Estimation of blood viscosity through fuzzy logic

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***Abstract*— Computational Health care is one of the state of the arts in the contemporary era. Many softwares are in use as diagnostic support systems(DSS) to develop knowledge based systems in clinical and diagnostic fields for detecting vital parameters which help medical fraternity and ultimately benevolent of patients betterment and successful treatment. In this context the Blood Viscosity(BV) is an highly and exceptionally important parameter in estimating physical fitness and disease characteristics of a patient. In majority of medical procedures the physician is in need of on hand and quick information about blood parameters. The blood viscosity (BV), hematocrit (HCT) and plasma viscosity (PV) remains to be all time demand to have better knowledge of patient's disease. The BV is least cared in the in clinical and diagnostic practices. Sometimes the BV is better to that of ESR(ElectroSedimation Rate). In the present work the BV is predicated using the HCT and PV as the input parameters using the fuzzy logic system in mat lab environment. Here a simple fuzzy logic model is developed with two inputs as HCT and PV respectively, and BV as an output. The five GUI(Graphical User Interface) units of fuzzy logic are successfully implemented. The BV predicted here with the fuzzy system in both Newtonian and non-Newtonian cases for PV low and high values respectively, which are in good agreement with those clinically observed values. The BV therefore estimated without clinical procedures. The blood viscosity obtained through fuzzy logic is 0.021 – 0.025 poise for low HCT values or Newtonian fluid, and 0.0213 to 0.029 poise for high values of HCT or Non-Newtonian behavior.**

***Keywords*— Fuzzy logic, Blood Viscosity(BV), Hematocrit(HCT), Plasma Viscosity(PV), Fuzzification, Fuzzy Interference System(FIS), Fuzzy Rules, Defuzzification**

I. INTRODUCTION

The fuzzy logic is powerful mathematical tool which rightly deals with the real world problems which have uncertainty and have improper precessions in decisions. Very particularly this is very much true in case of health care conditions, drug monitoring, clinical diagnostics of medical discipline, where clinical decisions are in vagueness and most uncertain. One such problem in the present work is to predict the whole Blood viscosity (BV) using two input parameters such as Hematocrit(HCT), and Plasma Viscosity (PV) without lab tests or scaling measurements. Fuzzy logic systems are helpful to explore learning and decision making capabilities. The application of fuzzy system in prediction of vital parameter such as blood viscosity using plasma viscosity and hemotocrit. It is a sort of decision support system. Lofti A. Zadeh the father of the logic theory has introduced the elimination of crisp sets of the classical logical system wherein, a parameter is either a member or not. As a result a new and innovative approach was introduced, which is based on approximate human reasoning and the outcome was the fair transition between two extremes of logic set 0, 1. The parameter value belonging to these two extremes is called membership function. The fuzzy inference system (FIS) is based on three parameters: 1) Fuzzy rules 2) Membership functions from the data base and 3) Procedure to draw output from the given rules or facts logic. Mamdani and Sugeno are the two popular inference systems are used in different kinds of applications. Similar to the Sugeno type, another inference system called Adaptive Neuro FIS was developed by Jang. The Sugeno fuzzy logic system was introduced by Takagi Sugeno, and Kang. With the time many more types FIS have been introduced, but in this work we have used Mamdani FIS system.

Blood viscosity can be defined as resistance offered to blood flow. Physically it can be viewed as thickness and stickiness of blood fluid while flowing in the blood vessel. It is a bio physical parameter which creates friction against the vessel walls. The blood viscosity is vital parameter of hemodynamics, as it

determines the friction of the wall, rate of venous return, rate of heart pump, and oxygen transportation. The deciding factors of blood viscosity are hematocrit, red cell deformability, red cell aggregation, and plasma viscosity. In the present work, blood viscosity is predicted depending on hematocrit and plasma viscosity using mat lab fuzzy logic system. The proposed blood viscosity fuzzy logic model is illustrated in figure1 below.

The blood viscosity fuzzy logic model components are described below:

The fuzzy logic model has two inputs, hematocrit, plasma as input1 and input2 respectively. These inputs are fed to fuzzification, which scales and maps input variables into fuzzy sets.

These fuzzy sets are fed to decision making fuzzy rules. The fuzzy rules are created by fuzzy inference mechanism (FIS). The FIS system has approximate reasoning using if – then – else rule. In this case about nine reasoning rules are set up.

