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Numerical Simulations of Lightnin Static Mixer with Perforated Holes

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Abstract- *Industrial products of mixture can be achieved by two methods static and dynamic methods. In Dynamic method two liquids are filled in an agitating tank for mixing. Where in static method two or more fluids are passed through one common pipe section. There are various types of mixers available which can be distinguished by its use and geometry, such as Lightnin Static mixer (LSM), Kenics Static Mixer (KSM), Modified Kenics Static Mixer MKSM, Sulzer Viscus Mixer (SMV)This work focuses on study of Lightnin Static Mixer (LSM). One particular set of Lightnin mixer is comprised of 12 elements, which are modelled and analysed using Ansys software. The validation of research is carried out by using simulated results of Z factor by using Reynolds numbers range varying between 0.1 to 100. Based on MKSM, new model of LSM i.e. Modified Lightnin Static Mixer is developed and analysed. The parameters such as, pressure drop and friction factor are considered for executing and comparing the mixing efficiency of LSM and MLSM. The product values of friction factor with Reynolds number for LSM and MLSM are 520.18 to 906.20 and 475.01 to 772.54 respectively for Re = 0 to 100. These values are in good agreement with the classical theory of mixing. MKSM mixes fluids at lower pressure drop, it is recommended that the other parameters which can be used for finding mixing performance are shear rate, stretching rate and Lyapunov exponent for different set of Reynolds number.*
Keywords-*Static Mixer, MKSM, MLSM, Z-factor, classical theory of mixing*

I. Introduction

Industries like pharmaceutical, chemical, polymer, polyurethane give more attention to the quality mixing of two or more components of mixture at the time of chemical processing [1][2]. Some products depend on mixture, like Engine oils, Edible oils etc. and some products depend on chemical and physical reactions that occurs between that chemicals e.g. puff and foam [3][4]. Various chemical reactions depend on their chemical composition and degree of homogeneity of the mixture [6].These mixtures can be achieved by static or dynamic methods [7] [11]. Most common mixing process uses dynamic mixing in which two liquids are filled in an agitating tank (Agitator) for batch mixing [1][5]. In the static mixing process, two or more fluids are passed through one common pipe section i.e. static mixer [1] [12]. Static mixer gives a fast, efficient and economical mixing. Static mixing depends on mixer components like size and profile of blade, fluid flow rate and viscosity of fluids.Sulzer static mixer (SMX), High Efficiency Value StaticMixer (HEV), Low Pressure Drop Static Mixer (LPD), Lightnin Static mixer (LSM), Kenics Static Mixer (KSM), Modified Kenics Static Mixer MKSM, Sulzer Viscus Mixer (SMV) are the types of static mixers [1][2][8][9] [15] [16]. The **Kenics Static Mixer** (KSM) is formed by twelve mixing blades, which has alternating counter-clockwise and clockwise directions of rotation. The front edge of every blade is counterbalanced by ninety degrees relative to the trailing edge of the previous blade. The mixing blade are projected to generate peripheral flows to blend divergent ----liquid streams as they pass on to the static mixer.One blade of **Lightnin Static Mixer**consists of two semi-elliptical flat surfaces and two trigonal surfaces making the edges.The two cross semi-elliptical flat surfaces are organised at 34° and 146° to the axis of flow [10]. Two trigonal flat surfaces arranged in the axial section are joint upright to the adjacent semi-elliptical plates. This arrangement of blade makes the upstream fluid separated. LSM with an aspect ratio of Ar = 1.5, dia = 40mm and twelve blades are known as standard LSM. Figure1[8] shows geometrical difference between LSM and KSM.

Numerical simulation of Modified Kenics Static Mixer was done for perforation [11]. It was found that MKSM gave more efficiency than that of KSM [10]. This is due to perforated holes possess more division of flow that directly reflects on mixers efficiency and striation thinning. It is possible to make holes and some other marginal geometric changes on the blades of Ligtnin Static Mixer. It will give more flow division and marginal changes in pressure drop.

