Numerical Study for the Prediction of Heat Transfer in a Pulsating Turbulent Flow in Microtube

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Abstract- A two dimensional numerical analysis is carried out to understand the thermo hydrodynamics of single phase pulsating laminar flow in a micro tube with constant flux boundary condition imposed on its outer surface while the cross-sectional solid faces exposed to the surrounding are insulated. The inlet velocity to the tube is the combination of a fixed component of velocity and fluctuating component of velocity which varies sinusoidally with time, thus causing pulsatile velocity at the inlet. The working fluid is water and enters the tube at 300K. Simulations have been carried out at a range of pulsating frequency between 2- 10 Hz and amplitude ratio (A) equals to 0.2. To study the effect of axial wall conduction micro tube, wall to fluid conductivity ratio is taken in a very wide range (k_{sf} = 0.344 – 715) at a flow Reynolds number of 100. Effect of pulsation frequency on heat transfer is found to be very small. Heat transfer is found to be increasing at lower thermal conductive micro tube wall material (or k_{sf}) while it is decreasing at higher ksf compared to steady flow in micro tube. Existing studies do indicate that pulsation (i) increases heat transfer (ii) decreases heat transfer, or (iii) no effect. The researchers actually failed to observe the present overall trend as none of the existing studies considered a widely varying thermal conductive wall material. Again, for a particular pulsating frequency (W_o), with very low ksf leads to lower the overall Nusselt number while the time averaged relative Nusselt number remains almost constant through the entire length of micro tube and it is less than the corresponding steady state Nusselt number. Higher ksf with a particular frequency again lowers overall Nusselt number slightly due to severe back conduction. From this, it is confirmed that for a particular pulsating frequency, there exist an optimum value of ksf which maximizes the overall Nusselt number while all other parameters like flow Reynolds number, micro tube thickness to inner radius ratio (δ_{sf}) remaining the same.
Keywords: Micro tube, Axial Wall Conduction, Pulsatile Flow, Pulsating Frequency, Relative Nusselt number, Conductivity Ratio.

I. INTRODUCTION

Late advancement of electronic gadgets with higher processor speed needs high intensity evacuation rate. Again according to customary hypothesis, heat move is straightforwardly relative to the surface region and the temperature contrast. While temperature contrast is confined by the application, so the surface region per unit volume is the main boundary which controls the intensity move rate. As microtubes/microchannels having higher surface region per unit volume when contrasted with traditional channels is much of the time utilized. With the advancement of micromachining/miniature assembling, their applications in the field of liquid stream and intensity move are expanding step by step. A few normal utilizations of micromachining in the field of liquid stream and intensity move can be found in Khandekar and Moharan. Microchannels of various sizes and shapes according to prerequisite can be fabricated without any problem. Subsequently microchannels/microtubes are acquiring significance in the vast majority of the designing applications.
The general thickness of the cylinder mass of a miniature cylinder contrasted with its internal span prompts multi-layered form heat move, contingent upon a few different elements, for example thermo actual properties of the cylinder wall and liquid included, and stream conditions. Different sort of stream happens in designing applications separated from unidirectional stream. In a large portion of the applications stream is wavering sort.
Expectedly, uniform liquid stream framework is utilized in numerous liquid stream and intensity move frameworks in customary size as well as microchannel frameworks. Accordingly, many examinations truly do exist in writing that arrangements with such frameworks which assisted with understanding the thermo-hydrodynamics of single stage as well as two-stage frameworks. Furthermore, two additional kinds of liquid stream that track down application in many designing frameworks (a) swaying stream (or oscillatory stream), and (b) throbbing stream (or pulsatile stream). At the point when there is no net mean speed of the liquid toward any path and it is just swaying to and fro about a proper point with a superimposed recurrence really at that time the stream is called wavering stream .Where in the event of throbbing stream, a wavering speed is superimposed with the

one directional translational speed. Along these lines in throbbing stream time-normal speed is non-zero though in swaying stream time-normal speed is no over a specific time of cycle at any moment. This kind of stream mostly described by two boundaries to be specific (I) recurrence of swaying, f (or Womersley number, Wo), and (ii) sufficiency of wavering (A). On account of fast movement, convective intensity move might build in such cases. The impact of throbs on heat move is a fascinating issue for scientists because of its wide events in many continuous circumstances at large scale as well as little/miniature level.

