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Scale Up of Water Injection Into the Pipe Flow: Reynolds Number Variations

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***Abstract* – Laboratories and pilot plants are set before going on to production. In present piece, the subject is an operation of pipeline jet injection mixing scale up. Water was let loose inside a pipe and a side injection at higher temperature was introduced at normal underneath. Experiments were carried out. Computational fluid dynamic package was used to model after geometry creation by a pre-processor and to simulate the same. Scale up of the system is reported with constant velocities. Reynolds number varies with scale up. Plots and contours are also generated. Results are fine and the downing from zero-incidence injection point for jet into pipe flow is measured. For larger diameters, it is noticed that heat transfer mixing is achieved earlier in bigger geometries. A support vector machine model is also trained to predict the data. Good agreement is obtained.**

***Keywords* – Pipeline, Computational Fluid Dynamics, Scale Up, Mixing, Water, Injection, Temperature, Simultaneous Flow, Heat Transfer.**

I. Introduction

The subject is that the fluid is in motion and by its contact with other material, heat transfer takes place. When the secondary material or fluid is also moving or flowing then the heat transfer occurs simultaneously with the flow motion. System may be open or close. In present circumstances a fluid flowing is injected to a fluid flowing inside a confined pipe in a tee shape. The fluid situation is compound.

The design and scale up problem associated with any process had been tackled by developing empirical design equations mainly due to the complexity of the fluid physics. New age technology advancements make it easier to develop geometries according to process and simulate the whole process as well as modify it accordingly. Theory and experience have been collectively embedded into these computational software packages and day by day advancements are being welcomed to enhance the efficiency as well as end result quality.

Computational fluid dynamics are being increasingly used to obtain better understanding of any operation or process, including detailed knowledge of the characteristics of the system under consideration. Such understanding of the process is essential for design, redesign, prediction, forecasting and selection. These improvements by using computational fluid dynamics become more effective when hybrid with the actual situation or laboratory experiments.

Pipeline is a common unit in any industry especially in oil and gas industry. Injection jet penetration has an important role to save cost and space for equipments. It is playing a key role in many industries to manage the equipments as well as for process intensifications. In these pipelines a very common operation is flow of any fluid and jet injection. Complete or incomplete (IC) jet results towards side unwanted, inadequate process or many associated problems. This injection in pipeline with many configurations is used to mix primary fluid into pipe fluid. Its various points have been covered in literature and many significant experimental and numerical works have been performed in this field in various dimensions of many areas encl. material processing, petroleum chemical and equalization to mention. Acid base dilution may be instantly carried out by pipeline mixing. Many other forms of injections are being applied in various types of operations.

Works varying many parameters to study a side injection had been carried out. A review was reported of such operations in pipelines [1]. Few experimental studies for an injection were mentioned. Measurements of the downward stream from the tee inlet required for the neutralization of a base indicator were found in [2] designing few correlations. Water injection in a super charged Jaguar air craft engine was reported [3]. The effects of water injection on the cooling characteristic were ported [4]. On the use of water injection to decrease gasoline consumption in an air craft engine cruising at high power was reported [5]. Report of direct water injection cooling for military equipments was presented [6]. The longitudinal mixing of liquids flowing successively in pipelines was reported in [7]. Pump jet mixing and pipeline transfer assessment for high-activity radioactive wastes were reported in [8]. Interfacial mixing in viscous pipe flows reported in [9]. Water coning control in oil wells by fluid injection was reported [10].

Numerical simulation of pipeline tee mixers was compared with data in [11]. An experimental study and computational fluid dynamics modeling of precipitation in a pipe were reported [12]. Computer simulation of tee mixers for non reactive and reactive flows was reported [13]. An on-line, in-situ, mixing assessment technique for pulp fiber suspensions was reported [14]. Large eddy simulations of jets in cross flow and its application was reported in [15]. Measurements of the flow and turbulence characteristics of round jets in cross flow [16] and heat transfer and film cooling effectiveness with injection [17] and film cooling effectiveness characteristics at various stream wise angles in a cross flow [18] were reported. Gas assisted repetitive pulsed heating [19] and heating of surfaces [20] were reported. Optimization of constant cross-sectional area was studied in [21]. Present work is a side hot injection into cold fluid and down mixed stream equivalency equilibrium temperature was used as a downstream measuring variable. Fluid was injected into fluid flowing in pipe. Many other forms of injections are being applied in various types of operations.

