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Profiles of Average Flow Velocity of Polar Solvent and Unprocessed Hydrocarbon in a Single Stage Symmetrical Bifurcated Channel

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A B S T R A C T

Flow distribution is a central subject in the processing industry, petroleum and industry, power industry amongst others. The concept of bifurcation has played key roles towards the realization of this science and engineering concept, as the application of bifurcation is identified in the human physiological system as it appears in the arterial system where it aids the distribution of blood plasma through the human system. In this study and experimental methos is used to ascertain the flow profile of water and crude oil representing polar solvent and unprocessed hydrocarbon, as they are allowed to flow through a bifurcated pipe with 10^{o}, 20^{o}, 30^{o}, 40^{o}, 50^{o}, and 60^{o} angles of bifurcation and a recovery volume of 100ml, 200ml, 300ml, 400ml and 500ml. The velocity profile obtained from this study has revealed the existence of a velocity range in the branched daughter channels of a symmetrical bifurcation, and the velocity range has its maximum and minimum values at the inner and outer walls of the branched daughter bifurcated channels, and the results further reveals the alternation of the maximum velocity between the inner and outer walls of the bifurcated daughter channels.

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INTRODUCTION

The branching of a main channel into two or more channels known as bifurcation has attracted a host of interest since the last decade because of its wild range of application and relevance in different works of life as [1] considered a rigid symmetrically bifurcated flow channel in their investigation of the steady flow of the Newtonian and incompressible fluid through the geometrical symmetric branched channel, with bifurcation angle of 60o, and an area ratio of 2.0 between the branched channel and the main channel, with the Navier-Stokes equation of the system used to analyze the bifurcated system with an upstream flow Reynolds number of 100 and 150, which enabled them to obtain results that is related to the predicted velocity pattern, the effect of secondary flow, a region of reverse flow, particle trajectory at the recirculation zone, and the shear stress at the point of bifurcation, also in [2] a velocity pattern that agrees quantitatively with other results obtained from experiments, their investigation here was extended as they considered unsteadiness in the flow of the non-Newtonian and incompressible fluid flow, and a great observation was done on the reversal region of the fluid with regards to the highest flow Reynolds number at the inlet pulse cycle, and other fascinating result that is related to the secondary flow, shear stress at critical areas of the symmetrically bifurcated system.

Also extending this study to analyze a case where there is a natural appearance of bifurcated system, that is in the human arterial system, where it enables the distribution of blood plasma throughout the human tissues and organs [3] in their bid to provide explanation to the effect of flow velocity of the blood on the Wall shear stress of the asymmetrical bifurcated arterial system, to investigate the pulsation effect of the bloodlike fluid in the simulated small bifurcation arterial channels, where the viscoelastic properties of the blood, and the local velocity of the bloodlike fluid were obtained using the micro-Particle Image Velocimetry (PIV), which enable the computation of the wall shear stress and how it relates to the associated pulse and the characteristic flow Reynolds number. Also considering the wild range of application and significance of flow distribution in heat exchanger, fluid packaging device, reactors, fuel cell etc [4] in their experimental investigation of the flow unification of fluid distribution through novel bifurcation channel, in their study they considered a bifurcated system with a symmetrical geometry to enable them to achieve a flow pattern with great uniformity [5] studied the impact of both asymmetric and symmetrical geometric bifurcated arteries on the flow of red blood cells, considering the heterogeneous nature of blood sample and its effective physical properties, the two dimensional simulation shows a significant effect of the blood component , effects such as cell deformation, internal migration of cells as they flow through a diverging and converging geometrical channels.

