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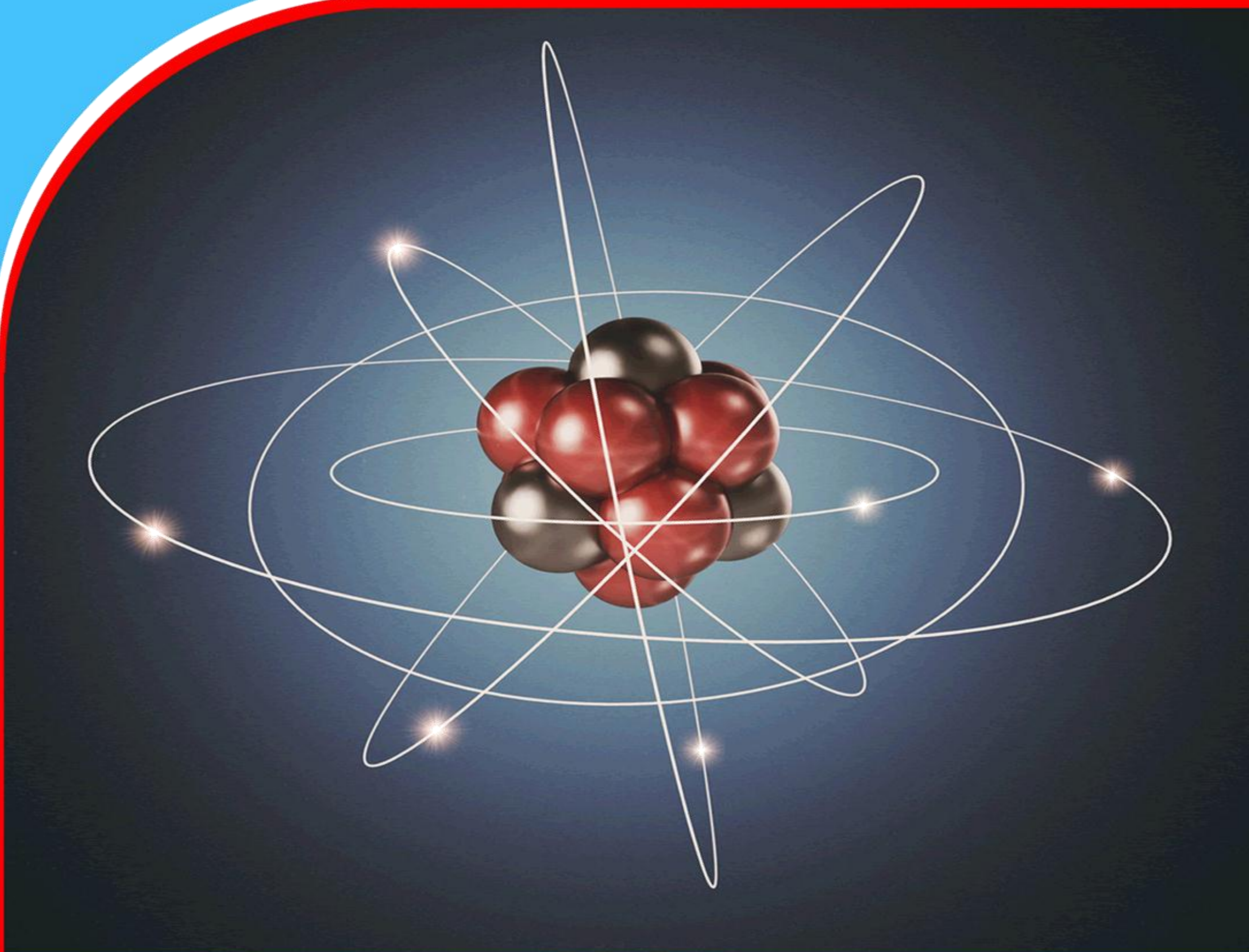

COMPARATIVE ANALYSIS OF THE FLOW STRUCTURE OF POLAR SOLVENT AND UNREFINED HYDROCARBON FLOWING IN A CYLINDRICAL BIFURCATED CHANNEL

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ABSTRACT

Objective: The effect of geometric bifurcated system on flow of fluid may be greatly influenced by the angle of bifurcation or the density, capillary action etc. and other physical properties of the fluid. The aim of this work is to carry out a comparative analysis of the flow structure of polar solvent and unrefined hydrocarbons in a cylindrical bifurcated channel.

Materials and Methods: An experimental method was used to study the flow structure of water and crude oil, representing polar solvent and unrefined hydrocarbon respectively flowing through a bifurcated channel, with angles of bifurcation ranging from 10º, 20º, 30º, 40º, 50º and 60º, corresponding to 5º, 10º, 15º, 20º, 25º and 30º measured from the centerline of the main channel. The fluid samples were allowed to flow through the bifurcated channels and the time taken to recover 100ml, 200ml, 300ml 400ml and 500ml in a beaker is recorded. The bifurcated angle is resolved into vertical and horizontal components and the total length for both components obtained, as the flow velocity is computed for both lengths and the results presented.

