A NEW APPROACH TO DETERMINE THE DIABETIC LEVEL IN PATIENTS

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Traditionally the experiments to measure the constituents of urine and their diabetic level are performed by qualified laboratory chemists mainly based on traditional clinical methodologies. In this article, we introduce a novel mechanism to determine the diabetic level by analyzing the urine drop of a diabetic patient using a drop dynamics process. In this mechanism, a urine sample of the diabetic patient is used and a drop test is created from a capillary nozzle with the help of FLUENT tool. Through this mechanism, we initially analyses and set the lowest limit of thread length for normal person's urine. With respect to this limit, we perform a comparative analysis and determine the variation of thread length in the diabetic patient's urine sample. A variation of thread length is plotted for different urine sample with detachment time of the drop.

Keywords: Diabetic Mellitus, Drop formation, Computational Fluid Dynamics (CFD), Urine

1. Introduction

Urine is the liquid which is generated as a byproduct of metabolic processes in the kidneys. This liquid is secreted by the kidneys via filtration and excreted through the urethra during urination. Constituent of the urine includes water, urea, sodium, chloride, potassium, creatinine along with certain ions, organic, and inorganic compounds.

Abnormality in Urine

Due to various medical reasons, sometimes body excretes abnormal components in urine.

Following are some of the common urine abnormities:

- Proteinuria — Protein content in urine, often due to leaky or damaged glomeruli. [1]
- Oliguria— an abnormally small amount of urine, often due to shock or kidney damage.
- Polyuria— an abnormally large amount of urine, often caused by diabetes.

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- Dysuria— Painful or uncomfortable urination, often from urinary tract infections.
- Hematuria— Red blood cells in urine, from infection or injury. [2], [3], [4]
- Glycosuria— Glucose in urine, due to excess plasma glucose in diabetes, beyond the amount able to be reabsorbed in the proximal convoluted tubule [5] [6].

During ancient time, lots of medical practitioners around the world used to analyze and examine physical characteristics of urine to diagnose medical conditions in patients. An ancient Athenian philosopher Hermogenes [7] marked about the color and other characteristics of the urine as indicators of certain diseases. Abdul Malik Ibn Habib of Andalusia [8] described a number of reports of urine examination in his book 'The Book of Arabian Medicine'.

When the sugar level in the blood reaches a high level it leads towards diabetes. The main reason behind this is the inability of the pancreas to produces enough insulin hormones. These hormones basically absorb the blood sugar and transform it into energy [9].

Diabetes is mainly classified into two groups:

Type 1 diabetes: In this type of diabetes, the insulin-producing cells in the pancreas are destroyed by the body's immune system [21] [22]. This type is known as juvenile diabetes and generally identified in childhood and this condition develops quickly. A basic symptom of Type-1 diabetes includes rapid weight loss, excessive thirst, urination, and fatigue.

Type 2 diabetes: This type of diabetes occurs mainly due to a condition known as insulin resistance. Insulin resistance is the inability of cells to respond adequately to normal levels of insulin, occurs primarily within the muscles, liver, and fat tissue [20]. Due to this abnormality, liver inappropriately releases glucose into the blood. This results in increasing the blood sugar level beyond normal ranges and causes a diabetic condition in the human body.

Due to plentiful and sweet smells, urine named as Diabetes Mellitus. It is a common practice to perform clinical urine test by examining the gross colour, turbidity, and odour of the urine. Urinalysis is a detailed examination of urine where the urine is chemically analysed to determine the amount of its various constituents. Table 1 shows the result of a typical normal urine dipstick test.

Table 1

Sample Results From Urine Dipstick Tests [10]

URINE DIPSTICK TEST RESULT		
Glucose in urine	mg/dl	mmol/l
Normal	100 – 180	5.55
Glucose 1+	250	11.1
Glucose 2+	500	27.75
Glucose 3+	1000	55.5
Glucose 4+	2000	111

Due to the absence of striking signs or symptoms, urinalysis is used to diagnose some diseases and bodily conditions [12]. Some example of such diseases includes diabetic mellitus and different types of glomerulonephritis etc. During urinalysis, a careful observation is required for qualitative analysis. In this analysis, change in colour of the dipstick is compared with a standard colour chart for investigating the disease. Yet, a careless nurse or the laboratory chemist may take misreading or misapprehend the results.

In recent years, various physical properties of human body fluids such as the viscosity of urine, the specific gravity of urine, surface tension for diagnostic purposes captivate scientists like Mills et al [11] and Syed Ismail Ahmad [17].