Effect of perpendicular flow entry on convective heat/mass transfer from pin-fin arrays were discussed in [22]. Numerical simulation was reported [23]. A modeling analysis of non-isothermal reactors was investigated in [24]. Solid suspensions in stirred tanks were reported in [25]. In bellow mentioned [26]-[35] fluid injection works are carried out for various jets to width ratios including ratio of quarter at small and at large scales for various target fluids and systems. A phase investigation of jet impact was carried out in deep wall boundaries [26] and investigations of jet injection onto viscous material on top of deep cold waters were reported in [27]. Simulations of high speed jet injections onto target fluid at rest were carried out in [28] were tested for jet throw onto zero depth targets [29]. A report was presented on high speed jet blown onto stagnant carbonyl sulfide surface [30]. Direct jet input onto the partially filled multiphase system inside deep wall boundaries was studied in [31]. Simulation of high density many phase system and the jet downing into the carbonyl sulfide inside a closure presenting mixture behavior were reported in [32] and [33] respectively. Fast jet reappearance within stagnant water layered at metallic wall boundary was checked in [34] and multiphase investigations of laminar jet penetrations at stagnant surface of fluid layered in a channel open on other side was shown in [35].

Many systems may be explored for such kind of jet penetrations in many varieties for small and large systems with drawing a mirror symmetric picture to tackle many industrial problems. Potential core of a submerged laminar jet was reported [36]. Computation of multiphase mixture flows with compressibility effects was reported [37]. The tee mixing is used to mix nitrogen and methane to obtain low parts per million concentration methane. Non-dispersive infrared detector methane gas-sensors have the application. Applications of jet operation may be found from industry to industry to usage of infrared-emitting gas jets in animal husbandry [38]. Water is abundant in nature and an essential nutrient [39]. Histological changes in the nasal mucosa after hot water irrigation was reported [40].

Mixing with various geometric configurations, with various rates and with various input-output orientations to achieve optimized completeness or reaction conversion preventing pipeline problems is fundamental. Acid and base dilution may be instantly carried out by pipeline mixing. Nitric acid is abundantly used in process industry and its dilution to a specific concentration is sometimes required before its particular use for instance. Pipeline mixing may be used for such kind of applications. Hence downstream length should be measured when installation of such kind of mixers is planned.

Computational fluid dynamics previously regarded as a methodology only for applications in “high tech” industries by experts has been undergone a change and has been adopted by a range of industries incl. chemical, petrochemical, oil, automotive, built environment to mention. It is an engineering tool to aid the design of a process. The development in industrial computational fluid dynamics was reviewed by [41]. Jet reactor scale-up for mixing controlled reactions was reported [42]. Computer simulations of flow phenomena have been applied to many industrial applications. Simulations using computational fluid dynamics of pipeline mixing had been performed. It is now extensively used in explorations of mixing operations.

In present work, a simple operation is considered. It is described as: water is flowing within a confined pipe and a side injection of same fluid at higher temperature is introduced at right angle. The mechanism of present work was to construct experimental set up and to do experiments for two different geometries recording the temperature at center of downing pipe that is water was flowing inside the pipe and the hot single compound stream was introduced normally to it.

On foundation of physical experiments of free direct contact of hot injection to pipe flow water, simulation experiments are presented with the help of computational fluid dynamic package limiting to a situation of one single injection; in which convection and bulk fluid motion play a role with free of mechanical constraints. Fluids were coming into contact with each other emphasizing on heating of water in pipe by side hot injection of water from one single at a time. In numbers, two injections, first smaller and then a side double scaled up were worked out but each at a time. Overall scale up of the system is also presented.

