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Experimental Study on the Effect of Skin Friction Drag and Convective Heat Transfer for Viscoelastic and Pseudoplastic Fluid Flow

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ABSTRACT

Drag Reducing Agents (DRAs) have a huge impact and major concern in engineering and industrial applications. It converts the fluid flow from turbulent to laminar, dampens eddy, reduces head loss up to a certain limit, and saves pumping energy costs. Viscoelasticity is the property contained by DRAs that dampens eddy/turbulence at the contact point of fluid and pipe surface, which decreases the head loss up to a certain limit. So, for the viscoelastic effect, the concentration of DRAs can be increased up to a certain limit to reduce the head loss. So, a small amount of DRAs increases the viscosity of fluid slightly at the contact point of pipe and fluid, restricting the eddy formation that consequently reduces head loss during flow. Still, during flow due to the pseudoplastic effect, the viscoelasticity will start decreasing which is a negative effect. Pseudoplasticity is the shear thinning effect that decreases viscosity or viscoelastic effect at the contact point of fluid and pipelines when the flow rate or shear rate increases. So, these combined effects are studied to reduce skin friction drag in the pipeline and save energy costs which will be convenient for the food industry, chemical, and pharmaceutical industries. Investigation is carried out for 0.3 g/L, 0.2 g/L, and 0.15 g/L of xanthan gum in turbulent flow to observe the pressure drop and heat transfer rate. The study reveals that after increasing concentration the pressure drop reduced significantly. Conversely, the heat transfer rate was reduced due to the poor mixing effect. A higher performance and less vibration of the pump were also observed after the addition of DRA (drag reducing agent). It was concluded that the frictional pressure drop was reduced up to 85% and the heat transfer rate was reduced by up to 90% by increasing the concentration of the DRA up to 0.3 g/L at 10 LPM than the pure water or base fluid as a working substance on the double pipe heat exchanger. As the heat transfer rate reduced up to 90% with reducing pressure drop, another aim of the study was to establish a concentration and flowrate for which the heat transfer rate is maximum and it was found at a concentration of 0.15 g/L of DRAs at 22 LPM.

Keywords: Friction, Viscoelasticity, Shear Thinning Effect, Concentration, Flow Rate.

1 Introduction

Nowadays food fluid application is very common for different commercial sectors. If a small amount of xanthan gum is added to water, then the Newtonian fluid becomes a non-Newtonian viscoelastic fluid. If friction/head loss can be reduced in the pipeline, then power/head to flow the fluid can be saved which will reduce the energy costs. The formation of eddy during flow dissipates the pump flow energy or head which is due to the effect of turbulence. So, a small amount of drag reducer reduces the eddy formation or turbulence during flow and saves energy. It acts to make the fluid slightly more viscous and makes the flow laminar. But the friction reduction phenomenon is done by the eddy dampening effect so the friction reduction in the pipeline consequently decreases the heat transfer rate in the heat exchanger. So, optimization is required if we use DRAs (drag reducing agents), and a denotation is required for which concentration, a pressure drop is minimum and the heat transfer rate is maximum if there is an issue of heat transfer rate. This study is regarding this type of combined effect of friction reduction and heat transfer rate in pipelines and heat exchangers. Another matter of concern is the pseudoplastic effect, for which the viscosity may decrease in the pipeline during flow which may hamper the activity or viscoelasticity of the drag reducing agents that need to be kept in consideration. Pseudoplasticity is the shear thinning effect that decreases viscosity or viscoelastic effect when the flow rate or shear rate increases. Several studies [1] stated that different types of material can be used as drag reducers. This work is about how fluidity can be increased by reducing friction in the pipeline and heat exchanger by the addition of xanthan gum. This fluid can be called food fluid after the addition of DRA (drag reducing agent) which is found in almost every food industry in orange juice, mango juice, apple juice, apple puree, etc. The xanthan gum is well soluble in water and very stable in high temperatures even in acidic environments. In this experiment, the amount of friction or drag was studied by the addition of xanthan gum as DRA (drag reducing agent). We studied whether friction and heat transfer rate were lower than normal Newtonian fluid or not. For this, we measured the pressure at the inlet and outlet of the test section and calculated the extent of the pressure drop. Here we tried to find out whether the heat transfer would decrease or increase compared to the normal water which was a Newtonian fluid. Then for different concentrations and flowrates of xanthan gum, we tried to find out an optimum concentration and flowrate for which the frictional loss was minimum in the pipelines and heat exchanger. If we can keep the friction or drag lower, then power consumption to pump the fluid can be saved. Heat transfer analysis is very important in all sectors. Base fluid (water) creates drag and turbulence more in pipelines [2]. A small amount of high molecular weight drag reducer reduces the drag and acts as a drag reducer by reducing turbulence. This is a positive impact for reducing friction/drag but when heat is