Results: The profile of resulted shows that for polar solvents such as water, the velocity gradient increases as the vertical distance increases and horizontal distance decrease correspondingly due to increasing bifurcation angle, as a similar trend is also observed for crude oil.

Conclusion: For both samples representing their respective class of fluid, the result further shows the existence of velocity difference at opposite walls of the bifurcated daughter channels. The wall at higher velocity is usually the site where the skin friction that changes the flow from laminar to turbulent is created. The experimental result confirmed the effects of bifurcation on flow stability to significant in a more viscous fluid.

Recommendation: Fluid samples with different physical properties should be investigated using this experimental technic, and the impact of two-stage bifurcated system can also be investigated to ascertain the degree of stability offer by the geometric bifurcated network system.

Keywords: *Flow Velocity, Bifurcation angle, Hydrocarbons, Polar solvents.*

INTRODUCTION

The importance of hydrodynamic flows in bifurcating channel cannot be overemphasized. This is principally because of its wide application in several works of life. Bifurcating system abound in nature, ranging from green plants, human arterial systems, rivers to domestic and industrial piping network. For example, the drainage network systems in civil engineering, electrical circuit designs in electronics, domestic and urban water distribution, in recoveries and distribution of hydrocarbon products as well as other multi-distribution system in the processing industries. The relevance of bifurcation has led to the development of several studies that has adopted both experimental and theoretical approach and methods ranging from analytical, numerical etc. been mentioned in literatures for over ten (10) decades. For instance [1] uses numerical method to analyze the flow performance of consecutive bifurcating distributors in two dimensions. In this study the inlet velocity and a bifurcation angle ranging from 15^o to 90 were considered, as they went further to obtain a relationship between the inlet velocity, flow distribution uniformity and the bifurcation angle. The study is also extended to investigated the impact of bifurcated microchannel on the breakup of viscous droplets, where [2] visually examine the dynamics of the breakup of viscous droplet, and were able to explain phenomena associated with the squeezing, transition and pinch-off stages of viscous droplets through the bifurcated microchannel. [3] further simulated the viscoelastic droplets through a two dimensional bifurcated capillary microchannel, there results revealed how the droplet size and capillary number will behave when it approaches the point of bifurcated.

[4] using numerical experimental technic, investigated the behavior of droplets as it gets to the tip at the junction of a symmetrically bifurcated system, they established a relationship between the Rayleigh-Plateau instability with the splitting and non-splitting regime of the viscous droplets. A mathematical model and a three-dimensional flow simulation were used to quantitatively predict the effect of bifurcation on microvasculature of hemodynamics, where they were able to show the degree of influence vessel bifurcation hold on the viscosity of blood [5]. And in addition to the Y-shaped geometric system, the curved T-junction and flat T-junction were also adopted by [6] to examine physical behaviors such as droplets deformation, droplets neck thickness as well as the time droplets spent at the junction point of bifurcation, and wettability and the capillary actions on selected geometric system. [7] used a T-shaped and Y-shaped geometrical systems for the sorting and isolation of cells of specific types, and bifurcation angles within the range of 30^o to 180^o and the method of computational algorithm were considered in the study of the separation of deformed cells in the Y-shaped microchannel for the selected bifurcation angles, and the effects of the various sizes of cell, cytoplasmic viscoelasticity, cortical tension, flow rate for this geometrical system and angles were identified.

[8] studied flow through bifurcated arteries of the human arterial system. They were able to show that in the coronary, carotid, aorto-iliac and in some other large arteries, the site of branching is associated with the development of atherosclerotic plague and hemodynamic factor such as shear stress and particle residence time with some implications. [9], in their analysis of various application of bifurcation, addressed the flow symmetry through a large bifurcated network segment in the presence of a loop. The profile of results obtained from their study shows that out-flow flux at a low Reynolds number can be represented by the distribution of electric current existing in an analog resistor network, they were also able to deduce that flows at the out-let depends on the velocity at the in-let and tends to become more homogeneous as the Reynolds

number increases. [10] investigated the fundamental flow in a converging bifurcated channel using the Particle Image Velocimetry (PIV) and the Laser Induced Florescence (LIF) in the experimental study. A transparent model of three machine tubes mated together in a Y-shaped to enable the determination of the amount of secondary flow through a bifurcated channel during respiration, and to enhance the understanding of how doses are distributed into the bloodstream. The study also explain airflow through the complicated series of bifurcation from the bronchi to the final alveoli of the human respiratory system. Egbo C. A. and Abbey T. M (2021), conducted an experimental study on the flow of viscous fluid in a cylindrical bifurcating channel, and they were able to show how bifurcation affects the flow rate of the selected fluid samples and how it makes the fluid samples flowing through it to maintain stability.

