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Numerical and Experimental Study to Predict the Entrance Length in Pipe Flows

H. Düz

Batman Universitesi, Batı Raman Kampüsü, Batman, 72100, Turkey

†*Corresponding Author Email: hasan.duz@batman.edu.tr*

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ABSTRACT

Here, a steady, incompressible and isothermal flow in the inlet region of a circular pipe were numerically and experimentally studied to predict the entrance length. The region in the upstream of fully developed pipe flow is referred to as the developing flow region, the effects of which on flow parameters are referred to as entrance effects. Entrance length shows the length of the developing flow region. The analysis of entrance flow is difficult and complicated as there are many parameters such as different pipe inserts affecting it. Earlier empirical results on the entrance region are inconclusive and inconsistent. Initially, an experimental study was performed with pipes of different roughness to validate the numerical results. Reynolds numbers used in the experiment ranged from 3000 to 25000. The entrance flow was numerically simulated in parallel to experimental pipe flows. Numerical results obtained were compared with those of the experimental study and of previous ones. Numerical and empirical data showed good agreement. Based on the numerical results, a well-defined numerical correlation was developed and proposed for the prediction of entrance lengths.

Keywords: Entrance length; Pipe flow; Developing flow.

1. INTRODUCTION

It has been well known since 18th century that there are two kinds of fluid flow; laminar flow and turbulent flow. The former refers to the smooth motion of fluid particles together in the flow stream while the latter refers to the irregular motion of fluid particles in the stream due to flow mixing. The laminar transition to a turbulent state has attracted the attention of many researchers who were interested in gaining insight into the nature of flow patterns, which is most significant in the design of turbo machinery, plane and wind turbine airfoils, and pipe flow has been a widely studied in those fields.

Figure 1 shows the development of flow at a pipe inlet region. In the figure, a free stream goes to the pipe with a mean flat velocity (U_∞) over the cross-section. Due to no slip occur on pipe wetted wall, the velocity change along the developing flow region due to fluid viscosity. As a result, a boundary layer develops which indicates a velocity gradient profile in the wall normal direction. Increasing along the pipe flow direction, the velocity boundary-layer thickness reaches maximum at the pipe axis, after which a filled region occurs where velocity profile change a little more and then no changes seen along the downstream region. The location where velocity profile no longer change is a sign to the beginning of a fully developed flow. Therefore mean velocity profile, pressure gradient and mean turbulent statistics do not vary along a fully developed flow whereas in a developing flow region, those flow properties vary along (Laufer, 1954). As shown in Fig. 1, first a laminar boundary layer develops and then it breaks down to transitional flow, which is uncertain type of flow nor a turbulent and nor a laminar flow, and finally a fully developed turbulent state governs the pipe flow .

As depicted on Fig. 1, the transition onset location (TOL) is a point where laminar flow first transit to a turbulent state and its location from the pipe inlet is named as transition length (L_t). The entrance length (L_e) is defined as the length of the developing flow region where begins from pipe inlet to the onset location of a fully developed flow. Some flow properties can be utilized to determine the entrance length in a pipe flow experiment. Pressure drop, velocity profile and turbulent statistics can be used to determine the entrance length. Shah and London (2014) define the entrance length from pipe inlet to where the centerline velocity equals 99% of the Poiseuille value U_{max}. According to the data conducted (Doherty *et al.*, 2007), the entrance length scaled to pressure drop or velocity profiles is no longer than scaled to high order turbulent statistics because some large turbulent motions have

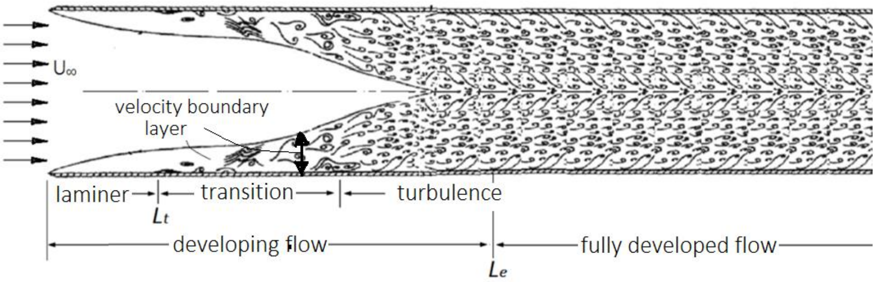

Fig. 1. Flow behavior in the entry flow of a pipe.

not yet completed their growing process while passing the normal entrance length location. In practical enginee-ring, due to velocity and pressure are regarded mostly, in this study the entrance length is scaled to constant pressure gradient to be investigated.