D2Q9 model and the relaxation time model of the famous Lattice-Boltzmann method were used by [6] to approach the examination of the fluid behavior of the non-Newtonian fluid flow in tow dimensional bifurcated, results obtained from simulation of the power-law index of 0.5, 1.0 and 1.5 and flow Reynolds number of 300 revealed some effects on streamline pattern, velocity distribution, recirculation zone as well as wall shear stress near the arterial bifurcation point. The impact of shear induced migration phenomenon at the centerline leads to the creation of blunt velocity profile at the point of bifurcation, in the study of the migration of particle of a concentrated suspension in a bifurcated channel conducted by [7] where they were able to observe the maximum velocity at the outer wall which consequently leads to the appearance of asymmetry in the velocity pattern in the branched daughter channel. [8,9] also conducted research on bifurcation with excellent results regards the distribution of some selected fluid samples in a bifurcated channel.

In this work we want to sample and analyze the different velocity values at critical stages of the single stage bifurcated network system, as water representing polar solvent and crude oil representing unprocessed are allowed to flow through each of a six cylindrical bifurcated glass tube, which will be further analyzed by resolving the branched daughter channels into components and the mean used to put up their respective velocity profile for analysis.

MATERIALS AND METHOD

Materials

The reservoir is fabricated at the wielding and fabrication department of the University of Port Harcourt Science and Engineering Workshop, using a cylindrical steel pipe with inner diameter of about 6inch and a height of about 30inch corresponding to a volume capacity of 12litrs. At one end of the reservoir a control valve is attached to enable proper and timely control of fluid samples that will be used in the experiment. While the glass tube is blown at the Glass blowing department of the same University of Port Harcourt Science and Engineering workshop. Six glass tubes (with inner diameter of 2inch and a length of about 20inch), of geometrically symmetrical bifurcation with total angle between the two branched daughter channels of 10^o, 20^o, 30^o, 40^o, 50^o, and 60^o were blown.

Setup

The reservoir is positioned so that it will be at a height of about 2.5ft from the surface of the ground, and the main channel of the glass tube connected to the control valve, and positioned in such a way that the outlet of the glass tubes, that is the two daughter channels are placed in such a way that fluid samples will be recovered into two beaker of 500ml each. Detailed description of the physical properties of the fluid samples and experimental procedure is given in [Egbo et al]

Governing Equation

For each cycle of the experiment, a designated volume of fluid is meant to be recovered, first is 100ml, then 200ml followed by 300ml, 400ml then 500ml. when a fluid sample of 100ml is recovered, it implies simply that the specified volume of fluid has flowed through a total length (L) of the pipe, given by

$$L_M + L_d = L_T \qquad 1$$

Where L_M is the length of the main channel, L_d is the effective angle of the daughter channels geometrical bifurcated system, given by

$$L_d = \frac{L_{sin}\theta + L_{cos}\theta}{2} \qquad 2$$

Hence the flow average velocity (V_A) is correspondingly given by the equation

$$V_A = \frac{L_T}{t} \qquad 3$$

This is computed for every designated volume of each of the bifurcated angle, which will result into obtaining five velocity (V_1, V_2, V_3, V_4, V_5) components for each of the symmetrical bifurcated.
This will further used to obtain a degree-two fitted equations of the form

$$c + bx + ax^2 \qquad 4$$

For all selected angles.

RESULTS AND DISCUSSION

The flow properties considered in this observation are meant to represent different categories of fluid with similar physical properties such as viscosity, density and specific gravity. Water representing polar solvent and other fluid samples with similar physical properties, crude oil representing unprocessed hydrocarbons and other fluid samples with physical properties that revolves around it. The numerical set observed from the fluid sample, shows some difference in the least square equation of degree two in equation 4, used to computed from the average flow velocity through each of the selected angles of presented in the table 1.

The tabulated result show higher value of coefficient for x^2, x and the constant of the least square equation of water compared to the least square equation of crude oil, which could be a consequence of their characteristic viscosity and density, as crude oil with high viscosity and low density tends to show a lower coefficient value of x^2, x and constant in the least square equation when compared with the viscosity and density of water and it's corresponding coefficient values of x^2, x and constants of its least square equations.