The aim of this work is to carry out a comparative analysis of the flow structure of polar solvent and unrefined hydrocarbons in a cylindrical bifurcated channel. Water and crude oil respectively representing these two categories of fluid are allowed to flow through selected angles of bifurcation, and the length of the bifurcated channel resolved into vertical and horizontal component. They are then used to obtain the total length of the flow channel, furthermore, relationship between the flow velocities of the fluid samples through the cylindrical bifurcated system and the selected recovery volumes will be established with regards to the angles of bifurcation.

MATERIALS AND METHOD

Crude oil and water are the fluid selected to represent fluid samples with similar physical properties such as density and viscosity and chemical properties such as chemical composition and structure. Water represents all polar solvent, while crude oil represents the unprocessed hydrocarbons. Table 1 presents some the physical properties of the selected fluid samples.

Table 1: physical properties of the selected fluid samples

Fluid Sample	Density ρ (kg/m^3)	Viscosity μ (cP)	SG $(kg/cu.m)$
Water	997.00	1.00	1000.00
Crude oil	920.00	3.28	847.00

DESIGN AND FABRICATION OF FLOW CHAMBER

Experimental setup

- Beakers (2 x 500ml) two
- Peanut oil (8litres)
- Crude oil (8litres)
- Diesel fuel (8litres)
- Water (8litres)

The reservoir is kept at a height of about 4ft from the surface of the ground, with the mother tube connected to the tap valve of the reservoir and the bifurcated ends of the tube decline at an angle where it's is kept at a height of about 2ft above the surface of the ground.

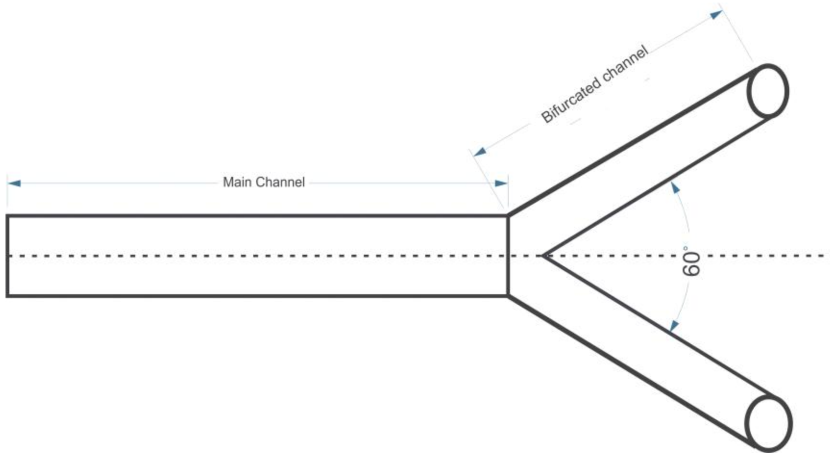

Figure 1: Geometry of a Symmetrical Bifurcated System

The two daughter channels of the bifurcated tube are then connected to the beakers for the recovery of the fluid samples. When fluid flowing continuously from the main channel down to the point of bifurcation, the flowing fluid experiences a resistance to this continuous flow that tends to oppose the continuity of this flow state as described by the second law of motion. For the purpose of this experimental investigation, the resistance which depends explicitly on the vertical component of bifurcation from the centerline of the main channel is obtained, and used to compute the total flow length is given by.

$$L_{\perp} = L_1 + L \sin\theta \qquad 1$$

Its horizontal counterpart is given by

$$L_{\parallel} = L_1 + L \cos\theta \qquad 2$$

Their respective velocities given by

$$v_{\perp} = \frac{L_{\perp}}{t} \qquad 3$$

$$v_{\parallel} = \frac{L_{\parallel}}{t} \qquad 4$$

Experimental Procedure

The experimental process begins by loading the reservoir with a fluid sample while the tap valve is closed, and in this experiment we started with water. While the valve remained closed the beakers are positioned at the recovering end of the two bifurcated channels glass tubes. The timing of the experiment begins as soon as the tap valve is opened to the extreme, and stops when the designated volume of the fluid sample is recovered, for the first cycle a volume of 100ml is required to be collected. The process is repeated for the recovery of 200ml, 300ml, 400ml and 500ml for the water sample. The entire experimental procedure is expected to be repeated for Crude oil and their respective timing recorded and the average computed.

The least square polynomial equation of degree two used to fit the experimental data is of the form

$$y = a + bx + cx^2 \qquad 5$$

Where a, b, and c are constants, x is the designated volume and y represents the velocity computed.