Many studies are available in literature investigating entrance length in pipe flows. Some empirical correlations are available to determine the entrance lengths in laminar pipe flow. Due to complex in nature, entrance lengths in fully developed turbulent flows lack in a well-defined theoretical or empirical framework. Previous studies have pointed out many parameters having a direct impact on the entrance length. Some of those parameters are pipe inlet inserts (bell-mouth, reentrant, square edged inlets), inlet smoothness, upstream turbulence level and wall roughness. Using reentrant, square-edged and bell-mouth inlets in pipe flow, it is concluded that the type of inlet shape had an effect on the TOL and that the entrance lengths in pipe flow were longer when a bell-mouth inlet was used than when a square edged or reentrant one was used. This result was due to the additional disturbance caused by the latters (Afshin&Lap-Mou, 1995 ; Hou Kuan *et al*. 2013). Nikuradse (1966) reported that the fully developed flow occured at distances between 25D and 40D by comparing the mean cross-sectional velocity profiles which were measured along the pipe flow. In a similar way, Laufer (1954) compared the mean velocity profiles and reported that the entrance length was 30D. In the experimental studies where the axis symmetric disturbances were imposed to the flow at pipe inlet, a fully developed flow was observed after 30D by Sarpkaya (1975) and 32D by Haung and Chen (1974). However, for the pipe flows where non axis symmetric disturbances were imposed, Huang and Chen (1974) was observed a fully developed flow between 40D and 48D. In their study, the non-axis symmetric disturbances were imposed to the flow by a wall-type barrier attached to pipe inlet and the critical Reynolds number observed in the study was 2300. Perry and Abel (1975) by disturbing the flow at pipe inlet, reported that the fully developed flow occured at distances of 71.9D and 86.2D at a Reynolds number of 3.10^5. Here, they have accepted the fully developed flow according to the conditions where both the mean velocity and the turbulence velocities are no longer change in the last two measured stations. Patel and Head (1969) reported an entrance length of 50D with mean velocity profiles comparison and of 80D with mean turbulent statistics comparison. However, they are also reported that the fully developed flow occurs earlier than others at distances between 10D and 20D with the pressure gradients comparisons. Barbin and Jones (1963) conducted a fully developed flow that occured after 15D on pressure gradient observations and did not occur still up to 40D on mean velocity profiles observations. The experimental study was carried out with a 40D long pipe at a Reynolds number of 388000. Zagarola and Smits (1998) noticed that a flow length of 160D should be taken to ensure that a fully developed flow is established definitely for those natural flows which is not imposed by any disturbances at inlet. Doherty *et al*. (2007) pointed out that a development length of over 50D is needed for the mean velocity to be a fully developed one and a flow distance of 80D is required for the mean high-order turbulence statistic no longer change along the flow. However, when the growth of large-scale turbulent structures was observed as a criterion, the entrance length was even higher than velocity or pressure gradient criterions. Because large scale structures require a longer development length, so the author suggested that the development of these structure should be emphasized as a main criterion for fully developed flow instead of the mean velocity profiles criteria. As a result of the literature survey above, entrance length can be different due to which flow characteristics are observed and pipe inlet inserts are also seen very effective on the entrance lengths according to the amount the turbulence produced at inlet.

Table 1 shows the entrance lengths and empirical correlations conducted by authors and the criterion which measurements the entrance length are based are specified also. As shown in Table 1, the dimensionless entrance lengths (L_e/D) are given for a wide range of Reynolds numbers. According to the entrance length conducted, entrance lengths are found between 25D-60D with mean velocity profiles and 10D-20D with pressure gradient and 70D-90D with mean turbulent statistics as being criterions. However, an authors were conducted entrance lengths about twice of that minimum ranges to ensure a fully developed flow. Additionally, the empirical correlations conducted by some authors only cover the narrow ranges of Reynolds number and also the pipe entry shape is not mentioned in most studies.

Table 1 Dimensionless entrance length measurements and empirical correlations

Dimensionless Entrance length (L_e/D=)		Reynolds Number	Authors
On constant pressure gradient or velocity profile measurements	On mean turbulent statistics measurements		
80	------	-------------	Osborne Reynolds (1800)
$2.09\text{x}10^{-8} * \text{Re}^{-1.66}$	------	5000-15000	Augustine (1988)
$1.6\ \text{Re}^{1/4}$	------	10^5 - 10^6	Fabien *et al*. (2009)
$4.4\ \text{Re}^{1/6}$	------		
a long empirical formula	------	$1.95\ 10^5$	Salami (1986),
25 and 40	------	$3\ 10^3 – 3\ 10^6$	Nikuradse (1966)
30	------	$5\ 10^4 – 5\ 10^5$	Laufer (1954).
50	80	10^3 - 10^4	Patel & Head (1969)
---------	70	$3\ 10^4 – 1\ 10^5$	Zanoun *et al*. (2009)
---------	72	$1.75\ 10^5$	Perry & Abell (1978)
50	80	$1.10^5 – 2.10^5$	Doherty *et al*. (2007)
more than 40	------	$3.88\ 10^5$	Barbin&Jones (1963)
----------	70	$1.5\ 10^5$- $8.5\ 10^5$	Zimmer *et al*. (2011)
min. 131	------	$3\ 10^4 – 3.5\ 10^7$	Zagarola& Smits (1998)

Despite the significant effort outlined above, the entrance length is still not completed in theory with all satisfaction and no any classification is made so far. However, to ensure that there is a fully developed flow, the fluids mechanic society suggest that the large *L / D* values should be taken to exceed the normal entrance length of the pipe. However, there is a scarcity in the numbers to investigate the entrance length in detail since many studies above regards another issue of pipe entrance flow so that the entrance length conducted were measured extra to ensure a fully developed flow exist in these studies. Many gaps can be seen in the developing flows since it includes laminer transition to turbulence phenomenon which is a very complicated flow type to deal.

