

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



A thesis is submitted in partial fulfillment of the requirements for the degree of
Master of Science
in
Mechanical Engineering

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October, 2024

The dissertation/thesis/project titled “Experiemntal Study on the Effect of Skin Friction Drag and Convective Heat Transfer for Pseudoplastic & Viscoelastic Fluid Flow” submitted by Meraz Ahammed Roll no 21MME007P, Session: 20211-2022, has been accepted as satisfactory in partial fulfillment of the requirement for the degree of Master of Science in Mechanical Engineering.

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ABSTRACT

Drag reducing agents (DRAs) has a huge impact and a major concern in the engineering field and industrial applications. It makes the fluid flow turbulent to laminar, dampens eddy and reduces head loss by up to a certain limit and saves pumping energy costs. Viscosity is the property which dampens eddy due to viscous effect increases the fluidity up to a certain limit. Pseudoplasticity is the shear thinning effect that decreases viscosity when flowrate increases. So for viscoelastic effect we can increase the concentration up to a certain limit to reduce head loss but during flow due to pseudoplastic effect the viscosity will start decreasing which is negative effect. So these combined effect is studied to reduce skin friction drag in pipeline and save energy cost which will be convenient for food industry, chemical and medicine industry. In this investigation, 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 viscosity the pressure drop reduced significantly. Conversely the heat transfer rate also reduced due to poor mixing effect. A higher performance and less vibration of pump was also observed. It was concluded that frictional pressure drop was reduced up to 85% and heat transfer rate reduced up to 90% by increasing the concentration of the DRA(drag reducing agent) up to 0.3 g/L at 10 LPM than the pure water or base fluid as working substance on double pipe heat exchanger. As the heat transfer rate reduced up to 90% with reducing pressure drop so another aim of the study was to establish a concentration and flowrate for which heat transfer rate is maximum and it was found at concentration of 0.15 g/L of DRAs(drag reducing agents) at 22 LPM(maximum flowrate at this setup).

Keywords: *Friction,viscoelasticity,shear thinning effect,concentration,flowrate.*

সারসংক্ষেপ

এই সমীক্ষায় সরল পাইপের মধ্য দিয়ে তরল প্রবাহের গড় অবস্থানে ল্যামিনার প্রকৃতির অধ্যয়ন করা হয় এবং প্রবাহের সময় বিদ্যুৎ খরচ এবং তাপ স্থানান্তর হারের মধ্যে অস্টিমাইজেশন অধ্যয়ন করা হয়। মৌলিক প্রবাহটি একটি ধ্রুব চাপ গ্রেডিয়েন্ট দ্বারা উৎপন্ন হয়। ড্র্যাগ রিডিউসিং এজেন্ট প্রকৌশল ক্ষেত্রে এবং শিল্প ক্ষেত্রে বিশাল প্রভাব ফেলে এবং একটি প্রধান আলোচনার বিষয়। এটি বিক্ষিপ্ত (টারবুলেন্ট) তরল প্রবাহকে শান্ত (ল্যামিনার) করে তোলে, এডি লস কমায় এবং একটি নির্দিষ্ট সীমা পর্যন্ত হেড লস কমায় এবং পাম্পিং শক্তির খরচ বাঁচায়। ভিসকোইলাস্টিসিটি এমন একটি বৈশিষ্ট্য যার সামান্য প্রভাবের কারণে এডি লস কমে, এবং এটি একটি নির্দিষ্ট সীমা পর্যন্ত তরলতা বাড়ে। পক্ষান্তরে, সিউডোপ্লাস্টিসিটি হল শিয়ার পাতলা করার প্রভাব/ধর্ম যা প্রবাহের হার বৃদ্ধি পেলে সান্দ্রতা হ্রাস করে। তাই ভিসকোইলাস্টিক প্রভাবের জন্য আমরা হেড লস কমাতে একটি নির্দিষ্ট সীমা পর্যন্ত তরলের ঘনত্ব বাড়াতে পারি কিন্তু সিউডোপ্লাস্টিক প্রভাবের কারণে প্রবাহের সময় সান্দ্রতা হ্রাস পেতে শুরু করবে যা প্রবাহে নেতিবাচক প্রভাব ফেলে। তাই এই সম্মিলিত প্রভাবগুলি পাইপলাইনের সারফেসের সঙ্গে তরল প্রবাহের ঘর্ষণ কমাতে এবং পাম্পের শক্তি খরচ বাঁচাতে অধ্যয়ন করা হয় যা খাদ্য শিল্প, রাসায়নিক এবং ওষুধ শিল্পের জন্য সুবিধাজনক হবে এবং প্রবাহের খরচ কমবে। এই তদন্তে, প্রেসার ড্রপ এবং তাপ স্থানান্তর হার পর্যবেক্ষণ করতে অশান্ত প্রবাহে ০.৩ গ্রাম/লিটার, ০.২ গ্রাম/লিটার এবং ০.১৫ গ্রাম/লিটার জ্যান্থান গামের জন্য তদন্ত করা হয়। গবেষণায় দেখা গেছে যে, ঘনত্ব ও সান্দ্রতা সামান্য বাড়ানোর পরে চাপ হ্রাস উল্লেখযোগ্যভাবে হ্রাস পেয়েছে, কিন্তু ফলশ্রুতিতে তাপ স্থানান্তর হার দুর্বল যা মিশ্রণের প্রভাবের কারণে হ্রাস পেয়েছে। পাম্প কম কম্পন পরিলক্ষিত হয়েছে। এটি উপসংহারে পৌঁছেছিল যে, বিশুদ্ধ পানি বা বেস ফ্লুইডের তুলনায় ১০ লিটার/মিনিট এ ০.৩ গ্রাম/লিটার পর্যন্ত জ্যান্থান গামের (ড্র্যাগ রিডিউসিং এজেন্ট) ঘনত্ব বাড়িয়ে ঘর্ষণজনিত চাপ ৮৫% পর্যন্ত হ্রাস করা গেছে এবং তাপ স্থানান্তর হার ৯০% পর্যন্ত হ্রাস পেয়েছে। ডাবল পাইপ হিট এক্সচেঞ্জারে বেস ফ্লুইডের সাথে ভিসকোইলাস্টিক পদার্থ হিসেবে জ্যান্থান গাম ব্যবহার করা হয়। যেহেতু তাপ স্থানান্তর হার চাপ কমানোর সাথে ৯০% পর্যন্ত হ্রাস পেয়েছে তাই এই অধ্যয়নের আরেকটি লক্ষ্য ছিল একটি নির্দিষ্ট ঘনত্ব এবং প্রবাহের হার প্রতিষ্ঠা করা যার জন্য তাপ স্থানান্তর হার সর্বাধিক এবং এটি ০.১৫ গ্রাম/লিটার জ্যান্থান গামের (ড্র্যাগ রিডিউসিং এজেন্ট) ঘনত্বে পাওয়া গেছে এবং এটি প্রবাহের ২২ লিটার/মিনিটে (যা এই সেটআপে সর্বাধিক প্রবাহ হার)।

ACKNOWLEDGEMENT

First of all, I want to be thankful to the almighty Allah who gave me strength to complete this task. Then I want to give my special gratitude to my honorable supervisor Dr. Md. Mahbubul Alam who gave me his valuable time, guidance, advise and mental support for the completion of this task. All the time I found my advisor beside me with full of his advice and proper guidance. Due to his proper guidance and direction I was able to find out the actual goal and usefulness of my experiment. Then I want to give special thanks to all the teacher of my department who gave all the information I need at any time. I want to give thanks to my family members, classmates as they provided mental strength and information which was very much helpful for me to successfully complete my work.

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NOMENCLATURE

Symbols	Meaning	Unit
ρ	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	$^{\circ}\text{C}$
$T_{h,out}$	Hot fluid out temperature at heat exchanger	$^{\circ}\text{C}$
$T_{c,in}$	Cold fluid in temperature at heat exchanger	$^{\circ}\text{C}$
$T_{c,out}$	Hot fluid out temperature at heat exchanger	$^{\circ}\text{C}$
X_x	Concentration of solution	% w/w
A	Surface Area	m^2
T_b	Bulk Temperature	$^{\circ}\text{C}$
T_i	Inlet temperature of cold fluid	$^{\circ}\text{C}$
T_e	exit temperature of cold fluid	$^{\circ}\text{C}$
g	Acceleration due to gravity	m/s^2
μ	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	$\text{W/m}^2.\text{K}$
Q	Flowrate	LPM(liter/m
LMTD	Log mean temperature difference	$^{\circ}\text{C}$
DRA	Drag reducing agent	-----
% w/w	% weight/weight	
XG	Xanthan gum	-----
LPM	Liter per min	

CHAPTER 1

INTRODUCTION

1.1 Introduction

Now a days food fluid application is very common for different commercial sectors. If a small amount of xanthan gum as DRA(drag reducing agent) is added to water then the Newtonian fluid becomes non-Newtonian pseudoplastic fluid. If friction is reduced in pipeline then power to flow the fluid can be saved. 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 as making the fluid slightly more viscous and makes the flow laminar. But the friction reduction is done by eddy dampening effect so the friction reduction in pipeline may decrease the heat transfer rate in heat exchanger. So optimization is required to use drag reducing agents(DRAs) and a denotation is required for which concentration 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. Again due to pseudoplastic effect the viscosity may decrease in pipeline that may hampers the activity of the drag reducing agents(DRAs) that need to keep in consideration. Several studies [1] stated that different types of material can be used as drag reducer. This work is about how fluidity can be increased by addition of xanthan gum. This fluid can be called food fluid 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 temperature even in acidic environment. In this experiment, the amount of friction or drag was studied and investigated whether it was lower than normal Newtonian fluid or not. For this, the pressure was measured at inlet and outlet of test section and was calculated at the extent of drop of pressure. Here, investigation was carried out to find out whether the heat transfer would decrease or increase compared to the normal water which was a Newtonian fluid. Then for different concentration of xanthan gum an optimum concentration was tried to find out. An optimum concentration for which the frictional loss was lower in pipeline and heat transfer rate was also satisfactory in heat exchanger. If friction or drag can be kept lower then power consumption to pump fluid can be saved. Heat transfer analysis is very important in all the sectors. So, for any material the extent of heat transfer and friction analysis need to be done to apply it in any field. Pseudoplastic fluid is a kind of fluid that gets thinned when shear is applied. Such a fluid is called shear thinning fluid. Shear rate of

shear thinning fluid is used widely in food, beverages and chemical industry. Slick water creates drag and turbulence more in pipelines [2]. So a small amount of high molecular weight drag reducer reduces the drag and acts as drag reducer as well as reduces eddy by reducing turbulence and saves pumping power. So gelled fluid is more effective to transport and save pumping energy. When heat is associated with this type of fluid it is important to know the heat transfer and frictional characteristics of such fluid. If drag or friction can be lowered by mixing the gum then power to flow the fluid can also be saved. Here how much heat energy could be transferred by the pseudoplastic xanthan gum solution and the friction occurs by this additive for different concentration was experimented and an optimum concentration was found out. There are various type of additive like guar gum but the reason for choosing this type of additive is that the xanthan gum is now widely used in many aspects of industry where complex engineering analysis and multidimensional aspects are related so it is necessary to know the heat transfer ability and flow characteristics of xanthan gum solution. The mechanism of drag reduction can be explained according to the pseudoplastic effect of the flow and shear thinning effect. 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 wall. This wall shear stress has significant effect on drag. The more the eddy formation, the more the wall shear stress and energy dissipation rate. 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 way of dampening eddy.

1.2 Importance of The Study

Heat transfer analysis is very important in all the sectors. So, for any material the extent of heat transfer and friction analysis is important to apply in any field. Pseudoplastic fluid is a kind of fluid that gets thinned when shear is applied. Such a fluid is called shear thinning fluid. The shear thinning fluid is used widely in food, beverage and chemical industry. Slick water creates drag and turbulence more in pipeline. So, a small amount of high molecular weight drag reducer reduces the drag as well as reduces the eddy by reducing turbulence and saves pumping power. So gelled fluid is more effective to transport and saves pumping energy. When heat is associated with this type of fluid it is important to know the heat transfer and frictional characteristics of such fluid. If drag or friction can be lowered by mixing the gum then power to flow the fluid can also be saved. Here the amount of heat energy that could be transferred by the pseudoplastic xanthan gum solution and the friction occurs by this additive for different concentration was experimented and an optimum concentration was found out. There are various types of additive like but the main reason for

for choosing this type of additive is that the xanthan gum is now widely used in many aspects of industry where complex engineering analysis and multidimensional aspects are related. So, it is necessary to know the heat transfer ability and flow characteristics of xanthan gum solution. This paper summarizes the results of the study to better define the frictional drag reduction, which can be obtained by flowing fluid to a double pipe heat exchanger. The mechanism of drag reduction can be explained according to the polymer molecules by the high flow. Under this particular condition, the turbulent structures interact with the molecules, causing a decrease in the pressure drop and an increase in the drag reduction. Wall shear has a huge effect in drag. The higher the wall shear, the higher the drag. Adding additives to the base fluid reduced the wall shear and reduced the eddy formation which further decreased the energy dissipation rate. The lesser the energy to flow the fluid, the more energy can be saved. Further, increase in pressure drop saving increased with respect to increased concentration with increasing total mixture velocity for all concentrations of the polymer, which means that the activity of these additives increases with the increasing velocity. Drag reduction in turbulent flow may be significantly reduced by adding tiny quantities of fiber, polymer, and surfactant particles to the liquid. Different drag reduction agents have proven to be effective in enhancing the flowability of the liquid when added. This study investigated the potential of decreasing the drag, in turbulent flow, and pressure drop in horizontal pipe flow by using a mixture of modified xanthan gums (XGs). Xanthan gum is an environmental friendly natural polymer complex. They can be extracted from xanthan gum plants and utilized to formulate different concentrations. The flowability of the xanthan gum was experimentally investigated [13] in a 1-m-long pipe by using addition concentrations of 300 to 950 ppm, an inner diameter of 0.254 inches, and four different flow rates. The results revealed that the pressure drop was reduced considerably with an increase in the concentration of the additives. The mixture (xanthan gums plus water) resulted a favorable reduction in the pressure, which reached 65% at a concentration of 950 ppm. The results of the computational fluid dynamic simulation using the COMSOL simulator showed a change in the fluid velocity profiles, which became more parabolic. This occurred because of an increase in the mean fluid velocity due to the addition of the drag-reducing polymers. Each of the used polymers is water soluble. The most significant property of the solution of xanthan gum is its ability to enhance viscosity slightly to dampen the eddy formation. However, when shear rates drop, the viscosity decreases, which makes the solution thin or behave like a pseudoplastic. As soon as the shear is removed, the solution returns to its former properties and dragging decreases that is elasticity. The greater the weight ratio of the XG components in a liquid, the thicker it becomes.

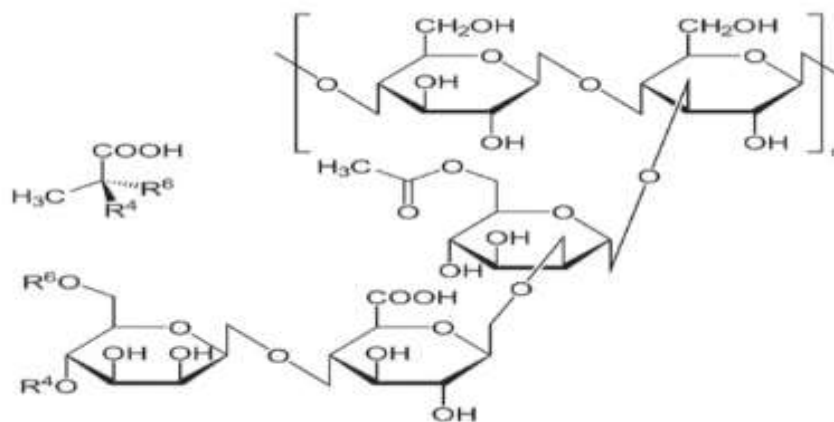


Fig 1.1 : Molecular structure of xanthan gum [3]

The experiment included a flow loop test like (Fig 1.2) and the creation of a modified XG mixture for aqueous drag reduction. To reduce drag XG solutions of a certain concentration were made. The desired concentration of the modified XG mixture was added to water and stirred at a high speed of for 15 min to produce stock solutions of the modified XG mixture with concentrations of 0.3 g/L, 0.2 g/L, 0.15 g/L. After that, additional water was added and the mixture was agitated. After that it was left for 1h for the complete equalization of the stock solution and the creation of aqueous xanthan gum. To begin the flow loop test, the water pump was turned on. The xanthan gum mixture passed through the flow meter and pumped before entering the test section of the pipeline through the intake. Afterthat, the test portions began receiving water. The experimental parameters were recorded, and photographs were taken after the flow stabilized and the pressure gradient fluctuated by 5%. The Fig 1.1 depicts the molecular structure of xanthan gum. From this figure, it is clear that the xanthan gum is a complex long chain polymer. This is an important property of the drag reducing agent.

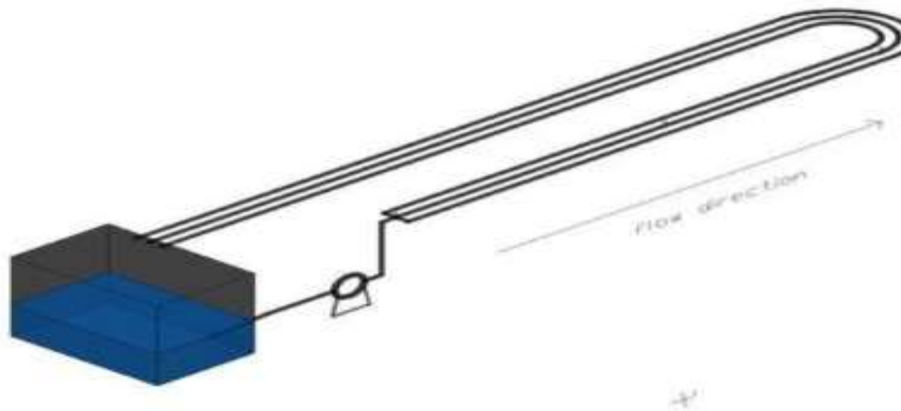


Fig 1. 2: Flow Loop [3]

Drag reduction in turbulent flow significantly reduced by adding tiny quantities of fiber, polymer, and surfactant particles to the liquid in flow loop test which also may be called circulating close loop system (Fig 1.2). Different drag-reduction agents have proven to be effective in enhancing the flowability of the liquid when added. This study investigated [3] the potential of decreasing the drag, turbulent flow, and pressure drop in horizontal pipe flow by using a mixture of modified xanthan gums(XG). Xanthan gum is an environmentally friendly natural polymer complex. They can be extracted from xanthan gum plants and utilized to formulate different concentrations of complexes. The flowability of the xanthan gum was experimentally investigated [13] in a 1-m-long pipe by using additional concentrations of 300 to 950 ppm. Drag reduction is the reduction of pressure drop and skin friction in turbulent flows. This is achievable by adding drag reducing agents (DRA) such as polymers, surfactant solutions and fiber particles. This investigation focuses specifically on the potential of the xanthan gum polymer as a DRA. The efficiency of xanthan gum injection is limited to the maximum injection rate executable. Some fields requires a higher amount of injection at one time to attain the desired reduction in pressure drop. Using DRA to improve the water transport in these could be an economic and efficient option for the oil and gas industry. The effectiveness of xanthan gum as DRA was investigated using a water flow system made up of MS pipes and centrifugal pumps. Among variables the concentrations and flowrates were selected to measure xanthan gum's performance as a drag reducing agent. From the experimental result [13], it was found that drag reduction increases as xanthan gum concentration increased up to a certain limit. The experimental results [13] prove that xanthan gum had great potential as a DRA. This research led to a widespread use of this polymer in improving water injection and transportation. Drag reducing agents (DRA) are also known as flow improvers. As example

there are various types of drag reducing agents such polymers, surfactant solutions and fiber particles. Among them, polymers are considered the most effective. DRA is one of the solutions that could be used to reduce drag in between the flowing fluid and the walls of the pipeline. This increases the operating pressure for fluid transfer and also lowers pumping costs as no extra energy would be required to achieve the pressure used. Small amounts of the polymer (parts per million, ppm) are injected into the pipeline to reduce the development of a large scale turbulent flow and reduces the frictional pressure loss at a given flow rate

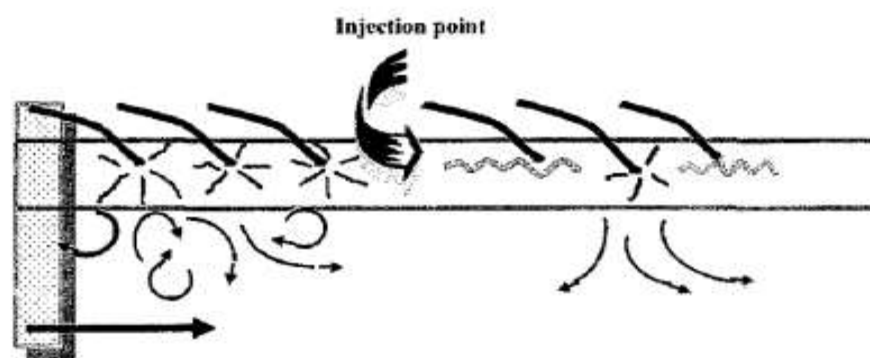


Fig 1.3: Illustration of how DRA works inside pipeline [4]

Transporting crude oil via pipelines over long distances (Fig 1.4) results in a larger pressure drop, hence a solution to this problem is to reduce drag by adding an additive. Crude oil transport by pipeline shown in (Fig 1.4) is mainly done in a turbulent flow regime. In addition, high frictional losses due to high viscosity result in the waste of a large portion of the energy used to transport crude oil (Fig 1.4). The radial transmission of flow momentum by fluid eddies is what contributes to the high drag in turbulent flow. Three types of additives can reduce drag: polymers, fibers, and surfactants. The primary function of these additives is to limit the formation of turbulent eddies by absorbing the energy produced by the breakup of lamellar layers which is shown in the Fig 1.3, thus allowing higher flow rates at constant pumping pressure. Additionally, DRAs help in lowering friction during transport close to pipeline walls and inside the turbulent fluid core. Drag reduction is therefore critical to energy conservation and crude oil transfer efficiency. Polymers are considered the most effective and widely used DRA in industrial applications. In turbulent flow, a small amount (ppm) of a high molecular weight polymer present in solution could produce a high degree of drag reduction [10]. This was also supported by experiments [10], who reported that a dilute solution of high molecular weight polymer in turbulent flow requires a smaller flow pressure gradient than a pure solvent to achieve the same flow rate. They also suggested that the reduction in drag was caused by the enhanced viscous effect

viscosity of polymer solutions by increasing flowrate and also proposed that stretching of polymer molecules led to the storage of elastic energy which was the elastic behavior of viscoelastic fluid (Fig 1.4).