This sort of stream every now and again experienced in organic frameworks. Course of blood (Cardio vascular framework) and trade of gas through the outer layer of lungs (respiratory framework) in human body are the best utilization of pulsatile stream. Cardio vascular framework basically comprises of four chamber strong organ known as heart which supplies blood to various pieces of the body by the assistance of veins, ventricles and vessels. Blood dissemination through the heart is altogether constrained by valve systems and opening and shutting of valves at explicit time stretches results in occasional pulsatile stream of blood.

Comparatively significant parts of respiratory frameworks are the aviation route, the lungs, and the muscles of breath. The significant capability of aviation route is to move the air between the lungs and outer pieces of the body. The really utilitarian units of the respiratory framework are lungs whose capability is to supply oxygen into the body parts by removing carbon dioxide from the body. Stomach alongside bury costal muscles called as muscles of breath which is going about as a siphon, driving air into and out of the lungs while relaxing. Inward breath and exhalation are the two cycles of breathing for example take in and inhale out separately by which the body get in oxygen and ousts carbon dioxide. Breathing course of lungs is basically done with the assistance of stomach. At the hour of take in or inward breath, constriction of stomach muscles happens in descending course. In this way regrettable strain will made for which natural air goes into the lungs. The circumstance is only inverse in the event of exhalation, where development of stomach muscles happens in vertical bearing, which brought about the arrival of air from the lungs. So because of this compression and unwinding of stomach an intermittent pulsatile stream of air happens.

Aside from organic application many designing frameworks likewise experience pulsatile stream for example responding motors, IC motors, beat combustor, ramjet and so on to give some examples. Throbbing stream finds broad application in many designing gadgets like throbbing intensity pipes utilized in numerous warm administration applications; which is to some extent loaded up with a functioning liquid. As a result of its little aspect, surface strain overwhelms and unconstrained fluid air pocket framework is created because of the activity of surface pressure. This framework gets heat from the evaporator segment, bubble extends and fluid agreements; consequently a self-supported warm determined oscillatory movement begins lastly moves intensity to the condenser area which lead to occasional oscillatory stream.

Additionally, numerous gadgets or frameworks go through serious vibration in functional designing applications which brings about oscillatory movement of working liquids inside the frameworks while it pushes ahead. In some occurrence, stream isn't ceaseless rather it sways because of certain obstacles or snags in the stream course or in the tightened sections of some perplexing calculation setup gadgets. Aside from this, changes or motions are once in a while related in the stream for example stream over tube packs where vortex shedding from the main cylinder prompts vacillations for resulting tubes. Much of the time outer throbs are superimposed on the consistent stream, model is 'beat fly cooling'. In numerous modern applications stream inside the gear is generally either responding or throbbing sort, where intensity move happens. Cavitations in water driven pipe lines and tension floods are the most famous instance of such streams in viable designing applications.

II. LITERATURE SURVEY

Karamercan and Gaine [2021] tentatively examined the impact of throb in a twofold line heat exchanger and considered boundaries of interest as Reynolds number, removal sufficiency, and throb recurrence. Explore was directed by changing the dislodging plentifulness by five unique qualities where for each stream rate the recurrence of stream throb fluctuated up to 300 cycles/minute. They reasoned that intensity move coefficient was expanding with throbs, prompting higher intensity move and the most extreme improvement was accounted for in the change stream system.

Mackley et al. [2020] completed explore in the twofold cylinder heat exchanger by embedding astounds in the intensity exchanger. Greasing up at temperature of 60oC was passed on the cylinder side of intensity exchanger which was thusly cooled though shell side of the intensity exchanger kept up with at steady temperature by giving faucet water at 11oC. Throbbing component given by the assistance of rotational engine which was driven by cam. Temperature at various areas at various time stretches in heat exchanger was recorded by thermocouples. By changing the rotational speed oscillatory boundaries was changed.