Ersin Akarsu et al. [13] investigated a case of a 46-year-old woman facing type 2 diabetes as she complained regarding polyuria disease with a daily output of 5 litres. This case study revealed the importance of precise computing of the urine specific gravity. Diabetic insipidus must be diagnosed if a patient suffering from low normal urine specific gravity value.

Some cases show the disagreement between the specific gravity of urine and osmolality. These cases include mannitol, uremia, uncontrolled diabetes mellitus etc. In these cases the concentration of urine does not change but there is an increase in specific gravity [14, 15, 16].

Syed Ismail Ahmad [17] investigated the variation in biophysical properties of human urine at various biological conditions. In this study, random samples at different times of the day are collected and examined for various biophysical properties. The values of specific gravity, viscosity and electrical conductivity in the first-morning sample are high when compared to the randomly collected samples. The values of biophysical properties are also calculated for various concentrations of albumin, bilirubin, urea and glucose.

X Zhang [23] investigates the effect of geometric parameters, physical properties and surface active materials on the dynamics of drop formation for low flow rate and also discovered that viscosity is the foremost stabilizing force for the drop formation. X Zhang et al. [24] proposed that surface tension forces the drop to be spherical in shape. Surface tension is directly proportional to the detachment length of the pendent drop which was similar to the experimental study of X. Zhang [25] who revealed the variation of breakoff time as a function of surface tension. Fawehinmi O B et al. [26] studies the effect of flow rate and viscosity on the drop dynamic process through experiments and CFD packages i.e. CFX and FLOW 3-D. Pardeep et al. [27] investigates the effects of variation in operating parameters as well as design parameters on the satellite drop formation. Increases in both flow rate and diameter of nozzle inlet size leads towards more satellite droplet formation. Also, the impact of velocity variation on smaller sized nozzle is less as compared to that of large sized nozzle.

To the best of our knowledge, it has been found from the literature review that no work exists on the use of drop dynamic process in determining the diabetes of the patient.

The authors have presented a new approach to diagnose the diabetic level of the patient through drop dynamic process which is the novelty of the work and have a scientific significance as it gives vital information regarding the disease.

2. Methodology

Study of Urine is basically done by biochemists, biomedical engineers; it does not fascinate the physicist. Nowadays, Physicists are applying certain concepts and techniques of Physics to find the solution of some biological problems.

Until now, diabetic condition in the patients is tested and diagnosed through various chemical methods. In this paper, we reveal the physical ways to determine the diabetic condition in patients. Effect of glucose in the body is determined by studying the thread length of the urine's drop. The increase in glucose level will increases the viscosity of the urine which will increase the thread length of the drop profile.

Samples of pathological urine are collected from Hyderabad Diagnostic Centre and Hyderabad Kidney and Laparoscopic Centre [17]. Disposable plastic bottles of 150 ml volume are used for the collection of all samples. These urine samples are kept in the water bath at room temperature. Data in Table 1 is prepared by spiking glucose into the urine. 10 g/dl solution is prepared by adding 5 g of glucose into 50 ml of urine, named as solution S1, 5 g/dl solution is developed by mixing 25 ml of S1 and 25 ml of urine, tagged it as S2. In a similar way, 2.5 g/dl solution is obtained by mixing 25 ml of S2 and 25 ml of urine and labeled it as S3.

Table 2 shows the data of various measured biophysical properties of urine. For a better understanding of the urine drop profile, the computational fluid dynamics based simulation is performed on commercial software ANSYS Fluent 14.0.

Table 2

Physical Properties of Normal Urine treated with Glucose

Concentration (g/dl)	Specific Gravity	Viscosity(poise)	Surface Tension(dyne/cm)
2.5	1.0252	0.0110	62
5	1.0347	0.0115	60.01
10	1.0497	0.0125	56.61

Table 3 shows various measurements of physical properties of diabetic mellitus urine with respect to the concentration of glucose in the blood sample.

Table 3

Physical Properties of Diabetic Mellitus Urine

Glucose Concentration in Blood	Physical Properties of Diabetic Mellitus Urine		
	Specific Gravity	Viscosity(poise)	Surface Tension (dyne /cm)
182 mg/dl	1.0210	0.0110	58.10
205 mg/dl	1.0215	0.0114	56.98
220 mg/dl	1.0218	0.0116	56.81
245 mg/dl	1.0234	0.0117	56.98
342 mg/dl	1.0263	0.0118	55.98
345 mg/dl	1.0265	0.0118	55.61

3. Computational domain with boundary conditions

Computational domain represents a basic form of the physical domain showing both the geometrical representation and imposed boundary conditions. The computational domain as shown in figure 1 consists of two regions. The green coloured zone consists of human urine sample whereas the grey coloured zone consists of air. The surface of the capillary tube is considered as wettable zone whereas the surface surrounding the capillary orifice is considered as non-wettable zone. To investigate the dynamics process of drop development, we use 'volume of fluid' method in computational process.

