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Analysis of Drag Reduction and Thermal Performance of Xanthan Gum-Water Mixtures in a Shell and Tube Heat Exchanger

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ABSTRACT

The use of food-grade fluids in various commercial and industrial processes has gained significant importance, particularly in the food and beverage industry. Many such fluids exhibit non-Newtonian behavior, especially when thickening agents like xanthan gum are introduced. When a small amount of xanthan gum is added to water, the fluid transforms from Newtonian to pseudoplastic, altering both its flow and thermal characteristics. This study aims to investigate the drag reduction and heat transfer performance of xanthan gum-water solutions at varying concentrations in a shell and tube heat exchanger. The primary objective is to identify an optimal concentration that minimizes frictional losses in pipelines while maintaining an acceptable heat transfer rate in heat exchangers. It was concluded that frictional pressure drop was reduced up to 95 % and heat transfer rate reduced up to 70% by increasing the concentration of the DRA(drag reducing agent) up to 0.25 g/L at 12 LPM than the pure water or base fluid as working substance on double pipe heat exchanger.

Keywords: Xanthan gum, Pseudoplastic fluid, Non-Newtonian fluid, Drag reduction, Heat transfer.

1. Introduction

Heat transfer analysis is very important in all the sector. So for any material the extent of heat transfer and friction analysis is need to be done to apply it in any field [1]. Pseudoplastic fluid is a kind of fluid that gets thinned when shear is applied. Such a fluid is called shear thinning fluid. Non-Newtonian liquids change in viscosity depending on the shear rate; some are shear thinning such as paint, whereas others are shear thickening such as corn starch, As a result of this, non-Newtonian liquids require special consideration when their transfer through closed conduit is considered[2]. Slick water 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 pumping power by transforming the Newtonian fluid to the pseudoplastic non-Newtonian fluid. So, gelled fluid is more effective to transport and in saving 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 can be transferred by the pseudoplastic xanthan gum solution and the friction occurs by this additive for different concentration will be experimented and an optimum concentration will be found. 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 and S. Tripathy and M. K. Das[3] studied the guar gum which is a shear thinning fluid agent so it is necessary for us to know the heat transfer characteristics of xanthan gum solution. A. Wang and W. Wang [4] studied this copolymer properties like guar gum which is similar like xanthan gum. C. Gorman Gilbert and John F. Ripken [5] 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. G.K.Patterson et al.[6] 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.[7] experimented the heat transfer rate for the turbulent flow of polycrylamide in water. The result was that the Stanton number was decreased for such type of additive solution flow and the drag was reduced also. S.D.Joshi and A.E.Bergles[8] studied the heat transfer characteristics of non Newtonian laminar fluid flow. They used a closed loop low pressure systems of piping's and 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 deg 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,H.G[9] published a book review of H.P

Skelland's book which describes the characteristics of non Newtonian flow and heat transfer characteristics. non Newtonian flow and the next four chapter describes the various internal fluid flow in various situation such as internal flow,parallel plate flow,flow through annuli etc. Lew concluded that the book is a excellent overview about non Newtonian fluid related heat and friction characteristics. B. Salam, S. Biswas, S. Saha, and M. M. K. Bhuiya [10] 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 variying the flow rate of the non Newtonian fluid. He showed that the heat transfer rate was increased for the non Newtonian nanofluid.S. Rozzi at el[11] investigated the heat transfer and friction loss characteristics for several fluid food such as orange juice,whole milk,apricot,apple puree. They tested for this pseudoplastic fluid food in shell and tube heat exchange. Xanthan gum is a polysaccharide with many industrial uses, including as a common food additive. It is an effective thickening agent and stabilizer that prevents ingredients from separating. M. Shojaeian at el [12] stated that polymeric solutions as a subcategory of non-Newtonian fluids are prepared by the dissolution of polymeric additives into a solvent and find applications in many areas. Their advantage over new generation fluids such as nanofluids is that they have no side effects such as agglomeration and sedimentation of particles, which is common for nanofluids

2. Objectives

- To find out the frictional drag reduction characteristics of the solution.
- To save pumping power by reducing drag, turbulence and eddy in pipe and heat exchanger.
- To find out the effect on heat transfer rate due to the gum. • To find out an optimum concentration at which friction/drag is lower and heat transfer is satisfactory.
- To find the flow characteristics and behaviour of the gelled fluid

3. Methodology

First of al the shell side of the heat exchanger by pump. The cold fluid was flowed to the tube side of 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 rotameter. When flow rate of both the two fluid was stable the thermometer reading was taken. Then by using equation the overall heat transfer coefficient (U) was found out. Firstly, normal water as cold fluid and then xanthan gum solution as cold fluid were used. Then the resuls were compared to find the difference in heat transfer rate.So, we can understand 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.