Computational fluid dynamic mixing downing point is computed by measuring down mixed stream equivalency equilibrium temperature that is where the mixed stream closes the equilibrium temperature. The side pipe is making shape of a 'T' tee , such as it is making right angle that is ninety with the pipe and is normal in the sense that it is connected to pipe at the center in the way as the center injection line and the center line of pipe are at cross with each other. Many flow rates with various side injection speed jet, counting velocity ratio, are trialed and a one single optimum velocity ratio suitable for side right injection, whereas the details of choice modeling is out of scope of present work and may be found elsewhere, is chosen for present scale up. However few velocity ratio cases are also a part to espousal the present matter.

Fluid mixing behavior: earlier and controlled, with suitable geometric configuration and input-output orientations for a process considered to achieve completeness or reaction conversion, avoiding any pipeline related problems, is investigated lying on heat transfer, mass transfer, simultaneous heat and mass transfer and reaction occurrence.. Volume flow rates of fluids, diameters of input ports, orientation of injection and direction of contact were a part of investigation. Flow conditions and geometric configurations are optimized to elaborate better performance of fluid-fluid mixing at larger scale.

Computational fluid dynamic mixing downing length is measured. A support vector machine training model predictions is also reported for the same. Scale up of normal single injection is presented here. Summarized ratiocination process of work carried out is mentioned and is detailed in next sections.

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II. METHODS AND MATERIALS

The mechanism of the work performed in this piece is designing the process, constructing and running the experimental rig. An assembly consisting of a poly vinyl chloride pipe three hundred centimeter long is employed as the main part of the rig. The experiments of hot water injection to cold flowing water were performed. Side diameter pipe was changed and experiments were repeated for that different diameter. For both cases experiments were repeated more than five times. Temperature at center of pipeline was recorded downstream and data was saved. Water was supplied always fresh. Temperature of cold stream was maintained by using ice cubes to ten degree centigrade. Heater was used to heat the side water to around fifty degree centigrade. Along execution of experiments and data recording, numerical models were validated with the experimental results. The numerical models which are being under consideration were repeatedly evaluated for accurate measurements and validation for the data generated from experiments. Upstream becomes significant in case of high speed impinging jets.

Numerical and experimental investigations of mixing in pipeline with side-tee; flush tees and protruding tees; was reported [43] for a range of velocities and smaller numerical length geometries. The work is being under revision to prepare for many variables, parameters, and sizes and scales, and direction and orientation to mention [44]. Mixing in pipeline with side and opposed tee was presented [45]. Experimental setup, numerical model, model validation and side tee mixing were reported [46]. Angle-tees were also studied. Direct contact high temperature side injection fluid into pipe experiments were [47] reported following certain discussions on practical of heating flowing water in pipeline [48]. Pre-cooling of supply water was carried out by adding ice cubes to water supply to maintain the cold water at ten degree Celsius. In summer months the supply water was at higher temperature. Mixed hot water was reused as hot water supply in winter months as well as to heat the cold water supply. Controlled cooling of hot effluent in a vertical pipe within allied assembly with fixed horizontal downstream hard core [49] and limited controlled heating of reusable discharge within an allied cross pipeline assembly with recycle overflow [50] were presented. Experiments were conducted and numerical model was validated and substantiation of essential genuine validation of computational fluid dynamic simulation and modeling of a hot compound water normal single side injection on, about jet-vicinity and -tail in cylindrical walled cold fluid flow pipeline [51] and the physics of jet and about tail [52] are reported whereas jet vicinity circa is explored for turbulence models in [53]. A method is proposed for measuring the downing downward thermal contact mixing lengths in [54] for a known percentage say: ninety five percent or ninety nine percent considering the zero-incidence as in no cent (zero per cent) which was used for comparison of jet kinetic efficiency design [55]. Preliminary short review in [56] about works of heat and mass transfer mixing enhancements in pipeline was reported with sections of numerical, computational fluid dynamics and experiments. Side tee experiments and their computation fluid dynamic investigations parts were worked out for half quarter of an inch and quarter of an inch side tee into one inch diameter pipeline for wide range of rates to find earlier mixing conditions. Replaying the injection and flow directions, investigations of flow pattern, gradient behavior and mixing time in opposed and engulfed tees and specifically of fast flow pattern in such tee are reported in [57] and [58], and [59] respectively. Restricted control volume jet travel undergoing thermal change in an equal opposite tee [60], thermal recognition flow in a tee cross compound head on injection pipe-line [61], rapid outline shape flow in a face to face tee cross pipe-line [62] are reported and rapid thermal flow in a tee cross fluid flow pipe-line is checked following an amendment [63] in design for better output.

