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(RESEARCH ARTICLE)

Effects of internal surface roughness and viscous friction on mass flow rate and conductive heat transfer across a pipe element: Simulink Approach

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Abstract

The study, effects of internal surface roughness and viscous friction on mass flow rate and conductive heat transfer across a pipe element using simulink approach was successfully achieved. Block models were used to represent all the elements of pipe flow model. Pipe element was modeled to retain hydraulic diameter of 0.4 m within a length of 100 m. The shape factor and internal surface roughness were chosen to be 80 and 3e+3m, respectively. Initial temperature and pressure were set to 300k or 27°C and 1 atm. turbulent regime Nusselt number correlation coefficients were 0.023, 0.8, 0.33, 0, and 0. The mass flow rate from the reservoir had initial value of 0.6 kg/s and signal block was adjusted to 1, 6, 5 for slope, start and maximum respectively. With Ode15s solver, simulation was allowed to run for 15seconds. System model mass flow rate, conductive heat transfer and temperature difference were found to be 0.6kg/s (same with initial value), 5.0346×10^4J/s and -80K or 193°C within 15seconds of simulation. Findings depicted the effects of internal surface roughness and viscous friction on mass flow rate and conductive heat transfer. Also, simulation was run with the shape factor and internal surface roughness chosen to be 64 and 1.5e-5m, respectively. Under viscous friction influence, initial temperature and pressure were set to 298k or 25°C and 1 atm. turbulent regime Nusselt number correlation coefficients were 0.023, 0.8, 0.33, 0, and 0. The mass flow rate from the reservoir had initial value of 0.6 kg/s. Results also showed that the system model mass flow rate, conductive heat transfer and temperature difference were found to be 0.058kg/s, -275J/s and 100K or -173°C within 15seconds of simulation. Hence, increasing value of internal surface roughness increases conductive heat transfer at a constant mass flow rate of fluid and increasing value of viscous friction, decreases mass flow rate of fluid as well as conductive heat transfer across the pipe wall.

Keywords: Internal surface roughness; Viscous friction; Conductive heat transfer; Simulink; Pipe

1. Introduction

Michael (2006)stated that viscous friction can be viewed in two rather different (although consistent) ways: it is a measure of how much heat is generated when faster fluid is flowing over slowly moving fluid, but it is also a measure of the rate of transfer of momentum from the faster stream to the slower stream. Looked at in this second way, it is analogous to thermal conductivity, which is a measure of the rate of transfer of heat from a warm place to a cooler place. In contrast to the liquid case, gas viscosity increases with temperature. Even more surprising, it is found experimentally that over a very wide range of densities, gas viscosity is independent of the density of the gas.

Rajput (2011) and Michael (2006) opined that viscous drag and pressure are not completely unrelated, the viscous force may be interpreted as a rate of transfer of momentum into the fluid, momentum parallel to the surface that is, and pressure can also be interpreted as a rate of transfer of momentum, but now perpendicular to the surface, as the

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molecules bounce off. Physically, the big difference is of course that the pressure doesn't have to do any work to keep transferring momentum, the viscous force does.

Within the boundary layer, adjacent layers of fluids are in relative motion, and because all fluids have viscosity, there will be friction between the layers as they slide over each other. This action, produces viscous stresses with magnitude given by the viscosity times the velocity gradient. Viscous frictional stresses cause energy dissipation in the fluid, which appears as heat. This heat can change the density of fluid significantly (Princeton.edu, 2023).

According to Karman-Prandtl equation for rough pipe velocity distribution, it can be deduced that as average height of roughness element increases, velocity distribution reduces, hence lowers mass flow rate.

There are no doubts that internal surface roughness of pipe and fluid viscous friction affects mass flow rate and conductive heat transfer through a pipe element. Hence, this research paper aimed at studying effects of internal surface roughness and viscous friction on mass flow rate and conductive heat transfer across a pipe element using simulink approach.