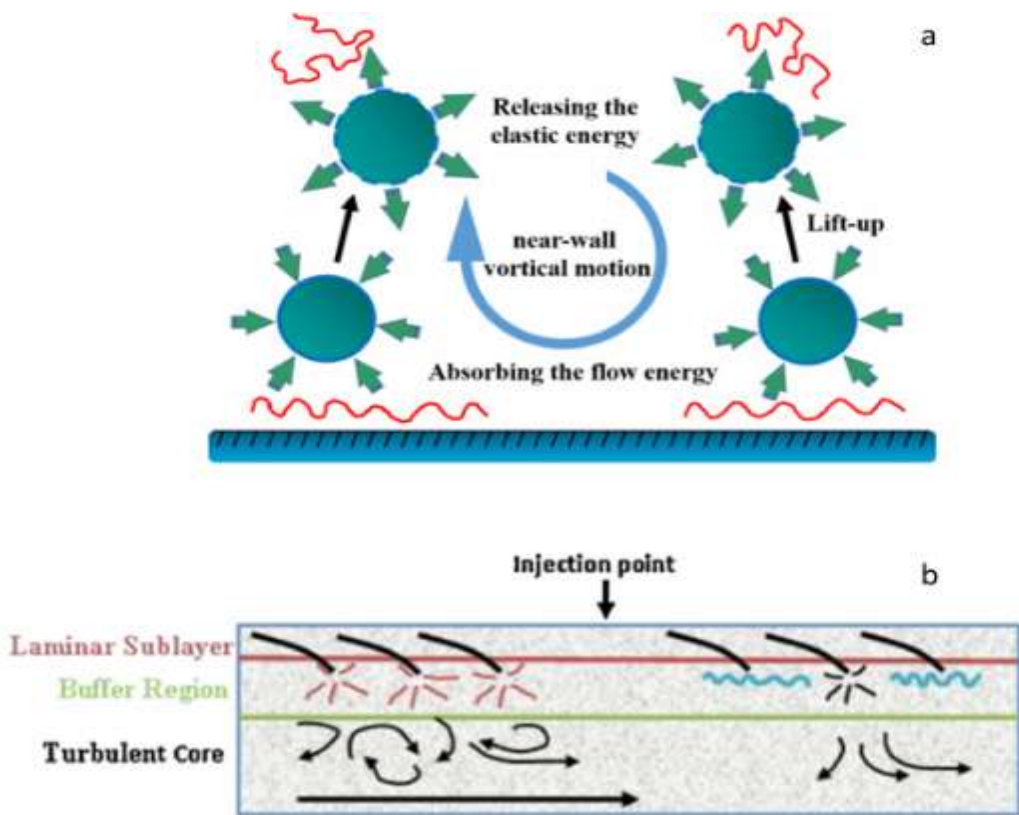


Fig 1.4 : Elastic behavior of DRAs [5]

It should be noted that DRA does not coat the internal pipeline wall but instead interacts with the pipeline flow. When DRA dissolves in water, the polymer molecules uncoil and outspreads (Fig 1.4). The long chain molecules of the polymer dampens the turbulent bursts near the pipe wall. This dampening effect reduces frictional pressure loss resulting in a decrease in energy consumption. One of the drag reducing agent recommended is xanthan gum. Besides xanthan gum, surfactants such as sodium stearate are also used as DRA. Surfactants require very little dosage (5 - 25 ppm) compared to xanthan gum (300 - 800 ppm). This makes it an excellent drag reducer to be applied for pipeline transport for crude oil. So, this can be used for further investigation. Surfactants can only be used for once-through applications (such as pipeline transport) and not for circulating fluid systems, such as distinct heating and cooling because the surfactant polymers degrades when they flow through pumps and lose their efficacy. So, this is a drawback and can't be used for circulating system. Drag reducing agent is a kind of chemical that can reduce the resistance of fluid during transportation. This chemical agent is used to reduce the resistance of fluid flow and is called drag-reducing agent (DRA). Drag reducers are widely used in crude oil and refined oil pipeline transportation (Fig 1.5). It is an important way to improve the circulation capacity of the pipeline and reduce energy consumption in specific locations. So,

if friction can be reduced inside pipelines then circulation capacity of pipelines can be greatly increased without much pressure drop. The frictional resistance of the fluid, limits the flow of fluid in the pipeline. This causes a reduction in pipeline throughput and an increase in energy consumption. Here drag reducing agent can play a vital role. The polymer drag reduction method is also used to inject a small amount of polymer into the fluid. Make it reduce the resistance of flow under turbulent flow [6].



Fig 1.5 : Liquid flowing through pipeline by the applications of DRA [6]

Drag reduction is a special phenomenon to convert turbulent flow to laminar. Drag reduction effect is the performance of drag reducing agent (DRA) to affect on the turbulent field. It is a purely physical effect. The drag reducer molecules do not react with the oil molecules. It also does not affect the chemical properties of the oil. The DRA is only closely related to its flow characteristics. In turbulent flow, the velocity of fluid particles varies randomly from large and small vortices. Large-scale vortices absorb energy from fluids, deform and break, and transform into small-scale vortices. After the drag reducing agent (DRA) is added to the pipeline, the DRA gets dispersed in the fluid as a continuous phase. Relying on its own unique viscoelasticity, the long molecular chain flows downstream to flow naturally. Its microelements directly affect the movement of fluid microelements. The radial force from the fluid micro-elements acts on the drag reducer micro-elements, causing them to twist and rotate and consequently dampens the eddy and restricts the further eddy formation.

1.3 Background and Present State of The Problem:

Now a days food fluid application is very important for different commercial sector. Different types of frictional and drag analysis is done before. The aim was to analyze the heat transfer and drag reduction characteristics for the solution of xanthan gum which is a viscoelastic fluid in nature. If drag is reduced then power to flow the fluid can be saved. So,

This fluid can be called food fluid 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 temperature even in acidic environment. In this experiment, the amount of friction or drag was studied and shown at what flowrate and concentration the frictional drag was minimum but heat transfer rate was maximum. For this, the pressure at inlet and outlet of test section was measured and was calculated the extent of drop of pressure. Here base fluid was studied and 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 flowrate of xanthan gum tried to find out an optimum concentration for which the frictional loss was lower and heat transfer rate was also satisfactory. If friction or drag can be kept lower then power consumption to pump fluid can be saved. In this experiment, a parallel flow double pipe heat exchanger was used. Four thermometers were used in the analysis. A solution of water and xanthan gum was used in the test section and allowed to flow through the tube side of the heat exchanger as cold fluid. Then necessary equations were used to determine the heat transfer characteristics of the flow. The findings were compared with normal water and a clear conception was developed where and which application pseudoplastic solution can be used. Xanthan gum solution behaves like viscoelastic fluid that means viscosity increases when concentration increases. Under high shear action the viscosity dropped sharply and it depended on flow velocity/flowrate. The aim was to determine the flowrate and concentration at which the shear action was minimum and the eddy formulation for turbulence was also minimum. At the same time due to low turbulence and eddy formation factor the heat transfer also decreased so heat transfer rate optimization was also a concern here. Viscoelastic fluids are a type of non-Newtonian fluid formed by a viscous component and an elastic one. For short, viscoelastic fluids are the blend of a solvent and some polymer. Examples of these are paints, DNA suspensions, some biological fluids and others from the chemical industry. The viscoelastic behavior decreased the absorption of energy at the time of flowing. That has an effect of decreased flow energy to transfer fluid. For that, a small amount of gum types agent was added to flowing fluid in industry. If the amount is excess then it starts showing viscoelasticity more dominantly which significantly increased the viscosity than required and the viscous effect started dominating over the rate of eddy dampening effect. So, power consumption increased. So, these DRAs can be used at a limited rate. But this type of fluid has a magical behavior of shear thinning means these viscosity decreases if shear strain or flowrate increases. So, this pseudoplasticity or shear thinning behavior has a positive impact that contributed to the compromization of increased viscous effect at higher concentrations. That is the combination of the viscoelastic and pseudoplastic behavior of the

such fluid in reducing drag. So, these properties were used to the fluid and an optimization was made. The properties spring back when stress was removed. However, it would not return completely to its original state/position. This is the elastic property and combinedly called viscoelasticity. So, due to elastic effect the fluid can regain these two of properties during higher flowrate and strain. The ability to choose how much viscous and elastic properties a material would behave gives the designer greater flexibility. The consequence on how each property would influence must be understood for further study to make the design to be successful. So, the aim was to balance between the opposite properties of the fluid that is viscous effect dampens eddy up to a certain limit and further rise in viscosity makes the fluid gelled types and to minimize the power consumption by combining these effect. Pseudoplastic property was also in consideration as it helps to decrease the viscous effect during higher flowrate. Heat transfer analysis is very important in all the sectors. So, for any material the extent of heat transfer and friction analysis is important in any field. Pseudoplastic fluid is a kind of fluid that gets thinned when shear is applied. Such a fluid is called shear thinning fluid. The shear thinning fluid is used widely in food, beverage and chemical industry. Slick water (base fluid) creates drag and turbulence more in pipeline. So a small amount of high molecular weight drag reducer reduces the drag and acts as drag reducer as well as reduces eddy by reducing turbulence and saves power consumption. So, viscoelastic fluid is more effective to transport and saves pumping energy but it must be under a optimized flowrate and concentration. When heat is associated with this type of fluid it is important to know the heat transfer and frictional characteristics of such fluid. If drag or friction can be lowered by mixing the gum then power to flow the fluid can also be saved. Here, how much heat energy can be transferred by the pseudoplastic/viscoelastic xanthan gum solution and the friction occurs by this additive for different concentration was experimented and an optimum concentration and flowrate were found out. There are various type of additive like guar gum but the reason for choosing this type of additive is that the xanthan gum is now widely used in many aspects of industry where complex engineering analysis and multidimensional aspects are related so it is necessary to know the heat transfer ability and flow characteristics of xanthan gum solution.

movement of different layers in the material actually causes the reduction in viscosity), but water cannot. Ketchup is a shear-thinning material, like yogurt and emulsion paint, exhibiting thixotropy, where an increase in relative flow velocity will cause a reduction in viscosity, for example, by stirring. Some other non-Newtonian materials show the opposite behavior, rheopecty (viscosity increasing with relative deformation), and are called shear-thickening or dilatant materials. Rheometers are instruments used to characterize the rheological properties of materials, typically fluids that are melts or solution. These instruments impose a specific stress field or deformation to the fluid, and monitor the resultant deformation or stress. Instruments can be run in steady flow or oscillatory flow, in both shear and extension. It is common that if material stress increases linearly with strain then it is called elastic material within proportional range or limit. If the material deformation strain rate increases linearly with increasing applied stress, then the material is viscous in the Newtonian sense. If the material shows combined property of viscous and elastic effect then the material is said to be viscoelastic material. Fig 1.6 depicts the chemical structure of a non-Newtonian viscoelastic and pseudoplastic materials exhibiting both viscoelastic and pseudoplastic behavior.

Rheology Applications:

- Materials Science
- Engineering
- Geophysics, Physiology
- Human Biology
- Pharmaceuticals
- Cement
- Paint

In addition, plasticity theory has been similarly important for the design of metal forming processes. The science of rheology and the characterization of viscoelastic properties in the production and use of polymeric materials has been critical for the production of many products for use in both the industrial and military sectors. Study of flow properties of liquids specially non-Newtonian fluid is important for pharmacists working in the manufacture of several dosage forms, such as simple liquids, ointments, creams, pastes etc. The flow behavior of non-Newtonian fluids under applied stress is of great relevance in the field of pharmacy. Flow properties are used as the important quality control tools to the

maintainance of the superiority of the product and reduce batch to batch variations. Examples may be given to illustrate the potential applications of these principles to practical problems in the processing and use of rubbers, plastics, and fibers. As in pharmaceuticals industry most of the fluid flow are non-Newtonian in nature. Polymers constitute the basic materials of the rubber and plastic industries and are of vital importance to the textile, petroleum, automobile, paper, and pharmaceutical industries. Their viscoelastic properties determine the mechanical performance of the final products of these industries, and also the success of processing methods at intermediate stages of production. In viscoelastic materials, such as most polymers and plastics, the presence of liquid-like behaviour depends on the properties of and so varies with rate of applied load, i.e., how quickly a force is applied.

Geophysics:

The scientific discipline of geophysics includes study of the flow of molten lava and study of debris flows (fluid mudslides). This molten lava exhibits viscoelastic and pseudoplastic properties. This disciplinary branch also deals with solid earth materials which only exhibit flow over extended time-scales. Those that display viscous behaviour are known as rheids. Implying DRAs to these can reduce the frictional loss. For example, granite can flow plastically with a negligible yield stress at room temperatures (i.e. a viscous flow). Applying DRAs slightly improves it's flowability.

Physiology:

Physiology includes the study of many bodily fluids that have complex structure and composition, and thus exhibit a wide range of viscoelastic flow characteristics. In particular there is a specialist study of blood flow called hemorheology. This is the study of flow properties of blood with pseudoplastic and its elements (plasma and formed elements, including red blood cells, white blood cells and platelets). Blood viscosity is determined by plasma viscosity, hematocrit (volume fraction of red blood cell, which constitute 99.9% of the cellular elements) and mechanical behaviour of red blood cells. Therefore, red blood cell mechanics is the major determinant of flow properties of blood. So, flow properties of these types of non-Newtonian fluid is also important. The leading characteristics for hemorheology has been shear thinning in steady shear flow. There are some other important non-Newtonian rheological characteristics that blood can demonstrate during flow includes pseudoplasticity, viscoelasticity, and thixotropy. There are two current major hypotheses to explain blood flow predictions and shear thinning responses. These thesis The two models also attempt to demonstrate the drive for reversible red blood cell aggregation by pseudoplastic effect. There is a direct effect of red blood cell aggregation on blood viscosity and circulation.

Disease and diagnostics

Changes to viscosity has been shown to be linked with diseases like hyperviscosity, hypertension, sickle cell anemia, and diabetes. Hemorheological measurements and genomic testing technologies that act as preventative measures and diagnostic tools. These study also related to primarily increasing the viscosity slightly and later using the pseudoplastic effect to compromise between increasing viscosity and eddy dampening effect.

Hemorheology has also been correlated with blood fluidity, and studies have shown that physical activity may improve the thinning of blood rheology.

Zoology:

In Zoology some planktons, fishes, organisms etc use the pseudoplastic effect of fluid during their movements. Almost all of biological tissues are viscoelastic and their viscoelastic mechanical properties are important in their characteristic functions. This is because constituents of tissues cells, extracellular matrices, structural proteins, and so on are viscoelastic. Even hard tissues have been shown to be viscoelastic.

Food rheology:

Food rheology is important in the manufacture and processing of food products, such as cheese and gelato. An adequate rheology is important for the indulgence of many common foods, particularly in the case of sauces, dressings, yogurt, or fondue.

Thickening agents, or thickeners, are substances which, when added to an aqueous mixture, increase its viscosity without substantially modifying its other properties, such as taste. They provide body, increase stability, and improve suspension of added ingredients. Thickening agents are often used as food additives and in cosmetics and personal hygiene products to improve the flowability. Some thickening agents are gelling agents, forming a gel. The agents are materials used to thicken and stabilize liquid solutions, emulsions, and suspensions. They dissolve in the liquid phase as a colloid mixture that forms a weakly cohesive internal structure. Food thickeners frequently are based on either polysaccharides (starches, vegetable gums, and pectin), or proteins.

Concrete rheology:

Concrete's and mortar's workability is related to the rheological properties of the fresh cement paste. The mechanical properties of hardened concrete increase if less water is used in the concrete mix design, however reducing the water-to-cement ratio may decrease the ease of mixing and application. To avoid these undesired effect sometimes pseudoplastic agent are typically added to decrease the viscosity of the fresh paste. Their addition highly improves concrete and mortar properties.

Filled polymer rheology:

The incorporation of various types of fillers as pseudoplastic agent into polymers is a common means of reducing cost and to impart certain desirable mechanical, thermal, electrical and magnetic properties to the resulting material. The advantages that filled polymer systems offer are better flowability. Usually when the use of fillers is considered, the viscoelastic effect should be considered. The viscoelasticity primarily increases the flowability by hindering the eddy formation rate but at higher concentration the viscous effect starts dominating so these effect can be minimized by pseudoplasticity effect. So, increasing the concentration of viscoelastic fluid considering the extent of pseudoplastic effect is important and important to investigate the influence of the pseudoplastic property.

Types of fluid

1.Newtonian Fluid:

The Newtonian fluid is the fluid that follows the Newton's law which states that the rate of deformation of a fluid is linearly proportional to the shear stress.Examples:water, air, gasoline [3].

2.Non-Newtonian Fluid:

If the rate of deformation is not directly proportional to the stress of a fluid then it is called non-Newtonian fluid.

Types of non-Newtonian fluid

- Pseudoplastic fluid

The fluid whose viscosity decreases by increasing the rate of deformation.Example:Xanthan gum,Guar gum,tomato sauce etc.

- Dilatant fluid

The fluid whose viscosity increases by increasing the rate of deformation.They are also called shear thickening fluid .Example:Solution of starch.

- Bingham plastic:

Some fluid behaves as solid when in low stress but behaves as liquid when they are applied stress above yield stress.Example:Toothpaste.

Fig 1.7 depicts the rheological behavior of different types of fluid.

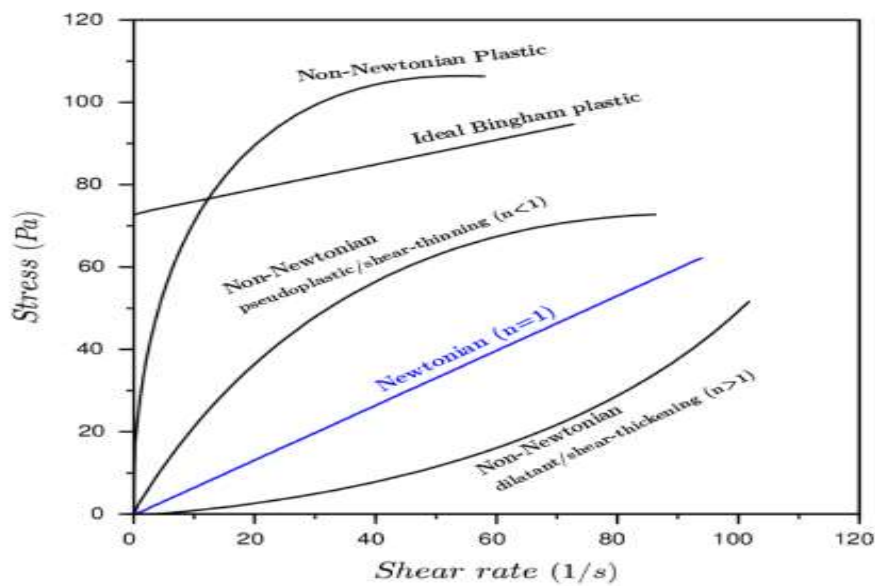


Fig 1.7 : Different types of non-Newtonian fluid stress-strain curve [7]

1.4 Classification of Additives

- Guar gum:

Guar gum is a novel agrochemical processed from endosperm of cluster bean. It is largely used in the form of guar gum powder as an additive in food, pharmaceuticals, paper, textile, explosive, oil well drilling and cosmetics industry. Industrial applications of guar gum are possible because of its ability to form hydrogen bonding with water molecule. Thus, it is chiefly used as thickener and stabilizer.[5].

- Xanthan gum and reason behind choosing xanthan gum:

Xanthan gum a polysaccharaide cream coloured which is much stable in water and acidic solution. It increases the viscosity of slick water when mixed . It is a widely used nature extracted polysaccharide . The Xanthan gum is a large chain polymer which is found naturally. This natural polymer is extracted from trees.Its aqueous solution is pseudoplastic means it shows high viscosity at low shear and shear thinning and odorless.Its solution is well soluble in hot and cold water at any temperature .It shows good stability at wide range of temperature and p^H . It shows high resistance to shear degradation.The molecular weight of the gum is approximately 1016 g/mol. The chemical formula is $C_{35}H_{49}O_{29}$. It is non corrosive,pumpable,squeezable and good water binder. Safe for human body and pipe materials as it is food grade and approved by the U.S. Food and Drug Administration(FDA). So it can be choosen for use.Xanthan gum is a good thickener but gets thinned when shear is applied.

Applications of xanthan gum

- Apple juice, apricot and chemical industry.
- Good stabilizer for various types of toothpastes.
- Lotions, medicines, stabilizer etc.

Properties of the additives

- Viscoelastic additives consists of long chain molecule.
- Molecules are interlinked and tangled together in a ordered state.

Fluid foods are often subjected to thermal treatment inside surface heat exchangers. Besides the need for high heat transfer performance, also low friction losses and easy cleaning and sanitizing properties of the surface are imperative. In food process industry these requirements are often met by the shell and tube heat exchanger equipped with helically corrugated walls. The present work concerns convective heat transfer and friction losses in double pipe heat exchanger for both Newtonian and non-Newtonian fluids. We can choose additives of correct mixture or blend of properties of both viscous and elastic effect. Viscoelastic fluids are common in very important applications. Many of these are so common that people usually do not pay attention to its importance. Paints are a very good example since almost all buildings are painted with a combination of a polymer and a solvent, for different reasons. On the other hand, not all viscoelastic fluids are paints and some of these may have biological nature or even may be intended for some optical application. Also, viscoelastic fluids may be so different to each other that a reasonable number of constitutive equations have been developed to model their behavior. At the same time, some applications involving viscoelastic fluids may require physical mechanisms for proper working, like natural convection. This thesis is dedicated to theoretical and experimental study on effect of polymer/viscoelastic fluid on small scale turbulence effect. But the turbulence has also an impact on heat transfer. So there is also a complex and interesting case of balancing the two issues of minimizing power consumption and maximizing the heat transfer rate on a specific concentration and flowrate. As the viscous effect and eddy formation effect are playing inversely for pressure drop reduction and heat transfer rate so an optimization is required. Also with increasing concentration after a certain amount the viscosity increases that increases power consumption and power loss of pump but reduces eddy that decreases eddy loss in the flow. But in the question of flowrate when flowrate increases for these fluid it gets thinned or called shear thinning fluid or incorporates pseudoplastic effect means viscous effect and elastic effect decreases. So, we

can take an advantage of this shear thinning behavior to compensate the negative impact of viscoelastic effect at higher concentration. On the heat transfer rate eddy plays a vital role. The eddy in the fluid creates layer to layer mixing and hinders the formation of thin film. But as adding these agent reduces eddy so there is a question of reducing heat transfer rate with increasing concentration. But as this study considered the flowrate and concentration both and the study is focused on flowrate, the chance of shear thinning behavior on maximizing the heat transfer rate can be considered. So the research is based on several flowrate for some specific concentration and to find out a flowrate and concentration and to what extent the power consumption can be decreased without sacrificing the heat transfer rate. Means the heat transfer rate was kept as maximum as possible and that point of concentration and range of flowrate was declared as the optimum point of concentration and optimum range of flowrate. But in these types of food fluid the importance of study the effect of these drag reducing agent on heat transfer rate is huge. Because in industry these fluid passes through various heat exchanger for various purposes. So, a study is required, how much affect is producing on these types of fluid due to adding drag reducing agent. By following these study some other study also may be done on how heat transfer rate can be increased on the presence of these DRA agent. These DRA agent dampens eddy which is a vital factor for heat transfer rate. So, heat transfer rate was decreased by adding these DRA agent. The effect of DRAs on fluid flow was studied. Such as at what concentration the rate of heat transfer was maximum or minimum was evaluated.