Mackley et al. [2018] presumed that Nusselt number increments with an entirely sensible way when contrasted with the framework where throb in the stream and confuses are not accessible.

Cho and Hyun [2015] mathematically contemplated thermo-hydrodynamics of throbbing stream in a line. They mathematically settled flimsy laminar limit layer condition for wide scopes of recurrence and the abundancy of wavering. From the arrangement it was inferred that, Nusselt number might increment/decline, contingent upon throbbing recurrence yet deviation of Nusselt number is extremely less from the consistent stream.

Kim et al. [2015] mathematically contemplated hydro powerfully grew, thermally creating liquid stream in a channel with isothermal wall. Reproduction was performed at Re = 50, Pr = 0.7, where the throb plentifulness (A) and nondimensional throb recurrence (M) taken in a wide reach. From the recreation it is affirmed that when M was low, no deviation found in consistent and flimsy speed profiles. However, for bigger worth of M, the impacts of throb bound to an extremely restricted region closer to the walls. What's more, at a similar second, for little and moderate throb recurrence the impact of throb on Nusselt number observable yet at higher recurrence the impact is immaterial. The impact of throb on Nusselt number primarily seen in the entry district, while the completely grown downstream area impact is less. Likewise, pressure inclination increments with recurrence and at extremely high frequencies, stream inversion happens for some piece of throbbing stage.

Guo and Sung [2014] had tried various forms of Nusselt number to explain the clashing outcomes and purposed a better rendition of Nusselt number which was intently coordinates with estimation. They found that for lower scope of amplitudes, heat move may upgraded or diminished inside a specific band of working recurrence yet at higher amplitudes, heat move was constantly increased regardless of recurrence.

III. PROBLEM IDENTIFICATION

- Pivotal wall conduction assume vital part in warm execution of miniature intensity exchangers.
- The exhibitions of gear are generally impacted by the throbbing stream boundaries exposed to warm designing applications.
- Committed study should be expected to comprehend the thermo-hydrodynamics of throbbing stream to expand the proficiency and for better warm plan of such frameworks.

IV. OBJECTIVES

- Impact of throb recurrence on heat move to be found.
- Heat move is viewed as expanding at lower warm conductive microtube wall material (or ksf) while it is diminishing at higher ksf contrasted with consistent stream in microtube.
- For a specific throbbing recurrence, there exist an ideal worth of ksf which boosts the by and large Nusselt number.

V. METHODOLOGY

A microtube with inward sweep (δf), tube thickness (δs) and length (L) has been considered as displayed in Fig. 4.1. Water is utilized as the functioning liquid and enters the microtube at 300 K (Pr = 7) with a slug speed that changing with time sinusoidally, subsequently causing throbbing stream in the microtube. The channel speed (Uin) subsequently comprises of a proper part (Uav) and a fluctuating part (Uav•A•sin (ωt)) which shifts sinusoidally with time. Because of pivot evenness, a two-layered computational space is thought of.

This aides in saving computational time. The thickness (δs), internal span (δf), length (L) of the microtube is kept steady in the computational model at 0.2 mm, 0.2 mm, and 60 mm separately. The sinusoidal bend for pulsatile stream extent is likewise displayed underneath, where the qualities close to various focuses showed on the bend addresses the stage point in degree.

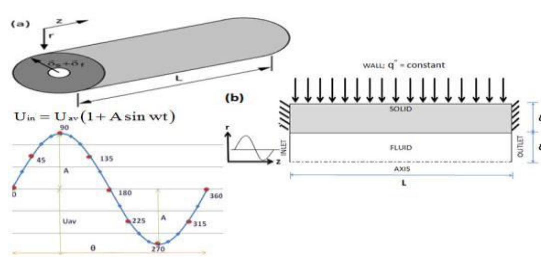


Figure 1: Microtube and Its Computational Domain with Pulsating Velocity at Inlet

Numerical analysis has been carried out with the following prior assumptions:

- Flow is laminar, incompressible, and in single phase.
- Thermo-physical properties of the fluid are constant.
- Heat transfer through natural convention and radiation mode is negligible.