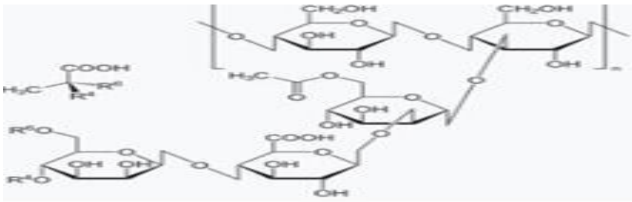

Fig.1: Chemical structure of the xanthan gum [13]

The difference in pressure or the loss of head is the loss of pressure due to skin friction. Then friction pressure drop for normal water and for Xanthan gum solution was compared. Then by calculation a concentration of solution was selected at which the heat transfer from hot fluid to xanthan gum is satisfactory and reduction of friction is also good. This was the optimum point of concentration.

3.1 Setup Design

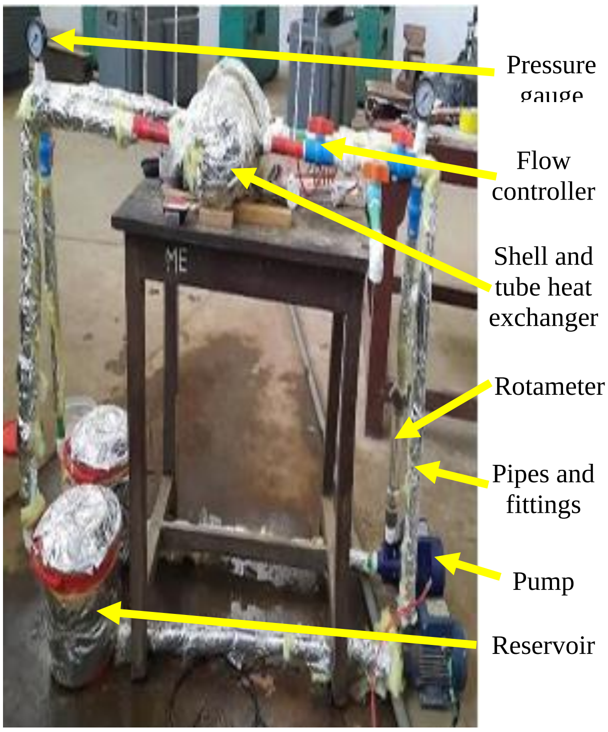

Fig.2: Experimental setup

3.2 Function of the System

The research framework is the process or category we will apply to do this investigation. This investigation is a experimental based where a standard setup will be used. Here the heat is transferred from hot shell side fluid to the tube wall by convection. Then conduction will occur at the tube wall. Another convection will happen and heat will flow to the inner tube side cold fluid from the tube wall. So my aim is to investigate how much heat can the pseudoplastic cold fluid take from the hot water. We will also analyze whether the heat taken by non newtonain fluid will be higher or lower than the cold Newtonian fluid. The convective heat transfer coefficient will be found out by the equation.LMTD will be found.

3.3 Assumptions

- The size of the particle of Xanthan Gum is not considered.
- The flow is considered to be laminar.
- Atomospheric temperature is considered to be constant.
- The heat transfer by radiation is included in the convection heat transfer.
- Forced convection heat transfer
- Recommended concentration is 0.1-2 % (by U.S food and Drug administration)

3.4 Component List

This design is comprised of two types of components. One is the structural components that are not related to power transmission like valves, fittings etc. Fig 4: Components 5. Bulk temperature of solution is considered here.

