International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Comparative Analysis of Mass Flow Rate, Conductive Heat Transfer, Temperature Difference and Internal Surface Roughness Across A Pipe Element

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ABSTRACT

The study, comparative analysis of mass flow rate, conductive heat transfer, temperature difference and internal surface roughness across a pipe element, were successfully investigated; using data gotten from simulink simulation of System block models in Matlab(R2015). The researchers adopted 5 variable pipe internal surface roughness, 20um, 5um, 100um, 45um, 10um and their corresponding mass flow rate, thermal loss and temperature difference were analyzed and graphs plotted, using Excel and Matlab. Results showed that at internal surface roughness of 25um fluid mass flow rate ranged from 0.58kg/s to 0.85kg/s. It was observed that below 45um, internal surface roughness is inversely proportional to mass flow rate of fluid and directly proportional above 45um. Also, between 20um and 100um, internal surface roughness is inversely proportional to thermal loss across a pipe element. Maximum value of thermal loss was found to be 5000000.00J/s at internal surface roughness value of 10um. In addition, within the ranges of 10um and 100um of internal surface roughness, optimal temperature difference was found to be 125K. Minimum temperature value of 75K happened at 0um. Hence, the value of internal surface roughness chosen, decides the mathematical flow characteristics in terms of mass, heat and temperature difference along a pipe element as the study showed.

Keywords *---- Internal surface roughness, Excel, Matlab, Thermal loss, Mass flow rate, Simulink*

INTRODUCTION

Kandlikar et al., (2003) and Yuan (2016) as cited in Goziya et al., (2020) stated that internal pipe wall roughness has significant influence on the pressure drop of the fluid flowing in pipes. This concept has given wider benefits in many systems due to the improvements it offers to the coefficient of heat transfers with very high surface to volume ratios making them highly applicable in cooling systems. Reviewed studies conducted showed that the flow characteristics and heat transfer pattern in small diameter pipes differ with pipes of larger diameter.

Knowledge of internal surface roughness value is especially important economically in the design optimization of hydrocarbon production and pipeline system. Surface roughness influences the pipe flow characteristics, by creating unfavorable pressure and energy losses because of friction (Farshad and Rieke, 2006).

According to Farshad and Rieke (2006), metrologically obtained data were statistically analyzed and average internal roughness value for plastic pipe, steel electro-polished pipe and glass fibre lined pipe were found to be 5μm, 12.5 μm, 30 μm and 38 μm respectively.

Goziya et al., (2020) studied effect of inner surface roughness on pressure drop in a small diameter pipe. The numerical analysis was performed using the ANSYS FLUENT software and the roughness on the pipe was modeled as a sphere with a size of 1µm. Two different cases were considered for the analysis; when the pipe was smooth and when the pipe was rough. The results showed there was a higher pressure drop in the rough pipe than in the smooth pipe. In addition, the size of the roughness was then increased for 1, 5, 10, 50,100 and 200 microns, and the result shows that as the roughness size increased the pressure drop also increase.

Nkwor et al, (2023) stated that fluid flow inertia increases conductive heat transfer and reduces mass flow rate through an insulated pipe element. In addition, the flow inertia must be compromised if maximum mass flow rate and heat leakage are of paramount. Similar results were stated by Dele et al., (202) that internal surface roughness increases conductive heat transfer at a constant mass flow rate of fluid and viscous friction decreases mass flow rate of fluid as well as conductive heat transfer across the pipe wall. It is on this note, researchers aimed at studying comparative analysis of mass flow rate, conductive heat transfer, temperature difference and internal surface roughness across a pipe element.

MATERIALS AND METHODS

The results or the data required for the comparative analysis of mass flow rate, conductive heat transfer, temperature difference and internal surface roughness across a pipe element were gotten using simulink simulation in MATLAB. Simulink in the MATLAB command window contains simscap-hydraulics block models that were used to represent the entire elements of hydraulic pipe flow model. Block ports were connected as shown in **Fig 1** below. Five (5) values of internal surface roughness were chosen and the corresponding values of mass flow, conductive heat transfer, temperature difference were recorded and analyzed using Excel, according to the table 1 and table 2.