The flow and heat transfer are governed by the Navier-Stokes and energy equations.
Hence time dependent, incompressible two-dimensional governing equations with constant Thermo-physical properties in axisymmetric cylindrical coordinate system can be written as:

Continuity equation

$$\frac{1}{r}\frac{\partial(rv)}{\partial r}+\frac{\partial u}{\partial z}=0$$

(4.1)

Navier-Stokes equation:

$$\text{z direction}: \frac{\partial u}{\partial t}+v\frac{\partial u}{\partial r}+u\frac{\partial u}{\partial z}=-\frac{1}{\rho}\frac{\partial p}{\partial z}+v\left(\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial u}{\partial r}\right)+\frac{\partial^2 u}{\partial z^2}\right)$$

(4.2)

$$\text{r direction}: \frac{\partial v}{\partial t}+v\frac{\partial v}{\partial r}+u\frac{\partial v}{\partial z}=-\frac{1}{\rho}\frac{\partial p}{\partial r}+v\left(\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial v}{\partial r}\right)+\frac{\partial^2 v}{\partial z^2}-\frac{v}{r^2}\right)$$

(4.3)

Energy equation

$$\rho c_p\left(\frac{\partial T}{\partial t}+v\frac{\partial T}{\partial r}+u\frac{\partial T}{\partial z}\right)=k\left(\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right)+\frac{\partial^2 T}{\partial z^2}\right)+\mu\Phi$$

(4.4)

Where Φ is known as Rayleigh dissipation function.
For solid domain

$$\nabla^2 T = 0$$

(4.5)

At z = 0 to z = L and r = 0

$$\frac{\partial U}{\partial r}=0$$

(4.6)

$$\text{At } z=0 \text{ and } r=0 \text{ to } r=\delta_f,\ U_{in}=U_{av}(1+A\sin\omega t);\ T_{in}=T_{atm}$$

(4.7)

$$\text{At } z=L \text{ and } r=0 \text{ to } r=\delta_f,\ P=0$$

(4.8)

$$\text{At } z=0 \text{ and } r=\delta_f \text{ to } r=\delta_s+\delta_f,\ \frac{\partial T}{\partial z}=0$$

(4.9)

$$\text{At } z=L \text{ and } r=\delta_f \text{ to } r=\delta_s+\delta_f,\ \frac{\partial T}{\partial z}=0$$

(4.10)

$$\text{At } z=0 \text{ to } z=L,\ r=\delta_s+\delta_f,\ q=\text{const}$$

(4.11)

The overseeing conditions (for example coherence, Navier-Stirs up and energy conditions) are addressed utilizing monetarily accessible Ansys Familiar 13.0 which depends on limited volume discretization.
The computational area of the microtube (L = 60 mm and R = 0.4 mm) can be taken as two layered square shape (as displayed in Fig. 3.1(b)) due to axi balance. For the production of above math in Ansys13.0 workbench on the tool compartment Liquid stream (Familiar) was chosen.
Then investigation type is changed from 3D to 2D by choosing property at the Calculation level. In the Plan MODLER (DM) screen 'mm' as the unit was picked. Then, at that point, two square shapes were outlined and aspect was determined in the ZY plane. Surfaces were made from the drawing with legitimate naming. After age of surfaces body type was characterized for example internal square shape as Liquid and the external square shape as Strong. For accomplishing of coupled condition for form heat move between two surfaces, one section with two surfaces was framed by choosing the two surfaces and by tapping on to shape NEW PART. Subsequent to naming the limits of the computational space as (Balance, Form wall, Top wall, Protected wall 1, Protected wall 2, Delta, and Power source), the calculation was saved.