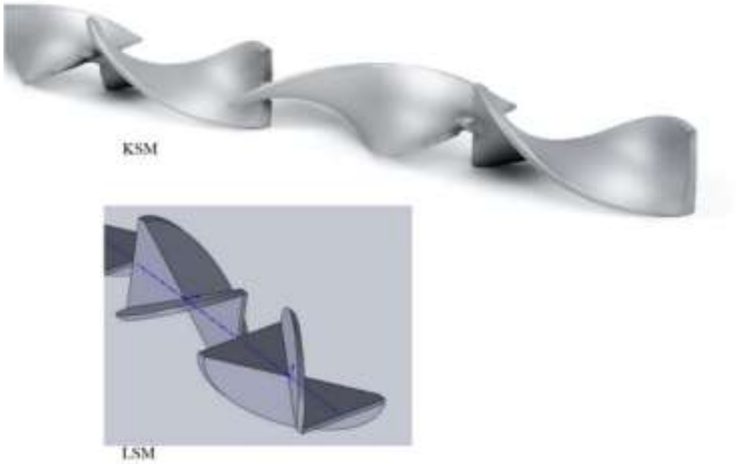


Figure-1 1 *KSM-LSM partial assembly and orientations of blades*

The LSM is more efficient than KSM not only because of its maximum pressure drop but also for its significantly more stretching rate [10]. LSM with aspect ratio (Ar) =1,1.5,2 has more stretching rate by 45.91 %, 36.05% and 24.32%. MKSM i.e. KSM with perforated holes on their mixing blades gives significantly better mixing than that of basic KSM [10]. Parameters such as pressure drop, friction factor and Z-factor are important for calculating mixing efficiency according to classical mixing theories. Z-factor is previously used for validating mixers is found out by comparing it with literature data [8]. The general purpose of this work is to validate standard LSM with the Z-factor literature and proposing new model of LSM. i.e. LSM with perforated holes (MLSM). Hence, purpose of this research is to predict the pressure drop of MLSM and to find out Darcy friction factors for improving mixing performance. Based on results and its correlations with parameters, the benefits of MLSM are presented.

II. Design and modelling

The geometry of LSM and MLSM is developed as a 3-D CAD model in Solid Works. Calculating the pressure-drop of standard(basic) LSM series 45 in Ansys fluent. Calculating the friction factor and the Z-factor and comparing it with previous experimental and literature work for validating it for LSM. Results are optimized for the new pressure-drop, Z-factor and friction factor modified Model of LSM i.e. MLSM or LSM with perforated holes.

III. Methodology

The pressure-based parameters are studied along with various flow rate and Reynolds number. This can be understood with the help of CFD software. The working fluid is similar to that of previous fluid which is obtained from previous simulation work [10]. In this work impact of mixers blade with its constant aspect ratio and fixed length is analysed for validation of LSM. The range of Reynolds number is varying between 0.1 to 100 [8] [10].

The modelling of LSM and MLSM is done in SOLID WORKS, followed by giving their geometrical descriptions. Meshing and boundary conditions for flow simulations is done in ANSYS Fluent for the pressure based segregate solver. The obtained results are compared with Literature and theories of mixing for making conclusion.

LSM and MLSM's each blade consists of two semi-elliptical flat surfaces and two trigonal surfaces making edges. The two cross semi-elliptical flat surfaces are organised at 34° and 146° to the axis of flow. Two trigonal flat surfaces arranged in the axial section are joint upright to the adjacent semi-elliptical plates. This arrangement of blade makes the upstream fluid separated. LSM with an aspect ratio of Ar = 1.5, is treated as standard LSM. Additionally, as per geometric changes in the KSM [11] i.e. perforated holes KSM, LSM also gave some geometric changes, like perforated holes on elliptical surface of the blade. Two holes are of certain fixed distance from each other. For additional flow division, every blade of LSM has one guide ball which has ¼ diameter of the static mixer inner diameter.