To eliminate such like uncertainties, the entrance lengths were investigated numerically in this study at low Reynolds numbers ranging from 3000 to 25000. Here, aim of the study is to investigate the entrance length at low Reynolds numbers which cover transitional flow and turbulent flow regimes both. Low Reynolds number pipe flows is complex type flows in which the flow regime is mostly not obeyed to a certain Reynolds number which to specify the flow as transition or full turbulent. The correlations suggested in literature are valids only for high Reynolds numbers except from the Augustine (1988) correlation. Augustine correlation is an empirical correlation to find entrance length at low Reynolds Numbers but is limited to pipe flows with square edged inlets so that do not include all parameter effects on the entrance length. In this context, this study aimed to investigate entrance lengths with other effects such as using different pipe inserts and free stream turbulence levels and to exist a general theory with new correlations and findings. In addition to, through this study, it will be tested whether numerical solution is a powerful tool or not by means of experimental comparisons. Therefore, in this study, a smooth velocity profile and a high turbulence level, on assuming the inlet shape is re-entrant, was assigned to pipe inlet flow.

2. NUMERICAL STUDY

2.1. Numerical Setup

Numerical solution is a mathematical method to solve the problems, the solutions of which require costly experiments or cannot be attained with analytical methods. In this numerical study, RANS (Reynolds Averaged Navier-stokes) equations are executed to solve the turbulent flows and an SST k-omega turbulence model were used to solve the Reynolds stresses in RANS equations to include the turbulence effects to mean flow. SST k-omega model is developed especially for flows where wall boundary layer separations and transitional flows occurs. It is a low Reynolds number flow model so that requires high mesh resolution in the boundary layer near wall flow regions. In this model the dimensionless wall distance should be as low as $y^+<1$. A Gamma Theta Model for TOL is also used, which is the recom-mended transition model for general-purpose applications. (Menter *et al*., 2004; Langtry& Menter, 2005).

Neither the direct numerical simulation (DNS) nor the large eddy simulation (LES) was used as a numerical solution due to their requirements to very high computations. All turbulent motions in spatial and temporal growth can be solved using DNS,

Table 2 Numerical Setup

Numerical Setup	
Flow state	steady state, isothermal and incompressible
Governing Equations	Time mean basic conservation equations (RANS equations)
Turbulence Model	SST together with Gamma Theta Model
Inlet	Smooth velocity profile and high turbulence intensity, T_U = 7%
Wall	Rough surface
Exit	At gauge pressure to atmosphere
Fluid	Newtonian fluid, water at 27 ˚C

which simulates turbulent flows as in nature but requires long computation time so with today computer capacity is not possible yet and, therefore, is limited to the solution of simple flows. LES also solves large turbulent eddies temporarily and spatially and uses RANS equations to model small motions. A RANS based numerical solution provides very low computations than a LES solution and allows also flow symmetry in the solution, which lowers the CPU time and increase the mesh density in the flow field on using the same mesh number as used in without symmetry. In the numerical study, due to the pipe flow is axisymmetric, a flow geometry sliced at 5 degree angle was used in the pipe flow simulations as shown in Fig. 2.

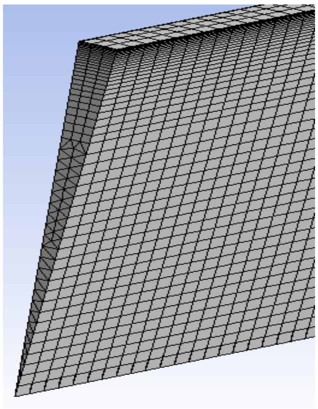

Fig. 2. Pipe flow meshed in axisymmetric geometry.

Table 2 shows the boundary conditions and flow properties as inputs to the numerical set-up, which is additional requirements to complete the solution.

2.1.1 Grid Independence

In the numerical solution, it is important to construct a fine mesh in the flow field to achieve healthy results. Since distribution, quality and number of the mesh elements in flow field plays a key role on the numerical results. Therefore a mesh independent study has always been required to ensure the numerical results are accurate. For that reason, mesh node numbers were intensified near the wall flow region using inflation layers (y^+<1) and rarefied in core region of the pipe flow, as shown in Fig.2. Through this way the mesh number in the flow field are optimized which is aimed to lower the CPU time. It must be known that the mesh elements should be increased at flow regions where the flow properties (velocity and pressure) change accelerated in spatial distribution. Here, the pipe flow field were meshed four times in the order the increasing the mesh element numbers. Fig. 3 shows the mesh independent study in terms of velocity and pressure. As shown in Fig.3, it is seen that mesh independence is provided with velocity curves at node numbers higher than 422669 and with pressure curves higher than 364182.

