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Effects of Surface Roughness on Friction Factors in Circular Galvanized Steel (GS) and Acrylonitrile Butadiene Styrene (ABS) Tubes

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ABSTRACT

The study of friction losses in pipes used in engineering and industry is important to improve flow efficiency and reduce the energy required to transport fluids. The surface roughness of a pipe affects its friction coefficient and its efficiency and performance. This numerical study explores numerically the impact of surface roughness on friction factors in circular tubes made of three distinct materials. The research employs computational fluid dynamics (CFD) ANSYS Fluent software to simulate turbulent flows, incorporating various surface roughness models in Galvanized steel (GS) and Acrylonitrile Butadiene Styrene (ABS) circular tubes. The simulation setup encompasses tube geometry, fluid properties, and boundary conditions. The simulation setup involves the pipe shape, fluid characteristics, and boundary conditions. The results indicate a precise link between surface roughness and friction factors, providing insights into pressure drop and flow characteristics. Validation against experimental data and known correlations enhances the dependability of the results. The findings help to optimise fluid transport systems and open the way for future study in this important technical subject. The friction factor decreases consistently with the increasing Reynolds number, and it is lower than the theoretical value. Galvanized steel (GS), with an absolute roughness of 0.15 mm, exhibits an 8% higher friction factor compared to Acrylonitrile Butadiene Styrene (ABS). This validation of the experimental data and known correlations enhances the reliability of the results.

1. Introduction

Pipeline systems are encountered in a lot of applications including oil and gas, thermal plants, air conditioning systems, and others [1,2]. Several researches on how surface roughness affects fluid flow inside pipes have been ongoing for a long time, aiming to understand the exact effect of

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roughness on flow at different Reynolds number ranges. However, discussions are still ongoing regarding possible deviations from conventional theories of laminar flow and the possibility of an early transition from laminar to turbulent flow. Galvanized steel (GS) and Acrylonitrile Butadiene Styrene (ABS) are commonly used materials in various industrial applications, each with unique physical and mechanical properties.

Darcy [3] and Fanning [4] laid the groundwork for understanding the effects of surface roughness in the nineteenth century [5,6]. However, Nikuradse [7] conducted systematic research to investigate the correlation between surface roughness and pressure drop. The Moody chart [8] is a widely utilized tool for determining friction factors over a wide range of Reynolds numbers in rough tubes. This chart, primarily derived from the extensive experimental investigations of Nikuradse [7], essentially plots the Colebrook equation [9] across a wide range of Reynolds numbers and relative surface roughness [10]. According to the Moody chart, laminar friction factors remain unaffected by surface roughness, while turbulent flow experiences an increase in friction factors with rising surface roughness. Kandlikar *et al.,* [10] created an adapted Moody chart, incorporating the constricted diameter for relative surface roughness, Reynolds number, and the Colebrook equation [11-13]. Everts *et al.,* [14] conducted experiments using circular tubes with varying surface roughness. Water was used as a working fluid for different ranges of Reynolds numbers. The measurements included the friction factors, Nusselt number, and the heat transfer coefficient. It was found that the increase in surface roughness generally increased the friction factors. Experimental study was conducted by Scaggs *et al.,* [15] to investigate the effects of surface roughness on turbulent pipe flow friction factors over wide range of Reynolds numbers and for different pipe rough surfaces. The research found that the experimental results were in very good agreement with predictions from a previously published discrete element roughness model [16].

Despite extensive research on friction factors in various pipe materials, limited studies have specifically addressed the comparative effects of surface roughness on friction factors in galvanized steel (GS) and acrylonitrile butadiene styrene (ABS) tubes. The main objective of this study is to investigate the effects of surface roughness on turbulent flow friction factors in circular tubes and to investigate how the Reynolds number influences the interaction between surface roughness and turbulent flow using ANSYS FLUENT software.

2. Methodology

2.1 Governing Equations

In the numerical setup, the simulation framework for investigating fluid flow within a straight pipe is established. This involves several key steps: firstly, parameters such as pipe diameter, length, and other relevant dimensions are defined within ANSYS DesignModeler based on Table 1 specifications. Surface roughness is represented within the model to mimic real-world conditions.

Table 1
Pipe specifications

Parameter	Galvanized steel	ABS pipe
Absolute roughness (m)	1.5×10^{-6}	7.0×10^{-6}
Relative roughness	1.5×10^{-3}	4.667×10^{-5}
L (m)	15	15
D (m)	0.15	0.15

Mesh generation follows employing appropriate refinement near the walls to capture boundary layer effects and roughness features accurately (Figure 1). Fluid properties such as density and viscosity are defined, and boundary conditions are set to simulate realistic flow conditions within the pipe, including inlet velocity and pressure outlet conditions. Turbulence models are selected to capture turbulent flow phenomena, and solver settings are configured to ensure robust convergence and accurate solution of the Navier-Stokes equations.