Further study of an optimization between these parameters such as

- Concentration
- Flowrate
- Velocity
- Reynolds Number
- Pipe Diameter
- Motor Rpm
- Different Dra Etc Can Be Studied

1.5 Worldwide use of DRA in crude oil transportation:

The transfer of crude oil by pipeline is very important to the world economy. In recent decades, the high growth in global crude oil consumption has posed problems for oil transportation due to the increase in energy loss from turbulent flows. The primary source of fluid energy loss in pipeline transport is frictional resistance. Therefore, several pump stations must be constructed along the line to supply extra power to overcome all the fluid

resistance. One of the solution of these extra pump usage is using DRAs. As the choice of pump station, equipment, and pipe size is conservative, which can result in higher construction capital costs than actual operation. These challenges have sparked particular interest in finding approaches to reduce the resistance loss in crude oil transportation. Thus, the implementation of chemical additives called drag-reducing agents (DRAs) to reduce the pressure drop in turbulent flows in pipelines by injection (Fig 1.9) and increase the amount of oil production has significantly reflected the economic benefits on the oil indust. DRAs are primarily polymers, surfactants and fibers, but can include other solvents or chemical materials. In practice, the injection of a small concentration of these additives in laminar sublayer region incorporates the eddy dampening (Fig 1.9) and reduces crude oil friction and increases pipeline capacity without changing pipeline conditions. DRAs can maximize the pumping flow rate of crude oil through the pipelines or minimize pumping costs. The first observation of the drag reduction phenomenon was made in 1948 using of DRAs.

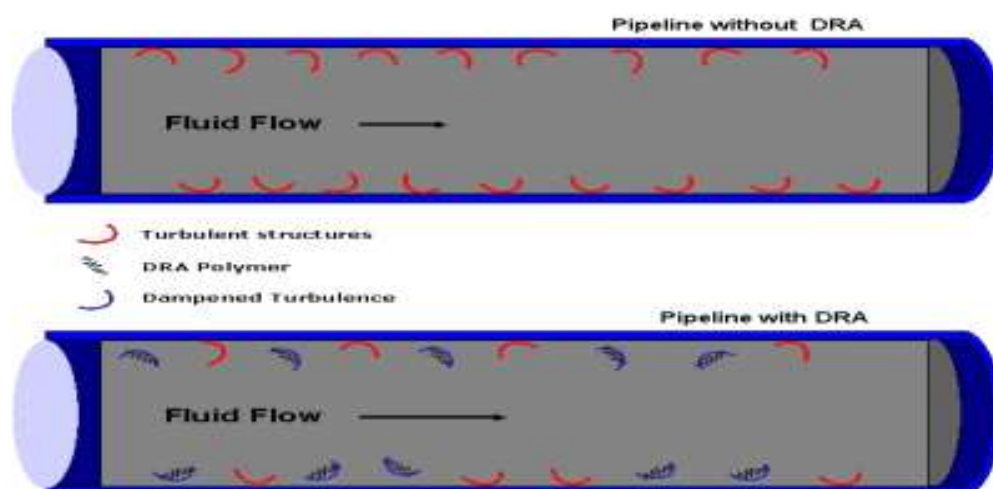


Fig 1.8: Drag reduction mechanism [16]

Drag reducer, also known as drag reducing agent and flow improvers ,are any material that reduces frictional pressure loss during fluid flow in a conduit or pipeline. Pressure loss reduction is achieved by reducing the level of turbulent motion in the flow. Using DRA allows increased flow using the same amout of energy or decreased pressure drop for the same flowrate of fluid in pipelines. Frictional pressure drop or drag is a result of the resistance encountered by flowing fluid coming into contact with the pipe wall. There are generally two types of flow-laminar and turbulent. The frictional pressure observed in laminar flow cannot be changed unless the physical properties of the fluid are changed. The current class of DRA like xanthan gum does not change fluid properties and hence is effective only in turbulent flow. This additive dampens the eddy and hindrances the further formation of eddy in pipeline shown in (Fig 1.8). In most of petroleum pipelines the liquid flows through the pipeline in turbulent regime (Fig 1.9). Therefore, current DRA can also be

perform very well in most pipelines, allowing treatment of light to medium crude, have crude, multiphase and refined product applications. In a turbulent flow regime, the fluid molecules move in a random manner, causing much of the energy applied to them to be wasted as eddy currents and other indiscriminate motion. DRA works by an interaction of the polymer molecules with the turbulence of the flowing fluid.

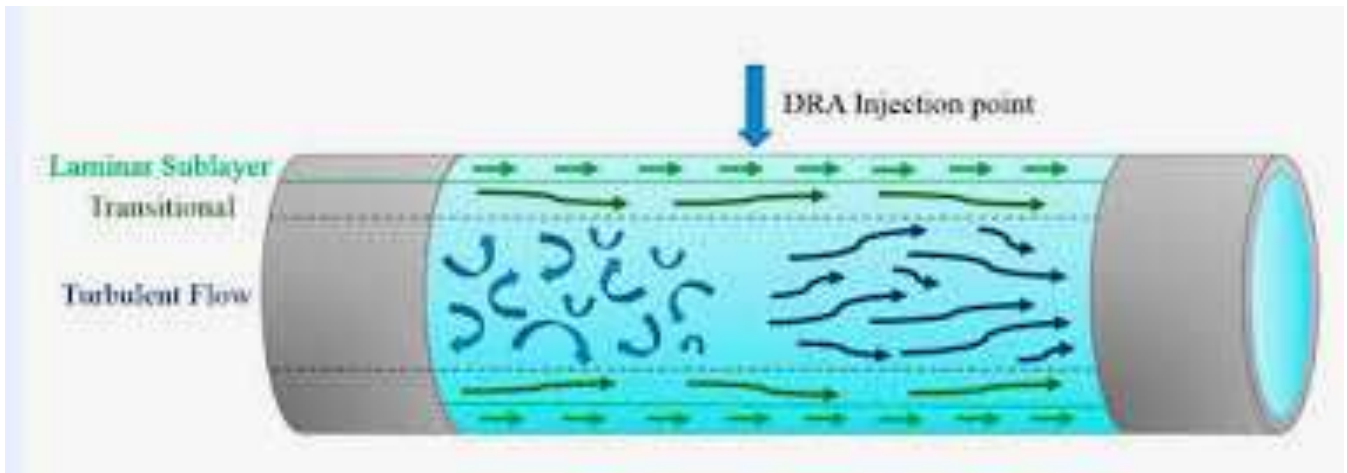


Fig 1.9: Drag injection in pipeline [16]

Drag reducing agent can be broadly classified under the following four categories-

- Polymers
- Solid particles
- Biological additives
- Surfactants

The agent are made out of high molecular weight polymers or chains. The polymers help with drag reduction by decreasing turbulence in the oil lines (Fig 1.9). This allows for oil to be pumped through at lower pressures, saving energy and money. Although these drag reducing agents are mostly used in oil lines there is a research to see how helpful polymers could be in reducing drag in veins and arteries. Using just a few parts per millions of the drag reducer helps to reduce the turbulence inside the pipe because the oil pushes up against the inside wall of the pipe ,the pipe pushes the oil back down causes a swirling of turbulence to occur which creates a drag force. The viscoelastic effect restricts the formation of eddy and swirling of eddies that consequently reduces the pump herad loss. When the polymer is added, it interacts with the oil and the wall to help reduce the contact friction of the oil with the wall. Degradation can occur on the polymer during the flow. Because of the pressure and temperature on the polymer, it is easier to break them down. Because of this, the drag reducing agent is re-injected after points like pumps and rotameter devices ,where the pressure and temperature can be extra high. Characteristics of the ideal drag reducer:

- High molecular weight
- Shear degradation resistance
- Quick dissolvable

Low degradation in heat, light. With drag reduction, there are many factors which play a role in how well the drag is reduced. A main factor is temperature. With a higher temperature the drag reducing agent is easier to degrade. At a lower temperature the drag reducing agent tends to cluster. This problem can be solved by adding a chemical such as aluminium to help to reduce intermolecular attraction.

Other factors are-

- Pipe diameter
- Surface roughness
- Pressure

Areas of use-

- Drag reducing agents have been found useful in reducing turbulence in the
- shipbuilding industry
- Fire fighting operations
- Irrigation system
- Central heating device
- Crude oil system

1.6 Objectives:

The thesis is mainly related to the study of combined effect of fluid flow characteristics and heat transfer behavior of non-Newtonian fluid. The non-Newtonian fluid chosen here was pseudoplastic fluid which was also viscoelastic in nature. The objectives of the thesis are given below:

- To fabricate a double pipe heat exchanger with MS sheet metal and pipings.
- To find out an optimum concentration and flowrate for minimum frictional drag.
- To establish an optimum concentration and flowrate and to study the effect of heat transfer rate for using drag reducing agent.

1.7 Organization of The Thesis

There are five chapter in this thesis. The five chapter describes five things.

Chapter 1: The chapter one gives an overview of the thesis. It describes the aspects, importance prospectus of the thesis.

Chapter 2: The chapter two is the literature review. The feasibility of the study ,who and when this type of studies were done are described here. Why this type of analysis and the material is choosen and the research that has rarely done, the research gap is given in this chapter.

Chapter 3: The chapter three is about methodology or research framework or the process that has ben adopted to to do this experiment.The apparatus and the calculation procedure, step by step flow chart,equation and descriptions are given here.

Chapter 4: The chapter four is the results and discussions that incorporates various types of graphs and analysis that is required to reach a conclusions.

Chapter 5: The chapter five is about the output that is desired to come after the study and the possibility of the extent of error.

1.8 Scopes of The Thesis

- Many industry frequently uses this type of pseudoplastic fluid like xanthan gum. So, this analysis will be helpful to use this additives. For heat transfer performance and for low friction loss many industries use double pipe heat exchanger for many purposes to transfer heat to the food fluid. By this analysis, if we can reduce the friction then pumping power and cost to flow a fluid can be saved.
- By knowing optimum concentration, we can use the xanthan gum so that skin friction drag can be kept as lower as possible and at the same time heat transfer will also satisfactory.
- In some cases heat transfer need to be high and in some cases we want to keep heat transfer rate as low as possible. So, based on application we can decide wheather to use this type of fluid or not.
- As we will analyze the frictional behaviour of xanthan gum solution so in many chemical, food and beverage industry so it will be helpul to understand the behavior of the solution.
- As food graded xanthan gum is non-corrosive and stable,well mixable in water and in acidic solution so by mixing small amount drag can be reduced.

1.9 Limitations of The Thesis

- In this study the heat transfer rate may decrease from normal water so optimization is required by sacrificing some heat transfer rate to decrease friction
- The fluid friction rate may increase.
- The xanthan gum may be slightly costly.
- After increasing the concentration up to a certain limit the fluid becomes too sticky that seizes the pump and flow.

CHAPTER 2

LITERATURE REVIEW

2.1 Literature Review

Jaafar and Poole [8] investigated semi-rigid biopolymers-scleroglucan (0.005 and 0.01% w/w) and xanthan gum (0.0124 and 0.07% w/w)-in a circular pipe and a concentric annular pipe (radius ratio $\kappa = 0.5$) experimentally. Rheological characterization of the polymers conducted over a wide range of concentrations (0.005-0.75% w/w) showed increased shear-thinning ability of the polymer solutions with increasing solution concentration. The pressure-drop measurements indicate that the effectiveness of these polymers as drag-reducing agents. They showed 40% drag reduction by using xanthan gum. Lawrence et al. [9] studied the effect of oil and polymers on the effect of drag. They showed Specifically, at Reynolds number of 59000, maximum drag reduction values of 39 % and 44 % were attained when 200 ppm of guar gum and xanthan gum solutions were added respectively. Marina et al. [10] studied the effect of xanthan gum solutions. They revealed that pressure drop measurements was estimated to be better than 64%. Maximum variability of pressure drop was best for tests performed using 0.075% XG solution. Atle et al. [11] studied the pressure drop measurement and results showed that the drag reduction effect of the two polymers increases with the increase of the solution concentration. According to the experimental data, xanthan gum performs better shear resistance than polyacrylamide solution and has a better drag reduction effect at low Reynolds number, but its maximum drag reduction rate is lower than that of polyacrylamide solution at high Reynolds number. Bashar et al. [12] 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. Bassam et al. [13] made a review paper on recent works on drag reducing agent in a single and multiphase flow pipeline. Focus is placed on the drag reduction, the influence on drag reduction agent types, hydrodynamic and heat transfer characteristics of flow. They showed that drag reducing agent imparts more drag reducing effect rather than corrosion inhibitor or detergent. They conclude that a 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). Farid and Ahmed [14] 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 in order to enhance crude oil flow conditions in long-distance pipelines. Effective chemical

techniques are seen to be the most efficient and practical ways to handle these problems. The pressure drop through a pipeline can be decreased by adding a tiny quantity of drag-reducing agents. Sreedhar and Saketharam [15] 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 with reference to many industries like oil, marine, irrigation, biomedical etc to reduce power consumption. Charles and John [16] studied the fluid friction reduction experiment in St. Anthony Falls Hydraulic Laboratory University of Minnesota. They showed that using different concentration 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 reduced. They also found the velocity parameter was also increased when guar gum solution was used rather than normal water as the friction is lower. Patterson et al. [17] in their paper revealed that the heat transfer rate decreases. 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 solution of soap solution, polymer solution and suspended particle solution. Pruitt et al. [18] experimented 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. [19] presented a review article on this type of heat transfer analysis by using nano fluid. He found in several cases that it was established nano fluid particle creates micro convection so the heat transfers developed in nano fluid. Mostafa et al.[20] investigated the heat transfer behaviors with pool boiling by using non-Newtonian xanthan gum solution. They used an experimental setup of aluminium heater plate, thermocouples, reflux heater, plexiglass block and gasket sealer. The dimension of plexiglass block is $50 \times 50 \times 50 \text{ mm}^3$. The plastic gasket sealing element was used as insulation, high resistant to heat was used between Plexiglass block and the plate. The reflux condenser is made of inner diameter 22mm, outer diameter 40mm and 40 cm length. The effective operation of condenser was found when the mass of liquid remained constant. They examined the stability of xanthan gum solution by using RAMAN test. According to RAMAN test the stability of Xanthan gum solution is constant when the content of xanthan gum powder content is increased in solution. They found that at boiling condition of certain concentration the pool boiling heat transfer decreases with the concentration of xanthan gum. They also visualized the bubble formation rate at pool boiling increases with increasing the rate of xanthan gum concentration in solution that shrinks the rate of heat transfer. Joshi and Bergles [21] studied the heat transfer characteristics of non-Newtonian laminar fluid flow. They used a closed loop low pressure systems of such pipings and all of

fittings made of copper and brass. A pump circulated the viscous fluid. They used two thin walled 304 stainless steel test section. Rotameters were used to measure the flow rate. They attached copper constantan thermocouples circumferentially 90 degree apart. Strong insulation was used so that no heat can escape from tube section. Aquous solution of 1% and 0.9% of Hydroxy Ethyl Methyl Cellulose(HEMC) was used as working fluid solution. Lew [22] published a book review of H.P Skelland's book which describes the characteristics of non-Newtonian flow and heat transfer characteristics. Anil and Venu [23] showed the heat transfer rate and heat transfer enhancement in double pipe heat exchanger. The thermal analysis was carried out to determine 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. [24] investigated the heat transfer and friction loss characteristics for several fluid food such as orange juice, whole milk, apricot,apple puree. They tested for these pseudoplastic fluid food in double pipe heat exchanger. They investigated the heat transfer rate for both Newtonian and non-Newtonian fluid. For test they used two counter flow double pipe 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 fluid had been tested. It is well known that apple puree is non-Newtonian pseudoplastic fluid. They showed that this food fluid requires heat treatment in corrugated tube as 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 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 These fluid follows the power law model. Jasim et al. [25] examined the rheological characteristics of 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 good rheological effect. The study examines the effect of addition of drag reducing agent. Hoyt [26] reviewed that the fluid friction resistance can be lower by adding additives but he did not show the exact concentration and heat transfer effect the effect of additives on fluid friction. Mehdi and Peter [27] 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. [28] studied the drag reduction of xanthan gum solutions for 10,50,100,500 ppm. They calculated the drag reduction by measuring the friction factor of 2 and 15 mm of

diameter pipe. They showed almost 60% drag reduction for 500 ppm concentration. Dosumu et al. [29] investigated the effect of two soluble polymers (xanthan gum and guar gum) on drag reduction for oil-water flow system. They used horizontal pipe of internal diameter 12 and 20 mm. Different concentrations, mixture flowrate and input oil volume 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 drag reduction (DR) of the individual polymer increased with the increase in additive concentrations and Reynolds numbers (Re). Bewersdorff and Singh [30] studied the turbulent drag reduction by xanthan gum at various concentrations in presence of salt (NaCl). They showed that xanthan gum is very much effective in decreasing turbulent drag reduction. But they showed this drag reducing behavior is not much influenced in presence of the salt. Haoyu et al. [31] studied the drag reduction effect and proved that rigid polymer exhibit 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. Zhu et al. [32] 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 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. Entian et al. [33] 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 with 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. Pengfei et al. [34] investigated by diutan gum a totally 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 depends 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.

2.2 Research Gap of The Previous Studies

It is observed from previous study that various studies were conducted separately for different concentrations and flowrates [12], combining different drag reducing agent (DRA) [25], combining salt [30], cellulose [21], varying diameter and roughness of pipe, some investigated the viscoelastic properties of the xanthan gum by combining with hydrolyzed polyacrylamide (HPAM) solution etc [33]. Heat transfer behavior was also studied but separately without studying drag reduction effect [20]. But there is a research gap of combined drag reduction and heat transfer effect. So this research is conducted to reveal the combined effect of drag reduction and heat transfer rate by xanthan gum and heat transfer rate for a double pipe heat exchanger by combining both the effect of concentrations of the solution and flowrate.

2.3 Problem Statement of This Study

This study particularly examines how pressure drop and heat transfer rate significantly varied by addition of the xanthan gum in various concentration and flowrate. Previously the heat transfer rate was not a on much concern but this study represents a benchmark of heat transfer rate and the corresponding concentration and flowrate also. The results indicates that the frictional pressure drop is lower due to the addition of the drag reducing agent as this DRA dampens the eddy. So a positive effect is depicted. Also due to eddy dampening the heat transfer rate reduces due to poor mixing which was taken into consideration and a heat transfer rate was also established for which the heat transfer rate is minimum. This effect are shown on graph one by one on this study highlighting the effect of concentration and flowrate. The objectives of the present study was to carry out an investigation 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. 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 eddy dampening effect so no comprehensive study was done before by taking consideration of this two effect and also combining the parameter 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 for 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 heat exchanger. Four thermometers were used in our analysis. A solution of water and xanthan gum is used in the test section and was allowed to flow through the tube side of the heat exchanger as cold fluid. Then necessary equation (1-9) were used to determine the heat transfer characteristics of the flow.