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RESULTS AND DISCUSSION

The properties of the fluid samples selected for this experimental investigation is presented in Table 1, and the geometric dimension of the bifurcated cylindrical channel is presented in figure 1, the flow velocity is computed based on the expressions presented in equation 3 and 4, the profiles of results for water sample presented in figure 2 and 3 compares the flow velocity of the samples through the specified geometric angles of bifurcation, figures 4 and 5 presents the velocity of crude oil all selected angles of bifurcation, figure 6 presented the velocity profiles of the vertical and horizontal of water, and figure 7 is the profile of the velocity gradients of the vertical and horizontal components of crude oil sample, while figures 8 and 9 both compares the respective profiles of the vertical and horizontal velocity components for the selected angles of bifurcation.

The results for water show's a relatively high velocity gradient for smaller recovery volume of 100ml, 200ml and 300ml and a low and stable velocity gradient is seen as the volume recovered increase between 400ml to 500ml, which implies that the flow will tends to be more stable in a continuous flow situation, further implication of the results observed is that, in a continuous flow situation the angles of bifurcation will always tend to stabilize the flow velocity of water. It is also observed from figure 2, that the flow velocity increase for bifurcation angles of 20^o, 30^o and 40^o, and decreases for 50^o and 60^o angles of bifurcation which could be as a result of the adhesive force between the glass tube and the water samples becomes more significant at these angles. Whiles on the horizontal component presented in figure 3, a decrease is observed in the flow velocity for bifurcation angles of 20^o, 30^o and 40^o and increases for 50^o and 60^o angles of bifurcation.

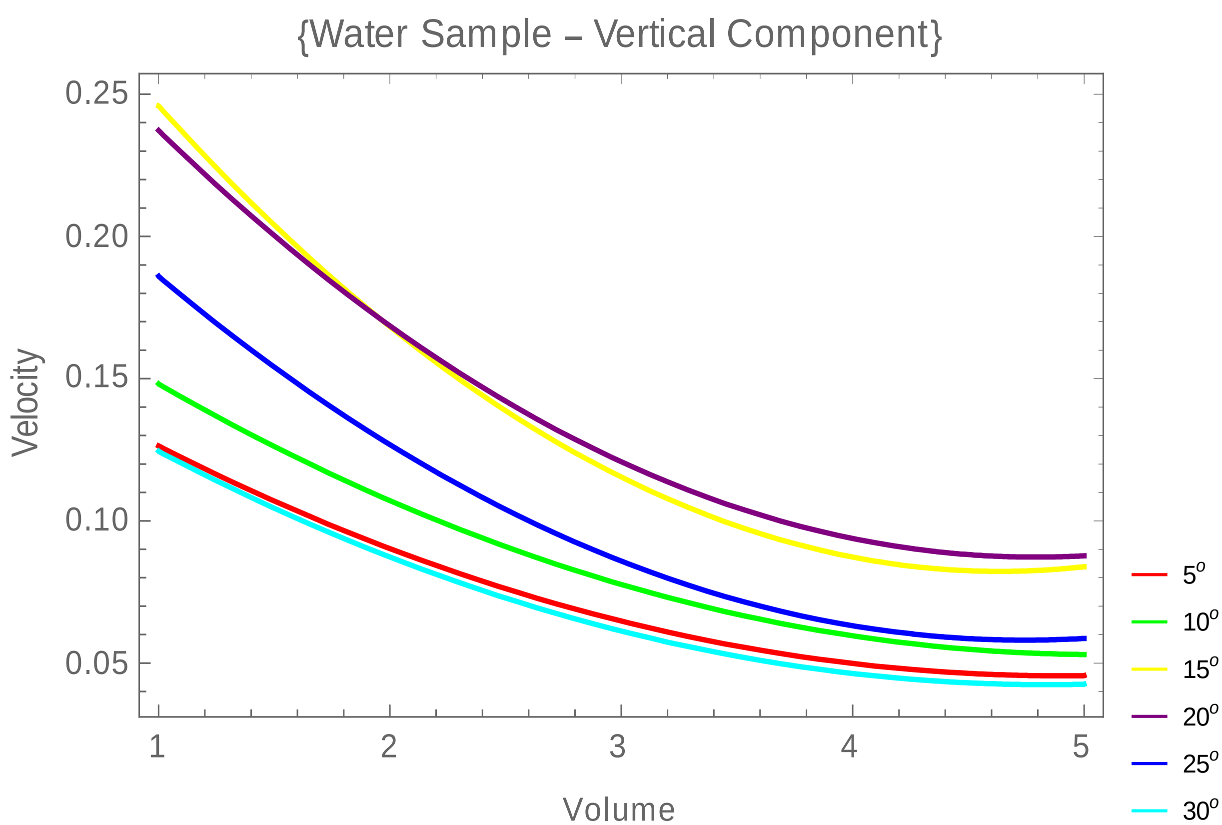

Figure 2: Velocity profile of the vertical component.