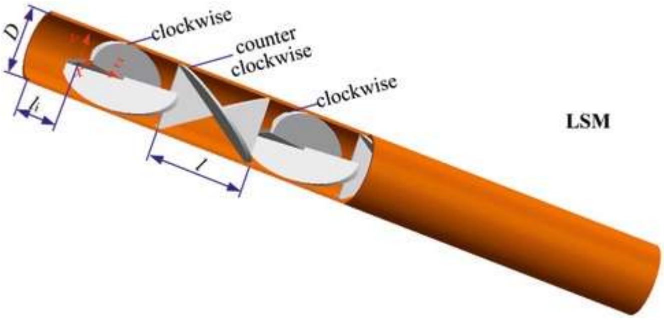


Figure -2 *LSM Details*

All dimensional details are provided in the table-1 figure -3 shows blade geometry of MLSM and assembly of MLSM. for the analysis purpose both models i.e. LSM and MLSM are created as per the tabulated dimensions mention in the table-1 in solid works. Figure-3 shows the blade geometry of MLSM clock wise and counter clock wise rotations.
The detailed parameters of geometry models are listed in Table 1.

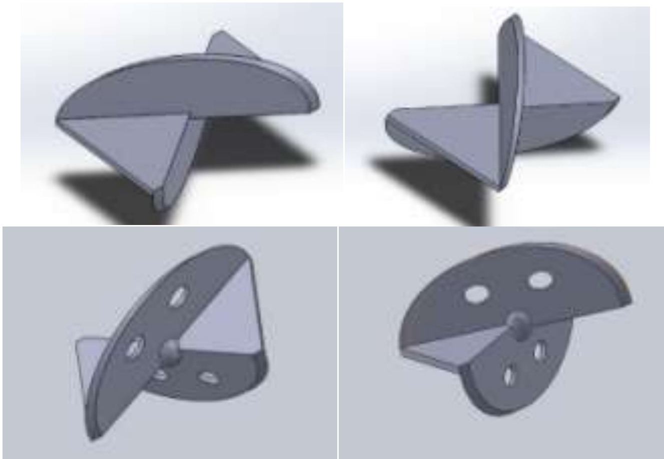


Figure -3 *CAD Model of LSM SERIES 45 Mixer*

Table-1 LSM and MLSM

Sr. No.	Nomenclature	Dimensions
1	Length of static mixer (l)	770 mm
2	Aspect ratio (Ar)	1.5
3	Blade length (L)	60 mm
4	Blade width (W)	40 mm
5	Entrance length (li)	25 mm
6	Exit length (lo)	25 mm
7	Mixing zone length (lm)	720 mm
8	Twist angle (θ)	1800
9	Blade thickness (t)	2 mm
10	Mixing elements	12 nos
11	Inner diameter of pipe (D)	40 mm
12	Perforated diameter (d)	6 mm
13	Perforated diameter spacing (dL)	25 mm
14	Guide ball diameter (dm)	10 mm

Governing Equations

The general assumptions under the current conditions are consideredto be three-dimensional with constant fluid properties [11]. Inthe case of incompressible flow, the mass continuity equation is simplifiedto a volume continuity equation [11]:

$\nabla . u = 0$ (1)

where u is the velocity vector.

The momentum conservation equation in the static mixers withperforated helical segments can be written as follows [11]**:**

$$\frac{\partial(\rho u)}{\partial t} + \nabla.(\rho u u) = -\nabla p + \nabla.(\tau) + F \qquad (2)$$