CHAPTER 3

METHODOLOGY

3.1 Outline of Methodology/ Experimental design:

Fabrication of double pipe heat exchanger:

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

Length: 24 Inch

Width of outer pipe: 4 inch

Width of inner pipe: 2 inch

Diameter of the side pipings: 1 inch

Main body length of the inner pipe: 18 inch

Material of the pipes: Mild Steel

Insulating material: Glass wool with Aluminium Foil

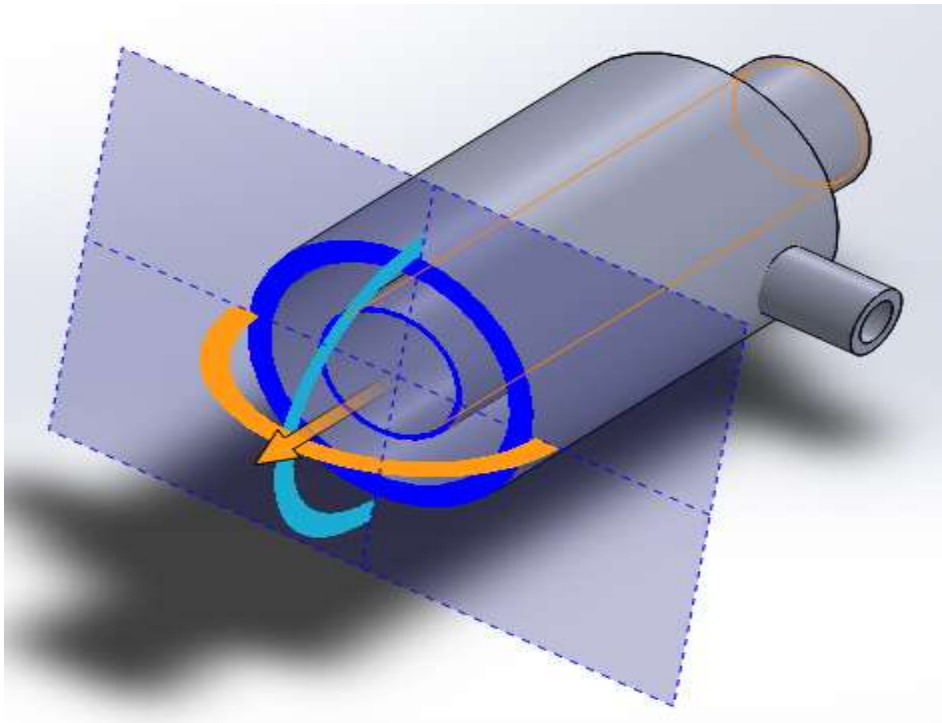
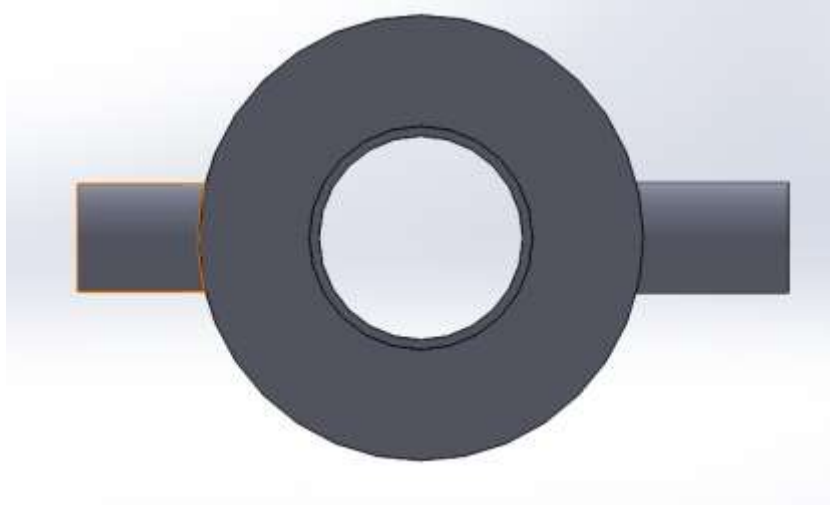


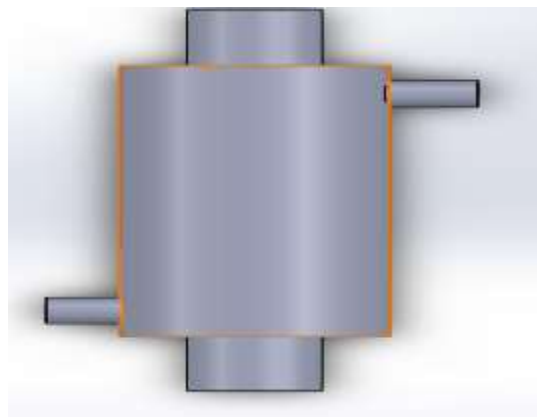
Fig 3.1 :Sectional view of double pipe heat exchanger

3.2 Different Orthographic Views Of The Heat Exchanger

- Right Side View



- Top view



- Front View

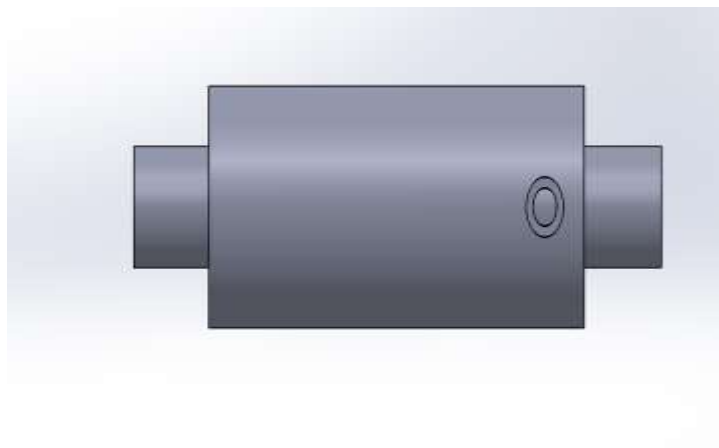


Fig 3.2 : Orthographic views of the heat exchanger

A double pipe heat exchanger (Fig 3.4) is fabricated from Bayezid Engineering Ltd. Fig 3.1 shows the sectional view and Fig 3.2 shows the different orthographic views of the heat exchanger. The heat exchanger consists of two concentric tube. The heat exchanger material is mild steel. The joints of the pipings are welded and thread cutting done by lathe machine. Then the heat exchanger tested by water flowing through it. The leakage are arrested by RTV gum. The surface area of the heat exchanger are determined by the following equation. The Fig 3.3 shows the overview of the calculated area of the heat exchanger.

Surface area, $A_s=2\pi rL$

Where

r =Outer diameter of the inner tube

L =Effective length of the tube

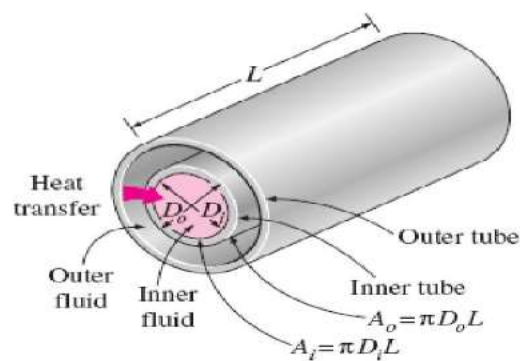


Fig 3.3: Surface area [7]



Fig 3.4 : Double pipe heat exchanger(fabricated)

Surface Area Calculation:

Length of the heat exchanger=0.457 m

Outside diameter of the inner tube=0.0508 m

Effective surface area= $\pi \times 0.0508 \times 0.457 \text{ m}^2 = 0.07 \text{ m}^2$

3.3: Solution Preparations

Xanthan gum can be extracted naturally which is large chain polymer. Its aqueous solution is pseudoplastic in nature. On the other hand xanthan gum can be made from a fermentation process from sugar by a bacteria called *Xanthomonas Campestris*. Fig 3.5 shows the procedure of solutions preparation. According to 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

Volume of solution=1 L

Grams per kg=grams solute/kg of solution

So concentration is 0.3, 0.2, 0.15 grams/kg

The solution is prepared by firstly measuring the Xanthan gum by a weighing scale. As example for preparing 0.3 g/Kg solution a 8 L base fluid (water) is taken and 2.4 g Xanthan gum powder is measured. Then the gum is dissolved in the water by stirring continuously with a mechanical stirrer and magnetic stirrer. The solution is heated upto 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 degree as above this temperature the solution will start to loss or change its properties like viscosity. The solution then mixed and stirred for 25 mins continuously by mechanical stirrer and 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;

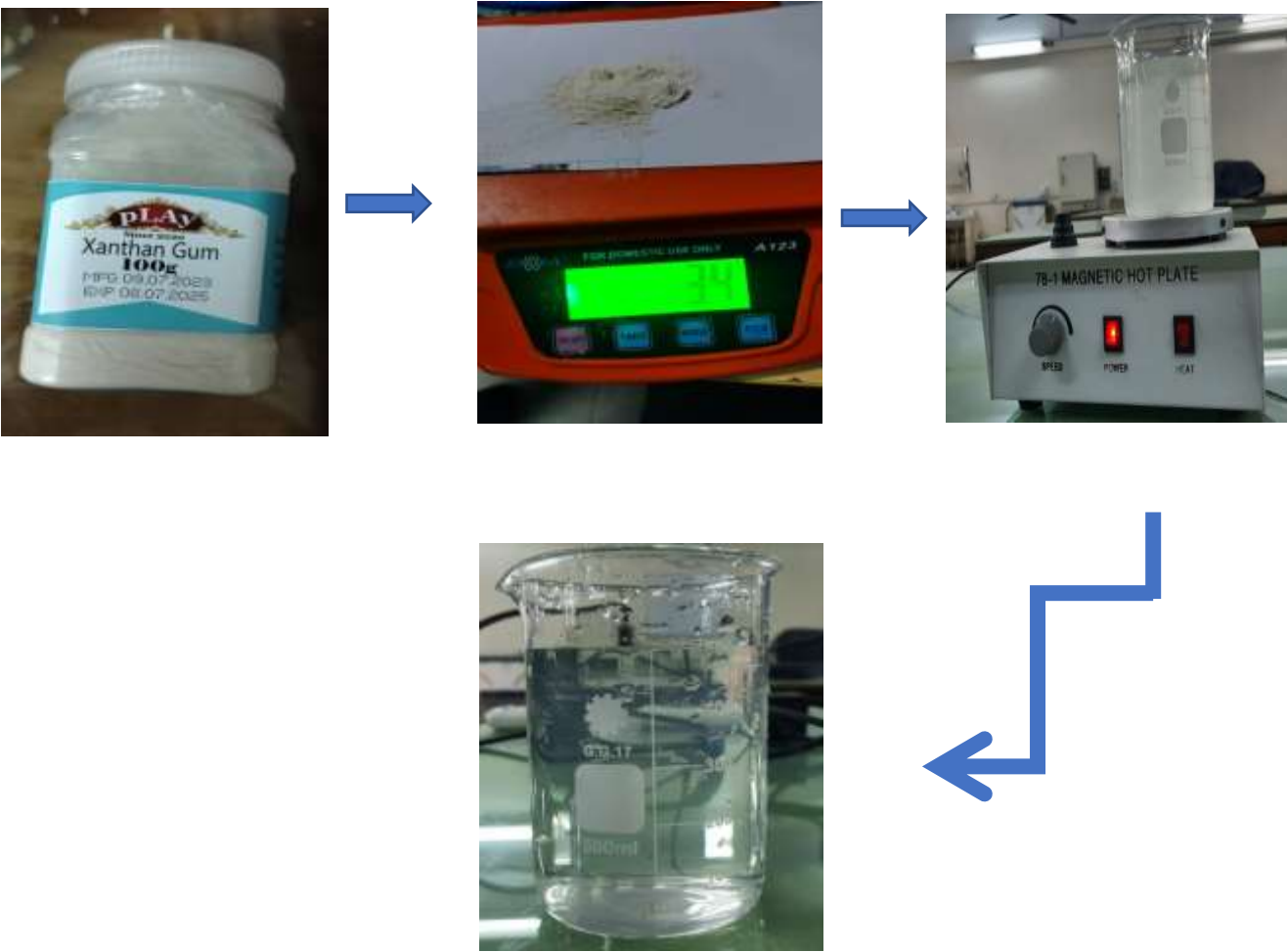


Fig 3.5 : Xanthan gum solution preparation

3.4 Method of Experiment

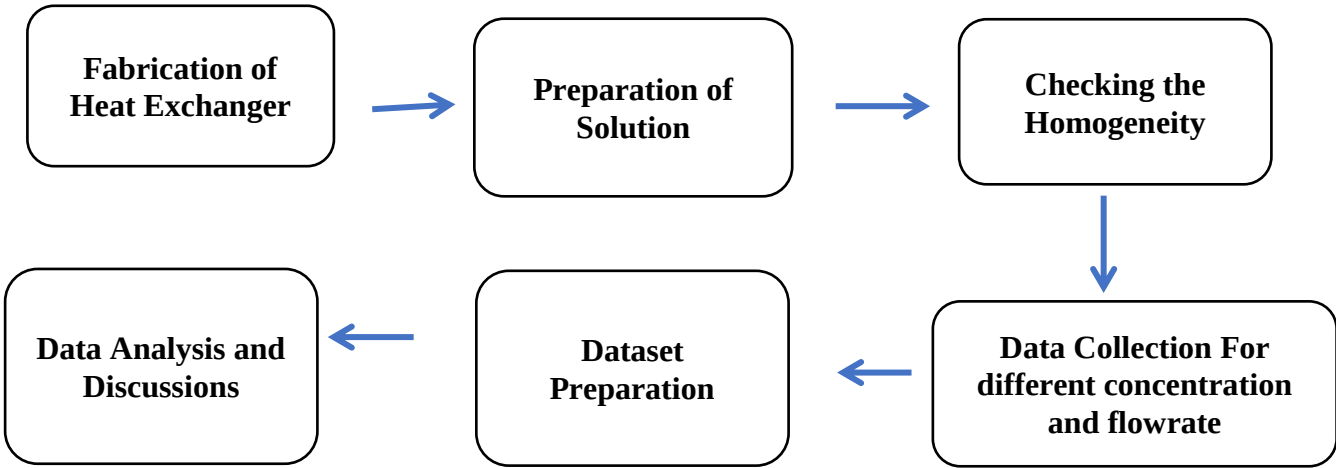


Fig 3.6 :Overview of the experiment

3.5 Line Diagram of The Setup

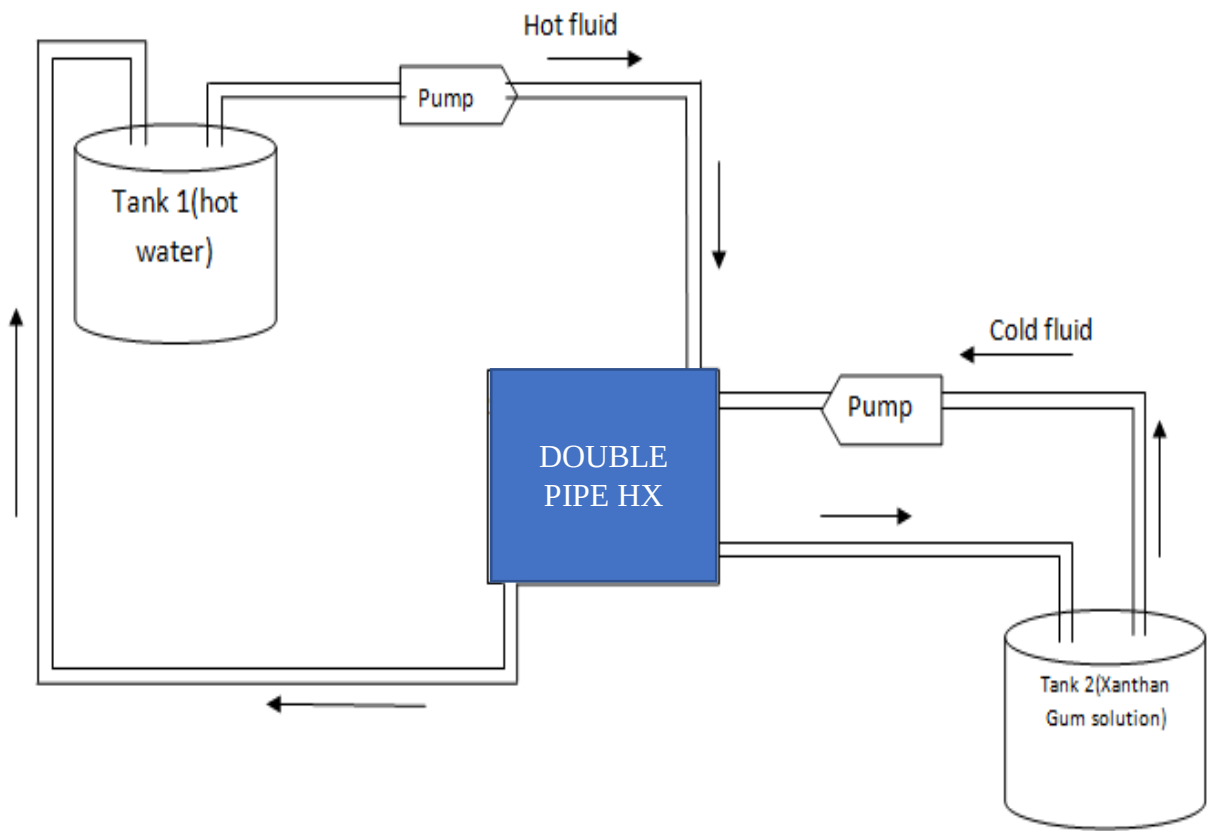


Fig 3.7 : Line diagram of the experimental setup

The double pipe heat exchanger is made of MS material and connected on parallel flow with two tank. One tank contains xanthan gum solution as coldfluid and other tank contains pure water as base fluid. Two pressure gauge is used to measure the pressure difference between outlet of pump and inlet of tank. Four thermometer is used to measure the temperature. Fig 3.7 depicts the positions of the different equipments of this setup. Rotameter was used to measure the flowarte at outlet of the pumps. The rotameters used are of column type. The readings are measured in LPM. The weighing scale is used to measure the weight of the gum to prepare required amount of concentration of the solution. An 1000W electric heater is used heat the base fluid to 60 degree cecius temperature. So It means the hot fluid temperature is 60 °C and cold fluid temperature is in room temperature 25 °C.

3.6 List of Equipments And Consumables:

It is noted that the the fabrication was facilitated by the help of Bangladesh Steel Re-Rolling Mills personnel by Bayezid Engineering and the xanthan gum was provided by the personnel of Abul Khair Group personnel and other experiments will be done according to the paper.

Detailed information on the chemicals and materials that will be used in this study is summarized in following Table 3.1:

Table 3.1 : Chemicals and materials used in this study.

Chemical/material name	Amount	Grade/Origin	Reason
PVC pipe	20 feet	100%	Connecting Pipe
MS Pipe	6 inch(2.5 feet) & 3 inch(2.5 feet)	100%	HX fabrication
PVC Tee	8 pcs	100%	HX fabrication
PVC Elbow	8 pcs	100%	HX fabrication
SS ball valve	3 pcs	90%	HX fabrication
Electric Heater	1 pcs	99.99%	Process Setup
Aluminum foil	1 reel	Chinese	HX fabrication
Loctite	1 pcs	Chinese	HX fabrication
Seal tape	5 pcs	-----	HX fabrication
Pump	2 pcs (0.5 hp)	Chinese	Process Setup
Bucket	3 pcs	RFL	Process Setup
Distilled Water	-----	100%	Process Setup
Xanthan Gum	0.5 Kg	100%	Main Agent
Pressure Gauge	2 pcs (Oil filled)	Gauge Hisco	Process Setup
Flowmeter	2 pcs(manual)	Chinese	Process Setup
Thermometer	6 pcs	100%	Process Setup

3.7 Experimental Setup Description

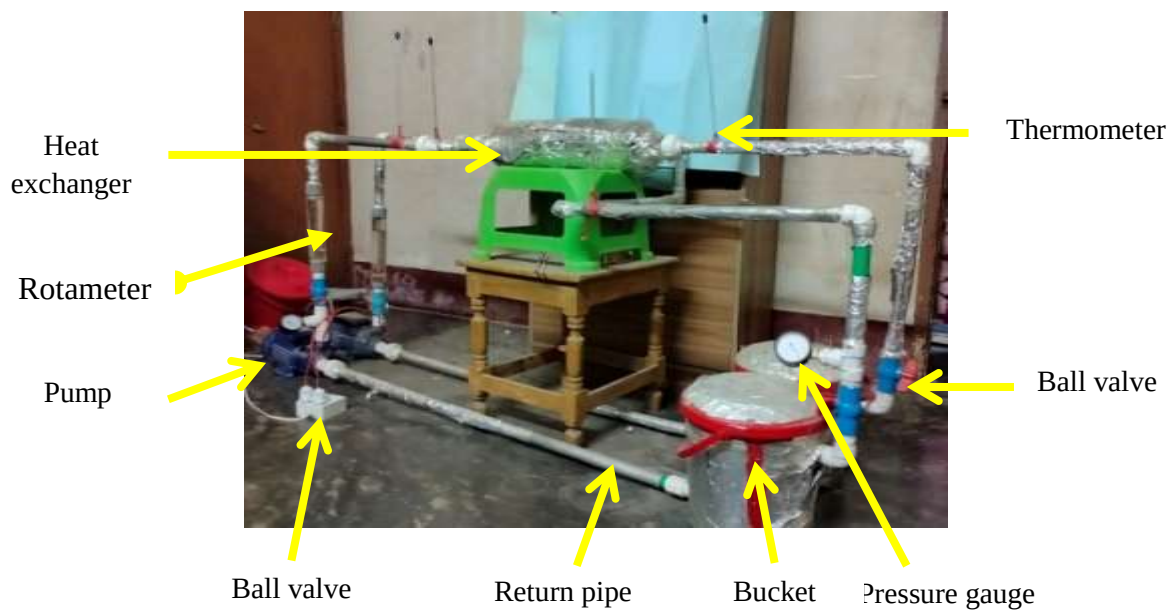


Fig: 3.8: Experimental setup

At first the xanthan gum was measured properly in a digital weighing scale. Then the mixture made homogenous by mixing it with magnetic stirrer. Fig 3.6 shows the flowchart of the experimental setup and Fig 3.8 shows the procedure of preparing the solution. Then the gum powder simply poured in a beaker and the mixed by 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. This solution was the cold fluid. Fig 3.8 shows the detailed experimental setup and equipments. In Fig 3.8 two fluids one is hot and another is cold (solution of xanthan gum) were at two different tanks. Then two pumps were connected to two tanks. The hot fluid 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 was flowed to the outer tube. the heat exchanger by another pump. Four thermometers were connected to the heat exchanger to measure the inlet and outlet temperature of the hot fluid and inlet and outlet temperature of the cold fluid. Flow rate was measured by two rotameters. When flow rate of both the two fluids were stable the thermometer reading was taken. Then by using the equation 6 the overall heat transfer coefficient (U) was found out. The frictional head loss will be found out by the equation 7. Normal water as hot fluid and xanthan gum solution as cold fluid. The flow directions of these fluids is clarified by the line diagram of the setup (Fig 3.7) Then the head loss and heat transfer rate for normal base fluid and from different concentrations of the solution is compared. Compared the result to find the difference in heat transfer rate. So, it could be understood that wheather Newtonian or non-Newtonian fluid transfers heat more. Then by using pressure gauge at inlet and outlet of heat exchanger the pressure difference was taken for water and then for xanthan gum solution for different concentrations and different flowrate .The difference in pressure or

the loss of head was the loss of pressure due to friction. Then friction pressure drop for xanthan gum solution for various flowrate and concentration was compared. A 1000W heater was used to heat the base fluid. The target temperature was raised to 60 degree cecious. But the temperature was raised to 62 °C to compensate the heat loss through the pipings, rotameter, tank etc.