At the initial time, t = 0 sec, urine fills the capillary tube zone whereas air captured the remaining zone. Initially, both fluids are considered at rest. To initiate the ejection process, a user defined function (UDF) is attached with the initial boundary conditions. The liquid moves as a fully developed profile in the capillary tube, gravity forces also acts towards z- direction as shown in Fig. 1.

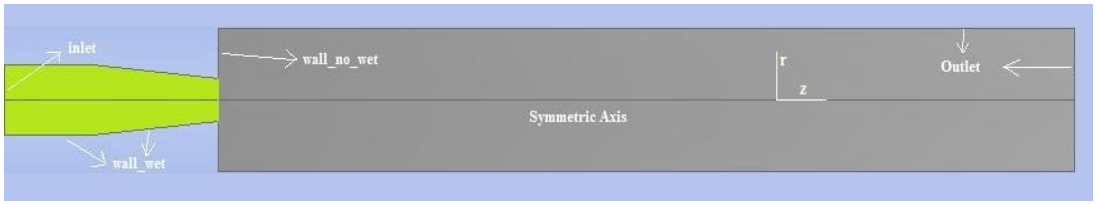

Fig. 1 Computational Domain with Boundary Condition for Simulation

4. Mathematical modeling

In free surface flow analysis, the dynamics of drop formation depends upon a lot of factors which includes flow rate, viscosity, and density of the liquid. A factor of surface tension between the liquid and the air is also analysed.

Following are the assumptions on which the governing equations are developed.

- The fluid flows are laminar and Newtonian.
- The model is axisymmetric.
- The surrounding air can be considered as incompressible.
- The liquid properties are known and constant.
- The evaporation of the liquid is neglected.
- At the inlet of the capillary tube, fluid flow is assumed to be fully developed flow.
- The thickness of the nozzle is neglected [18].

After applying the assumptions, Navier – Stokes equation in non-dimensional form for the liquid's transient motion is given as:

$$\nabla . v = 0, \tag{1}$$

$$Re\left(\frac{\partial v}{\partial t} + v.\nabla v\right) = \nabla.\tau + \left(\frac{G}{Ca}\right)j \tag{2}$$

$$\tau = -pI + [\nabla v + (\nabla v)^T] \tag{3}$$

The variable in equation (1) i.e. ∇ is the gradient operator; v is the resultant velocity vector. Similarly, in equation (2), τ is the stress tensor; j is the unit vector in the z-direction. In equation (3), p represents the dimensionless pressure and I is the identity tensor.

Also during the non-dimensionalization process, three dimensionless numbers are introduced in the equation (2),

Reynolds number, $Re = \rho UD/\mu$,

Gravitational Bond number, $G = \rho gR2/\sigma$,

Capillary number, $Ca = \mu U/\sigma$

The flow is considered as fully developed, so its velocity profile become,

$$v_z = \frac{2Q}{\pi R^2}\left\{1 - \left(\frac{r}{R}\right)^2\right\}, 0 \leq r \leq R \tag{4}$$

Where r is the radial coordinate of drop phase and vz is the flow velocity in z direction.

The maximum velocity of liquid phase flow for the fully developed flow is given as

$$U = \frac{2Q}{\pi R^2} \tag{5}$$

Tracking of the interface between the two phases (i.e. pth and qth phase) is done by solving the mass conservation equations. The mass conservation equation is given as following for qth fluid:

$$\frac{1}{\rho_q}\left[\frac{\partial}{\partial t}\left(\alpha_q \rho_q\right) + \nabla.\left(\alpha_q \rho_q \vec{v}_q\right) = S_{\alpha_q} + \sum_{p=1}^{n}(\dot{m}_{pq} - \dot{m}_{qp})\right] \tag{6}$$

Where, $\acute{m}_{pq}$ the mass transfer from phase p to phase q is,$\acute{m}_{qp}$ is the mass transfer from phase q to phase p. Generally, the source term, S_{α_q} on the right hand side is zero [19]. Only the volume fraction for the secondary phase fluid is solved. And the volume fraction of the primary phase fluid can be calculated by the following equation:

$$\sum_{p=1}^{n} \alpha_q = 1 \quad (7)$$

The boundary conditions for the solution of Equations (1) and (2) which are also shown in Figure 1 stated as:

- Inlet of the domain is velocity inlet.
- Axis is considered as an axisymmetric axis.
- Free slip velocity condition near the wall because the fluid near the wall is air.
- Outlet of the computational domain is atmospheric pressure outlet.