Fig 1: System Hydraulic Pipe Flow model

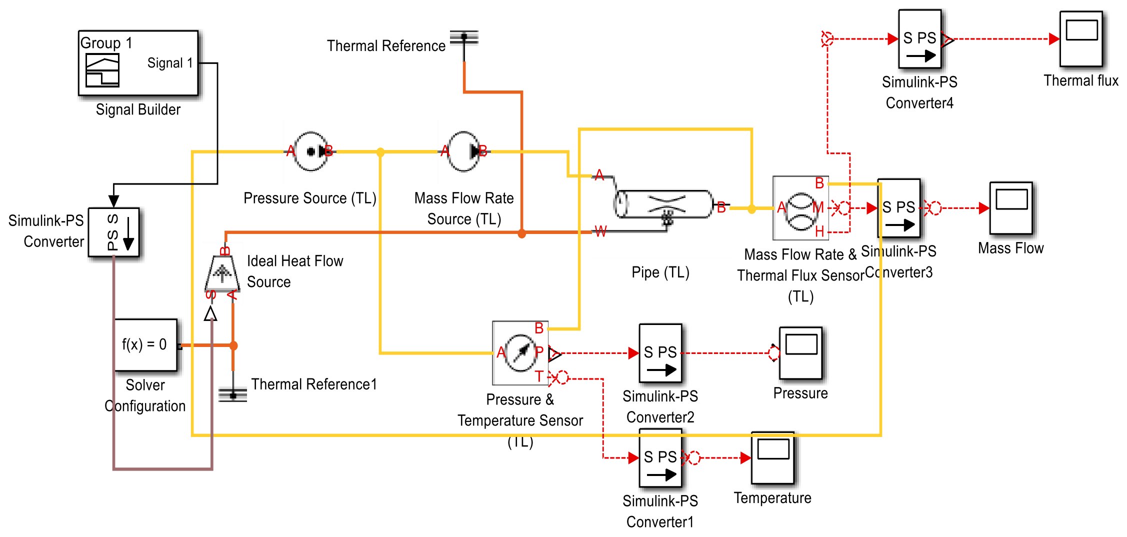

Table 1: Hydraulic Pipe Model

Pipe length	**230 m**
Hydraulic diameter	0.6m
Cross area	2.5 m2
Shape factor	50
Internal surface roughness	2e+1m
Laminar flow upper margin	2e+3
Turbulent flow lower margin	2e+3
Laminar regime nusselt number correlation coefficients	[1.86 0.33 0.33 0.33 0.14]
turbulent regime nusselt number correlation coefficients	[0.023 0.8 0.33 0 0]
Fluid dynamic compressibility	off
Fluid inertia	off
Initial temperature	300k
Initial pressure	1 atm
Initial mass flow rate from A to B	0.76 kg/S
Solver	Ode15s

RESULTS AND PRESENTATIONS

Table 2: Internal surface roughness, mass flow rate, thermal loss and temperature difference

S/N	**Internal Surface Roughness, μm**	**Mass flow rate(kg/s)**	**Thermal loss (J/s)**	**Temperature difference (K)**
1	20	0.600	3666.67	300
2	5	0.58	50346	-80
3	100	0.83	275	100
4	45	0.47	1558.33	126.65
5	10	0.82	1223.75	99.46

