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PARAMETRIC EVALUATIONS OF LIQUID FLOW IN CAPILLARY TUBE UNDER VARIABLE HEADS THROUGH COMPUTATIONAL FLUID DYNAMICS METHODS.

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Abstract
Parametric evaluations have been made for the flow of Newtonian and incompressible liquid at constant ambient temperature and through a capillary tube under variable pressure heads in respect of the time. Variations of all flow parameters of the fluid like pressure, velocity, flow rate and Reynolds number with respect of time have been graphically as well as numerically presented. The liquid jet through capillary tube has been discretized with meshing type of tetrahedral of fine size and Computational Fluid Dynamics (CFD) method has been exercised with the help of COMSOL, Multi Physics software in respect of Poiseuille's equation for the analysis and presentation purposes. The liquid potential with total energy across the length of the pipe and at different span of time have also been graphically presented and total energy comprising the pressure, velocity and datum head, appears almost at constant value with inclusion of losses and hence Bernoulli's theorem gets also satisfied.

Keywords: Parametric evaluations; Computational Fluid Dynamics; Capillarity; Newtonian Flow.

Introduction

Poiseuille's equation is a physical law that gives the pressure drop in an incompressible and Newtonian fluid in laminar flow flowing through a long cylindrical pipe of constant cross section. For velocities and pipe diameters above a threshold, actual fluid flow is not laminar but turbulent, leading to larger pressure drops than calculated by the Hagen–Poiseuille equation. Normally, Hagen-Poiseuille flow implies not just the relation for the pressure drop, but also the full solution for the laminar flow profile, which is parabolic. Laminar flow in a round pipe describes that there are a bunch of circular layers (lamina) of liquid, each having a velocity determined only by their radial distance from the center of the tube. Also assume the center is moving fastest while the liquid touching the walls of the tube is stationary (due to the no-slip condition). The pressure force pushing the liquid through the tube is the change in pressure multiplied by the area. This force is in the direction of the motion of the liquid. Effects will pull from the faster lamina immediately closer to the center of the tube. Viscosity effects will drag from the slower lamina immediately closer to the walls of the tube. To get the total volume that flows through the tube, it is needed to add up the contributions from each lamina and hence to multiply the velocity with the area of the lamina.
Liquid flow in the form of jet has been arranged by fittings a capillary tube of inside diameter of 20 mm and length 2 meter horizon tally near the bottom of a cylinder of diameter 4 m and height about 2.02 meter filled with water. Liquid has been allowed to flow through the capillary tube initially under the full head of 2 meter water column and the head gradually reduced while the flow further proceeds through the tube and discharged into the atmosphere openly. The liquid flow has been considered as a incompressible Newtonian at a constant ambient temperature of 25°C. Variations of all flow parameters of the fluid like pressure, velocity, flow rate and Reynolds number with respect to time and across the length of the tube have been considered to be graphically as well as numerically presented.

The fundamental principles of conservation of mass, momentum and energy have been considered in its usual nature in respect to a finite control volume.

Materials and method

A 20 mm diameter and 2 meter long capillary tube, fitted near the bottom of a water tank of 4 meter diameter is considered for flowing of fluid against a water column of varying height with respect to time. Initially the height of the water column in the tank was 2 meter and it gradually decreases by satisfying the Poiseuilles equation.

$$V=\frac{\pi p r^4}{8\eta l}$$

p= pressure difference
r= Radius of tube
η= Dynamic viscosity

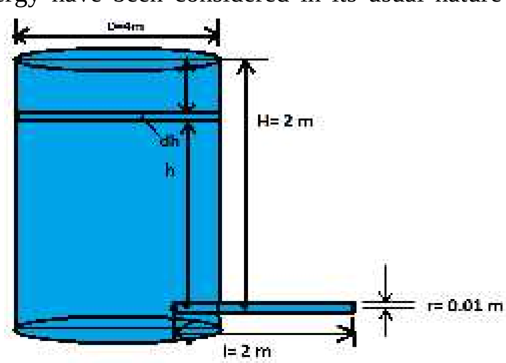

Fig 1.Figure of the tank with capillary tube at bottom

l= length of tube

$h = H * e^{-\left(\frac{\rho g r^4}{8 \eta l R^2}\right) t}$

h= Head of water column at the inlet of the tube inside thecylinder at time t.