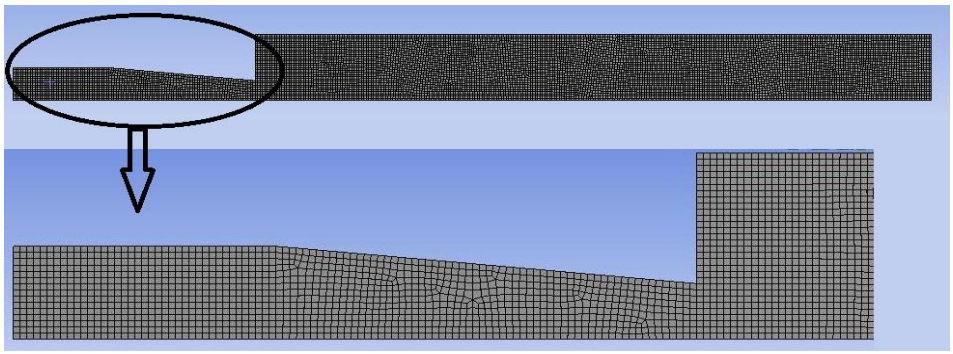

Fig. 2 Finite element meshes used to tessellate the computational domain

5. Grid generation

For the computational analysis, the generation of grids in the computational domain is a necessary step. A computational domain is sliced into a number of cells. The sample meshed geometry is shown in Fig. 2. As the drop profile moves near the axis so the cell density in this zone is higher as compared to the other. Quadrilateral meshing is done throughout the computational domain. For the simulation work, domain is sliced into 125000 cells.

6. Numerical solution procedure

Meshing plays an important role in the numerical solutions obtained through the computational methods. The accuracy of results is directly proportional to the number of cells in the computation. Having a large number of cells in the computation will produce much accurate results. Geometric models meshed with a sufficiently small size such that the accuracy of the results obtained

would be within the desired limit. The bounding surfaces of the system have been defined by names, and the top surface has been defined as open to atmosphere. An unsteady pressure-based solver, using laminar flow model has been adopted with gravity acting towards z directions. A user-defined function (UDF) source code for the fully developed flow was invoked and interpreted using the interpreter and was hooked to boundary conditions. The zones representing the two phases were marked and the material properties were assigned by patching. The nature of the movement of the drop was studied. FLUENT version 14.0 uses a grid solver which solves the Navier-Stokes equations in an iterative manner by applying the above-mentioned boundary conditions. Pressure Implicit with Splitting of Operators (PISO) algorithm along with PREssure STaggering Option (PRESTO) Scheme is used for the discretization process. Under relaxation factor for pressure is 0.3 and that for momentum is 0.7, were used for the convergence of all variables. In general, regular quadrilateral cells were used for the entire computational domain.

7. Validation of proposed CFD program

On the basis of above numerical solution procedure, computational analysis work is done and the comparison of different structures of drop formation attained from the experimental method [18] and the Volume of Fluid (VOF) numerical method is shown in Fig. 3. The actual detachment time for the 85% glycerin drop in the air is 5.07 s (from initial) and 2.29 s (after previous drop's detachment), which is within 3% error as compared with the literature [18]. Fig. 3 also verifies that the VOF method also provides the precise information regarding the motion of drop during the detachment process.

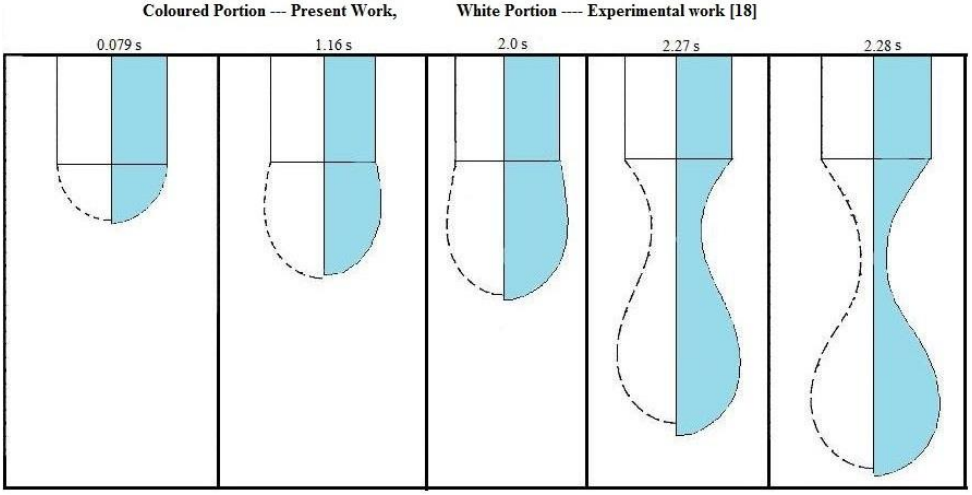

Fig. 3 Comparison of detachments profile of pendent drop at various time sequences for experimental and computational methods

Fig. 4 shows the thread length's dependency on the percentage of glycerine composition. The limit of glycerine composition is varying from 0 - 100 %. It also validates the computational domain outcomes with the experimental one. Thread length is increasing exponentially with the increasing percentage content of the glycerine.