The HCT and PV are selected as inputs to predict the blood viscosity (BV) as output. The FIS generate the control action with inputs from fuzzyfication. Based on the fuzzyfication the defuzzyfication process generate the output control signals which is BV in this case.

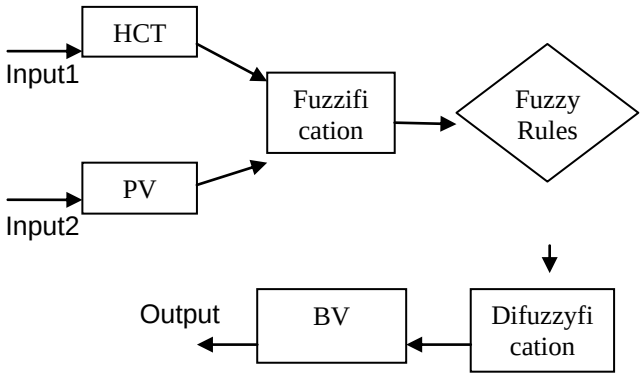

Fig.1: Fuzzy logic model of Blood Viscosity

II. FUZZY LOGIC THEORY

As explained by LA Zadeh in his proceedings [8], fuzzy logic is based on set of mathematical rules for knowledge which is represented by membership functions. A fuzzy set has fuzzy boundaries. The defined fuzzy sets which have variables which allow intermediate membership in the range 0 to 1. If X is said to be universal set then its elements are represented byX. Then the fuzzy set is defined as

$\mu_A = X\ [0, 1]$ (1)

Then we can write

$\mu_A(X) = 1$, where $X \in A$ (2)

$\mu_A(X) = 0$, where $X \notin A$ (3)

Therefore it maps various shapes between [0 1]. The shapes are triangular, trapezoidal, sigmoid, and Gaussian. The most commonly used function is triangular. In the present work triangular function is used for the mapping purpose. This triangular mapping function is discussed briefly here.

$$\mu_A(X) = \begin{pmatrix} 0\ if\ x \le a \\ \frac{x-a}{c-a} if\ x \in [a,c] \\ \frac{b-x}{c-b} if\ x \in [b,c] \\ 0\ if\ x \ge c \end{pmatrix} \quad (4)$$

This equation is general equation for trapezoidal membership function. This equation will be equally well for triangular membership function when two shoulders of trapezoidal points are made equal or the triangular membership function is derived from trapezoidal membership function by merging two shoulder points into one.

The terms a, b and c are defined as high, medium and low respectively of each member ship functions.

A. Blood viscosity

Viscosity, is defined as the internal friction between the layers of fluid, is a measure of thickness of a fluid. The higher the viscosity, thicker the fluid. Depending on whether the viscosity of fluids changes with flow rate or not, fluids may be classified as Newtonian or non-Newtonian behaviour. The viscosity of Newtonian fluids like water, honey and oil does not change with flow rates. The viscosity of blood, a non-Newtonian fluid, blood viscosity increases with falling shear rates. The increase is dramatic at low shear rates.Theblood viscosity depends on plasma viscosity.hemotocrit (HCT). The HCT defined as percentage of erythrocytes in the wholeblood. This can be seen in the figure 2 below. The HCT is otherwise known as packed red cell volume (PCV). The average HCT ranges are mentioned below.

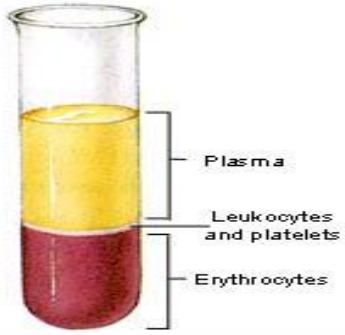

Fig2. Blood hemotocrit (HCT)

The reported standared ranges of HCT or PVC are mentioned below:

- Males..... 40-50%
- Females..... 38-45%
- Athletes..... > 50%
- High altitude living > 55

B. Plasma viscosity

Plasma viscosity varies with the concentration of its constituents. Fibrous proteins like fibrinogen contribute more to plasma viscosity than globular proteins like albumin. Acute phase reactants increase plasma viscosity. Of the plasma constituents immunoglobulin and cholesterol are clinically relevant. Clinically significant increases in viscosity are most common in patients with increased immunoglobulin, both monoclonal and polyclonal.

