

SYNTHESIS AND EVALUATION OF PROPERTIES AND  
ENERGY TRANSPORTATION CHARACTERISTICS OF  
GUM ARABIC AND GUM GUAR IN HEAT EXCHANGER

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FACULTY OF ENGINEERING  
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KUALA LUMPUR

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## ABSTRACT

Current interest in “oil and gas” sectors, as well as in the use of reduced pumping energy, have driven the use of drag lowering additives for such sectors. Slurry transportation by cost-effective and environmentally friendly means by using biodegradable compounds, as the additives can achieve these advantages. To examine the drag lowering polymeric additive in the turbulent flow regime, a closed loop of an insulated circular (ID 41.5mm) aluminium pipe test rig was used. Gum guar and gum Arabic were the adaptive or drag lowering agent used by mixing in distilled water. For the experimental research, the pulp disintegrator was utilized to generate a diluted combination of additive in distilled water. For composition in all the cases, some general correlations for pressure drop, friction factor, and drag reduction percentages were established by applying heat and without heat to the following solution. The degree of pressure drop decrease (drag reduction) was depending on concentrations and technique of dispersion. Additive concentration, flow velocity and temperature of the water affected the pressure drop results. An empirical correlation was used to verify the water data and found satisfactory results with error about 8% in the specified range of Reynolds number (18,000 to 167,000). In the present work Guar Gum (GG) and Gum Arabic (GA) solutions were investigated individually, and then mixture of the two were also investigated for drag reduction. For the mixture of GG:GA-70:30 (200 ppm of additive concentration) the decrease in drag reduction was in between 30-35% without heat and at lower velocity and 20-25% at higher velocity and with and without heating. From this experimental research, it showed that the Gum Guar was more helpful in enhancing the drag reduction in pipelines compared to that of Gum Arabic alone in the solution and a little addition of on in the other have changed significant drag reduction data.

## ABSTRAK

Kepentingan semasa dalam sektor "minyak dan gas", serta dalam penggunaan jumlah yang berkurangan, telah mendorong penggunaan bahan tambahan seretan untuk sektor tersebut. Pengangkutan bubur adalah cara yang kos efektif dan mesra alam untuk mengangkut sebatian biodegradasi, kerana bahan tambahan mampu mengeksploitasi kelebihan ini. Untuk memeriksa seretan menurunkan aktif polimerik dalam rejim aliran bergelora, gelung tertutup sistem paip aluminium pekeliling terlindung (diameter dalaman 41.5mm) telah digunakan. Gum guar dan gusi Arab adalah ejen penyesuaian atau seretan merendahkan yang digunakan oleh campuran dalam air sungkai. Untuk penyelidikan eksperimen, disintegrator pulpa digunakan untuk menjana gabungan aditif yang dicairkan dalam air sutera. Untuk penyelidikan eksperimen, disintegrator pulpa digunakan untuk menjana gabungan aditif yang dicairkan dalam air sutera. Untuk setiap komposisi, beberapa korelasi umum untuk penurunan tekanan, faktor geseran, dan peratusan pengurangan seret ditubuhkan dengan memohon haba dan tanpa haba. Tahap penurunan tekanan bergantung kepada kepekatan dan teknik perseoruan. Kepekatan tambahan, halaju aliran dan suhu air menjejaskan hasil penurunan tekanan. Persamaan empirikal tepat dikira 8% dalam julat pertanyaan nombor Reynolds (18,000 hingga 167,000). Apabila diberi makan GG:GA-70:30 (200 ppm kepekatan aditif) penurunan dalam pengurangan seret adalah di antara 30-35% tanpa haba pada kelajuan yang lebih rendah dan 20-25% pada kelajuan yang lebih tinggi untuk dan tanpa haba. Dari penyelidikan eksperimen ini, ia menunjukkan guar gusi mungkin lebih membantu dalam mengurangkan pengurangan seretan saluran paip berbanding dengan gusi arab sahaja.

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## LIST OF SYMBOLS AND ABBREVIATIONS

For examples:

|                  |                                   |
|------------------|-----------------------------------|
| $A$              | Area, m <sup>2</sup>              |
| $C$              | Concentration, %                  |
| $f$              | Friction Factor                   |
| $H$              | Head Loss (m)                     |
| ID               | Inner Diameter of the tube, m     |
| $k$              | Length of the tube, m             |
| $P$              | Power, Watts                      |
| Ppm              | Chemical Mass Weight              |
| $Pr$             | Prandtl Number                    |
| $Re$             | Reynolds Number,                  |
| $T$              | Temperature, °C                   |
| $v$              | Velocity, m/s                     |
| DRA              | Drag Reduction Agent              |
| DRP              | Drag Reduction Polymer            |
| %DR              | Drag Reduction Percentage         |
| %FI              | Flow Increase Percentage          |
| UHMW             | Ultra-High Molecular Weight       |
| $V_{DRA}$        | Drag Reduction Additive<br>Volume |
| CO <sub>2</sub>  | Carbon Dioxide                    |
| H <sub>2</sub> O | Hydrogen                          |
| RNA              | Ribonucleic Acid                  |
| DNA              | Deoxyribonucleic                  |
| PEO              | Polyethylene Oxide                |
| PAM              | Polyacrylamide                    |

|       |   |
|-------|---|
| HPAM  | Hydrolysed Polyacrylamide                 |
| CMC   | Carboxymethyl Cellulose                   |
| XG    | Xanthan Gum                               |
| GA    | Gum Guar                                  |
| GGV   | Unsonicated Virgin Gum Guar               |
| GG30  | Gum Guar Ultrasonicated at thirty minutes |
| GG60  | Gum Guar Ultrasonicated at sixty minutes  |
| RDA   | Rotating Disk Apparatus                   |
| [C]   | Intrinsic Concentration                   |
| [DR]  | Intrinsic Drag Reduction                  |
| F     | Friction Factor                           |
| V     | Solution Volume                           |
| $t^*$ | Non-Dimensional Time                      |
| Hz    | Hertz                                     |
| Rpm   | Revolution Per Minute                     |
| LPM   | Litre Per Minute                          |
| m     | Meter                                     |
| mm    | Millimetres                               |
| min   | Minute                                    |
| kpa   | Kilo Pascal                               |
| Q     | Volumetric Flow Rate                      |

*Greek symbols*

|               |                                |
|---------------|--------------------------------|
| $\Delta p$    | Pressure Drop                  |
| $\varepsilon$ | Surface Roughness              |
| $\lambda$     | Wall thermal conductivity      |
| $\mu$         | Viscosity, kg/m <sup>2</sup> s |
| $\rho$        | Density, kg/m <sup>3</sup>     |
| $\tau$        | Shear stress                   |
| $\omega$      | Gum coarseness, kg/m           |
| $\eta$        | Thermal Efficiency             |
| $\pi$         | Pi                             |

*Subscripts*

|     |        |
|-----|--------|
| $b$ | Bulk   |
| $i$ | Inlet  |
| $m$ | Mass   |
| $o$ | Outlet |
| $w$ | Wall   |



## CHAPTER 1: INTRODUCTION

### 1.1 BACKGROUND

Research is focused on biopolymers being used as drag reduction additives in numerous sectors for transportation of various materials, such as petroleum, food processing, and agriculture. This helps to draw in scientists who want to explore the phenomenon of biopolymers and their effects on pressure drop. Pipelines are often utilized to transport or transfer fluids at high velocity around the globe. Reduction of pressure losses or drag in the flowing fluid is called drag reduction (Hasan & Khalid, 2017; Ma et al., 2020). The "turbulent streak" from the laminar sublayer is drawn to the buffer zone, and as it advances towards the buffer, it begins to oscillate and vortex (Pittendrigh, Bruce, & Kaus, 1958; Amir Raghem-Moayed, 1999). Later tends to travel quickly because it gets closer to the centre of the disturbance and ultimately disintegrates, releasing fluid into the centre. "Turbulent burst" is a waste of energy phenomena. In order to prevent additional turbulent bursts, you need use a drag lowering agent (inhibits bursting) (Daily & Bugliarello, 1958; Forgacs & Mason, 1959). With more burst absorbed, less energy is squandered, and as a consequence, the frictional pressure loss is reduced. Drag reduction agents (DRA) or drag reduction polymers (DRP's) are additives that are injected into the pipes, improving the pipeline's performance by increasing the amount of turbulence that is reduced. They help to reduce turbulence and boost the fluid flow efficiency in the pipeline. as a result of the use of a few ppm of additives, this significant decrease in turbulent friction fluid occurred (Henaut, Darbouret, Palermo, Glenat, & Hurtevent, 2009). Fluid flow and pressure loss reduction is said to be possible in certain instances (through drag reduction) (Campbell & Jovancicevic, 2001). Drag reduction results from turbulent flow that suppresses energy near the pipe wall. The research Tom did on different types of polymers has played a huge and crucial part in

popularising the phrase “drag reduction effect” and bringing it to the world with significant analyses on the different components of polymers. Drag reducing compounds are extensively employed in the industry owing to their excellent efficacy in drag reduction and their low cost. Both synthetic and natural polymers are used in the polymers. Natural polymers (biopolymers) are derived from many sources, whereas synthetic polymers (biopolymers) are created by multiple chemical mixes (Campbell & Jovancicevic, 2001). Global researchers studied biopolymers as a potential substitute for synthetic polymers after doing study based on the current situation. Bio and manufactured polymers will be employed in the current research to look into drag reduction for prospective industry use (Kumar, Kaur, Bhatia, & Science, 2017).

## 1.2 PROBLEM STATEMENT

Pumping power usage, along with other influencing factors, has determined the methods by which slurries may be transported. There are many drag reduction additives that may be used to the suspension fluid, in order to reduce the pumping power needed to move the suspension. The present work has undertaken the investigation of additives for drag reduction.

## 1.3 OBJECTIVES

The project's goal is to study the flow behavior using gum Arabic and gum Guar, which is a drag reduction additive, in a straight pipe.

- 1) To analyse the effect of adaptive on pressure drop and drag reduction.
- 2) To investigate the heat transfer coefficient of gum Arabic and gum Guar in pipe flow.
- 3) The correlation of drag reduction achievement with concentration.

#### 1.4 Organization of the thesis

Chapter 1 illustrates the challenges that already exist in this field, which prompts this project and the study goals.

Chapter 2 highlights the most significant portions of the research literature on drag reduction, including different forms of drag reduction agents, theoretical techniques, data gathering, solution, and research into work and the needed amount. This chapter reviews previous research on the influence of additives on the pressure drop of fibre suspensions.

Chapter 3 highlight the techniques and procedures utilised for the testing rig to carry out experiments, get data, conduct the experiment, prepare the materials, and what to anticipate.

Chapter 4 presents the calculated loss of pressure, friction factor, and drag reduction percentage, as well as the comparison with previously calculated correlations, are kept for every installation. the influence of varied amounts of gum Arabic and gum guar derived in various amount of concentration. Additionally, additives' effects on pressure loss are explored in detail.

Chapter 5 provide an accurate description of the most significant conclusions of this effort. Also included in this chapter are future studies to further the present investigation.

## LITERATURE REVIEW

### 2.1 INTRODUCTION

In pipelines, turbulent flow is seen regularly with both drag and friction force. When an object collides with another object, the fluid resist motion caused by the impact is termed drag. It is important to increase the pump capacity to compensate for the pressure reduction due to down force in the flow. To counteract this upgrade to the pump and a larger number of pumps, the capacity of the tank should be increased. As a general rule, most research was based on axisymmetric modelling owing to its simplicity. One of the first to research and categorise the drag reduction process, when pulp suspension is used, into flow regimes with "plug," "mixed," and "turbulent" characteristics (Kumar et al., 2017). Once this further investigation is completed, it may expand to include these details (Karp-Boss, Jumars, & Oceanography, 1998; A Raghem-Moayed & Dodson, 1999).

When these fluids are passed through the pipes, a crisis of change will occur, as pressure and velocity both decrease. The pipe length, inclination angle, and pipe diameter vary based on the characteristics of the fluid, and those process characteristics also rely on the density, velocity, and viscosity of the fluid. The two different flow patterns may be characterised as high-Reynolds-number turbulence and laminar flow (Qi et al., 2017). In this section, there occurs a shift from laminar flow ( $N_{re} > 2100$ ) and turbulent flow ( $N_{re} > 4000$ ). When laminar and turbulent flow occur concurrently, then the flow is transitioning to transitional ( $2100 < N_{re} < 4000$ ). This, in essence, means that it is turbulence which is the most significant source of pressure decrease in transportation operations (Ikoku, 1984). Turbulent flow in fluid transport is an essential research topic that will be useful in practical applications for drag reduction (Campbell & Jovancicevic, 2001). Since its invention, several methods have been created and invested in attempts to eradicate or lower turbulence intensities, but as of today, no technique exists to completely rid a huge turbulence of intense velocity. Drag reduction agent is a way of

using additives to lessen pipe line turbulence (Kühnen et al., 2018). Organic compounds such as fibres or wood pulp, organic liquids such as surfactants or oil soluble and polymers are organic compounds which are often found in DRA compounds that may help minimise drag by lowering the pressure drop on pipelines (Jainuddin, 2015; Tze-Shyuen, 2014).

## 2.2 Drag Reduction

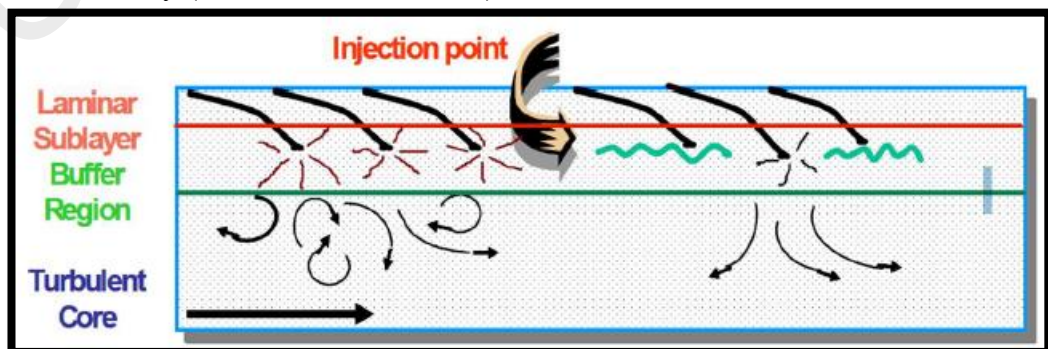
From Figure 2.1, three primary layers formed as a result of fluid moving in parallel. These include a laminar sub-layer, a buffer area, and a turbulent core. The flow will oscillate as it changes from laminar sublayer to buffer area. The flow will start to vortex, which is known as a “turbulent streak.” It will rapidly start to get closer to the turbulent core layer and then fall apart. "Turbulent burst" is a stage when energy is generally lost. When vortices arise, the characteristics of the turbulent boundary layer are altered, therefore the turbulent boundary layer around the structural wall has been altered (Jainuddin, 2015). When DR is less than one, it's known as drag reducing fluid (Lee & Duffy, 1976), (Kazi, Duffy, & Chen, 1999), (Kazi et al., 1999), (Kang, Vedapuri, & Jepsen, 2000).

In order to save on costs, extra pumps have been installed in order to take advantage of drag reduction techniques. As an addition, a drag reduction agent (DRA) will reduce the pressure loss, and boost the flow performance. To lower the flow from a process which has beyond its design parameters, a DRA (drag reduction agent) will be used to create a turbulence in the fluid that dampens the process overpressure and as a shock absorber. This is possible to modify turbulent structures and boost flow velocity considerably thanks to a modest number of polymers as additives ((Bridson et al., 2015; Hosseinipour, Japper-Jaafar, & Yusup, 2018). By using this procedure, the frictional pressure loss in the

pipeline will be reduced, and as a result, the pipeline will be able to sustain a higher flow rate and save further energy (Hasan & Khalid, 2017). According to (Zhang, Duan, & Muzychka, 2020) and (Zhang et al., 2020), most examples include a drop in drag reduction efficiency, and understanding the influence of drag-reducing agents (DRA) on flow augmentation is important to counteract the deterioration of flow drag (Zhang, Duan, & Muzychka, 2019; Zhang et al., 2020). Drag reduction agents are often affected by a number of variables, including the amount of time the drag reduction agent is present in the flow, the temperature, the shear rate, the types of polymers, and the polymer ratio.

When more drag reduction agents are applied, this will result in lower turbulence and more fluid flow, allowing pipeline capacity to be increased and lost energy minimised. A few of parts per million off the additives in the pipeline results in a 70% decrease in turbulent friction (Hasan & Khalid, 2017). Study shows that an improvement in fluid flow capacity may be obtained by adding drag reduction agent additions, according to (Campbell & Jovancicevic, 2001). When turbulent eddy currents near the wall are depleted of their energy owing to the drag reduction taking place (Ibrahim & Braimoh, 2005).

Reduction of inner wall surface friction or Tom's is defined as lowering drag. Fig. 2.1 depicts the occurrence of a collision effect in a turbulent flow situation according to drag reduction theory (Hasan & Khalid, 2017).



**Figure 2.1:** Drag Reduction Theory

In 1906, (Turian & Yuan, 1977) stated that substantial pressure decrease would occur when some additive was introduced to the flow, but in 1948, after more analysis, Tom confirmed this hypothesis. It is Tom's groundbreaking and influential research paper, "Some Observation on the Flow of Linear Polymer Solution Through Straight Tubes at Large Reynolds Number," which had extensive influence on the exploration of various sources of polymers and with the formula presented (Equation 2.2), Tom found a drag reduction percentage (DR) :

$$\left[ \%DR = \frac{|\Delta P_f - \Delta P_{fDRA}|}{\Delta P_f} \times 100 \right] \quad (2.1)$$

It is quite usual to see this formula in research publications for the purpose of cross-checking results from flow with DRA and pressure drop (Hasan & Khalid, 2017).

### 2.3 Turbulent Mechanism

To solve the energy balance equations for turbulent pipe flow, we have done experiments to help us infer the polymer turbulence interaction that is responsible for drag reduction and its influence on the energy balances of turbulent pipe flow. Physical framework, polymer turbulence interaction, and energy balances are all covered by the mechanism. For drag reduction, the framework had to be sketched out in detail. Then, when macromolecules were added, the area was changed. When discussing the flow, the elements of the flow that are relevant include: turbulence burst. Flow field models fluid particle deformation during a burst by interacting with a macromolecule. Due to the dilute polymer, elongation flow is evident at the stagnation sites as well as throughout the approach. This means that considerable magnitude near the wall visualization shows fluid particle elongations.

Many investigations show that polymers are greatly influenced in the wall close area. To lower the shear stress in the pipeline, polymeric solution is inserted into the flow of water and turbulence. Later, once the macromolecules had diffused to the wall area, the drag decrease

was substantially increased. See Figure 2.2: The Potential Torque and Friction Loss Curves (Wole-Osho, Okonkwo, Kavaz, & Abbasoğlu, 2021) Later, as part of the drag reduction process, all of the data points between polymer solution and solvent constitutive equations were examined and the differences calculated. Drag reduction has been a well studied issue for almost 60 years. In general, the viscoelasticity of the turbulent drag reduction solution is responsible for drag reduction phenomena. It has explained the drag phenomena by analysing the energy dissipation of viscoelastic liquids.