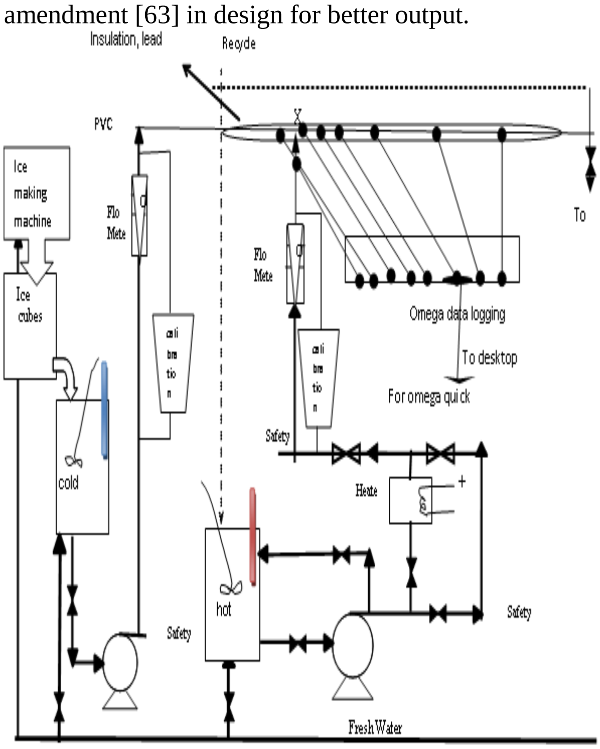

Fig.1. Experimental setup diagram scheme

The effects of obliqueness of normal injection [64] and adjustment of injection angle [65] were reported. Discussions for number of angles are drafted [66]. Kinetic energy fall and dissipation of fluid flow [67] were investigated. An injection may result in some stagnant zones and impingement on opposite wall leading towards fluctuations causing thermal fatigue in the pipe wall. A design on impingement of underneath vertical jet-side-injection into horizontal pipeline [68] and hot jet dissipations [69] were reported. Manufacturing a drilled perforated pipe, the hot additive mixture distribution at downstream is preliminary expressed for industrial flows [70]. Multiple tees were also numerically simulated. At single cross-section around the pipe circumference injection points were equally spaced. Four in number were initially created. Such injections were reported to reduce length required for mixing [71]. Comparative commentary on multiple injections in spite of a single injection was reported [72]. In [73] sectional paragraphs are joined on the lattice from the chorus of water shell within the tee cross to draw mirror symmetry, relaxation and injection relations. Scale up initiation works were reported [74].

Support vector machine SVM was fired with data measured by computational fluid dynamics simulations [75]. On the same line, in present work, mixing data measured by computational fluid dynamics for small and scale up geometries is loaded to SVM training. The clipping is explored by adjusting parameters and kernel runs and mixing data is predicted. Flow conditions and geometric configurations are optimized to elaborate better performance of fluid-fluid mixing at larger scale. Fluids used in this work were both water and it was in liquid form. Liquid-liquid mixing better performance on timely fashion: earlier and controlled, and good geometric configuration for any process considered to achieve completeness, avoiding pipeline related issues, is targeted on heat transfer. Scale up of normal single operation is presented here following verifications by support vector machine training runs. Many Kernal functions [76] are varied adjusting the parameters of machine. Results found are in good agreement.

III. Experimental Setup

The experimental apparatus is shown schematically in Figure 1. An assembly consisting of a poly vinyl chloride pipe three hundred centimeter long is employed as the main part of the rig. The rig has a replaceable facility (unions at both ends of a replaceable pipe) so that different diameters of pipe may be used. Experiments reported in this piece of work are carried out for 1: 2.54centimeter diameter pipe and side of 0.3175 centimeter and 2: 2.54centimeter diameter pipe and side of 0.635 centimeter. In second case the side diameter is double scale up. Experiments with different velocities are carried out. Suitable centrifugal pumps are installed to supply fresh water for side injection and pipe flow respectively. Output data from thermocouples is fed to desktop computer with suitable hardware having data logging software for data logging and storage. Thermocouple installation is based on points, avoiding any effect on flow and need of thermocouple as well as availability of thermocouple. Flow meters were calibrated and thermocouple reading for cold water supply pump and hot water supply pump was logged.

