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Mathematical Modeling of two-phase Blood flow in Artery Presence of breathing problem affected by Lung Cancer

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ABSTRACT

The aim of the present study is to examine a mathematical model (based on non Newtonian flow) of two phase blood flow in artery presence of breathing problem affected by Lung cancer. We have applied power law model in bio fluid mechanical setup. We have presented the relationship between hemoglobin and blood pressure drop. In the present study overall presentation is in Tensor form and the solution technique used is both analytical and numerical. Which, given the medical point of view, will be beneficial and useful in the field of medicine.

Keywords : Hemoglobin, Blood pressure drop, Hematocrit

1 INTRODUCTION

The most important part of the circulation in human body is that is a continuous circuit. If a given volume of blood is pumped from the heart, the same will be return heart after passing through the different sub-system of the circulatory system[3,5]. Shortness of breath can be caused by cancer and its treatment, according to the American Cancer Society. Dyspnea is the medical term for this. When people have problems breathing, it's possible that their bodies aren't getting enough oxygen because their lungs can't take in enough air or their bloodstream can't carry enough oxygen[16]. The human lungs performed just like purification station of blood [11]. The function of the arteries is to carry blood to the tissues under high pressure. The arteries have thick vascular walls and blood flows through the arteries at high speed. The arterioles are the last small branches of the arterial system; the act as control lines through which blood is released in to the capillaries.

Since the pressure in the venous system is very low, the walls of the veins are thin. Even so, they are muscular enough to contract of expand and thus as a controllable reservoir for extra blood, either in small or large amounts, depending on the needs of the circulatory system [1]. Blood is an unpredictable liquid as non-Newtonian. Its stream laws don't comply with the laws of basic liquids depicted by the Navier-Stokes conditions [5]. The amount of blood in the human body is significant, making up around 7% of the aggregate body weight. Blood functions in the transport of oxygen, nourishment, hormones (food hormones) and waste material in the guideline of temperature and in control of disease.

Blood and its subordinate lymph form a sort of inward sea that ceaselessly bathes our cells. Blood is a fluid tissue. It streams promptly in light of the fact that its constituent cells are not consolidated in an inflexible or semi – unbending system, however are suspended in watery medium. The cell floats independently and is

conveyed along like flotsam or jetsam in spilling current. As blood courses through the vessels of the circulatory system, it comprises of a complex, straw shaded liquid plasma in which float that suspended RBC, WBC and platelets. The liquid plasma makes around 55% out of the aggregate volume and cells make up the staying 45% of the aggregate volume [3,6].

1.2 HEMATOCRITAND ITS RELATION:

According to Upadhyay & Kumar blood is not an ideal liquid, but a mixture of plasma and blood cells. These blood cells, packets of semi-permeable fluid with a density greater than that of plasma, can change in shape and size, and the behavior of blood is almost Newtonian at high shear rates, while at low shear rate of blood exhibits yield stress and non-Newtonian behavior. Blood flow is affected by the presence of blood cells and this effect is directly proportional to the volume absorbed by the blood cells [10,7,9].

1.3 MATHEMATICAL FORMULATION:

Whenever the hematocrit increases, the effective viscosity of the blood flowing in the arteries remote from the heart depends on the rate of stress. In this condition, the blood flow becomes non-Newtonian. In this situation the constitutive equation for blood is

$$\tau^{ij} = -pg^{ij} + \eta_m(e^{ij})^n = -pg^{ij} + \tau'^{ij} \qquad (1.2.1)$$

Where, τ^{ij} is stress tensor and τ'^{ij} is shearing stress tensor.
The equation of continuity in tensorial form for power law will be as follows:

$$\frac{1}{\sqrt{g}}(\sqrt{g}v^i)_{,i} = 0 \qquad (1.2.2)$$

Again, write down the equation of motion as follows

$$\rho_m\left(\frac{\partial v^i}{\partial t}\right) + (\rho_m v^j)v^i_{,j} = \tau^{ij}_{,j} \qquad (1.2.3)$$