Viscosity of the liquid is an important parameter to curb the interfacial undulations of the breakoff drop. It smoothens the detachment profile of the drop at every stage before breakoff. When we compare the spring balance system with the drop dynamic system, then the viscosity of the liquid used in the drop process plays the similar character as damping force plays in the spring balance system. Increase in viscosity of the liquid will eliminate the oscillation that occurs during drop formation process and also increase the breakoff period of the process.

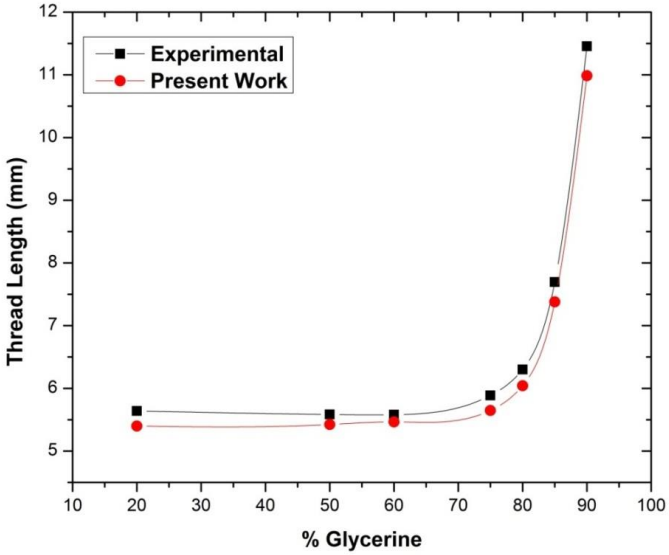

Fig. 4 Variation of thread length as a function of different glycerin compositions

8. Results and discussion

As the computational domain is validates with the experiment results. In this paper, diabetes in patient is determined by the laws of physics applied to a urine sample instead of chemical analysis of urine samples. Patients having diabetic condition has more sugar content in his or her body. The diabetic level of a patient can be determined after analyzing thread length of their urine samples.