Performance that deviates from expectations results from a little addition of polymer additives to the turbulent flow. As the building approaches the wall, the vortex stretching will occur, polymer molecules will elongate, and fluid flow will face high elongation forces. The drag on the system was reduced due to resistance to vortex stretching. If you try to change a huge eddy by constructing a huge polymeric chain with a longer relaxation period, it will decay the eddies very instantly. Migration of the polymeric chains due to shear flow may change fluid flow structure and viscosity solution characteristics in a non-isotropic manner. considering the non-isotropic features, changes in turbulent organisation and the drag reduction phenomena are influenced directly (Han, Dong, & Choi, 2017).

#### 2.4 DRAG REDUCTION AGENT

Drag reduction is a word to improve fluid flow capacity while minimising pressure drop (Hasan & Khalid, 2017). More water flows as a result, which also minimises the risk of floods. In the last decade, drag reduction agents (or DRA) have typically been created using polymers with a high molecular weight or surfactants have been utilised to increase and minimise pressure drop in fluid pipelines (Campbell & Jovancicevic, 2001). This kind of surfactant may self-assemble and produce thread-like micelles in the fluid. The self-assembly characteristics of surfactants are dependent on temperature, concentration, and kind of surfactants. Due to the quick manner in which surfactant molecules recombine at high shear,



this is the case. With this, the surfactants were able to withstand mechanical degradation, which resulted in more steady flow (Qi et al., 2017).

Using fibres to reduce drag would make the rheological properties of the water change (Montazer et al., 2020). In summary, the majority of researchers believed that this phenomena was the consequence of polymer molecules interacting with turbulent flow (Owolabi et al., 2017). Fibers, surfactants, and polymers are well recognised as drag decreasing agents that may be used in all three (3) primary categories. The three (3) classifications often used in the industries have a high level of efficiency and a low cost. known as biopolymers, polymers are constructed of mixes of chemicals and natural polymers, which are referred to as synthetic polymers (Hasan & Khalid, 2017). The combination of chemicals used to make synthetic polymers is referred to as "synthetic polymers." According to (Simeoni, 2016), the larger proportion of biopolymers in drag reduction is attained when the concentration of biopolymers is 4000 times greater than for synthetic polymers.

There is a big demand for synthetic polymers owing to their superior performance as drag reduction agents in industry. While synthetic polymers have a broad range of possible applications, their long-term use poses a significant concern in terms of the amount of pollution, which affects the environment (Edomwonyi-Otu, Simeoni, Angeli, & Campolo, 2016). Biopolymers became more advantageous when they were threatened with the loss of the environment, which spurs academics to perform more study on biopolymers in an effort to save the environment. One aspect among many other influences impacts the effectiveness of the medication. To have the best success, use a linear flexible chain structure and ultra-high-molecular weight of the drag reduction agent.

## 2.5 BIOPOLYMERS

Polysaccharides are a frequent natural polymers that are formed by living cells and biodegradable since bio is a synonym for "alive." Monomeric units are linked together to

create long, monomeric chains. The environment was protected from any deterioration by organism, which left behind organic byproducts such as carbon dioxide and water. Find another substance that conforms with nature's needs because of being biodegradable, renewable, and plentiful. the polypeptide, carbohydrate, and polynucleotide primary class categorization shown in Figure 2.3 by (Edomwonyi-Otu et al., 2016).

Biopolymers may be found in both natural and manufactured environments, and in numerous sectors, and hence serve as a solution in those businesses. Carbohydrates, produced from cellulose, starch, chitosan, agar, and carrageenan, are found in natural biopolymers used in food processing. Gelatine, gluten, alginate, whey protein, and collagen are all used to produce food supplements from the protein business. Because of the existence of state-of-the-art technology, the synthetic biopolymer has been created for use in two separate sectors. These types of polyhydroxyalkanoates (PHAs), polyhydroxybutyrate (PHB) and poly(3-hydroxybutyrate-co-3-hydroxyvalerate) are common microbial polymers used in the microbial production business (PHBV).

Biomass industry used polylactic acid (PLA) as their chemical synthesis, while petroleum industry used polycaprolactone (PCL), polyvinyl alcohol (PVA), and polyglycolic acid (PGA) in their active processing (PGA). Consider (Dasman, Othman, Ahmad, Yacob, & Ishak, 2014): Gum guar (GG), gum arabia (GA), carboxymethyl cellulose (CMC), polyacrylamide (PAM), polyethylene oxide (PEO), xanthan gum (XG) are the most often utilised biopolymers in the market, and each has its own distinct benefit and disadvantages.

#### 2.51 GUM ARABIC (GA)

Acacia gum is sometimes known as gum arabic. A material secreted from a tree gum is known as gum Sudani or acacia gum (Figure 2.7). It was a valuable commodity in ancient Egypt. It was a component used in the mummification process and was also used to paint and carve hieroglyphic text. (Williams & Phillips, 2021).

Because of its high levels of stability, self-renewing, excellent emulsifying and binding capabilities, gum arabic is used in a wide range of sectors today, including paint, petroleum, food, and much more. Gum guar, which is also known as gum arabic, lost around half of its adhesive ability after fifteen days in a water emulsion formulation (Sokhal, Dasaroju, & Bulasara, 2019). It is possible to dissolve gum arabic in water, resulting in a clear solution. Gum arabic contains arabinosyl, black circles indicate 3-linked galactose, and white circles show 6-linked galactose. Additionally,  $R_1$  and  $R_3$  show galactose-3arabinose and arabinose-3arabinose-3arabinose. These branches will finish in Rhamnose and Glucuronic Acid near the border of the molecules (Padala, Williams, Phillips, & Chemistry, 2009). When dissolved in water, gum arabic exhibits Newtonian behaviour. It may be used as a shear thickening or a shear lining, depending on how it is prepared. It is also attributable to the thixotropy effect, which occurs due to time when the forces that the particles exert on each other are adjusted (Tynell, Karppinen, & Technology, 2014).

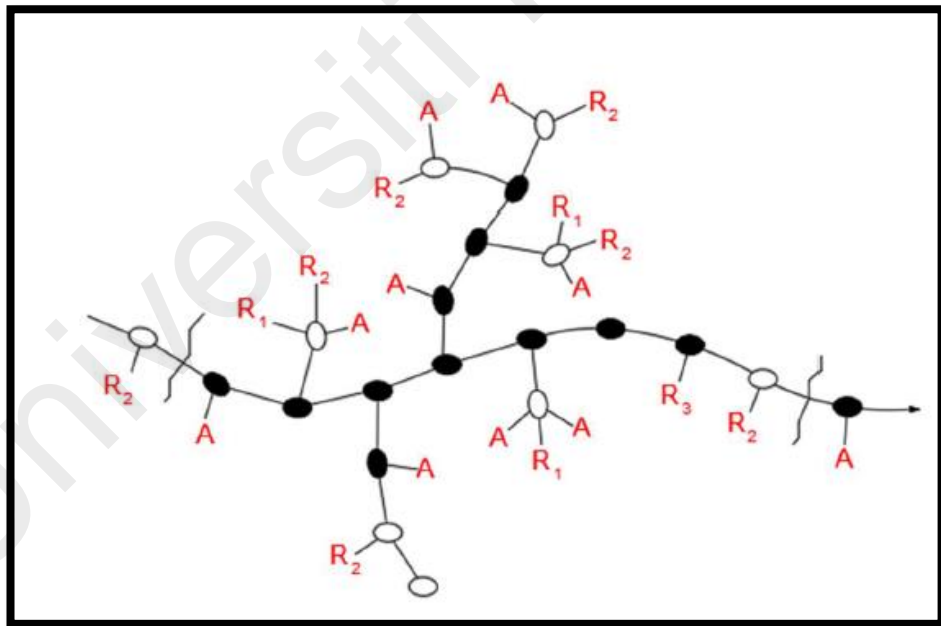
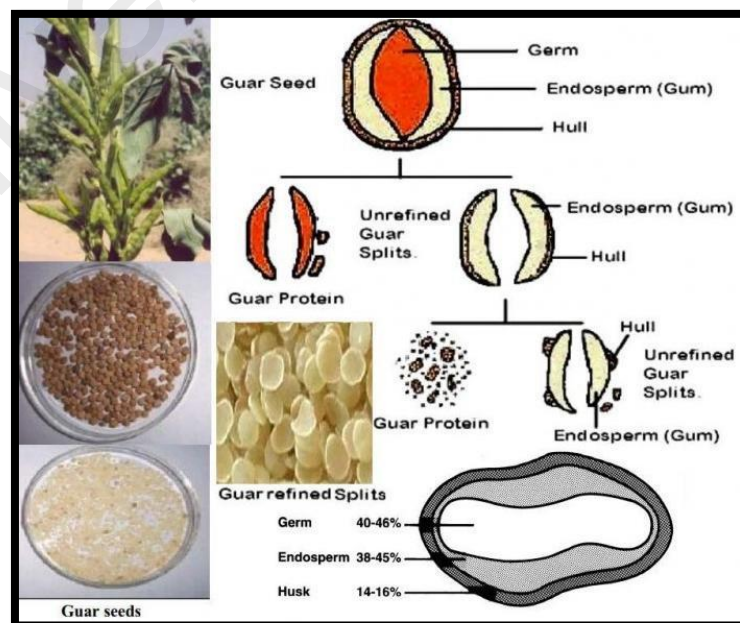


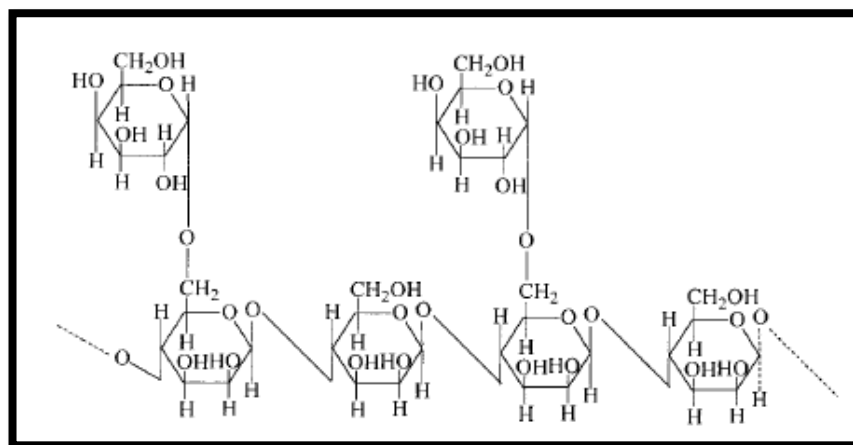
Figure 2.2: Structure of Gum arabia (Williams & Phillips, 2021)

## 2.52 GUM GUAR (GG)

While guar (grown in India, Pakistan, the USA, Australia, and Africa) is called guar, extracted from the beans with thickening liquid and higher-stability qualities, gum guar is also known as guaran grown in India, Pakistan, the USA, Australia, and Africa. The industrial, food, and feed industries may all profit from these qualities. Guar seeds are mechanically dehusked, hydrated, milled, and screened before being produced. Many studies have focused on this trait, which is capable of withstanding temperature 80°C for five minutes. Because of this, the powdery finished product will be supplied to sectors such as cosmetic, agricultural, medicines, and hydraulic fracturing, all of which are in the oil and gas business. GG (as an example of a galactomannan polysaccharide) is water soluble and galactomannan according to the research conducted by (Demirci, Yılmaz, Demirci, & technology, 2014; Sokhal, Gangacharyulu, & Bulasara, 2018; Williams & Phillips, 2021) and (Zheng et al., 2019). The guar plant is a linear chain of 1,4-linked  $\beta$ -D-mannopyranosyl units connected together at both ends by  $\alpha$ -D-galactopyranosyl units. The two component units are in a 2:1 ratio. Choi et al. illustrate the extraction process and structure of Figure 2.5 with the guar seed in Figure 2.3.



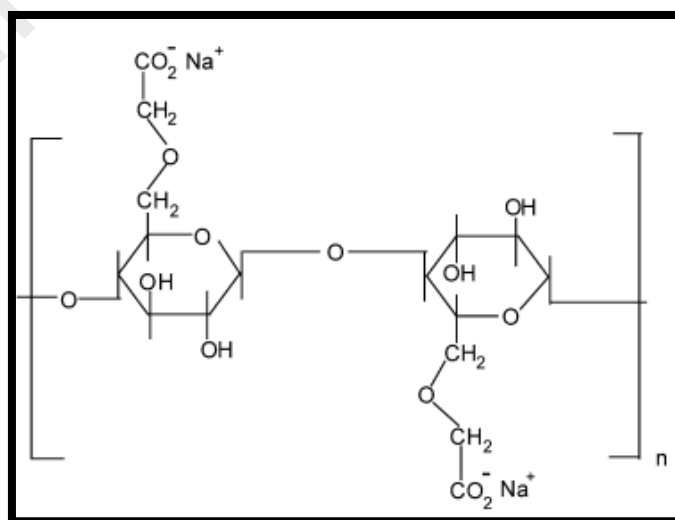
**Figure 2.3:** Guar Seed (Zheng et al., 2019)



**Figure 2.4:** Gum Guar (GG) Chemical Structure (Murali, Vidhya, & Thanikaivelan, 2014)

### 2.5.3 Carboxymethyl Cellulose (CMC)

CMC, or cellulose gum, is described in the paper published by (Ma et al., 2020) as a result of a reaction between cellulose and the chemical known as chloroacetic acid and salt. (Xing et al., 2019) examined the relationships between sodium carboxymethyl ( $\text{CH}_2\text{COONa}$ ) and cellulose molecules, starting with figure 2.5. Three things influence the qualities of a compound: molecular weight, the number of carboxyl content per anhydroglucose unit, and the distribution of carboxyl substituents. To describe these three crucial features, a medical writer may use the phrase "flocculation, viscosity buildup, and shear stability." It is easy to get and inexpensive.



**Figure 2.5:** Carboxymethyl Cellulose Chemical Structure (Xing et al., 2019)

#### 2.5.4 Polyacrylamide (PAM)

PAM, the most commonly used drag reducing agent, is a synthetic organic macromolecule that is synthesised from acrylamide subunits (Figure 2.6). Dispersing is commonly done with flocculation, which is commonly used in water treatment and papermaking processes. PAM (Polyacrylamide) is less concentrated in the oil and gas industries, which can create a very viscous aqueous solution (L. Han et al., 2017; W. J. Han et al., 2017).

While poly(ethylene oxide) (PEO) exhibited high shear resistance and mechanical stability at high temperatures, polyacrylamide (PAM) maintained its high shear resistance and mechanical stability even at higher temperatures. Therefore, polyacrylamide (PAM) is an excellent drag reduction agent and long-term transportation application, as demonstrated in the above discussion.

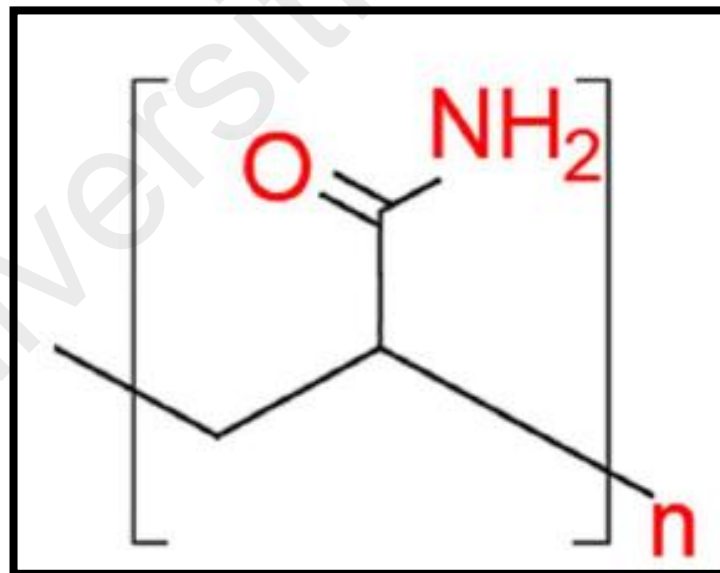


Figure 2.6: Structure of Polyacrylamide

#### 2.5.5 POLY (ETHYLENE OXIDE) (PEO)

Polyethylene oxide (Poly) is a linear, flexible chain polymer of average molecular weight, and its wide-ranging study is attributed to its high average molecular weight and flexible

chain structure. Shown in Figure 2.10 Polyethylene oxide (also known as poly(ethylene oxide) or PEO) is a drag reduction in water systems owing to its flexible chain structure and average molecular weight. Drag decreasing, or drag cutting, is an asymptotic value that is linked to pipe diameter and molecular weight; as the pipe diameter increases, the value for drag decreasing approaches infinity. As polymer concentration is increased and the pipe diameter is decreased, drag will rise and the overall efficiency will be reduced. When there is a rise in temperature, the mechanical chain will deteriorate (Yue et al., 2019).

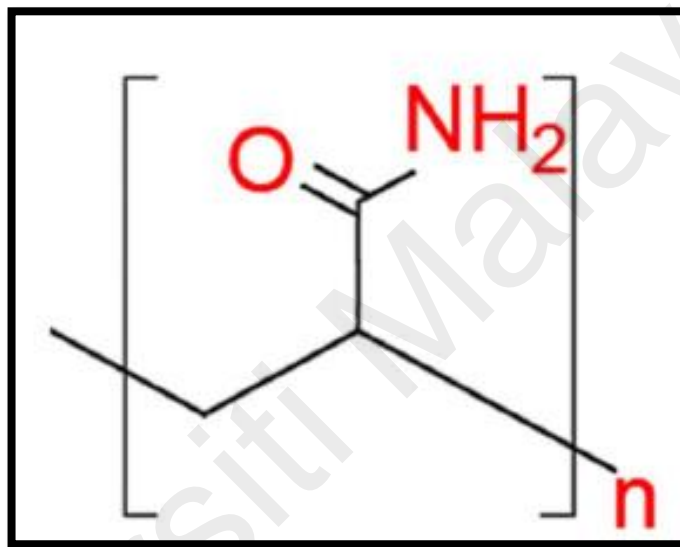


Figure 2.7: Structure of Poly(ethylene oxide) (Yue et al., 2019)

#### 2.5.6 XANTAN GUAR

Xanthan gum is a kind of extracellular cellulose, also known as expellan or soluble in cold water, that is generated by microorganism *Xanthomonas campestris*. The solution demonstrated highly pseudoplastic flow and had exceptional stability in viscosity, was resistant to enzymatic degradation, and was extremely resistant to protein and non-protein chemical modification. Bacterium *Xanthomonas campestris* normally manufacture cellulose by an enzymatic mechanism at the cell wall. It's possible to find bacteria on the leaves of cruciferous vegetables, such as cabbage (Figure 2.11) Until get an inoculum build-up, the fermentation is forced to the end of the fermentation process, and after that the inoculum is

removed using isopropyl alcohol. Then, the finished product is dried and milled (Ouweland et al., 2009). Xanthan gum has a molecular weight from  $2 \times 10^6$  to  $5 \times 10^6$ , which corresponds to its flexible (Figure 2.12) structure. To compare to polyamide and polyethylene glycol, flexible polymers such as PAM and PEO are used, which have higher drag reduction. Although PEO's drag reduction fades with time, xanthan gum does not experience significant mechanical deterioration (Ouweland et al., 2009).