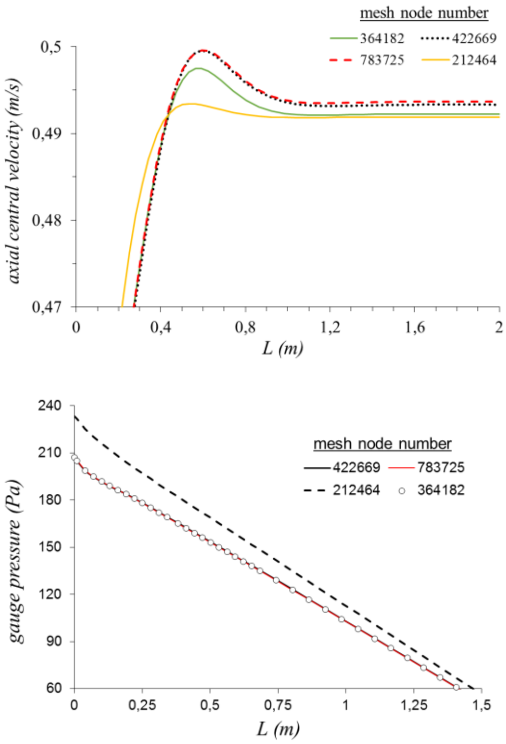

Fig. 3. Mesh independence study in terms velocity and pressure results.

Therefore, in this numerical study, the mesh node numbers in the pipe flow fields has been changed between 500000 and 700000.

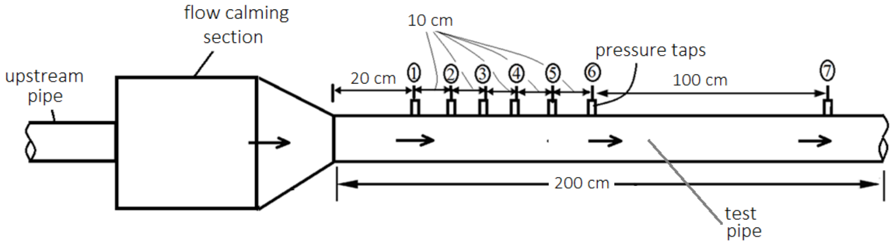

Fig. 4. Test pipe used in experiment and pressure taps mounted.

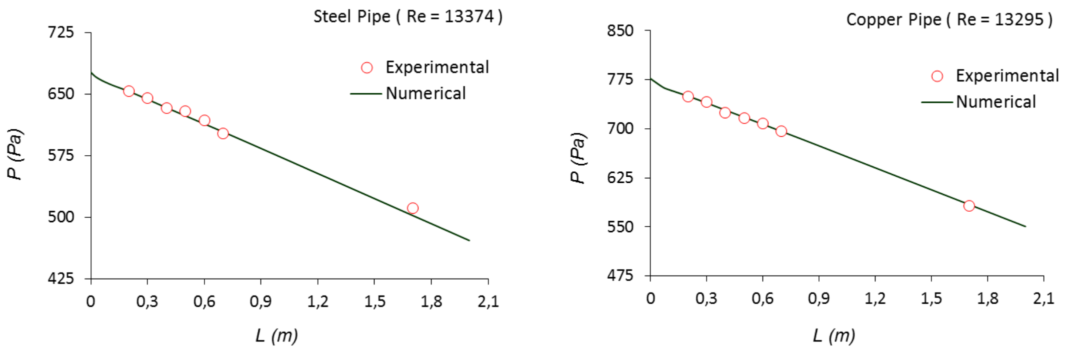

Fig. 5. Comparison of experimental and numerical data in terms of pressure drop.

2.2 Comparisons with Empirical Data

Numerical results must be tested across experimental data for validation. Therefore, an experimental study was performed as well as the numerical study conducted at Reynolds numbers ranging from 3443 to 24317. Five types of pipes (aluminum, copper, steel, galvanized and plastic) were used in the experiments with 2 m in pipe lengths, which was sufficient to enable the flow to be fully developed in. Water was circulated in the experiments as working fluid and its physical properties were taken at mean temperature of 27 ˚C, which is the average of the flow temperatures measured at each experimental runs. The roughness values and diameters of the test pipes has been given in Table 3. In the experiments, static pressures were measured along the flow at locations where seven pressure taps mounted on the pipes with equal spacing of 10 cm in the developing flow region and two taps with a span of 1 m in the fully developed flow region as depicted in Fig.4.