III. RELATED WORK

As per the studies of[X.Y. Dijam, et al 2011],the malaria management was explained by fuzzy expert system. The fuzzy expert system was designed using clinical observations, medical diagnosis and expert's knowledge. According to[Abbas K. Ali et al, 2010], an expert system was designed to diagnosis the diseases based on 20 doctors opinion. In this paper three respiratory diseases pneumonia (PEN), tuberculosis (TB), and normal influenza (INF) are diagnosed using fuzzy logic system. Heart echo signals were obtained through STFT which described heart diseases and heart conditions. For this purpose fuzzy logic system was used by [Mohamed Reza Karimi Rad, et al, 2012] to study the heart diseases classification. Symptom based Tuberculosis diagnostic decision system was developed by[K.Soundararajan,et al, 2012] based on fuzzy logic system.A comparative study wascarried out by [Dharamniwas, et al, 2012], in which fuzzy logic liquid level controller for tank level and Lab view controller were compared.

The textures classification was done by [Pankaj H. Chandankhede, 2012] using two techniques such as artificial neural network and adaptive neuro - fuzzy interference system. The neuro fuzzy interference model gave better results compared to neural network in texture classification. Using neural network and fuzzy logic system, diseases diagnosis support system (DDSS) was designed by [Le HoaiBac and Nguyen ThanhNghi, 2004].The results obtained through DDSS were encouraging. In the studies established by [Md. Ashrafuzzaman, et al, 2013], blood viscosity was a vital parameter in clinical and diagnostic procedures of medical sciences, but least cared by medical fraternity. The elevated blood viscosity (BV) in majority cases of the myocardial infractions, causing necrosis or tissue death. The Meridian valley lab[Meridian Valley lab, 2014] was reported as, the work of heart mainly depended on systolic blood pressure (BP), blood viscosity, and volume of blood the myocardium had to pump. Blood viscosity of unadulterated blood was determined by [Sanghokim et al, 2000], which was as low as 1 $s^{-1}$by scanning viscometer with capillary tube. As per the studies of [G.A.M. Popet al, 2002], the hematocrit was one of the factors influencing the blood viscosity, apart from macromolecules, temperature and red cell deformation. In an important experimental result, the BV is hemodynamically significant in contributing to thrombotic risk and hyper viscosity leading to inflammatory pain. Blood viscosity was basal index and determined by hematocrit, plasma viscosity, and aggregation of RBC.

As per the report from [Wiley on line library, 2009], the blood viscosity was affected by four parameters such as hematocrit value, the degree of aggregation of the red cells, the viscosity of the plasma, and the internal viscosity of the red cells. In another investigation by [Robert Rosencranz, and Steven A. Bogen, 2006], plasma and serum viscosity played an important role in clinical management of patients health in case of hyper viscosity syndrome. In the research report of [Chao-Hung Ho, 2004], it was found that blood viscosity was caused of cerebral blood flow and cardiac output. Elevated viscosity contributes to thrombosis and thromboembolic interventions. The hematocrit and hemoglobin are factors responsible for blood viscosity. As per the contributions of [M. Karsheva, et al, 2009], the parameters such as HCT, hemoglobin, and RBC influence the blood viscosity. The increased viscosity was reported by the observations of [V. Kostova, et al, 2012]. The cause of elevated viscosity was due to the factors like HCT, fibrinogen, and erythrocytes. The observation of smoker's blood viscosity was reported by [Cakmak et al. 2013]. As per this study, the BV in the pulmonary circulation among ex- smokers and smokers of 10 packs/daily and non-smokers was recorded. The BV of non-smoker was 1 lower than the smokers of 10pakes/daily. Elevated BV was reported insmoker's blood. The viscosity of blood was stated to be indicator of treatment of disease as per the studies of [Dmitry A. Fedosov et al, 2013]. The BV result helped in understanding cell-cell interaction. Whole blood viscosity [WBV], according to the reports of [Ezekiel UbaNwose, 2010], was indicesof foratherothrombosis, endothelial dysfunction and stasis respectively. The literature survey indicates the blood viscosity (BV) is a potential parameter in both fields of diseases analysis, and diseases treatment. Throughout the literature, no information is found about the prediction of blood viscosity using fuzzy logic. In view of this an attempt is made to investigate the blood viscosity through fuzzy logic in matlab environment.