2. Methodology

Effect of internal surface roughness and viscous friction on mass flow rate and conductive heat transfer across a pipe element was carried out using SIMULINK in MATLAB. Simulink in the matlab command window contains block models that were used to represent all the elements of pipe flow model. The block models gotten from simscap- thermal and hydraulics, includes:

- Clock Block Properties
- Conductive Heat Transfer Block Properties
- Ideal Heat Flow Source Block Properties
- Ideal Temperature Sensor Block Properties
- Mass Flow Rate Source (TL) Block Properties
- Mass Flow Rate & Thermal Flux Sensor (TL) Block Properties
- PS-Simulink Converter Block Properties
- Pipe (TL) Block Properties
- Ramp Block Properties
- Reservoir (TL) Block Properties
- Simulink-PS Converter Block Properties
- Solver Configuration Block Properties
- Thermal Liquid Settings (TL) Block Properties
- Thermal Reference Block Properties
- Transfer Fcn Direct Form II Block Properties
- XY scope. Block Properties
- Block Type Count

Block ports were connected as shown in fig. 1 and fig. 2 below. The insulated pipe element as shown in table 1.0 was modeled to retain hydraulic diameter of 0.4 m within a length of 100 m. the shape factor and internal surface roughness were chosen to be 80 and 3e+3m, respectively. Initial temperature and pressure were set to 300k or 27℃ and 1 atm respectively. Turbulent regime Nusselt number correlation coefficients were 0.023, 0.8, 0.33, 0, and 0.

Ode15s solver was chosen due to its tight tolerance in fixed step solving. Simulation was allowed to run for 15seconds, see table 2 below.

3. Results and presentations

Table 1 Hydraulic Pipe Model

Pipe length	100 m
Hydraulic diameter	0.4m
Cross area	2.5 m2
Shape factor	80
Internal surface roughness	3e+3m
Laminar flow upper margin	4e+3
Turbulent flow lower margin	4e+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	0.6 kg/S
Solver	Ode15s

Table 2 Simulation Parameter

Simulation Parameter	**Value**
Solver	ode15s
RelTol	1e-3
Refine	1
MaxOrder	5
ZeroCross	on

Table 3 PS-Simulink Converter Block Properties

Name	**Physical Domain**	**Sub Class Name**	**Left Port Type**	**Right Port Type**	**Pseudo Periodic**	**Unit**	**Affine Conversion**
PS-Simulink Converter	network engine_domain	ps_output	input	output	off	K	off
PS-Simulink Converter1	network_engine_domain	ps_output	input	output	off	kg/s	off
PS-Simulink Converter2	network_engine_domain	ps_output	input	output	off	J/s	off

Table 4 Ramp Block Properties

Name	Slope	Start	X0
Ramp	1	5	6

Table 5 Transfer Fcn Direct Form II Block Properties

Name	Num Coef Vec	Den Coef Vec	Vinit	Rnd Meth	Do Satur
Transfer Fcn Direct Form II	[0.2 0.3 0.2]	[-0.9 0.6]	0.0	Floor	off

Table 6 XY Scope Block Properties

Name	Xmin	Xmax	Ymin	Ymax	St
XY Graph	-1	200	-1	10	-1

Table 7 Block Type Count

BlockType	Count	Block Names
Scope	4	Scope, Scope1, Scope2, Scope4
PS-Simulink Converter (m)	3	PS-Simulink Converter, PS-Simulink Converter1, PS-Simulink Converter2
Reservoir (TL) (m)	2	Reservoir (TL), Reservoir (TL)1
Conductive Heat Transfer (m)	2	Conductive Heat Transfer, Conductive Heat Transfer1
XY scope. (m)	1	XY Graph
Transfer Fcn Direct Form II (m)	1	Transfer Fcn Direct Form II
Thermal Reference (m)	1	Thermal Reference
Thermal Liquid Settings (TL) (m)	1	Thermal Liquid Settings (TL)
Solver Configuration (m)	1	Solver Configuration
Simulink-PS Converter (m)	1	Simulink-PS Converter
Ramp (m)	1	Ramp
Pipe (TL) (m)	1	Pipe (TL)
Mass Flow Rate & Thermal Flux Sensor (TL) (m)	1	Mass Flow Rate & Thermal Flux Sensor (TL)

Mass Flow Rate Source (TL) (m)	1	Mass Flow Rate Source (TL)
Ideal Temperature Sensor (m)	1	Ideal Temperature Sensor
Ideal Heat Flow Source (m)	1	Ideal Heat Flow Source
Clock	1	Clock