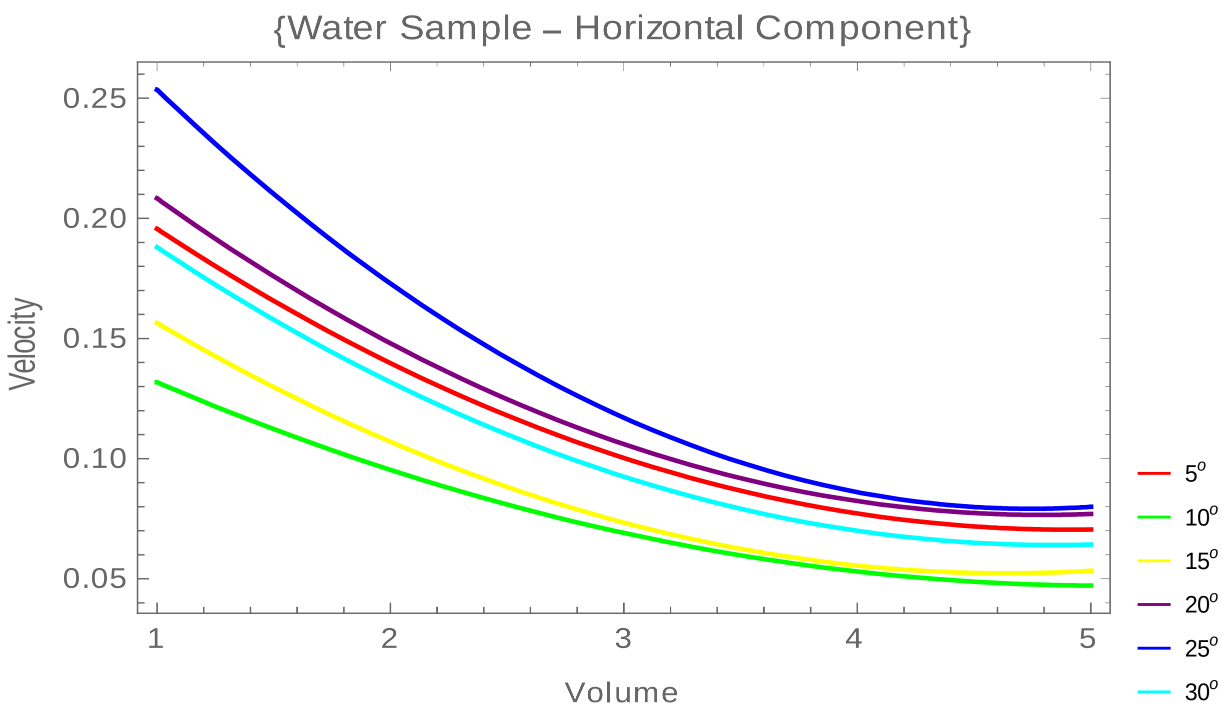

Figure 3: Velocity profile of the vertical component.