3.8. Description of The Instruments:

Pump:



Fig 3.9: Centrifugal pump

Specifications:

Maximum head: 34 m

Maximum flowrate: 33 LPM

Rotation: 2850 RPM

Power: 0.5 hp

Opearting condition: 220 V ac supply with 50 hz

The technical specifications and performace curve of the pump given below [35]

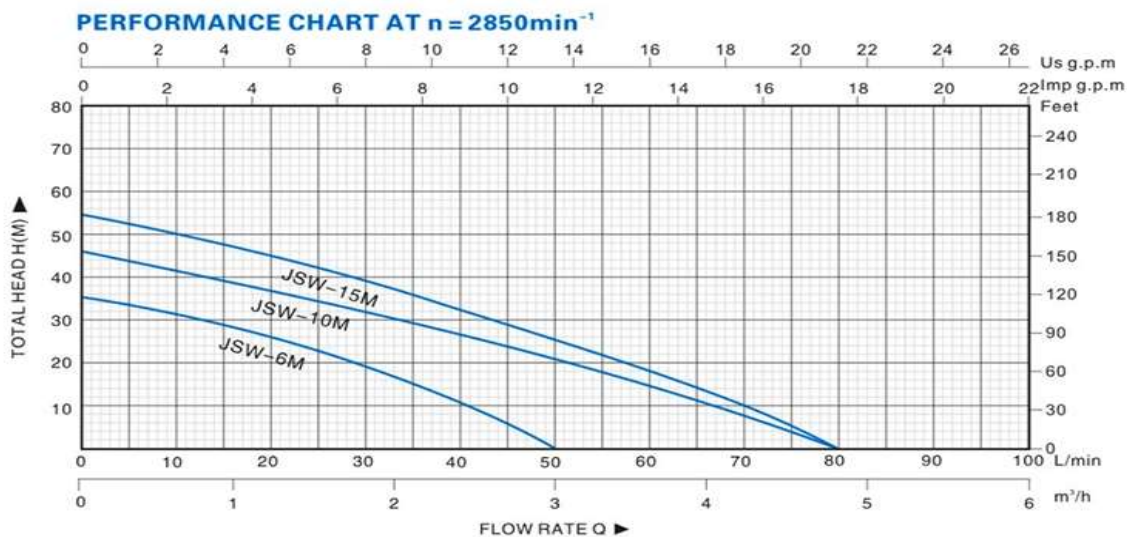


Table 3.1: Technical data of pump [36]

TECHNICAL DATA									
Model	Power		Q.Max (l/min)	H.Max (m)	S.Max (m)	Inlet/Outlet (inch)	G.W. (kg)	Packing dimension (mm)	20GP (pcs)
	(Kw)	(HP)							
JSW-6M	0.37	0.5	50	35	9	1"x1"	9.5	438 x 196 x 235	1400
JSW-10M	0.75	1	80	46	9	1"x1"	15	438 x 196 x 235	1300
JSW-15M	1.1	1.5	80	55	9	1"x1"	15.5	438 x 196 x 235	1200

Table 3.2 : Technical specification of pressure gauge

Brand	HISCO
Material	Case & Cover: Black finished steel Window: Glass Pointer: Aluminium Alloy Connection Socket: Brass Element: Bourden tube(Brass) Movement: Brass Dial: White Al
Pressure Connection	½ inch PT
Degree of protection	IP 44
Dial Size	2 inches
Reference accuracy	40 mm±3.0 % of full scale
MPN	CL 1.5
Face	Glass
Pressure	30 psi
Condition	Dry
Application	Non corrosive gas,air,oil,water



Fig 3.10 : Pressure gauge

Pressure gauges (Fig 3.10), which are devices that measure the internal pressure of media within a system, are among the most often used instruments in any given industrial facility. Table 3.2 depicts the detailed technical specifications of the pressure gauge. Pressure measurement is, along with temperature measurement, one of the most important measurements for operations in a wide variety of applications especially industrial applications and it is essential in ensuring both the quality of a product. Pressure gauges are used to monitor and control pressure – which is often a necessity in industrial processing. Without pressure gauges, industrial processing systems would be both unpredictable and unreliable. Pressure gauges are used by industry professionals to troubleshoot fluid power machines – which are designed to work within a set pressure range. With properly installed gauges, leaks and unwanted pressure changes can be monitored and addressed immediately. The pressure gauge used in this experiment was mechanical pressure gauge to measure the pressure at the outlet of the pump and at inlet of the bucket. The two pressure gauge were checked by measuring the pressure before taking the data. The pressure gauge was marked with two readings in psi and kgf/cm². Kgf/cm² reading was used in this experiment.

Rotameter:

Rotameter was used to measure flowrate. Tapered tube were positioned vertically in the fluid flow since the float position was based on gravity. A liquid entered the bottom of the tube and the float begins to rise. When there was no liquid the float rested. It had graduated scale on the side to allow the operator to take measurement. The rotameters were calibrated by liquid with specific gravity of 1.0. Changing of the density of flow

would effect the rotameter reading. The in and out of the rotameter was same and uniform in size. Two rotameters (Fig 3.11) were used to measure the rate of liquid or gas flowing through a system of pipes at any given time. Table 3.3 depicts the technical specifications of the rotameter. They provide a constant flow rate measurement and can also offer optional switching capabilities to control the flow in a system or process. The rotameter principle of operation is a mechanical means of flow measurement. They measure flow using a float that is able to move freely up and down within the flow tube. The buoyancy force acting on the float, the flow resistance, and the weight of the float itself are all in equilibrium. This position of equilibrium provides the flow rate by referencing the top of the float against the scale printed on the flow tube. Guide rods are sometimes used to help stabilize the float and are more common in gas rotameters or large flow body liquid flow meters. Types of rotameters can be defined by the material used for the flow meter. Most rotameter flow bodies are made of glass or plastic, some are metal. Acrylic and polyamide are common plastic types used in rotameter construction. Metal rotameters are generally made in stainless steel or brass bodies. Rotameters can also be classified by their common applications areas. Rotameters are commonly found in laboratories, chemical injection systems, boiler control, purge applications, filtration loading, process analyzers, oil lubrication circuits, coolant flow, and as early warning tools for clogged systems

Table 3.3 : Technical Specifications of Rotameter

Fluid	Water
S.G of Liquid	1.0
Max Operating pressure	5 bar
Maximum Flowrate	35 LPM & 10 GPM
Maximum Operationg Temperature	70 degree celcius
Accuracy	± 2 %
Body Material	Polycarbonate
End Connection	¾ inch to ¾ inch
Configuration	Bottom-Top
Float	SS
End material socket	ABS



Fig 3.11 : Rotameter

Table 3.4 : Technical specification of thermometer:

Brand	Zeal England
Range	-10 deg to 110 deg
Scale	Celsius
Material	Tempered glass
Accuracy	± 0.2 deg

The thermometers used in this experiment were Zeal thermometer. The technical specifications of the thermometers are depicted in Table 3.4. Other equipments are depicted in the Fig 3.12.



Thermometer



Magnetic stirrer



Aluminium foil



Weighing machine



Electric heater



Fittings



Weighing scale

Fig 3.12 : Necessary Equipments

3.9 Some Design Parameters

Density of xanthan gum, $\rho_x = 1500 \text{ kg/m}^3$ at 20°C

Specific heat of xanthan gum, $C_p = 4.133 \text{ kJ/kg.K}$ at 27.25°C with concentration of 0.2% w/w (minimum) [30].

Specific heat of xanthan gum, $C_p = 7.459 \text{ KJ/kg.K}$ at 60.95°C with a concentration of 0.5% w/w (maximum) [30].

Viscosity of water, $\mu = 0.0091 \text{ poise}$ or $8.90 \times 10^{-4} \text{ pa.s}$

Density of base fluid (water) $= 1000 \text{ kg/m}^3$

Specific heat of water $= 4182 \text{ J/kg.}^\circ\text{C}$ or $4.186 \text{ J/gm}^\circ\text{C}$

Correction factor, $F = 0.99$

Flow: Parallel

3.10 Assumptions

- The size of the particle of xanthan gum is not considered.
- The flow was considered to be laminar.
- Atmospheric temperature was considered to be constant.
- The heat transfer by radiation was included in the convection heat transfer.
- Bulk temperature of solution was considered here.
- Xanthan gum was viscoelastic [28]

3.11 Some Criteria

- Shell and tube heat exchanger.
- Parallel flow.
- Forced convection heat transfer
- Recommended concentration is 0.1-2 % (by U.S food and Drug administration)

3.12 Governing Equations:

Density of xanthan gum, $\rho_x = 1500 \text{ kg/m}^3$ at 20°C

Specific heat of xanthan gum, $C_p = 4.133 \text{ kJ/kg.K}$ at 27.25°C with concentration of 0.2% w/w(minimum) [36].

Specific heat of xanthan gum, $C_p = 7.459 \text{ KJ/kg.K}$ at 60.95°C with a concentration of 0.5% w/w(maximum) [36].

Viscosity of water, $\mu = 0.0091 \text{ poise}$ or $8.90 \times 10^{-4} \text{ pa.s}$

Density of base fluid(water) $= 1000 \text{ kg/m}^3$

Density of xanthan gum $= 1500 \text{ kg/m}^3$

Specific heat of water=4182 J/kg °C or 4.186 J/gm °C

Heat transfer area of the heat exchanger=0.07m²

ΔP=Pressure difference across the heat exchanger

$\Delta T1 = T_{h,in} - T_{c,in} \dots\dots\dots (1)$

$\Delta T2 = T_{h,out} - T_{c,out} \dots\dots\dots (2)$

$LMTD, \Delta T_M = \frac{\Delta T1 - \Delta T2}{\ln(\frac{\Delta T1}{\Delta T2})} \dots\dots\dots (3)$

Heat transfer rate, $Q = m_c \times C_{pc} \times (T_{c,out} - T_{c,in}) \dots\dots\dots (4)$

Maximum heat transfer rate, $Q_{max} = m_c \times C_{pc} \times (T_{h,in} - T_{c,in}) \dots\dots\dots (5)$

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

Overall heat transfer coefficient, $U = \frac{Q}{AF\Delta T_M} \dots\dots\dots (6)$

Head loss in pipe for laminar flow, $h_L = \frac{\Delta P_L}{\rho g} \dots\dots\dots (7)$

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

Here,

ΔP_L=Loss of pressure in Pa

P=Density of solution in Kg/m³

Bulk temperature, $T_b = \frac{T_i + T_e}{2} \dots\dots\dots (8)$

Where, Ti=inlet temperature of cold fluid (Xanthan gum solution)

Te=Exit temperature of cold fluid (Xanthan gum solution)

$C_{pc} = 98.78575 - 0.6495T - 15.9955X_x + 0.06TX_x + 0.001109T^2 - 0.5X_x^2$ [34]

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

X_x=Concentration of solution(% w/w)

CHAPTER 4

RESULTS & DISCUSSIONS

4.1 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 highest possible concentration (0.3 g/L) resulted in a best pressure drop that was reduced by 85% compared to that without the modified XG (xanthan gum) mixture. The drag reduction was affected by flowrate, which increased with decreasing velocity. The effects of using modified xanthan gums mixtures for heat transfer rate in water flow in horizontal pipes and in heat exchanger was examined. The effects of the xanthan gum on base fluid and solution flowrate, pressure gradient, and heat transfer rate were analyzed. The following conclusions can be drawn from this study. 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 low flowrate (10 LPM) that was reduced by 90% compared to that without the modified xanthan gum mixture. The heat transfer rate was affected by flowrate, which increased with increasing flowrate.

From 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 concentration of guar gum additive in solution reduced the frictional drag up to 60% for smooth disk. Another previous investigation [18] revealed that five different concentrations of xanthan gum mixtures were prepared to investigate the improvement of the 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 double pipe heat exchanger we are able to 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 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 not discussed. In this investigation heat transfer rate reduced almost 90% and the maximum heat transfer rate found at a higher concentration (0.3 g/L) with low flowrate (10 LPM).

4.2 In Case of Frictional Effect:

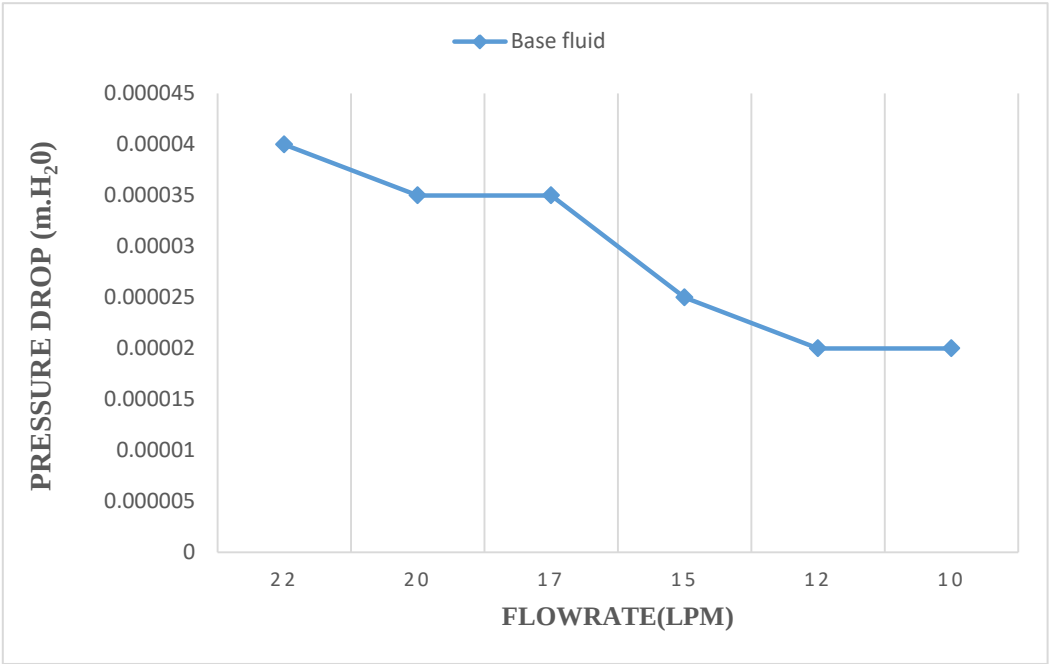


Fig 4.1: Pressure drop graph for base fluid

From data sheet (Table A3,A5,A7) & graph (Fig 4.2, Fig 4.3, Fig 4.4) it has been clearly observed that for a fixed concentration the pressure drops, or head loss decreases with decreasing the flowrate. This is due to the increased frictional forces in pipeline and roughness of pipe. Another investigation may be done by changing the material of pipe. But if we keep the flowrate constant and then change concentration then in the combined graph (Fig 4.5) the head loss found to be reduced up to 85% for 0.3 g/L concentration at 10 LPM. From data sheet (Table A3,A5,A7) & graph (Fig 4.5) it has been observed that the pressure drop is maximum for base fluid water for any other concentrations of gum due to friction and turbulence is maximum for Newtonian fluid. The pressure drop also increases with increasing flowrate due to pseudoplasticity observed from same base fluid graph (Fig 4.1). So pressure drop is maximum for base fluid water for maximum possible concentrations.

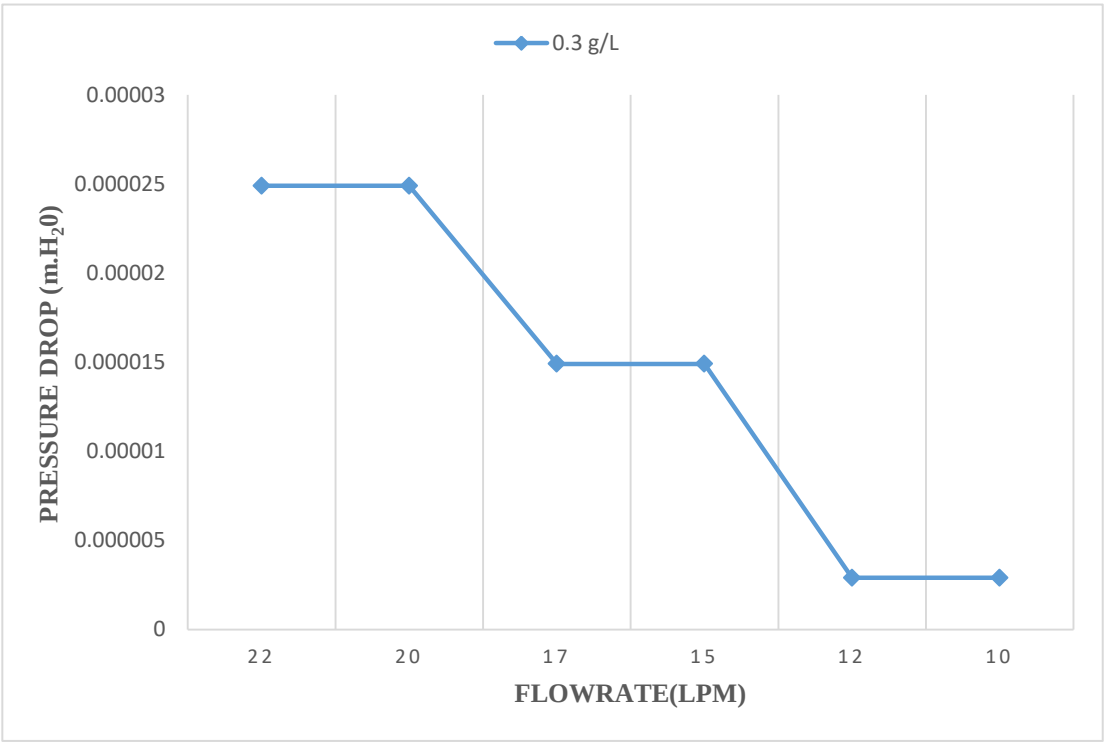


Fig 4.2: Pressure drop graph for 0.3 g/L of xanthan gum

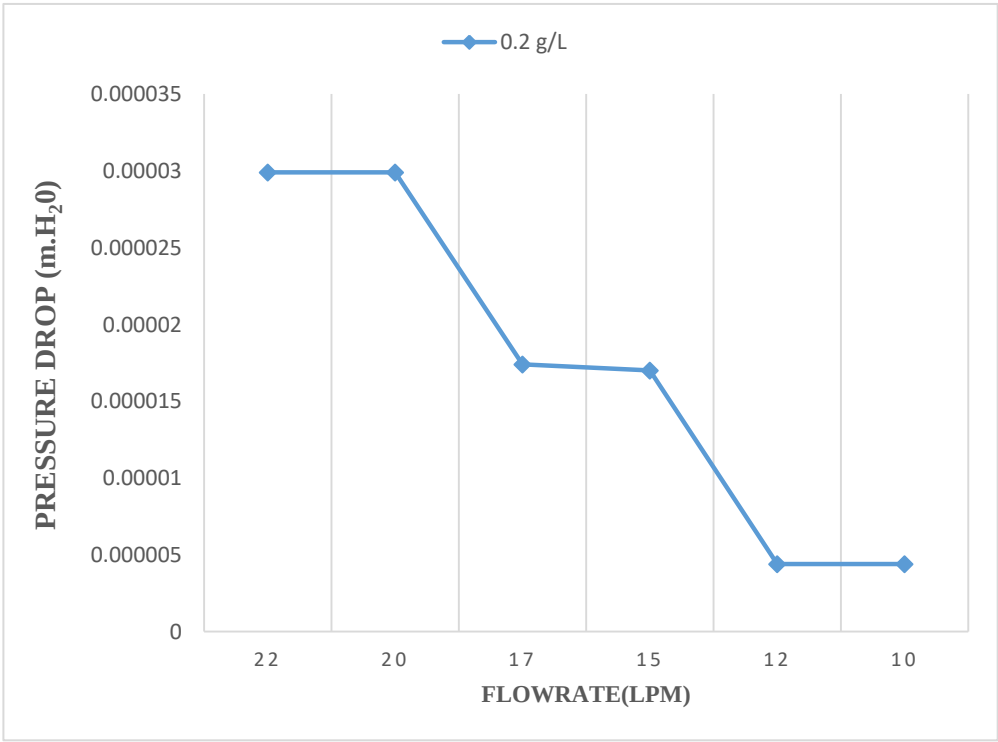


Fig 4.3: Pressure drop graph for 0.2 g/L xanthan gum

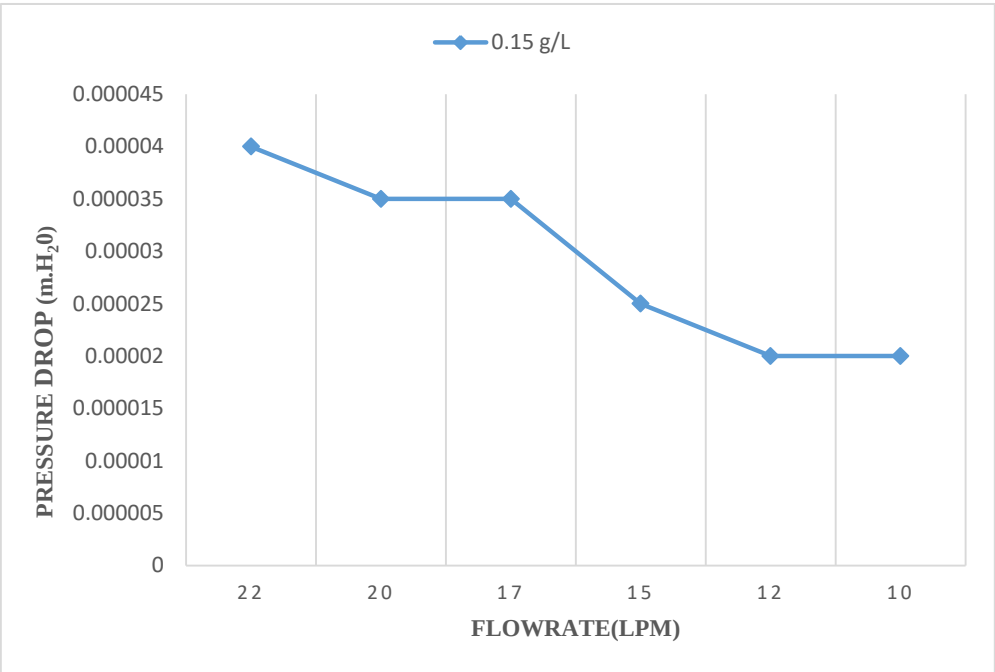


Fig 4.4: Pressure drop graph for 0.15 g/L of xanthan gum

For the same flowrates it has been observed that when the concentrations of the gum increases the frictional pressure drop decreases. This is due the flow becomes gradually laminar when concentrations increases. The eddy formations becomes lower and frictional

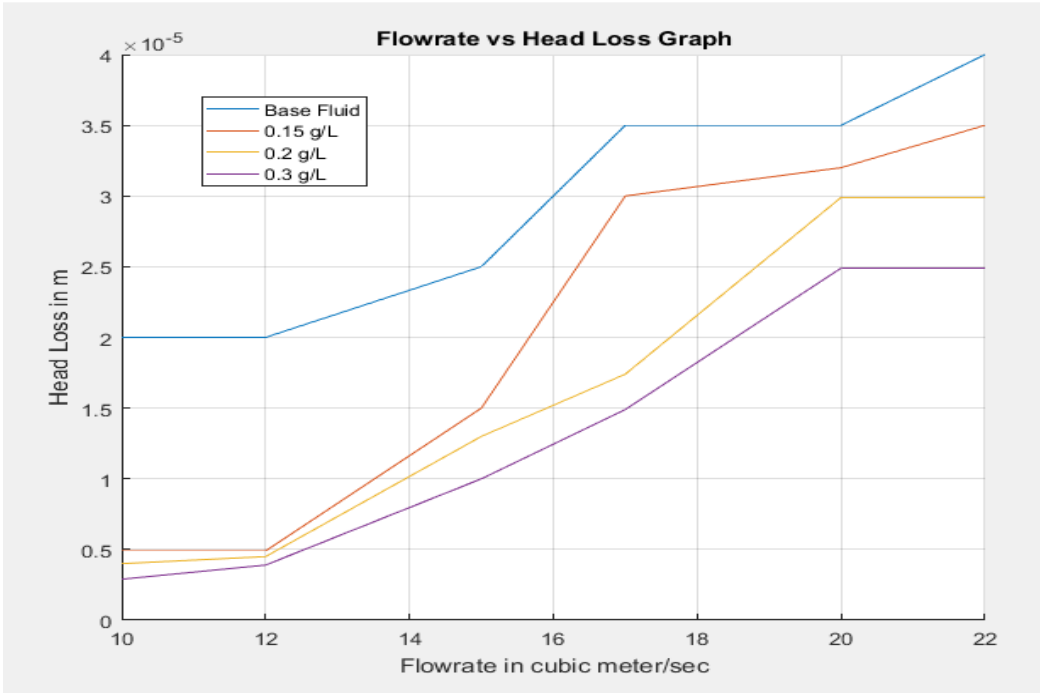


Fig 4.5: Flowrate vs head loss graph (MATLAB)

pressure drop due to eddy loss decreases. The flow becomes turbulent to laminar. We know eddy formation induces pressure drop by wake zone. By increasing concentrations the friction of the solution with the wall shear reduces as the fluid becomes slick. So, the best concentration is 0.3 g/L of the gum to achieve the best effect of viscoelasticity with a minimum possible flowrate (10 LPM) as minimum flowrate imparts minimum wall shear.