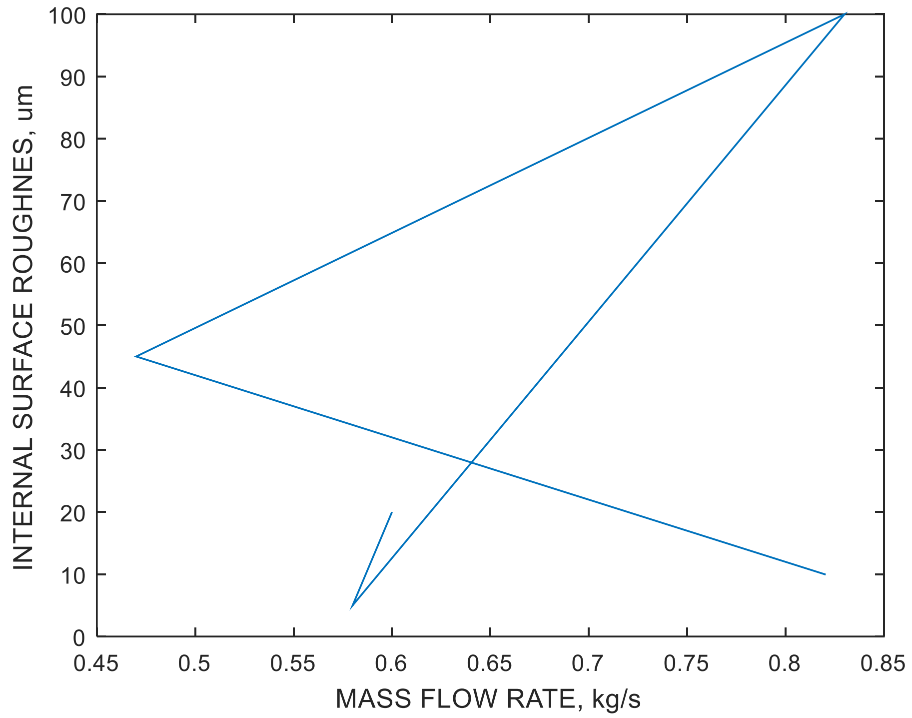

Fig 2: Matlab Graph of Internal surface roughness against mass flow rate

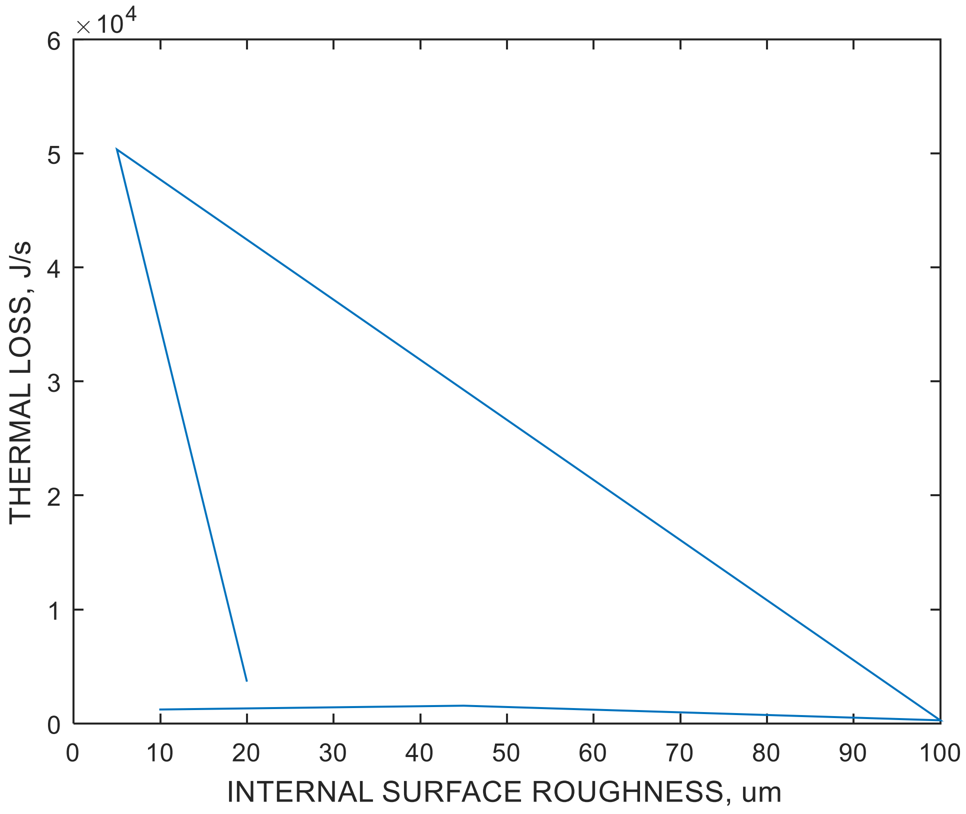

Fig 3: Matlab Graph of Internal surface roughness against Thermal loss

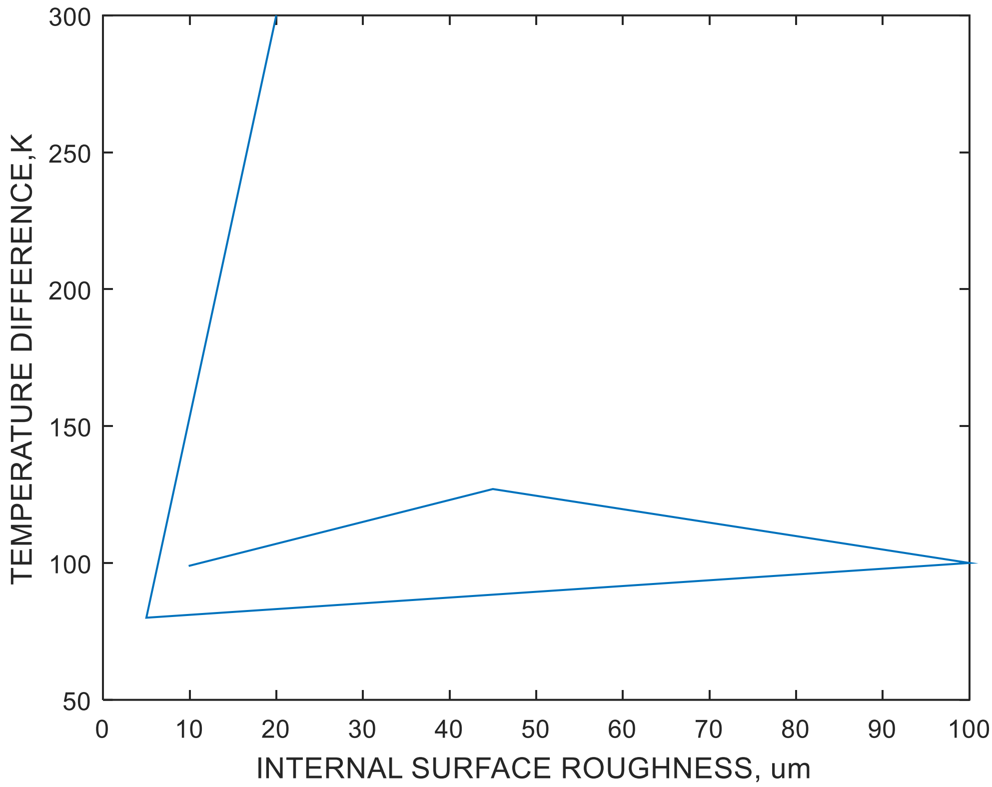

Fig 4: Matlab Graph of Temperature Difference against Internal surface roughness

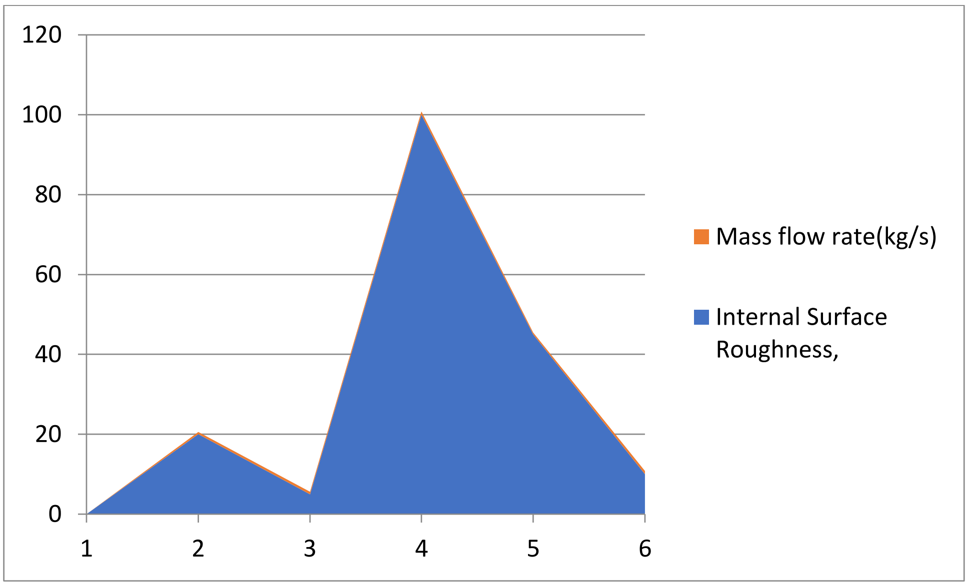

Fig 5: Area Graph of Internal surface roughness against mass flow rate

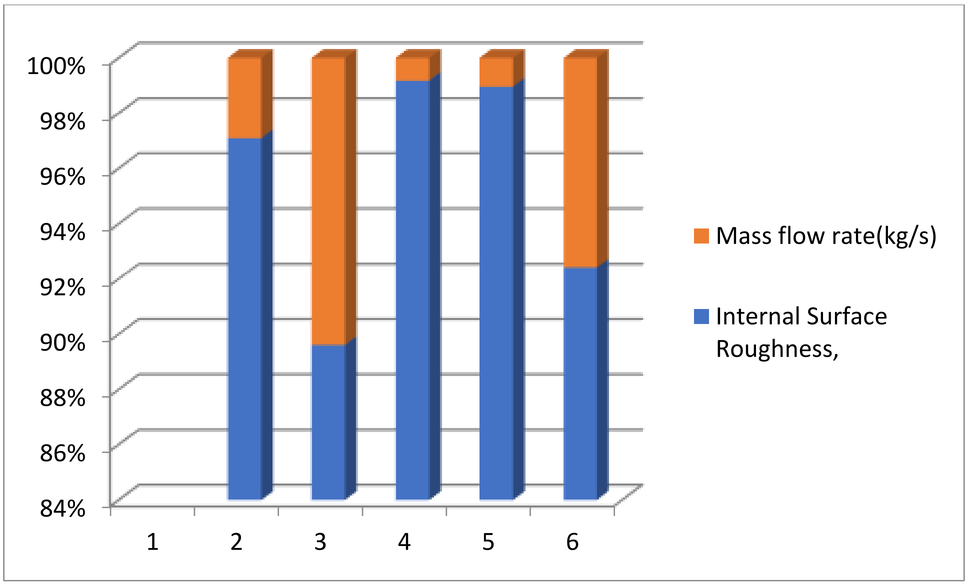

Fig 6: Bar Graph of Internal surface roughness against mass flow rate

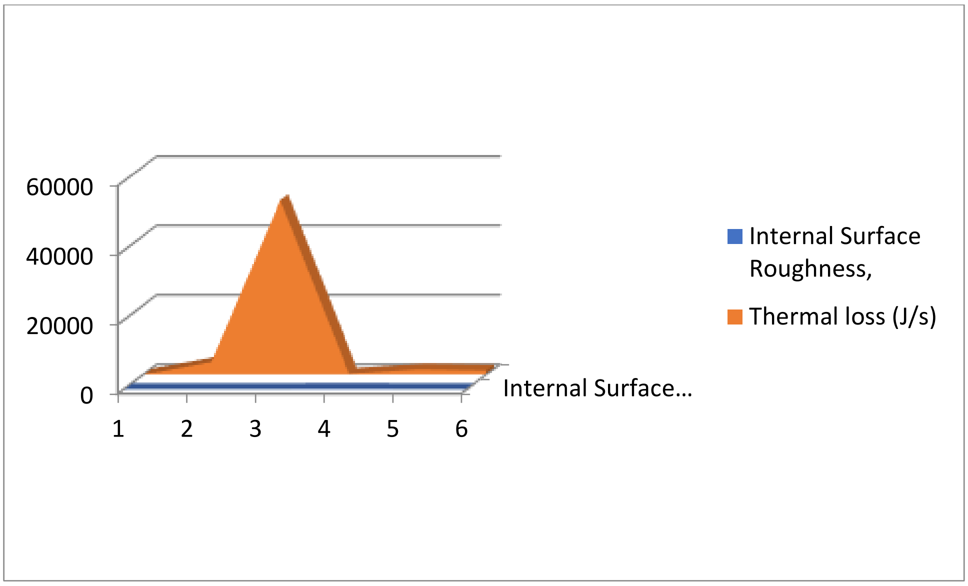