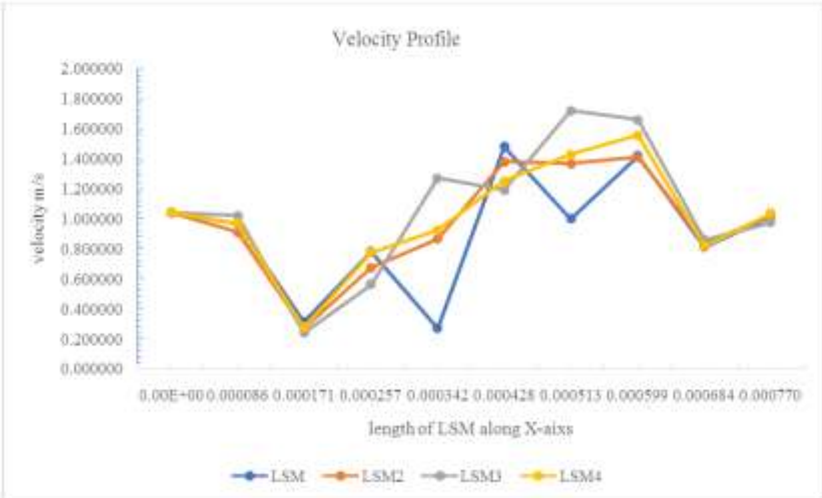
where ρ is the fluid density, t is the time, p is the static pressure, τis the stress tensor, and F is external body forces.

The governing equations in Cartesian coordinates were discretized on an unstructured grid using a finite-volume approach. A pressure-based solver was employed with a second implicit scheme for incompressible flows in the static mixers. The well-known SIMPLEC algorithm was used to deal with the pressure-velocity coupling between the momentum and the continuity equations of steady incompressible flows in the static mixers with perforated helical segments. The green-gauss, cell based standard scheme and second-orderupwind scheme were employed for gradient, pressure, and momentum discretization, respectively.

Grid Convergence

Selection of quality mesh for solving the problem is very important and it's a critical task. Refined mesh gives closer solutions for the problem [11]. Four times different velocity magnitudes are obtained for the same fluid domain by solving same problems with different meshes. By keeping the same inlet conditions i.e. same flow rates, the velocity magnitude along the length of static mixer calibrated and plotted in ghrapg-1. The four LSM meshed models are obtained by using growth rates 1.2, 1.3, 1.5, 1.6 respectively.

figure 4 show velocity variations along the length of static mixer. From the figure it is observed that the path followed by the LSM2 and the LSM 4 are very close to each other as compared to LSM1 and LSM3 and also have magnitudes intermediate between LSM1 and LSM3. The velocity profile of the LSM2 is approximately an average profile. Hence for further resolution it is better to choose LSM2 meshing.



Graph 1*velocity profile along length of static Mixer*

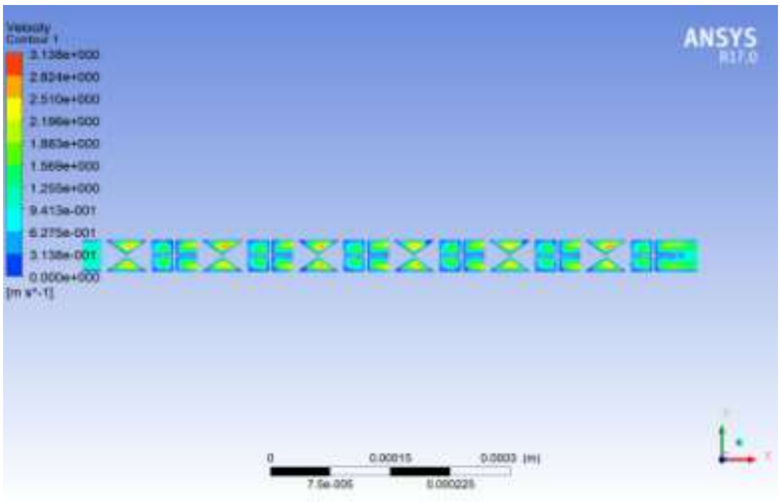


Figure 4 *velocity profile along the length of static mixer*

IV. Boundary Conditions

The governing equations in the laminar flow were discretizedand solved by using the ANSYSFluent.The Reynolds numberfor entrance is defined as

$$Re = \frac{\rho D u}{\mu} \qquad (3)$$

where D is the diameter of the tube, and μ is the viscosity of the fluid. The inlet velocity employed in the simulations is in the range of u=0.001042 to 1.042 m/s. In other words, Re ranges from 0.1 to 100.In the numerical simulation, the employed high viscosity fluid has a constant density of ρ = 1,200 kg/m3 and a viscosity of μ = 0.5 Pa·s.