Where τ^{ij} is equation of power law flow (1.2.1). $\rho_m = X\rho_c + (1-X)\rho_p$, is the density of blood and $\eta_m = X\eta_c + (1-X)\eta_p$ is the viscosity of mixture of blood, $= \frac{H}{100}$, (where X is volume ratio of blood cells). Other symbols have their usual meanings. Since the blood vessels are cylindrical, the above major equations have to transform the equations in cylindrical form. As we know for cylindrical co-ordinates,

$$X^1 = r,\ X^2 = \theta, X^1 = r, X^3 = z$$

As we know earlier:
Matrix of metric tensor in cylindrical coordinates is fallows:

$$[g_{ij}] = \begin{bmatrix} 1 & 0 & 0 \\ 0 & r^2 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

While matrix of conjugate metric tensor is follows:

$$[g_{ij}] = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1/r^2 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Whereas the Chritoffel's symbol of 2nd kind is as follow-
$\begin{Bmatrix} 1 \\ 2\ 2 \end{Bmatrix} = -r, \begin{Bmatrix} 1 \\ 2\ 2 \end{Bmatrix} = \begin{Bmatrix} 1 \\ 2\ 2 \end{Bmatrix} = \frac{1}{r}$, Remaining others are zero.
The relation between covariant components and physical component of the velocity of the blood flow are as follows will be as:

$$\sqrt{g_{11}}v^1 = v_r \Longrightarrow v_r = v, \sqrt{g_{22}}v^2 = v_\theta \Longrightarrow v_\theta = rv^2, \sqrt{g_{33}}v^1 = v_z \Longrightarrow v_z = v^3$$

Again the physical components of $-p_{,j}g^{ij}$ is $-\sqrt{g_{ii}}p_{,j}g^{ij}$
The matrix of physical components of sharing stress tensor $\tau'^{ij} = \eta_m(e^{ij})^n = \eta_m(g^{ik}v_{,k}{}^i + v_{,k}{}^j)^n$ will be as follows

$$\begin{bmatrix} 0 & 0 & \eta_m\left(dv/dr\right)^n \\ 0 & 0 & 0 \\ \eta_m\left(dv/dr\right)^n & 0 & 0 \end{bmatrix}$$

The covariant derivative of τ'^{ij} is

$$\tau^{ij}_{,j} = \frac{1}{\sqrt{g}}\frac{g}{\partial X^i}\left(\sqrt{g}\tau^{ij}\right) + \left\{ \begin{matrix} i \\ j \end{matrix} \quad \begin{matrix} \\ k \end{matrix} \right\}\tau^{ik}$$

Keeping in view the facts, the governing tensorial equations can be transformed into cylindrical form which is as follows:

Equation of continuity

$$\frac{\partial v}{\partial z} = 0 \qquad (1.2.4)$$

Equation of motion

Components of equations of motion

r- Component

$$-\frac{\partial P}{\partial r} = 0 \qquad (1.2.5)$$

θ – Component

$$0 = 0 \qquad (1.2.6)$$

Z – Component-

$$0 = -\frac{\partial P}{\partial z} + \frac{\eta_m}{r}\frac{\partial}{\partial r}\left[r\left\{\frac{\partial v_z}{\partial r}\right\}^n\right] \qquad (1.2.7)$$

Here this reality has been taken in see that the blood stream (flow) is pivotally (axially) symmetric in supply routes concerned[4].

i.e. $v_\theta = 0$ And $v_r = 0$,

v_z and p do not depend upon θ. Also the blood flow steadily, i.e.

$$\left(\frac{\partial \mathrm{p}}{\partial \mathrm{t}}\right) = \left(\frac{\partial v_\mathrm{r}}{\partial \mathrm{t}}\right) = \left(\frac{\partial v_\theta}{\partial \mathrm{t}}\right) = \left(\frac{\partial v_\mathrm{z}}{\partial \mathrm{t}}\right) = 0 \qquad (1.2.8)$$

1.4 SOLUTION

The blood glide in arteries is symmetric w.r.t. axis. As a result $v_\theta = 0$ (v_r , v_z and p do now not really on θ also). When you consider that best one component of the rate that's effective, $v_r = 0, v_\theta = 0$ and $v_r = v$ say, the glide is regular, we have

$$\left(\frac{\partial \mathrm{p}}{\partial \mathrm{t}}\right) = \left(\frac{\partial v_r}{\partial \mathrm{t}}\right) = \left(\frac{\partial v_\theta}{\partial \mathrm{t}}\right) = \left(\frac{\partial v_\mathrm{z}}{\partial \mathrm{t}}\right) = 0$$