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associated with this type of fluid it is important to know the heat transfer rate along with frictional characteristics of such fluid because DRAs (drag reducing agents) reduces turbulence as stated before. Here how much heat energy can be transferred by the viscoelastic xanthan gum solution for different concentrations and flowrates was also experimented and an optimum concentration and flowrate for maximum heat transfer rate was established. There are various types of additives like guar gum but the reason for choosing this type of additive is that xanthan gum is now widely used in many aspects of industry where complex engineering analysis and multidimensional aspects are related, so we must know the heat transfer ability and flow characteristics of xanthan gum solution. The mechanism of drag reduction can be explained according to the viscoelastic effect of the flow. Under this particular condition, the turbulent flow interacts with the molecules, causing a decrease in the pressure drop and an increase in the drag reduction. However, wall shear stress means the friction of the flowing fluid with the wall. This wall shear stress has a significant effect on drag. The more the eddy formation the more the wall shear and energy dissipation rate will be. So, by dampening eddy, the wall shear stress can be significantly reduced. This is the mechanism of the drag reducing agent. But different drag reducer has different ways of dampening eddy. Kadhim et al. [3] studied the effect of rigid xanthan gums on flow and pressure drops to improve drag. They made a flow loop test and created a modified xanthan gum mixture for aqueous drag reduction. Jubran et al. [4] made a review paper on recent works on drag reducing agents in a single and multiphase flow pipeline. Focus is placed on drag reduction, the influence on drag reduction agent types, and hydrodynamic and heat transfer characteristics of flow. They showed that drag reducing agent imparts a more drag reducing effect rather than a corrosion inhibitor or detergent. They concluded that 1000 ppm of detergent produces the same results as 25 ppm of drag reduction agent. So, we can effectively use the drag reducing agent. But they did not conclude the amount or optimum value of the DRA (drag reducing agent). Sauas and Salah [5] made a mini review on DRA (drag reducing agent). They said it is well recognized that a major issue for fluid flows in many industrial pipe systems, including the transportation of crude oil, is the high energy consumption in the pipeline system brought on by significant pressure losses in turbulent flows. The reduction of apparent viscosity and drag are two important challenges to enhancing crude oil flow conditions in long-distance pipelines. Chemical techniques are seen to be the most efficient and practical way to handle these problems. The pressure drop through a pipeline can be decreased by adding a tiny quantity of drag reducing agents. Sreedhar et al. [6] studied the drag reduction in polymer and the main focus of the study was enhancing the flow rate by reducing the drag in turbulent flows of fluids which is a highly significant phenomenon concerning many industries like oil, marine, irrigation, biomedical, etc. to reduce power consumption. Gilbert and Ripken [7] studied the fluid friction reduction experiment at St. Anthony Falls Hydraulic Laboratory University of Minnesota. They showed that using different concentrations of guar gum additive in solution reduced the frictional drag up to 60% for smooth disk. They used a rotating smooth disk and 550 ppm of pseudoplastic guar gum concentration. They showed when guar gum concentration is increased the frictional torque is reduced. They also found the velocity parameter was also increased when guar gum solution was used rather than normal water as the friction was lower. Patterson et al. [8] in their paper revealed that the heat transfer rate decreases by using drag reducer. He expressed that the heat transfer is suspicious to be lower in drag reducing flow. The drag or friction reduction is significant by the use of the soap solution, polymer solution, and suspended particle solution. Pruitt et al. [9] experimented with the heat transfer rate for the turbulent flow of polyacrylamide in water. The result was that the Stanton number was decreased for such type of additive solution flow and the drag was reduced also. Ganvir et al. [10] presented a review article on this type of heat transfer analysis with approximately same type of setup by using nanofluid. He found in several cases that nanofluid particle creates micro convection so the heat transfer developed in such type of setup is good. Shojaeian et al. [11] investigated the heat transfer behaviors with pool boiling by using a non-Newtonian xanthan gum solution. They used an experimental setup of an aluminum heater plate, thermocouples, reflux heater, plexiglass block, and gasket sealer. The dimension of the plexiglass block is $50\times50\times50$ mm^3. The plastic gasket sealing element was used as insulation, and high resistance to heat was used between the plexiglass block and the plate. The reflux condenser is made of an inner diameter of 22 mm, an outer diameter of 40 mm, and a 40 cm length. The effective operation of the condenser was found when the mass of liquid remained constant. They examined the stability of the xanthan gum solution by using the Raman test. According to the Raman test, the stability of the xanthan gum solution is constant when the content of xanthan gum powder content is increased in the solution. They found that at boiling conditions of a certain concentration, the pool boiling heat transfer decreases with the concentration of xanthan gum. They also visualized that the bubble formation rate at pool boiling increases with increasing the rate of xanthan gum concentration in solution which shrinks the rate of heat transfer. Joshi and Bergles [12] studied the heat transfer characteristics of non-Newtonian laminar fluid flow. They used closed-loop, low-pressure systems of pipes and fittings made of copper and brass. A pump circulated the viscous fluid. They used two thin-walled 304 stainless steel test sections. Rotameters were used to measure the flow rate. They attached copper constantan thermocouples circumferentially 90 degrees apart. Strong insulation was used so that no heat could escape from the tube section. Aqueous solution of 1% and 0.9% of Hydroxy Ethyl Methyl Cellulose (HEMC) was used as a working fluid solution. Lew [13] published a book review of Skelland's book which describes the characteristics of non-Newtonian flow and heat transfer characteristics. Naik and Vinod [14] showed the heat transfer rate and heat transfer enhancement in shell and tube heat exchangers. The thermal analysis was carried out to determine the overall heat transfer coefficient and shell side Nusselt no at different conditions such as by varying the flow rate of the non-Newtonian fluid. He showed that the heat transfer rate was increased for the non-Newtonian nanofluid. Rozzi et al. [15] investigated the heat transfer and friction loss characteristics for several fluid foods such as orange juice, whole milk, apricot, and apple puree. They tested for these viscoelastic fluid foods in shell and tube heat exchangers. They investigated the heat transfer rate for both Newtonian and non-Newtonian fluids. For the test, they used two counter-flow shells and a tube heat exchanger. The tube was made of AISI 304 stainless steel tube 2707 mm long. The smooth outer tube was internally 10 mm and externally 12 mm diameter. The four fluids had been tested. It is well known that apple puree is non-Newtonian pseudoplastic and viscoelastic fluid. They showed that this food fluid requires heat treatment in the corrugated tube as the heat transfer rate may decrease for this type of pseudoplastic fluid. So, we can conclude heat transfer rate for such fluid is not satisfactory. Their results can be summarized as follows: for such pseudoplastic fluid with sufficiently low values of the generalized Reynolds number the flow maintains laminar, with negligible heat transfer enhancing effects; for increasing Reynolds number the flow becomes unstable This fluid follows the power law model. Ahmed et al. [16] examined the rheological characteristics of the combined effect of Arabic gum with xanthan gum and guar gum. They showed that the xanthan gum showed pseudoplasticity separately and the Arabic and xanthan gum mixture showed dilatancy. But guar gum showed a good rheological effect. The study examines the effect of the addition of drag reducing agent. Hoyt [17] reviewed that the fluid friction resistance can be lower by adding additives but he did not show the exact concentration and heat transfer effect of the effect of additives on fluid friction. Habibpour and Clark [18] studied the drag reduction behavior of hydrolyzed xanthan gum mixed polymer solution. Five different concentrations of xanthan gum mixtures were prepared to investigate to improve the shear rate of fluid flow. The drag reduction increased from 30%-67% with increasing the concentrations from 100-1000 ppm. Tochigi et al. [19] studied the drag reduction of xanthan gum solutions for 10, 50, 100, and 500 ppm. They calculated the drag reduction by measuring the friction factor of 2- and 15-mm diameter pipe. They showed almost 60% drag reduction for 500 ppm concentration. Dosumu et al. [20] investigated the effect of two soluble polymers (xanthan gum and guar gum) on drag reduction for an oil-water flow system. They used horizontal pipe of internal diameter 12- and 20-mm. Different concentrations, mixture flow rates, and input oil volume were investigated. Optimal polymer concentration of 200 ppm and 150 ppm was established for xanthan gum and guar gum respectively. The experimental results also showed that the drag reduction (DR) of the individual polymer increased with the increase in additive concentrations and Reynolds numbers (Re). Bewersdorff and Singh [21] studied the turbulent drag reduction by xanthan gum at various concentrations in the presence of salt (NaCl). They showed that xanthan gum is very effective in decreasing turbulent drag reduction. However, they showed this drag reducing behavior is not much influenced in the presence of the salt. Gu et al. [22] studied the drag reduction effect and proved that rigid polymer exhibits remarkable resistance to mechanical shear. Therefore, mixing flexible and rigid polymers could offer improvements in comprehensive drag-reduction performance. This letter reports an experimental study on the drag-reduction performance of binary polyacrylamide (PAM) and xanthan gum (XG) solutions with the PAM concentration fixed at 10 ppm. Bo et al. [23] studied the drag reduction and anti-shearing characteristics of xanthan gum solutions with NaCl For different mass fractions of XG solution with NaCl addition (XG/NaCl solution), the relationships of the drag reduction efficiency with the flow Reynolds number and the shearing duration time were obtained and compared with the drag reduction and anti-shearing characteristics of XG solution. The results showed that the drag reduction percentage of the XG/NaCl solution tends to stabilize rapidly with increasing Reynolds number, and it is lower than that of the XG (xanthan gum) aqueous solution in the low Reynolds number regime. Li et al. [24] studied the rheological properties, drag reduction properties, and flow field characteristics of xanthan gum solution. They investigated the viscoelastic properties of the xanthan gum by combining it with a hydrolyzed polyacrylamide (HPAM) solution. They showed that compared with single-component solution of xanthan gum (XG) drag reduction rate is higher for hydrolyzed polyacrylamide (HPAM)- xanthan gum (XG) solution is higher. Shi et al. [25] investigated a DRA (drag reducing agent) named diutan gum a new additive that can greatly reduce turbulence resistance. The results show that diutan gum solution is a shear-thinning fluid. The viscosity and elastic properties are not much affected but depend on concentration. The drag reduction effect of DG (diutan gum) increases firstly and then decreases with the Reynolds number, and increases monotonically with the injection rate. We observe from previous studies that various studies were conducted separately for different concentrations and flowrates [3], combining different drag reducing agents (DRA) [16], combining salt [21], cellulose [12], varying diameter and roughness of pipe, some investigated the viscoelastic properties of the xanthan gum by combining with hydrolyzed polyacrylamide (HPAM) solution [24]. Heat transfer behavior was also studied but separately without studying the drag reduction effect [11]. However, there is a research gap in combined drag reduction and heat transfer effect. So, this research is conducted to reveal the combined effect of drag reduction by xanthan gum and heat transfer rate for a double pipe heat exchanger by combining both the effect of concentrations of the solution and flow rate. This study particularly examined how pressure drop varied by the addition of the xanthan gum in various concentrations and flow rates and the effect of heat transfer rate. The results indicate that the frictional pressure drop is lower due to the addition of the drag reducing agent as this DRA dampens the eddy. Also due to eddy dampening the heat transfer rate reduces due to poor mixing. These effects are shown on graphs one by one in this study highlighting the effect of concentration and flow rate. The objectives of the present investigation are to investigate 0.3 g/L, 0.2 g/L, and 0.15 g/L of xanthan gum in turbulent flow to observe the pressure drop and heat transfer rate. Especially there is a lack of study combining the effect of heat transfer rate and frictional pressure drop reduction. As these parameters are opposite to each other on the question of the eddy dampening effect no comprehensive study was done before, taking the consideration of these two effects combining the parameters of flowrate and concentration at the same time. Also, as in our country heat exchanger usage is very common so this study will have a great effect on our industry in the question of reduction of cost by reducing pumping power by increasing the fluidity of the fluid by adding DRA. In this experiment, we used a parallel flow double pipe type heat exchanger. Four thermometers were used in our analysis. Solution of water and xanthan gum was used in the test section and was allowed to flow through the inner tube side of the heat exchanger as cold fluid. Then pressure drop and heat transfer rate were calculated. The findings were compared with normal water and a clear concept was developed about where and on which application viscoelastic solution can be used.