Table 3 Relative roughness values and pipe diameters of pipes

Type	Diameter	Relative Roughness
	(mm)	*ε / D*
Aluminum	26	0.00159
Copper	26	0.000163
Steel	28	0.00237
Galvanized	28	0.00256
Plastic	21	0.00033

Figure 5 shows pressure drops along the flow to compare numerical results with experimental data at arbitrarily chosen Reynolds number for all pipe types. Fig. 5 shows that the numerical results are well agree with the experimental data for the given Reynolds numbers. The mean and max. deviations of the nume-rical results from the experimental data for all pipe types, which were calculated based on pressure at each pressure tap, has been %8 and %20, respectively

3. NUMERICAL RESULTS AND FINDINGS

As has been stated earlier, the entrance length is a length of the developing flow region. Fully developed flow definition can vary according to flow character-ristic, and therefore, the entrance length varies according to flow characteristic chosen where those are mean flow values and turbulent statistics. In this study, the entrance lengths are scaled to wall shear stress observations. Wall shear stress has direct relation with velocity gradient and also with pressure gradient. Both gradient is constant in the fully developed region. The following equation show the flow shear stress at the wall.

$$\tau_w = \mu \frac{du}{dy}$$

Where τ_w is named as the wall shear stress and $\boldsymbol{y}$ and $\boldsymbol{u}$ is the wall normal direction and mean flow velocity, respectively. μ is the fluid dynamic viscosity and has a constant value for incompressible flows. Velocity profiles is the same along the fully developed flow as well its gradient so that wall shear stress is constant in the fully developed flow. Fig. 6 illustrates the variation of wall shear stress along the 2m flow length as a

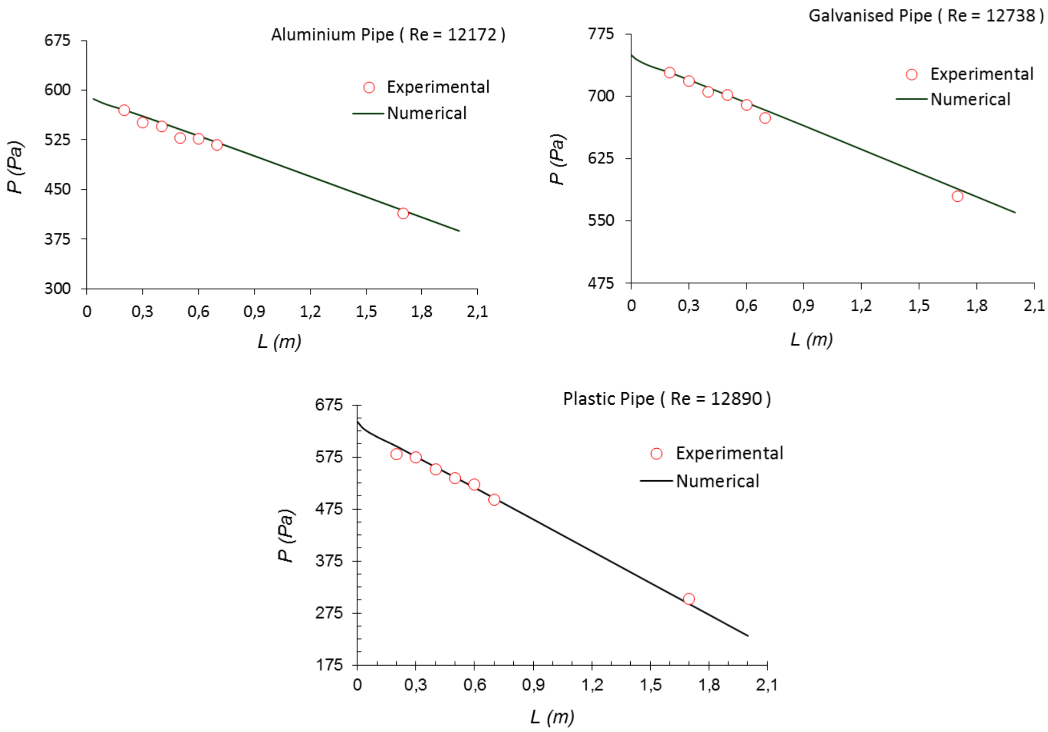

Fig. 5. Comparison of experimental and numerical data in terms of pressure drop.

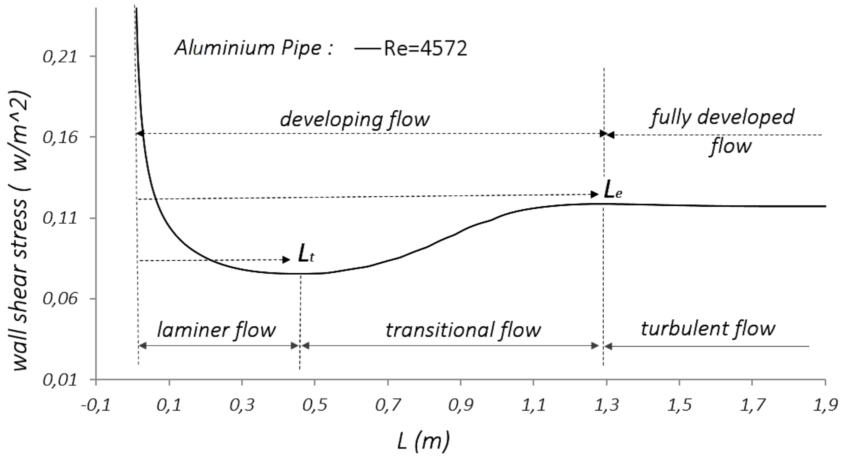

Fig. 6. Variation of wall shear stress along pipe flow, numerical.