Now we keeping in view these facts and we obtain the following consequence

Then equation of continuity reduces to

$$\left(\frac{\partial v_z}{\partial \mathrm{z}}\right) = 0 \Longrightarrow v_z = v(\mathrm{r}) \qquad (1.3.1)$$

The r^{th} component of equation of motion reduces to

$$\rho_\mathrm{m}(0) = -\left(\frac{\partial \mathrm{p}}{\partial \mathrm{r}}\right) + \eta_\mathrm{m}(0) \Longrightarrow \left(\frac{\partial \mathrm{p}}{\partial \mathrm{r}}\right) = 0 \Longrightarrow \mathrm{p} = \mathrm{p}(\mathrm{z}) \qquad (1.3.2)$$

Again θ – Component of equation of motion reduce to

$$\rho_\mathrm{m}(0) = -(0) + \eta_\mathrm{m}(0) \Longrightarrow 0 = 0 \qquad (1.3.3)$$

Also, the z^{th} component of equation of motion reduces to

$$\rho_\mathrm{m} \mathrm{v_z}\left(\frac{\partial v_\mathrm{z}}{\partial \mathrm{t}}\right) = -\left(\frac{\partial \mathrm{p}}{\partial \mathrm{z}}\right) + \eta_\mathrm{m}\left[\frac{1}{\mathrm{r}}\frac{\partial}{\partial \mathrm{r}}\left\{\mathrm{r}\frac{\partial(v_\mathrm{z})}{\partial \mathrm{r}}\right\} + \left(\frac{\partial^2 v_\mathrm{z}}{\partial \mathrm{z}^2}\right)\right] \qquad (1.3.4)$$

From equation (1.3.1) and (1.3.4) we get-

$$0 = -\left(\frac{\partial \mathrm{p}}{\partial \mathrm{z}}\right) + \eta_\mathrm{m}\left[\frac{1}{\mathrm{r}}\frac{\partial}{\partial \mathrm{r}}\left\{\mathrm{r}\frac{\partial v(\mathrm{r})}{\partial \mathrm{r}}\right\}\right] \qquad (1.3.5)$$

Where, the equation (1.3.2) expresses the actuality that the pressure p depends only on z. We additionally written the details that pressure gradient $-\left(\frac{\partial \mathrm{p}}{\partial \mathrm{z}}\right)$ within the artery far off from heart is constant, say p then the equation (4.5) and we take the equations following shape-

$$0 = \mathrm{P} + \eta_\mathrm{m}\left[\frac{1}{\mathrm{r}}\frac{\partial}{\partial \mathrm{r}}\left\{\mathrm{r}\frac{\partial v(\mathrm{r})}{\partial \mathrm{r}}\right\}\right] \qquad (1.3.6)$$

Now, integrating the equation (1.3.6), we get,

$$\mathrm{r}\left(\frac{\mathrm{d}v}{\mathrm{dr}}\right) = -\left(\frac{\mathrm{Pr}^2}{2\eta_\mathrm{m}}\right) + \mathrm{A} \qquad (1.3.7)$$

Where, A is the constant and we have applied the first boundary condition (4.7) and we have get-

$$A = 0$$

Hence equation (1.3.7) reduces to

$$\mathrm{r}\left(\frac{\mathrm{d}v}{\mathrm{dr}}\right) = -\left(\frac{\mathrm{Pr}^2}{2\eta_\mathrm{m}}\right) \qquad (1.3.8)$$

Integrating the equation (1.3.8), we get-

$$v = -\frac{\mathrm{Pr}^2}{4\eta_\mathrm{m}} + \mathrm{B} \qquad (1.3.9)$$

Again using 2nd boundary condition on the equation (4.9) and we can evaluate the integration constant as follows-

$$B = \frac{PR^2}{4\eta_m}$$

Putting the value of B in the equation (1.3.9) and we obtain the velocity of blood flow in the arteries remote from the heart as follows-

$$v = \frac{P}{4\eta_m}(R^2 - r^2) \qquad (1.3.10)$$

1.5 Mathematical Analysis for Pulmonary Arteries

Now we have integrated equation (1.2.3), $v_z = v(r)$ {v does not depend upon θ} and the integrating of equation of motion (1.2.5) yields:

Where, $P = P(z)$ {p does not depend upon θ}.