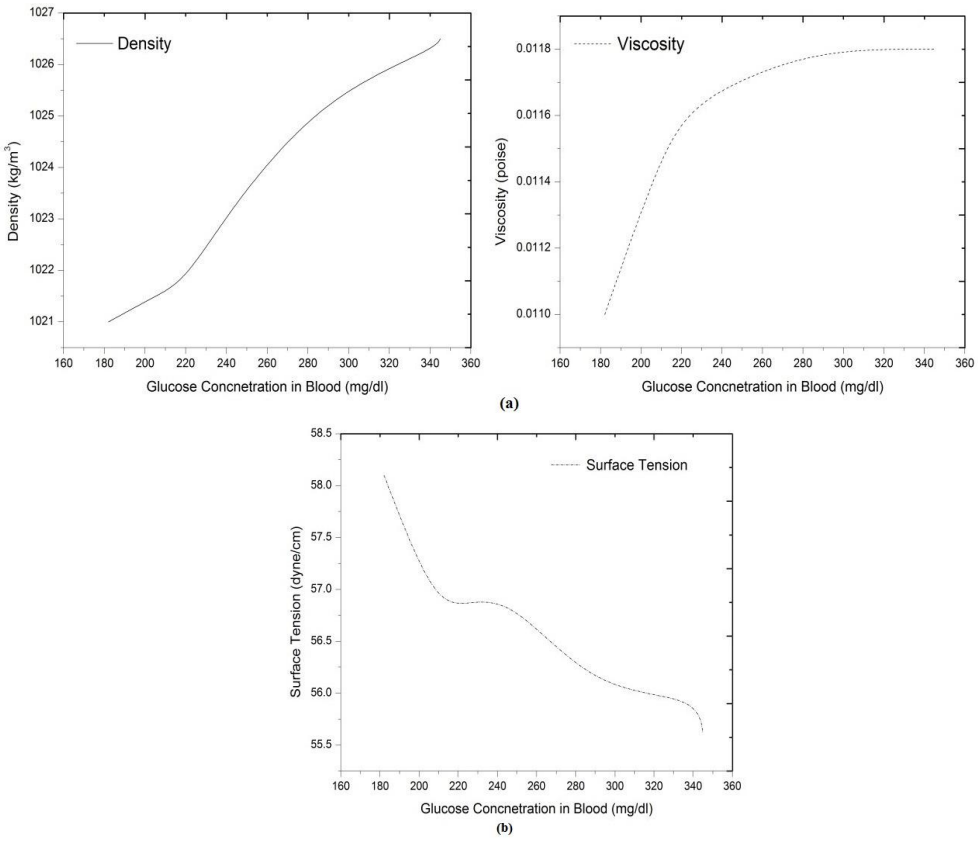

Fig. 5(a, b) Variation of Physical properties of urine [17]

Fig. 5 (a, b) shows the variation of physical properties of urine. The density of urine increases linearly whereas surface tension decreases as glucose concentration in blood increases. Also, viscosity of urine increases exponentialy as the glucose concentration in blood increases.

Tracking of detachment profile

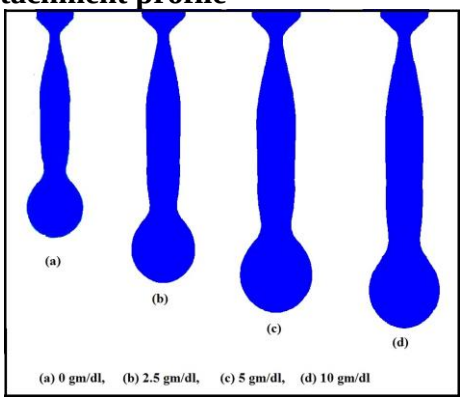

Fig. 6 Variation of detachment profile of Drop formation for glucose mixed urine sample

Detachment profile of glucosed mixed urine samples are shown in Fig. 6. Values of physical properties used in this detachment process are given in Table 2. As the concentration of glucose mixed urine increases, intermolecular attractive force also rises, that increases the breakoff thread length of the droplet during drop formation process.

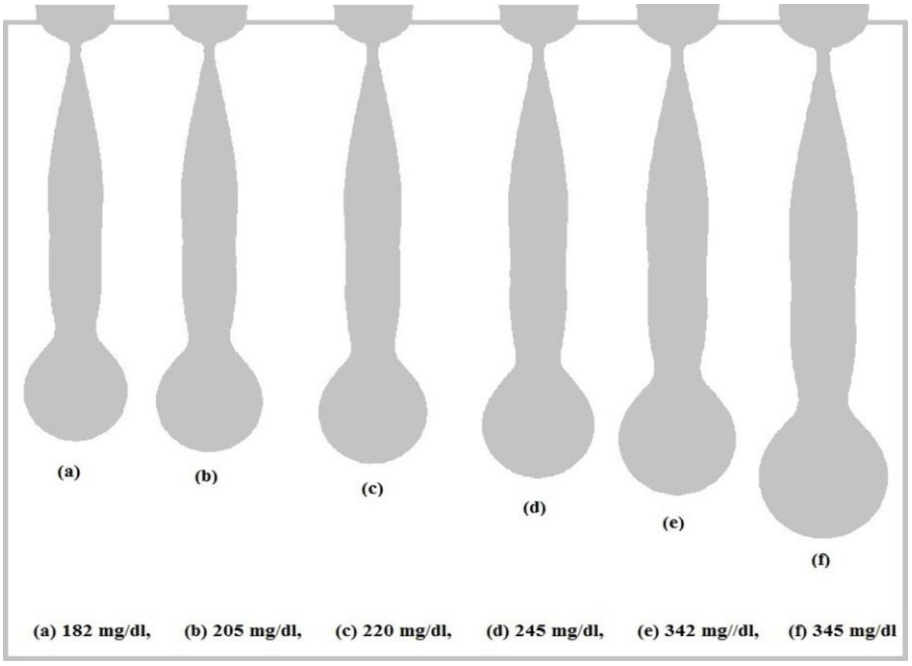

Fig. 7 Variation of detachment profile of Drop formation for various diabetic mellitus urine sample

Drop's detachments profile for various diabetic mellitus urine sample is shown in Fig. 7. As the quantity of diabetes increases in urine sample, it will also the thread length of the urine drop fallen through the capillary tube.

9. Variation of thread length for various samples collected

Fig. 8 shows the variation of thread length with respect to various samples of diabetes mellitus urine. With lower stimulation time, the thread length for various urine samples doesn't differ much but with higher the simulation time values, a significant variation in length is observed.