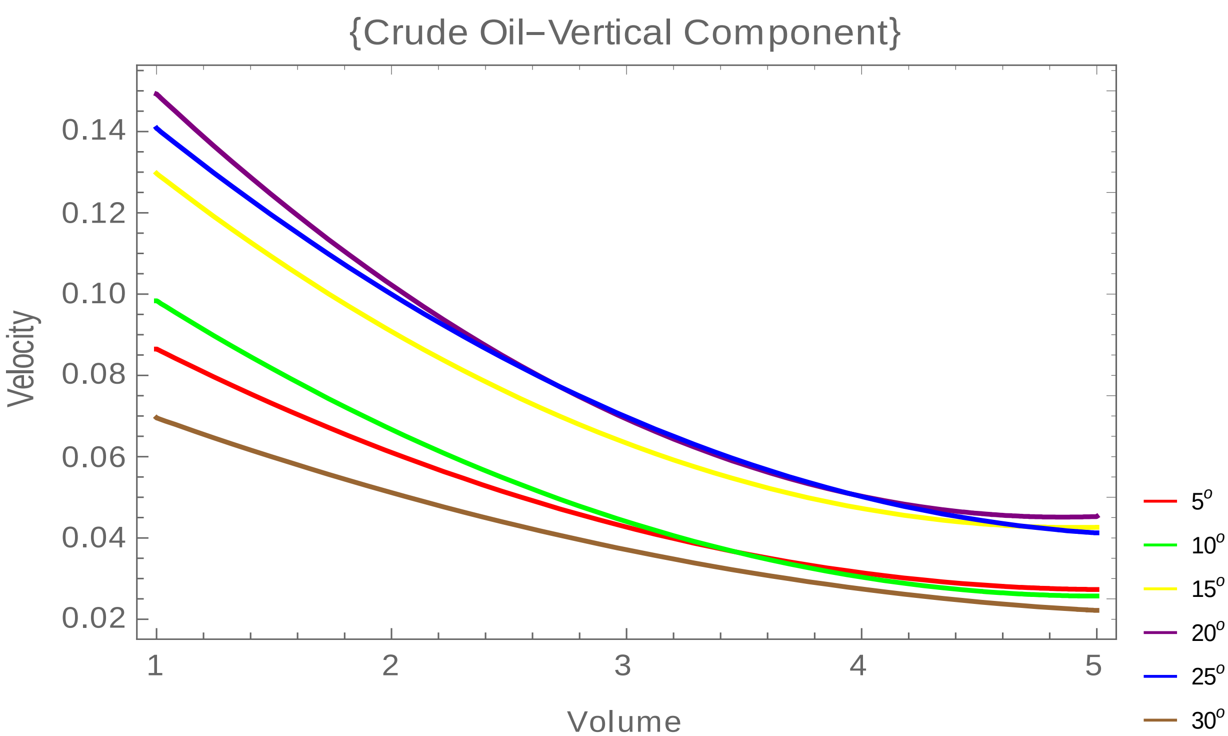

Figure 4: Velocity profile of the vertical component.

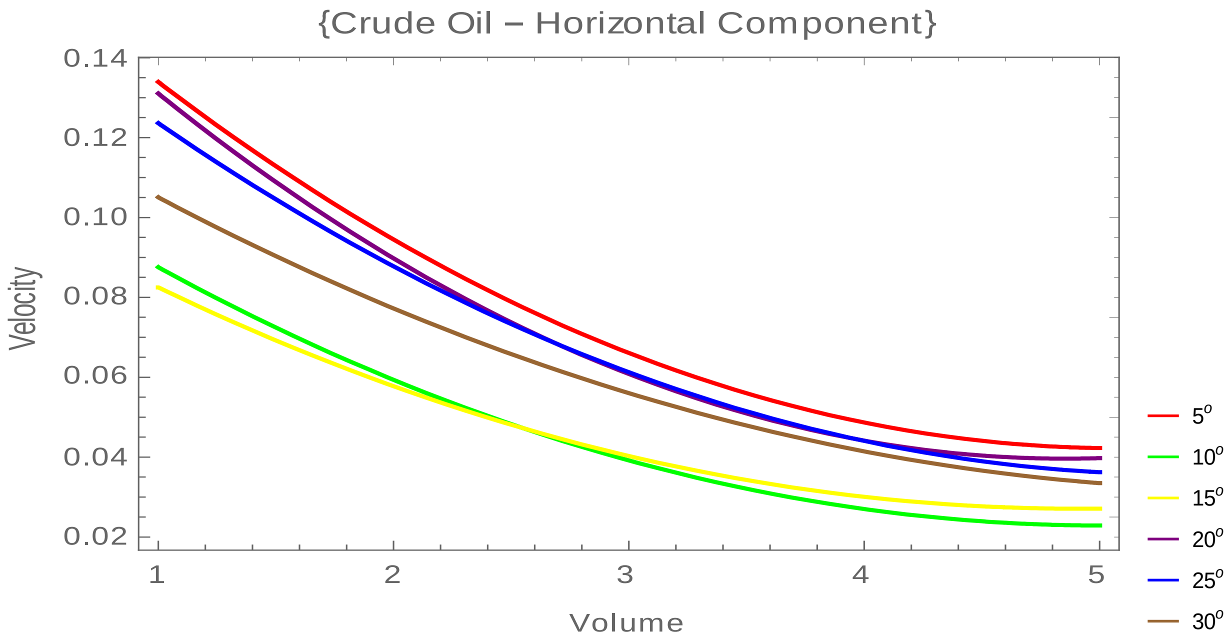

Figure 5: Velocity profile of the vertical component.

The volume-velocity profile for vertical and horizontal components of figure 6 and 7 respectively for the selected angles of bifurcation for crude oil. The profile of result presented for the vertical velocity component shows an increase in the velocity gradient as the angle of bifurcation increases from 5º, 10º, 15º, 25º and 25º for crude oil, the implication of the trendlines obtained is that for an unrefined hydrocarbon flowing with a laminar structure through a bifurcated glass tube, the adhesion force that exist between the fluid sample and the glass tube dominates over the cohesion force between the atoms of the unrefined hydrocarbon, which makes it easier for the fluid to split up at the point of bifurcation without resistance and increases the drag force that exist between the fluid sample and the hydrocarbon which further increase the speed of the flow. While the trendlines obtained for the horizontal components of figure 6 shows a decreasing velocity gradient as the horizontal distance decreases due to increasing angles of bifurcation.

