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# Heat and Mass Transfer Mixing Enhancements in Pipe-Line; Numerical CFD and Experimental Chores: A Review

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***Abstract*— In this piece of work, numerical and experimental research chores are surveyed and a descriptive trend is adopted to present the discussions. There has been done a lot of work in pipelines and its comprehensive study is a task of years. We dealt here with heat and mass transfer mixing enhancements in pipeline with a side injection. After introducing the pipeline mixing and its importance two aspects are canvassed: Numerical and experimental. Till 2002 excluding but not eliminating, we have covered the literature available with us and finally a very brief conclusion is drawn. With updates and with various subsections further studies may be communicated in iambus.***

*Index Terms*—**Pipeline, Mixing, Numerical, Experimental, Heat and Mass transfer, CFD**

## I. INTRODUCTION

Pipeline which, by side injection, is used to transport various materials is also simple heat and mass transfer equipment. Mixing is a common operation playing an important, and sometimes controlling, role in industrial processes including metallurgical, chemical, petrochemical, and oil industries. Mixing is used in diverse process situations such as suspending, blending, dispersing, emulsifying and enhancing heat and mass transfer. Consequently, a very broad range of mixers and or mixing equipment is available to suit for selected purposes. The problems, such as the design and scale-up of a mixer and quantification of mixing, have been traditionally tackled by developing empirical design equations mainly due to the complexity of the fluid dynamics of mixing. The empirical equations are usually highly specific and seldom contribute to the development of theory.

In the last thirty years computational fluid dynamics (CFD) is increasingly used to obtain better understanding of the process, including detailed knowledge of the flow characteristics. Such a detailed understanding of the process is essential for equipment design and selection. These improvements become more effective if coupled with the significant advances made in the theoretical understanding of fundamental processes governing mixing. Computer simulation of turbulent flow phenomena has been successfully applied to many industrial applications. Reference [1] described the principles of applying mathematical models to various mixing operations. More recently, the advances in CFD software and computer power raised the possibility of determining the performance of pipeline heat and mass transfer mixing with tees by simulation rather than by experiments. A survey of the literature shows that simulation using CFD of pipeline mixing with tees has been carried out by [2] and [3]. Now CFD is extensively being used in application explorations and design investigations. Reference [4] studied CFD modeling of a two phase jet aerator under the influence of a cross flow. Advances towards better understanding of processes have not been only numerical and experimental but also theoretical. Reference [5] proposed a kinematics theory of mixing rate. Other work, which dealt with mixing, includes [6]-[8] presented a theoretical tool for optimum design of a mixer and visualization and quantification of mixing performance based on Ottino theory and using CFD results. In this study, the main focus is on mixing in pipe-lines with side injection. The literature has been surveyed for numerical and experimental studies of pipeline mixing. The literature survey sheds light on the problem of mixing and shows clearly the applicability and usefulness of the side tee mixers.

### *A. Mixing*

It is applied to processes used to reduce the degree of non-uniformity or system gradient property such as temperature, concentration, and viscosity. Mixing occurs when a material is moved from one region to another region. In the past it may have been of interest to achieve a required degree of homogeneity but now it is also being used to enhance heat and mass transfer, often with a system undergoing chemical reaction.

In order to produce a uniform mixture by mixing, two things need to occur. First, there must be a bulk or convective flow so as to avoid any dead/stagnant zones. Secondly, there must be an intensive or high-shear mixing zone, in which the homogeneities are broken down. Laminar and turbulent flow type occur simultaneously in the different part of the mixer with a substantial transitional zone in between them depending upon the fluid properties, primarily viscosity.