Table 1: Least square equation of

S/N	CRUDE OIL	WATER	ANGLES
1	$0.1517 - 0.04605x + 0.004533x^2$	$0.2205 - 0.06626x + 0.006753x^2$	5°
2	$0.1313 - 0.04269x + 0.004254x^2$	$0.1895 - 0.05497x + 0.005417x^2$	10°
3	$0.1472 - 0.04582x + 0.004670x^2$	$0.2849 - 0.09389x + 0.01012x^2$	15°
4	$0.1974 - 0.06388x + 0.006578x^2$	$0.3068 - 0.09387x + 0.009794x^2$	20°

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5	$0.1698 - 0.05016x + 0.004697x^2$	$0.3112 - 0.1022x + 0.01077x^2$	25º
6	$0.1159 - 0.03137x + 0.002750x^2$	$0.2168 - 0.06759x + 0.006982x^2$	30º

Shown by the profile of result presented in Figure 1 for the average flow velocity against volume are trends that shows a decrease in the mean velocity gradient as the angle of bifurcation increases from 5º, 10º and 15º represented by the red, green and yellow trends respectively. While for bifurcation angle of 20º, 25º respectively represented by the purple and blue trends shows highest velocity gradient, while the brown trend for the bifurcation angle of 30º shows the least mean velocity gradient in the profile.

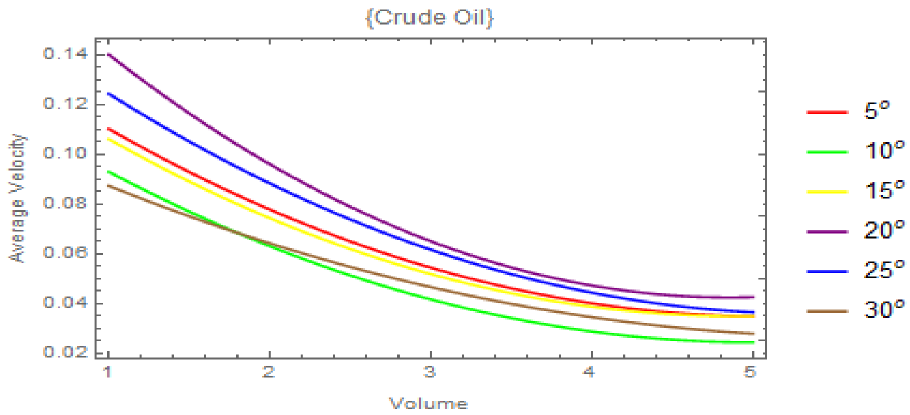

Figure 1 Velocity profile of Crude oil for the selected angles of bifurcation

The profile of result presented in figure 2 shows an irregular increase in the average flow velocity in the order of 10º, 30º, 5º, 15º, 20º, and 25º corresponding to the green, brown, red, yellow, blue and purple trends which can be further stated on average is an increase in the velocity gradient as the angle of bifurcation increases.