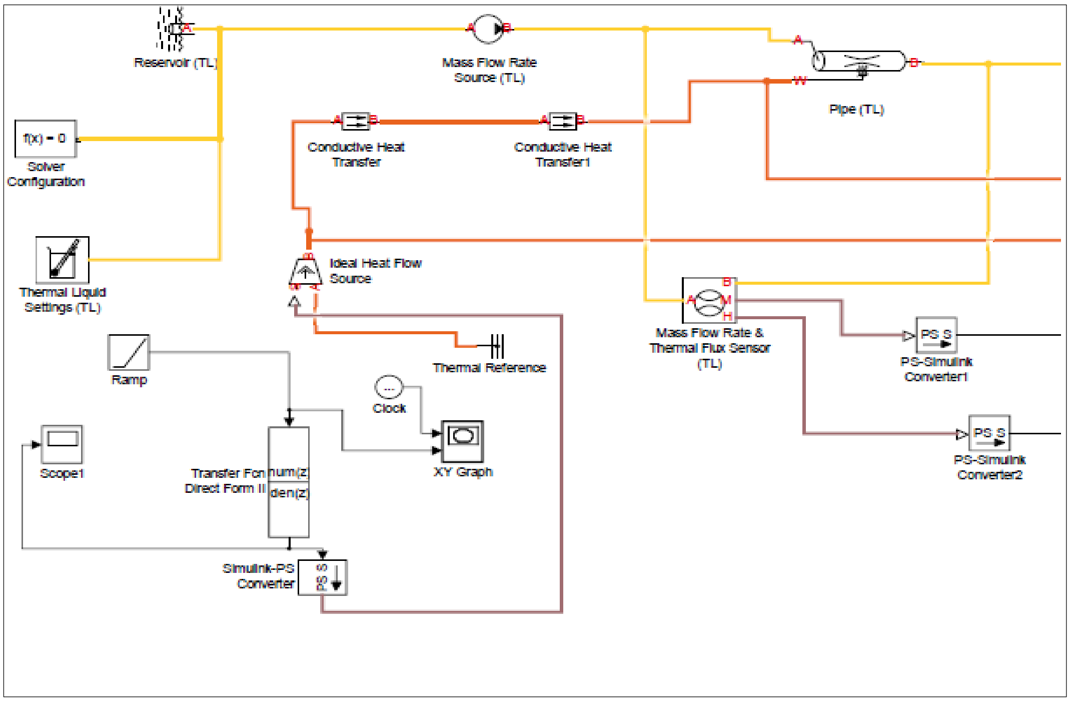

Figure 1 MODEL_PIPE_FLOW [User: Tennison Ifechukwu Ewurum : 02-Feb-2023 04:00:59]