Urine samples' having a higher value of viscosity has higher thread length. It is clearly observed that the viscosity plays a greater role across the squeezing to dripping regime. At high viscosity, more shear stress acts between continuous fluid and dispersed fluid. This increases the length of detachment drop profile.

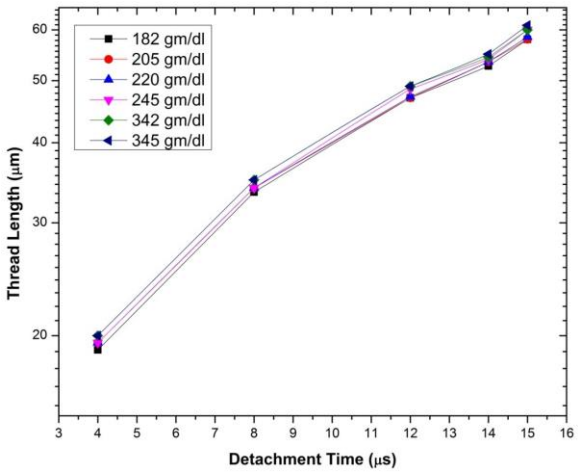

Fig. 8 Variation of Thread lengths for various Diabetic Mellitus Urine Samples

Variation in thread length when glucose is mixed with urine

Fig. 9 shows the variation of thread length and detachment time for various concentration of urine mixed with glucose. Length of thread depends mainly on viscosity of the material. Material having more viscosity has more thread length when compared to the lower viscous material.

At initial time, thread length for each case is same because here no such forces acts on the pendent liquid drop but as the detachment time increases, more portion of the liquid comes outside the capillary tube into continuous zone, now the effects of different physical properties starts acting on the hanging drops. Just before the drop formation i.e. 1 ms (millisecond) prior to detachment, thread length of 10 g/dl urine sample is more than other samples. This is because the viscosity of 10 g/ dl urine is more as compared to the other samples.

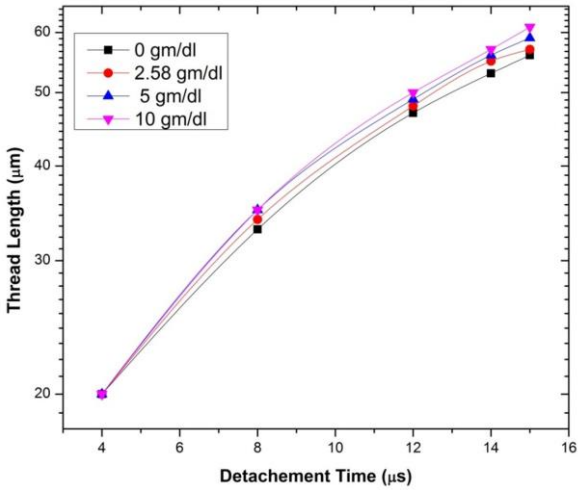

Fig. 9 Variation of Thread length for glucose mixed urine sample

10. Conclusions

The current work signifies the application of drop formation technique to determine the diabetes level of humans. This paper shows the variation in thread length at different diabetic urine levels. In this investigation, a computational domain is developed and validated with the literature. For locating the free surface of the drop during the breakoff process, we consider 'Volume of fluid' method.

Increase in the diabetic level in body, increases the viscous nature of the urine. For the entire analysis, thread length is the major factor to compare the diabetic level between normal person and diabetic person's urine. In the drop dynamics process, thread length of more viscous urine is obtained by comparing it with the thread length obtained from the drop dynamics process of the normal urine. Through this mechanism, diabetic level of the patient can easily be determined with accuracy. This investigation also proves the excellently role of CFD software in biomedical science.

R E F E R E N C E S

[1] *MF Carroll, JLTemte*, "Proteinuria in Adults: A Diagnostic Approach", American Family Physician, Vol. 62, no. 6, 2000, pp. 1333 - 1340.

[2] *JA Simerville, WC Maxted and JJ Pahira*, "Urinalysis: A Comprehensive Review", American Family Physician, Vol. 71, no. 6, 2005, pp. 1153-1162.

[3] *MH Lam*, "False 'Hematuria' due to Bacteriuria", Archives Pathology & Laboratory Medicine, Vol. 119, no. 8, 1995, pp. 717 - 721.

[4] *PK Rao, JS Jones*, "How To Evaluate 'Dipstick Hematuria': What To Do Before You Refer". Cleveland Clinical Journal of Medicine, Vol. 75, no. 3, 2008, pp. 227-233.

[5] *WA Alto*, "No Need for Glycosuria/Proteinuria Screen in Pregnant Women", Journal of Family Practices, Vol. 54, no. 11, 2005, pp. 978-983.