2 Methodology

This research investigated the frictional pressure drop for different concentrations and flow rates along with the study of heat transfer rate. This section contains the points: fabrication procedure, dataset description, data processing, discussions of the experimental setup, and the entire working process is depicted in Fig. 4.

2.1 Fabrication of Double Pipe Heat Exchanger:

A double pipe type heat exchanger was fabricated according to the following dimensions and design:

$$LMTD, \Delta T_M = \frac{\Delta T1 - \Delta T2}{ln\left(\frac{\Delta T1}{\Delta T2}\right)} \quad (1)$$

Length: 24 inch
Width of outer pipe: 4 inch
Width of inner pipe: 2 inch
Diameter of the side pipes: 1 inch
Main body length of the inner pipe: 18 inch
Material of the pipes: Mild Steel
Insulating material: Glass wool with Aluminum Foil

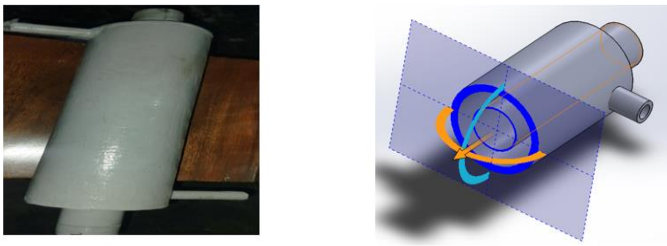

Fig. 1 CAD drawing and fabricated double pipe heat exchanger

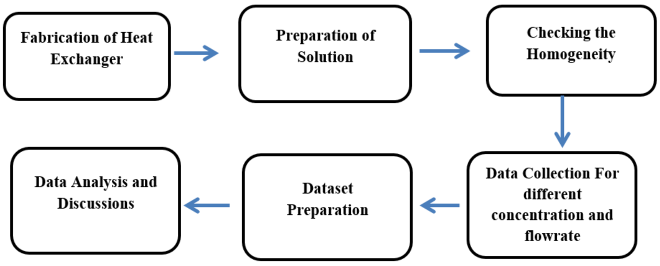

Fig. 2 Overview of the proposed experimental process

2.2 Dataset Description

Table 1 contains the heat transfer rate for various flow rates. The concentration of the solution is 0.3 g/L. The four temperatures were recorded from four sides of the heat exchanger, two at the entry sides of the heat exchanger and the other two at the exit sides from the same direction to make the flow parallel. Six flow rates variations are taken as 22- 10 LPM. For each of the flowrate, the four side temperatures were recorded. The initial temperature of the cold side of the base fluid water was at room temperature (26 ºC) and the hot fluid (solution) temperature was 60 ºC. The system was run for 15 minutes for each set of data.

Table 1: Data collection for heat transfer rate for xanthan gum (0.3 g/L) solution

Xanthan Gum (0.3 g/L)					
Flowrate (LPM)	**$T_{h,in}$(ºC)**	**$T_{h,out}$(ºC)**	**$T_{c,in}$(ºC)**	**$T_{c,out}$(ºC)**	**U(W/m^2.K)**
22	47	44	35	38	7267
20	46	45	35	38	7108
17	46	45	36	38	5009
15	46	45	36	38	5009
12	46	44	37	38	2861
10	47	44	37.5	38	1393

Table 2 contains the data regarding the frictional head loss. Two pressure gauges read the pressure at the outlet of the pump and at the exit of the flow near the bucket. The difference in pressure gave the drop of pressure in heat exchangers and pipelines. The data were taken for the same as flow rate of 22-10 LPM. The % w/w indicates how much (in kg) xanthan gum is added. For example, 2.4 g xanthan gum in 8 L water means 0.0003 kg/L (%w/w) or 0.3 g/L of the solution. Similarly, 0.0002 kg/L and 0.00015 g/L solutions are prepared and tested. It needs to ensure that the same concentration is maintained for the heat transfer rate also.

Table 2: Data collection for pressure difference for xanthan gum (0.3 g/L) solution.