Results showed that thermocouples were working correctly and data logging software was also running correctly. Trials of bare hand heat loss measurement and naked eye turbulence dissipation pre techniques were performed to predict the mixing downstream. During experiments data and observation were collected by in case of poly vinyl chloride pipe by bare hand on outside pipe wall, in case of poly ethylene/glassy pipe by bare hand and in case of poly ethylene/glassy pipe bare eye turbulence dissipations judgements. Experiment plots were drawn at centre line of pipe in the direction of flow downstream. Computational fluid dynamics measurements were used to validate and compare the same as presented in next section.

IV. Numerical Model

Flow in a pipeline was simulated by solving the mass and momentum conservation equations which are shown in next section. The system was investigated by solving the energy equation and by monitoring the temperature at various positions along the flow. A general purpose three-dimensional computational fluid dynamic package was used to solve these math equations. It allowed the investigation of a range of conditions and geometries quite efficiently once a general model was established and validated against experimental results. Three-dimensional numerical models representing the pipe with the side were constructed. An unstructured tetrahedral grid was chosen. To test the dependence of the numerical solution on the grid size and to test the effects of various turbulence models, a case was selected and run for different conditions and assumptions until satisfaction level of numerical validation achieved. Runs reported in this piece of work were carried out for 1: 2.54 centimeter diameter pipe and side of 0.3175 centimeter, 2: 2.54 centimeter diameter pipe and side of 0.635 centimeter and 3: 10.16 centimeter diameter pipe and side of 2.54 centimeter. In second case the only side diameter was double scaled up to quarter of an inch. Then an overall geometric scale-up factor of (4) four was chosen, i.e. a 152.4 centimeter long pipe of 10.16 centimeter diameter and a side- of 2.54 centimeter are considered with side-injection at 20.32 centimeter. Flow conditions are optimized to get better performance of fluid-fluid mixing.

V. Math Equations

The flow of fluids in a pipe is governed by the equations of continuity and motion. The equation of motion is:

the $z-$component,

$$\left[\frac{\partial u_z}{\partial t}+u_r\frac{\partial u_z}{\partial r}+\frac{u_\theta}{r}\frac{\partial u_z}{\partial \theta}+u_z\frac{\partial u_z}{\partial z}\right]=$$

$$-\frac{1}{\rho}\frac{\partial p}{\partial z}+\nu\left[\begin{array}{l}\frac{\partial}{\partial r}\left(r\frac{\partial u_z}{\partial r}\right)+\\ \frac{1}{r^2}\frac{\partial^2 u_z}{\partial \theta^2}+\frac{\partial^2 u_z}{\partial z^2}\end{array}\right]+g_z$$

The boundary conditions used in it were: at all walls, slip condition was applied as velocity equalled to zero. Values of velocities were specified at the entrance of the pipe and entrance of the side.

Temperatures were specified for the fluid and the side fluid. Initial conditions were required such as all the runs in it were carried out under steady state conditions.

The temperature field of the fluid flowing in pipes can be resolved by solving the energy equation.

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$$\rho \hat{C}p\left(\frac{\partial T}{\partial t}+u_r\frac{\partial T}{\partial r}+\frac{u_\theta}{r}\frac{\partial T}{\partial \theta}+u_z\frac{\partial T}{\partial z}\right)=$$

$$k\left[\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right)+\frac{1}{r^2}\frac{\partial^2 T}{\partial \theta^2}+\frac{\partial^2 T}{\partial z^2}\right]+$$

$$2\mu\left\{\left(\frac{\partial u_r}{\partial r}\right)^2+\left[\frac{1}{r}\left(\frac{\partial u_\theta}{\partial \theta}+u_r\right)\right]^2+\left(\frac{\partial u_z}{\partial r}\right)\right\}$$

$$+\mu\left\{\begin{array}{l}\left(\frac{\partial u_\theta}{\partial z}+\frac{1}{r}\frac{\partial u_z}{\partial \theta}\right)^2+\left(\frac{\partial u_z}{\partial r}+\frac{\partial u_r}{\partial z}\right)^2\\ +\left[\frac{1}{r}\frac{\partial u_r}{\partial \theta}+r\frac{\partial}{\partial r}\left(\frac{u_\theta}{r}\right)\right]^2\end{array}\right\}$$