[6] *MD Rotblatt, MA Koda-Kimble*, "Review of Drug Interference with Urine Glucose Tests", Diabetes Care, Vol. 10, no. 1, 1987, pp. 103-110.

[7] https://En.Wikipedia.Org/Wiki/Hermogenes_(Philosopher)

[8] *Ibn Habib, Abdul Malik D*, "Kitaab Tib Al'Arab" (The Book Of Arabian Medicine), Published By Dar Ibn Hazm, Beirut, Lebanon 2007(Arabic)

[9] http://www.Healthline.Com/Health/Type-2-Diabetes/Urine-Tests#Overview1

[10] http://www.Bloodtestsresults.Com/Urine-Sugar-Levels-Chart-What-Does-Sugar-In-Urine-Mean/

[11] *Mills et al.*, "Surface Tension of Urine and Bile Salt Concentration" , Journal of Clinical Chemistry and Clinical Biochemistry, Vol. 26, 1988, pp. 187-194.

[12] http://Library.Med.Utah.Edu/Webpath/TUTORIAL/URINE/URINE.html

[13] *Ersin Akarsu*, "The Value of Urine Specific Gravity in Detecting Diabetes Insipidus in a Patient with Uncontrolled Diabetes Mellitus", Journal of General Internal Medicine, Vol. 21, no. 11, 2006, C1–C2.

[14] *CH Lin, YJ Lee, CY Huang, Wolfram et al.*, "DIDMOAD Syndrome: Report of Two Patients". Journal of Pediatric Endocrinology & Metabolism, Vol. 17, 2004, pp. 1461–1464.

[15] *KP Paulose, N. Padmakumar*, "Diabetes Insipidus in a Patient with Diabetes Mellitus", Journal of the Association of Physicians of India.Vol. 50, 2002, pp. 1176–1183.

[16] *GB Fogazzi*, "Urinalysis and Microscopy", Cameron JS, Davison AM, Grunfeld JP, Kerr O, Ritz E, eds. Oxford Textbook of Clinical Nephrology, New York, Oxford University Press; 1992:pp. 16–24.

[17] *Syed Ismail Ahmad, Mohammed Abdul Moiz and Adeel Ahmad*, "A Study on Biophysical Properties of Normal First Morning and Randomly Collected Human Urine", Journal of Pure & Applied Phys., Vol. 22, no. 4, 2010, pp. 623 – 629.

[18] *ED Wilkes, Scott. D Phillips, OA Basaran*., "Computational and Experimental Analysis of Dynamics of Drop Formation", Physics of Fluids, Vol. 11, no. 12, 1999, pp. 3577-3598.

[19] ANSYS Fluent User Guide, 2006.

[20] "Diabetes Mellitus A Guide to Patient Care", Philadelphia: Lippincott Williams & Wilkins, 2007, P. 15. ISBN 978-1-58255-732-8.

[21] *JA Bluestone, K Herold and G Eisenbarth*, "Genetics, Pathogenesis and Clinical Interventions in Type 1 Diabetes", Nature, 464 (7293) (2010), pp. 1293–1300.

[22] *A Chatzigeorgiou, V Harokopos, C Mylona-Karagianni, E Tsouvalas, V Aidinis and EF Kamper*, "The Pattern of Inflammatory/Anti-Inflammatory Cytokines and Chemokines in Type 1 Diabetic Patients over time", Annual Med. Vol. 42 , no. 6, 2010, pp. 426–38.

[23] *X. Zhang,* "Dynamics of drop formation in viscous flows". Chemical Engineering Science, Vol. 54, 1998, pp. 1759-1774.

[24] *X. Zhang and O.A. Basaran*, "An experimental study of dynamics of drop formation". Physics of Fluid, Vol.7, no. 6, 1995, pp. 1184-1203.

[25] *X Zhang,* "Dynamics of Growth & Breakup of viscous pendant drops into air. Journal of colloid and interface Science", Vol. 212, no. 1, 1999, pp. 107-122.

[26] *O.B Fawehinmi, P.H. Gaskell, P.K. Jimack, N. Kapur and H.M Thompson*, A combined experimental and computational fluid dynamics analysis of the dynamics of drop formation. Proc. IMechE, Part C: Journal of Mechanical Engineering Science. Vol. 219, 2005, pp. 1-15.

[27] *Pardeep Bishnoi, Dhaval Patel, Mayank Srivastava and MK Sinha*, "CFD analysis of the factors affecting the satellite drop formation". International Journal of Advance Research in Science and Engineering, Vol. 5, no. 8, 2016, pp. 707- 713.