Xanthan Gum (0.3 g/L)					
Flowrate (LPM)	**P_{in} (kgf/cm^2)**	**P_{out} (kgf/cm^2)**	**ΔP_L (kgf/cm^2)**	**H_L(m)**	**% w/w**
22	0.35	0.1	0.25	0.0000249	0.0003
20	0.35	0.1	0.25	0.0000249	0.0003
17	0.5	0.25	0.25	0.0000149	0.0003
15	0.6	0.45	0.15	0.0000149	0.0003
12	0.64	0.6	0.04	0.0000029	0.0003
10	0.95	0.92	0.03	0.0000029	0.0003

2.3 Data Processing

Density of Xanthan gum, ρ_x =1500 kg/m^3 at 20ºC

Specific heat of Xanthan gum, C_p=4.133 KJ/kg.K at 27.25 c with the concentration of 0.2% w/w (minimum) [26]

Specific heat of Xanthan gum, C_p=7.459 KJ/kg.K at 60.95 c with a concentration of 0.5% w/w (maximum) [26].

$$C_{pc} = 98.78575 - 0.6495T - 15.9955X_x + 0.06TX_x + 0.001109T^2 - 0.5X_x^2 \text{ [26]} \quad (2)$$

Where, T = Bulk temperature of the cold fluid (Xanthan gum solution)

X_x = Concentration of solution (% w/w)

Bulk temperature,

$$T = \frac{T_i + T_e}{2} \quad (3)$$

Where, T_i = inlet temperature of cold fluid (Xanthan gum solution)
T_e = Exit temperature of cold fluid (Xanthan gum solution)
Viscosity of water, μ = 0.0091 poise or 8.90×10^{-4} pa.s
Density of base fluid (water) =1000 kg/m^3
Density of Xanthan gum =1500 kg/m^3
Specific heat of water = 4182 J/kgºC or 4.186 J/gmºC
Heat transfer area of the heat exchanger, A = 0.07 m^2
ΔP = Pressure difference across the heat exchanger

$$\Delta T_1 = T(h, in) - T(c, in) \quad (4)$$

$$\Delta T_2 = T(h, out) - T(c, out) \quad (5)$$

Heat transfer rate,

$$Q = m_c \times C_{pc} \times [(Tc, out) - (Tc, in)] \quad (6)$$

Maximum heat transfer rate,

$$Q_{max} = m_c \times C_{pc} \times (T_{h,in} - T_{c,in}) \quad (7)$$

Where, C_{pc} = Specific heat of cold fluid at constant pressure;

Overall heat transfer coefficient,

$$U = \frac{Q}{AF\Delta T_M} \tag{8}$$

Head loss in the pipe for laminar flow,

$$h_L = \frac{\Delta P_L}{\rho g} \tag{9}$$

h_L is the additional head that has to be raised by the pump to overcome friction

Here, ΔP_L = Loss of pressure in Pa and ρ=Density of solution in Kg/m^3.

2.4 Experimental setup

At first, the xanthan gum was measured properly on a digital weighing scale. Then the mixture is made homogeneous by mixing it with a magnetic stirrer. Then the gum powder was simply poured into a beaker and mixed with a magnetic stirrer. Then to make 0.3 g/L solution, 8L water was taken in a bucket and the solution of the beaker was poured in the bucket. Fig. 5 shows the procedure of preparing the solution and Section 2.4 is the brief description of the preparation of the solution. This solution was the cold fluid. Fig. 3 shows the detailed experimental setup and equipment. In Fig. 3 two fluids one was hot and another cold (solution of xanthan gum) were in two different tanks. Then two pumps was connected to two tanks. The hot fluid (water) was flowed to the inner tube of the heat exchanger by pumps and returned to the tanks by the outline of the heat exchanger. The cold fluid (xanthan gum solution) was flowed to the outer tube side of the heat exchanger by another pump. The flow directions of these fluids are clarified by the line diagram of the setup (Fig. 4).

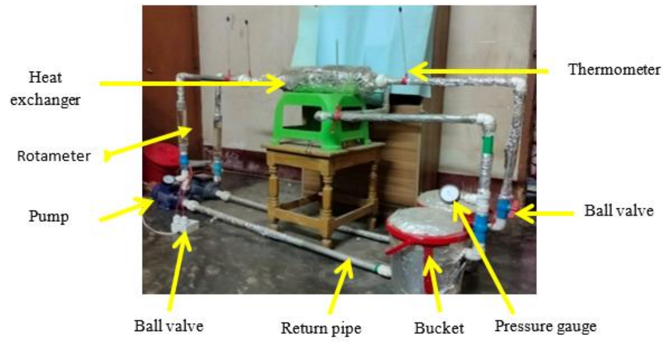

Fig. 3 Experimental setup and equipment

Four thermometers were connected to the heat exchanger to measure the inlet and outlet temperature of the hot fluid and the inlet and outlet temperature of the cold fluid. The flow rate was measured by two rotameters. When the flow rate of both the two fluids was stable, the thermometer reading was taken. Then by using Eq. (8) the overall heat transfer coefficient (U) was found out. The frictional head loss was found by Eq. (9). Then the head loss & heat transfer rate for normal base fluid and for different concentrations of the solution was compared. Then one optimum flowrate and concentration was established for minimum frictional pressure drop and another optimum flowrate and concentration was also established for maximum heat transfer rate. So, we can understand whether Newtonian or non-Newtonian fluid transfers heat more. A brief explanation of how pressure difference is measured by using a pressure gauge at the inlet and outlet of the heat exchanger is: the pressure difference was taken for water and then for xanthan gum solution for different concentrations and different flowrates. The difference in pressure or the loss of head is the loss of pressure due to friction. Then frictional pressure drop for the xanthan gum solution for various flow rates and concentrations was compared. A 1000W heater was used to heat the base fluid. The target temperature was raised to 60 °C. But the temperature was raised to 62 °C to compensate for the heat loss through the pipings, rotameter, tank, etc.

During the experiment, the following assumptions were made

- The flow is steady.
- Xanthan gum is stable at different conditions [11]
- Heat loss by conduction and radiation was neglected
- The size and shape of the xanthan gum particle was not considered.
- Xanthan gum solution is viscoelastic [24]

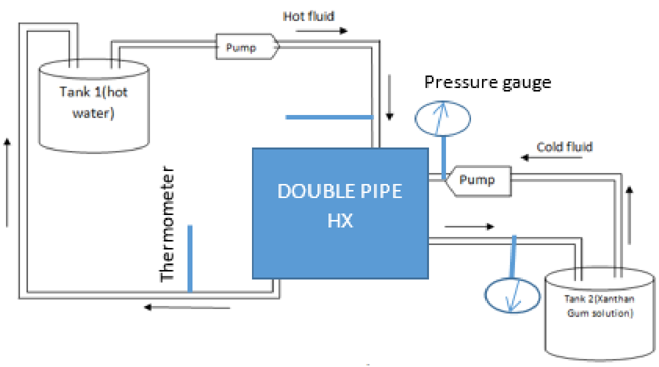

Fig. 4 Schematic diagram of the experimental setup

2.5 Solution Preparation

According to the U.S. Food and Drug Administration, the concentration (w/w) of Xanthan Gum should be between 1-10 g/kg of solution.