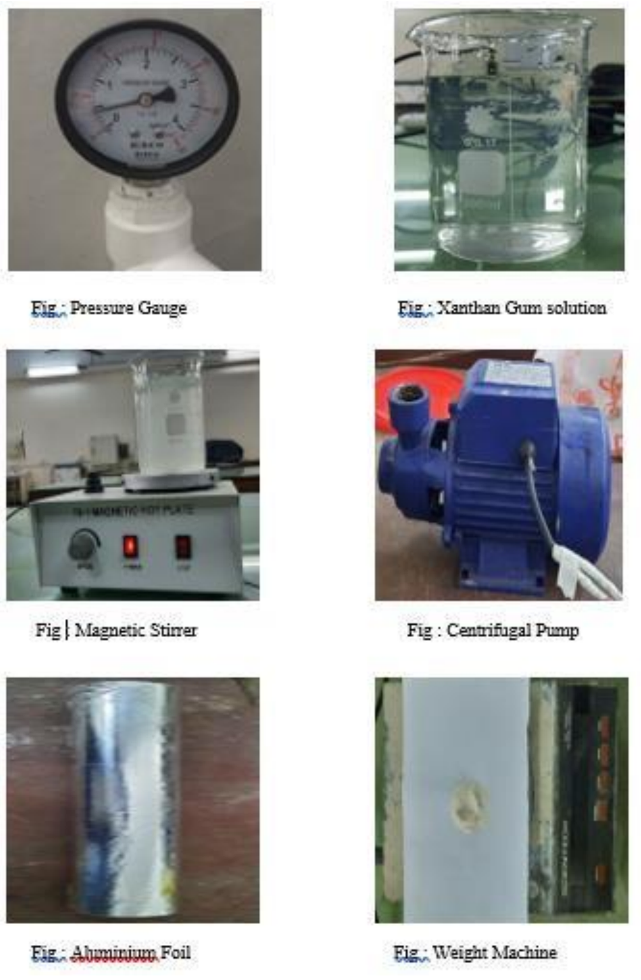

Fig.3: Components List

4. **Implementation and Results**

4.1 Heat Transfer Rate

From graph 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. 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) 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(Fig 4) it has been observed that for base fluid water the heat transfer rate is maximum for the highest flowrate (20 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 (20 LPM) which is the fully opposite scenario in case of frictional effect.

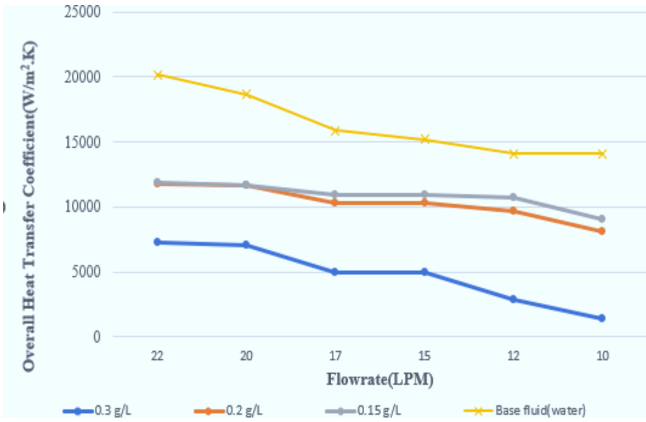

Fig.4: Heat transfer rate vs concentration for various flowrates

4.2 Frictional Head Loss:

After increasing the concentration of xanthan gum(Solute) in water the frictional pressure drop or parasitic drag or skin friction drag starts to reduce. The test is done for concentration range (0.0125-0.15 % w/w).The skin friction drag reduction is lowest for concentration 0.02-0.033 % w/w. Further increase of concentration will not decrease the frictional head loss for upto 1.5 % w/w.For concentration above 1.5 % w/w the flow ceases and net positive suction head reduces drastically and cavitation forms.

4.3 Optmization

The optimization is based on the fact that at which point the frictional head loss is minimum and the rate of heat transfer is also close to water. At this point the frictional head is approximately constant and further increase of concentration for a certaion limit does not produce any significant effect on decreasing head loss.Further increasing concentration will arrest the flow and cavitaion starts forming. For concentration 0.033 % w/w we studied that the frictional head loss due to skin friction drag is minimum.Upto concentration 1.5 % w/w the head loss is minimum and the value of loss is approximately remains same (1.756 m) and varies very slightly (1.754-1.756 m). A graph of pressure drop vs flowrate at different concentration for the optimization has been shown below (Fig. 6)