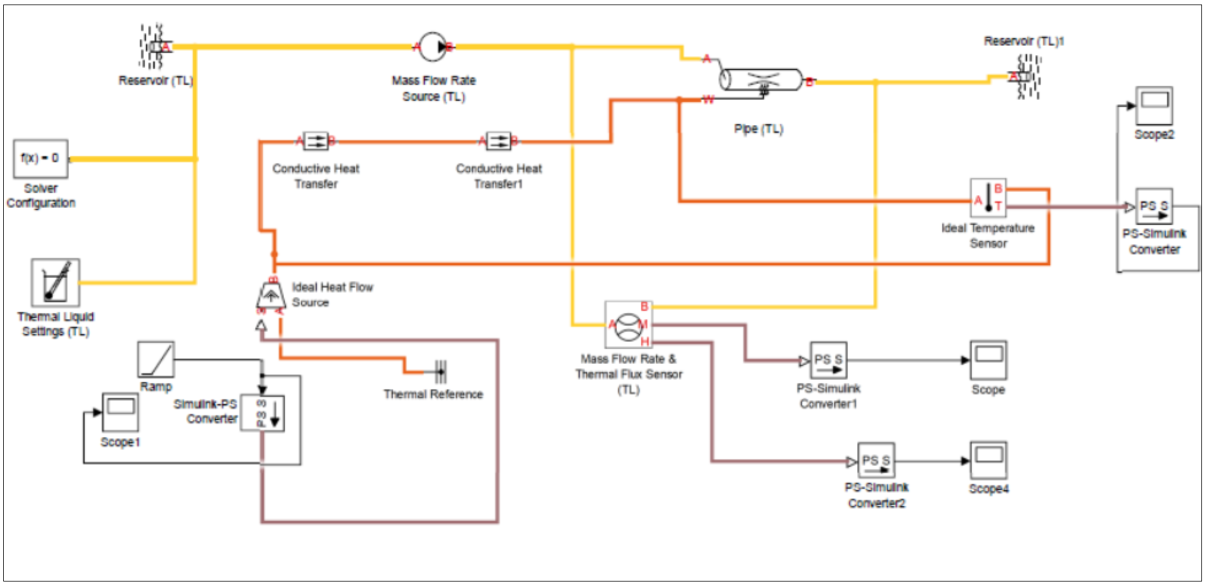

Figure 2 MODEL_PIPE_FLOW [User: Tennison Ifechukwu Ewurum : 02-Feb-2023 04:00:59]

3.1. Design analysis

Navier –Stokes equations of motion for general analysis of a dynamic viscous flow is given below;

$$B_x - \frac{1}{\rho}.\frac{\partial p}{\partial x} = \frac{du}{dt} - v[\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}] \text{ ...(1)}$$

$$B_y - \frac{1}{\rho}.\frac{\partial p}{\partial y} = \frac{dv}{dt} - v[\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} + \frac{\partial^2 v}{\partial z^2}] \text{ ...(2)}$$

$$B_z - \frac{1}{\rho}.\frac{\partial p}{\partial z} = \frac{dw}{dt} - v[\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} + \frac{\partial^2 w}{\partial z^2}] \text{ ...(3)}$$

Where B represents body force or gravity force per unit mass of fluid.

The universal velocity distribution equation, according to Prandtl's hypothesis for both smooth and rough pipe is as below:

$$u = u_{max} + 2.5\ u_f In(\frac{y}{R}) \text{ .....(4)}$$

$$u_f = shearfrictionvelocity, = \sqrt{\frac{\tau_0}{\rho}}\ , u_{max} = velocityatpiperadius, R$$

$$y = radiusatanygivenpoint.$$

Karman-Prandtl equation for rough pipe velocity distribution is as shown;

$$\frac{u}{u_f} = 5.75\ log_{10}(y/k) + 8.5 \text{ .....(5)}$$

$$wherek = avaerageheightofroughnesselement = y \times 30$$

In case of one dimensional flow, mass per second = $constant = \rho AV$ ....(6)

$$whereA = crosssectionalarea, V = velocity$$

$$modelmassflowrate = \rho(hotliquid) \times V \times A$$

$$0.6\ kg/s = 1000 \times V \times 2.5$$

$$V = \frac{0.6}{1000 \times 2.5} = 0.00024\ \mathbf{m/s}$$

Heat loss by conduction through the pipe element is given as below:

$$Q_L = \frac{2\pi L(T_1 - T_2)}{thicknessofpipe/K} \ldots..(7)$$

Where $K = thermalconductivity, inW/mK$

$$T_1 andT_2 = insideandoutsidetemperatures, L = pipelength$$

For an insulated pipe element, we have:

$$Q_L = \frac{2\pi L(T_1 - T_O)}{\frac{In\frac{r_2}{r_1}}{k_1} + \frac{In\frac{r_3}{r_2}}{k_2} \ldots} \text{ .....(8)}$$

$T_O = outsidetemperature, r = radiusofpipe$ and insulated material.

When fluid flows through a pipe, it experiences some resistance to its motion, due to which its velocity and energy (head) are reduced. The loss of head or energy is given in Darcy-Weisbach formula below:

$$h_f = \frac{4fLV^2}{D \times 2g} \ldots \ (9)$$

$$h_f = lossofheadduetofriction, f = coefficientoffrictionandafunctionofReynoldsnumber$$