Fig 7: Area Graph of Internal surface roughness against Thermal loss

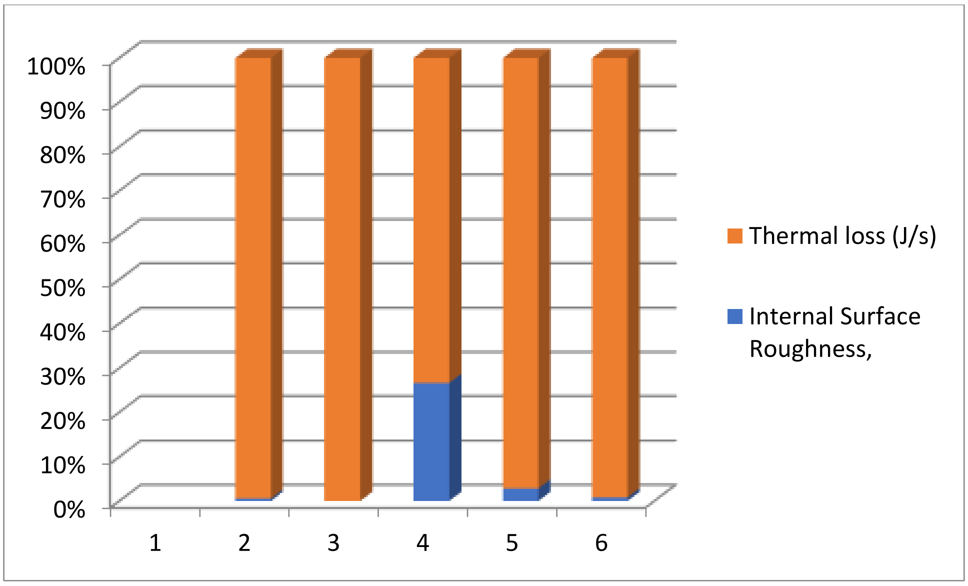

Fig 8: Bar Graph of Internal surface roughness against Thermal loss

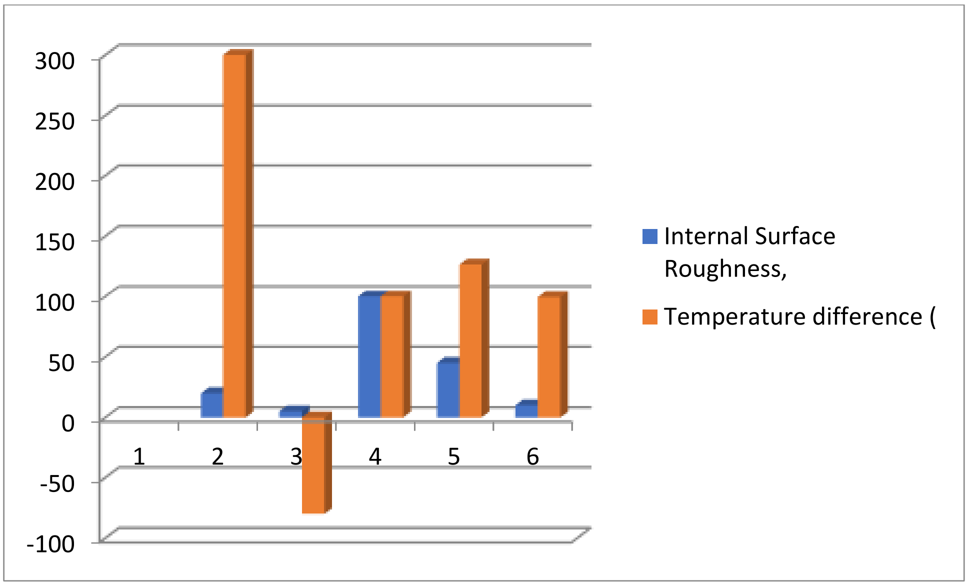

Fig 9: Bar Graph of Temperature Difference against Internal surface roughness

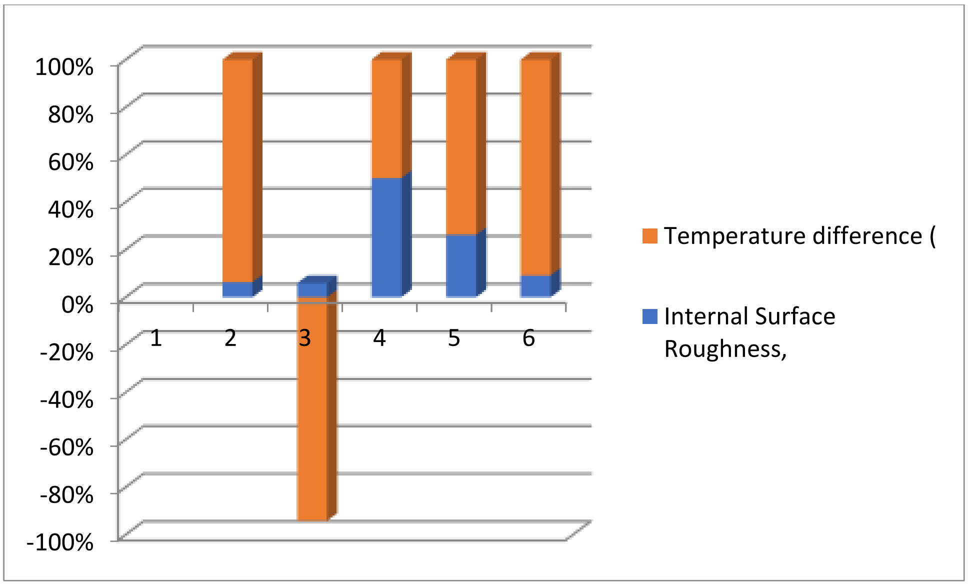

Fig 10: Bar Graph of Temperature Difference against Internal surface roughness

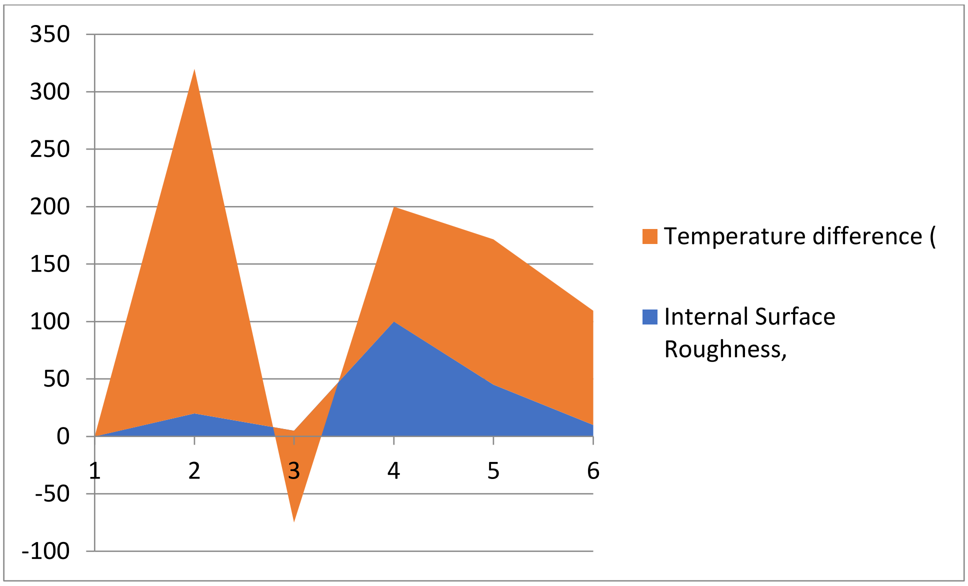

Fig 11: Area Graph of Temperature Difference against Internal surface roughness

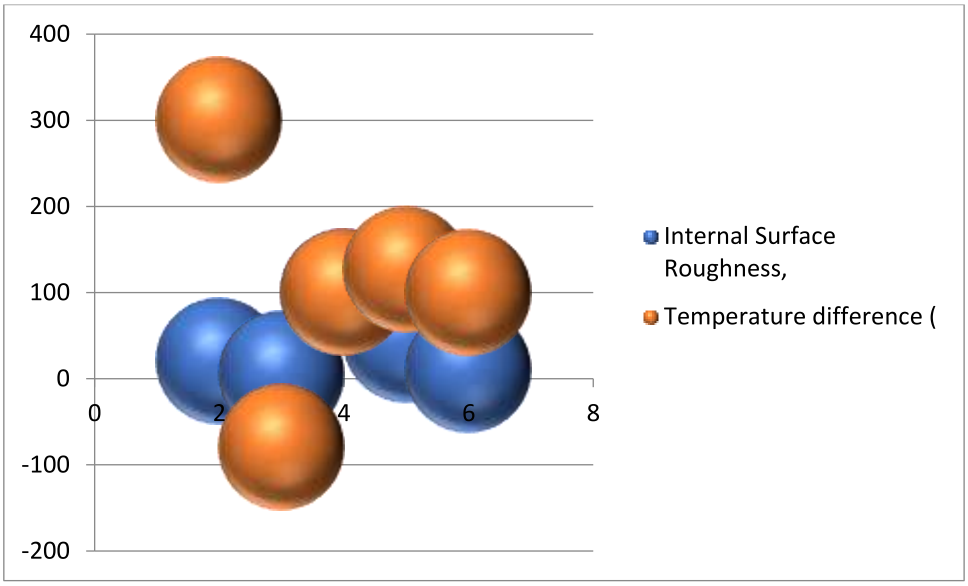

Fig 12: Ball Graph of Temperature Difference against Internal surface roughness