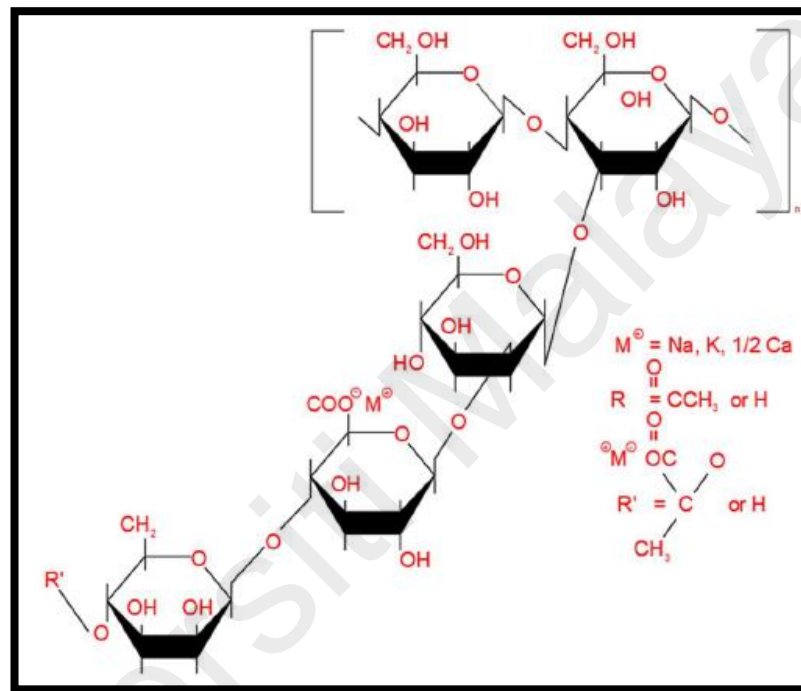


Figure 2.8: Structure of xanthan gum(Sworn, 2021)

## 2.6 STUDIES ON ANALYSIS

Reynolds number, friction factor, and drag reduction ratio are the primary variables studied in drag reduction analytical research. Experimental equation and empirical equation are comparable equations.

### 2.6.1 PRESSURE LOSS

There have been a tremendous amount of resources applied to bringing in fresh data that may be used in the businesses. Along with the rise of industries, a host of new problems arise and contribute to the continued development of the industry. A simple, empirical method



such as correlation is useful because of its ease of use. Turbulent flows use Colebrook and White equation to compute flow friction factors (Equation 2.2).

$$\frac{1}{\sqrt{f}} = -2 \log \left( \frac{\epsilon}{3.7D} + \frac{2.51}{Re\sqrt{f}} \right) \quad (2.2)$$

The Reynolds number and the  $\epsilon/D$  have a significant impact on the turbulence in turbulent pipe flow (relative roughness). This only applies roughness range from 0 to 0.05 for the Colebrook and White equation, and for Reynolds number, 4000 to 1022. These formulas may be utilised with the following seven individuals in mind.

Equation is used to determine flow velocity and pressure drop in pipes based on laminar and turbulent flow conditions. The average pressure drop, or  $\Delta P/L$ , is the pressure drop proportional to the whole length of pipe, calculated as  $\Delta P/L = (P_{out} - P_{in})/L$ . The unit of Pa/m is illustrated in the figure below, while the Darcy-Weisbach equation is given below.

$$\frac{\Delta P}{L} \quad (2.3)$$

## 2.6.2 REYNOLDS NUMBER

Laminar flow and turbulent flow may be predicted using the Re. Under the influence of viscous forces, flow that has a low Reynolds number is generally referred to be laminar. Such flow is described as smooth, and steady fluid motion is seen. There are instabilities when the flow is turbulent and has high Reynolds number. In laminar flow, the Reynolds number is typically less than 2300, but in turbulent flow, it is more than 4000 (Cheng, 1997).

$$Re = \frac{\rho v D}{\mu} \quad (2.4)$$

### 2.6.3 FRICTION FACTOR

A different friction coefficient (one that results in a higher measurement error) is used in turbulent flow calculations than in Colebrook, White, Swamee, and Jain, and Blasius equation, when using the Darcy-Weisbach and Fanning experimental equation, compared to Colebrook, White, Swamee, and Jain, and Blasius equation, when using the empirical equation. Friction factor values and Reynolds number are connected; further, relative roughness ( $\epsilon/D$ ) is a component of friction factor values. It has been shown that the Darcy-Weisbach laminar flow equation works (Haaland, 1983).

Darcy-Weisbach experimental equation.

$$f = \frac{\Delta P}{\frac{\rho v^2 L}{2 D}} \quad (2.5)$$

Fanning experimental equation.

$$f = \frac{\Delta P \cdot \frac{D}{4L}}{\rho \frac{v^2}{2}} \quad (2.6)$$

Colebrook and White turbulent equation

$$\frac{1}{\sqrt{f}} = -2 \log \left( \frac{\epsilon}{3.7D} + \frac{2.51}{Re \sqrt{f}} \right) \quad (2.7)$$

Swamee and Jain turbulent equation

$$f = \frac{1.325}{\left[ \ln \left( \frac{k_s}{3.7D} + \frac{5.74}{Re^{0.9}} \right) \right]^2} \quad (2.8)$$

Blasius turbulent equation

$$f = \frac{0.316}{Re^{0.25}} \quad (2.9)$$

Fanning turbulent equation

$$\frac{1}{\sqrt{f}} = 4 \log_{10}(\text{Re}\sqrt{f}) - 0.4 \quad (2.10)$$

Hagen-Poiseuille laminar equation

$$f = \frac{64}{\text{Re}} \quad (2.11)$$

Darcy-Weisbach laminar equation

$$f = \frac{16}{\text{Re}} \quad (2.12)$$

#### 2.6.4 DRAG REDUCTION

A multitude of research and tests have been undertaken on various fluid and pipeline characteristics to identify the most efficient natural polymer drag reduction additives, because of their copious availability, inexpensive price, and one of the better drag reducers (Hasan & Mohamed Khalid, 2017). Figure 2.12 offers evidence that supports Duffy's hypothesis, which claims that the head velocity curve is the same for each regime utilising chemically prepared pulp (Duffy, Moller, & Titchener, 1972).

##### 2.6.4.1 DRAG REDUCTION RATIO

Friction factor data between fluid and additive is used to compute the drag reduction percentage. The greater the percentage that is shown is a greater indication of drag reduction.

$$DR\% = \left( \frac{f_{fluid} - f_{fluid\ additive}}{f_{fluid}} \right) \times 100 \quad (2.13)$$

## 2.7 INDUCED DRAG REDUCTION STUDIES

Conventional drag reduction techniques have been evaluated by extensive investigations on various fluid, mixture, pipeline, and parameter combinations. In order to cut the price, the investor has been scouring for cheaper and lower prices. In view of the above, research on several polymers has been mentioned.

### 2.7.1 GUM GUAR (GG)

Choi et al., (2002) and Hong et al., (2010) state that polysaccharides can be selectively produced from ultrasonic degradation with various different molecular weight selection, having a weight percent concentration of 0.5% and stirred for one week in deionized water in a custom-designed ultrasonic generator at a frequency of 28kHz, with 750W of sound input. Three distinct molecular weight samples were collected such as GG<sub>V</sub>, GG<sub>30</sub>, and GG<sub>60</sub> (GG<sub>60</sub>). In order to better deal with both mechanical shear deterioration of polymeric materials and frictional reduction, a rotating disc device (RDA) was designed. The RDA system, together with the computerised control unit, speed governor, motor, thermocouple, container, water bath, water circulation system, and thermometer, communicate with one another through a system that permits inter-device communication. From 10 ppm to 400 ppm. This equation was developed using the Re symbol displayed below (Duffy et al., 1972).

$$N_{Re} = \frac{\rho r^2 \omega}{\mu} \quad (2.14)$$

Data collected reveals the magnitude of turbulence  $NRe$  to be more than  $3 \times 10^5$  or  $\omega$  to be more than 570rpm and the intensity of a litre of 1-litre container at  $25 \pm 0.5^\circ\text{C}$  to be 1800rpm DR was reduced to about 10% (Kim, Lim, Choi, Sohn, & Jhon, 2002). (Motta et al., 2019).

$$\%DR = \left( \frac{T_0 - T_P}{T_0} \right) \times 100 \quad (2.15)$$

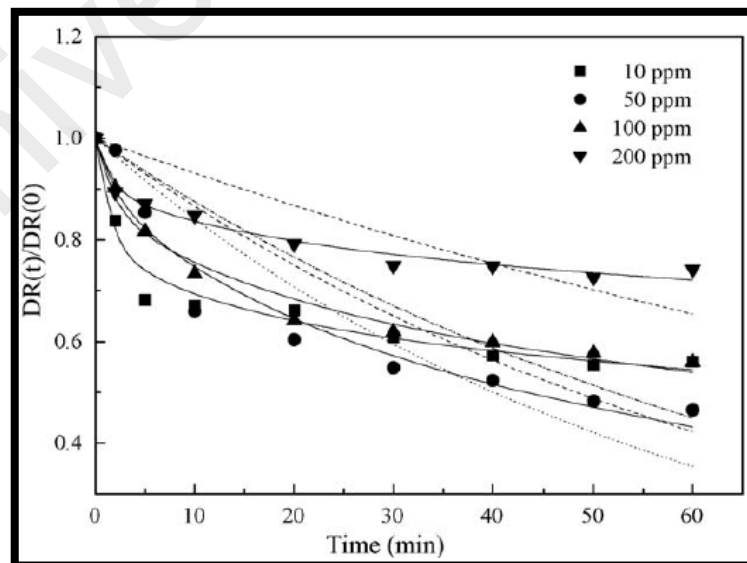
Drag reduction, when it is mentioned in reference to PEO, PEO Plus, and XG, is compared with various concentrations. GG solution is not as good as the PEO solutions since less concentration is required. GG has good shear resistance. GG are more resistant to mechanical deterioration than Xanthan Gum (XG). GG behaviour was seen at 10% DR for more than 10 hours when the device was running at 1800 rpm. The drag reduction efficiency of this product plateaued around 62% to 80%.  $R^2 = 0.81$ . To arrive at the K value, use the formula below:

$$\frac{c}{DR} = \frac{K[C]}{DR_{max}} + \frac{c}{DR_{max}} \quad (2.16)$$

$$[C] = \frac{DR_{max}}{\lim(\frac{DR}{c})} \quad (2.17)$$

$$[DR] = \frac{DR_{max}}{[C]} = \lim \frac{DR}{c} \quad (2.18)$$

Intrinsic concentration and intrinsic drag reduction are defined as follows: C is wppm, K is a parameter that depends on the solvent system, and  $DR_{max}$  is the greatest drag reduction. The Hong et al. (2010) comparative parameters are included in Tables 2.1 and 2.2, where the varied concentrations of the GG polymer are given. GV concentration and mixture decrease in drag and duration in minutes in Figure 2.10 and Figure 2.11 by Hong et al. (2010).



**Figure 2.9:** GG at 50 to 200 PPM Drag Reduction versus Elapsed Time

## 2.7.2 GUM ARABIC (GA)

Rheological of gum arabic at 25 °C for concentration of 50 ppm to 300 ppm was examined by Sokhal et al. (2019). For the investigations, a solution of 10,000 ppm was agitated for seven hours, let to sit overnight, then diluted to its concentration ratio for testing. As the polymer concentrations increased from 50 ppm to 300 ppm, the shear rate was maintained between 0.1 and 1000 s<sup>-1</sup>. In the case of low concentrations of 50 ppm to 100 ppm, viscosity behaves much like a Newtonian (Figure 2.10). The 150 ppm to 300 ppm concentration level allows for the observation of shear thinning behaviour. the viscosity of a solution increases as its concentration decreases, but, when the concentration increases to about 300 ppm, viscosity begins to decrease (Figure 2.16). When extra gum arabic is added to the water flow, there is a considerable impact in the trials described. Drag reduction was influenced, as illustrated in Figure 2.17, when concentration and Reynolds number rose. Drag reduction results in pressure decreases of 25% and 40% on Reynold number 17,000 and Reynolds number 45,000 respectively. At 300 ppm concentration and with a Re number of 45,000, a drag reduction of 62.15 percent was achieved. (Dror, Cohen, & Yerushalmi-Rozen, 2006; Williams & Phillips, 2021).

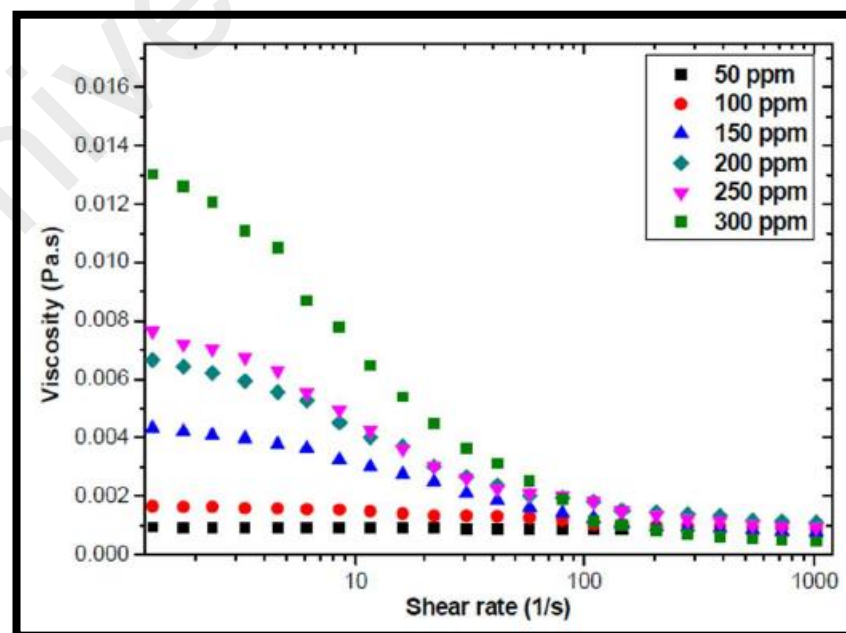


Figure 2.10: GA solution's Shear viscosity from 50 ppm to 300 ppm (Sokhal, Dasoraju, et al., 2019)

### 2.7.3 GUM ARABIC AND GUM GUAR DRAG REDUCTION

In a study published in the journal Sokhal et al. (2019), gum arabic and gum guar were evaluated as drag reduction additives. These 2 proved useful because of their stability, ease of production, and self-reinforcement. The medium for the water pump was tap water that had a pH of 6.93. To prevent lumps formation, a combination of water and oil was agitated, followed by the gradual addition of polymers powder until the appropriate concentration was reached. It was kept overnight after stirring. A research concluded that gum guar and gum arabic each used at a concentration of 3000 ppm is useful for reducing drag in water and oil flow. Gum guar results in the greatest possible drag reduction percentage of 65.9 percent, whereas gum arabic can only achieve a drag reduction percentage of 43.26 percent (Sokhal, Dasaraju, et al., 2019).

### 2.7.4 DIFFERENT TYPES OF GUM GUAR

GG, soxhlet extraction with 95% ethanol and acrylamide monomer recrystallization from acetone was performed by Deshmukh et al. (1985). Both reagent and grade for practical usage A temperature of 30.0°C, with a reaction implement set up under N<sub>2</sub> at 29.0°C ± 1.0°C for 3 hours, giving a reaction result of 30.0°C. Graft copolymers 1,2, and 3 (GM1, GM2 and GM3). 1M NaNO by temperature 30°C uses the viscosity measurement When preparing the solution for all samples shown in Table 2.3, be sure to use the grafting reaction.

Table 2.1 Grafting Reaction Details (Pandey, Verma, Yadav, & Behari, 2014)

| Sample no.      | Acrylamide (mol/L) | HNO <sub>3</sub> (mmol/L) | Ce(IV) (mmol/L) | Guargum (g/L) | Monomer conversion | [η] <sup>b</sup> (mL/g) |
|-----------------|--------------------|---------------------------|-----------------|---------------|--------------------|-------------------------|
| Gm <sub>1</sub> | 0.1408             | 50                        | 2.5             | 10            | 0.53               | 260.0                   |
| Gm <sub>2</sub> | 0.3052             | 50                        | 2.5             | 10            | 0.57               | 272.8                   |
| Gm <sub>3</sub> | 0.7004             | 50                        | 2.5             | 10            | 0.77               | 408.7                   |

One hundred millilitres of distilled water was added to each gramme of GG and monomer with the initiator. Everything, including the temperature and the response time, was exactly the same. The product reaction data was gathered due to the excess of

acetone, which triggered the combination to undergo a reaction. The product will be dried at above 45°C in a vacuum afterwards. Re 14,000 using a turbulent rheometer, the DR concentration is anything between 50 and 1000ppm. CGG:62% , PGG:65% , GM1:15% , GM2:46% , and GM3:66% At 400ppm concentration, the shear resistance results are consistent no matter how many passes are made (CGG:56, PGG:61, GM1:8, GM2:35 and GM3:62). In order to have 0.1% of biodegradation carried out during a period of 256 hours, the process must use 1% during that duration. To lower frictional drag in turbulent flow, Han and Choi (2017) performed an experiment employing polymeric additives. Several biopolymers have been investigated and may be used to replace synthetic polymers as drag-reducing agents. Because of this, it is more safe and better for the environment. The eleven biopolymer additive selections were put through a solvent-based screening at the following concentrations: ppm. Three solvents: water, “water and KCl”, and “water and NaCl” were all evaluated using the XG additive, with each solvent present at the same concentration of 200ppm. This is seen by the results of water-based XG drag reduction which results in 36.2% drag. In DR% chitosan has the greatest drag with 80.4% and CT-DNA has the lowest drag with 5.8%. Surprisingly, the  $\lambda$ -DNA molecule has the greatest average conversion (lambda-DNA with concentration used), at 7.3 percent, whereas carrageenan, with concentration used, has the lowest average conversion (0.03 percent). One ppm of lambda-DNA has the capacity to provide 7.3% drag reduction, whereas carrageenan at one ppm has the capacity to provide 0.03% drag reduction. Because of the lower ppm use and significant conversion of drag, low ppm additives should be thought of for future experiments (W. J. Han et al., 2017).