### *B. Quantification of Mixing*

Various criteria are available to quantify mixing and the most common criterion is 95% mixing. This is defined when the value of the measured variable (conductivity or temperature) at any point satisfies: $\left|\frac{C-\overline{C}}{\overline{C}}\right| < 0.05$, where $C$ is the concentration of the tracer any where in the mixing vessel and $\overline{C}$ is the equilibrium concentration. This relationship implies that the initial value of $C$ before the addition of electrolyte is zero. If the measured variable is temperature, the main flow is set initially at a certain temperature, while the flow through the side-tee is set also at a known temperature higher or lower than main flow temperature. Thus, the equilibrium temperature $\overline{T}$ can be calculated. The 95% mixing is reached when the temperature anywhere across a plane inside the pipe is within the range of $(\overline{T} \pm (\overline{T} - T_{im}) * 0.05)$ where $T_{im}$ is the initial temperature of the fluid in the main pipe, i.e. before the inlet of the side-tee. The length required for the injected fluid to mix is then measured according to this criterion, that means the maximum temperature difference between any two points across a cross sectional area of the pipe should not exceed a certain value which is a function of the initial temperatures and the flow rates of the fluids in the main and side pipes.

### *C. Turbulent Mixing*

Most important chemical reactions, heat transfer operations, combustion processes and mixing are promoted with turbulence. Effective use of turbulence creates small contagious masses of reactant species or eddies which reduce the necessary time for molecular mixing and reaction, increasing reactant contact on the scale of eddy size, which can significantly reduce the cost of producing many chemicals.

Turbulent flows are characterized by fluctuating velocity fields. These fluctuations mix transported quantities such as momentum, energy, and species concentration, and cause the transported quantities to fluctuate as well. Since these fluctuations can be of small scale and high frequency, they are too computationally expensive to simulate directly in practical engineering calculations. Instead, the instantaneous (exact) governing equations can be time-averaged, ensemble-averaged, or otherwise manipulated to remove the small scales, resulting in a modified set of equations that are computationally less expensive to solve. However, the modified equations contain additional unknown variables, and turbulence models are needed to determine these variables in terms of known quantities.

### *D. Pipe Mixing*

Mixing in pipe flow has applications in numerous industries including chemical manufacturing, waste processing and combustion related industries but the specific mechanisms governing mixing in pipe flow are not fully understood. The design of the most efficient mixing process is of interest. In waste processing, for example, a hazardous substance requires neutralization. The level of mixing efficiency directly impacts the amount of harmful pollutant emitted in this case. Mixing in a pipe approximates a one-dimensional domain because the length over which scalar fluctuations can exist is potentially much larger than the pipe diameter.

Most methods of bringing two fluid components together to mix them in a pipe involve injection at right angles to the mixing pipe axis. However, parallel and tangential injection of feeds can be used. The different geometries are basically side injection geometry. There are three considerations for each configuration of geometry, 1) a main fluid pipe, 2) a side fluid pipe, which is combining with the first one and 3) a downstream pipe, where heat or mass transfer mixing takes place starting at the point of combination of first two parts or even earlier depending upon the arrangement of the flow.

### *E. Tee Mixing*

If the Reynolds number, Re, is greater the flow in a pipe is turbulent and mixing results from turbulent diffusion. For good mixing to obtain profitable yields or to eliminate excessive corrosion in reactor or combustion chambers it is common in many existing chemical process units to continuously mix two fluids in a pipeline with subsequent transport to other location. Although the continuous mixing of two fluid streams can be achieved using a number of mixer geometries, many procedures such as the use of baffles or complex geometries will introduce excessive pressure drop and significantly increase the cost of the mixing device.

A pipe tee provides an effective and simple method of bringing together two fluid streams for mixing. One stream may pass straight through the tee while the other enters vertically at one side such that jet contact with pipeline walls is minimized and mixing occurs within the turbulent core of the flow in the pipe. For fast reaction applications that require short residence times, a tee-mixer is an attractive alternative to stirred tanks.

A tee mixer is easier to scale up and represents a more economical, reproducible and efficient design for rapid mixing. Examples of specific applications of tee mixing are such as dilution of concentrated acids or bases, wastewater treatment, or blending petrochemical products. Mixing performance data for tee mixers are presented in [9].

### *F. Angle Injection*

In chemical engineering, it is sometimes said that it is desirable to have the side-issued jet contact the opposite wall in order to enhance rapid mixing and it is assumed that at that time optimal mixing and reaction take place [10]. In some industries like paper industry, in order to minimize the pressure pulsation and flow disturbance in the approach flow system, it is desirable to avoid having the jet impact on the wall and the jet is often issued at an angle $45^o$ to $60^o$ [11]. Contrary to the above statement, this study will show that, for efficient and rapid mixing the side-jet should not impinge on the opposite wall.