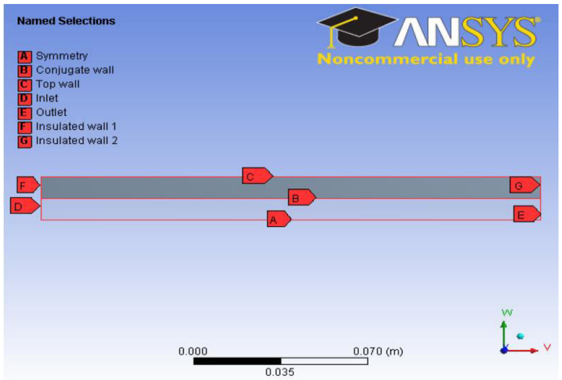


Figure 2: Computational Domain with Named Boundary

Since quality, number and construction of framework are the three significant boundaries which will influence the exactness mark of a computational issue, network age presents one of the significant stages in mathematical arrangements. After formation of math Plan MODLER screen was shut and Work was chosen on Undertaking Schematic screen.

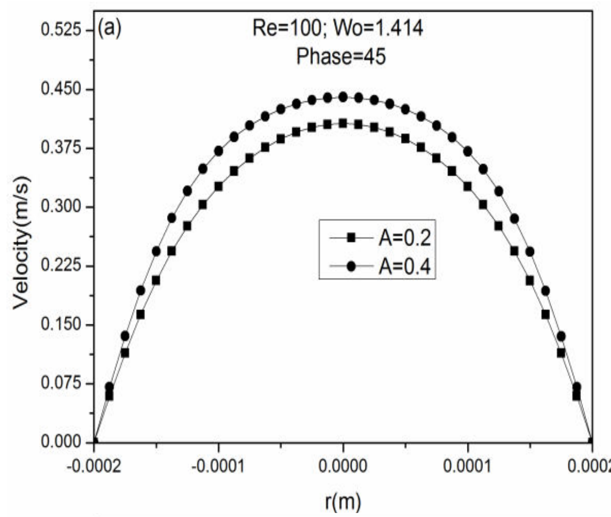
VI. RESULT AND ANALYSIS

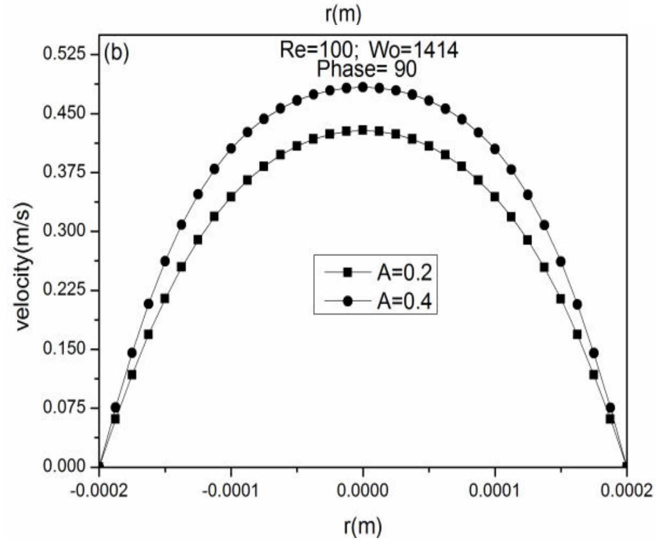
The typical stream Re (in light of mean speed over a cycle) is kept up with at 100. Water is utilized as the functioning liquid and enters the microtube at 300K (Pr = 7) with a slug speed that differing with time sinusoidally. For the consistent intermittent arrangement, all investigation is finished for a specific cycle (seventh cycle) at various stage points going from 0-360.

Hydrodynamic examination of pulsatile stream is done under ideal condition (zero wall thickness). At first, confirmation of UDF is finished with the hypothetical outcomes for various stage points and plentifulness of motions over a time of cycle. Confirmation is completed for a specific throb recurrence (f) is for example 2 Hz which compares to Wo = 1.414 while sufficiency of throb (A) is shifted from 0.2 to 0.4. From the confirmation, it has been observed that hypothetical outcomes are in great concurrence with the mathematical outcomes by UDF programming.