V. Results and discussions

Validation of LSM

Z-factor is previously used for validation of mixers by comparing it with literature data [8]. Pressure is more impactful parameter than that of velocity and concentration use in CFD.Pressure drop is used to calculate energy consumption by the mixers. Therefore, it is very important parameter that have to be consider.

Z-Factor.

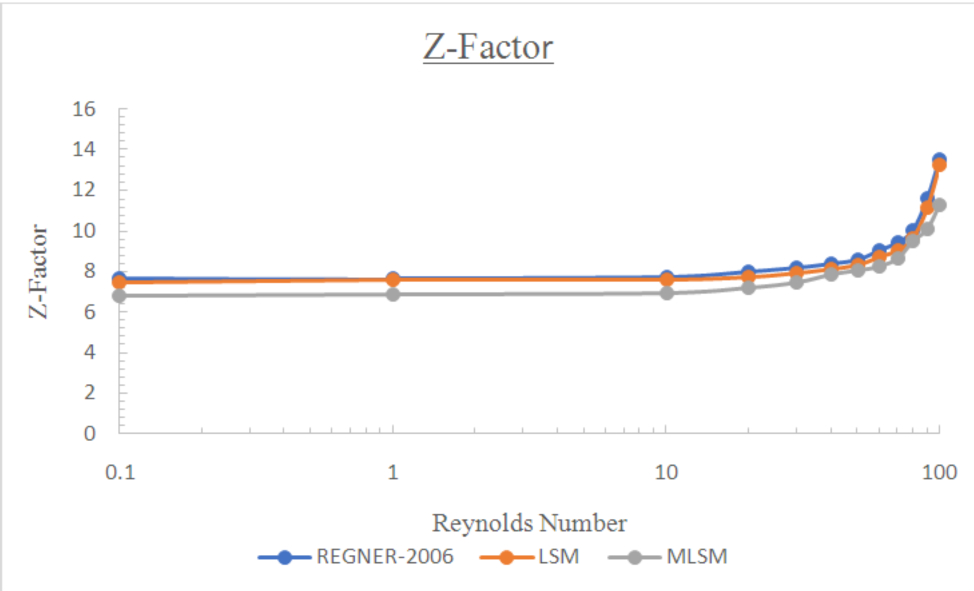
Z-factor is common unitless parameter which is obtained from pressure drop that is used traditionally to validate mixer models. It is defined as the ratio of the pressure drop of the specific static mixer to the pressure drop of same dimensional empty pipe for the same flow conditions [8].

$$Z = \frac{\Delta Psm}{\Delta Pot} \qquad (4)$$

where ΔPSM represents the real pressure drop in the static mixers.
ΔPOT represents the pressure drop of empty pipe for the same flow conditions in the static mixers and it is numerically calculated as in below empirical equation [8],

$$\Delta Pot = \frac{64}{Re} \times \frac{L}{D} \times \frac{\rho \times u^2}{2} \qquad (5)$$

As per numerical data of smooth tube and simulated data of the Static mixers, the Z-factor of two static mixer models are obtained and plotted in graph-2 of Z-factor. For Reynolds number 0.1 to 10, Z factor of all mixers remain almost constant (LSM 7.66 to 7.73, MLSM 6.76 to 6.94) and for Re 10 to 80 it increases marginally (LSM 7.33 to 10.11, MLSM 6.94 to 9.46). For Re 80 to 100 Z-factor for all mixers increases significantly (LSM 10.11 to 13.52, MLSM 9.46 to 11.29). With the increasing Reynolds number, the Z factor of LSM with Ar.1.5 are 7.66 to 13.52 and MLSM with Ar. 1.5 is 6.94 to 11.29.Because of perforated geometry of MLSM, it gives less pressure drop than LSM. but follows same way for the Z-factor. The simulated data of mixers are in good agreement with literature data [8] [10] and shows minimum deviation. This argument valid the simulation work for LSMas well as it grants permission for study of MLSM.