IV Materials and Methods

Fresh samples of normal human blood of volume nearly 20ml of different groups (A, B, AB and O) were collected from blood bank. Anticoagulant is added at the rate of 300 µl per 20ml of blood samples. Blood samples were collected and stored at about 10° C until use. Plasma was separated from blood samples by centrifuging the blood at the rate of 1500 rpm for about 15 minutes and the blood samples were prepared by mixing equal amount of plasma and red blood cells. To study the effect of hematocrit on viscosity, blood samples of different hematocrit were obtained by mixing RBC and plasma at different proportions. These blood samples are used to study the viscosity of plasma and whole blood using the indigenous capillary viscometer. The capillary viscometer is two sided opened with inner radius of 0.05cm and length of 30

cms. The blood or plasma sample of different length such as 2 to 8cm was sucked in to the capillary viscometer and set into one dimensional motion betweenpre-set distance of 20cm, and time is recorded for each length of the sample. From the time and distance, the velocity is calculated. For different lengths of samples velocity is calculated. A plot is drawn between velocity (V) and distance inverse (d^{-1}). From the Y-intercept the characteristic velocity (V_o) is estimated. While the blood sample in the capillary set into motion, various forces would be acting upon it. The upward forces such as, viscous force (F_v), surface tension force (F_s) counter balancing the downward forces such as gravitational (F_g) and accelerating force (F_a) . These forces are equated as

$$\Sigma F_y = F_g - F_v - F_S = F_a = 0 \quad (5)$$

For thevertical or one dimensional motion of blood sample,from the equation (5) the viscosity formula is deduced as below

$$\eta = \frac{R^2}{8V0} \rho g \quad (6)$$

Where

η = Viscosity of sample

R = Radius of capillary,

ρ = Density of blood sample

g = acceleration due to gravity

V_o= Characteristic velocity from the graph.

The versatility of this equation is verified by the standard organic liquids. The results are recorded in the following table1.

Table 1: Comparison of Viscosities of standard organic liquids with that of capillary viscometer.

Sample	Density ρ(gr/cc)	Velocity V_o(cm/sec)	Viscosity from proposed Capillary viscometer η_1 (Poise)	Standard Viscosity η_2 (Poise)
Alcohol	0.789	20.57	0.01174	0.0122
Benzene	0.879	49.50	0.0054	0.0056
CCl4	1.632	53.75	0.00929	0.00969

From above table1,the viscosities from proposed capillary viscometer are in close agreement with the viscosities of standard liquids, as result the versatility of the technique is verified. Using this technique the viscosities of normal human blood and plasma are estimated. About 500 samples of normal and healthy samples of four blood groups are scanned and results are recorded as below table2.

Experimentally the plasma and whole blood viscosities are estimated and these results are reported as per the work of [Mohammed GulamAhamad et al, 2009] and [Mohammed GulamAhamad, 2010]. Based on the above work, in the present experiment of the prediction of blood viscosity using fuzzy logic system, the minimum and maximum plasma and blood viscosities values are fixed in the range 0.01 – 0.02 poise and 0.02 – 0.03 poise respectively.

Table 2: Blood and plasma viscosities of capillary Viscometer

Blood Sample	Blood Viscosity (Poise)	Plasma Viscosity (Poise)
Group A	0.027	0.017
Group B	0.027	0.0163
Group AB	0.028	0.017
Group O	0.028	0.017

The hematocrit value however is fixed in the range 40 – 60 percentage, because the blood does not remains to be normal below and above the range of HCT.

A. EXPERIMENTAL PROCEDURE

In the present work the blood viscosity (BV) is predicted using mat lab GUI fuzzy logic tool box (FLT). The FLT has five GUI tools.

1) Fuzzy Interference System (FIS) editor: It maps the input domain to output domain using fuzzy logic. In the present case the inputs are hemtocrit (HCT) and plasma viscosity (PV). It contains the collection of fuzzy membership functions and rules. The rules often called fuzzy expert system.