numerical data. A sudden drop from a high value is seen in wall shear stress at near region of pipe inlet and then a slow decrease to a minimum value is observed in the location where the flow first changes from laminar to transitional. The minimum value is scaled to TOL. In the transition region, the wall shear stress ascend along the gradually sloping curve till a fully developed turbulent state is established and then wall shear stress follow the constant values, which also indicating the end of entrance length. The reason why a gradual increase seen in the wall shear stress in the transitional flow region is due to the turbulence to exist in the stream and a gradual increase in its inten-sity is seen along the downstream. The turbulence intensity in the stream affect the wall shear stress amount in direct proportional. Fig. 7 shows the variation in wall shear stress along the flow for all Reynolds numbers of aluminium pipe for sampling. The fully developed empirical wall shear stress calculated in terms of the Darcy friction which is determined through the Colebrook equation is also given in Fig. 7 so to compare the numerical with empirical data. It will be necessary to cite about Colebrook Equation, as shown below, since it is a well-known empirical correlation which gives the Darcy friction factors *(f)* in fully developed turbulent pipe flows.

$$\frac{1}{\sqrt{f}} = -2\log\left(\frac{\varepsilon/D}{3.7} + \frac{2.51}{Re\sqrt{f}}\right)$$

Figure 7 indicates that the numerical results in the

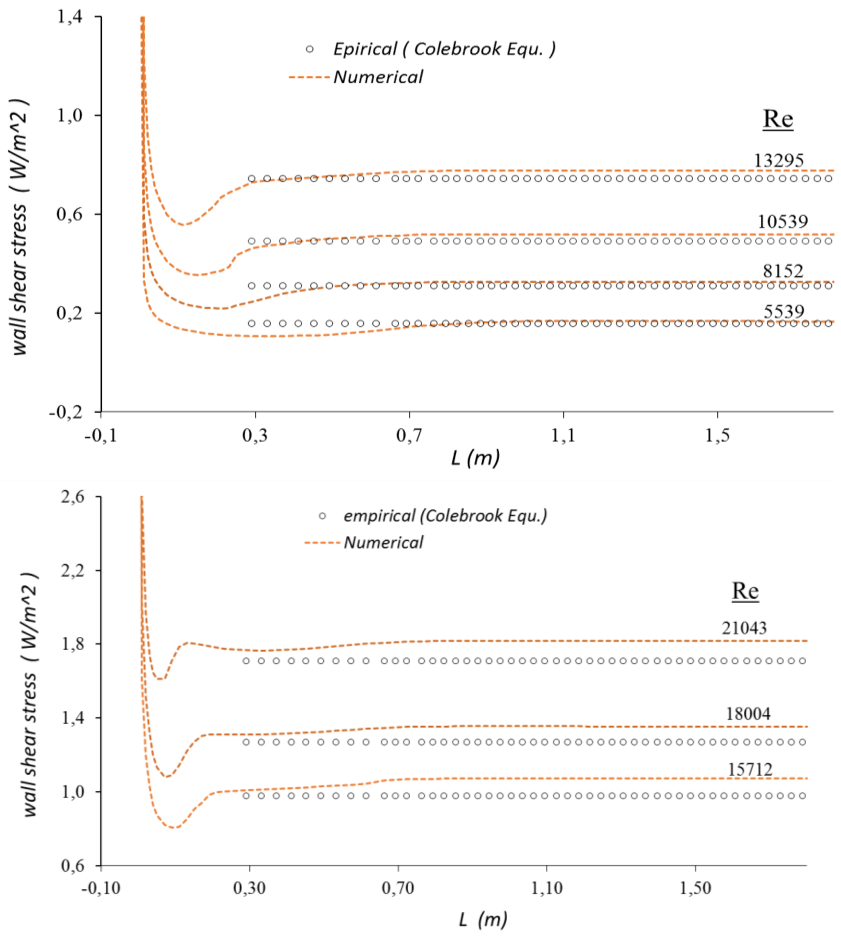

Fig. 7. Comparison with empirical data in terms of wall shear stress in fully developed pipe flow.