Graph 2- Z-factor

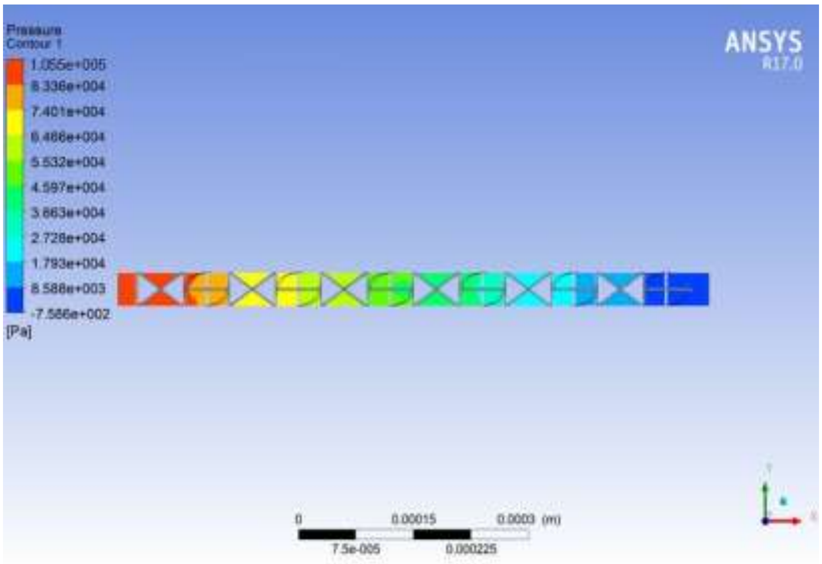


Figure 5 *Pressure drop of LSM for Re=100*

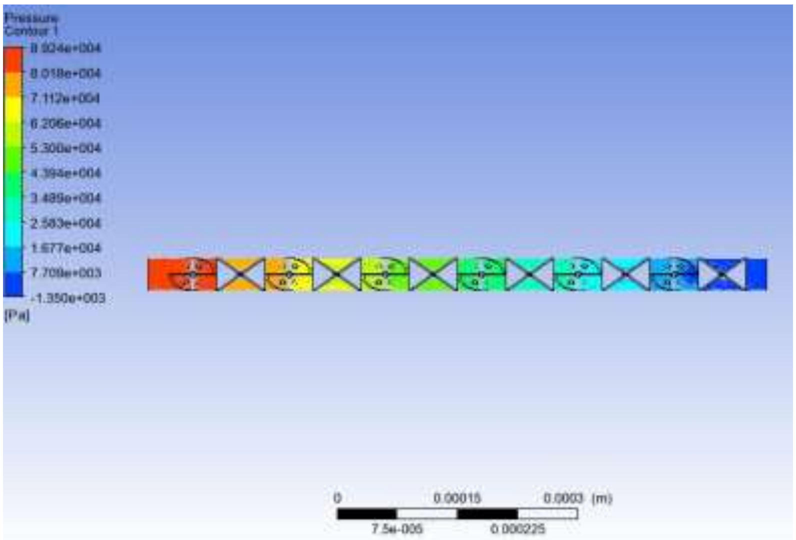


Figure *Pressure drop of MLSM for Re=100*

Darcy friction factor

The Darcy friction factor or the Darcy-Weisbach friction factor is the resistance coefficient or friction factor use for the illustration of pressure drop in open channel flow or the pipe flow. We know that Pressure drop is the basic factor used to calculate the pressure loss caused by friction across a given length. It is better that the pressure drop data is to straight associate the friction factor Fd, preferably than the ratio of pressure drop only [10]. The pressure drop correlation with friction factor is calculate by the following equation [10]