Mass of the Xanthan gum = 2.4, 1.6, 1.2 g

The volume of solution = 8 L

Grams per kg = grams solute/kg of solution

So, the concentration is 0.3, 0.2, 0.15 grams/kg

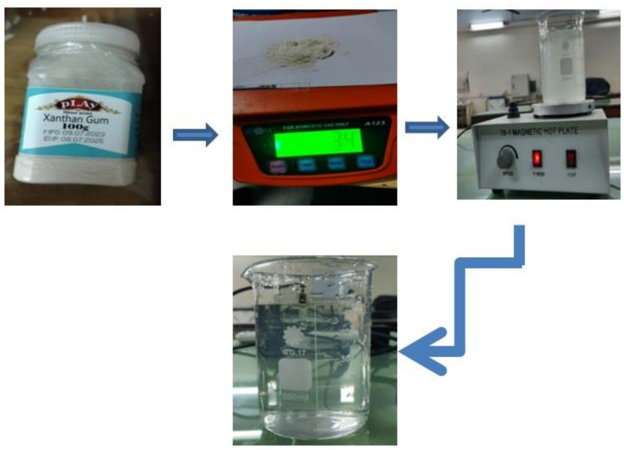

Fig. 5 Xanthan gum solution Preparation by magnetic stirrer

The solution is prepared by first measuring the xanthan gum by a weighing scale. As an example, for preparing 0.3 g/Kg solution an 8 L base fluid (water) is taken & 2.4 g xanthan gum powder is measured. Then the gum is dissolved in the water by stirring continuously with a mechanical stirrer & magnetic stirrer. The solution is heated up to 20 °C when required to dissolve the gum perfectly as the gum dissolves more accurately and uniformly when heated. But during heating it should be kept in mind that the temperature should not rise to more than 80 °C as above this temperature the solution will start to lose or change its properties like viscosity. The solution is then mixed & stirred for 25 minutes continuously by a mechanical stirrer & a magnetic stirrer is used when required. For 0.3 g/L= 2.4 g Xanthan gum mixed with 8 L water; For 0.2 g/L= 1.6 g Xanthan gum mixed with 8 L water; For 0.15 g/L= 1.2 g Xanthan gum mixed with 8 L water.

3 Result and Discussion

3.1 Result Analysis

The addition of the xanthan gum efficiently affected the frictional head loss and was efficient in improving the fluidity of mixture solutions at constant environmental conditions of 26°C. The pressure drop reduction varied with polymer concentration, and the highest possible concentration (0.3 g/L) resulted in the best pressure drop reduction that was reduced by 85% compared to that without the modified XG (xanthan gum) mixture(base fluid). The drag reduction was affected by the flow rate. The drag reduction increased with decreasing velocity/flowrate. The minimum pressure drop found at the maximum concentration of 0.3 g/L accompanied with minimum flowrate of 10 LPM. The effects of using modified xanthan gum mixtures on heat transfer rate in water flow (base fluid) in horizontal pipes and in heat exchanger were also examined. The effects of the xanthan gum on base fluid and solution, pressure gradient, and heat transfer rate were analyzed. The addition of the xanthan gum efficiently affected and decreased the heat transfer rate of solutions at constant environmental conditions of 26 °C. The heat transfer reduction differed with polymer concentration, and the most reduction resulted from a higher concentration (0.3 g/L) with a low flow rate (10 LPM) that was reduced by 90% compared to that without the modified xanthan gum mixture (base fluid). So, best heat transfer occurs at base fluid (water) with maximum flowrate (22 LPM) and if we consider solution then best heat transfer occurs at minimum concentration 0.15 g/L with maximum flowrate (22 LPM). So, the heat transfer rate was affected by flow rate, which increased with increasing flow rate.

From the previous study [3] section it was revealed that by using DRA (drag reducing agent) the drag reduction was around 65%. Several studies [7] showed that using different concentrations of guar gum additive in solution reduced the frictional drag by up to 60% for smooth disks. Another previous investigation [18] revealed that five different concentrations of xanthan gum mixtures were prepared to investigate the improvement of the shear rate of fluid flow. The drag reduction increased from 30%-67% with increasing the concentrations from 100-1000 ppm but in this investigation with a double pipe heat exchanger, we can reduce the frictional pressure drop up to 85 % for the maximum concentration of 0.3 g/L at 10 LPM. At the question of heat transfer rate another study, [11] that was discussed in detail in the previous section revealed that the bubble formation rate increases with increasing the rate of xanthan gum concentration in solution that shrinks the rate of heat transfer. But in that study how much or in what percentage heat transfer rate reduced was not discussed. In our investigation heat transfer rate was reduced by almost 90% & the minimum heat transfer rate was found at a higher concentration (0.3 g/L) with a low flow rate (10 LPM). Maximum heat transfer rate found at a minimum concentration (0.15 g/L) with maximum flowrate (22 LPM) due to better mixing effect and enhanced turbulence.

3.1.1 In case of frictional effect:

From the datasheet (Table 2) & graph (Fig. 6) it has been observed that the pressure drop is maximum for base fluid water than any other concentrations of the xanthan gum. This is due to the turbulence which is maximum for a Newtonian fluid(water).

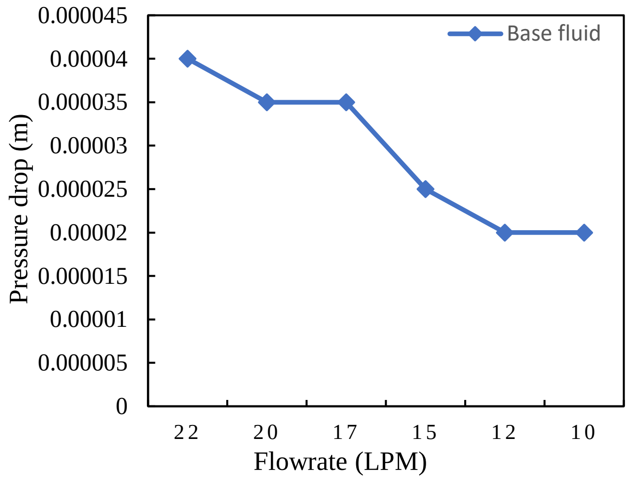

Fig. 6 Pressure drop graph for base fluid (water)

The pressure drop also increases with the increasing flow rate of the base fluid. This is due to a higher flowrate means higher friction which is observed from the base fluid graph (Fig. 6). So, the pressure drop is maximum for base fluid water for maximum possible flowarte.

From the datasheet (Table 2) & graphs (Fig. 7-Fig. 9), it has been observed that for a fixed concentration of the xanthan gum the pressure drops or head loss increases with increasing the flow rate. This is due to the increased frictional forces in the pipeline and the roughness of the pipe. With increasing concentration pressure drop decreases due to the viscoelastic effect (Fig. 11).