$$L = lengthofpipe, V = meanvelocity, D = diameterofthepipe.$$

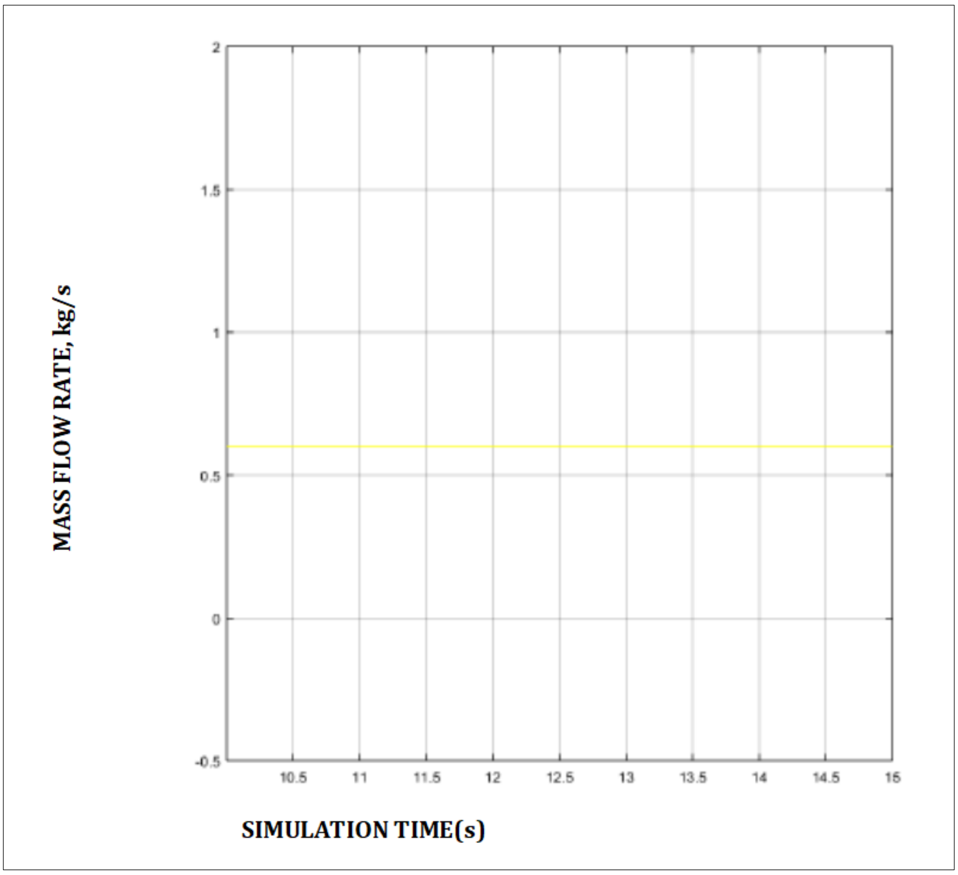

Figure 3 Mass Flow Rate

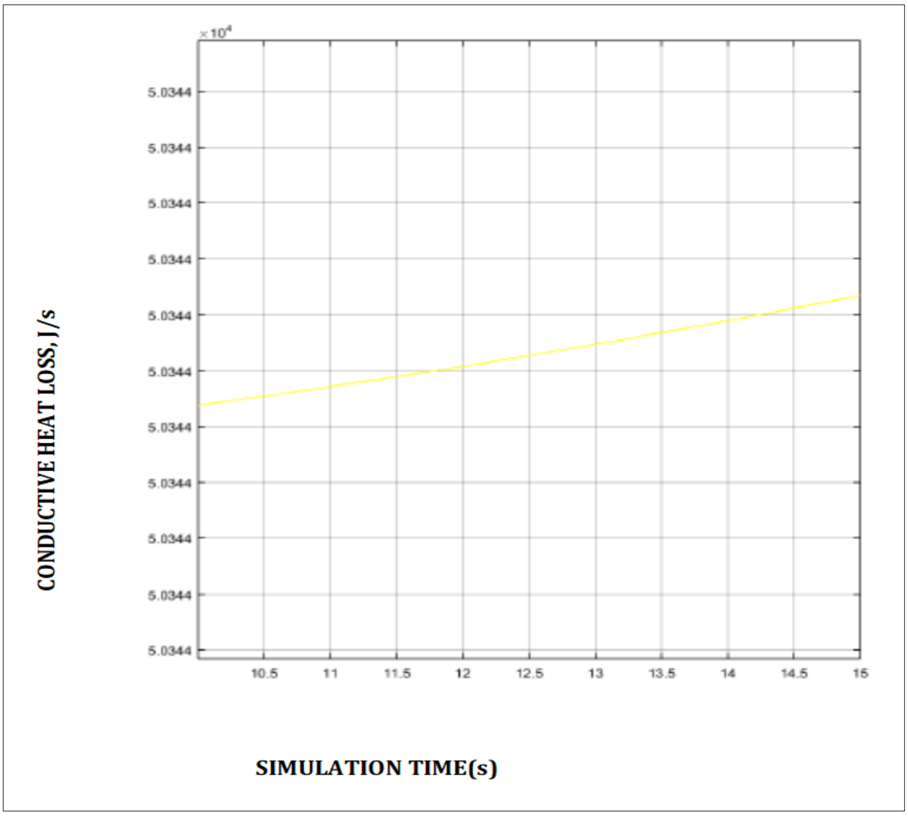

Figure 4 Conductive Heat Loss

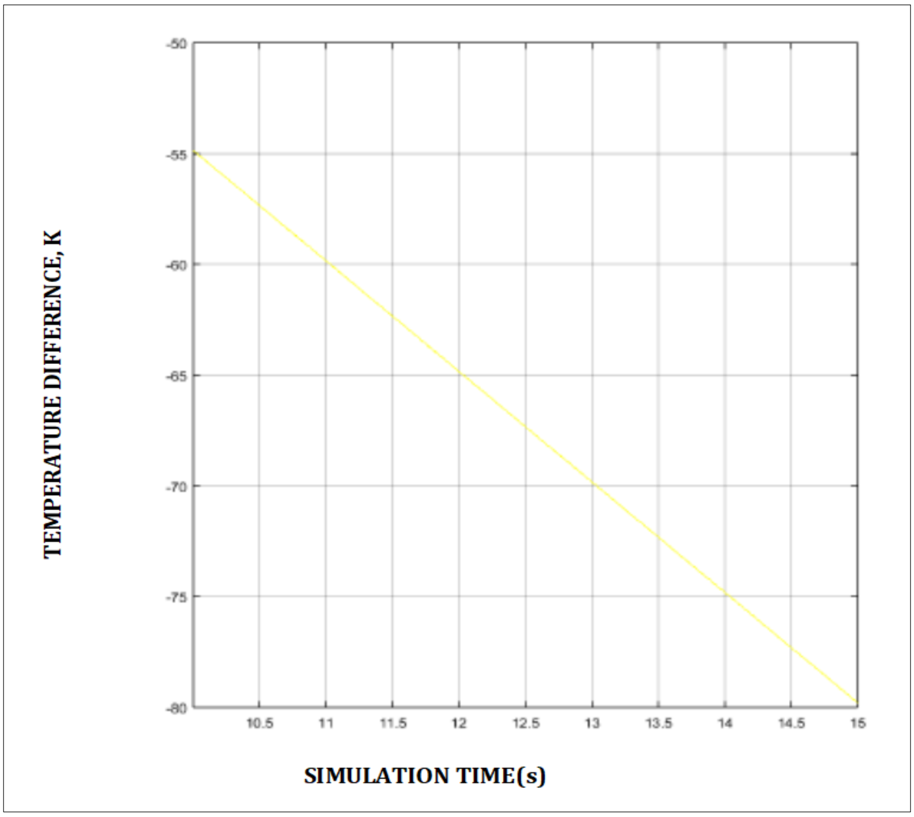

Figure 5 Temperature Difference

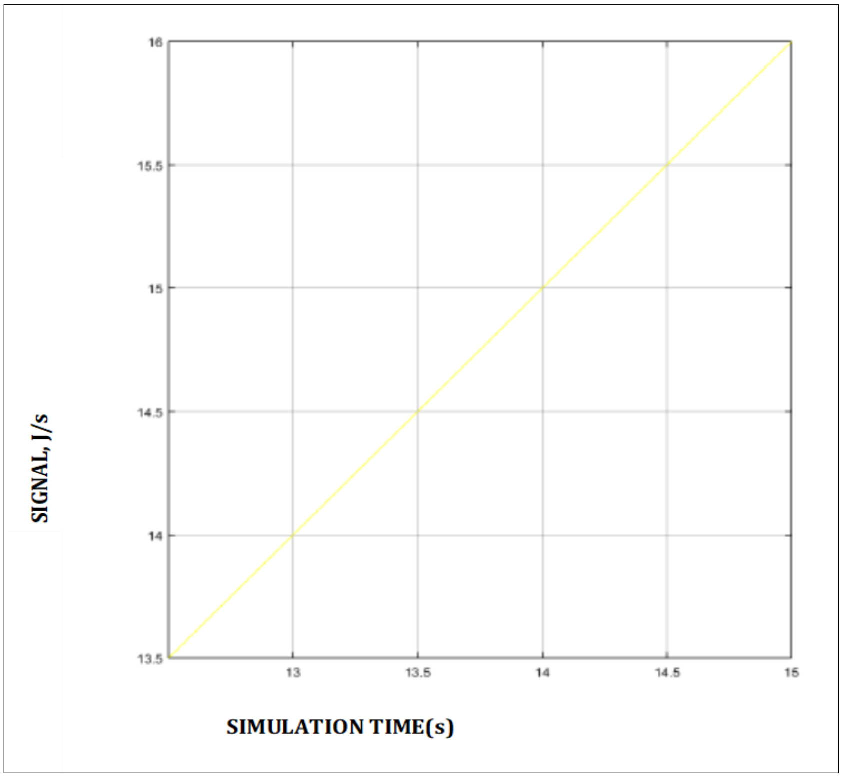

Figure 6 Ramp Signal

4. Discussion

Influence of internal surface roughness and viscous friction on mass flow rate and conductive heat transfer across a pipe element was investigated using simulink. According to Fig.1 and Fig. 2, block models were used to represent all the elements of pipe flow model.

According to table 1 pipe element was modeled to retain hydraulic diameter of 0.4 m within a length of 100 m. The shape factor and internal surface roughness were chosen to be 80 and 3e+3m, respectively. Initial temperature and pressure were set to 300k or 27℃ and 1 atm respectively. Turbulent regime Nusselt number correlation coefficients were 0.023, 0.8, 0.33, 0, and 0. The mass flow rate from the reservoir has initial value of 0.6 kg/s. Furthermore, table 4 showed that the signal block was adjusted to 1, 6, 5 for slope, start and maximum respectively.

With Ode15s solver, simulation was allowed to run for 15seconds, according to table 2.