### *G. Computational Fluid Dynamics*

In most operations high pressure, high temperature and processes with hazardous materials are often involved. With limited access during operations and, except for a few temperature or pressure measurements, there is often little data available on the structure of the flow within the bowl, pipe, container, carrying or storage equipments and bulk vessel, to mention. The performance of any process unit is only measured in terms of the output of that unit or even some other unit farther downstream. To measure the details of operation of the unit is normally not practical. Consequently, the effects of any malfunctioning and its cause may only be observed at shut down as well as maintenance performance may be implemented during operation.

Computational Fluid Dynamics (CFD), previously regarded as a methodology only for applications in ‘high-tech’ industries by highly trained specialists has undergone a significant change during the period from 1980’s until now. It has been adopted by a whole range of industries, including chemical, petrochemical, oil, automotive, built-environment (architecture, industrial design, building construction management, town planning), food processing and many others enabling the process engineer to begin to understand in greater detail the internal operation of individual units by relating an analysis of the flow field and other transfer processes with observed phenomena and thereby identify the cause of a problem and evaluate solutions. Moreover, it has steadily spread from research groups into the design and development departments. In short, CFD is being used as an engineering tool to aid in the understanding and design of process operations. Reference [12] reviewed the developments in industrial computational fluid dynamics over the last decade. The key area of development has been geometry handling, which has been greatly improved with techniques such as unstructured mesh methodology combined with the ability to insert or remove selected regions. With this and other development in numerical solvers and physical modeling, CFD can be applied to virtually all types of industrial equipment.

## II. LITERATURE SURVEY

### *A. Pipeline Mixing with Tees*

A pipe tee is a simple device for mixing two fluid streams. A tee is formed by two pipe sections joined traditionally at a right angle to each other. In this study, the benefits of angles other than $90^o$ are highlighted. One stream passes straight through the tee while the other enters perpendicularly at one side is known as a side-tee. However, other flow arrangements may be used, such as having the two opposing streams entering co-axially and leaving through a pipe, which is perpendicular to the entering direction, is known as an opposed-tee. A third configuration is a coaxial one, when the (feed) stream (the one to be mixed) enters co-axially with the main stream. For all designs of pipe tees, mixing takes place in shorter distances compared with distances required for mixing in a pipe with undisturbed turbulent flow [9]. Applications where pipeline mixing with tees is used include low viscosity mixing such as the dilution of concentrated acids or bases, waste water treatment and blending of some oils (injection of additives) and petrochemical products. Other applications include blending of fuel gas, mixing of feed streams for catalytic reactors and mixing of hot flue gases with ambient air. A number of local companies use many of the above mentioned processes. In the absence of substantial re-circulating flows, all pipeline mixers, such as simple pipes, baffled pipes, tees and in-line motionless mixers are continuous radial mixers. In contrast to mixing in stirred tanks, no significant back mixing is present in pipeline mixing.