Now, from equation (1.2.7) and (1.2.8) the equations of motion (1.2.6) change in to the subsequent shape-

$$0 = -\left(\frac{dp}{dz}\right) + \left(\frac{\eta_m}{r}\right)\frac{d}{dr}\left\{r\left(\frac{dv}{dr}\right)^n\right\} \qquad (1.4.1)$$

We know that the pressure gradient $-\frac{\partial p}{\partial z} = P$ of blood flow in the arteries remote the heart may be hypothetical to be steady and for this equation (3.8) the following form-

$$\frac{d}{dr}\left\{r\left(\frac{dv}{dr}\right)^n\right\} = -\left(\frac{P_r}{\eta_m}\right) \qquad (1.4.2)$$

Again equation (1.2.8), we obtain

$$r\left(\frac{dv}{dr}\right)^n = \frac{P_r}{2\eta_m} + A \qquad (1.4.3)$$

The rate of the blood go with the flow at the axis of cylindrical arteries is most and constant. So that we've concern the boundary conditions at r = 0, $v = v_0$ (constant), on equation (1.4.2) takes the subsequent shape-

$$r\left(\frac{dv}{dr}\right)^n = \frac{P_r}{2\eta_m} \Longrightarrow -\frac{dv}{dr} = \left[\frac{P_r}{2\eta_m}\right]^{\frac{1}{n}} \qquad (1.4.4)$$

Again integrating equation (1.4.4), we get-

$$v = -\left[\frac{P}{2\eta_m}\right]^{\frac{1}{n}} \frac{r^{\frac{1}{n}+1}}{\frac{1}{n}+1} + B \qquad (1.4.5)$$

To finish the arbitrary steady B, we are able to be applying the non-slip condition on the inner wall of the arteries at $r = R, v = 0$,

where R = radius of blood vessels, on equation (1.4.5) so as to get

$$B = \left[\frac{P}{2\eta_m}\right]^{\frac{1}{n}} \frac{nR^{\frac{1}{n}+1}}{n+1}$$

Hence the equation (1.4.5), we take the following form-

$$V = \left[\frac{P}{2\eta_m}\right]^{\frac{1}{n}} \frac{n}{n+1}\left[R^{\frac{1}{n}+1} - r^{\frac{1}{n}+1}\right] \qquad (1.4.6)$$

Which conclude that the velocity of the blood flow in the artery remote from heart. Now, we know that, $Q = 0.00708333\ m^3/\text{sec}$[15,8], $\eta_p = 0.0013$ pascal second[12] and $\eta_m = 0.0271$ pascal second[13]. Approximately pulmonary artery length is $(z_f - z_i) = 5\ cm$ or 0.05 m., pulmonary arterioles and venules length = 0.0015 m.[14].

1.5 Bio-physical interpretation for artery blood vessel

The flow flax of blood through the arteries is-

$$Q = \int_0^R V.2\pi r dr = \int_0^R \left[\frac{P}{2\eta_m}\right]^{\frac{1}{n}} \frac{n}{n+1}(R^{\frac{1}{n}+1} - r^{\frac{1}{n}+1})$$

$$Q = \left[\frac{P}{2\eta_m}\right]^{\frac{1}{n}} \frac{n2\pi}{n+1}\left[\frac{R^{\frac{1}{n}+1}.r^2}{2} - \frac{nr^{\frac{1}{n}+3}}{3n+1}\right]_0^R$$

$$Q = \left[\frac{P}{2\eta_m}\right]^{\frac{1}{n}} \frac{n2\pi}{n+1}\left(\frac{(n+1).R^{\frac{1}{n}+3}}{2(3n+1)}\right)$$

$$Q = \left[\frac{P}{2\eta_m}\right]^{\frac{1}{n}} \frac{n\pi R^{\frac{1}{n}+3}}{3n+1} \qquad (1.5.1)$$