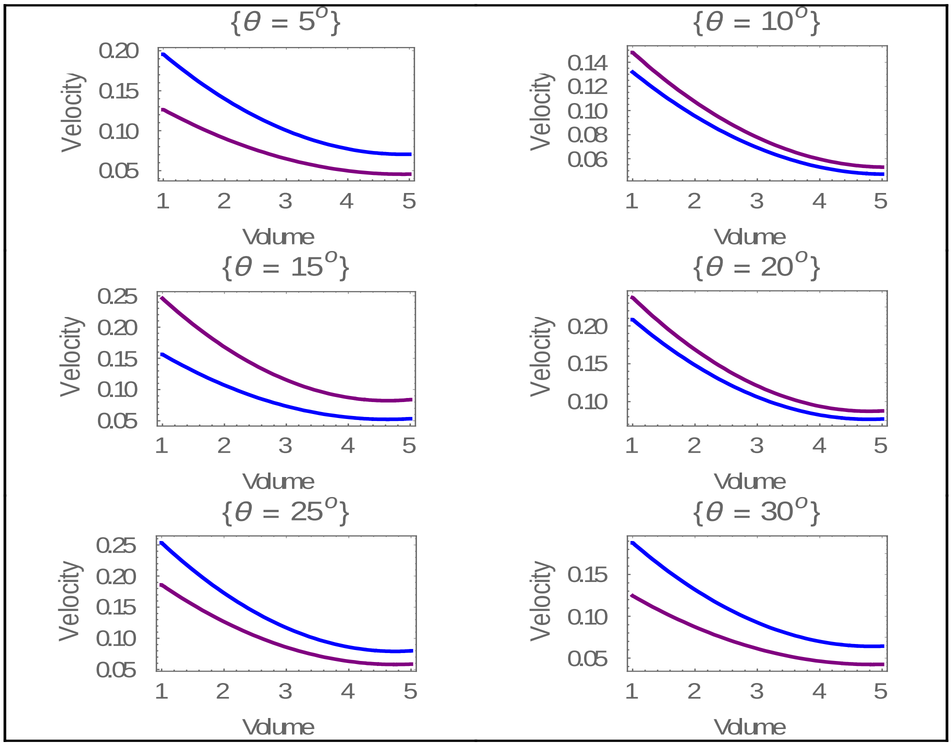

Figure 6: Profiles of velocity gradient of the vertical and horizontal components of Crude oil

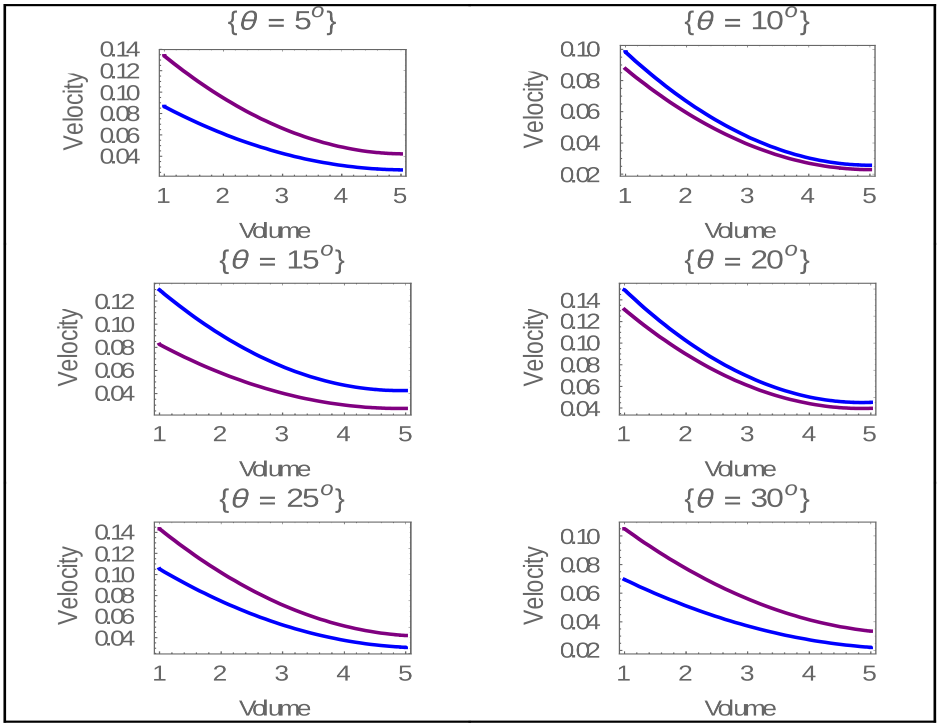

Figure 7: Profiles of velocity gradient of the vertical and horizontal components of Crude oil sample

The velocity profiles of the selected fluid samples were compared for both the vertical and horizontal velocity components, and the profiles of results respectively presented in the figure 8 and 9 for the selected fluid samples geometric angles of bifurcation, trendlines in the results shows a higher velocity gradient for water sample, and a lower velocity gradient, and a more stable flow state for crude oil which reaffirms that bifurcation of a single channel into two channels separated by an angle stabilizes the flow of viscous fluid such as unrefined hydrocarbon much more than polar solvents such as water.