2) Membership Function Editor (MFE): Its job is to define the nature of membership functions related to each variable. Since HCT, PV are the two input variables and BV is the out put variable. Membership function is the curve of degree of truth of concurrent input parameter between 0 and 1. The mat lab MFE includes 11 built in membership functions such triangular, trapezoidal, and Gaussian etc. In the present case trapezoidal member suitable is therefore selected for implementation.

3) Rule Editor(RE): The job of this block is to take up the editing work according to the behaviour of the system. It shows the information of associated with FIS. It generates possible combinations of the logic.

The BV is predicted as per the different combination of the two inputs HCT, and PV respectively.

4) Rule Viewer (RV): This read only tool not meant for editing. It is used as diagnostic tool to indicate which rules are active and influencing effect on output result. The possible nine combinations of HCT and PV are displayed for the output of BV.

5) Surface Viewer (SV) : This is also the read only tool and has no editing facility as rule Viewer. It displays the relationship of the outputs with one or more inputs. It creates the Graphical map of the

output. The predicated BV is related to the two inputs of HCT and PV. This is called defuzzification.

In the experimentation all the above five tools have been successfully used in the prediction of the blood viscosity.

B. RESULTS

Fuzzy Interference System (FIS) which is nominated as BVHCTPV and the output is blood viscosity (BV) with the two inputs as HCT and PV. The two inputs are applied to rule editor. Based on the rules or knowledge, which consists of if-then-else rules, which are written in rule editor, the rule editor generates the appropriate blood viscosity value. Here Mamdani interference system is used as it is simple and appropriate for the present study. This is shown in the figure 3below.

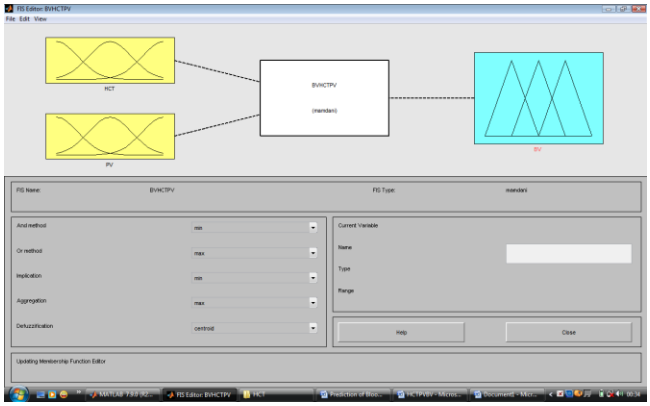

Fig 3: FIS Interference of HCTPVBV

The fuzzy logic rule editorwith if –then-else rules is presented below figure. The linguistic rules are three and two with two inputs. As a result the possible combination rules are 3^2 = 9. The nine (9) rules are shown in the figure 4 and described below.

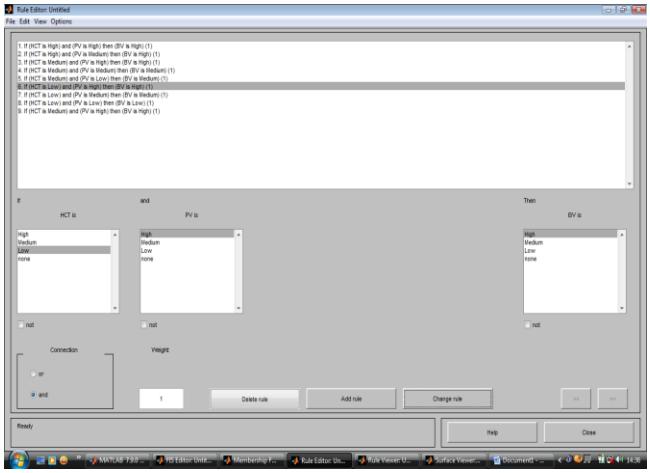

Fig 4: The rule editor of BV with inputs as HCT and PV

The rule editor in the figure 4 above defines actual logic of the input and output relation . In the present case HCT and BV are the inputs and PV is the output. The logical introduced here is the heart of the system functionality or output behavior. The system logic therefore are described below

1. If HCT is high and PV is high then BV is high
2. If HCT is high and PV is medium then BV is high
3. If HCT is medium and PV is high then BV is high
4. If HCT is medium and PV is medium then BV is medium
5. If HCT is medium and PV is low then BV is medium
6. If HCT is low and PV is high then BV is high
7. If HCT is low and PV is medium then BV is medium
8. If HCT is low and PV is low then BV is low
9. If HCT is medium and PV is high then BV is high.

