Limestone (Mesh 5 and 10)	489
Limestone (Mesh 35)	442
Arkose Sand (Mesh 5 and 10)	241
Arkose Sand (Mesh 35)	190

IV. CONCLUSION

In this experiment, , the Gel polymer (40F), polypropylene pellets, clay pellets, and limestone all had a high permeability rate which determined that the void spaces between the particles are very large so therefore has a high porosity. These results established that the particles are not efficient enough for filtering on its own. However, the arkose sand had a much lower permeability with all the different grades that were tested so there is a possibility that this particle can assist in filtering if it could be associated with another medium. The medium with the highest permeability was the gel polymer (40F) and the medium with the lowest level of permeability was arkose sand (Mesh 35). Finally, Darcy flows can be observed when the flow rates are small whereas Non-Darcy flows can be seen whenever the flow rates are large.

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