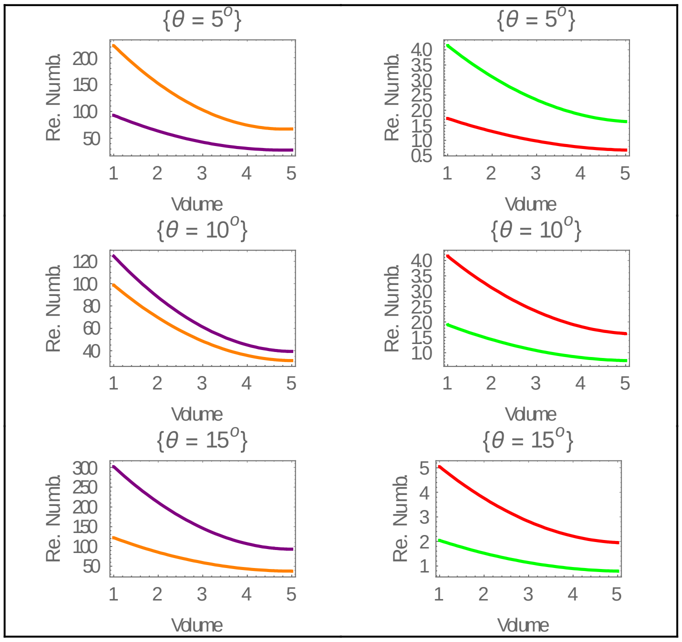

Figure 8: Reynolds number of Diesel (Left) and Peanut oil (Right)

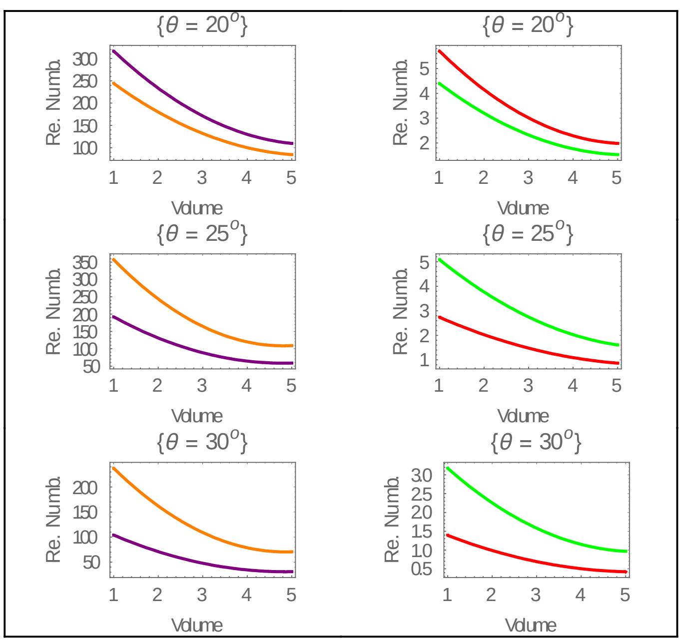

Figure 9: Reynolds number of Diesel (Left) and Peanut oil l (Right)

The profile of results presented in figure 8 and 9 compared the Reynolds number representing the flow stability observed from the vertical and horizontal component respectively denoted by orange and purple for water, and green and red for crude oil. The results presented shows a more stable flow situation for the vertical components of Y-shaped angles of 5^o, 25^o, 30^o, while for the angles of 10^o, 15^o, and 20^o shows a more stable flow on the horizontal component. Similar observation is made from the profile of results obtained for the vertical and horizontal components peanut oil. Figures 8 and 9 also revealed the vales of the flow Reynolds number plotted on the y-axes of the profiles. A relatively large values of the flow Reynolds number is observed from the profile of results obtained for water, while low values of flow Reynolds number is obtained from the denser crude oil, which agrees completely with [8] and the result obtain from the volume-velocity profile presented above.

CONCLUSION

Velocity difference is observed between opposite walls of the bifurcated channels, the side of the wall with higher velocity is the site where skin friction is created, which will further lead to the change in the flow structure of the fluid from laminar to turbulent flow structure. For diesel samples which represent the refined hydrocarbon, the velocity gradient increase as the vertical distance increases, i.e increasing angle of bifurcation, and the decreases for as the horizontal distance decreases (for the increasing angle of bifurcation). While peanut oil represents the unrefined hydrocarbons, the velocity gradient also increases as the vertical distance increases, i.e increasing angle of bifurcation, and decreases for decreasing horizontal distance.

Bifurcation of a single channel into two channels separated by an angle stabilizes the flow of more viscous peanut oil much more than refined hydrocarbon, and this stability increases as the geometric Y-shaped angle increase, this agrees with [1,5].

RECOMMENDATIONS

The researchers recommend that this study be extended by considering other category of fluid samples, and their results compared with the results obtained in this experimental investigation. The authors also recommend that a theoretical study be carried out and a model be developed to enable the prediction of flow structure and stability of all categories of fluid samples of various physical properties in different angles of bifurcation. The authors finally recommend that a two-stage bifurcated system be considered, i.e a situation where each of the daughter channels further bifurcated into two extended channels

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