The rule viewer is shown in the figure 5 below.

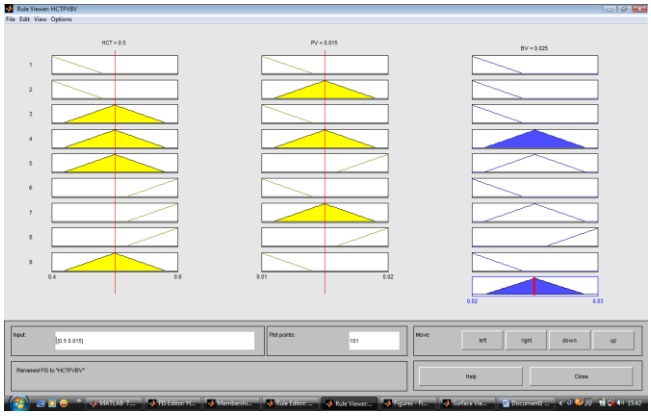

Fig 5: The rule viewer of BVHCTPV with inputs of HCT and PV and BV as output

DEFUZZIFICATION:

The defuzzification process can be carried out in surface viewer. This is depicted in figure 6. The surface viewer in this case presents with two dimensional curve which maps the HCT and PV as inputs with BV output. The typical value is computed for each linguistic variable and appropriate value is determined from different methods such as centre of sums, centre of areas and centre of maximum sums. But very frequently centroid method is used. In the present study also the centroid method is adopted. The BV based on the centroid distances of PV and HCT inputs. The surface viewer has HCT and PV as two surface inputs and the output is BV. The tests are carried out as shown in figure 4, while inputting different values of HCT and PV and obtained BV values.

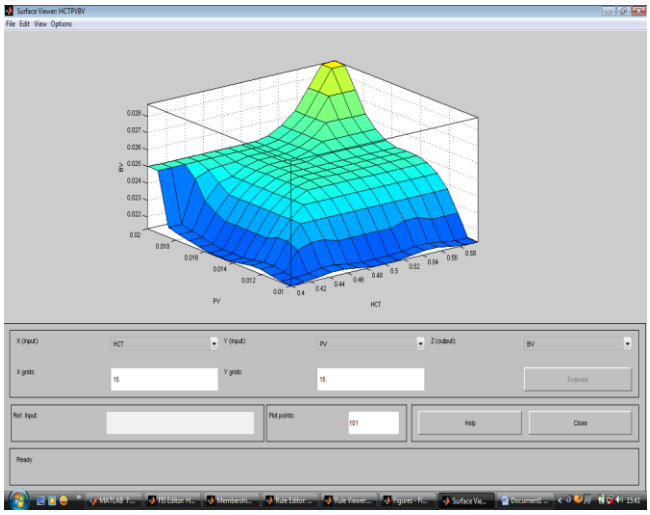

Fig 6: The surface viewer indicating BV for corresponding inputs HCT and PV

This is very interesting to note that the most common output BV value is 0.025 poise as per the surface viewer. This is in nearly close agreement with the experimental results recorded in table2.

Table3: BV- Non-Newtonian results for high values of PV

SNO	HCT	PV	BV
1	.4	0.015	.0213
2	.4	.02	.025
3	.45	0.015	.0241
4	.45	.02	.025
5	.50	.015	.025
6	.50	.02	.025
7	.55	.015	.025
8	.55	.02	.026
9	.6	.015	.025
10	.6	.02	.029

Table 4: BV- Newtonian results for low values of PV

SNO	HCT	PV	BV	$\eta_{BV} = \eta_{PV}(1+2.5HCT)$
1	0.4	0.01	0.0213	0.02
2	0.45	0.01	0.0216	0.0213
3	0.5	0.01	0.0213	0.022
4	0.55	0.01	0.0216	0.023
5	0.6	0.01	0.0213	0.025