Table 1 : Clinical Data– Data between real clinically blood pressure drop

Date	Hemoglobin (gram/dl)	Hematocrit $(3 \times HB)$ (kg/l)	Blood Pressure (mmhg)	BPD in Pascal Second $\left(\frac{S+D}{2}\right) - S$ (BPD*132.133)
21/05/2016	12.0	0.033963	110/60	-3328.3
09/07/2016	11.8	0.033397	110/80	-1996.98
12/10/2016	11.9	0.0336793	110/60	-3328.3
24/12/2016	11.7	0.0331133	100/80	-1331.32
26/03/2017	11.2	0.03169812	100/60	-2662.64
12/05/2017	10.0	0.02830189	130/80	-3328.3
17/08/2017	10.2	0.02886793	110/70	-2662.64

In according to used clinical data (Table: I) (Hematocrit) $H = 0.0331133$ and Pressure drop $(P_f - P_i) = 1331.32\ Pascal\ second.$

$$P(z) = \frac{P_f - P_i}{z_f - z_i}$$

And by using relation $\eta_m = \eta_c X + \eta_p (1 - X)$ …….. (W)

We get η_c

$$\Rightarrow 0.0271 = \eta_c(0.000331133) + 0.0013(0.999668867)$$

$$\eta_c = 77.91561238 \text{ Pascal second}$$

Again using (W) relation and change in to the hematocrit-

$$\Rightarrow \eta_m = 0.779156124H + 0.00129957$$

From equation (1.5.1)

$$P = -\frac{d_p}{d_z}$$

We get

$$Q = \left[\frac{\Delta P}{2\eta_m \Delta_z}\right]^{\frac{1}{n}} \frac{n\pi R^{\frac{1}{n}+3}}{3n+1} \qquad \text{..... (Y)}$$

Putting the values of Q, ΔP, Δ_z and R in equation (Y)

$$0.0070833 = \left[\frac{1331.32}{2\times 0.0271\times 0.05}\right]^{\frac{1}{n}} \frac{n\times 3.14\times (0.015)^{\frac{1}{n}+3}}{3n+1}$$

By apply trial and error method, we get- $n = 0.88958$

Again apply equation (Y) and putting $n = 0.88958$

$$0.0070833 = \left[\frac{\Delta P}{2\eta_m \Delta_z}\right]^{\frac{1}{n}} \frac{0.88958\times 3.14\times (0.015)^{\frac{1}{0.88958}+3}}{(3\times 0.88958)+1}$$

$$\Delta P = \eta_m (3190.330273)$$

$$\Delta P = (0.779156124H + 0.00129957)(98269.04)$$

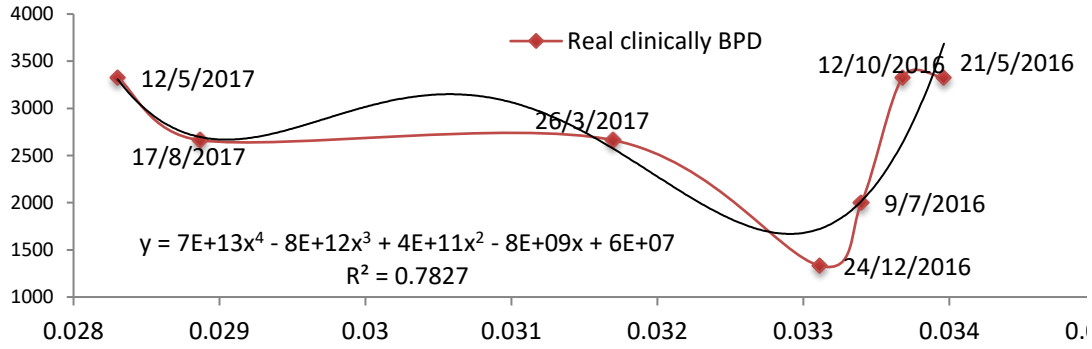
$$\Delta P = 2485.765369H + 4.146056004$$