**Table 2.2:** Drag Reduction Performance for Bio Polymer Additives (W. J. Han et al., 2017)



| Biopolymer                   | Solvent        | Concentration (ppm) | Max DR% |
|------------------------------|----------------|---------------------|---------|
| Xanthan gum [66]             | Water          | 200                 | 36.2    |
| Xanthan gum [66]             | Water and KCl  | 200                 | 34      |
| Xanthan gum [62]             | Water and NaCl | 200                 | 33      |
| Guar gum [71]                | Water          | 200                 | 32      |
| $\lambda$ -DNA [79]          | Water          | 2.7                 | 19.8    |
| CT-DNA [84]                  | Water          | 20.25               | 5.8     |
| Amylopectin [87]             | Water          | 30                  | 27.3    |
| Hydroxyethyl cellulose [88]  | Water          | 300                 | 42      |
| Carboxymethyl cellulose [89] | Water          | 1000                | 42      |
| Carrageenan [93]             | Water          | 2000                | 60      |
| Okra [95]                    | Water          | 1000                | 71      |
| Aloe vera [99]               | Water          | 400                 | 63      |
| Chitosan [100]               | Water          | 300                 | 80.4    |

### 2.7.5 NANOPARTICLES

Dai et al. (2017) indicate that nano composite with two additives, one of which is “nano silica” and the other “poly- $\alpha$ -olefin,” were synthesised. Drag reduction will be measured while surface modification on Nano silica is implemented. While surface hydroxyl alterations were studied and reviewed, it was also explored via research on immersing oil. The amount of hydroxyl groups in the Y-aminopropyltriethoxysilane alteration has decreased, with a resultant decrease in lipophilicity and better oil immersion. The needed 50°C, Y-aminopropyltriethoxysilane was Nano-Si-10, Nano-Si-20, and Degussa-R972, which is 10 percent of the total volume. Changes in the nano silica surface characteristics and the poly- $\alpha$ -olefin connection were discovered after the improvements. For this test, the disc is rotated for 40 minutes and the test loop is conducted twice to shear. Each of the two cycles is able to provide a 15% drag reduction and outstanding shear resistance with respect to the nano composite's capabilities. Nano-SiO<sub>2</sub> particles (20 to 30nm) combined with distilled water were used in a technique developed by Pouranfard et al. (2015) to produce nanofluids with density 2.4 g/cm<sup>3</sup> with 180-600 m<sup>2</sup>/g. By adding the little amount of liquid, which amounts to 0.5% of the total weight, the solid particles are combined with a surfactant solution to form stable nanofluids. When adding hydrophilic, beneficial groups to the nanoparticle surface, and

acid mixes to modify the nanoparticle surface, the supplement approach is used. To prepare the mixtures, the magnetic stirrer is run through a sonication process using an ultrasonic processor with a frequency of 40kHz, temperatures of 25°C, and viscosities and densities of the solutions. Pipe ID 1.27, 1.905, 2.54, 3.175cm and length 9m investigated utilising nanofluid to investigate drag reduction in horizontal smooth pipes. Water pressure range of 250-1500 L/h and air pressure range of 300-2400 L/h. When maximum nanofluid concentration is reached, the drag reduction rises. In contrast to smooth pipes, which often yielded worse drag reduction outcomes, rough pipes produced superior results (Li et al., 2017).

#### 2.7.6 HYDROPHOBIC COMPOSITION

According to Tan et al., (2020), in addition to producing PHWAM = 1, PHWAM = 2, and PHWAM = 3, the drag reducer used in this study self-produced PHWAM = 1, PHWAM = 2, and PHWAM = 3. The list of materials included in the raw materials preparation consisting of AA, AM, SDS, Span80, Tween60, NaCl, mgClO<sub>2</sub>6H<sub>2</sub>O, CaCl<sub>2</sub>, Acetonitrile, Dichloromethane, white oil, dodecylamine, 1-bromododecane, 2-methylpropenoyl chloride, AMPS, NaHSO<sub>3</sub>, (NH<sub>4</sub>)<sub>2</sub>S<sub>2</sub>, and ammonium persulphate (NH<sub>4</sub>)<sub>2</sub>S<sub>2</sub> (DiC12AM). Because various hydrophobic monomers are used, every drag reducer will behave differently in various kinds of water. 1 for fresh water and 2 & 3 for salt (NaCl) in water (H<sub>2</sub>O) provide excellent results with hydrophobic monomers. PHWAM has the highest concentration of salt brine amongst the three. As opposed to a linear polymer, the molecular chain structure is capable of creating a mutual support in order to help raise DR results. Because there is minimal Re in molecular chains, PHWAM 1 had the best DR performance in fresh water. Good in shear stress under the impact of intramolecular hydrophobic association effect, the cohesive strength is measured as 2 and 3 PHWAM.

Table 2.3 Drag Reducer of Synthetic Scheme (Tan et al., 2020)

| Samples | Water Phase (110 g, pH = 7) |          |            |                          |                            | Oil Phase (110 g, HLB = 6) |               |              |             |
|---------|-----------------------------|----------|------------|--------------------------|----------------------------|----------------------------|---------------|--------------|-------------|
|         | AM (mol)                    | AA (mol) | AMPS (mol) | C <sup>12</sup> AM (mol) | DiC <sup>12</sup> AM (mol) | SDS (mol)                  | White Oil (g) | Tween-60 (g) | Span-80 (g) |
| PHWAM-1 | 0.4                         | 0.14     | 0.03       | \                        | \                          | 0.01                       | 100           | 1.6          | 8.4         |
| PHWAM-2 | 0.4                         | 0.14     | 0.03       | 0.001                    | \                          | 0.01                       | 100           | 1.6          | 8.4         |
| PHWAM-3 | 0.4                         | 0.14     | 0.03       | \                        | 0.001                      | 0.01                       | 100           | 1.6          | 8.4         |

### 2.7.7 PAMC AND TWEEN 20 – INDUCED DRAG REDUCTION

The drag-reduction properties of turbulently flowing fluids are studied by (Hawege & Abushina, 2019), who use pumps and elbows to perform experiments without piping. Prior to the introduction of a nonionic surfactant (tween 20) and cationic polymer (poly (acrylamide-co-diallyl-dime-thylammonium chloride)) to a solution, the effect of reducing pipeline friction by the use of a rotating disc apparatus (RDA) was investigated. Reduced friction in pipelines is possible with the RDA. The surfactant and Reynolds number are both able to be enhanced by the addition of polymers. over 40% drag reduction was accomplished through this method.

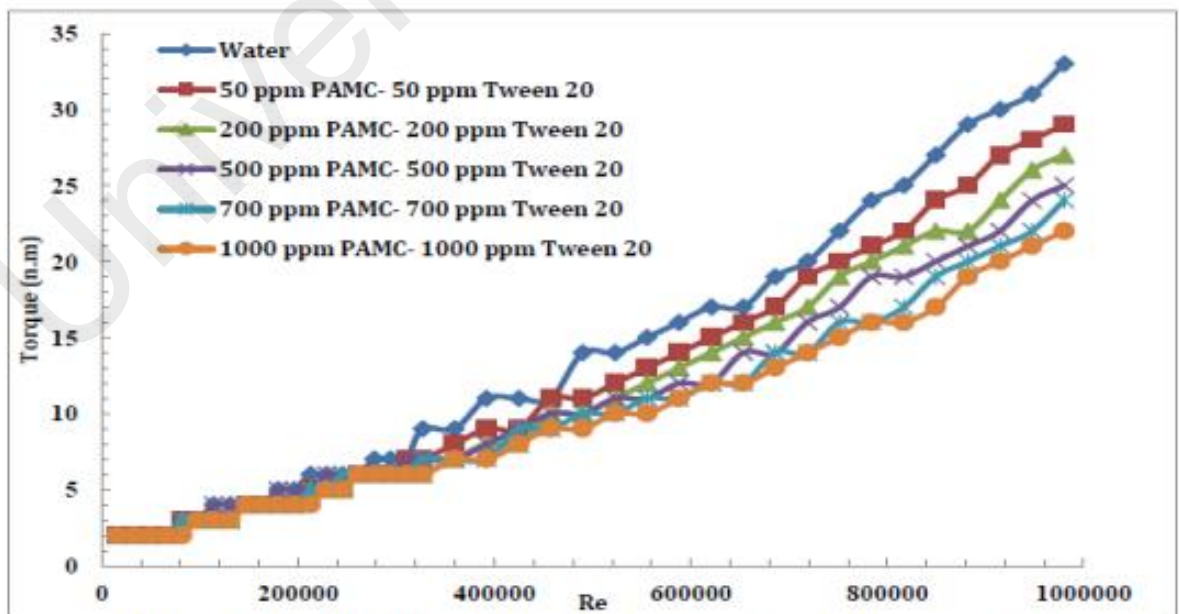


Figure 2.11: PAMC and Tween20 Effect on Drag Reduction (Hawege & Abushina, 2019)

### 2.7.8 ALOE VERA – INDUCED DRAG REDUCTION

Aloe Vera, which was examined by Ling, Abdulbari, Kadhum, and Heng (2020), was used as an organic polymeric additive to improve flow by testing a custom-built micro channel that simulates flow. Table 2.8: Dragging a Reducer: Fake Scheme (Tan et al., 2020) Inverse Emulsion 2.28 Formation of PHWAM1, PHWAM2, and PHWAM3 (polymerization) (Tan et al., 2020) It's just as natural as an artery in a human body. In order to properly test for enhancement, the flow system includes an open loop micro fluidics flow system and a rheometer that is able to identify the benefits flow test. An investigation was done on the flow rate for main additive concentrations and solutions. 94% of “100 ppm” and “400 mbar” at the “100 ppm, 400 mbar” pressure. While straight channel design reduced flow performance, the design for micro channels provided better flow performance.

High back pressure is a possibility. To determine the maximum friction factor percentage (percent FI), we use the result obtained with a straight channel at 100ppm and enhancement of lower flow. The largest percentage of FI represents additives showing better flow enhancement performance.

### 2.8 SUMMARY

The result of these effects is as follows: Drag reduction, formula use, and flow design (e.g. closed loop flow) are all important. To learn more about the creators of GG, GA, various GG, GG mixed GA, GG mixed with other polymers, and GG mixed with biopolymers, read on. Drag reduction field and polymer associations are summarised in Table 2.4.

Decreasing the effect of contaminants is done by running the gum guar and gum arabic drags investigation over distilled water, which is a base of fluid for water treatments.

Work on drag reduction in turbulent flow regimes has been reported, with a wide variety of conduit materials being investigated. Due to limited information about the aluminium test section, present work considers it.

Table 2.4: Authors Contribution

| Author and Year  | Contributions   |
|--|---|
| <p><b>Gum Guar</b></p> <p>(Choi et al., 2002)</p> <p>(Hong et al., 2010)</p> <p>(Dosumu et al., 2020)</p> <p>(Motta et al., 2019)</p> <p>(Sokhal et al., 2019)</p> | <p>analysis of how well a design will stay together and how it will perform</p> <p>determine the breakdown and effectiveness of mechanical parts with RDA</p> <p>studies on the effectiveness of GG</p> <p>the amount of power (E) required to operate the pump and remove degradation</p> <p>looked at the emulsion when it was in water and oil</p> |
| <p><b>Gum Arabic</b></p> <p>(Sokhal, Dasoraju, et al., 2019)</p>   | <p>Test the drag reduction compounds using gum Arabic solutions. They determined that the pipe's drag reduction percent increased with fluid velocity.</p>  |

|  |   |
|--|---|
| <p><b>Gum Arabic mixed Gum Guar</b></p> <p>(Sokhal, Dasaraju, et al., 2019)</p>  | <p>Findings on the efficacy and comparability of gum arabic and guar gum in water/oil flow. They found that guar gum is better for drag reduction than gum arabic.</p>  |
| <p><b>Polymers Blend</b></p> <p>(Sokhal et al., 2018)</p> <p>(Novelli et al., 2019)</p> <p>(Williams &amp; Phillips, 2009)</p> <p>(Xing et al., 2019)</p> <p>(K.D.Magit, L.C.Edomwonyi-Otu, N. Yusuf, A. Abubakar, 2002)</p> | <p>Investigate the DR effect and shear stability of GG and salt, and do a cost/benefit analysis.</p> <p>In depth studies of the polymer complex relationships People often associate GG with PAM, PEO, and XG. In general, the GG with PAM has the most durable components.</p> <p>Review of the science and technology of gum Arabic</p> <p>A study into the properties of CMC solutions.</p> <p>Determine the impact of pipe diameter and temperature on the PEO effect</p> |

|                           |  |
|---------------------------|--|
| (Campolo et al., 2015)    | in order to build a validated XG self-consistent data base |
| (Dai et al., 2017)        | Nano silica modification investigation                     |
| (Pouranfard et al., 2015) | the study of the injection of Nanofluid properties         |
| (Zheng et al., 2020)      | superhydrophobic composite coating examination             |

Universiti Malaysia

## METHODOLOGY

### 3.1 Introduction

This part describes experimental setups, designing, and drag reduction approaches, all of which were extensive. This study will follow the guidelines and methods recommended by literature study.

### 3.2 Experimental Setup

This is an experimental study, and it is implemented on the basis of a design and build implemented by the University of Malaya (UM). Figure 3.1 and 3.2 show the experimental set-up. Recirculating cooler (for cooling suspension in the tank), 100L tank, agitator motor, variable speed pump, control board, magnetic flow transmitter, magnetic flow tube, pressure transducer on test section, and piping system. A centrifugal pump was used to pump the fluid and material into the tank. The agitator pump will be activated by the inverter control board in order for the agitator blade to spin or disintegrate the material. The suspension was then transmitted through a 12195mm-long circular stainless steel pipe with an inner diameter of 41.5mm and an exterior diameter of 50.3mm. To avoid heat loss to the atmosphere, the whole pipe was insulated. The magnetic flow transmitter and flow metre were used to continually monitor the flow rate and measure the suspension's pressure decrease. For data collecting, the pressure transducer is attached to an aluminium pipe with a length of 2450mm on the test section. The fluid was then returned to the storage tank through the pipeline, and the chiller was used to cool the fluid in the tank to the necessary temperature. The pipe is also connected with thermocouple and heater to heat up the fluid to investigate the impact of drag reduction during heating. The thermocouple total of 5 numbers are fixed at the center of the piping to measure the temperature of the pipe.



### 3.3 Data Procurement

To conduct the data collection, reference materials were used such as the Inverter Control Board (rpm), Recirculating Cooler (temperature), Storage Tank utilising a lab thermometer (temperature), and the Figure 3.1 image. The Magnetic Flow Transmitter (L/min) and Pressure Transducer (kPa). Flow rate has been established as the new steady state once all measurements have been made. The flow rate of the inverter must be calibrated to meet the requirements. There will be a rise in the velocity at a steady rate. It was important to carry out a calibration of equipment to guarantee the data obtained is correct.

### 3.4 Experimental Design

Drag reduction and pressure loss are explained in this portion of the report as the production and characterisation of gum guar and gum arabic per experimental circumstances to perform.

#### 3.4.1 Preparation of Adaptive

Two gums, namely gum guar and gum arabic, were used throughout the study. These biopolymer sources are also known as biopolymer sources. These were acquired from Sigma-Aldrich Corporation (USA) with product number G4129 of Chemical Abstracts Service (CAS) No. 9000-30-0 as shown in Figure 3.5. Guar, which is widely used in the food industry, was reported to be 100% by weight, as well as according to SARA 302 and SARA 313 regulations, having no chemical content. In this paper, total of 6 experimental runs are required, where the first run is only by distilled water without any mixture of adaptive. Followed by 100ppm and 200ppm of gum Arabic, and at 200ppm mixture of gum Arabic and gum Guar at the ratio of GG:GA 30:70, 50:55 and 70:30. The weigh of the gum powders are measured using the formula below:

$$1 \text{ ppm} = 1000 \text{ g/L} / 100 \text{ L} = 10 \text{ g} \quad (3.1)$$

Table 3.1: Compensation of particles used for each run

| RATIO       | GUM ARABIC | GUM GUAR | CONCENTRATION | DISTILLED WATER |
|-------------|------------|----------|---------------|-----------------|
| NO MIXTURE  | 0 g        | 0 g      | 0 ppm         | 100 L           |
| GA          | 10 g       | 0 g      | 100 ppm       | 100 L           |
| GA          | 20 g       | 0 g      | 200 ppm       | 100 L           |
| GA:GG 30:70 | 14 g       | 6 g      | 200 ppm       | 100 L           |
| GA:GG 50:50 | 10 g       | 10 g     | 200 ppm       | 100 L           |
| GA:GG 70:30 | 6 g        | 14 g     | 200 ppm       | 100 L           |

Figure 3.1 and 3.2 shows sample of gum Arabic and gum Guar.

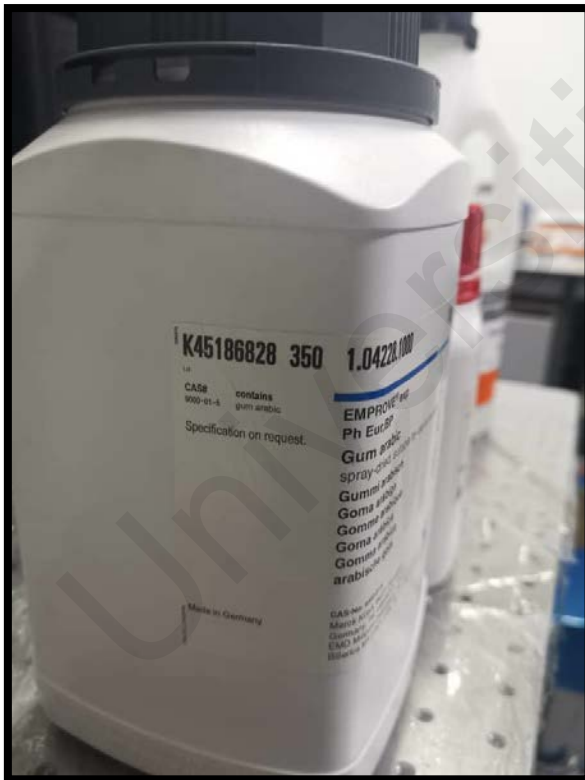


Figure 3.1: Gum Arabic

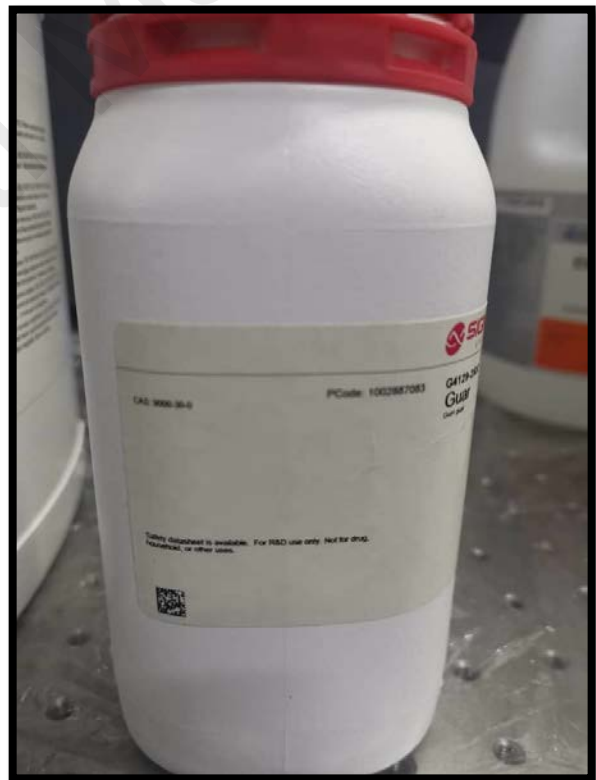


Figure 3.2: Gum Guar



Figure 3.3: Measurement of adaptive

Figure 3.3 shows preparation of gum powders using weigh scale machine.