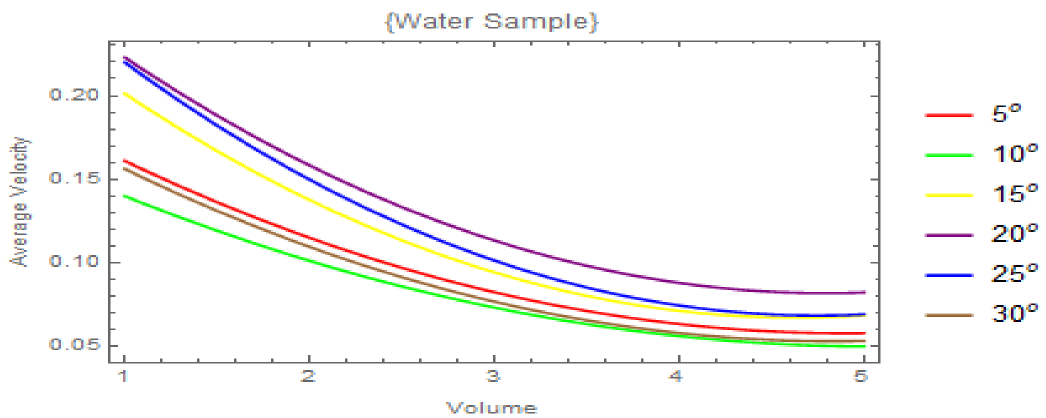

Figure 2 velocity profile of Water for the selected angles of bifurcation

Figure 3 compares the computed vertical and horizontal components of the flow velocity through the selected bifurcated channel with their mean velocity component respectively represented by the blue, purple and green trends. The results presented shows that the mean flow velocity represented by the green trend lies in between the vertical trend represented by the blue trend and the horizontal component represented by the purple trend. Also observed by [8] the alternation of the blue and purple trends in this profile within the selected angles of bifurcation, which implies the existence of a maximum and minimum flow velocities at opposite walls of the branched tubes, which further indicate that the velocity values represented by the blue and purple trends for the vertical and horizontal velocity of component constitute the maximum and the minimum flow velocity upon bifurcation. The vertical component represented by the blue trend become the upper band of the maximum velocity value when the blue trend is at a higher velocity gradient, and minimum value when the blue trend is at the lower velocity gradient, and the horizontal component represented by the purple trend indicates that the horizontal velocity component become the maximum value when the purple trend is at a higher velocity gradient and minimum velocity when the trend is at a lower velocity gradient. The mean value which usually lies in between the resolved velocity component, that is a velocity value that must exist with the branched channel of the bifurcated tube.

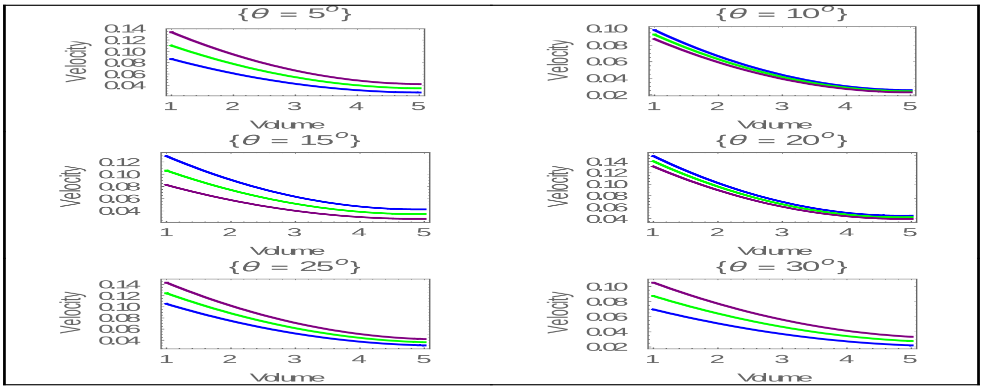

Figure 3 Velocity profiles of the horizontal, vertical component and their mean component for crude oil

A similar result is observed in figure 4 representing the velocity components of water, the existence of velocity band, with blue trend representing the outer wall velocity component been the top of the band when it is at a higher velocity gradient, to been the bottom of the band when it is at lower velocity gradient. And an alternation of the maximum average flow velocity between the inner and water wall of the branched daughter channel, implying that the outer wall of the branched daughter channels is at a higher average velocity at 10^{o}, 15^{o} and 20^{o} where the inner walls correspondingly are at lower velocity gradient respectively, and seen to be at lower average velocity at 5^{o}, 25^{o} and 30^{o} where the inner wall of the branched daughter channel is at higher average velocity.