Wall shear has a huge effect in drag. The higher the wall shear ,the higher the drag. Adding a additives to the base fluid will reduce the wall shear and reduces eddy formation which will further decrease the energy dissipation rate. The lesser the energy the more energy will be saved. Further the increase in pressure drop saving increased with respect to increased concentration with decreasing the flowrate. This phenomena has been showed to a MATLAB for both xanthan gum concentrations and base fluid (Fig 4.5, Fig 4.7) and a bar chart (Fig 4.6) by combining the effect of flowrate and concentrations.

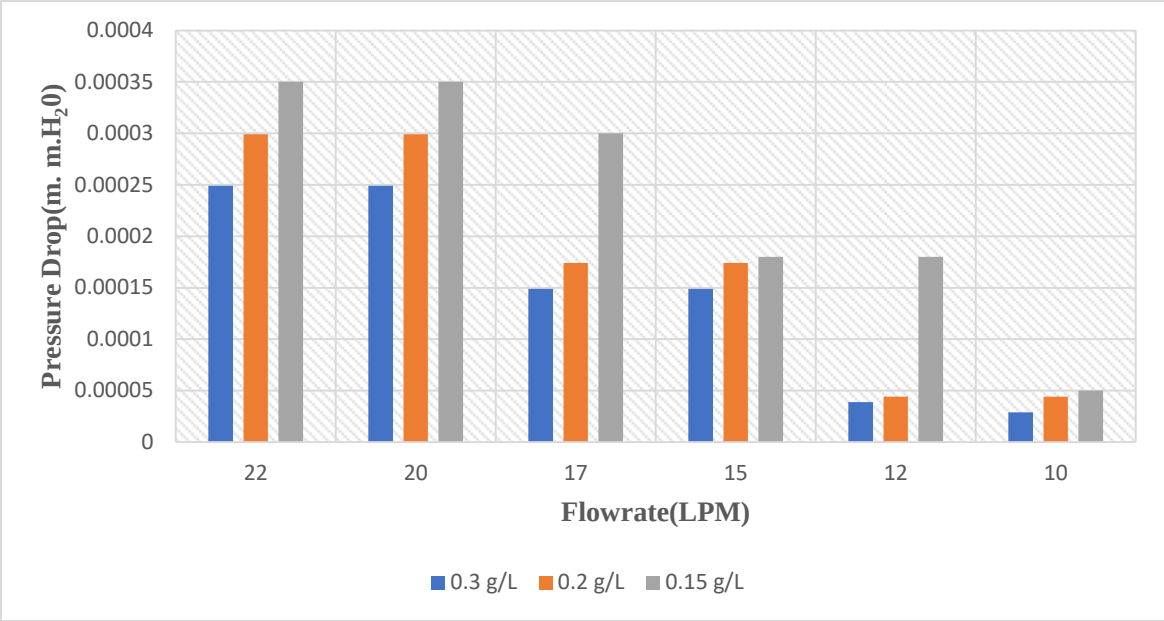


Fig 4.6: Bar chart of frictional pressure drop against flowrate and concentration

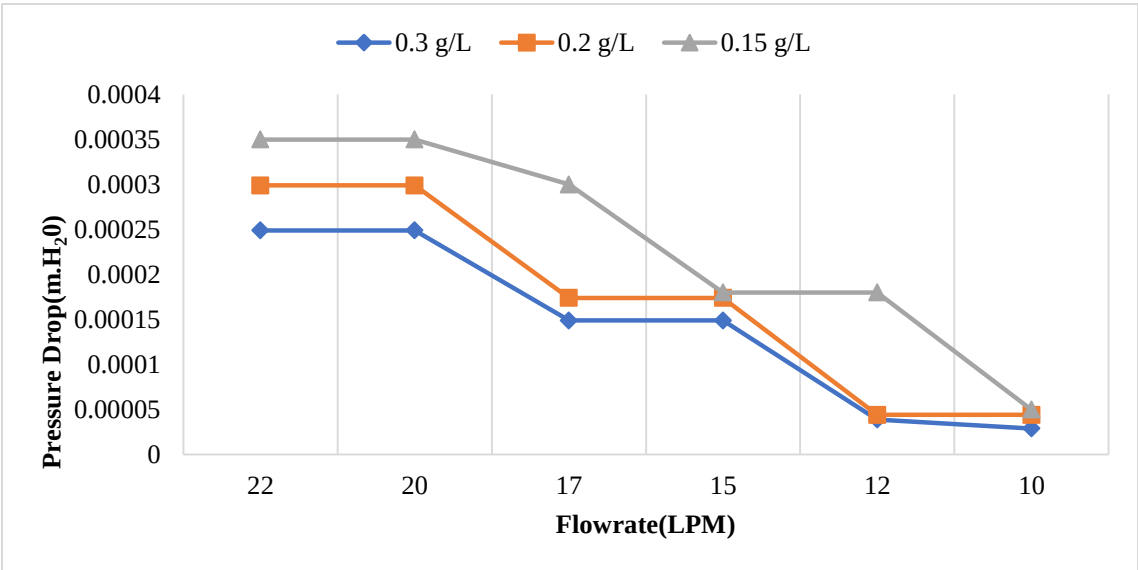


Fig 4.7: Flowrate vs pressure drop graph

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 modified XG (xanthan gum) mixtures are shown in Fig 4.7 for different concentrations. The figure clearly shows that

with an increase in the concentration of the gum from 0.15 g/L to 0.3 g/L, the pressure drop decreased up to 90% compared to base fluid(water).

4.3 In Case of Heat Transfer Rate:

From data sheet (Table A2, A4, A6,A8) and graph (Fig 4.8, 4.9, 4.10, 4.11) it has been observed that for a fixed concentration when flowrate increases the heat transfer rate also increases due to pseudoplasticity and better mixing effect. But when concentration increases the heat transfer rate decreases due to viscoelasticity (Fig 4.9, 4.10, 4.11). This is because higher flowrate leads to increased turbulence in the fluid due to lesser viscosity, which improves heat transfer by prompt mixing and enhancing the contact between the fluid and the effective heat transfer surface area. The higher flowrate creates more eddy in the fluid which leads to enhance mixing. The higher the mixing and pseudoplasticity the more will be the heat transfer rate. From the combined graph (Fig 4.12) it has been observed that when the concentration of the solution increases the heat transfer rate decreases. This is the complete opposite scenario of the flowrate. 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 decreases. From bar chart (Fig 4.13) it has been observed that for base fluid water the heat transfer rate is maximum for the highest flowrate (22 LPM) for better mixing effect and lowest possible concentration(0.15 g/L) for increased turbulence. The eddy formation & turbulence is maximized due to pure base fluid water and due to maximum flowrate the turbulence and eddy formation is also at maximum rate. So maximum heat transfer can be obtained by 0.15 g/L of the gum with maximum flowrate (22 LPM) which is the fully opposite scenario in case of frictional effect.

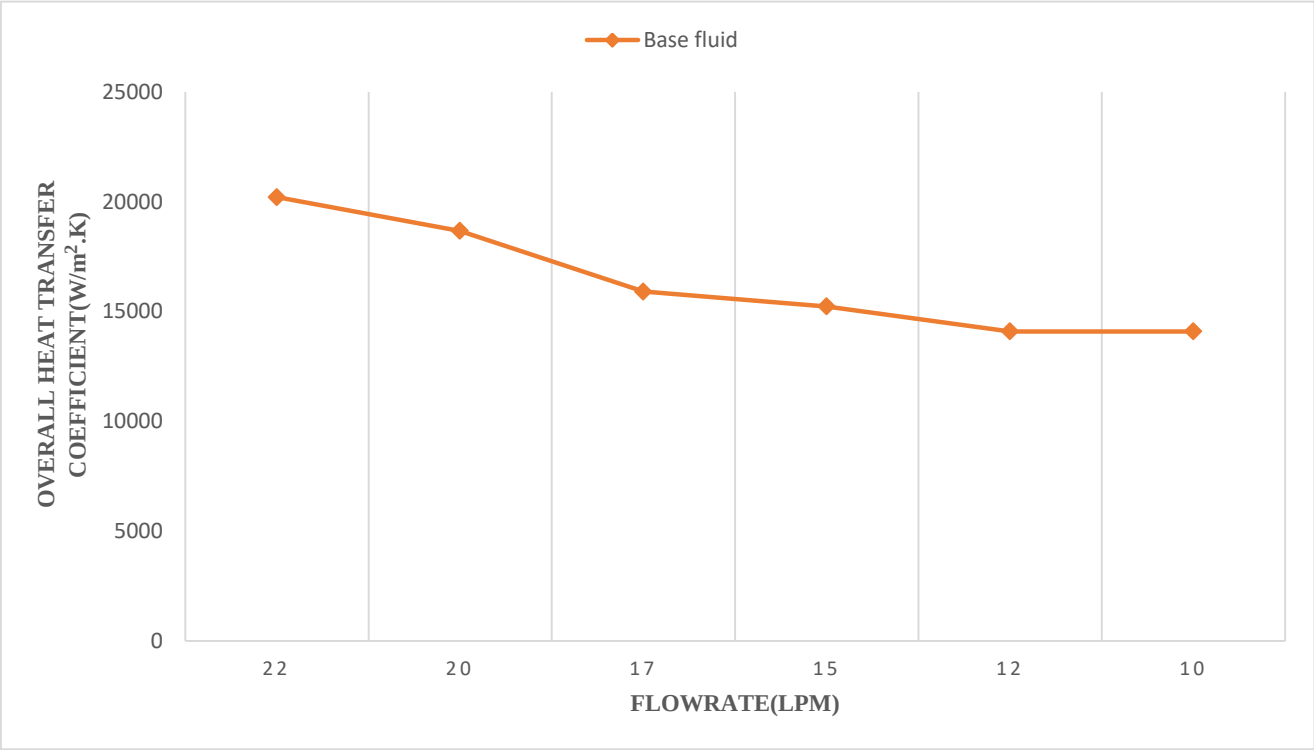


Fig 4.8: Heat transfer rate for base fluid

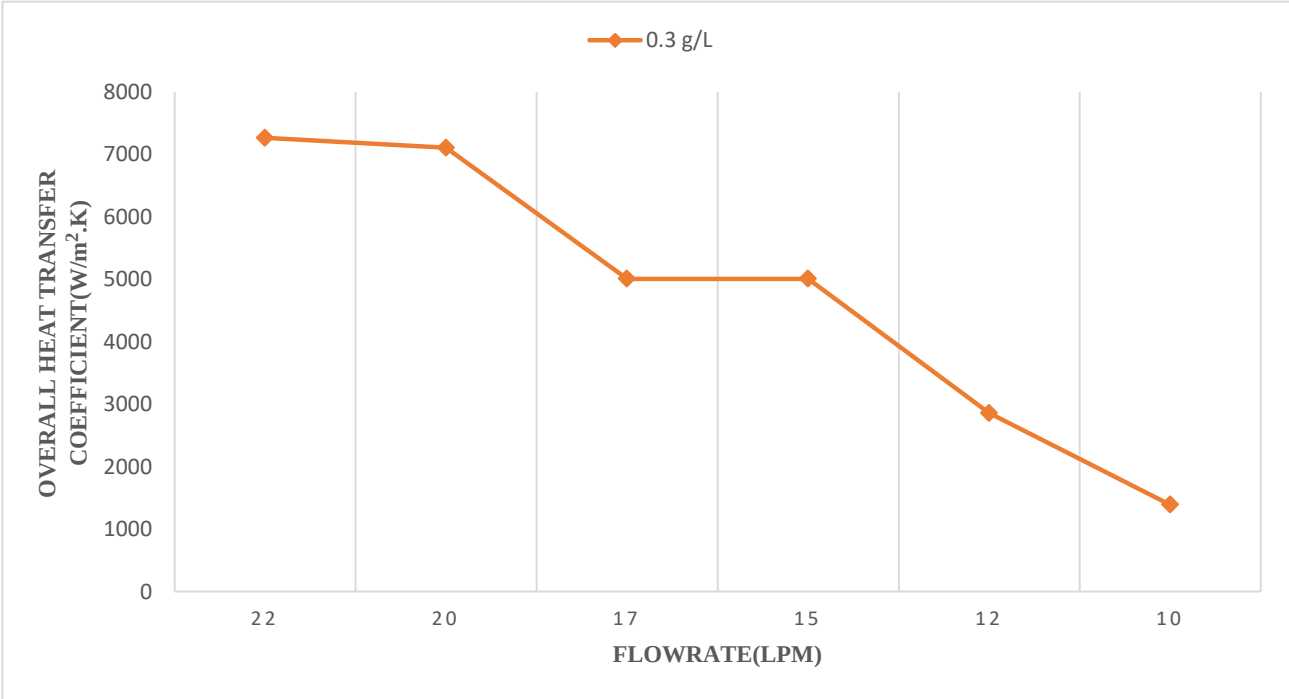


Fig 4.9: Heat transfer rate for concentration 0.3 g/L xanthan gum

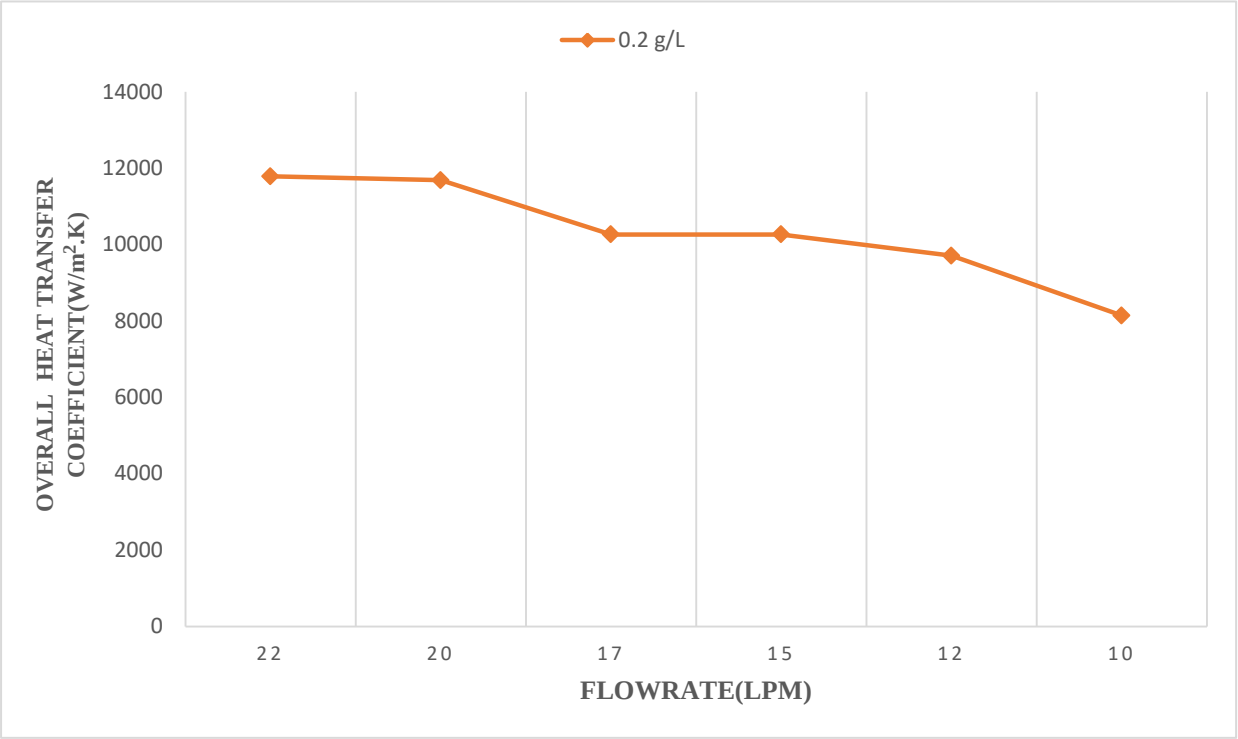


Fig 4.10: Heat transfer rate for concentration 0.2 g/L xanthan gum

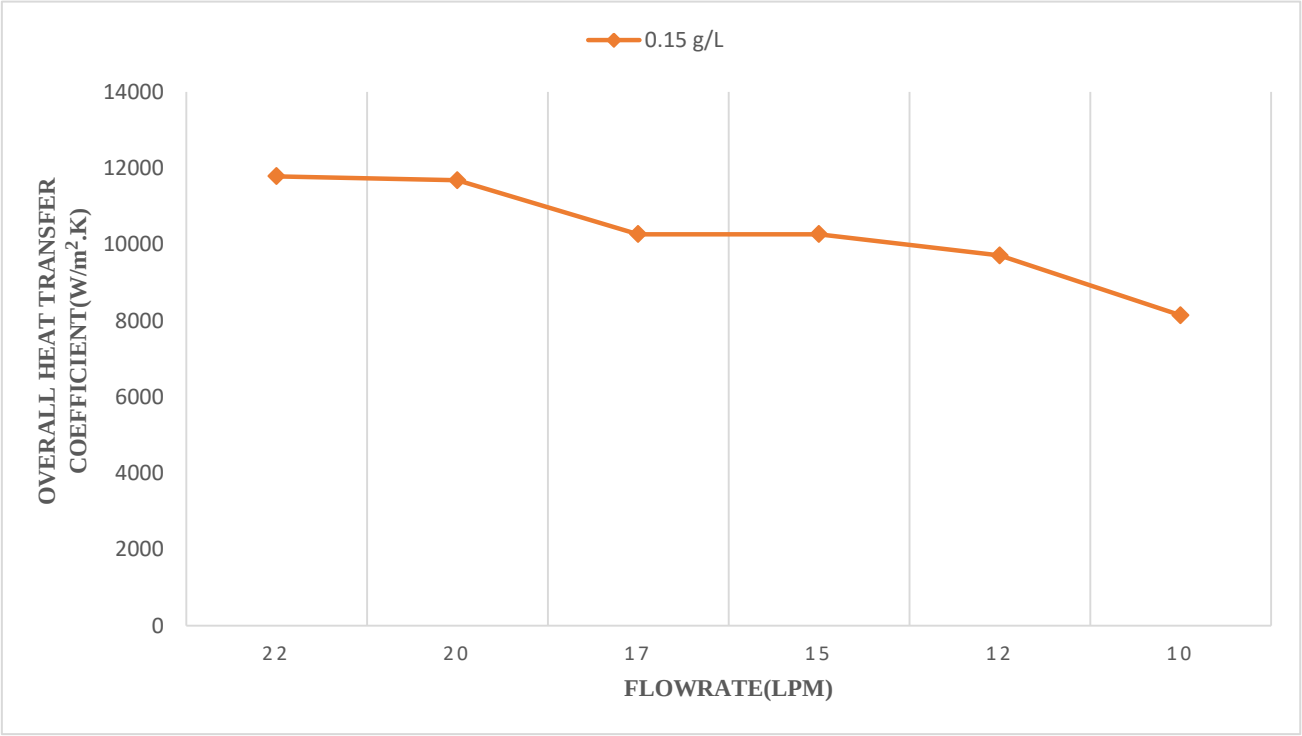


Fig 4.11: Heat transfer rate for concentration 0.15 g/L xanthan gum

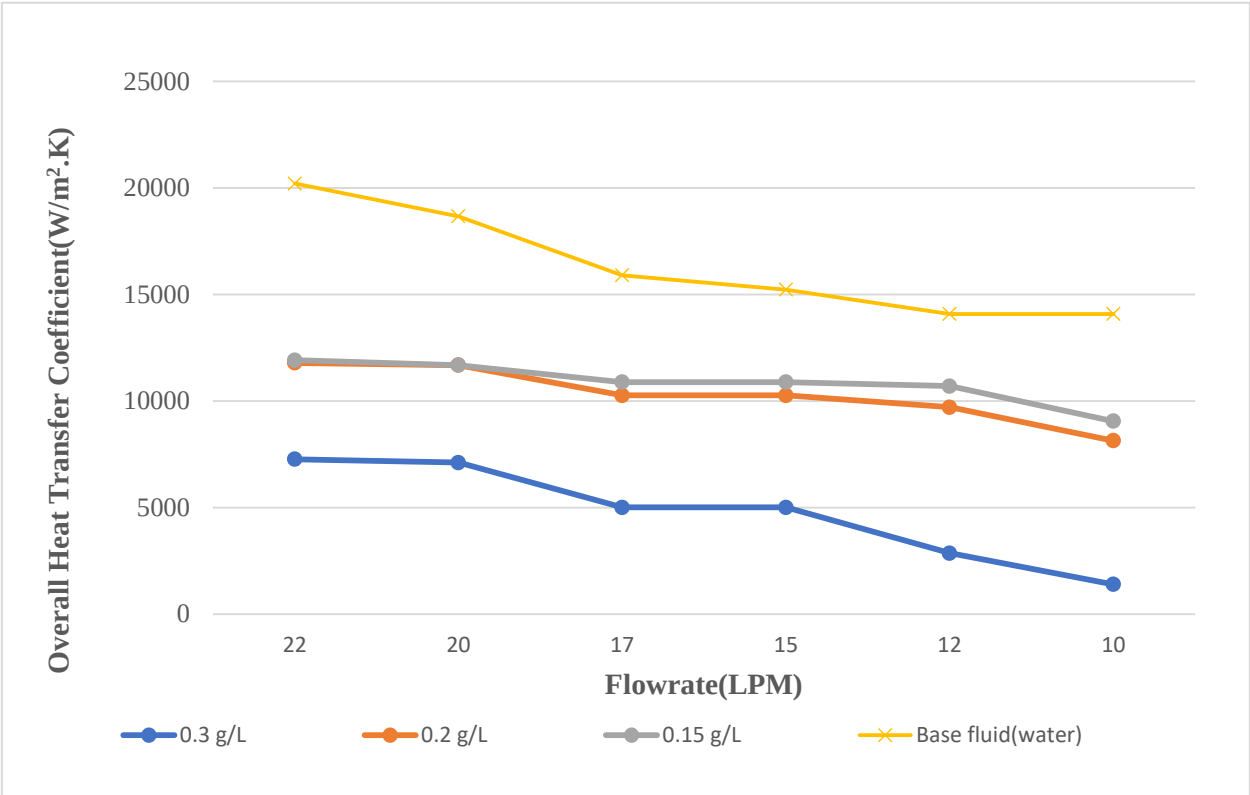


Fig 4.12: Flowrate vs heat transfer rate graph

It is clear from the trend graph that (Fig 4.12) heat transfer rate tends to reduce when concentration increases due to eddy dampening effect. This is due to reduction in turbulence. The maximum heat transfer rate is marked at 0.15 g/L of xanthan gum for 22 LPM flowrate. 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). It should be notified that above 0.3 g/L the flow tends to seize so it is the maximum possible concentraton for this setup or threshold point. Fig 4.13 depicts the comparison of the results for different concentrations and flowrates.