#### 3.4.2 Distilled Water Preparation

The distilled water was made by boiling, which turned it into a vapour. The cleaned liquid was collected and condensed before being put into a temporary container. The distiller brand is Water Stills, the Model W4L Favorit with just a single distillation function. It takes 4 litres of the distiller process in an hour, and the temporary plastic container holds 200 litres as illustrated in Figure 3.6. To maintain a necessary level of 100L of distilled water, it is continuously fed into the container. Each runs requires 100 L of distilled water. Figure 3.4 shows the distiller used in the lab to collect the distilled water. The distiller connected to a filter which connected to tab water. The water was filtered before entering the distiller.

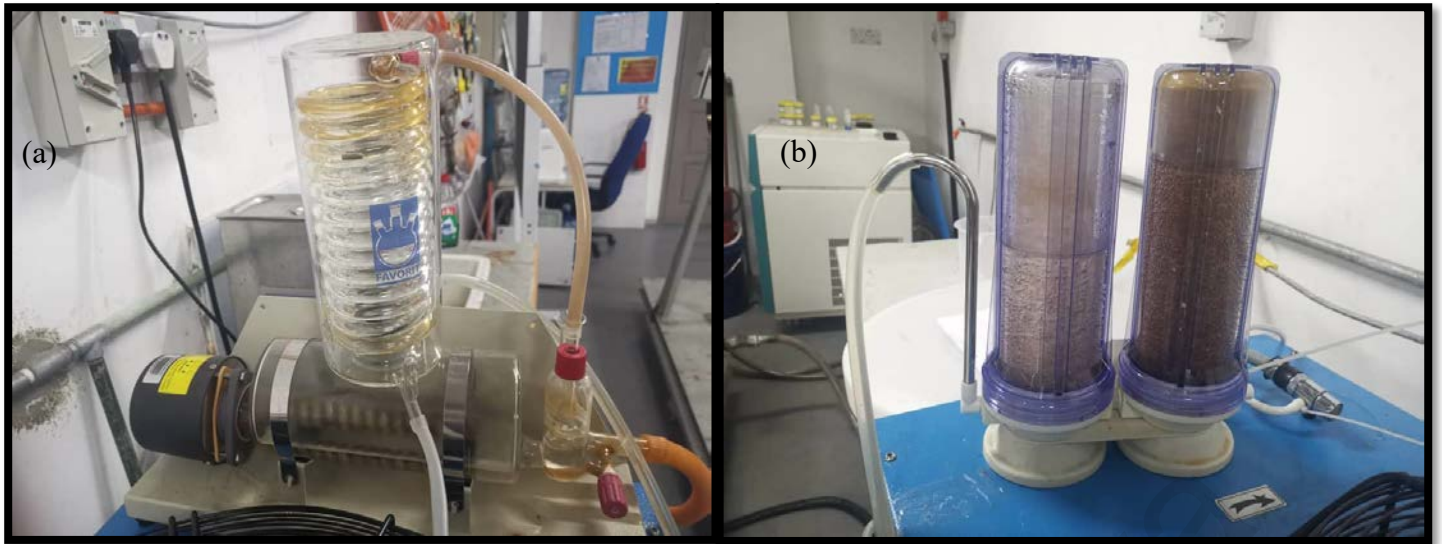


Figure 3.4: (a) Distiller (b) filter



Figure 3.5: Plastic tank

### 3.4.3 Gum Solution Preparation

After prepare the gum powder followed the required weight for each concentration, the powder then mixed in 2L of distilled water by using the pulp disintegrator-. Dilute the specimen powder to 2000 mL. Disintegrate in the ordinary disintegrator at 5000 rpm, but not more than 50,000 revolutions. Also provide the number of rotations. If above 50,000 revolutions or if the pulp has not been effectively disseminated after 50,000 revolutions.



Figure 3.6: Pulp Disintegrator

### 3.4.4 Reservoir Tank

The reservoir tank is constructed from stainless steel cylinders, which are 0.450 m in diameter and 1.57 m in length, and have rubber insulation. The tank has a nominal capacity of 100 litres. Down at the bottom is the reservoir tank pipe outlet, which leads to the pump with a diameter of 41.5 m. Moving up, there are three more piping sections: a return line, a bypass line, and a stirrer or agitator. The agitator is installed on the

reservoir tank and is controlled by a speed control motor (5GN-15K). The agitator is controlled by a control panel with a maximum speed of 100 rpm. To assure solution mixing and to avoid lump formation, the three-blade stirrer/agitator are used and for safety reasons, we set the speed of the agitator at 75 rpm throughout the experiment. In picture below you will find the specifications for the item. The reservoir tank is filled with 98L of distilled water where then 2L of samples solution is added to the tank. The agitator is then switched on for 1 hour for the solution to mixed well in distilled water. The solution then left for 24 hours to mix well before start the test run.



Figure 3.7: (a) Reservoir tank (b) Agitator motor

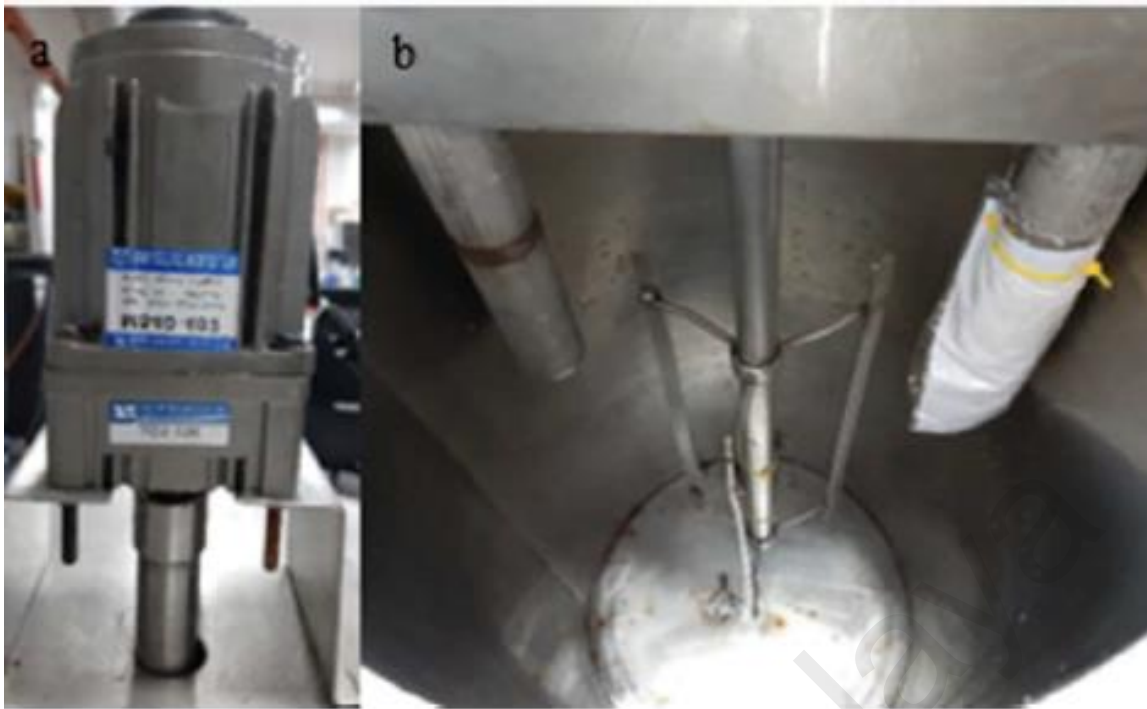


Figure 3.8: (a) Gear motor (b) Agitator blade

#### 3.4.5 Centrifugal Pump

Centrifugal pump was used to circulate the solution inside the system loop. This system can flow up to 800 LPM at a flow rate of 7.7 m head and achieve maximum operating speed of 2850 revolutions per minute. The exit of the reservoir is linked to the pump suction inlet. The pump is capable of pumping fluids with a temperature range of -10 degrees Celsius to 110 degrees Celsius. It has been estimated that the entire loop pressure loss is equal to the pump characteristic curve and that it allows the pump to run at a constant velocity throughout the system. The speed of the pump can be adjusted in the inverter. Set to the required RPM based on the velocity we required for each run. The pumps specifications are shown in table below.

Table 3.2: Centrifugal Pump Specification

| Description         | Specification                     |
|---------------------|-----------------------------------|
| Brand               | Lowara                            |
| Model               | CO(M) 500/22                      |
| Power/HP/current    | 2.2 kW/3/12.A<br>220-240 V 50 Hz) |
| Working temperature | -10 °C to 110 °C                  |



Figure 3.9: Pump





Figure 3.10: Inverter

#### 3.4.6 Magnetic flow meter transmitter

Magnetic flow meter transmitter used in this experiment to measure the flow rate of a fluid. Discharge waste water applications are appropriate for determining volumetric flow. Magnetic flow tube employs a pulsed dc to generate a digital signal from the lower-level signal voltage. This table presents the technical information.

Table 3.3 Magnetic flow meter Specification

| Description                | Specification   |
|----------------------------|---|
| Brand                      | Foxboro   |
| Model                      | Displayed: IMT25 – 1/A Series<br>Flanged magnetic flowtube: 8000A |
| Flow Velocity Range        | 0.01m/s – 10m/s   |
| Measurement Accuracy       | ±0.25%  |
| Application Temperature    | –20 °C to 70 °C   |
| Minimum fluid Conductivity | 5µs/cm %  |
| Electrodes                 | Platinum  |

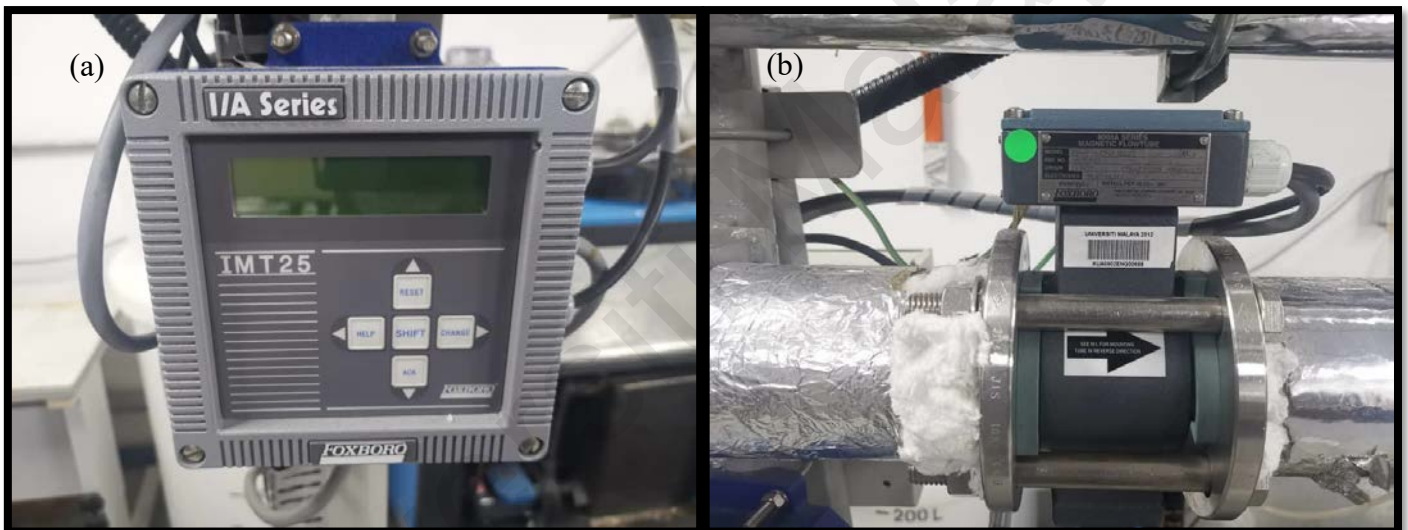


Figure 3.11: Magnetic Flow Meter (a) Flow Meter Display (b) Magnetic Flowtube (Sensor)

#### 3.4.7 Differential Pressure Transducer

The differential pressure transmitter used in the experiment is produced by Schneider Electric and is shown in Figure 3.10. Between the span linked at the test part, it is capable of reaching accuracies of ±0.05 percent.

Table 3.4: Differential Pressure Transducer Specification

| Description          | Specification  |
|----------------------|--|
| Brand                | Foxboro  |
| Model                | IDP10 I/A Series with HART Communication Protocol            |
| Measuring Range      | 0.12 to 21000 kPa  |
| Accuracy / Stability | $\pm 0.05\%$ / $\pm 0.05\%$                                  |
| Working Temperature  | $-7\text{ }^{\circ}\text{C}$ to $82\text{ }^{\circ}\text{C}$ |
| Maximum Pressure     | 25 MPa   |

#### 3.4.8 Overview system

Figure 3.14 below shows the overview of the experimental piping system used for this research. The isometric schematic of the test rig, as shown in Figure 3.15, illustrates the circulation flow direction on the rig, marked with an aluminium pipe, where it meets the rig. Only one direction of fluid flow flowed in the test apparatus.



Figure 3.12: Overview of the system

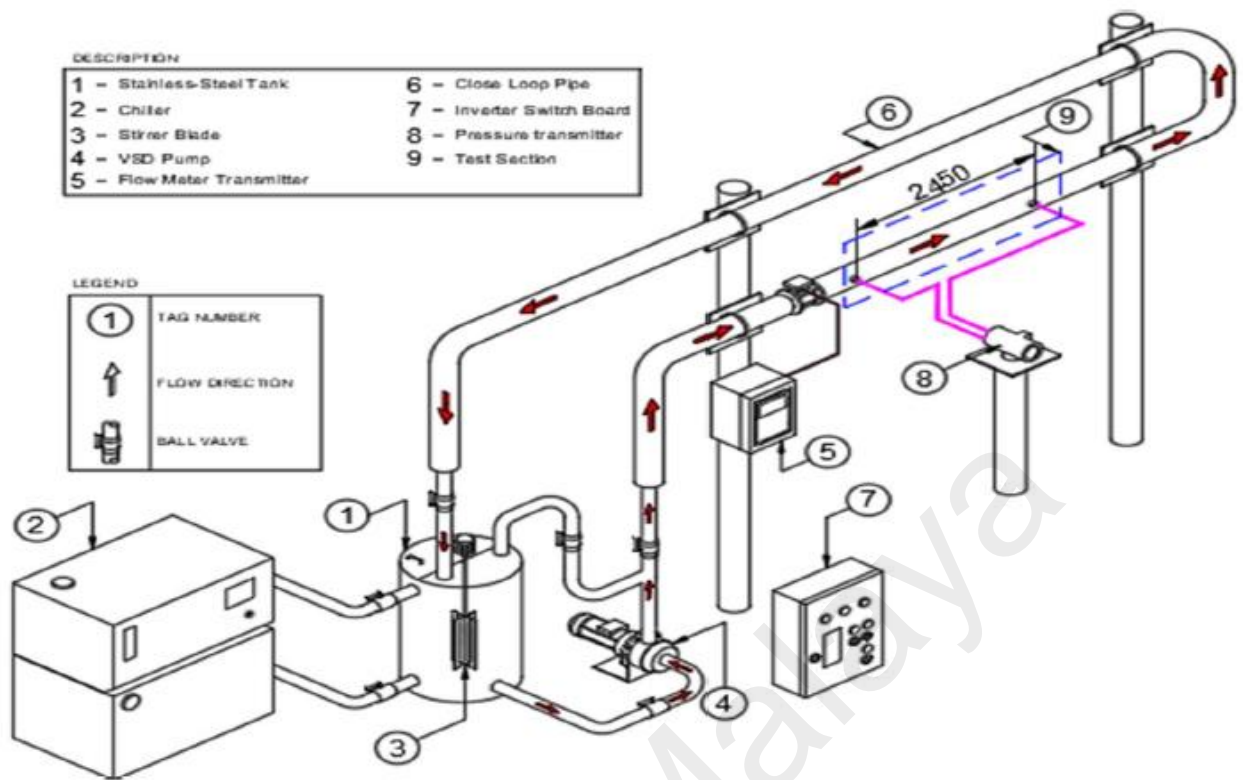


Figure 3.13 Experimental test rig isometric drawing

## 4.1 INTRODUCTION

This section will explore experimental results which were obtained for distilled water (100 L) and different gum arabic concentrations (50 and 100 ppm) with a constant temperature of 30°C. In order to compare gum Arabic and gum Guar, done an experiment at concentration of 200 ppm and compensation ratio GG:GA at 30:70, 50:50 and 70:30 to be compared with GA 200 ppm (100%). After testing each gum Guar and gum Arabic concentration and determining the results, the next step will be to investigate the pressure ( $\Delta P/L$ ), friction factor, and drag reduction percentage (percent DR) for velocities ranging from 0.4 m/s to 3.6 m/s.

## 4.2 RESULTS

### 4.2.1 PURE DISTILLED WATER RUN TEST

Table 4.1 Experimental Data for Pure Distilled Water Run Test

| PURE DISTILLED WATER OF 100 L at 30°C |          |                  |             |               |           |             |                      |
|---------------------------------------|----------|------------------|-------------|---------------|-----------|-------------|----------------------|
| V (m/s)                               | (LPM)    | $\Delta P$ (KPa) | f (Darcy)   | f (Colebrook) | f (Jain)  | f (Haaland) | $\Delta P/L$ (KPa/m) |
| 0.4                                   | 32.403   | 0.265            | 0.056777859 | 0.026460851   | 0.0264928 | 0.0261893   | 0.108606557          |
| 0.8                                   | 63.489   | 0.519            | 0.028965029 | 0.023014833   | 0.0230262 | 0.0227063   | 0.212704918          |
| 1.2                                   | 97.625   | 0.958            | 0.022612417 | 0.021282809   | 0.0213077 | 0.0209826   | 0.392622951          |
| 1.6                                   | 131.788  | 1.627            | 0.021073632 | 0.020264276   | 0.0203045 | 0.0199806   | 0.666803279          |
| 2                                     | 161.6275 | 2.4075           | 0.020731912 | 0.019652935   | 0.0197047 | 0.0193844   | 0.986680328          |
| 2.4                                   | 192.652  | 3.557            | 0.021559585 | 0.019176522   | 0.0192383 | 0.0189232   | 1.457786885          |
| 2.8                                   | 228.857  | 4.548            | 0.0195342   | 0.018751478   | 0.0188226 | 0.0185145   | 1.863934426          |
| 3.2                                   | 260.657  | 5.7825           | 0.019146105 | 0.01845676    | 0.0185345 | 0.0182329   | 2.369877049          |
| 3.6                                   | 291.849  | 6.9425           | 0.018335934 | 0.018218377   | 0.0183015 | 0.0180064   | 2.845286885          |

The reading shows, the pressure loss increases with the velocity. This experiment done is only for pure distilled water without any adaptive. This data then will be compared

with the nanofluids (mix of gum arabic and gum guar) to see the effect in the pressure loss.