Table 2 : Mathematically modulated blood pressure drop v/s hematocrit

Date	**Hematocrit $(3 \times HB)$ (kg/l)**	**BPD (Blood Pressure drop) Pascal –second**
21/05/2016	0.033963	88.57009398
09/07/2016	0.033397	87.16315078
12/10/2016	0.0336793	87.86488235
24/12/2016	0.0331133	86.45793915
26/03/2017	0.03169812	82.94013371

12/05/2017	0.02830189	74.49790279
17/08/2017	0.02886793	75.90494542

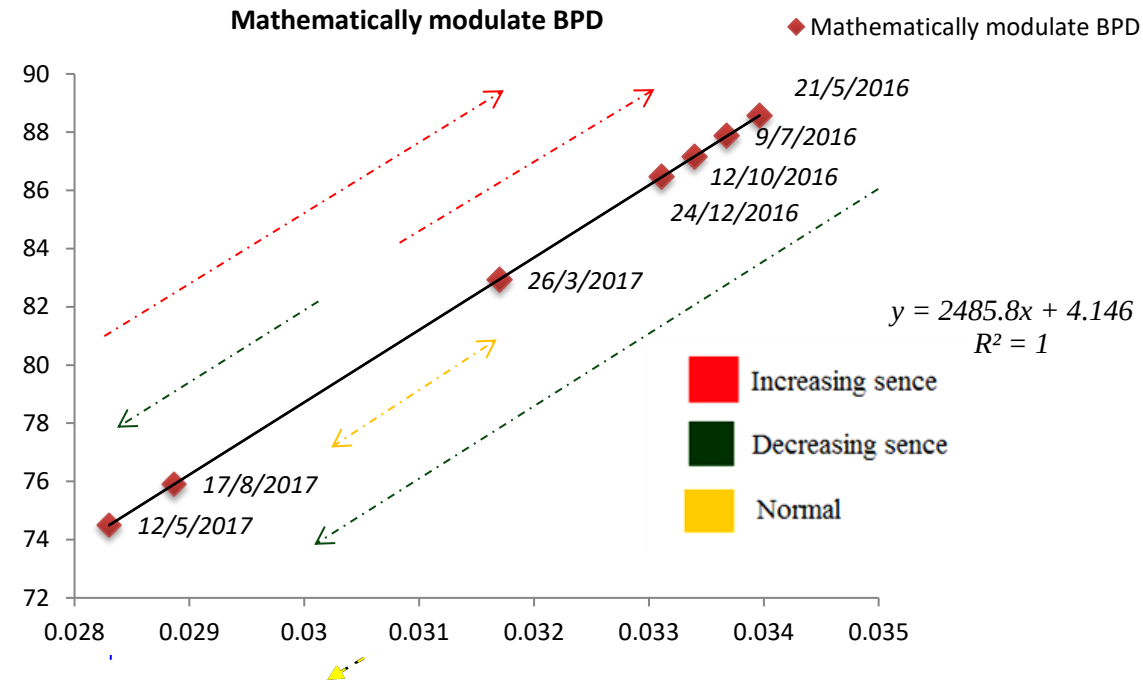
Graph : (a, b) relation between real clinically blood pressure drop and hematocrit, mathematically modulated blood pressure drop v/s hematocrit



Graph a (Table 1) relation between real clinically blood pressure drop and hematocrit. $BPD = \left(\frac{S+D}{2} - S\right)$, Where S = Systolic blood pressure and D = Diastolic blood pressure.

Measuring the proportion of red blood cells in our blood can help to make a diagnosis or monitor our response to a treatment. A lower than normal hematocrit can indicate an insufficient supply of healthy red blood cells. Increasing blood viscosity via an increase in hematocrit reduces peripheral vascular resistance, lowering blood pressure and increasing perfusion via the increase in cardiac index. P value of less than 0.05 was considered statistically significant. The ratio of hematocrit to hemoglobin has been generally accepted to be 2.941 for long time and it is simplified to be 3.0 in the daily clinical practice. Hematocrit will always be three times the hemoglobin value, regardless patient's hydration status.