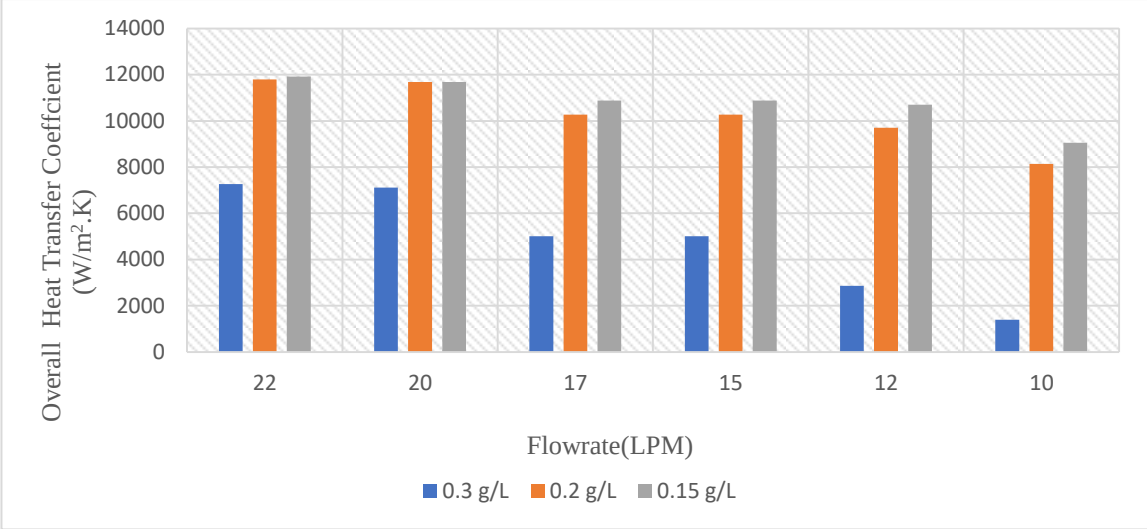


Fig 4.13: Convective heat transfer coefficient against flowrate and concentration

CHAPTER 5

CONCLUSIONS

5.1 Conclusions and Discussions:

The effects of utilizing modified xanthan gums mixtures for drag reduction in water flow in horizontal pipes were examined. The effects of the rigid xanthan gum, flowrate and water velocity on the flow pattern, pressure gradient, and drag reduction rate were analyzed. The following conclusions can be drawn from this study that from above flowrate range (22 LPM -10 LPM) the heat transfer rate decreases as the concentration increases and pressure drop also decreases. So from the view of cost saving the best concentration and flowrate can be selected as 0.3 g/L for 10 LPM. But from viewpoint of heat transfer rate the best conditions are 0.15 g/L at 22 LPM and the base fluid will be best for maximum heat transfer. 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, in 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 and drag reduction rate were analyzed. The effects of utilizing modified xanthan gums mixtures for drag reduction in water flow in horizontal pipes were examined. The effects of the rigid xanthan gum, flowrate and water velocity on the flow pattern, pressure gradient, and drag reduction rate were analyzed. The following conclusions can be drawn from this study that from above flowrate range (22 LPM -10 LPM) the heat transfer rate decreases as the concentration increases and pressure drop also decreases. So, from the view of cost saving the best concentration and flowrate can be selected as 0.3 g/L for 10 LPM. But if we want better heat transfer so from viewpoint of heat transfer rate the best conditions are 0.15 g/L at 22 LPM and the base fluid will be best for maximum heat transfer. However the study shows that from above flowrate range (22 LPM –10 LPM) the heat transfer rate decreases as the concentration increases and pressure drop also decreases. So, from the view of cost saving the best concentration and flowrate can be selected as 0.3 g/L for 10 LPM. If we see from the base fluid the head loss reduced drastically for this concentration. Further concentration increasing is not possible due to the increase in viscosity of the solution seize the flow and pump impeller. As the Reynolds number decreases and enters

laminar flow, the drag-reducing agent shows a drag reduction effect. The greater the Reynolds number, the more obvious the drag reduction effect. When the Reynolds number is quite large and the fluid shear stress is sufficient to destroy the molecular chain structure of the drag reducer, the DRAs degrades and the drag reduction effect decreases instead. It has even completely lost its drag reduction effect. The added concentration of the DRA affects the thickness of the elastic bottom layer formed in the pipeline. The greater the concentration, the thicker the elastic bottom layer, and the better the drag reduction effect. In theory, when the elastic bottom layer reaches the axis of the tube, the drag reduction reaches the limit, that is, the maximum drag reduction. The drag reduction effect is also related to factors such as oil viscosity, pipeline diameter, water content etc.

5.2 Precaution:

- The gum powder should be added very slowly with continuous stirring
- The gum should be kept in air tight container not to coagulate
- The heat exchanger should be rinse with pure water before the use of every time
- Anti-coagulating agent may be used if necessary
- The loss of heat to surroundings should be kept in mind so the temperature of the hot side fluid should be raised some more like 2-3 degree from standard temperature before the running of system
- After each time of taking data the system should be kept at rest to fully cool down before taking other data.
- The heater should be kept as dry as possible.
- The pressure gauge should be calibrated
- The weight of the gum should be taken very carefully and the weight of the gum that stick to paper should be considered so an allowance should be kept
- During the fabrication of the heat exchanger MS should be instead of SS
- The whole system should be wrapped with glass wool if PVC pipe is used. But if CPVC is used no wrapping is required

5.3 Characterization:

Characterization interprets the physical and chemical properties of a material of interest. The characterization of xanthan gum solution has the characteristics of low concentration and high viscosity (the viscosity of 1% aqueous solution is equivalent to 100 times that of gelatin

and it is an efficient thickener. The xanthan gum aqueous solution has a high viscosity under static or low shear action or viscoelastic fluid. Under high shear action the viscosity drops sharply but the molecular structure does not change. The viscosity of the Xanthan gum solution will not change greatly with the change of temperature.

- Xanthan gum is a good DRA.
- It reduces the pressure drop.
- After a certain concentration it becomes very viscous and further increasing would seize the system.
- It hinders the heat transfer rate so it is not a good heat transfer enhancing element.
- It is a long chain polymer.
- It coagulates very easily.
- It should be used in PPM range.
- Its solution is pseudoplastic in nature.

REFERENCES

1. J. K. Fink, “Drag reducers”, Petroleum Engineers Guide to Oil Field Chemicals and Fluids, DOI: 10.1016, (pp.379-389), 2012”.
2. J. Eds and F. Karl, “Gulf Professional Publishing”, 2012, pp.379-389. (DOA: 9-Sept-2024).
3. L. Zhiyu and F. Fan, “Drag reduction mechanism of viscoelastic slick water fracturing fluid in tortuous and rough fractures”, Journal of Geofluids, vol. 2021, 5827114.
4. <https://www.sciencedirect.com/topics/engineering/drag-reducer> (DOA: 9-Sept-2024).
5. W. Aiqin and W. Wenbo, “Gum-g-copolymers: synthesis, properties, and applications”, Polysaccharide Based Graft Copolymers, chapter 5, pp. 149-203, April 2013.
6. <https://www.liquidpower.com/what-is-dra/about-dra-and-how-it-works> (DOA: 9-Sept-2024).
7. A. C. Yunus and M. C. John, “Fluid Mechanics”, McGraw Hill Education, 3rd edition, 2014.
8. A. Jaafar and R. J. Poole, “Drag reduction of biopolymer flows”, Journal of Applied Sciences, vol. 11, pp. 1544-1551, 2011.
9. C. Lawrence, O. Edomwonyi, I. D. Abdulwahid and Y. Nurudeen, “Effect of oil on the performance of bopolymers as drag reducers in fresh water flow”, Journal of Heliyon, vol.7, 2021.
10. C. Marina, S. Mattia, L. Romano and S. Alfredo, “Turbulent drag reduction by biopolymers in large scale pipes”, Journal of Fluids Engineering, vol. 137, 2015, DOI: 10.1115/1.4028799.
11. J. Atle, O. Valery and T. Victor, “Comparative study on turbulent drag reduction characteristics of flexible polymer and rigid polymer”, International Journal of Fluid Mechanics Research, vol. 49, pp. 1-18, 2022.
12. J. K. Bashar, S. M. Omar, S. S. A. Sajda and Majdi, “Effect of rigid xanthan gums on flow and pressure drops to improve drag reduction rates in horizontal pipe flow”, Journal of Chemical Engineering, vol. 7(2), pp. 36, 2023.
13. J. Bassam and Z. Yousef, “The use of drag reduction agent and a detergent for drag reduction in circulatory vertical pipe flow, polymer-plastics technology and engineering”, Journal of Polymer-Plastics Technology and Engineering, vol. 45, 2006.
14. S. Farid and S. Ahmed, “Drag reduction in single phase crude oil flow-a mini review”, Journal of Pipeline Science and Engineering, vol.02, 2022.
15. I. Sreedhar and R. Saketharam, “Drag reduction studies in water using polymers and other combinations”, Materials Today: Proceedings 24, pp.601-610, 2020.

16. G. G. Charles and R. F. John, "Drag reduction on a rotating disk using a polymer additive", *Journal of Viscous Drag Reduction*, pp. 251-263, 1969.
17. G. K. Patterson, J. L. Jakin and J. M. Rodriguez, 'Drag reduction polymer solutions, soap solutions and solid particle suspensions in pipe flow', *Industrial and Engineering Chemistry*, vol. 61(1), pp. 22-30, 1969.
18. Pruitt, G.T. Whittsitt, N. F. Crawford and H. R. Western, "Company Report to NASA", *Contr. NAS7-369*, Sept-1966.
19. R. B. Ganvir, P. V. Walke and V. M. Kriplani, "Heat transfer characteristics in nanofluid-a review", *Renewable and Sustainable Energy Reviews*, vol.75, pp.451-460, 2016.
20. S. Mostafa, S. Meltem and K. Ali, "Pool boiling heat transfer characteristics of non-Newtonian xanthan gum solutions", *Experimental Thermal and Fluid Science*, vol.70, pp.77-84, 2016.
21. S. D. Joshi A, and E. Bergles, 'Experimental study of laminar heat transfer to in-tube flow of non-Newtonian fluids', *Journal of Heat Transfer*, vol.102(3), pp. 397-401, 1980.
22. H. G. Lew, "Non-Newtonian flow and heat transfer", *Journal of The Franklin Institute*, vol. 285(4), pp.319, 1968.
23. K. N. Anil and V. A. Venu, "Heat transfer enhancement using non-Newtonian nanofluids in a shell and helical coil heat exchanger", *Experimental Thermal and Fluid Science*, pp.132-142, vol 90, 2018.
24. S. Rozzi, R. Massini, G. Paciello, G. Pagliarini, S. Rainieri and A. Trifiro, "Heat treatment of fluid foods in a double pipe heat exchanger: comparison between smooth and helically corrugated wall tubes", *Journal of Food Engineering*, vol.79, pp. 49-254, 2006.
25. A. Jasim, H. S. Ramaswamy and M.O. Ngadi, "Rheological characteristics of arabic gum in combination with guar and xanthan gum using response surface methodology: effect of temperature and concentration", *International Journal of Food Properties*, vol. 8, 2007.
26. J. W. Hoyt, "The effect of additives on fluid friction", *Journal of Basic Engineering*, pp. 258-285, 1972.
27. H. Mehdi and E. C. Peter, "Drag reduction behavior of hydrolyzed polyacrylamide/xanthan gum mixed polymer solutions", *Journal of Petroleum Science*, vol.14, pp. 412-423, 2017.
28. H. Tochigi, D. Nakamura, S. Ogata and K. Watanabe, "Drag reduction of xanthan gum solutions", *European Drag Reduction and Flow Control Meeting – EDRFCM*, pp. 69-70.
29. A. I. Dosumu, O. L. C. Edomwonyi, N. Yusuf, and Abubakar, "Drag reduction performance of natural gums in oil-water flow through pipes of different diameters", *Journal of Engineering and Environmental Sciences*, vol. 4(1), pp. 17-26. 2019.

30. H. W. Bewersdorff and R. P. Singh, “Turbulent drag reduction and relaminarisation by xanthan gum”, International Conference on Turbulence Management and Relaminarisation, pp. 333-348, 1987.
31. G. Haoyu, S. Pengfei, L. Hao, H. Haibao, W. Jun, Z. Tao and X. Luo, “Drag reduction performance of binary polyacrylamide and xanthan gum solution”, Journal of Physics of Fluids, vol.36, 2024.
32. B. Zhu, W. Zhao, M. Li, Y. Yuan, W. Yu and C. Li “Experimental study on drag reduction and anti-shearing characteristics of xanthan gum solution with NaCl”, Journal of Experiments in Fluid Mechanics”, vol 32(5), pp. 61-66, 2018.
33. L. Entian, Z. Lehua, L. Yingping, F. Liutong, Z. Shushi and L. Songling “Investigation of the drag reduction of hydrolyzed polyacrylamide–xanthan gum composite solution in turbulent flow”, Asia Pacific Journal of Chemical Engineering, DOI 10.1002/apj.2791, 2022.
34. S. Pengfei, D. Wei, H. Haibao, F. Jiaying and X. Luo, “Experimental study on drag reduction characteristics of diutan gum solution by slit injection”, Journal of Theoretical and Applied Mechanics”, vol. 54(5), pp. 1254-1263.
35. <https://dalangpump.en.made-in-china.com/product> (DOA: (01 May,2024).
36. K. Muthamizhi, P. Kalaichelvi, A. Arunagiri and A. Rudhra, “Measurement and model validation of specific heat of xanthan gum using Joules Calorimeter method”. International Journal of Research in Engineering and Technology, vol. 2, pp. 232-238, 2013.

APPENDIX:

278-1

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Table A1: pressure drop for base fluid (water)

Flowrate (LPM)	% w/w	T _{h,in} (°C)	T _{h,out} (°C)	T _{c,in} (°C)	T _{c,out} (°C)	U (W/m ² .K)
22	—	46	40	35	39	20206
20		47	44	38	42	18667
17	—	47	45	38	42	15907
15	—	47	40	36	39	15228
12	—	47	46	38	42	14090
10	—	47	46	38	42	14090

Table A2: Heat transfer rate for base fluid (water)

Flowrate LPM	% w/w	P _{in} (N/m ²)	P _{out} (N/m ²)	ΔP (N/m ²)	h _L (m)
22	—	0.45	0.05	0.4	0.00004
20	—	0.4	0.05	0.35	0.000035
17	—	0.4	0.05	0.35	0.000035
15	—	0.35	0.1	0.25	0.000025
12	—	0.35	0.15	0.20	0.000020
10	—	0.35	0.15	0.20	0.000020

Table A3 :Pressure drop for concentration 0.3 g/L or 0.0003 kg/L

Flowrate (LPM)	% w/w	T _{h,in} (°C)	T _{h,out} (°C)	T _{c,in} (°C)	T _{c,out} (°C)	U (W/m ² .K)
22	0.0003	47	44	35	38	7267
20	0.0003	46	45	35	38	7108
17	0.0003	46	45	36	38	5009
15	0.0003	46	45	36	38	5009
12	0.0003	46	44	37	38	2861
10	0.0003	47	44	37.5	38	1393

Table A4 : Heat transfer rate for concentration 0.3 g/L or 0.0003 kg/L

Flowrate LPM	% w/w	P _{in} (N/m ²)	P _{out} (N/m ²)	ΔP (N/m ²)	h _L (m)
22	0.0003	0.35	0.1	0.1	0.0000249
20	0.0003	0.35	0.1	0.1	0.0000249
17	0.0003	0.5	0.25	0.15	0.0000149
15	0.0003	0.6	0.45	0.15	0.0000149
12	0.0003	0.64	0.6	0.04	0.0000039
10	0.0003	0.95	0.92	0.03	0.0000029

Table A5 : Heat transfer rate for concentration 0.2 g/L or 0.0002 kg/L

Flowrate (LPM)	% w/w	T _{h,in} (°C)	T _{h,out} (°C)	T _{c,in} (°C)	T _{c,out} (°C)	U (W/m ² .K)
22	0.0002	47	41	38	40	11787
20	0.0002	46	40	37	39	11685
17	0.0002	47	41.5	38	40	10268
15	0.0002	47	41.5	38	40	10268
12	0.0002	50	41	38	40	9709
10	0.0002	49	42	38	40	8141

Table A6 : Pressure drop concentration 0.2 g/L or 0.0002 kg/L (% w/w)

Flowrate LPM	% w/w	P _{in} (N/m ²)	P _{out} (N/m ²)	ΔP (N/m ²)	h _L (m)
22	0.0002	0.35	0.05	0.3	0.0000299
20	0.0002	0.35	0.05	0.3	0.0000299
17	0.0002	0.35	0.175	0.175	0.0000174
15	0.0002	0.7	0.55	0.175	0.0000170
12	0.0002	0.8	0.75	0.045	0.0000044
1	0.000	0.8	0.75	0.045	0.0000044

Table A7 : Heat transfer rate for concentration 0.15 g/L or 0.00015 kg/L (% w/w)

Flowrate (LPM)	% w/w	T _{h,in} (°C)	T _{h,out} (°C)	T _{c,in} (°C)	T _{c,out} (°C)	U (W/m ² .K)
22	0.00015	46	40	35	38	11915
20	0.00015	46	40	37	39	11685
17	0.00015	46	40	37	39	11668
15	0.00015	46	40	37	39	10885
12	0.00015	48	40	35	38	10704
10	0.00015	45	40	36	38	9053

Table A8 : Pressure drop for concentration 0.15 g/L or 0.00015 kg/L (% w/w)

Flowrate LPM	% w/w	P _{in} (N/m ²)	P _{out} (N/m ²)	ΔP (N/m ²)	h _L (m)
22	0.00015	0.4	0.05	0.35	0.000035
20	0.00015	0.4	0.35	0.35	0.000035
17	0.00015	0.5	0.2	0.3	0 00003
15	0.00015	0.6	0.15	0.15	0.000018
12	0.00015	0.65	0.6	0.05	0.0000049
10	0.00015	0.65	0.6	0.05	0.0000049

CALCULATIONS

ΔP =Pressure difference across the heat exchanger

$$\Delta T1 = T_{h,in} - T_{c,in} \dots\dots\dots (1)$$

$$\Delta T2 = T_{h,out} - T_{c,out} \dots\dots\dots (2)$$

$$LMTD, \Delta T_M = \frac{\Delta T1 - \Delta T2}{\ln\left(\frac{\Delta T1}{\Delta T2}\right)} \dots\dots\dots (3)$$

$$\text{Heat transfer rate, } Q = m_c \times C_{pc} \times (T_{c,out} - T_{c,in}) \dots\dots\dots (4)$$

$$\text{Maximum heat transfer rate, } Q_{max} = m_c \times C_{pc} \times (T_{h,in} - T_{c,in}) \dots\dots\dots (5)$$

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

$$\text{Overall heat transfer coefficient, } U = \frac{Q}{AF\Delta T_M} \dots\dots\dots (6)$$

$$\text{Head loss in pipe for laminar flow, } h_L = \frac{\Delta P_L}{\rho g}$$

For Base Fluid

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Head Loss Calculations

$$\rho_w = 1000 \text{ kg/m}^3$$

$$\text{Pressure at the inlet} = 0.45 \text{ kg/cm}^2 \text{ or bar}$$

$$\text{Pressure at outlet} = 0.05 \text{ kg/cm}^2 \text{ or bar}$$

$$\text{Pressure drop} = (0.45 - 0.05) = 0.4 \text{ kg/cm}^2 \text{ or bar}$$

$$\text{Head loss} = h_L = \frac{\Delta P_L}{\rho g} = \frac{0.25}{1000.3 \times 9.81} = 0.0004 \text{ m.H}_2\text{O}$$

Heat transfer coefficient calculations

$$\text{Specific heat of water, } c_{p,\text{water}} = 4186.8 \text{ J/kg.K}$$

At 22 L/min in the outer tube side and the 22 L/min in the inner tube side,

$$\dot{m}_h = (\rho \times V/t) \text{ kg/s} = (1000 \times 22 \times 10^{-3})/60 \text{ kg/s} = 0.366 \text{ kg/sec}$$

$$\dot{m}_c = (\rho \times V/t) \text{ kg/s} = (1000.3 \times 22 \times 10^{-3})/60 \text{ kg/s} = 0.367 \text{ kg/sec}$$

$$T_{c,in} = 35^\circ\text{C}$$

$$T_{c,out} = 39^\circ\text{C}$$

$$T_{h,in} = 46^\circ\text{C}$$

$$T_{h,out} = 40^\circ\text{C}$$

$$\Delta T1 = (T_{h,in} - T_{c,in}) = (46 - 35) = 11^\circ\text{C}$$

$$\Delta T2 = (T_{h,out} - T_{c,out}) = (40 - 39) = 1^\circ\text{C}$$

$$A_0 = \pi d_o l \text{ m}^2 = 3.1416 \times 0.0508 \times 0.457 \text{ m}^2 = 0.07 \text{ m}^2 \text{ [} d_o = \text{Outer diameter of inner tube]}$$

$$\text{Thermal balance, } Q_c = m_c \times C_{pc} \times (T_{c,out} - T_{c,in}) = 0.366667 \times 4186 \times (39 - 35) = 6042 \text{ W}$$

$$\text{Log mean temperature difference, } \Delta T_m = (\Delta T1 - \Delta T2) \ln(\Delta T1/\Delta T2) = (11 - 1) / \ln(11/1) = 4.17^\circ\text{C}$$

$$\text{Overall heat transfer coefficient, } U = Q_c / A \Delta T_m = 6042 / (0.07 \times 4.17) = 20206 \text{ W/m}^2 \cdot \text{K}$$