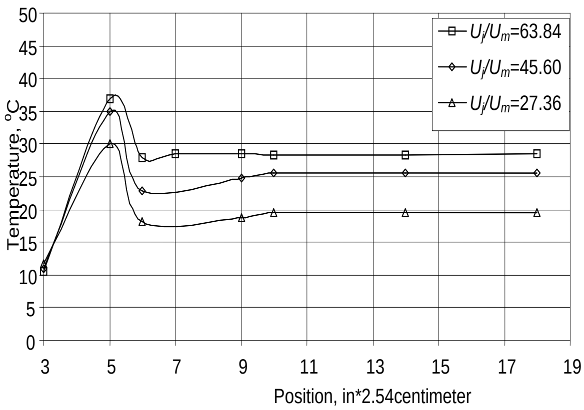

Fig.2. Experimental plots of temperature Celsius versus position along centerline for Um = 23 cm/s for Uj/Um = 63.84, 45.60, and 27.36 for 0.3175cm side.

VI. Results and Discussions

In this section, various scaling-up criteria of one base case are tested numerically. Better performance is concerned in terms of mixing. Geometries are run for numerical experiments after checking grid independence and model validations with various criteria. As jet penetration strongly depends upon velocities, many flow rates with various side injection speed jet, counting velocity ratio, are trialed and a one single optimum velocity ratio suitable for side right injection, whereas the details of choice modeling is out of scope of present work and may be found elsewhere, is chosen for present scale up study. 0.3175 centimeter into 2.54 centimeter case is an initial one which is then scaled to 0.625 centimeter into 2.54 centimeter pipe converting to a base case of 0.625 centimeter 90^o injection side and 2.54 centimeter pipe with an injection to pipe velocity ratio, U_j/U_m of 45.6 whereas pipe flow velocity Um is 23 cm/s. A geometric scale up factor of four was chosen by me. An about 152.4 centimeter long pipe of 10.16 centimeter diameter and a side of 2.54 centimeter are considered with side injection at 20.32 centimeter. Experiments and numerical results are compared. Temperature and velocity contours are drawn and downstream length of jet penetration was measured at temperature of mixed stream closeness equilibrium temperature. Figure 2 shows experimental plots of temperature versus position along centerline for U_m = 23 centimeter per second for U_j/U_m = 63.84, 45.60, and 27.36 for 0.3175 centimeter side and figure 3 shows experimental plots of temperature versus position for U_j = 10.52 meter per second for U_j/U_m = 16.58, 26.06, and 45.60. The temperature dip going away from zero-incidence for the lowest velocity ratios can be seen and is due to hot stream. An increase in Uj that is an increase in velocity ratio makes the mixed stream further away from the opposite wall resulting in a smaller temperature dip. At five the zero-incidence exists that is jet enters at this point. From adjacent to this jet vicinity zone, which expands and contracts for velocity to velocity, to around eight, nine downing the agitated zone is. Behind this calmness of fluid-fluid the mixing achieved. Figure 4 shows velocity contours of (a) U_j/U_m = 16.58 (b) U_j/U_m = 26.06 (c) U_j/U_m = 45.60 for 0.3175 centimeter side. The jet injection crosses the centerline of pipe and hits the opposite wall for higher injection rates. It turns to both sides. Therefore there are now three streams: upstream, upturn stream and downturn stream. However, the upturn stream meets the incoming upstream fluid and travels down with it, mixing with it. This happens at jet vicinity circa. At first set of contours it can be seen that as the high speed side injection velocity increases the back flow region increases. It depends on the upstream flow and mixing occurs at jet vicinity; however velocity contours show that after jet penetration the low velocity zone expands with higher rate of injection. Diameter of side is doubled that is quarter of an inch and figure 5 shows velocity (centimeter per second) contours, for U_j/U_m = 3.9, and U_j = 157 centimeter per second using 0.625centimeter side which is double of 0.3175 centimeter. At such speed the jet bending is towards the center of pipe. A high speed jet is selected with the quarter inch side injection geometry to carry out the scale up studies. A geometric factor 4 for scaling up the side and pipe diameters is considered. In the set, the velocities are kept constant which means the values of Reynolds number have been increased by a factor of 4. Data for scale up is shown in Tables 1 keeping the velocity ratio, as well as velocities, constant all the time.