Spiral variety of speed for various stage points at a specific area in the completely evolved locale is displayed in Figs. 3 and 4 separately. From the Fig. 3 and Fig. 4, it is affirmed that, when the stage point is 270 the speed is most reduced and when the stage point is 90, speed is most noteworthy which is additionally hypothetically right. At the stage point 135, speed is higher from the speed comparing to stage point 45 in the closer to focal locale of the cylinder while circumstance is simply converse closer to the wall for example speed comparing to stage point 45 is more than the speed relating to stage point 135.

Comparable to perception is found for the stage point 225 and 315 which is obviously displayed in Fig. 4. Because of the impact of idleness this little deviation in speed is accounted for. Again from the Fig. 4, obviously the speed profiles covers for three different stage points (0,180,360). Expansion in speed is accounted for the positive half cycle with stage points going from 45-135, by changing the sufficiency of throb from 0.2 to 0.4. Also, simultaneously decline in speed because of throb is accounted for negative half cycle with stage points going from 225-315 by expanding the plentifulness proportion in a similar reach taken before. (See Fig. 3 (a)- (f)).





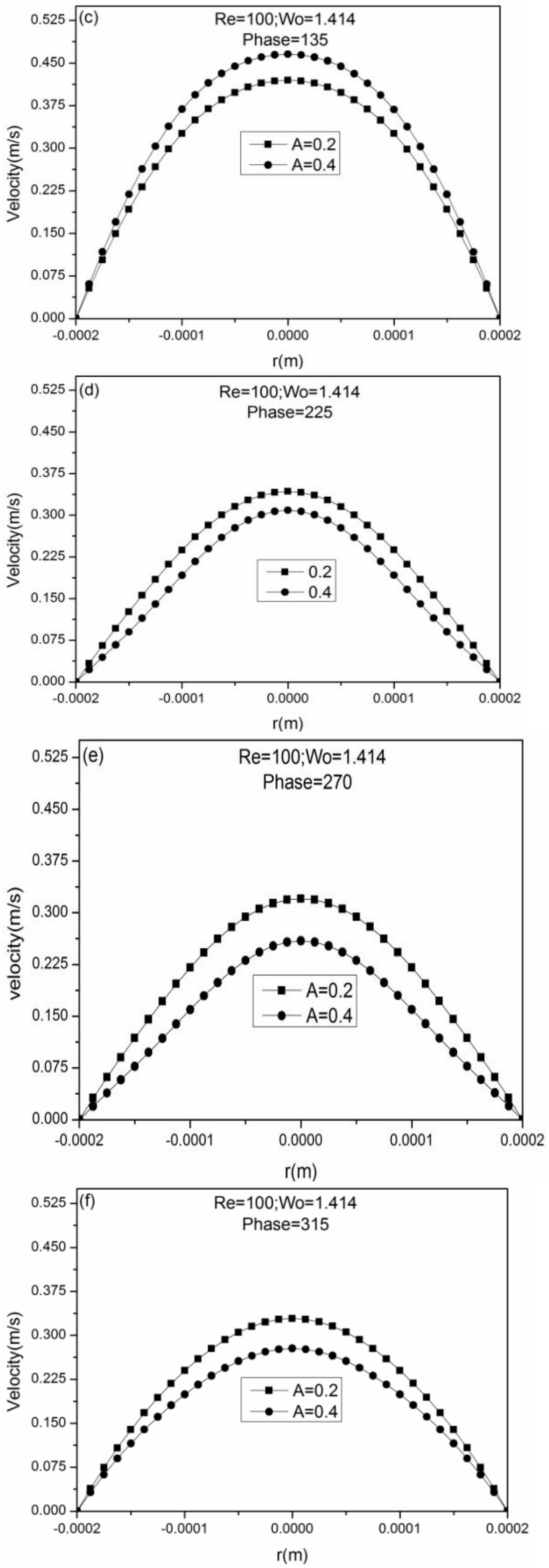


Figure 3: Verification of Velocity at Two Different Amplitudes, for Different Phase Angle.