H= Initial head; $\rho = Densityofwater$; R= Radius of cylinder

This head largely governs the inlet pressure of the capillary tube at its centre line.

P= h ρg

P= Pressure at inlet of the capillary tube

The simulation of the water domain inside the capillary tube is solved by the time dependent equation.

$$\rho \frac{\partial u}{\partial t} + \rho(u.\nabla)u = \nabla\{-pl + \mu(\nabla u + \nabla u^T)\} + F$$

$$\rho \nabla . u = 0$$

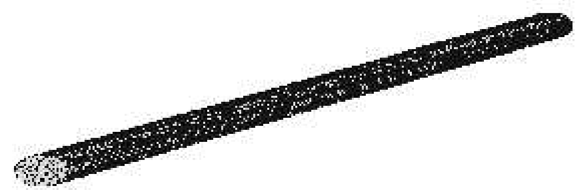

Fig 2.Tetrahedral mesh of capillary tube

The physics of the flow is considered as the laminar flow. Meshing of the domain is furnished in the Table -1.

Table 1: Meshing of the domain

Name	Value
Calibrate for	Fluid dynamics
Maximum element size	0.00493
Minimum element size	0.00148
Resolution of curvature	0.7
Resolution of narrow regions	0.6
Maximum element growth rate	1.2

Results and Discussions

The flow characteristics across the capillary tube under variable head at the inlet of the tube have been shown graphically. Under the specified parametric conditions, the pressure head gets reduced exponentially from initial value of 19584.68 p.a. to 242.0464 p.a. over a period of 220 seconds as shown in Fig2.The variations of pressure head in terms of water column have also been furnished analytically in the following Table -2. During further span of time, the liquid flow will be continued over a long period in a very marginal value and gradually it tends to be insignificant, but never be zero. Similarly, the variations of pressure head in respect of time at the different span of length have also been graphically presented in Fig3. As the length proceeds towards outlet and away from the inlet along the centre line of the tube, available pressure head was getting decreased exponentially with respect of time and became marginal value at a time of 217th sec and the pressure head became insignificant.

Table 2. Variations of Pressure in respect of time at the inlet of the capillary tube.

Time (Sec)	0	10	50	90	130	170	210	220
Head(MWC)	2	1.5669	0.5902	0.2223	0.0838	0.0316	0.0119	0.0093

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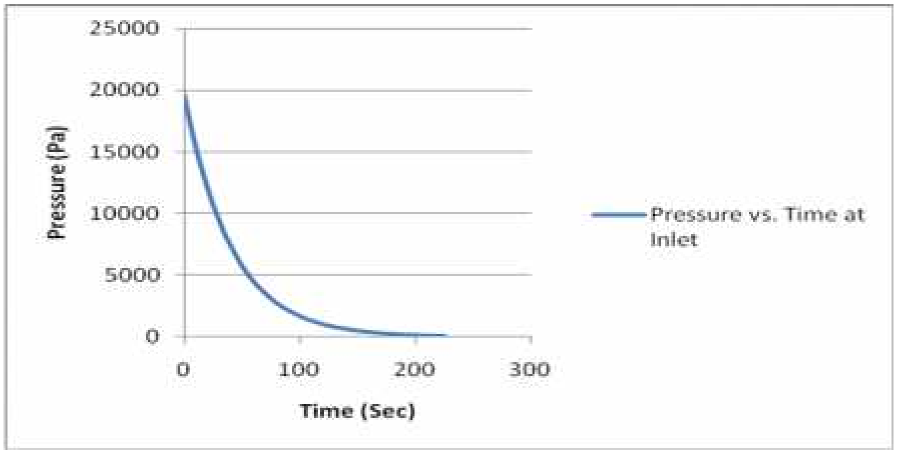