Head Loss Calculations

$$\rho_w = 1000 \text{ kg/m}$$

$$\text{Pressure at the inlet} = 0.45 \text{ kg/cm}^2 \text{ or bar}$$

$$\text{Pressure at outlet} = 0.05 \text{ kg/cm}^2 \text{ or bar}$$

$$\text{Pressure drop} = (0.45 - 0.05) = 0.4 \text{ kg/cm}^2 \text{ or bar}$$

$$\text{Head loss} = h_L = \frac{\Delta P_L}{\rho g} = \frac{0.25}{1000.3 \times 9.81} = 0.0004 \text{ m.H}_2\text{O}$$

Heat transfer coefficient calculations

$$\text{Specific heat of water, } c_{p,\text{water}} = 4186.8 \text{ J/kg.K}$$

At 22 L/min in the outer tube side and the 22 L/min in the inner tube side,

$$\dot{m}_h = (\rho \times V/t) \text{ kg/s} = (1000 \times 22 \times 10^{-3})/60 \text{ kg/s} = 0.366 \text{ kg/sec}$$

$$\dot{m}_c = (\rho \times V/t) \text{ kg/s} = (1000.3 \times 22 \times 10^{-3})/60 \text{ kg/s} = 0.367 \text{ kg/sec}$$

$$T_{c,\text{in}} = 35^\circ \text{C}$$

$$T_{c,\text{out}} = 39^\circ \text{C}$$

$$T_{h,\text{in}} = 46^\circ \text{C}$$

$$T_{h,\text{out}} = 40^\circ \text{C}$$

$$\Delta T_1 = (T_{h,\text{in}} - T_{c,\text{in}}) = (46 - 35) = 11^\circ \text{C}$$

$$\Delta T_2 = (T_{h,\text{out}} - T_{c,\text{out}}) = (40 - 39) = 1^\circ \text{C}$$

$$A_0 = \pi d_o l \text{ m}^2 = 3.1416 \times 0.0508 \times 0.457 \text{ m}^2 = 0.07 \text{ m}^2 \text{ [} d_o = \text{Outer diameter of inner tube]}$$

$$\text{Thermal balance, } Q_c = \dot{m}_c \times c_{p,c} \times (T_{c,\text{out}} - T_{c,\text{in}}) = 0.366667 \times 4186 \times (39 - 35) = 6042 \text{ W}$$

$$\text{Log mean temperature difference, } \Delta T_m = (\Delta T_1 - \Delta T_2) \ln(\Delta T_1 / \Delta T_2) = (11 - 1) / \ln(11 / 1) = 4.17^\circ \text{C}$$

$$\text{Overall heat transfer coefficient, } U = Q_c / A \Delta T_m = 6042 / (0.07 \times 4.17) = 20206 \text{ W/m}^2 \cdot \text{K}$$

For 0.3 g/L of Xanthan gum

Head Loss Calculations

Density of Xanthan gum for concentration of 0.3 g/L:

$$\rho_{xg} = (\text{mass of xanthan gum} + \text{mass of water}) / \text{volume of solution} =$$

$$= (2.4 \times 10^{-3} + 8) / (8 \times 10^{-3})$$

$$= 1000.3 \text{ kg/m}^3$$

$$\text{Pressure at the inlet} = 0.6 \text{ kg/cm}^2 \text{ or bar}$$

$$\text{Pressure at outlet} = 0.45 \text{ kg/cm}^2 \text{ or bar}$$

$$\text{Pressure drop} = (0.6 - 0.45) = 0.15 \text{ kg/cm}^2 \text{ or bar}$$

$$\text{Head loss} = h_L = \frac{\Delta P_L}{\rho g} = \frac{0.15}{1000.3 \times 9.81} = 0.0000149 \text{ m.solution}$$

$$\text{Head Loss, } \rho_{\text{soln}} \times g \times h_{\text{soln}} = \rho_w \times g \times h_w \text{ or } h_w = \frac{1000.3 \times 0.0000249}{1000} = 0.0000249 \text{ m.h}_2\text{O}$$

Heat transfer coefficient calculations

$$\text{Specific heat of water, } c_{p,\text{water}} = 4186.8 \text{ J/kg.K}$$

[19] Specific heat of Xanthan gum solution for concentration 0.3 g/L = 0.0003 kg/L = 4010 J/kg.k [By using the empirical equation $C_p = 98.78575 - 0.6495T - 15.9955X + 0.06TX + 0.001109T^2 - 0.5X^2$ where T = Room temperature in Kelvin and X = concentration(w/w). The specific heat of Xanthan gum does not change for concentration range (0.0625-0.1 % w/w).

Density of Xanthan gum for concentration of 0.3 g/L: [8L water & 2.4 g gum]

$$\rho_{xg} = (\text{mass of xanthan gum} + \text{mass of water}) / \text{volume of solution}$$

$$=(2.4 \times 10^{-3} + 8) / (8 \times 10^{-3})$$

$$=1000.3 \text{ kg/m}^3$$

At 22 L/min in the outer tube side and the 22 L/min in the inner tube side,

$$\dot{m}_h = (\rho \times V / t) \text{ kg/s} = (1000 \times 22 \times 10^{-3}) / 60 \text{ kg/s} = 0.366 \text{ kg/sec}$$

$$\dot{m}_c = (\rho \times V / t) \text{ kg/s} = (1000.3 \times 22 \times 10^{-3}) / 60 \text{ kg/s} = 0.367 \text{ kg/sec}$$

$$T_{c,in} = 36^\circ\text{C} \quad T_{c,out} = 38^\circ\text{C} \quad T_{h,in} = 46^\circ\text{C} \quad T_{h,out} = 45^\circ\text{C}$$

$$\Delta T_1 = (T_{h,in} - T_{c,in}) = (46 - 36) = 10^\circ\text{C} \quad \Delta T_2 = (T_{h,out} - T_{c,out}) = (45 - 38) = 7^\circ\text{C}$$

$$A_0 = \pi d_o l \text{ m}^2 = 3.1416 \times 0.0508 \times 0.457 \text{ m}^2 = 0.07 \text{ m}^2 \text{ [} d_o = \text{Outer diameter of inner tube]}$$

$$\text{Thermal balance, } Q_c = \dot{m}_c \times C_{pc} \times (T_{c,out} - T_{c,in}) = 0.366667 \times 4010 \times (38 - 35) = 2945 \text{ W}$$

$$\text{Log mean temperature difference, } \Delta T_m = (\Delta T_1 - \Delta T_2) \ln(\Delta T_1 / \Delta T_2) = (10 - 7) / \ln(10 / 7) = 8.41^\circ\text{C}$$

$$\text{Overall heat transfer coefficient, } U = Q_c / A \Delta T_m = 4398 / (0.07 \times 8.65) = 5009 \text{ W/m}^2 \cdot \text{K}$$

For concentration 0.2 g/L

Head loss calculation

Density of Xanthan gum for concentration of 0.2 g/L:

$$\rho_{xg} = (\text{mass of xanthan gum} + \text{mass of water}) / \text{volume of solution} =$$

$$= (1.6 \times 10^{-3} + 8) / (8 \times 10^{-3})$$

$$= 1000.2 \text{ kg/m}^3$$

Pressure at the inlet = 0.35 kg/cm² or bar

Pressure at outlet = 0.05 kg/cm² or bar

Pressure drop = (0.35 - 0.05) = 0.3 kg/cm² or bar

$$\text{Head loss} = h_L = \frac{\Delta P_L}{\rho g} = \frac{0.3}{1000.2 \times 9.81} = 0.0000299 \text{ m.solution}$$

$$\text{Head Loss, } \rho_{\text{soln}} \times g \times h_{\text{soln}} = \rho_w \times g \times h_w \text{ or } h_w = \frac{1000.3 \times 0.00003}{1000} = 0.0000299 \text{ m.h}_2\text{O}$$

Heat transfer coefficient calculations

Specific heat of water, $c_{p,\text{water}} = 4186.8 \text{ J/kg.K}$

[19] Specific heat of Xanthan gum solution for concentration 0.3 g/L = 0.0003 kg/L = 4096 J/kg.k [By using the empirical equation $C_p = 98.78575 - 0.6495T - 15.9955X + 0.06TX + 0.001109T^2 - 0.5X^2$ where T = Room temperature in Kelvin and X = concentration(w/w). The specific heat of Xanthan gum does not change for concentration range (0.0625-0.1 % w/w).

Density of Xanthan gum for concentration of 0.2 g/L: [8L water & 1.6 g gum]

$$\rho_{xg} = (\text{mass of xanthan gum} + \text{mass of water}) / \text{volume of solution}$$

$$= (1.6 \times 10^{-3} + 8) / (8 \times 10^{-3})$$

$$= 1000.2 \text{ kg/m}^3$$

At 22 L/min in the outer tube side and the 22 L/min in the inner tube side,

$$\dot{m}_h = (\rho \times V / t) \text{ kg/s} = (1000 \times 22 \times 10^{-3}) / 60 \text{ kg/s} = 0.366 \text{ kg/sec}$$

$$\dot{m}_c = (\rho \times V/t) \text{ kg/s} = (1000.3 \times 22 \times 10^{-3})/60 \text{ kg/s} = 0.367 \text{ kg/sec}$$

$$T_{c,in} = 38^\circ\text{C} \quad T_{c,out} = 40^\circ\text{C} \quad T_{h,in} = 47^\circ\text{C} \quad T_{h,out} = 41^\circ\text{C}$$

$$\Delta T_1 = (T_{h,in} - T_{c,in}) = (47-38) = 11^\circ\text{C} \quad \Delta T_2 = (T_{h,out} - T_{c,out}) = (41-40) = 1^\circ\text{C}$$

$$A_0 = \pi d_o l \text{ m}^2 = 3.1416 \times 0.0508 \times 0.457 \text{ m}^2 = 0.07 \text{ m}^2 \text{ [} d_o = \text{Outer diameter of inner tube]}$$

$$\text{Thermal balance, } Q_c = m_c \times C_{pc} \times (T_{c,out} - T_{c,in}) = 0.366667 \times 4096 \times (40 - 38) = 3004 \text{ W}$$

$$Q_h = \dot{m}_h C_{ph} (T_{h,in} - T_{h,out}) = 0.367 \times 4186.8 \times (47 - 41) = 9217.78 \text{ W}$$

$$\text{Log mean temperature difference, } \Delta T_m = (\Delta T_1 - \Delta T_2) \ln(\Delta T_1/\Delta T_2) = (11 - 1) / \ln(11/1) = 3.64^\circ\text{C}$$

$$\text{Overall heat transfer coefficient, } U = Q_c / A \Delta T_m = 3004 / (0.07 \times 3.64) = 11787 \text{ W/m}^2 \cdot \text{K}$$

Head loss calculation

Density of Xanthan gum for concentration of 0.2 g/L:

$$\begin{aligned} \rho_{xg} &= (\text{mass of xanthan gum} + \text{mass of water}) / \text{volume of solution} = \\ &= (1.6 \times 10^{-3} + 8) / (8 \times 10^{-3}) \\ &= 1000.2 \text{ kg/m}^3 \end{aligned}$$

Pressure at the inlet = 0.35 kg/cm² or bar

Pressure at outlet = 0.175 kg/cm² or bar

Pressure drop = (0.35 - 0.175) = 0.175 kg/cm² or bar

$$\text{Head loss} = h_L = \frac{\Delta P_L}{\rho g} = \frac{0.3}{1000.2 \times 9.81} = 0.0000174 \text{ m.solution}$$

$$\text{Head Loss, } \rho_{\text{soln}} \times g \times h_{\text{soln}} = \rho_w \times g \times h_w \text{ or } h_w = \frac{1000.3 \times 0.0000174}{1000} = 0.0000174 \text{ m.h}_2\text{O}$$

Heat transfer coefficient calculations

Specific heat of water, $c_{p,\text{water}} = 4186.8 \text{ J/kg.K}$

[19] Specific heat of Xanthan gum solution for concentration 0.3 g/L = 0.0003 kg/L = 4009 J/kg.k [By

using the empirical equation $C_p = 98.78575 - 0.6495T - 15.9955X + 0.06TX + 0.001109T^2 - 0.5X^2$

where T = Room temperature in Kelvin and X = concentration (w/w). The specific heat of Xanthan gum

does not change for concentration range (0.0625-0.1 % w/w).

Density of Xanthan gum for concentration of 0.2 g/L: [8L water & 1.6 g gum]

$$\begin{aligned} \rho_{xg} &= (\text{mass of xanthan gum} + \text{mass of water}) / \text{volume of solution} \\ &= (1.6 \times 10^{-3} + 8) / (8 \times 10^{-3}) \\ &= 1000.2 \text{ kg/m}^3 \end{aligned}$$

At 22 L/min in the outer tube side and the 22 L/min in the inner tube side,

$$\dot{m}_h = (\rho \times V/t) \text{ kg/s} = (1000 \times 22 \times 10^{-3})/60 \text{ kg/s} = 0.366 \text{ kg/sec}$$

$$\dot{m}_c = (\rho \times V/t) \text{ kg/s} = (1000.3 \times 22 \times 10^{-3})/60 \text{ kg/s} = 0.367 \text{ kg/sec}$$

$$T_{c,in} = 38^\circ\text{C} \quad T_{c,out} = 40^\circ\text{C} \quad T_{h,in} = 47^\circ\text{C} \quad T_{h,out} = 41.5^\circ\text{C}$$

$$\Delta T_1 = (T_{h,in} - T_{c,in}) = (47-38) = 11^\circ\text{C} \quad \Delta T_2 = (T_{h,out} - T_{c,out}) = (41.5-40) = 1.5^\circ\text{C}$$

$$A_0 = \pi d_o l \text{ m}^2 = 3.1416 \times 0.0508 \times 0.457 \text{ m}^2 = 0.07 \text{ m}^2 \text{ [} d_o = \text{Outer diameter of inner tube]}$$

$$\text{Thermal balance, } Q_c = m_c \times C_{pc} \times (T_{c,out} - T_{c,in}) = 0.366667 \times 4009 \times (40 - 38) = 3004.586 \text{ W}$$

$$\text{Log mean temperature difference, } \Delta T_m = (\Delta T_1 - \Delta T_2) \ln(\Delta T_1/\Delta T_2) = (9 - 1.5) / \ln(9/1.5) = 3.64^\circ\text{C}$$

Overall heat transfer coefficient, $U = Q_c / A\Delta T_m = 3004.586 / (0.07 \times 3.64) = 10254 \text{ W/m}^2 \cdot \text{K}$

For concentration 0.15 g/L

Head loss calculation

Density of Xanthan gum for concentration of 0.15 g/L:

$$\begin{aligned}\rho_{\text{Xg}} &= (\text{mass of xanthan gum} + \text{mass of water}) / \text{volume of solution} \\ &= (1.2 \times 10^{-3} + 8) / (8 \times 10^{-3}) \\ &= 1000.15 \text{ kg/m}^3\end{aligned}$$

Pressure at the inlet = 0.4 kg/cm^2 or bar

Pressure at outlet = 0.05 kg/cm^2 or bar

Pressure drop = $(0.4 - 0.05) = 0.35 \text{ kg/cm}^2$ or bar

$$\text{Head loss} = h_L = \frac{\Delta P_L}{\rho g} = \frac{0.35}{1000.15 \times 9.81} = 0.000035 \text{ m.solution}$$

$$\text{Head Loss, } \rho_{\text{soln}} \times g \times h_{\text{soln}} = \rho_w \times g \times h_w \text{ or } h_w = \frac{1000.3 \times 0.00003}{1000} = 0.000035 \text{ m.h}_2\text{O}$$

Heat transfer coefficient calculations

Specific heat of water, $c_{p,\text{water}} = 4186.8 \text{ J/kg.K}$

[19] Specific heat of Xanthan gum solution for concentration 0.15 g/L = $0.00015 \text{ kg/L} = 3997 \text{ J/kg.k}$ [By using the empirical equation $C_p = 98.78575 - 0.6495T - 15.9955X + 0.06TX_x + 0.001109T^2 - 0.5X_x^2$ where T = Room temperature in Kelvin and X_x = concentration (w/w). The specific heat of Xanthan gum does not change for concentration range (0.0625-0.1 % w/w).

Density of Xanthan gum for concentration of 0.15 g/L: [8L water & 1.2 g gum]

$$\begin{aligned}\rho_{\text{Xg}} &= (\text{mass of xanthan gum} + \text{mass of water}) / \text{volume of solution} \\ &= (1.2 \times 10^{-3} + 8) / (8 \times 10^{-3}) \\ &= 1000.15 \text{ kg/m}^3\end{aligned}$$

At 22 L/min in the outer tube side and the 22 L/min in the inner tube side,

$$\dot{m}_h = (\rho \times V / t) \text{ kg/s} = (1000 \times 22 \times 10^{-3}) / 60 \text{ kg/s} = 0.366 \text{ kg/sec}$$

$$\dot{m}_c = (\rho \times V / t) \text{ kg/s} = (1000.3 \times 22 \times 10^{-3}) / 60 \text{ kg/s} = 0.367 \text{ kg/sec}$$

$$T_{c,\text{in}} = 35^\circ\text{C} \quad T_{c,\text{out}} = 38^\circ\text{C} \quad T_{h,\text{in}} = 46^\circ\text{C} \quad T_{h,\text{out}} = 40^\circ\text{C}$$

$$\Delta T_1 = (T_{h,\text{in}} - T_{c,\text{in}}) = (46 - 35) = 11^\circ\text{C} \quad \Delta T_2 = (T_{h,\text{out}} - T_{c,\text{out}}) = (40 - 38) = 2^\circ\text{C}$$

$$A_0 = \pi d_o l \text{ m}^2 = 3.1416 \times 0.0508 \times 0.457 \text{ m}^2 = 0.07 \text{ m}^2 \text{ [} d_o = \text{Outer diameter of inner tube]}$$

$$\text{Thermal balance, } Q_c = \dot{m}_c \times C_{p,c} \times (T_{c,\text{out}} - T_{c,\text{in}}) = 0.366667 \times 4096 \times (40 - 38) = 4397 \text{ W}$$

$$Q_h = \dot{m}_h C_{p,h} (T_{h,\text{in}} - T_{h,\text{out}}) = 0.367 \times 4186.8 \times (46 - 41) = 9217.78 \text{ W}$$

$$\text{Log mean temperature difference, } \Delta T_m = (\Delta T_1 - \Delta T_2) \ln(\Delta T_1 / \Delta T_2) = (11 - 1) / \ln(11 / 1) = 5.27^\circ\text{C}$$

$$\text{Overall heat transfer coefficient, } U = Q_c / A\Delta T_m = 3004 / (0.07 \times 3.64) = 11915 \text{ W/m}^2 \cdot \text{K}$$

Head loss calculation

Density of Xanthan gum for concentration of 0.15 g/L:

$$\begin{aligned}\rho_{\text{Xg}} &= (\text{mass of xanthan gum} + \text{mass of water}) / \text{volume of solution} \\ &= (1.2 \times 10^{-3} + 8) / (8 \times 10^{-3}) \\ &= 1000.15 \text{ kg/m}^3\end{aligned}$$

Pressure at the inlet= 0.5 kg/cm² or bar

Pressure at outlet=0.2 kg/cm² or bar

Pressure drop= (0.5-0.2)=0.3 kg/cm² or bar

Head loss= $h_L = \frac{\Delta P_L}{\rho g} = \frac{0.3}{1000.15 \times 9.81} = 0.00003 \text{ m.solution}$

Head Loss , $\rho_{soln} \times g \times h_{soln} = \rho_w \times g \times h_w \text{ or } h_w = \frac{1000.3 \times 0.00003}{1000} = 0.00003 \text{ m. h}_2\text{O}$

Heat transfer coefficient calculations

Specific heat of water, $c_{p,\text{water}} = 4186.8 \text{ J/kg.K}$

[19] Specific heat of Xanthan gum solution for concentration 0.15 g/L=0.00015 kg/L=4.055 K j/kg.k

[By using the empirical equation $C_p = 98.78575 - 0.6495T - 15.9955X + 0.06TXx + 0.001109T^2 - 0.5Xx^2$ where T=Room temperature in Kelvin and Xx=concentration(w/w).The specific heat of Xanthan gum does not changes for concentration range (0.0625-0.1 % w/w).

Density of Xanthan gum for concentration of 0.2 g/L: [8L water & 1.6 g gum]

$\rho_{xg} = (\text{mass of xanthan gum} + \text{mass of water}) / \text{volume of solution}$

$$= (1.2 \times 10^{-3} + 8) / (8 \times 10^{-3})$$

$$= 1000.15 \text{ kg/m}^3$$

At 17 L/min in the outer tube side and the 17 L/min in the inner tube side,

$$\dot{m}_h = (\rho \times V / t) \text{ kg/s} = (1000 \times 22 \times 10^{-3}) / 60 \text{ kg/s} = 0.366 \text{ kg/sec}$$

$$\dot{m}_c = (\rho \times V / t) \text{ kg/s} = (1000.3 \times 22 \times 10^{-3}) / 60 \text{ kg/s} = 0.367 \text{ kg/sec}$$

$$T_{c,\text{in}} = 37^\circ\text{C}$$

$$T_{c,\text{out}} = 39^\circ\text{C}$$

$$T_{h,\text{in}} = 46^\circ\text{C}$$

$$T_{h,\text{out}} = 40^\circ\text{C}$$

$$\Delta T_1 = (T_{h,\text{in}} - T_{c,\text{in}}) = (46 - 37) = 9^\circ\text{C}$$

$$\Delta T_2 = (T_{h,\text{out}} - T_{c,\text{out}}) = (40 - 39) = 1^\circ\text{C}$$

$$A_0 = \pi d_o l \text{ m}^2 = 3.1416 \times 0.0508 \times 0.457 \text{ m}^2 = 0.07 \text{ m}^2 \text{ [} d_o = \text{Outer diameter of inner tube]}$$

$$\text{Thermal balance, } Q_c = \dot{m}_c \times C_{pc} \times (T_{c,\text{out}} - T_{c,\text{in}}) = 0.366667 \times 4005 \times (39 - 37) = 2973 \text{ W}$$

$$\text{Log mean temperature difference, } \Delta T_m = (\Delta T_1 - \Delta T_2) \ln(\Delta T_1 / \Delta T_2) = (9 - 1) / \ln(9 / 1) = 3.64^\circ\text{C}$$

$$\text{Overall heat transfer coefficient, } U = Q_c / A \Delta T_m = 300 / (0.07 \times 3.64) = 11915 \text{ W/m}^2 \cdot \text{K}$$