### *B. Experimental Measurements of Mixing in Pipeline with tees*

A number of researchers have experimentally investigated mixing in pipelines with side tees. The first systematic study of pipeline mixing by side injection was conducted by [13], who used smoke visualization technique to determine optimum mixing conditions at a glass tee. They concluded that right-angle configurations were effective for good mixing. They also found that when the ratio of the velocity of side-to-main flow was in the range of 2 to 3, satisfactory mixing was obtained in 2 to 3 pipeline diameters. Reference [14] used quantitative methods to measure the degree of mixing of air-carbon dioxide feed streams in three pipeline mixers. They , like [13], found it was possible to achieve quality mixing in a few diameters with perpendicular jet/side injection devices but that parallel flow geometries required up to 250 pipeline diameters. A general review of turbulent mixing in chemically reactive flow is provided by [15]. A common method of mixing fluids for the purpose of promoting chemical reactions is to use turbulent jets. Fluid jets play an important role in pipe mixing, combustion, jet mixing in tanks or reactors and the dilution of toxic by-products from power plants and other industrial operations. Reviews of the mechanics of jet behavior of many kinds are given by [16] and [17]. Investigations of chemically reactive flows within turbulent jets have been largely confined to studies of fully developed turbulent jets in a stagnant or coaxial flowing ambient fluid. References [18]-[20], and [21] studied this problem. The turbulent properties of simple asymmetric jets in a stagnant environment are well established. The flow fields are self-similar and several theoretical approaches such as dimensional considerations, similarity analyses, Prandtl mixing length arguments and several entrainment hypotheses can be used to correlate empirical results [16]. It is common, however, to employ turbulent jets in an ambient cross flow. Deflected jet of this nature diluting more rapidly than jets without cross flows, are not axisymmetric or uniformly self similar. Deflected jets are further complicated if they are buoyant relative to the ambient cross flow. In this case, the trajectories of the jet and dilution rate are dominated by momentum in the near field, buoyancy in the far-field and intermediate transition regions. The physical extent of each of these regimes may be difficult to predict [17].

Reference [22] and [23] compared standard deviations of measured tracer concentrations far downstream (7-120 pipe diameters) from the side tee. Although the objective of the above mentioned research, in both the near and the far field, was to establish optimum conditions for pipeline mixing, the experimental data were limited and the results were inconclusive. Typically, the standard deviation or second moment of the tracer concentration was observed to decrease with increasing jet momentum at a fixed measurement point downstream. However, it was difficult to establish a distinct minimum in the second moment of the tracer concentration distribution with increasing jet momentum, particularly within the first twenty pipe diameters from the injection point. References [10], [24]-[29] studied the jet injection of fluid into a pipeline over the first twelve pipe diameters from the injection point. Reference [29] suggested that impaction of the jet against the opposite wall was necessary to optimize mixing over short distances downstream from the injection point.

Reference [30] developed a new method to monitor mixing along a tubular reactor. Hydro chloric acid solution and Sodium hydro oxide solutions with a color indicator were introduced co-axially, one of them as an annular jet. Continuous change of color along the axial distance was related to local degree of mixing through a calibration curve generated by a photocell transmittance. The mixing criteria in many of the experiments assumed that optimum mixing in a pipeline was achieved if the side jet was centered along the pipeline axis after entering the main flow. The above assumption of a geometrically centered jet appeared to be useful if the measurement point was at distances far from the injection point or $15 < x/D < 120$ [10], [24] and [31]. References [32] and [33] provided a mathematical basis for the prediction of concentration second moments for the first 15 pipe diameters downstream from the injection point. The latter results indicate that the second moment of the tracer concentration decreases with the increasing jet momentum and distance from the injection point. The simple scaling law developed by [32]-[33] appeared to correlate the data of [22] and [23] and [27], [29]. Although these conclusions are correct for certain values of jet-to-pipe diameter ratio or distance to mix, clearly additional experimental data would be useful to characterize the quality of mixing downstream from a pipeline tee.

It may be desirable, however, to promote rapid mixing of two fluids with a tee mixer in a short distance downstream from the injection point at $x/D < 3$. In particular, the suitability of pipeline mixing tees for reactor applications, where the reaction times are small, depends on achieving homogeneity of the reactant concentrations in short times. Reference [34] studied the product yield of tee mixer with competitive consecutive reactions. The experimental data of [34] demonstrated a distinct minimum in the undesirable product yield for certain tee mixer geometries. Reference [35] measured the distance downstream from the tee inlet required for the neutralization of a base indicator. They found a minimum distance to mix for certain tee mixer geometries. The experimental work of [35] demonstrated that it is necessary to increase the momentum of the side tee such that the secondary side tee fluid impinges on the opposite wall of the pipe near the tee inlet. In [2], it was attempted to show for a polymerization reaction that the narrowest copolymer composition at one diameter ratio occurred at the same condition that optimized mixing in the absence of reaction. Some of the data of [27] and [36] also indicated that mixing of an inert tracer could be improved by the impingement of secondary/side tee fluid against the opposite wall of the pipe near the tee inlet. Reference [37] carried out a set of experiments specifically designed to match the idealized conditions utilized in the work of [38]. In particular, a distinctive inlet condition was achieved in which the scalar field was introduced in cylindrical blocks with a length equal to the pipe diameter in a fully developed pipe flow. The initial flow-field therefore contained scalar and velocity length scales of equal magnitude. This idealized inlet condition was accomplished using “caged” fluorescent dyes, as described by [37]. Reference [39], using a mass transfer analogy, carried out an experimental study, to investigate the effect of three different perpendicular flow entries on the heat transfer performance of a pin-fin array. Reference [40] experimentally investigated side-jet injection near a rectangular duct entry with various angles. They obtained reasonable agreement between laser-doppler velocimetry measurements and numerical computations with the numerical model under-predicting. Other experimental studies of a jet issuing in an open rectangular channel have been done by [41] and [42].