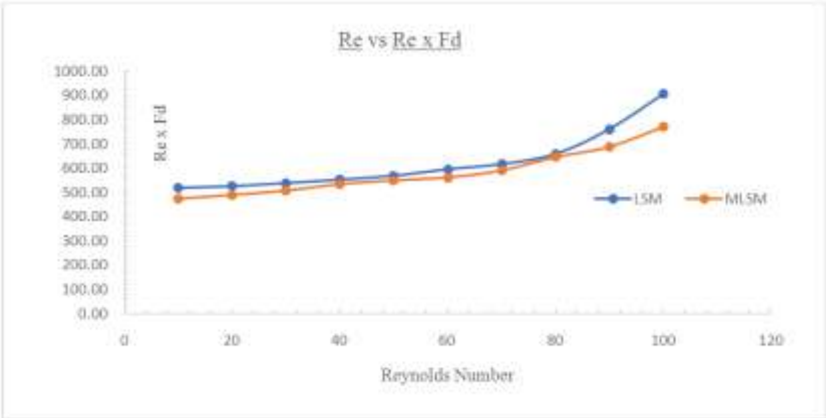
$$f_d = \frac{2D\Delta Psm}{\rho l_m u^2} \qquad (6)$$

Classical theory of mixing

For the given control conditions of static mixer and fluid the friction factor fd is varied and lay totally on fluid flow i.e. Reynolds number. [10] [11]

According to the classical theory of prediction of mixing, for the better mixing and validation of static mixer, the slope of product of Fd and Re has to constant with respect to increase in Re. from the ghraph-3 (Re vs Re x Fd)the slope of product of Fd and Re is in good agreement with classical; theory of mixing and literature for laminar flow. For the given conditions of laminar fluid flow, the product of Reynolds number and Friction factor increases linearly in constant manner. For the Re 0 to 100, the values of LSM and MLSM are 520.18 to

906.20 and 475.01 to 772.54 respectively. In graph-2 slope of product Fd and Re is constant and gives validation for mixing according to classical theory of mixing of fluids [17] [11] [18].



***Graph 3** Re vs Re x Fd*

Flow division; -

In laminar flow, fluid streams are dividing at the leading edge of each element of the mixer and follows the channels created by the element shape. At each succeeding element, the two channels are further divided, resulting in an exponential increase in stratification. The number of striations produced is 2n where 'n' is the number of elements in the mixer [19]. Because the adjacent leading and ending edges of helical blades the generation of secondary flow takes place. These types of operation take place continuously till the last blade.The continuous division and mixing of flow stream results in good mixing. More the flow division results better in the mixing. For 100 stream lines in the static mixers figure-7 and figure 8-shows there is continuous division and mixing in stream lines respectively. MLSM shows more division virtually than that of LSM because of perforated holes and guide ball on the blades of MLSM**.**Chaos is more visual or random disturbance of streamlines are more in MLSM than LSM.