DISCUSSION

The blood viscosity is an essential index of healthy and diseased subjects. In view of this an attempt has made to the estimation of blood viscosity based on hematocrit and plasma viscosity using the fuzzy logic technique. The cause and effects of BV are many. The elevation of BV is cause of many non communicable diseases, such as hypertension, blood pressure, atherosclerosis, diabetes, thrombosis, polycythemia, many varieties of heart diseases, and renal diseases. The communicable diseases as malaria, billurubin, steno sis and many infectious diseases. The fall in BV below the normal is indication of diseases such as cancer, pulmonary diseases of type as tuberculosis (TB) Leukaemia Anaemia and Fatigue. The output blood viscosity (BV) obtained with the inputs as hematocrit (HCT) and plasma viscosity (PV). The results are recorded in the table 3 and 4. The BV relation with HCT and PV can be described with Einstein's relation $\eta_{BV} = \eta_{PV}$ (1+2.5 HCT) according to the studies of[Alessandro M Vannucchi, 2012]. As per this, the relation between HCT and BV is linear. The values so obtained are recorded in table 4 along with calculated values. The Einstein equation holds good for low value of PV such as PV = 0.01poise, and does not hold good for remaining high PV values. For low PV values the BV behaves as Newtonian fluid, therefore the relationship will be linear. This linearity between HCT and BV is shown in figure 8. For remaining values HCT and higher values PV such as PV = 0.015 and 0.02 the dynamics of blood will be non – Newtonian. This causes the relation between BV and HCT non linear or exponential, which is illustrated in the graph as shown in figure 7.Below and the BV values obtained in this case are recorded in table 3.

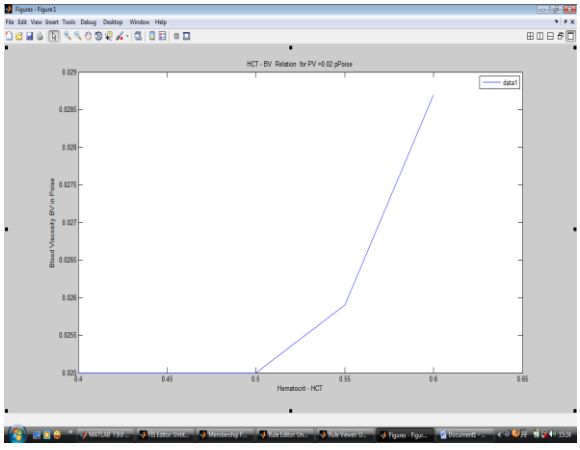

Fig 7: Non-Newtonian relationship between BV-HCT[For higher values of PV]

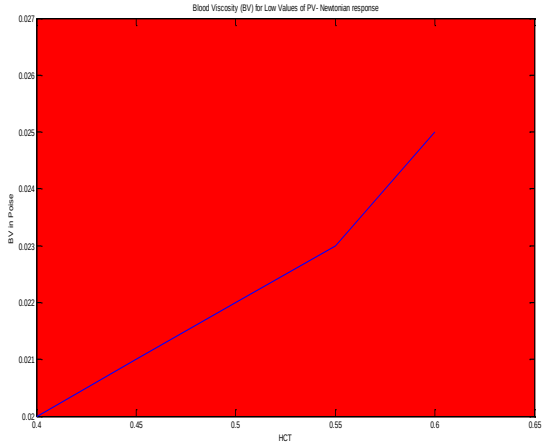

Fig 8:Newtonian relationship between BV – HCT [For low PV values]

The higher values of PV causes blood concentration high and BV will be high. The observed results are in excellent agreement with the Einstein relation for linear values and non linear graph for higher concentrations of PV. The observed graph is exponential which is as per already established resultsof [Yıldırım C¸ ınar,etal, 1999] work. This technique used through fuzzy logic is therefore almost appropriate and in good agreement with the reported results.

CONCLUSIONS

The fuzzy logic technique is successfully implemented in predicting the blood viscosity (BV) using the HCT and PV. The blood viscosity is an exceptionally important parameter or otherwise patient's health index. Even after assuming so much importance, the BV parameter is unnoticed and least cared clinically and diagnostically. In some context it is observed that BV is better to ESR. The BV is an indicator of physical fitness and health of patients. In view of this BV is predicated here with the fuzzy logic tool in mat lab environment without clinical procedures. The results reported herewith are in good agreement with that of clinical observations. The results obtained through fuzzy logic recorded in table 4, table 5 and in figure 6 surface viewers are in close agreement with the results obtained through viscometer which are recorded table 2.

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