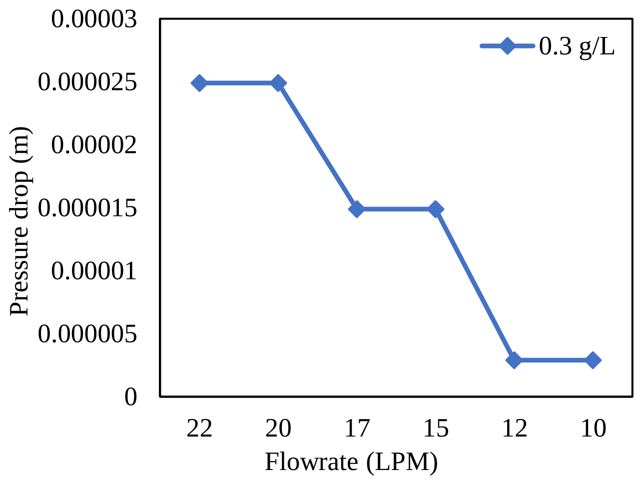

Fig. 7 Pressure drop graph for 0.3 g/L of xanthan gum

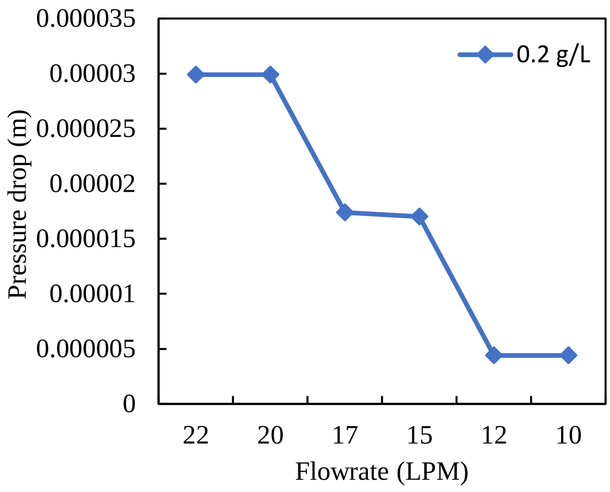

Fig. 8 Pressure drop graph for 0.2 g/L xanthan gum

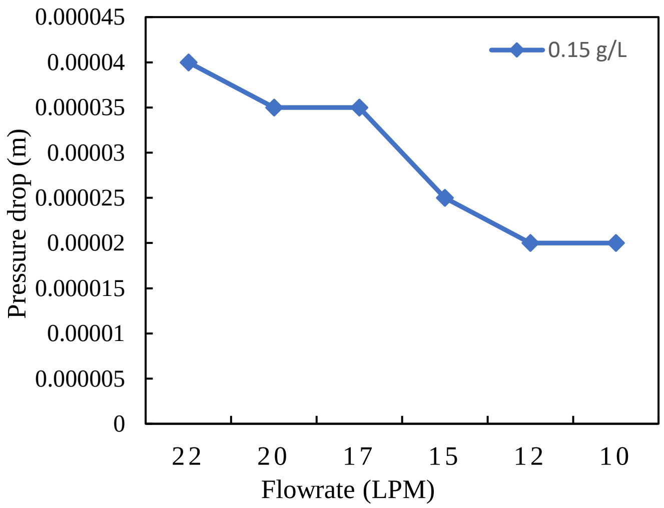

Fig. 9 Pressure drop graph for 0.15 g/L of xanthan gum

So, if we keep the flow rate constant and change the concentration then in the combined graph (Fig. 10) the head loss is found to be reduced up to 85% for 0.3 g/L concentration at 10 LPM compared to that of base fluid (water).

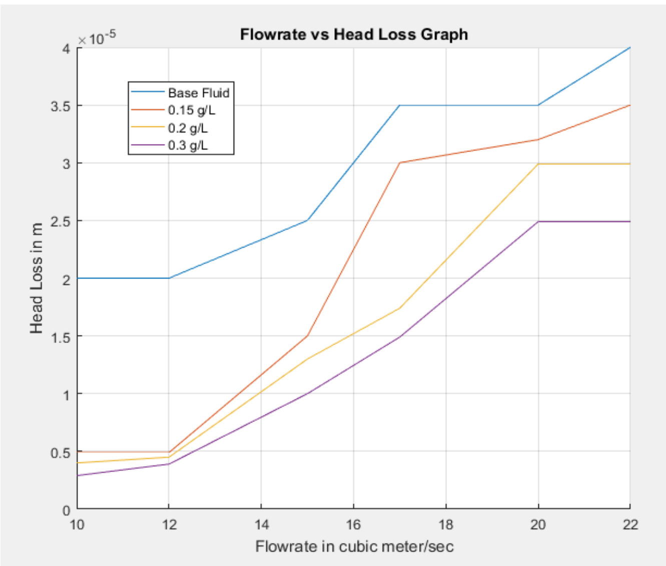

Fig. 10 Flowrate vs head loss graph of xanthan gum and base fluid

For the same flow rates, when the concentration of the gum increased the frictional pressure drop decreased. This was due to the flow becoming gradually laminar. The eddy formations became lower which reduced frictional pressure drops. We know eddy formation induces pressure drop by the wake zone. By increasing concentrations, the friction of the solution with the wall shear reduced as the fluid becomes laminar. So the best concentration is 0.3 g/L of the gum to achieve the best effect of viscoelasticity with a minimum possible flow rate (10 LPM) as minimum flowrate imparts minimum wall shear. Wall shear has a huge effect on drag. The higher the wall shear, the higher the drag. So, adding an additive to the base fluid reduces the wall shear and reduce eddy formation which will further decrease the energy dissipation rate. The lesser the energy consumption the more energy will be saved. This phenomenon has been shown for both xanthan gum concentrations and base fluid (Fig. 10) and a bar chart (Fig. 12) by combining the effect of flow rate and concentrations for xanthan gum solution. The drag reducing agent used in this study was a xanthan gum mixture. Three xanthan gum concentrations were evaluated for their drag-reduction effect. The experimental results of the pressure drop values along the total length of the pipe with the XG (xanthan gum) mixtures are shown in for different concentrations and flowrates of xanthan gum. The figure clearly shows that with an increase in the concentration of the xanthan gum from 0.15 g/L to 0.3 g/L along with decreasing flowrate from 22 LPM to 10 LPM, the pressure drop decreased up to 90% compared to the base fluid (water).