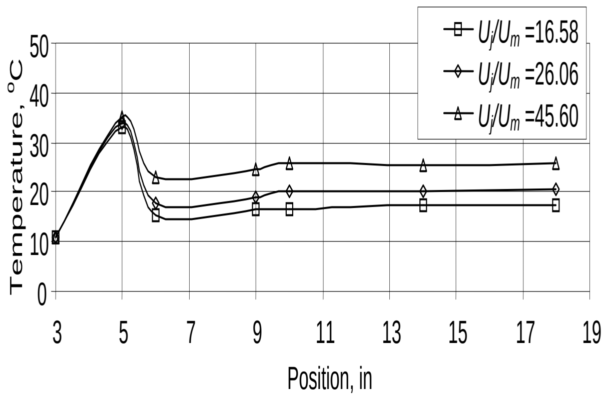

Fig.3. Experimental plots of temperature Celsius versus position for Uj = 10.52 m/s for Uj/Um = 16.58, 26.06, and 45.60.

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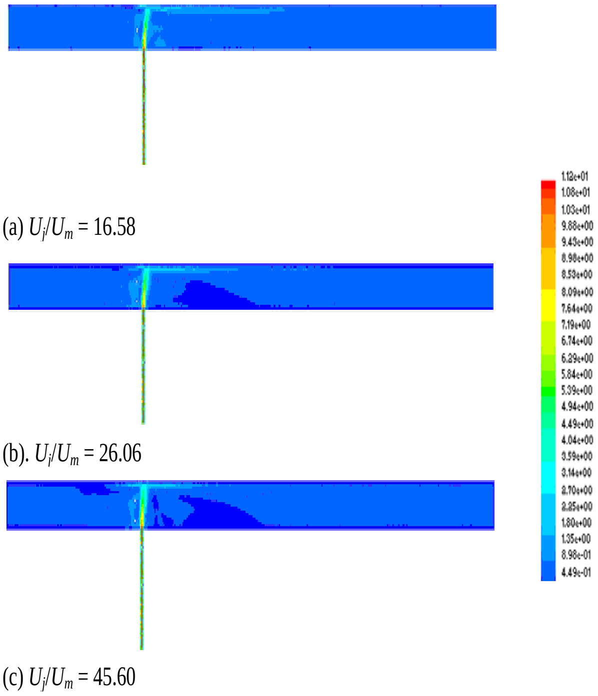

Fig.4. Velocity (m/s) contours of (a) Uj/Um = 16.58 (b) Uj/Um = 26.06 (c) Uj/Um = 45.6 for 0.3175cm side.

Table 1 is framed with velocity kept constant for pipe and side where velocity is in meter per second. Controlled flow rates were in liter per minute. Old Reynolds numbers are shown and for scale up diameters, hence variation in Reynolds number occurs. Reynolds number are recalculated which shows the comparison of data for 2.54 centimeter-0.6251 centimeter; and 10.16 centimeter-2.54 centimeter cases keeping the velocities constant.

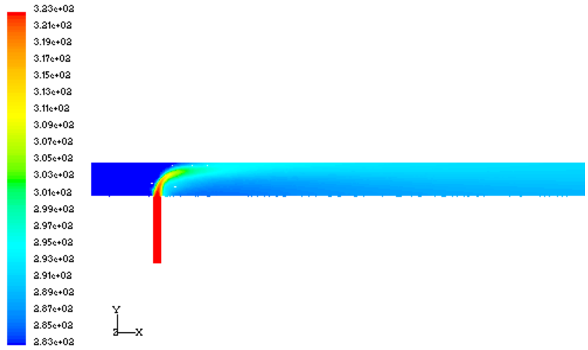

Fig.5. Velocity (m/s) contours, for Uj/Um = 3.9, and Uj = 157 cm/s using a 0.625cm side.