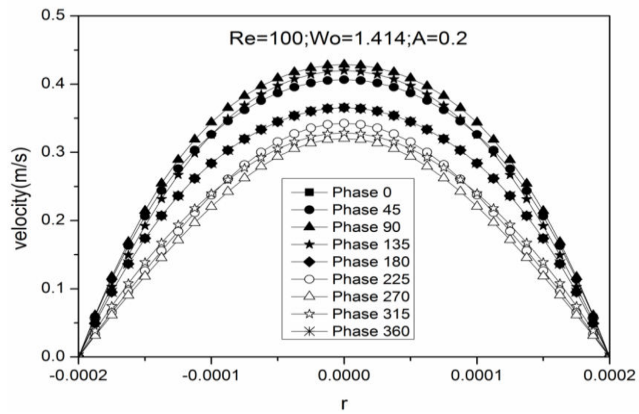


Figure 4: Variation of Velocity Magnitude in Radial Direction for Different Phase Angles (0-360)

VII. CONCLUSIONS

A mathematical examination is completed to feature the impact of throb on pivotal wall conduction for the laminar stream in a microtube with steady intensity motion limit condition forced on its external surface. For this recreation, conductivity proportion is taken at a wide reach (ksf 0.344-715) while the thickness proportion (δsf), plentifulness (A), and stream rate (Re) stay steady. To grasp impact of throb, recurrence of wavering (f) is changed by taking four different Womersley numbers (1.414, 2, 2.45, and 3.163). In view of the mathematical recreation, it are made to follow determinations:

• Because of the stream throb, most noteworthy speed is noticed for the stage point 90 while least speed is accounted for at 270 stage point. Speed profile covers for various stage points (0, 180, and 360).
• For a specific throbbing recurrence (Wo), with exceptionally low ksf prompts bring down the by and large Nusselt number (Nu) while the time found the middle value of relative Nusselt number remaining parts [Nur(z)] practically consistent through the whole length of microtube and it is not exactly the comparing consistent state Nusselt number.
• Moderate worth of ksf at a specific throb recurrence (Wo) boosts the generally speaking Nusselt number.
• However, at higher ksf, with a specific recurrence again brings down generally speaking Nusselt number (Nu) somewhat because of extreme back conduction.
• For a specific throb recurrence (Wo) there exists an ideal worth of ksf (moderate worth of ksf) at which in general Nusselt number (Nu) is greatest. Comparable pattern was noticed for a consistent stream in square microchannel and roundabout microtube with steady intensity transition as the limit condition for

consistent stream in a microtube exposed to fractional warming on its external wall under consistent intensity motion as the limit condition. Relative momentary nearby Nusselt number wavers over the hub length for various stage points. Motions more articulated at the entry area where it rots in the created district drawing nearer towards the consistent state Nusselt number.

• Quantitatively, impact of throb recurrence (Wo) on heat move is viewed as tiny.

• From the subjective investigation, found heat move expanding at lower warm conductive microtube wall material (or ksf) by expanding throbbing recurrence.

• Yet, with expanding throbbing recurrence heat move rate lessens in the event of higher warm conductive material.

Survey of writing demonstrates that throb (I) increments heat move (ii) diminishes heat move, or (iii) no impact. The scientists really neglected to notice the current generally speaking pattern as none of the current investigations thought about a broadly fluctuating warm conductive wall material.

Since in the majority of the pragmatic designing applications, working liquid goes through stage change, warm examination of pulsatile stream with multi-stage stream is one representing things to come extents of This venture. Aside from this, thermo-hydrodynamic examination for a pulsatile stream should likewise be possible for the fierce stream having exceptionally high Reynolds number or low Reynolds number under the positive states of violent stream. At a few viable circumstances, tube wall may likewise dependent upon consistent wall temperature or somewhat warmed rather than full warming. Thus, these necessities will starts further work in the above project. It is normal that, this Current work will give huge thought and make a way for new future work.

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