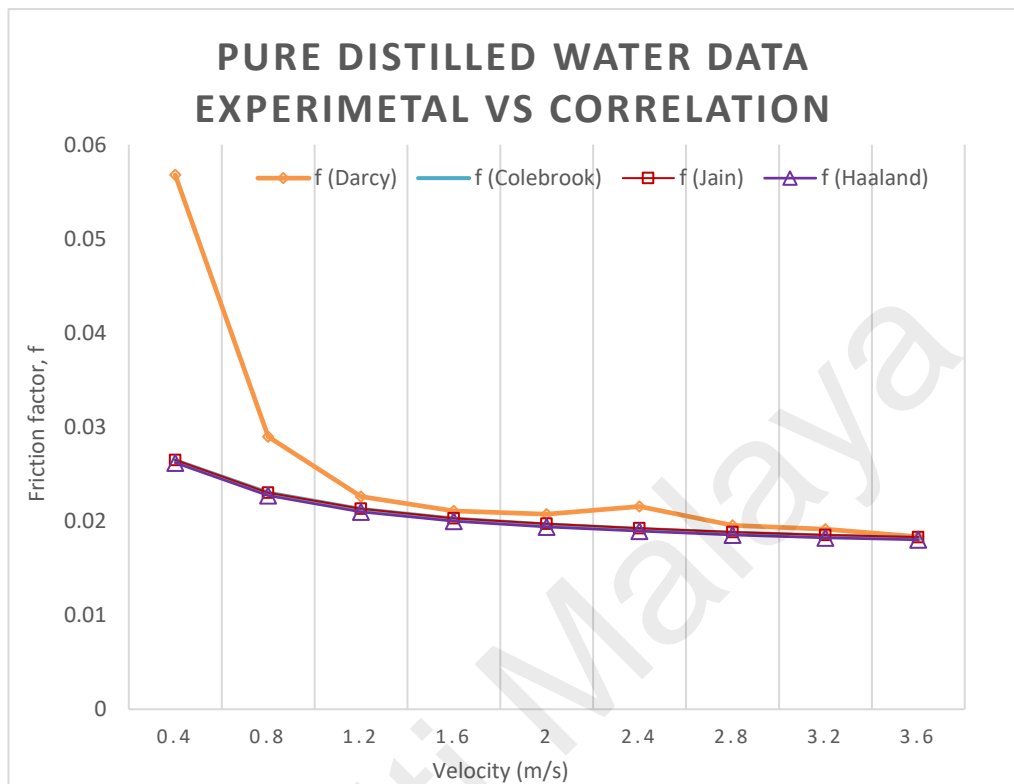


Figure 4.1 friction factor vs velocity for Pure Water Distilled Water Data

The experimental equation and empirical equations for friction factor in distilled water operate at constant temperature of 30 degrees Celsius, as shown in Figure 4.1. The velocity range is 0.4 m/s to 3.6 m/s. It seems that the results demonstrate significant agreement between experimental data and the existent correlations. Both the experimental loss data and the correlation results (the result of "Swamee and Jain" and "Colebrook and White") contained an average error of 9.01 percent and 9.98 percent, respectively. As velocity increases, the experimental deviation is reduced.

#### 4.2.1.1 FRICTION FACTOR AND PRESSURE LOSS WITHOUT AND WITH HEATING

Table 4.2 Results for Pure Distilled Water Run Test

| PURE DISTILLED WATER OF 100 L at 30°C |                 |           |                  |                      |              |           |                  |                      |
|---------------------------------------|-----------------|-----------|------------------|----------------------|--------------|-----------|------------------|----------------------|
|                                       | WITHOUT HEATING |           |                  |                      | WITH HEATING |           |                  |                      |
| V (m/s)                               | (LPM)           | f (Darcy) | $\Delta P$ (KPa) | $\Delta P/L$ (KPa/m) | (LPM)        | f (Darcy) | $\Delta P$ (KPa) | $\Delta P/L$ (KPa/m) |
| 0.4                                   | 32.403          | 0.048665  | 0.265            | 0.176742459          | 33.5         | 0.067653  | 0.3375           | 0.169167782          |
| 0.8                                   | 63.489          | 0.028064  | 0.519            | 0.325711103          | 67           | 0.028439  | 0.5675           | 0.338335564          |
| 1.2                                   | 97.625          | 0.023879  | 0.958            | 0.479729531          | 98           | 0.022838  | 0.975            | 0.494878885          |
| 1.6                                   | 131.788         | 0.021657  | 1.627            | 0.65647199           | 131.5        | 0.022766  | 1.75             | 0.664046667          |
| 2                                     | 161.6275        | 0.020765  | 2.4075           | 0.815540203          | 165          | 0.020814  | 2.519            | 0.833214449          |
| 2.4                                   | 192.652         | 0.019418  | 3.557            | 1.025106262          | 198          | 0.019866  | 3.462            | 0.999857339          |
| 2.8                                   | 228.857         | 0.018927  | 4.548            | 1.174074906          | 227.5        | 0.019409  | 4.4655           | 1.148825983          |
| 3.2                                   | 260.657         | 0.019023  | 5.7825           | 1.320518657          | 259.5        | 0.018875  | 5.65             | 1.310419088          |
| 3.6                                   | 291.849         | 0.018443  | 6.9425           | 1.469487301          | 290.5        | 0.018308  | 6.868            | 1.466962409          |

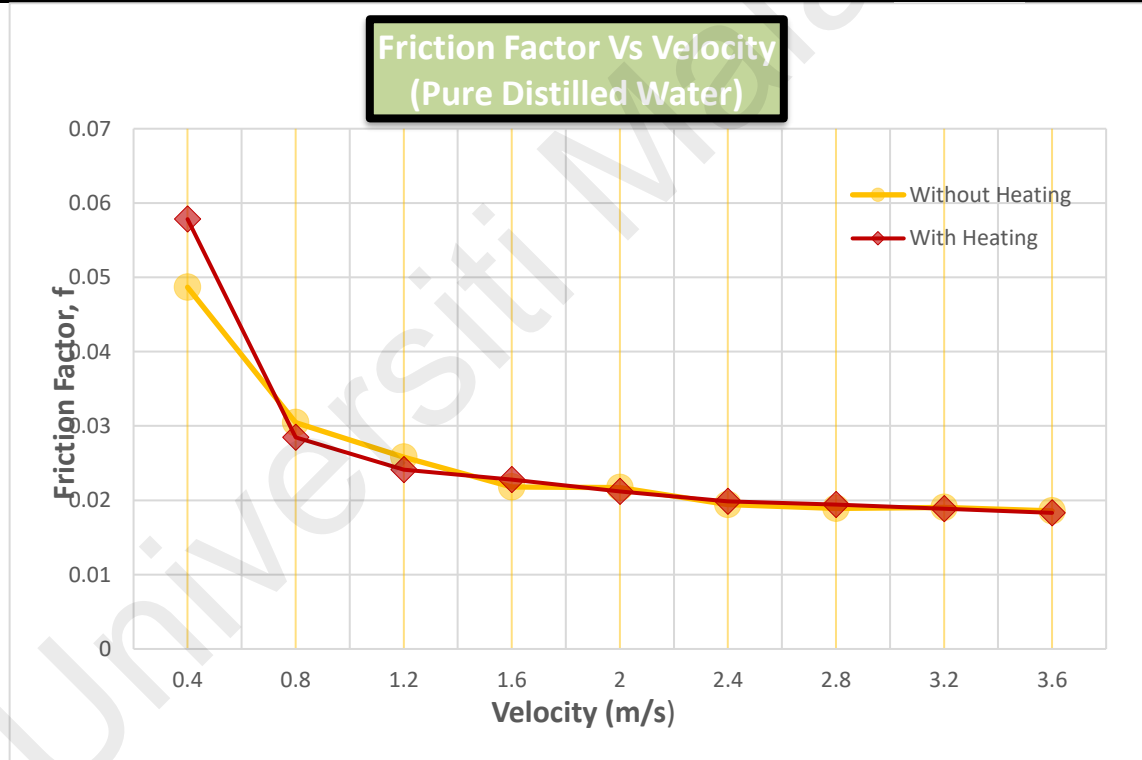


Figure 4.2 Pure Distilled Water (100L) Friction Factor Comparison for With and Without Heating

Figure 4.2 shows frictional factor,  $f$  of the distilled water is high with applied of heat compared to without heating at lower speed however, the FF reduces as the speed increases.

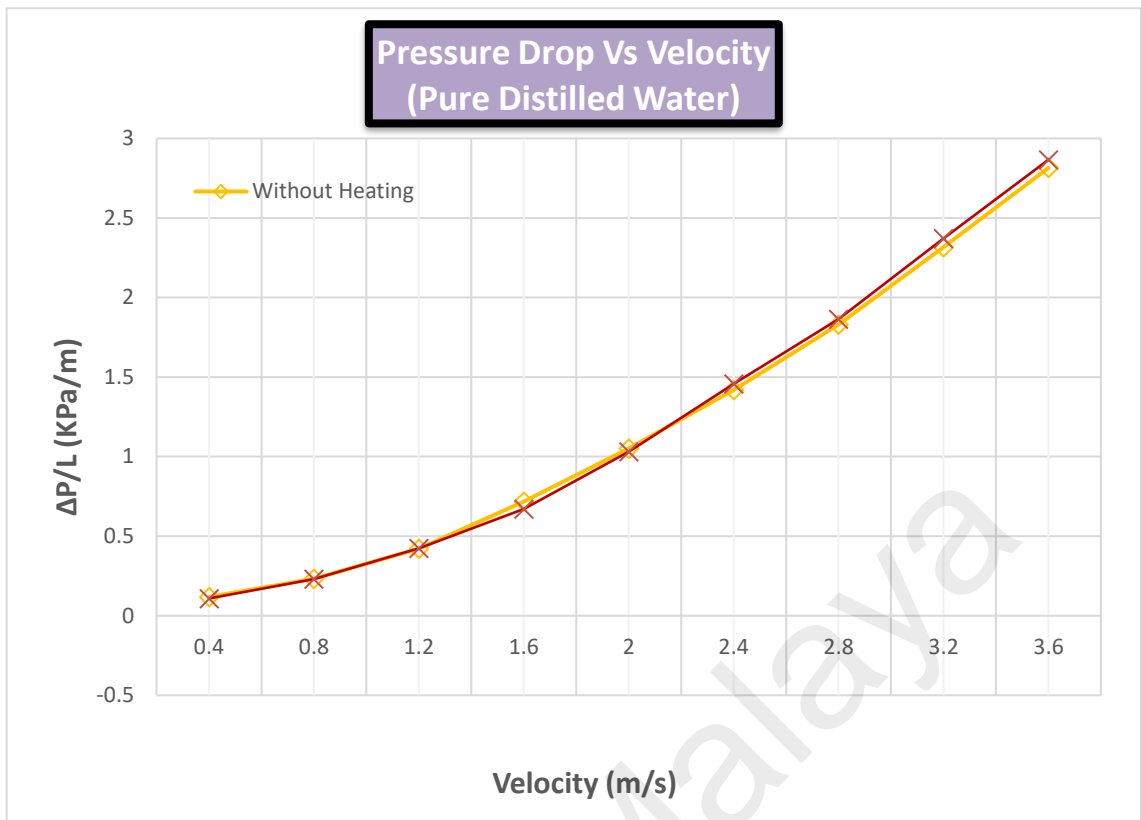


Figure 4.3 Pure Distilled Water Pressure Drop Comparison for Without and With Heating

Figure 4.3 shows the pressure drop is lower at lower speed and recorded at lower value when the heat is applied at lower speed. However, the pressure drop increases as the speed increases and eventually the pressure drop during heat is applied is higher compared to no heat applied.



## 4.2.2 GUM ARABIC AT 100 PPM

Table 4.3 GA 100 ppm Water Run Test

| GA (200 PPM) at 30°C |                 |           |                  |                      |              |           |                  |                      |
|----------------------|-----------------|-----------|------------------|----------------------|--------------|-----------|------------------|----------------------|
|                      | WITHOUT HEATING |           |                  |                      | WITH HEATING |           |                  |                      |
| V (m/s)              | (LPM)           | f (Darcy) | $\Delta P$ (KPa) | $\Delta P/L$ (KPa/m) | (LPM)        | f (Darcy) | $\Delta P$ (KPa) | $\Delta P/L$ (KPa/m) |
| 0.4                  | 33.5            | 0.045804  | 0.2285           | 0.093647541          | 33.5         | 0.041594  | 0.2075           | 0.085040984          |
| 0.8                  | 65.5            | 0.028761  | 0.5485           | 0.224795082          | 65.5         | 0.02897   | 0.5525           | 0.226434426          |
| 1.2                  | 97.5            | 0.024291  | 1.0265           | 0.420696721          | 97           | 0.023311  | 0.975            | 0.399590164          |
| 1.6                  | 129             | 0.021873  | 1.618            | 0.663114754          | 128          | 0.02166   | 1.5775           | 0.646516393          |
| 2                    | 164.5           | 0.020904  | 2.5145           | 1.030532787          | 168          | 0.020428  | 2.563            | 1.050409836          |
| 2.4                  | 196.5           | 0.019718  | 3.3845           | 1.387090164          | 198          | 0.019533  | 3.404            | 1.395081967          |
| 2.8                  | 228.5           | 0.019091  | 4.431            | 1.815983607          | 228.5        | 0.019223  | 4.4615           | 1.828483607          |
| 3.2                  | 263             | 0.018481  | 5.6825           | 2.328893443          | 259          | 0.018803  | 5.607            | 2.29795082           |
| 3.6                  | 290             | 0.018667  | 6.9785           | 2.860040984          | 294          | 0.017627  | 6.773            | 2.775819672          |

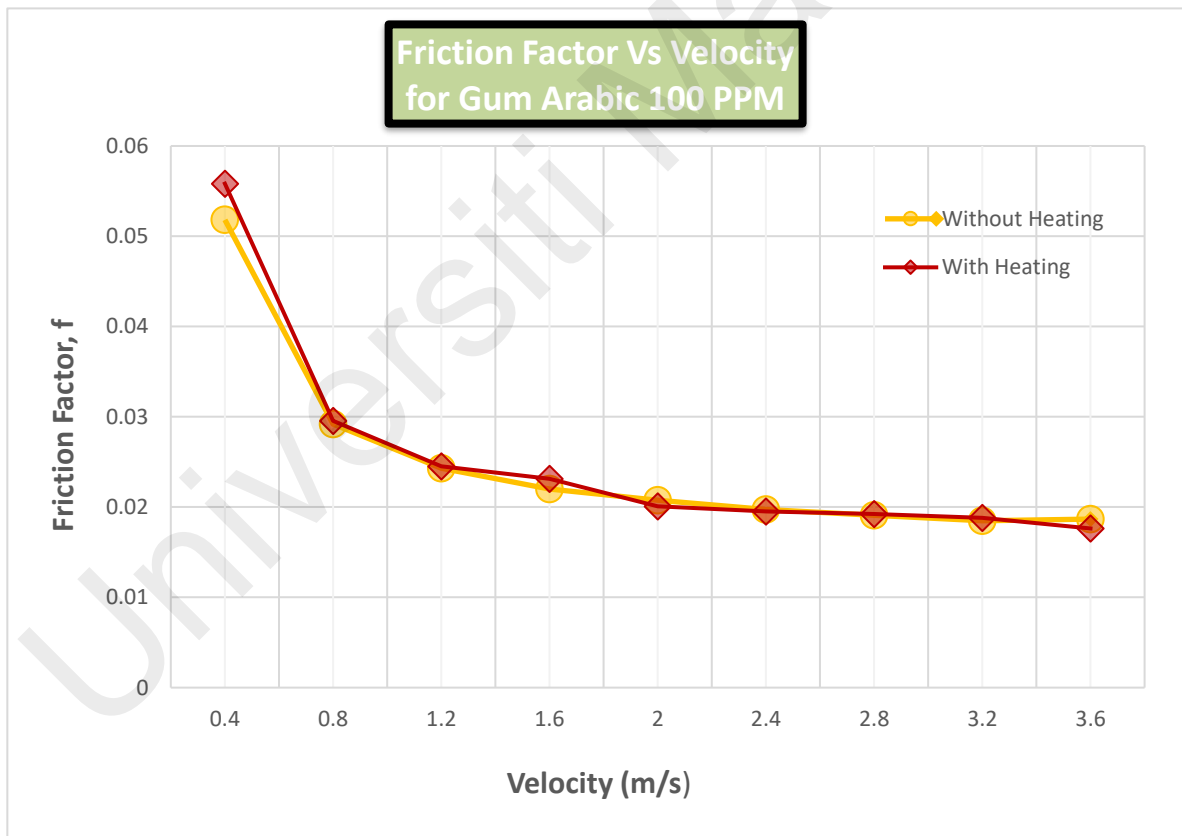


Figure 4.4 GA (100%) 100 PPM Friction Factor Comparison for With and Without Heating

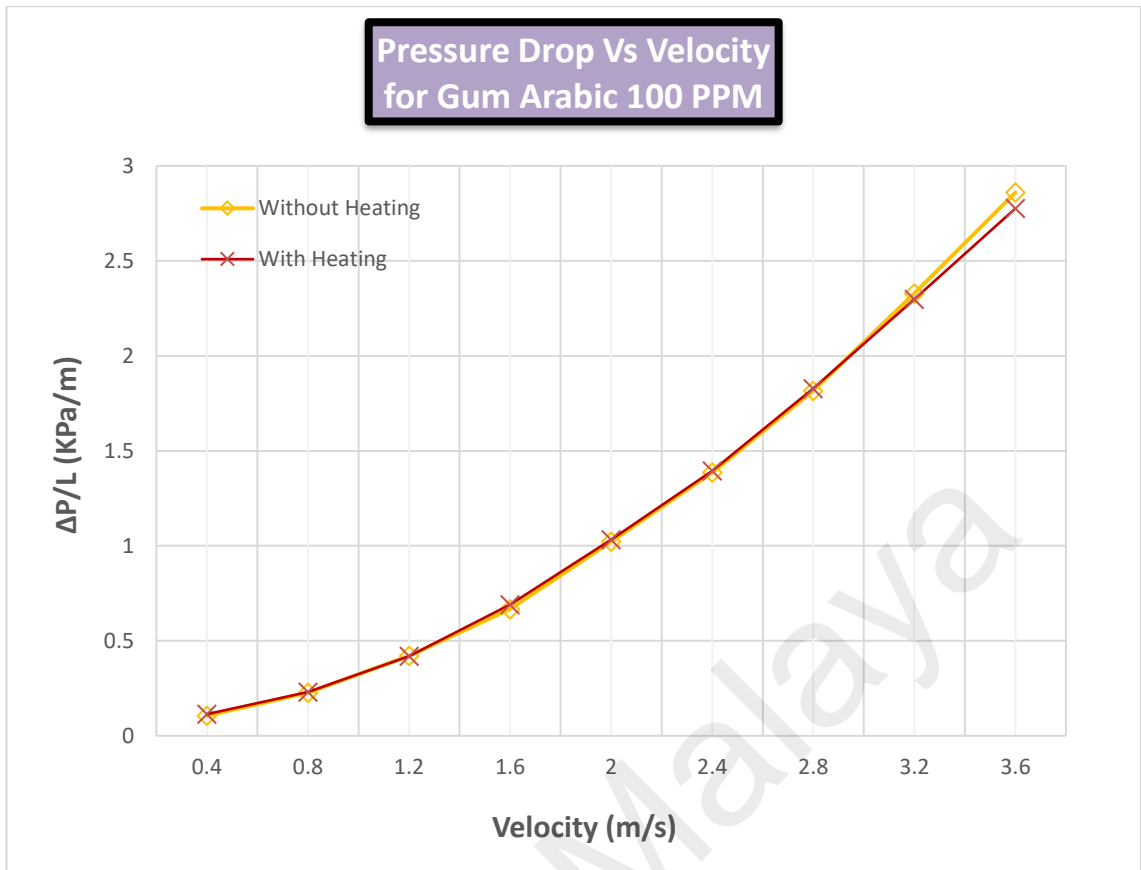


Figure 4.5 GA (100%) 100 PPM Pressure Drop Comparison for Without and With Heating