ANOVA						
	df	***SS***	***MS***	***F***	***Significance F***	
Regression	1	205.789	205.7890306	3.19953E+19	3.27784E-48	
Residual	5	3.22E-17	6.43185E-18			
Total	6	205.789				
	Coefficients	***Standard Error***	***t Stat***	***P-value***	***Lower 95%***	***Upper 95%***
Intercept	4.14604473	1.4E-08	295430134.1	8.43393E-42	4.146044694	4.146044767
X Variable 1	2485.76537	4.39E-07	5656440092	3.27784E-48	2485.765369	2485.765371



In above we have taken blood characteristic as a homogeneous non-Newtonian fluid. An alternative approach is to describe it as a complex fluid that consists of blood plasma and blood cells. Blood plasma can be considered as Newtonian fluid and described by the Navier-Stokes equations or by particle methods. Blood cells can also be modeled with partial differential equations of continuum mechanics or they can be considered as ensemble of particles with various forces acting between them. In both cases, the interaction of cells with the fluid and between them should be taken into account.

Graph b (Table 2) relations between mathematically modulated blood pressure drop v/s hematocrit. $\Delta P = 2485.765369H + 4.146056004$, Where Δp is denoted by Relation between blood pressure drop v/s hematocrit (trained line). The linear model is found for the given data.

Observation

Graph (a) shows that these 7 different dates were observed minimum about 1331.32 on dated 24/12/2016 and maximum value obtain 3328.3 on dated 12/5/2017. The value from 0.0380189 to 0.03169812 via 0.02886793 of hematocrit value, the blood pressure drop down convex in decreases sence and the value from 0.02886793 to 0.0331133 via 0.03169812 of hematocrit value, the blood pressure drop proper upper convex in decreasing sence. Again the value from 0.0331133 to 0.0336793 via 0.033397 of hematocrit value, the blood pressure drop straightly increasing sence and the value from 0.0336793 to 0.033963 of hematocrit value, the blood pressure drop decreasing sence. Graph (b) shows that these 7 different dates were observed minimum about 74.49790279 on dated 12/5/2017 and maximum value obtains 88.57009398 on dated 21/5/2016 (BPD). At the value from 0.033963 to 0.02830189 via 0.033397, 0.0336793, 0.0331133, 0.03169812 & 0.02886793 of hematocrit value, the blood pressure drop straightly decreases on dated 21/5/2016 to 12/5/2017 via 9/7/2016, 12/10/2016, 24/12/2016, 26/3/2017 & 17/8/2017.

Result of Analysis

From above **clinical data (table 1)** a mathematically investigated and concluded figure II; graph b (table. II) Shows from 21/5/2016 to 12/5/2017 via 9/7/2016, 12/10/2016, 24/12/2016 & 26/3/2017 decreasing sense whereas from 12/5/2017 to 17/8/2017 shows increasing sense. In the above graphs (a & b) we have observed "relation between real clinically blood pressure drop" and "relation between mathematically modulated blood pressure drop v/s hematocrit" graph are shows different nature but there trend line are not different. Trend lines of above graphs shows that if trend is upward it means fluctuation of blood (pressure drop) increases with respect to the hematocrit. Trend is downward that means fluctuation of blood pressure drop decreases with respect to the hematocrit. According to present study work concluded that designate the function of

hematocrit inside the will power of blood pressure drop. For this reason the hematocrit is extended then the blood pressure drop is likewise multiplied.

Conclusion

We are using numerical technique with analytical approach to find the value of parameter n and solution of equations and get continuous solutions. Similarly we can do work different disease in same tissue. If used numerical techniques with numerical approach and by using these techniques, we can get discrete numerical solutions in special points. With the help of these solutions we can more study of critical situations and better explain of these critical situations. The result will be improved with the help of numerical methods and further can be formulated. We can conclude that blood is generally a non-Newtonian fluid, which can however be regarded as a Newtonian fluid to model blood flow in arteries with diameters larger than 100 μm where measurements of the apparent viscosity show that it ranges from 0.003 to 0.004 P a.s and the typical Reynolds number is about 0.5. The behaviour of many fluids at low shear stress, including blood, has led researchers to believe in the existence of a critical value of stress below which the fluid will not flow. This critical stress level, called the yield value or yield, is typically treated as a constant material property of the fluid.

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