Fig 2.*Pressure vs. time at inlet*

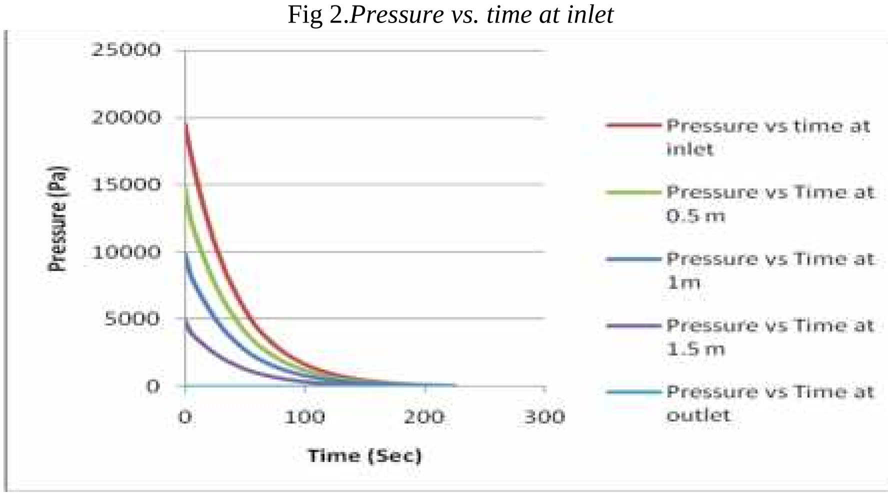

Fig 3.*Pressure vs. time across the length*

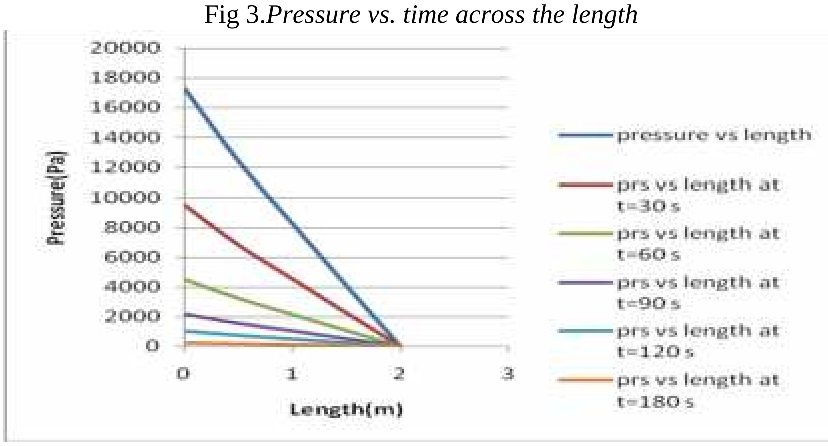

Fig 4.*Pressure across the length of the capillary tube in respect of time.*

The variation of available pressure across the length at different instants of time like at initial moment when the flow is about to commence, at 30^{th}, 60^{th}, 90^{th}, 120^{th},180^{th} have been graphically shown in Fig4.It is observed that the flow becomes insignificant at 220^{th} sec under very low head in the range of 0.0093MWC.

In case of velocity profile, it can be observed that the velocity initially increases within a short period of time as flow commences and as time proceeds , it gradually decreases exponentially and after a period 221 seconds , flow became insignificant, but continues for a long time as shown in Fig.5. The time period while the velocity of water is increasing is called as velocity regain time (Fig 5). Variations of velocity across the length but at different instant of time have also been

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presented in Fig.6. As the fluid is assumed to be incompressible and cross sectional area of the tube is uniform along the length, the afore-furnished variations in velocity indicates the commencement and initiations of variation of flow velocity along the length of the tube. It appears from the specified Figure that the variations of flow velocity and hence, flow rate get initiated at the length of 1.5m of the tube from its inlet and flow variations get gradually propagated towards outlet and followed by its propagation finally at the inlet of the tube.

It has been estimated that the total amount of liquid content in the cylinder is 25.38 cubicmeter considering the bottom of the pipe line as datum and the total amount of liquid discharged openly through tube during the period of first 500seconds isequal to25.133 cubic meter. The remaining amount (25.38 - 25.133) =0.127 cubic meter will remain in the tank and will be flowing through the tube during further span of time in a large scale.