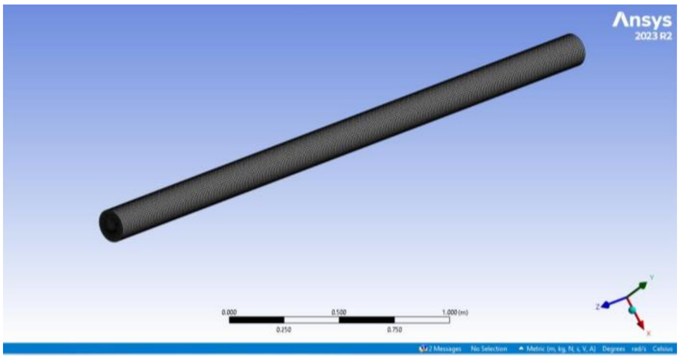

Fig. 1. Pipe meshing from Ansys

The general governing equations are as follows [17-20]:

Continuity equation:

$$\nabla . \left(\rho_{nf} V\right) = 0 \tag{1}$$

Momentum equation:

$$\nabla . \left(\rho_{nf} VV\right) = - \nabla P + \nabla . \tau \tag{2}$$

Energy equation:

$$\nabla . \left(\rho_{nf} V C_{p,nf}\right) = - \nabla . \left(k_{nf} \nabla T - C_{p.nf} \rho_{nf} \overline{\nabla t}\right) \tag{3}$$

3. Results

Tables 2 and 3 below show the pressure inlet and outlet of the pipes and the friction factor calculated for Galvanized steel (GS) and Acrylonitrile Butadiene Styrene (ABS) pipes. Figure 2 shows friction factors for different Reynolds numbers (representing varying flow velocities) for both GS and ABS tubes. The figure demonstrates how friction factors change with increasing Reynolds number for both materials. It's evident that ABD tubes generally exhibit higher friction factors compared to GS tubes across all Reynolds numbers, highlighting the influence of surface roughness on flow resistance. Additionally, the figure illustrates the decreasing trend of friction factors with higher Reynolds numbers.

Table 2
Friction factor for galvanised steel pipe

Reynolds number	P inlet	P outlet	Pressure difference	Friction factor (*f*)
7000	4.8558863	1.210051	3.6458353	0.033348633
10000	9.1653086	2.4601361	6.7051725	0.030052944
12000	12.712115	3.5359071	9.1762079	0.02856129
15000	19.011227	5.512134	13.499093	0.026890516

Table 3
Friction factor for Acrylonitrile Butadiene Styrene (ABS) pipe

Reynolds number	P inlet	P outlet	Pressure difference	Friction factor (*f*)
7000	4.8655869	1.2112236	3.6543633	0.033426639
10000	9.1819404	2.4621201	6.7198203	0.030118596
12000	12.734773	3.5386894	9.1960836	0.028623154
15000	19.044709	5.5164234	13.5282856	0.026948669

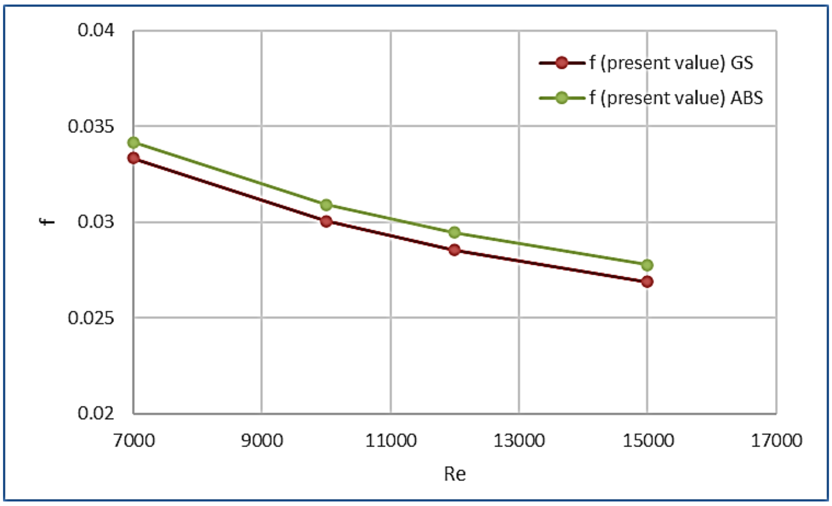

Fig. 2. Friction factor against Reynolds number

5. Conclusions

This study demonstrates the considerable influence of surface roughness on friction factors in galvanised steel (GS) and acrylonitrile butadiene styrene (ABS) tubes. The results show the relationship between surface roughness and friction factors for different Reynolds number, indicating decrease of friction factors with the increase of Reynolds number in both GS and ABS tubes. GS tube has lower friction coefficients than ABS. The findings indicate that as surface roughness increases, friction factors generally rise, indicating greater flow resistance and higher energy losses within the tubes. Additionally, the results emphasize the need for accurate modeling and characterization of surface roughness in engineering analyses to ensure reliable predictions of flow behavior and frictional losses.

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