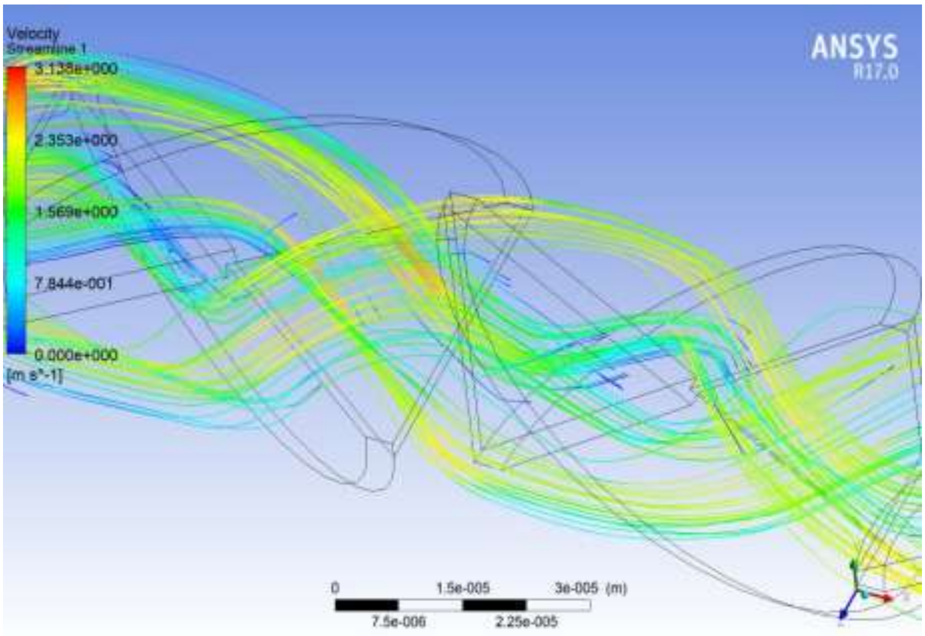


***Figure 7** 100-Stream line division of LSM for Re=100*

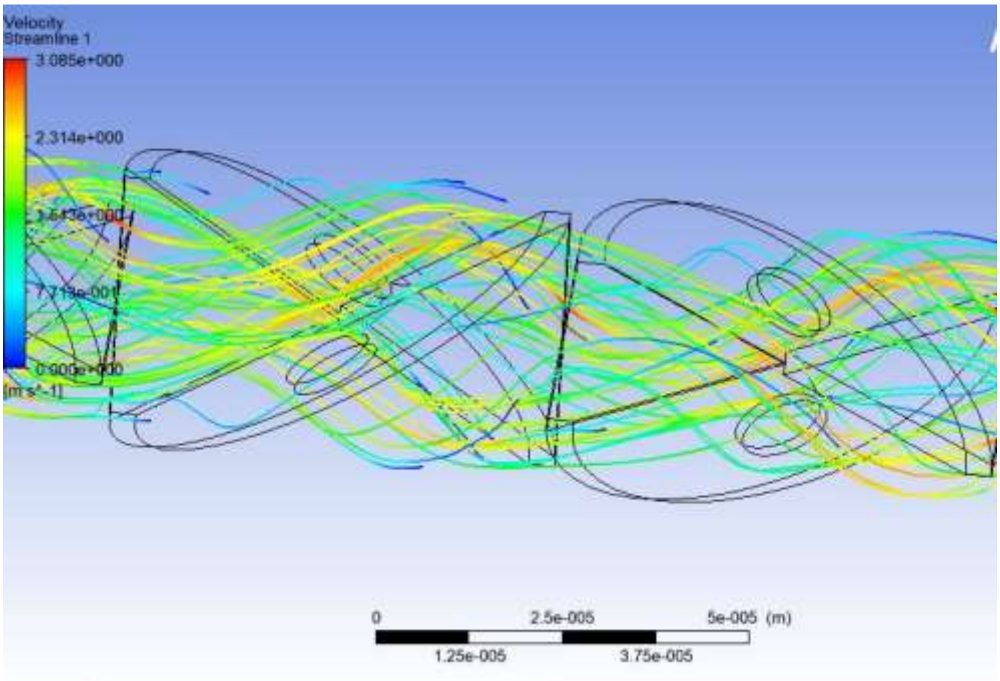


Figure 8 *100-Stream line division of MLSM for Re=100*

VI. Conclusion

The parameters like Pressure drop, Z-factor, Darcy friction coefficient, shear rate, stretching rate, Lyapunov exponent, and degree of striation thinning required for calculating mixing efficiency. The current simulations were conducted only for pressure-based mixing parameters as pressure drop, Z-factor and Darcy friction factor with the help of ANSYS fluent. For Re 0 to 100, the Z-factor for LSM (Regner el. At 2006) [8] and LSM current simulations were between 6.23 to 12.05 and 6.134 to 11.57 respectively. The Z-factor values for Modified Lightnin Static Mixer (MLSM) were between 6.06 to 11.29 (Re =0 to 100), which were in good agreement with Regner el.at 2006 [8].

As per classical theory of mixing [11] the product of Darcy friction factor and Reynolds number propagates with constant slope as the value of Reynolds number increases. For the Re 0 to 100, the values of LSM and MLSM fits and supports the classical theory graph and the values lies between 520.18 to 906.20 and 475.01 to 772.54 respectively. This shows that MLSM is in good agreement with classical theory of mixing and have 15673 pascals less pressure drop than the LSM for Re=100.

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