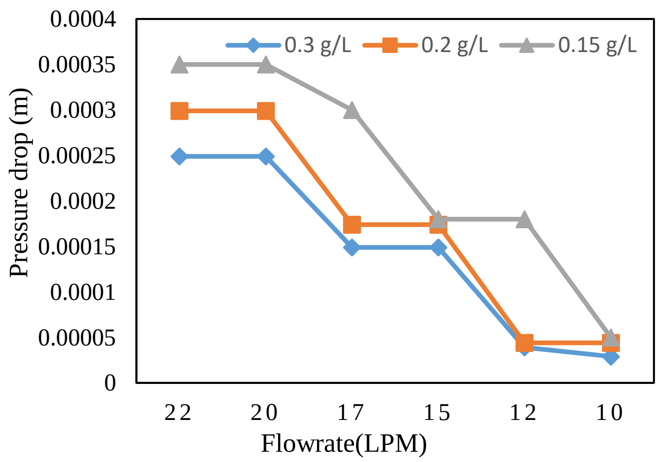

Fig. 11 Flowrate vs pressure drop graph of xanthan gum solution

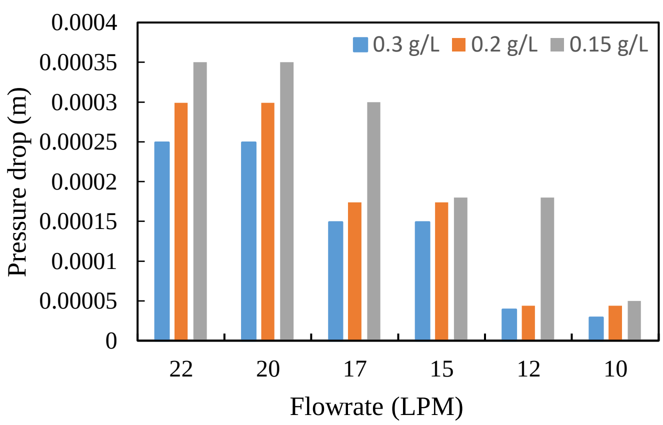

Fig. 12 Bar chart of frictional pressure drop against flowrate and concentration of xanthan gum

3.1.2 In case of heat transfer rate effect

From the datasheet (Table 1) & graph (Fig. 13) when flowrate increases heat transfer rate increases for base fluid for better mixing. From Fig. 14-Fig. 16 it has been observed that for a fixed concentration when the flow rate increases the heat transfer rate also increases due to pseudoplasticity (viscosity decreases when flowrate or shear rate increases) and better mixing effect. But when concentration increases, the heat transfer rate decreases due to viscoelasticity. (Fig. 14-Fig. 16).

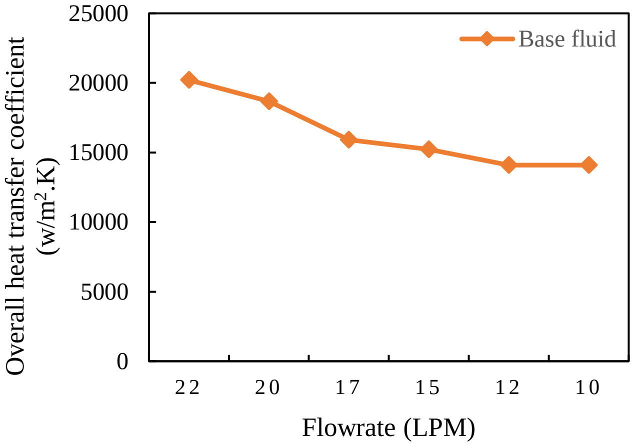

Fig. 13 Heat transfer rate for base fluid (water)

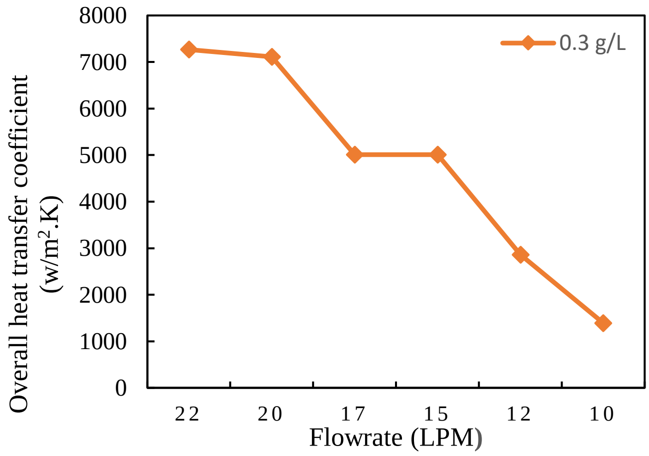

Fig. 14 Heat transfer rate for concentration 0.3 g/L xanthan gum

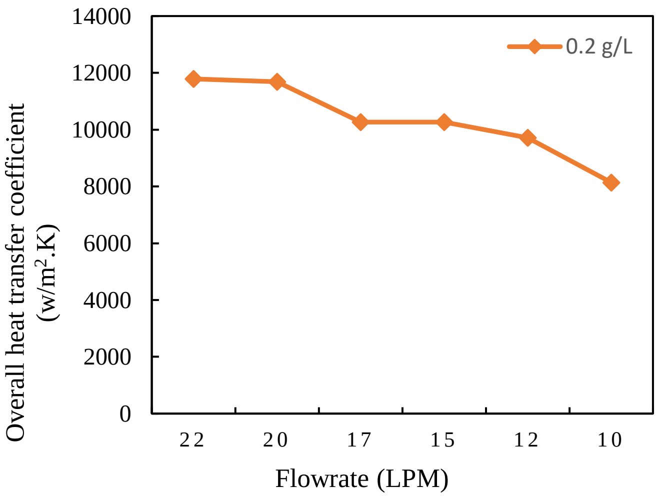

Fig. 15 Heat transfer rate for concentration 0.2 g/L xanthan gum

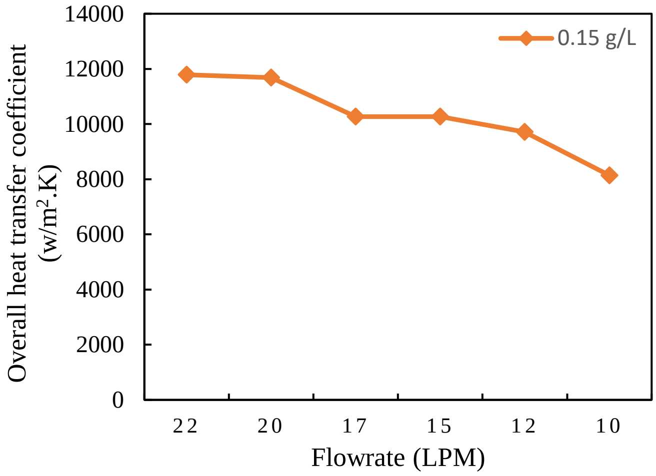

Fig. 16 Heat transfer rate for concentration 0.15 g/L xanthan gum

Higher flowrate increases heat transfer rate because a higher flowrate leads to increased turbulence and better mixing of the fluid in pipelines and heat exchanger due to lesser viscosity, which improves the heat transfer by prompt mixing which enhances the contact between the fluid and the effective heat transfer surface area. Lesser viscosity occurs due to the effect of pseudoplasticity during flow that was mentioned earlier. The higher flow rate creates more eddy in the fluid which leads to enhanced mixing. The higher the mixing and pseudoplasticity (decrease of viscosity when shear rate increases), the more will be the heat transfer rate.
From the combined graph (Fig. 17) it has been observed that when the concentration of the solution increases the heat transfer rate decreases. This is the complete opposite scenario regarding the pressure drop issue. In this situation when concentration increases the flow becomes laminar from turbulent so eddy formation reduces. As a result, the mixing and contact of fluid with heat transfer surface area of pipe decreases.