Reference [43] studied the effects of inlet condition on downstream mixing in turbulent pipe flow with the use of photo-activable fluorescence techniques. The different inlet conditions included both geometry changes and changes in the manner in which the constituents were introduced into the flow. Results indicate that small changes in inlet geometry can affect the downstream mixing more than the manner in which constituents were introduced into the flow. They also did experiments including static mixer. Reference [44] presented a model to investigate the interactive effects of the segregation and mixing of crystals assuming that the liquid phase moves upward through the fluidized bed crystallizer operated in a batch mode in plug flow and the solid phase is represented by a series of equal sized ideal mixed bed of crystals.

Reference [45] studied vertical mixing using the theory of vertical diffusion (or dispersion) coefficient injecting fresh water (lighter fluid) upward at very low velocity through a circular porous plate into a tank containing heavier brine. Reference [46] investigated the characterization of the near field dilution and plume trajectories for tee diffusers over wide range of momentum reactors. Extensive experimental work was carried out in order to collect mixing and dilution data for tee diffuser. Reference [47] presented an experimental investigation of turbulent mixing in a round tee mixer. They carried out a relatively detailed experimental study of turbulent scalar mixing in the near field region of a tee mixer using full-field, laser-based non intrusive experimental techniques for this complex geometry. They focused on the near field region of the tee mixer not only because it is critical for rapid chemical reaction, but also because the turbulent flow in this region deviates greatly from the homogeneous and isotropic flow assumptions employed by common turbulence models in CFD. A summary of experimental work on side-tee mixers is shown in Table I.

**Table I: Work on Side-Injection Tee Mixers**

| Jet (Side feed) fluid | Pipe (Straight through feed) fluid | Jet dia. (cm) | Pipe dia. (cm) | Velocity ratio $U_{jet}/U_{pipe}$ | Mixing tube Re, $Re_m$ | Measurement point in diameters | Measured Variable | Mixing criterion | Reference |
|---|---|---|---|---|---|---|---|---|---|
| Air/ $TiCl_4$ Vapor | Air | 0.64 - 3.8 | 4.45 | 1 to 6 | 4000 to 18000 | 2-3 | $TiCl_4$ smoke (by eye) | Visual smoke uniformity | [13] |
| 0.5 N $HNO_3$ | 0.5 N NaOH | 0.635<br>0.635<br>0.635 | 0.635<br>0.635<br>0.635 | 1<br>1<br>10 | $10^4$<br>$2.1\times10^4$<br>$4\times10^4$ | 7<br>6.4<br>6 | Temperature | Periphery 97% of final temp. rise | [9] |
| 3-6 °C water | 50-70 °C water | 0.48, 1.0 | 12.5 | | $2.5\times10^5$ | 4-5 | Temperature | $(T_m-T_p)/(T_m-T_s)_I$ | [9] |
| Air & $TiCl_4$ | Air | 0.42-1.5 | 5.0 | 1.5-3.3 | $4\times10^3$ - $2\times10^4$ | 2-3 | Visual smoke conc. | Visual smoke uniformity | [26] |
| Aq. NaCl | Water | 0.32<br>0.158<br>0.079 | 15.24 | 6<br>12<br>24 | $6\times10^4$ | 105<br>105<br>105 | Electrical Conductivity | $\sigma_o/\overline{c} = 0.01$ | [22] |
| 19% $CO_2$, | Air | 1.58 | 5.25 | 2.7 | $4.6\times10^4$ | 10 | $CO_2$ conc. | Approx. | [14] |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 81% air, | | | | | | | Calc. from specific gravity | equal $CO_2$ conc. at pipe axis and periphery | |
| Air at 25 C | Air at 35 | 0.5-1.3 | 5.1 | 3-4 | $1.6\times10^4$ - $6.3\times10^4$ | 2-10 | Temp. | Temp. std deviation | [29] |
| Air & 0.3% $CH_4$ | Air | 0.1-1.27 | 11.43 | 2.9-28.3 | $1.3\times10^4$ - $3.2\times10^4$ | 2-10 | $CH_4$ conc. | Max. conc. Centered on pipe axis | [24] |
| HCl Solution | NaOH solution | d/D=0.0468-0.250 | 4m of 2.54cm pipe | 2.0-6.7 | 60000 | | Indicator color | Disappearance of indicator color | [35] |
| 99.7% Air 0.3% $CH_4$ | Air | 0.07- 0.95 | 10.1 | | $4\times10^4$ - $1.2\times10^5$ | 2, 5 & 10 | $CH_4$ conc. | | [33] |
| Dilute dye | Water | 2.5 | 2.5 | | | L/D = 390 | Photoactivated fluorophores, Light/ conc. | Scalar Variance | [43] |
| Water | Water | 1.27 | 7.62 | 3.06, 5.04 | | | PIV, PLIF (Conc) | | [47] |
| Fluorescein dye | Water | 2.5 | 2.5 | | | Conc. | conc./ Photoactivable fluorescence techniques | Scalar Variance | [48] |