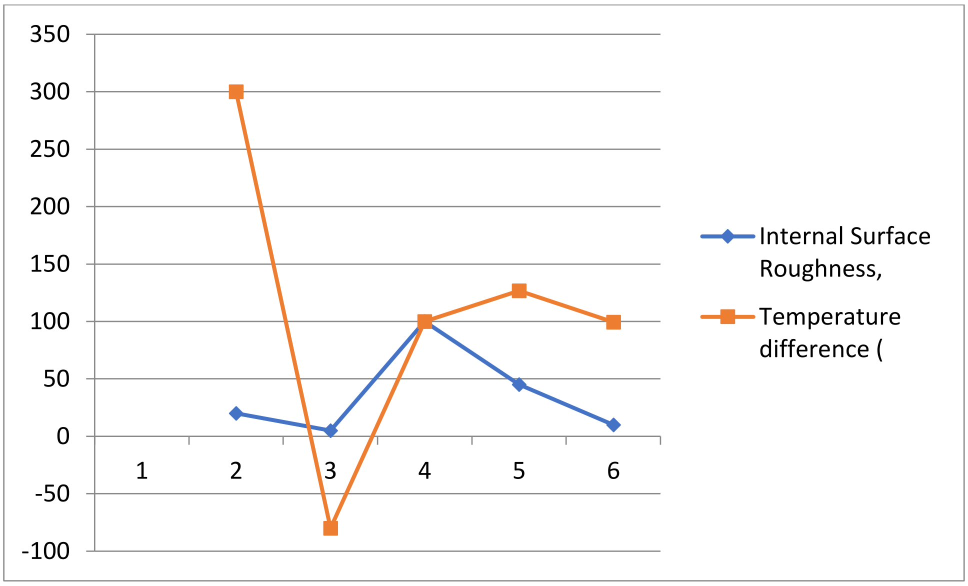

Fig 13: Line Graph of Temperature Difference against Internal surface roughness

DISCUSSION

Comparative analysis of fluid dynamic compressibility, mass flow rate and thermal loss along an insulated pipe

The study of comparative analysis of mass flow rate, conductive heat transfer, temperature difference and internal surface roughness across a pipe element, were investigated using results from simulink simulation method, Matlab and Excel graphical analysis were discussed here. According to Fig 2 to Fig 4, at 25um internal surface roughness would yield