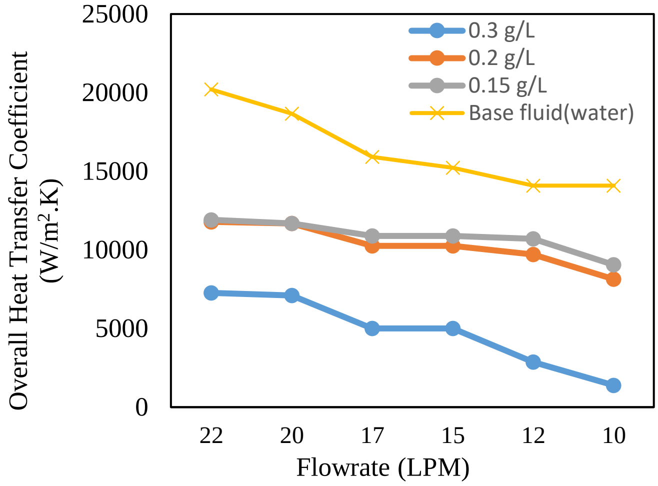

Fig. 17 Flowrate vs heat transfer rate graph of xanthan gum solution and base fluid (water)

From (Fig. 17) it has been observed that for base fluid water the heat transfer rate is maximum for the highest flow rate (22 LPM) for better mixing effect. In case of xanthan gum solution (Fig. 18) the maximum heat transfer rate is found at a lowest possible concentration (0.15 g/L) for increased turbulence and at 22 LPM for a better mixing effect. The eddy formation and turbulence is maximum due to pure base fluid water and it is assisted by the maximum flow rate that contributes to the turbulence and eddy formation. So, the maximum heat transfer occurs at pure base fluid. Then if we consider DRAs (drag reducing agent) then maximum heat transfer can be obtained by 0.15 g/L of the gum with maximum flowrate (22 LPM) but it is lower compared to the base fluid.

It is clear from the bar chart (Fig. 18) that the heat transfer rate tends to reduce when concentration increases due to the eddy-dampening effect. This is due to a reduction in turbulence. The maximum heat transfer rate is marked at 0.15 g/L of xanthan gum for a 22 LPM flow rate. But to obtain minimum friction due to DRA (drag reducing agent) xanthan gum the required concentration is 0.3 g/L at 10 LPM which reduces the heat transfer rate up to 90% than base fluid (water). So select 0.3 g/L of xanthan gum with 10 LPM flowrate if head loss/friction loss reduction is the prime concern and select 0.15 g/L of xanthan gum at 22 LPM flowrate if heat transfer rate is the prime concern. We can also choose base fluid water to obtain maximum heat transfer rate but it will lead to severe head loss as depicted above. It should be noted that above 0.3 g/L the flow tends to seize so it is the maximum possible concentration for this setup or threshold point.

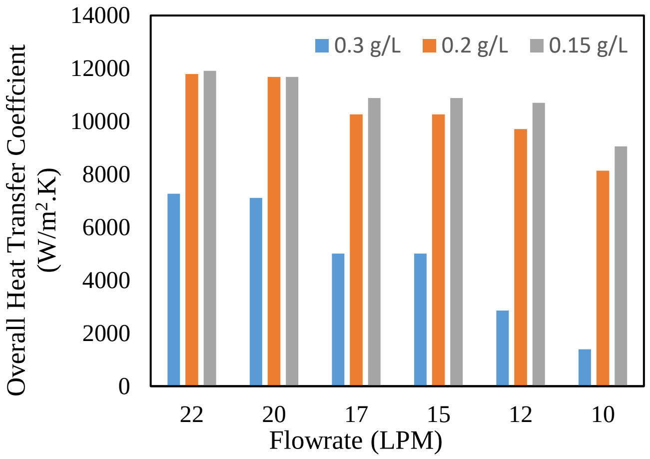

Fig. 18 Bar chart of convective heat transfer coefficient against flowrate & concentration of xanthan gum

3.2 Discussion

Polymer addition caused a decrease in the pressure drop at all concentrations. The mechanism can be explained according to elastic theory. In other words, the high kinetic energy of the turbulent flow near the wall will be absorbed by polymer molecules and converted into elastic energy, and this elastic energy near the wall will be lifted by the wall vortices and dissipated in the buffer region. Hence, the polymer actively affects the energy system. Thus, to transfer the elastic energy from the near-wall, the polymer should be long enough to transfer the elastic energy into the buffer region. The mechanism of drag reduction can be explained according to, which the polymer molecules are stretched by the high flow. Under this particular condition, the turbulent structures interact with the molecules, causing a decrease in the pressure drop.

4 Conclusion

The effects of utilizing xanthan gum for drag reduction in water flow in pipes and heat exchanger were examined. The effects of the rigid xanthan gum on head loss/pressure drop and heat transfer rate was analyzed for different concentrations and flowrate. The following conclusions can be drawn from this study that from the flow rate range (22 LPM -10 LPM), head loss decreases as the concentration increases and flowrate decreases and the best head loss reduction found at 0.3 g/L at 10 LPM. So, from the view point of head loss reduction and cost saving the best concentration and flow rate can be selected as 0.3 g/L of xanthan gum for 10 LPM. Heat transfer rate decreases when concentration increases with decrease in flowrate. So from the viewpoint of heat transfer rate in the presence of xanthan gum, the best conditions are 0.15 g/L (minimum concentration) of xanthan gum at 22 LPM (maximum flowrate). At this condition maximum heat transfer occurs. But the base fluid will be best for maximum heat transfer at 22 LPM but it will create severe head loss/pressure drop.

Nomenclature

Symbols	Meaning	Unit
P	Density	Kg/m^3
ρ_x	Density of xanthan gum	Kg/m^3
C_p	Specific heat at constant pressure	J/kg.K
C_{pc}	Specific heat of cold fluid at constant pressure	J/kg.K
$T_{h,in}$	Hot fluid in temperature at heat exchanger	ºC
$T_{h,out}$	Hot fluid out the temperature at heat exchanger	ºC
$T_{c,in}$	Cold fluid in temperature at heat exchanger	ºC
$T_{c,out}$	Hot fluid out temperature at heat exchanger	ºC
X_x	Concentration of solution	% w/w
A	Surface Area	m^2
Tb	Bulk Temperature	ºC
T_i	Inlet temperature of cold fluid	ºC
T_e	Exit temperature of cold fluid	ºC
G	Acceleration due to gravity	m/s^2
M	Dynamic viscosity	Ns/m^2
$h_L/\Delta P_L$	Head Loss/Pressure loss	m
P_{in}	Pressure at inlet of pipeline	N/m^2
P_{out}	Pressure at outlet of pipeline	N/m^2
U	Overall heat transfer coefficient	$W/m^2.K$
Q	Flowrate	LPM(l/min)
LMTD	Log mean temperature difference	ºC
DRA	Drag reducing agent	
% w/w	% weight/weight	
XG	Xanthan gum	
LPM	Liter per min	

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