Table 4 Percent deviation of numerical with empirical in terms of wall shear stress in the fully developed flow

Absolute Percent deviation	Aluminium Pipe	Copper Pipe	Steel Pipe	Galvanized Pipe	Plastic Pipe
Max (%)	8,9	10	8	8,8	7,8
Mean (%)	6,1	6,17	6,11	6,87	5,69

fully developed flow region are in good agreement with the empirical wall shear stress values, which are obtained from the empirical Darcy friction factors through the relationship of both with pressure gradient. A small deviation is observed towards high Reynolds Numbers, but it does not exceed 9%. Table 4 shows the percent deviations of the numerical data with empirical values in terms of wall shear stress in fully developed flow. Percent mean value is the average value of the percent values taken in all Reynolds number flows belong to pipe considered. As shown in Table 4 mean deviations is about between 5-7 % and max. deviations is about between 8-10 %. These small deviations as well as validate the numerical study it also prove the Darcy friction factors given by Colebrook Equation being well experimented. The location where the wall shear stress goes to constant values about is marked as to measure the entrance length. Figure 7 shows that the entrance lengths become closer to the pipe inlet with an increase in Reynolds Number.

Figure 8 shows the numerical entrance lengths of all pipe types across Reynolds numbers. There are many parameters which effect the entrance length significant or negligible. Surface roughness is one of them and considered being effective in respect to available literature data. So to analyze the roughness effects on entrance lengths numerically, other parameters must be kept constant and then roughness must be changed to see its effects. Copper and aluminium pipe are the same in diameter but have different roughness so both can be compared through Fig. 8. As shown in Fig. 8, pipe roughness has no significant effects on the entrance lengths since very close entrance length values are found for both in the same Reynolds

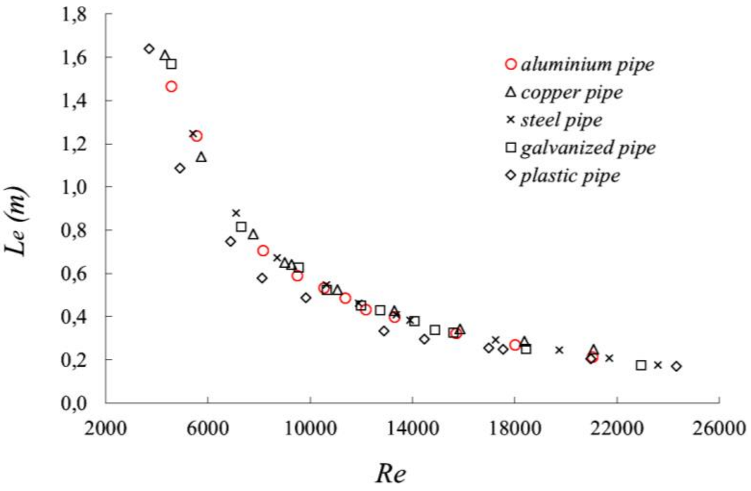

Fig. 8. Entrance lengths of pipes at different Reynolds numbers.

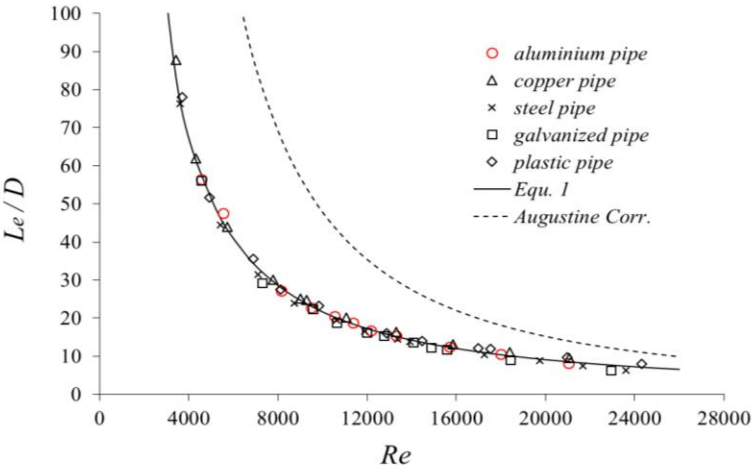

Fig. 9. Dimensionless entrance length versus Reynolds Numbers.

number. However, the pipe diameter is seen an effect on the entrance length since the plastic pipe, which is the smallest diameter one, and therefore shortest entrance length. Since why the shortest entrance length observed in the small pipe diameter is the flow velocity which is higher in than in bigger pipe diameters for the same flow rate. Higher flow velocity create more instability in the pipe flow so that the turbulence produced in the flow is increased and consequently the flow transition to turbulence is carried out at short pipe lengths. Here it is seen that the Reynolds number is primarily effective on the entrance length and secondarily effective is the pipe diameter or velocity of the flow. The percent difference in entrance length between small diameter and large diameter is high in low Reynolds number then the gap gets closer as the Reynolds number increases. This can be expressed as the Reynolds numbers is increased the pipe diameter effect on entrance length is getting smaller and also the same is true for the Reynolds number effect on the entrance length.