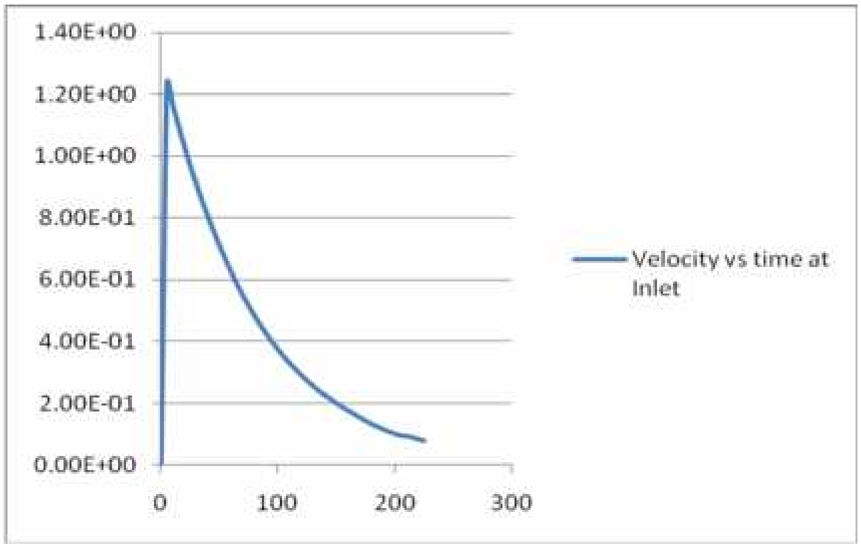

Fig 5.*Velocity vs. time at inlet*

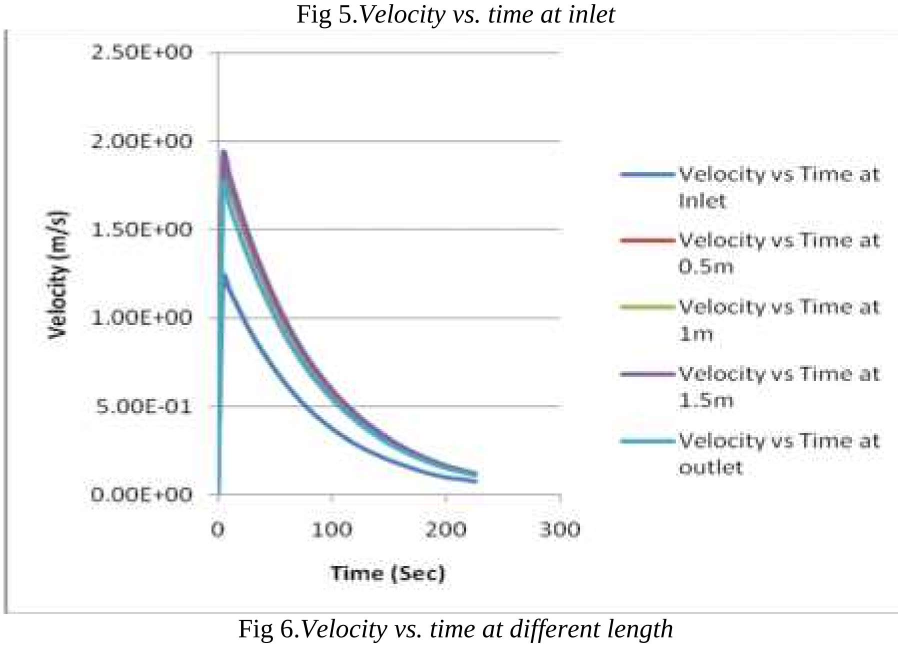

Fig 6.*Velocity vs. time at different length*

As the Reynolds no is directly proportional to the velocity of the water inside the tube so the characteristics profile of Reynolds number with respect of time is almost similar to the characteristics profile of velocity under constant temperature and hence, constant value of kinematic viscosity and the same has been shown in Fig7.The Reynolds number for the flow through the capillary tube has also been graphically presented and it varies from 1391.6 to 156.90 over a span from 5^{th} second

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to 180 seconds at the inlet respectively and at the outlet it gets reduced gradually from 1978.886 to 225.6496 over the same span of time during open discharge through the pipe and indicate the flow as laminar. Now during further span of time, asflow continues in a very insignificant manner, Reynolds number gets substantially reduced at a very lower value of 1.3752 and it remains almost constant and insignificant for long time.