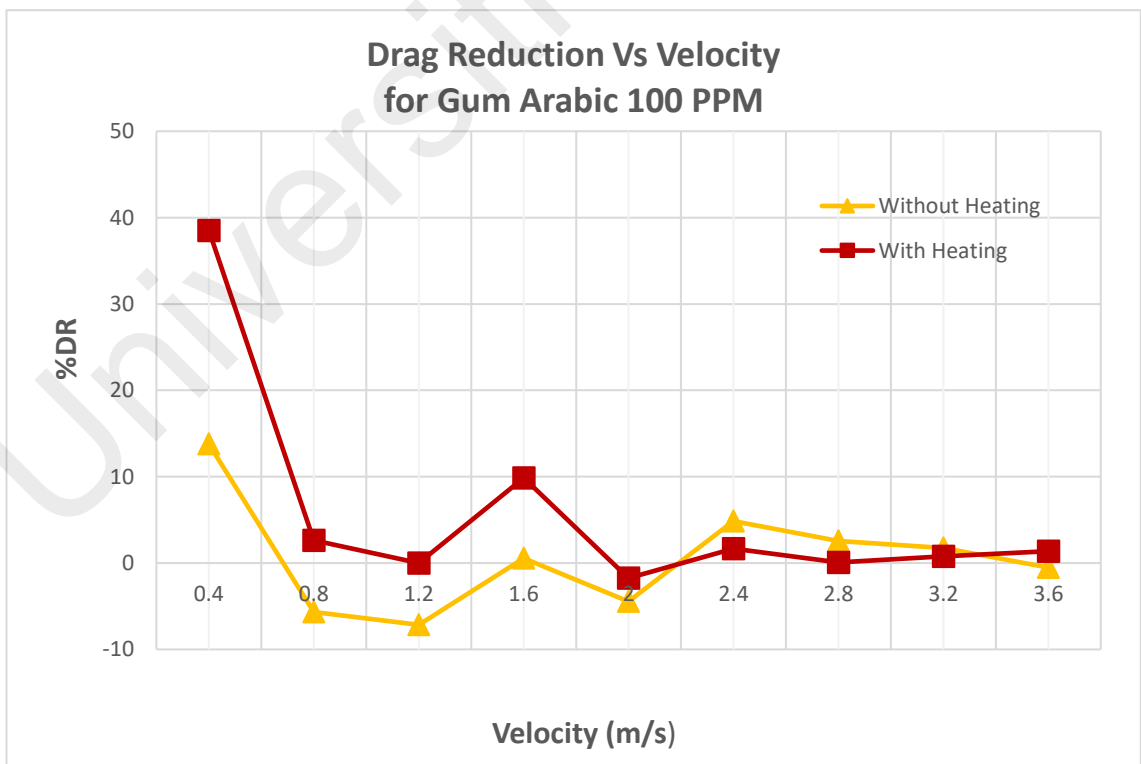


Figure 4.6 GA (100%) 100 PPM Drag Reduction Comparison for Without and With Heating

### 4.2.3 GUM ARABIC AT 200 PPM

Table 4.4 GA 200 ppm Water Run Test

| GA (200 PPM) at 30°C |                 |           |                  |                      |              |           |                  |                      |
|----------------------|-----------------|-----------|------------------|----------------------|--------------|-----------|------------------|----------------------|
|                      | WITHOUT HEATING |           |                  |                      | WITH HEATING |           |                  |                      |
| V (m/s)              | (LPM)           | f (Darcy) | $\Delta P$ (KPa) | $\Delta P/L$ (KPa/m) | (LPM)        | f (Darcy) | $\Delta P$ (KPa) | $\Delta P/L$ (KPa/m) |
| 0.4                  | 33.5            | 0.047207  | 0.2355           | 0.096516393          | 32           | 0.040862  | 0.186            | 0.076229508          |
| 0.8                  | 64              | 0.028751  | 0.5235           | 0.21454918           | 65           | 0.028007  | 0.526            | 0.21557377           |
| 1.2                  | 97              | 0.024172  | 1.011            | 0.414344262          | 99           | 0.023194  | 1.0105           | 0.414139344          |
| 1.6                  | 128             | 0.022305  | 1.6245           | 0.665778689          | 129          | 0.021934  | 1.6225           | 0.664959016          |
| 2                    | 163             | 0.020808  | 2.4575           | 1.007172131          | 161.5        | 0.020872  | 2.42             | 0.991803279          |
| 2.4                  | 193.5           | 0.019767  | 3.29             | 1.348360656          | 195          | 0.019511  | 3.298            | 1.351639344          |
| 2.8                  | 226.5           | 0.018985  | 4.3295           | 1.774385246          | 227          | 0.019231  | 4.405            | 1.805327869          |
| 3.2                  | 260             | 0.018458  | 5.5465           | 2.273155738          | 259.5        | 0.018893  | 5.6555           | 2.317827869          |
| 3.6                  | 291             | 0.01841   | 6.93             | 2.840163934          | 290.5        | 0.018184  | 6.8215           | 2.795696721          |

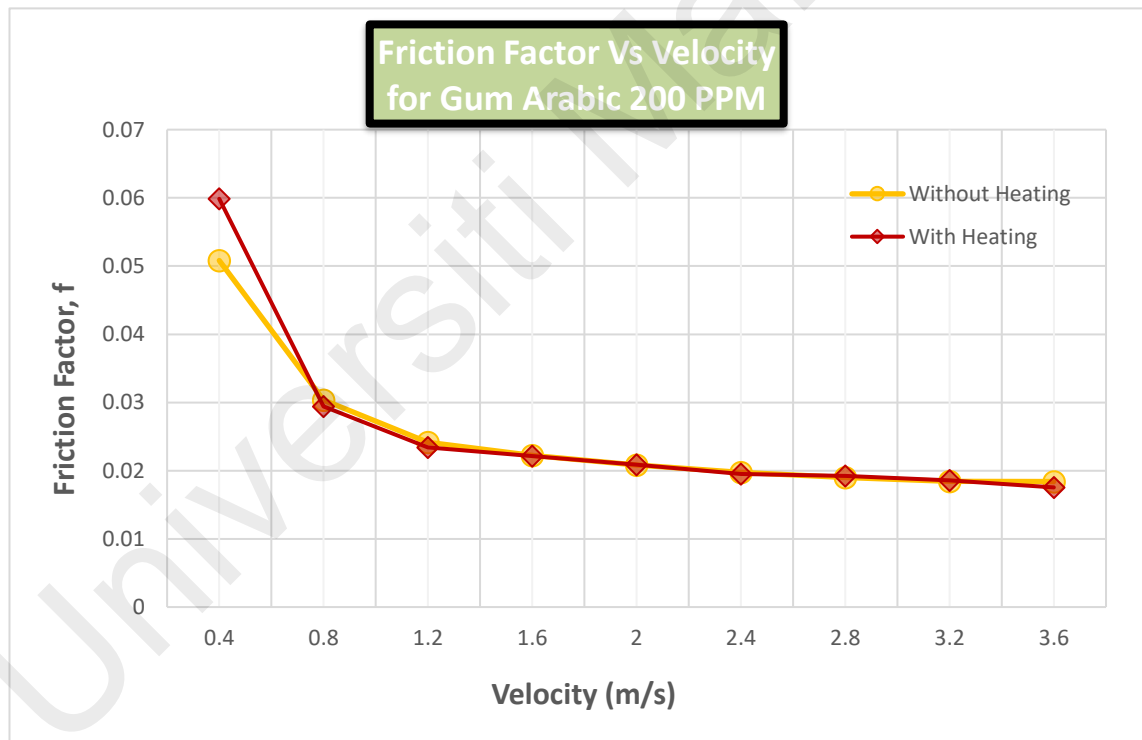


Figure 4.7 GA (100%) 200 PPM Friction Factor Comparison for With and Without Heating

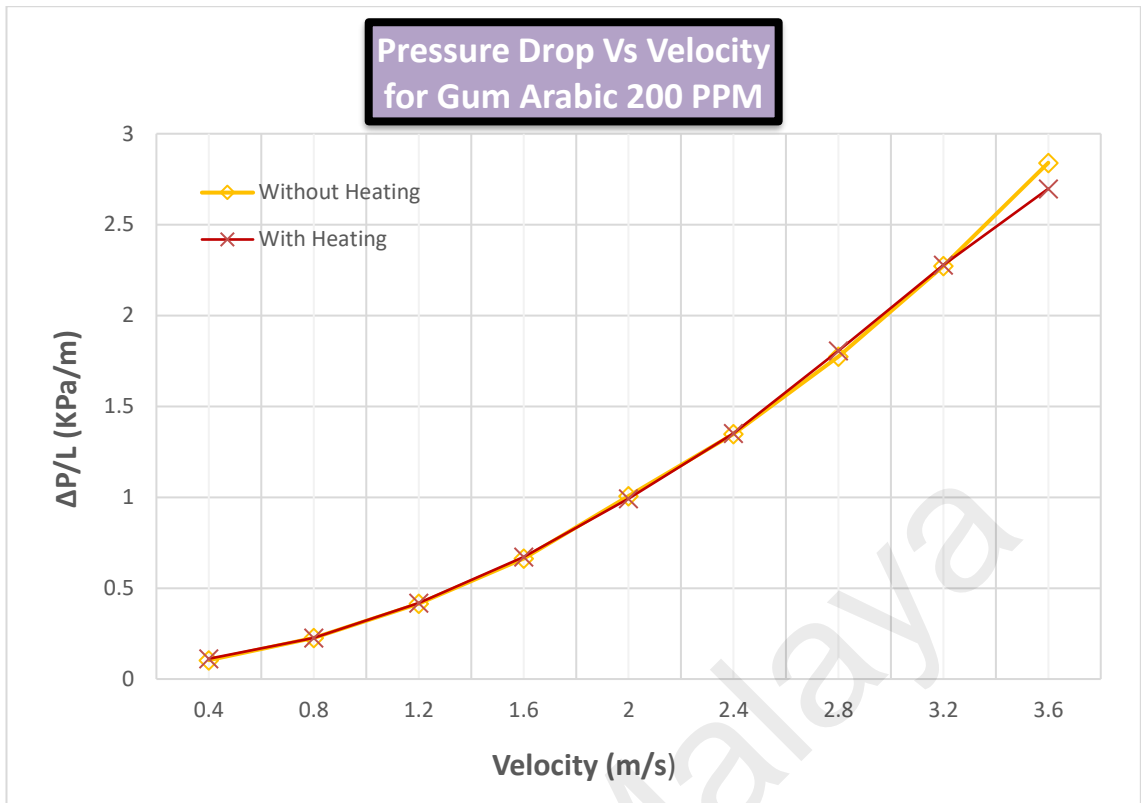


Figure 4.8 GA (100%) 200 PPM Pressure Drop Comparison for Without and With Heating

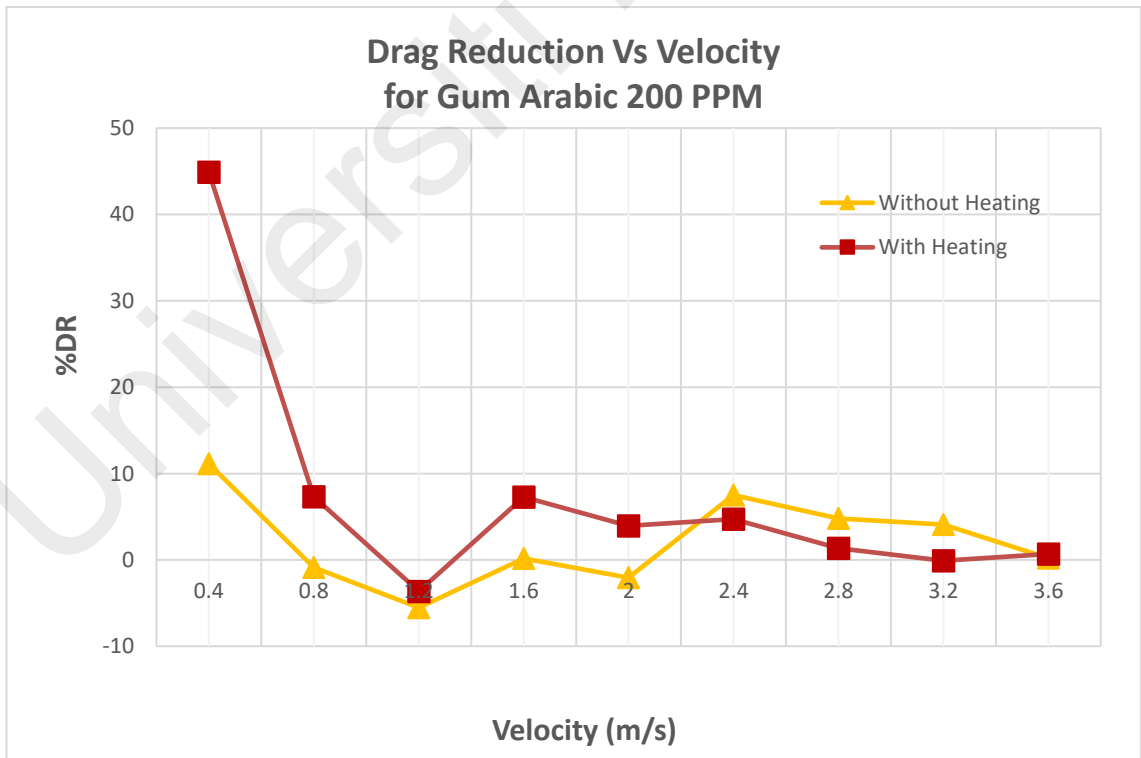


Figure 4.9 GA (100%) 200 PPM Drag Reduction Comparison for Without and With Heating

#### 4.2.4 GUM GUAR:GUM ARABIC 30:70 AT 200 PPM

Table 4.5 GG:GA 30:70 200 ppm Water Run Test

| GG:GA 30:70 (200 PPM) at 30°C |                 |           |                  |                      |              |           |                  |                      |
|-------------------------------|-----------------|-----------|------------------|----------------------|--------------|-----------|------------------|----------------------|
|                               | WITHOUT HEATING |           |                  |                      | WITH HEATING |           |                  |                      |
| V (m/s)                       | (LPM)           | f (Darcy) | $\Delta P$ (KPa) | $\Delta P/L$ (KPa/m) | (LPM)        | f (Darcy) | $\Delta P$ (KPa) | $\Delta P/L$ (KPa/m) |
| 0.4                           | 32.5            | 0.049837  | 0.234            | 0.095901639          | 32.5         | 0.042809  | 0.201            | 0.082377049          |
| 0.8                           | 63.5            | 0.029987  | 0.5375           | 0.220286885          | 64.5         | 0.02901   | 0.5365           | 0.219877049          |
| 1.2                           | 96.5            | 0.024133  | 0.999            | 0.40942623           | 97.5         | 0.023712  | 1.002            | 0.410655738          |
| 1.6                           | 129             | 0.021129  | 1.563            | 0.64057377           | 129.5        | 0.021785  | 1.624            | 0.66557377           |
| 2                             | 163.5           | 0.019002  | 2.258            | 0.925409836          | 162.5        | 0.01962   | 2.303            | 0.943852459          |
| 2.4                           | 194.5           | 0.017953  | 3.019            | 1.237295082          | 195          | 0.018257  | 3.086            | 1.264754098          |
| 2.8                           | 227             | 0.016889  | 3.8685           | 1.58545082           | 226          | 0.017446  | 3.961            | 1.623360656          |
| 3.2                           | 259.5           | 0.016229  | 4.858            | 1.990983607          | 256          | 0.016616  | 4.8405           | 1.983811475          |
| 3.6                           | 290.5           | 0.015617  | 5.8585           | 2.40102459           | 290.5        | 0.015924  | 5.9735           | 2.448155738          |

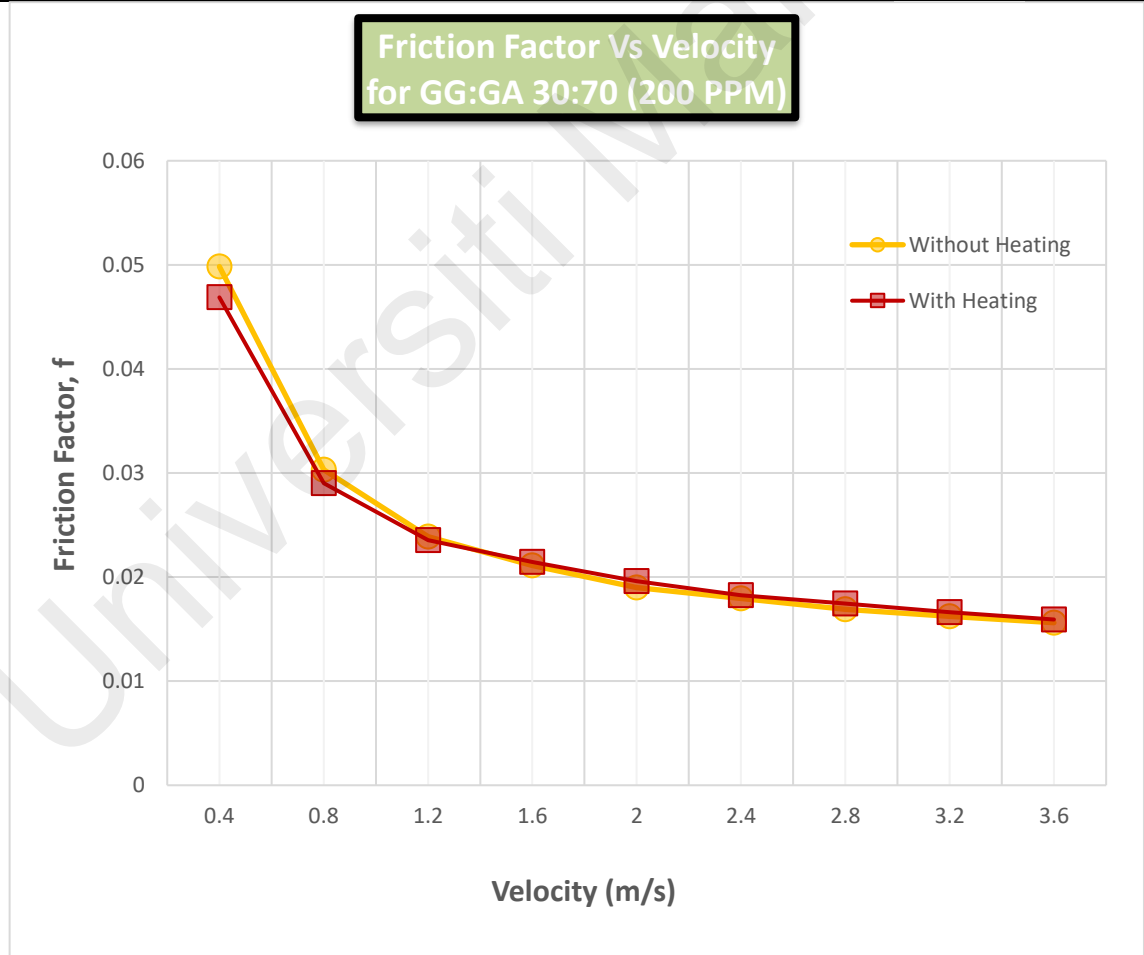


Figure 4.10 GG:GA (30:70 %) 200 PPM Friction Factor Comparison for With and Without Heating