Figure 9 shows the entrance lengths in dimensionless form, indicating that the dimensionless form brought the values closer together at the same Reynolds numbers. Here, the effect of roughness on entrance length is very low as stated before and therefore, can be neglected. Fig. 9 also includes the empirical correlation developed by Augustine (1988) based on empirical entrance length data at Reynolds Numbers ranging from 5000 to 15000. The comparison indicates that the difference between the numerical results and the empirical correlation of Augustine (1988) increases especially towards low Reynolds numbers (Re<20000). This difference is predomi-nantly due to the pipe inlet turbulence intensity because inlet flow turbulence are primarily respon-sible in triggering the flow transition to turbulence, and therefore, high pipe inlet turbulence level in the numerical study led to an early flow transition and thus resulted in shorter entrance length. Pipe inlet shape is the first degree responsible on TOL according to the degree of turbulence it produced at pipe inlet. In the numerical study, high turbulence intensity (%7) at pipe inlet correspond to an entrant pipe inlet since it produces more turbulence than a square edged inlet. However, the square edged inlet

Table 5 Percent deviation between Eq. (1) and numerical values

PERCENT DEVIATION BETWEEN 3500 < Re < 16000					
PIPE TYPE	Aluminium Pipe	Copper Pipe	Steel Pipe	Galvanized Pipe	Plastic Pipe
MAX. (%)	4,72	7,81	7,20	9,89	4,76
MEAN (%)	0,23	3,94	4,78	5,63	1,67
PERCENT DEVIATION BETWEEN 16000 < Re < 25000					
MAX. (%)	3,96	11,21	17,58	21,36	11,65
MEAN (%)	1,52	9,86	9,28	16,5	10,15

used by Augustine (1988) in experiments might be the reason for the difference observed between the numerical results and Augustine empirical correlation data. The difference between both is appeared from the difference in the amount of the turbulence intensity present at pipe inlet flow.

A correlation (Eq.(1)) was developed which fit the numerical entrance length data well enough as shown in Fig. 9. The method used to derive Eq.(1) just consist of curve fittings works since the distribution of numerical data on Fig. 9 looks like a parabolic curve which is inverse proportional to Reynolds number. So that using excel, the power of the Reynolds number and the constant value in Eq.(1) was changed by trials to get its curve on good agreement with numerical datas. As a result of many curve fitting works, Eq.(1) was derived.

$$\frac{L_e}{D}=\frac{2166718}{\mathrm{Re}^{5/4}} \tag{1}$$

Equation (1) is seen in good agreement with the numerical data especially in the Reynolds number range of 3500 < Re < 16000 however deviation from the numerical data in the Reynolds number range of 16000 < Re < 25000 has been little greater. These percent deviations are given in Table 5 as max. and mean deviations for the two ranges mentioned. According to the Table 5, mean and max. deviations in low Reynolds numbers range are not exceeded 6% and 10% respectively and also both are not in bad limits in the high range Reynolds numbers.

As an outcome of the section, experimental data of this study and empirical value of Colebrook equation

has validated the numerical results of this study and good agreement was observed. However the estimation of the entrance length with Augustine (1988) correlation has been far away from curve of Eq.(1) especially in low Reynolds numbers. Here the reason was linked to pipe insert used in the experiment or the turbulence intensity present at pipe inlet. Since the turbulent intensity at inlet given in the numerical study is considered being higher than the experimental of Augustine. It was seen that Eq.(1) has provided good agreement with the numerical values in the Reynolds numbers range 3500 < Re < 16000 so it can be suggested in that range to estimate the entrance length for pipe inlets containing high turbulence.

4. CONCLUSION

A numerical study was conducted for entrance lengths in pipe flows. In addition to, an experimental study was carried out to validate the numerical results. Steady, incompressible and isothermal (constant properties) pipe flows were performed in both studies. Both identical studies covered the same Reynolds numbers ranging from 3000 to 25000. Pipe flow simulations were performed with RANS equations and SST k-omega model, and a Gamma-Theta transition model was also used for the onset of transition. The simulation data were validated with the empirical data of this study as well as with those reported in the literature. The plots of variations in wall shear stress along pipe inlet flow were used to obtain the entrance lengths, which were then analyzed across Reynolds number, pipe diameter and pipe roughness. It was seen that to put the entrance length in dimensionless form has mitigated the pipe diameter or velocity effect on the entrance length in the same Reynolds number. Due to negligible effect of wall roughness, the entrance length has been just a power function of Reynolds number only in inverse proportionality.

The numerical results were also used as a basis for a numerical correlation (Eq. (1)) defining the variation in dimensionless entrance lengths across Reynolds numbers. Eq. (1) was compared with Augustine (1988) empirical correlation and they were found similar as an inverse proportional to Reynolds numbers. The empirical correlation deviate from Eq. (1) great towards low Reynolds numbers (Re<20000) however, both correlations yielded close values at Re > 20000. Differences between both was linked to the pipe inlet shape used in the experiment which has an effect on pipe inlet conditions in terms of the quantity of turbulence it produced. Though Eq.(1) are in good agreement with numerical values in the Reynolds number range 3500 < Re < 16000 and also not bad agreement observed in the Reynolds number range 16000 < Re < 25000. So propose the numerical correlation to literature is seen early since it should be well satisfied with experimental datas before. And also further comparative studies are warranted to elucidate the effect of different parameters on entrance lengths in pipe flow.

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