Comparison of downward mixing required for jet to finish its penetrations to achieve mixing for 2.54 centimeter-0.635 centimeter and 10.16 centimeter-2.54 centimeter cases keeping the velocities same with the case 45.6 U_j/U_m is shown in Table 2. It is the downstream length from injection point to where the mixed stream temperature closes the equilibrium temperature. The downing mixing for the geometry 2.54 centimeter-0.3175 centimeter for same velocity ratio is also mentioned. For present case of high speed injection a part of back flow length is also approximated. For scaled up geometries the jet penetration is reduced that is penetration of jet is finished earlier in bigger geometries. Mixing data measured by computational fluid dynamics was loaded to Support vector machine training mode. By adjusting parameters and kernel runs, mixing data is predicted as column in Table 2 shows. Best response is received when parametric optimization was carried out and thus good agreement is obtained.

Table 1: Comparison of data for 2.54cm-0.6251cm; and 10.16cm-2.54cm cases keeping the velocities constant with Reynolds number variation

Velocity Kept Constant	Velocity *m/s*	Old Reynolds number	Diameter *cm*	Scale-up Diameter, cm	New Scale up Reynolds number
Pipe	0.23	5842.	2.54	10.16	23368.
Injection	10.52	66802.	0.625	2.54	267208.
Ratio, Injection/ pipe	45.6	11.4	0.25	0.25	11.4

Table 2: Comparison of downward length required for jet penetration for 2.54cm-0.3175cm, 2.54cm-0.635cm and 10.16cm-2.54cm cases keeping velocities constant: velocity ratio constant 45.6 Uj/Um

D_m - d_j	Length required, of side-jet for penetration finish, centimeters	
	CFD measured	SVM predicted
2.54cm-0.3175cm	11	11.2
2.54cm-0.635cm	29	29.2
10.16cm-2.54cm, Velocity constant	72	71.8

VII. Summary and Recommendations

Fluid is injected into fluid flowing in pipe. Injected fluid is at different temperature. Thus simultaneous flow and heat transfer occurs. Experiments were performed. Computational fluid dynamics simulations of the same had been performed. Computational fluid dynamic mixing downing length was measured. Flow conditions and geometric configurations were optimized to elaborate better performance of fluid-fluid mixing at different scales. The experiments of hot water injection to cold flowing water were performed. Runs reported in this piece of work were carried out for 1: 2.54centimeter diameter pipe and side of 0.3175 centimeter and 2: 2.54centimeter diameter pipe and side of 0.635 centimeter and 3: 10.16 centimeter diameter pipe and side of 2.54 centimeter.

Suitable centrifugal pumps were installed to supply fresh water for side injection and pipe flow. Temperatures are specified for the fluid and the side fluid. Scale up geometry was also simulated and mixing data measured by computational fluid dynamics was loaded to SVM training.

Experimental setup was well built to run the experiments. Computational fluid dynamic model was very well established the model with validating the physical geometry and experiments. Procedure was interrelated to modify experiments as well as numerical model. Scale up proves to be necessary after laboratory or pilot plant experiments and package for these types of problem is very good tool in exercising and repeating to design and modify existing design. The piece overall noticed that for larger diameters jet penetration was achieved earlier in bigger systems.

Pipeline issue many constraints during scale up actually which should be explored, hence investigations may be carried out at different scales. Temperature was measuring variable during present work. Measurements of pH [77] may be used for larger and reactive environments to find mixing and reaction conversion. Interfacial mixing in viscous pipe flows; water coning control in oil wells by fluid injection and jet mixing reactor scale-up may be investigated. Many factors may be varied and further scale up investigations may be performed. Pressure on opposite walls may be focused for smaller as well as larger scales. Circulation flow may also be magnified. Mirror symmetrical rotational scale up may also be investigated. Thermodynamic laws' involvements may be explored in the present subject. The high speed jet streamlines travel a path which looks like Fourier series lines. It should be mathematically investigated. Statistical modeling may also be carried out.

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