fluid mass flow rate ranging from 0.58kg/s to 0.85kg/s. It was observed that below 45um, internal surface roughness is inversely proportional to mass flow rate of fluid and directly proportional above 45um. Also, between 20um and 100um, internal surface roughness is inversely proportional to thermal loss across a pipe element. Maximum value of thermal loss was found to be 5000000.00J/s at internal surface roughness value of 10um.

Similarly, within the ranges of 10um and 100um of internal surface roughness, optimal temperature difference was found to be 125K. Minimum temperature value of 75K was found at 0um.

According to Fig 5 and Fig 6, maximum mass flow rate occurred between 3 and 6 which represent 10um and 100um, with the least value occurring at 1 and 3, that are 20um and 5um respectively.

According to Fig 7 and Fig 8 and table 2, maximum thermal loss was found to occur at 20um and 5um respectively. According to Fig 9 and Fig 13 and table 2, minimum temperature difference was found to occur at 3, that is when internal surface roughness pipe element was 5um.

CONCLUSION

From the findings of the study, we can conclude that internal surface roughness of pipe element, influences mass flow rate, conductive heat transfer and temperature difference across a pipe element. Hence, the value of internal surface roughness chosen, decides the mathematical flow characteristics in terms of mass, heat and temperature along a pipe element.

RECOMMENDATIONS

The following recommendations are suggested based on the study:

1) The influence of internal surface roughness must be compromised if maximum mass flow rate, temperature difference and heat leakage are of paramount.

2) This research can also be done in future using different pipe flow design models and other advanced software such as ANSYS fluent for generalization.

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