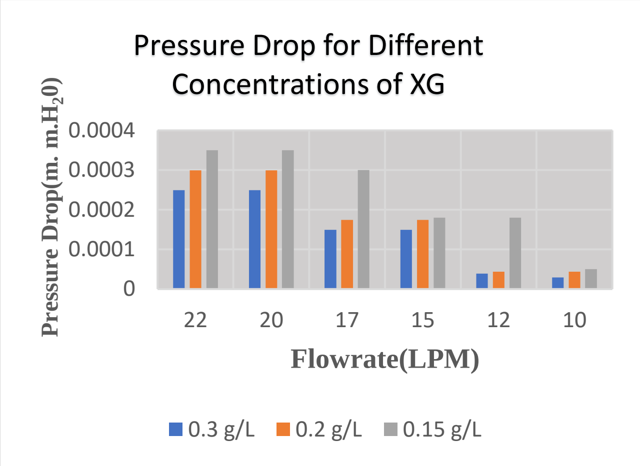

Fig.5: Bar chart of pressure drop for different concentrations and flowrates

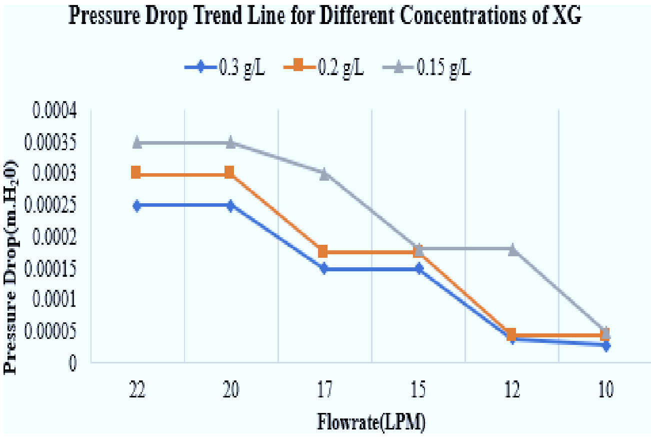

Fig.6: Pressure drop for different concentrations and flowrates

5. Discussion and Interpretation

The findings of the experiment demonstrate how strongly the concentration of xanthan gum affects the water-based solution's flow resistance and heat transfer properties. The solution showed clear pseudo plastic behavior as the xanthan gum content rose, which had a major impact on how well it worked in the pipeline and heat exchanger. In accordance with the study, at optimal concentrations, xanthan gum–water mixtures show encouraging drag reduction qualities while preserving respectable heat transfer rates. The solution's pseudo plastic properties are advantageous in regulated processing settings and energy efficient flow systems. Future research might concentrate on examining how temperature, flow geometry, and different biopolymer mixes interact to affect heat transmission and drag reduction properties. Computational fluid dynamics (CFD) simulations can also be used to evaluate experimental trends and better visualize the flow structure, which helps with the design of industrial systems that use food-grade, ecologically acceptable additives for increased energy efficiency. This study reveals a further investigation for optimization of the heat tranfer rate and concentration based on different diameter of pipe and different materials. So, any further investigation regarding this materials will predict a complete study based on flowrate, concentration, heat transfer rate and diameter of pipe including the roughness and friction factor of pipe considering the turbulent flow. A prediction based on numerical study by the turbulent flow may be done further by proper steps and precautions.

6. Conclusion

According to the study, adding trace amounts of xanthan gum changes water into a pseudo plastic substance, which has a big impact on thermal and frictional behavior. Significant drag reduction and reduced pressure decreases as a result of turbulence suppression were demonstrated in the studies, which might save pumping power. However, the rate of heat transfer decreased along with this increase in flow efficiency. The ideal equilibrium between drag reduction and heat transfer performance was found to be achieved at an optimal concentration of around 0.033% w/w, where good thermal exchange is maintained while frictional losses stay relatively constant. While lower concentrations necessitated more pumping effort, higher concentrations resulted in excessive viscosity and decreased heat transfer. To sum it up, a reasonable concentration of xanthan gum provides a workable way to achieve energy-efficient flow in the chemical, food, and beverage sectors. In order to better enhance performance, future research may build on this work by investigating the impacts of temperature, shape, and additional biopolymers.

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Nomenclatures

Symbols	Meaning	Unit
ρ	Density	Kg/m^3
ρ_x	Density of xanthan gumım	Kg/m^3
C_p	Specific heat at constant pressur	J/kg.K
$T_{h,in}$	Specific heat of cold fluid at constant pressur	°C
$X_{s,in}$	Surface Area	°C
T_b	Bulk Temperature	°C
T_i	Inlet temperature of cold fluid	°C
g	exit temperature of cold fluid	m/s^2
μ	Acceleration due to gravity	m/m^2
$h_J/\Delta P_L$	Head Loss/Pressur	N/m^2
P_a	Pressure at inlet of pipeline	N/m^2