### *C. Numerical Simulation of Pipeline Mixing with Tees*

The flows generated by a tee mixer have been studied by [49], [50] and [51]. Simulation studies appeared somewhat later. Reference [2] simulated tee mixing characteristics in both the absence and presence of a reaction for a tee with d/D = 0.188 over a range of side stream/main stream velocity ratios from 1.2 to 6.5. The flow and pressure fields for a tee mixer were solved using the TEACH-T flow code which uses the SIMPLE algorithm of [52]. A three-dimensional model was constructed and the $k$-$\varepsilon$ model was used to model turbulence. Reference [53] while evaluating four models of turbulence through comparisons of their extensive turbulent conical wall-jet data observed that $k$-$\varepsilon$ model successfully predicted most of their flows. Earlier literature also recommends and uses the $k$-$\varepsilon$ model especially for non-circulating flows, although with the increased availability of high powered computers, more advanced turbulence models are being used including Reynolds averaged Navier-Stokes (RANS) model or Large eddy simulation (LES) or the direct numerical simulation (DNS).

Reference [2] compared their numerical results with the experimental results of [35] and got reasonable agreement for concentration trajectory for x/D > 0.7. Concentration trajectory is defined as the locus of maximum concentration. Other comparisons also showed qualitative agreement between experimental and numerical results. They also simulated the case of reactive flows. A copolymerization reaction mechanism was used to investigate the effects of mixing on the reaction rate. It was found that the copolymer composition distribution is considerably broader than for the instantaneous mixing case due to in-homogeneity in concentration. Reference [3] simulated pipeline side-tee mixing quality with the commercially available fluid flow package PHOENICS. The k-e model was used to model turbulence. They compared numerical results with the experimental results of [32] and obtained reasonable agreement. Both of the above numerical models solved the conservation equations for mass and momentum in primitive variables for steady turbulent flow of a single-phase fluid with an inert tracer introduced at the injection point. Both models also used a mixing criteria based on the standard deviation of the component mixed and the mean value of the tracer over the pipe cross sectional area.