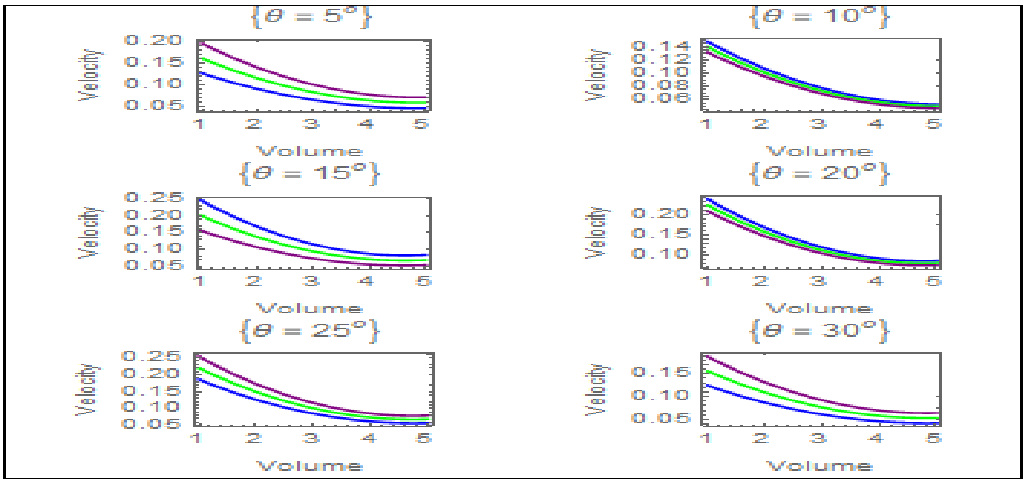

Figure 4 Velocity profiles of the horizontal, vertical component and their mean component for water

Figure 5 compares the average velocity against volume for each of the selected angles all revealed crude oil which is at lower average velocity gradient for all the angles compared to water, is most likely be as a result of the difference in their physical properties such as viscosity and density

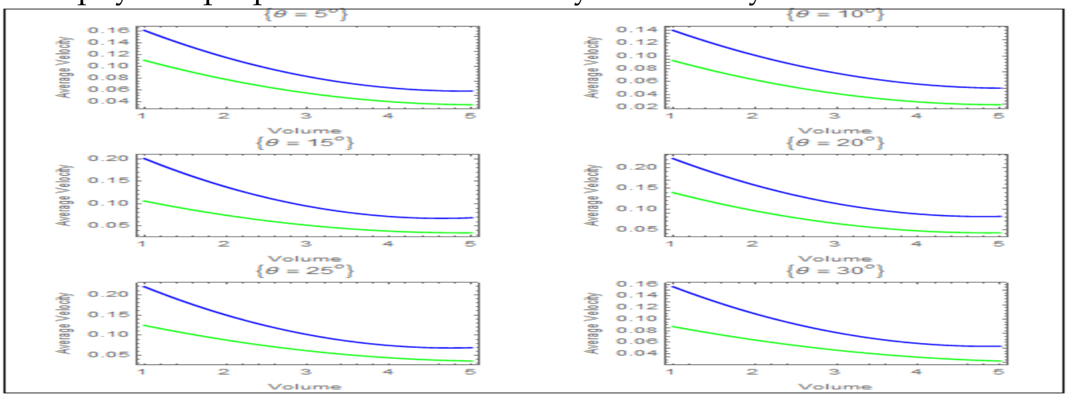

Figure 5 mean velocity profiles of crude oil and water

CONCLUSION

There exist a range of velocity values defined by the components of the velocity in the branched channel, unlike the conventional flow in a straight pipe where the flow velocity is zero at the walls of the pipe and increases gradually to a maximum value at the center of the pipe, while for a bifurcated network pipe the maximum flow velocity alternate between direct opposite wall, normal to the surface of the branched channel. There exists an average flow velocity identified in this experimental investigation that will always be observed at the center of the bifurcated daughter channel. The alternation of the flow velocity gradient defined by the upper bound and the velocity gradient defined by the lower band always passes through a mean velocity value for all the angle.

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