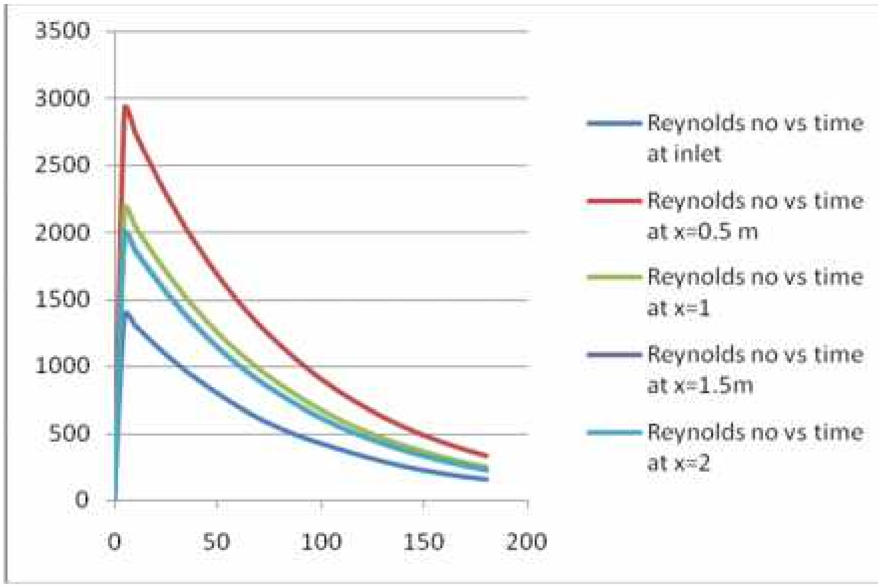

Fig 7.*Reynolds no vs. time across the length*

The liquid potential with total energy across the length of the pipe and at different span of time has also been graphically presented in Fig.8.and total energy comprising the pressure head, velocity head and datum head, appears almost at constant value with inclusion of losses and hence Bernoulli's theorem gets also satisfied.