System model mass flow rate, conductive heat transfer and temperature difference were found to be 0.6kg/s (same with initial value), 5.0346×10^{4}J/s and -80K or 193℃ within 15seconds of simulation, according to Fig 3 to Fig 5, respectively. The findings depicted the effects of internal surface roughness and viscous friction on mass flow rate and conductive heat transfer. Also , simulation was run with the shape factor and internal surface roughness chosen to be 64 and 1.5e-5m, respectively. Under fluid dynamic compressibility and inertia influences, initial temperature and pressure were set to 298k or 25℃ and 1 atm respectively.

Turbulent regime Nusselt number correlation coefficients were 0.023, 0.8, 0.33, 0, and 0. The mass flow rate from the reservoir has initial value of 0.6 kg/s. System model mass flow rate, conductive heat transfer and temperature difference were found to be 0.058kg/s, -275J/s and 100K or -173℃ within 15seconds of simulation.

Results indicated that increasing value of internal surface roughness increases conductive heat transfer at a constant mass flow rate of fluid and increasing value of viscous friction, decreases mass flow rate of fluid as well as conductive heat transfer across the pipe wall.

5. Conclusion

According to the results, we concluded 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.

Recommendations

The following recommendations are suggested based on the study:

- The values of internal surface roughness and viscous friction must be compromised if maximum mass flow rate and heat leakage are of paramount.
- This research can also be done in future using different design models and other advanced software for generalization.

Compliance with ethical standards

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Disclosure of conflict of interest

This research article is original and the corresponding author hereby confirms that all of the other authors have read and approved the manuscript with no ethical issues and with declaration of no conflict of interest.

References

[1] Anderson, J.D. (2009). Computational Fluid Dynamics.*National Air and Space Museum, Smithsonian Institution, Washington, DC.* Springer-Verlag Berlin Heidelberg.

[2] Michael, F. U. (200 6). Viscosity:Friction at the Molecular Level.

[3] Nataraj, M. & Singh, R.S. (2013). Analyzing pump impeller for performance evaluation using RSM and CFD. www. Researchgate.com

[4] Princeton.edu. (2023). Flows with Friction.

[5] Rajput, R.K. (2008). *Fluid Mechanics and Hydraulic Machines.* New Dehi: Khanna Publishers.

[6] Rajput, R.K. (2011). *Fluid Mechanics and Hydraulic Machines.* New Dehi: Khanna Publishers.