The use of CFD, despite the two above-mentioned papers, has still a lot to offer in analyzing and understanding mixing at pipeline tees. Simulation of variations of tees mixers, opposed flow tee, multiple side stream mixers and the orifice and annulus baffles have not been reported in literature. Simulation can help, for example, explain and understand the findings of [37], and [48]. Based on experimental work, they stated that changes in the geometry of the inlet at which the scalar is introduced can lead to substantial differences in the rate of scalar variance decay downstream. Reference [48] investigated the effects of two different initial conditions on mixing in turbulent pipe flow in addition to the open pipe, partitioned pipe and T-junction conditions tested by [37]. These experiments demonstrated that the method used to introduce two constituents to be mixed in pipe flow can profoundly affect the downstream mixing rate. Reference [54] presented an analysis of errors in numerical simulations of mixing. They identified and examined three types of errors: discretization, time integration and round off. They reported that accurate quantitative information including the location of periodic points and the length of a deformed line can be obtained from numerical simulations. A degree of mesh refinement is desirable but it is limited by the increase in computational costs. Reference [55] worked at jet reactor scale-up for mixing-controlled reactions. Product distributions of fast reactions were measured at small scale in turbulent viscous and aqueous solutions as well as using two larger nozzles (0.012 m and 0.031 m) and two larger semi-batch reactors (0.10 m$^3$ and 0.25 m$^3$).

Reference [56] reported a series of large-eddy simulations of a round jet issuing normally into a cross flow. Simulations were performed at two jet-to-cross flow velocity ratios, 2.0 and 3.3, and two Reynolds numbers, 1050 and 2100, based on cross flow velocity and jet diameter. Mean and turbulent statistics computed from the simulations match experimental measurements reasonably well. Reference [11] stated that impingement might be desirable in some cases in order to enhance rapid mixing. However in the paper industry, the tracer is often injected at an angle $\theta^\circ(45 \le \theta^\circ \le 60)$ to avoid impingement and to minimize pressure pulsation. Reference [4] studied CFD modeling of a two phase jet aerator under influence of a cross flow.

Reference [57] studied self-sustained oscillations in opposed impinging jets in an enclosure. They examined the flow field of opposed axi-symmetric jets in a confined cavity for instabilities due to various geometrical and fluid parameters using flow visualization, laser Doppler anemometry, and numerical simulations. Reference [58] did an experimental study and CFD modeling of barium sulphate precipitation in a pipe. A closure previously proposed by [59] employed the presumed beta PDF of the inert type composition variables formed with the local values of Ba2+ and SO42- concentrations and the turbulent mixer model. They computed flow field using the k- model. Some other studies are summarized as. Reference [60] and [61] discussed mixing and fast chemical reactions. Reference [62] applied finite-element to simulate mixing. Reference [63] discussed pipeline mixing.

Reference [64] studied jet injection for optimum mixing in pipe flow. Reference [65] reported optimum design of a tee mixer for fast reactions. Reference [66] studied steady state particle flow in mixer tubes equipped with motionless mixer elements. Reference [67] simulated mixing in unsteady flow through a periodically obstructed channel. Reference [68] contributed in fluid mechanics of mixing: modeling, operations and experimental techniques. Reference [69] noted polymer processing in the field. Reference [70] modeled jet mixed tanks using computational fluid dynamics. Reference [71] numerically simulated laminar-confined impinging streams to study the flow and mixing characteristics. They found that both the geometry of the system and inlet jet Reynolds number have strong effects on mixing in impinging streams. All Above discussed chore studies and explorations, numerical and experimental works, and computational information with basic turbulence and industrial mixing [72] theories have lot to offer further in this field to design, redesign, modify, remodify, rectify and run the process for a better and wonderful operation with suitable economics and worthy product which is follows in [73], [74] and [75] and on.

## III. CONCLUSION

It is clear from surveying the literature that heat, mass and mixing enhancements in pipelines with side introduction tees has been investigated experimentally and to a less degree numerically. There is a need for further investigations as there are many differences in opinion regarding the need for the side jet to impinge or not to impinge on the opposite surface, to have smooth flow or high turbulence, and with less bends or complex geometry for the enhancements of mixing and reduction in corrosion type problems. Gaps are there to find out near-perfect criteria of fluids to be mixed. It is also clear that the angle of injection has not been fully investigated. Moreover, previous numerical simulation of mixing in pipeline with tees is very limited and it has still a lot to offer towards better understanding. Further chores are to survey till date and to contribute many further sections based on different selections.

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