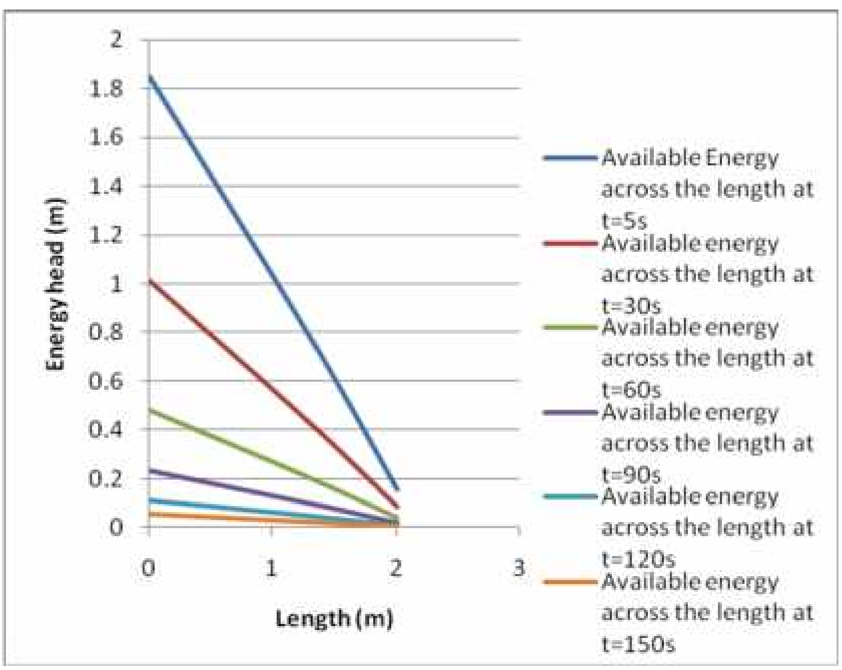

Fig 8.*Available energy across the length at different interval of time*

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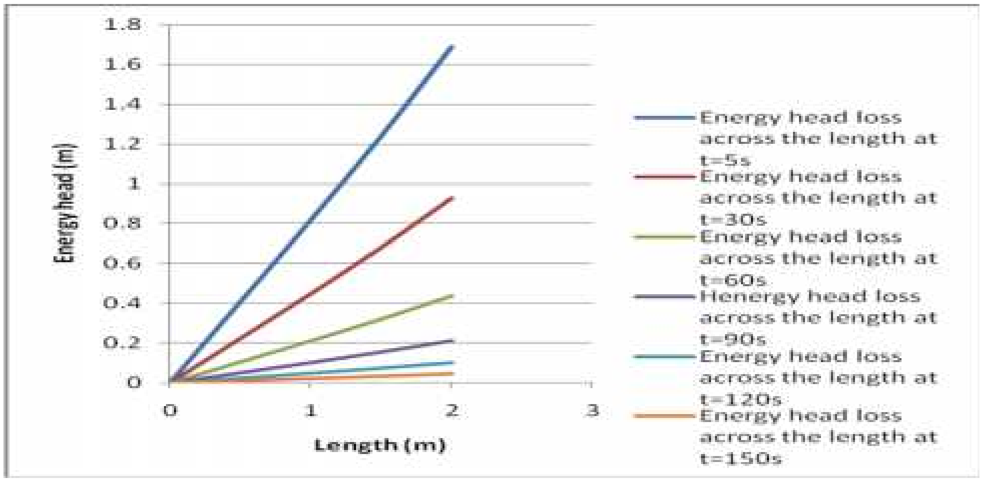

Fig 9.*Energy head loss across the length at different interval of time*

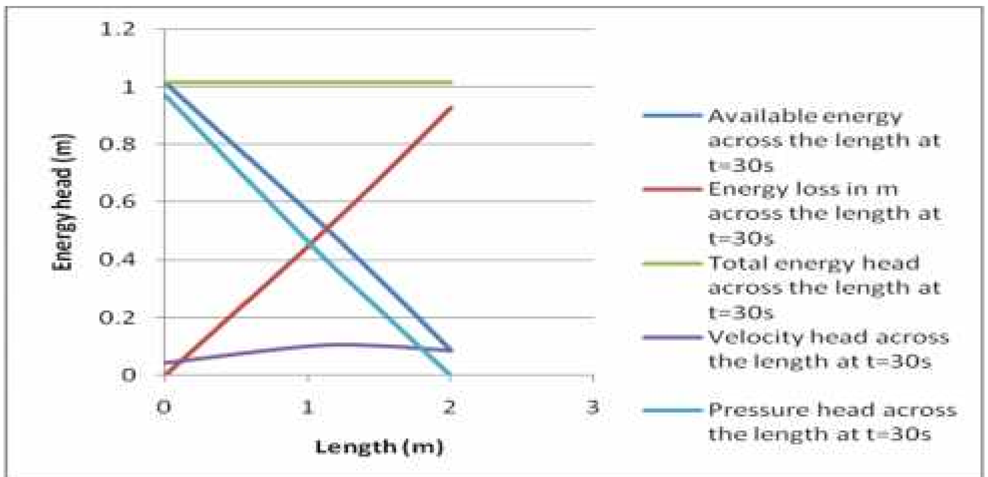

Fig 10.Energy graph across the length of the pipe at the instant of 30th second

Conclusions

All the results as obtained through CFD simulations are convergent in nature and liquid flow parameters through the capillary tube have been evaluated in respect of time. Flow remains laminar throughout the period during which the flow rate, pressure head and Reynolds number appears significant and flow continues over a large scale of time. variations of flow velocity and hence, flow rate get largely initiated at the length of 1.5m of the tube from its inlet and flow variations get gradually propagated towards outlet and followed by its propagation finally at the inlet of the tube and the same has been presented graphically with the velocity regain time under constant ambient temperature. Total energy comprising the pressure head, velocity head and datum head, appears almost at constant value with inclusion of losses along the length of the tube and also in respect of time and hence Bernoulli's theorem gets also satisfied in the specified evaluation. .

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