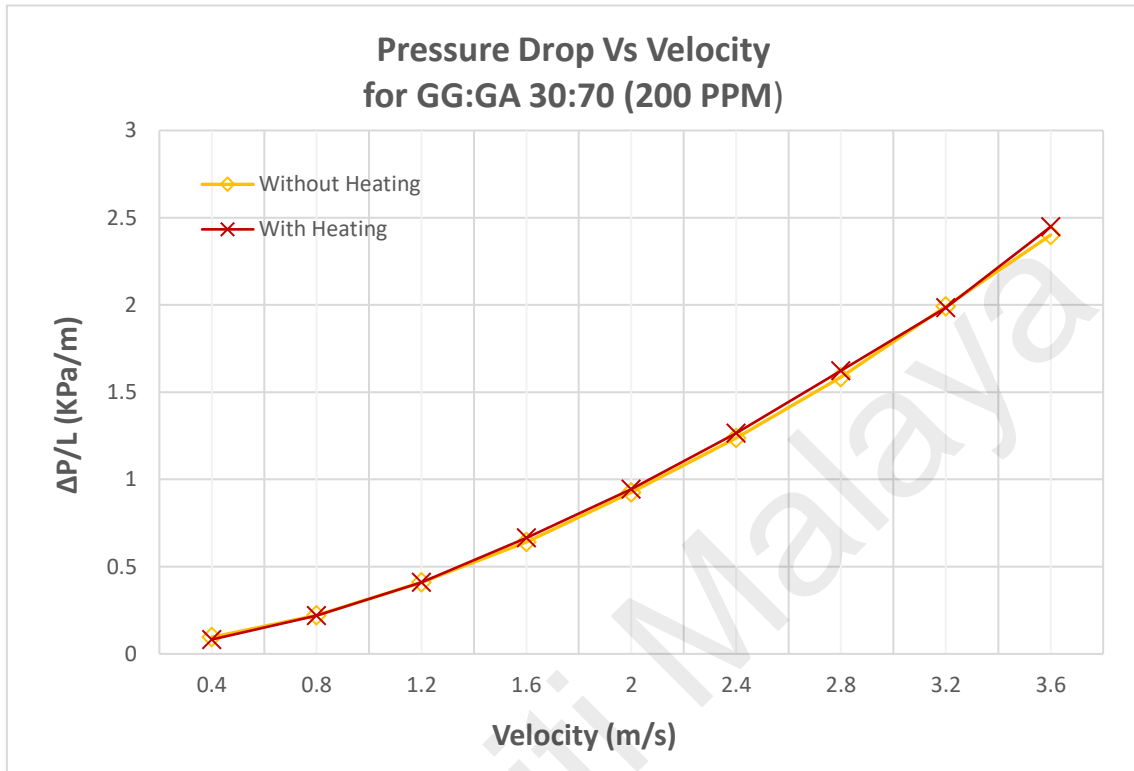


Figure 4.11 GG:GA (30:70 %) 200 PPM Pressure Drop Comparison for Without and With Heating

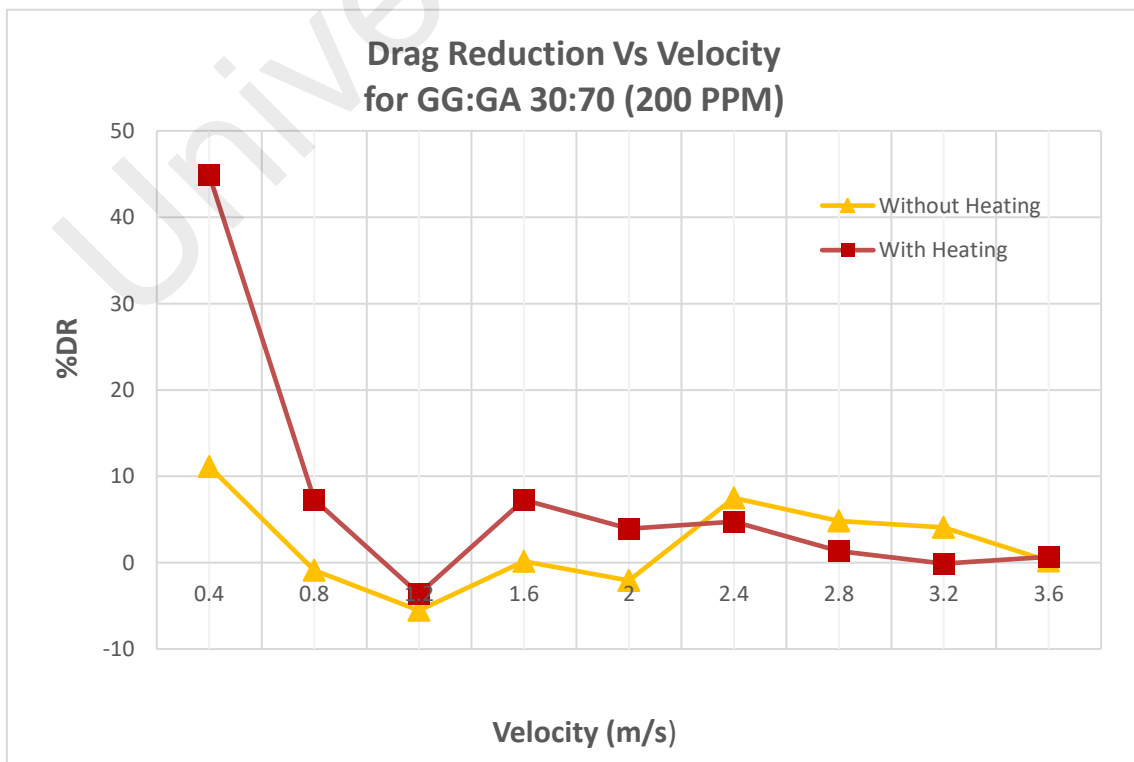


Figure 4.12 GG:GA (30:70 %) 200 PPM Drag Reduction Comparison for Without and With Heating

4.2.5 GUM GUAR:GUM ARABIC 50:50 AT 200 PPM

Table 4.6 GG:GA 50:50 200 ppm Water Run Test

| GG:GA 30:70 (200 PPM) at 30°C |                 |           |                  |                      |              |           |                  |                      |
|-------------------------------|-----------------|-----------|------------------|----------------------|--------------|-----------|------------------|----------------------|
| V (m/s)                       | WITHOUT HEATING |           |                  |                      | WITH HEATING |           |                  |                      |
|                               | (LPM)           | f (Darcy) | $\Delta P$ (KPa) | $\Delta P/L$ (KPa/m) | (LPM)        | f (Darcy) | $\Delta P$ (KPa) | $\Delta P/L$ (KPa/m) |
| 0.4                           | 32.5            | 0.058782  | 0.276            | 0.113114754          | 32.5         | 0.049305  | 0.2315           | 0.094877049          |
| 0.8                           | 64              | 0.029438  | 0.536            | 0.219672131          | 65.5         | 0.029783  | 0.568            | 0.232786885          |
| 1.2                           | 97.5            | 0.022824  | 0.9645           | 0.395286885          | 96.5         | 0.024133  | 0.999            | 0.40942623           |
| 1.6                           | 128             | 0.021344  | 1.5545           | 0.637090164          | 130          | 0.020712  | 1.556            | 0.637704918          |
| 2                             | 161             | 0.01875   | 2.1605           | 0.88545082           | 163          | 0.018856  | 2.227            | 0.912704918          |
| 2.4                           | 194             | 0.017265  | 2.8885           | 1.183811475          | 192          | 0.018002  | 2.95             | 1.209016393          |
| 2.8                           | 228             | 0.016356  | 3.7795           | 1.54897541           | 228.5        | 0.016355  | 3.796            | 1.555737705          |
| 3.2                           | 260.5           | 0.015135  | 4.5655           | 1.871106557          | 257          | 0.015679  | 4.6035           | 1.886680328          |
| 3.6                           | 291.5           | 0.014444  | 5.456            | 2.236065574          | 292          | 0.014797  | 5.6085           | 2.298565574          |

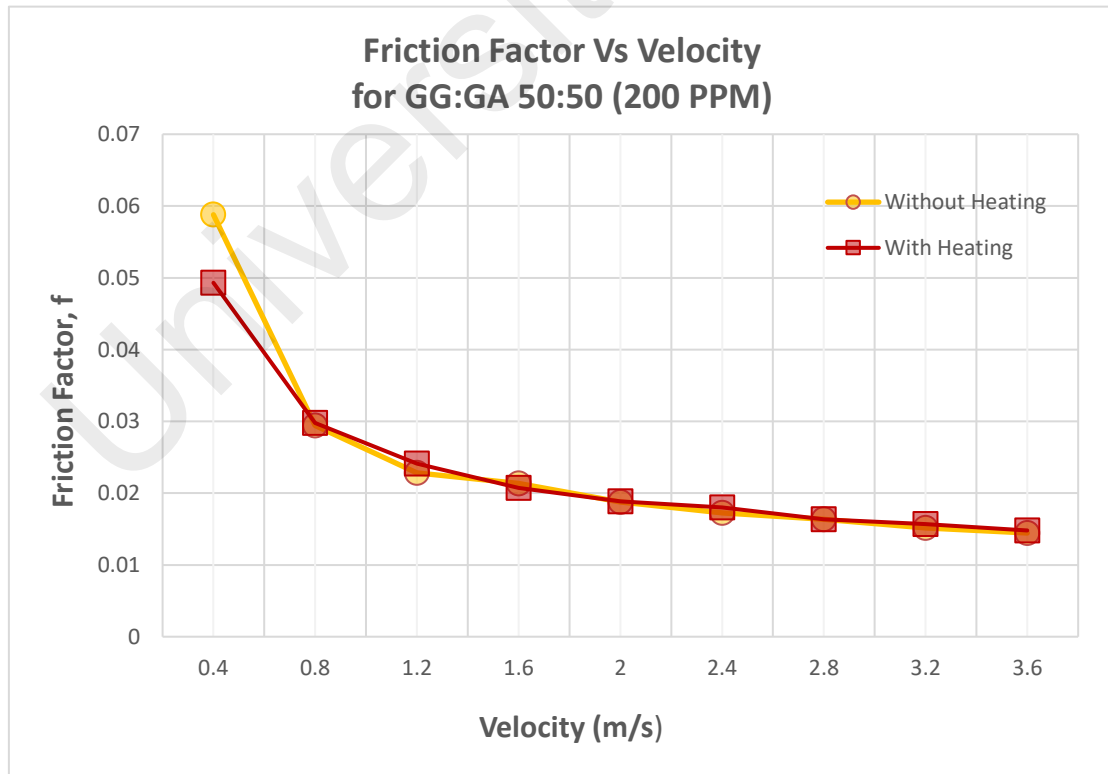


Figure 4.13 GG:GA (50:50 %) 200 PPM Friction Factor Comparison for With and Without Heating

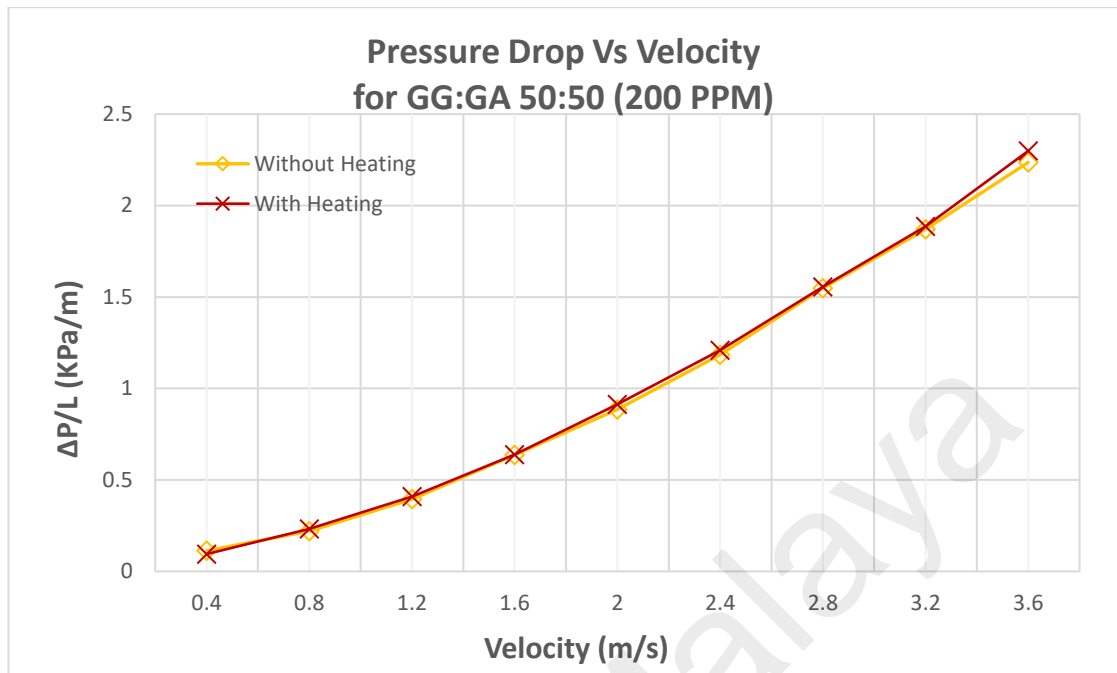


Figure 4.14 GG:GA (50:50 %) 200 PPM Pressure Drop Comparison for Without and With Heating

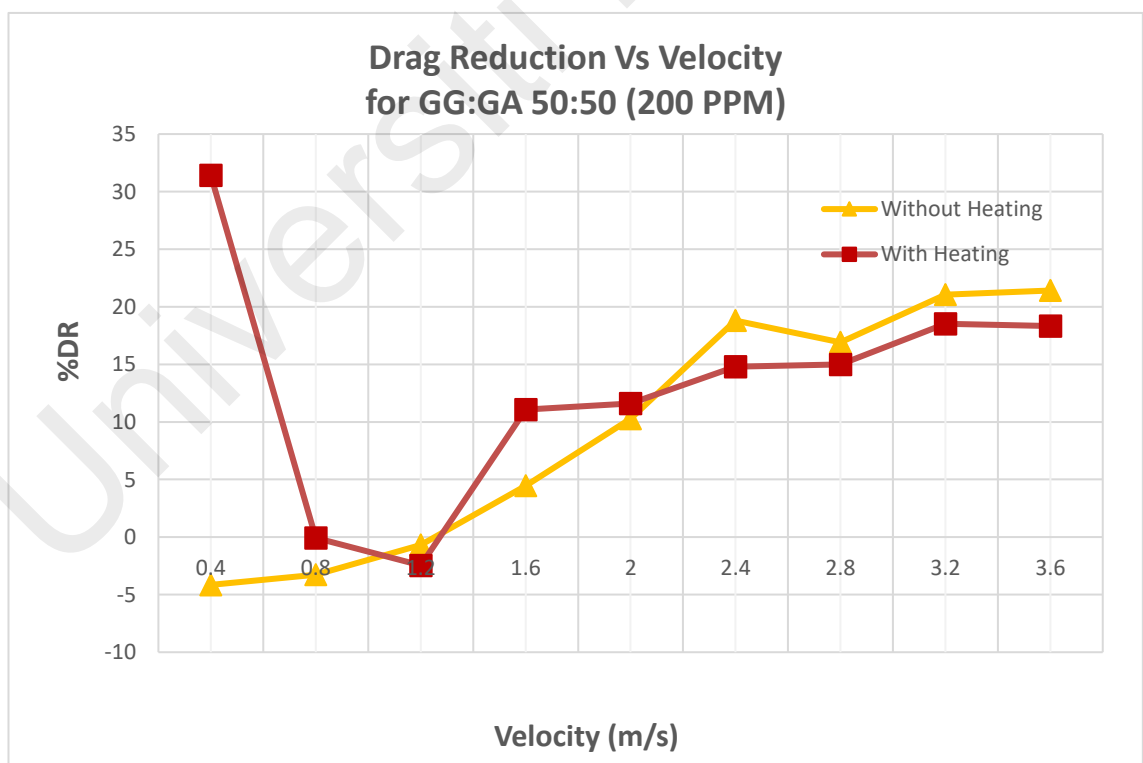


Figure 4.15 GG:GA (50:50 %) 200 PPM Drag Reduction Comparison for Without and With Heating



#### 4.2.6 GUM GUAR:GUM ARABIC 70:30 AT 200 PPM

Table 4.7 GG:GA 70:30 200 ppm Water Run Test

| GG:GA 30:70 (200 PPM) at 30°C |                 |           |                  |                      |              |           |                  |                      |
|-------------------------------|-----------------|-----------|------------------|----------------------|--------------|-----------|------------------|----------------------|
|                               | WITHOUT HEATING |           |                  |                      | WITH HEATING |           |                  |                      |
| V (m/s)                       | (LPM)           | f (Darcy) | $\Delta P$ (KPa) | $\Delta P/L$ (KPa/m) | (LPM)        | f (Darcy) | $\Delta P$ (KPa) | $\Delta P/L$ (KPa/m) |
| 0.4                           | 32.5            | 0.040466  | 0.19             | 0.077868852          | 32           | 0.049539  | 0.2255           | 0.092418033          |
| 0.8                           | 63.5            | 0.030127  | 0.54             | 0.221311475          | 63.5         | 0.030043  | 0.5385           | 0.220696721          |
| 1.2                           | 97.5            | 0.024185  | 1.022            | 0.418852459          | 96.5         | 0.02394   | 0.991            | 0.406147541          |
| 1.6                           | 130.5           | 0.021029  | 1.592            | 0.652459016          | 128.5        | 0.021512  | 1.579            | 0.647131148          |
| 2                             | 163.5           | 0.018745  | 2.2275           | 0.912909836          | 161.5        | 0.018682  | 2.166            | 0.887704918          |
| 2.4                           | 193.5           | 0.017072  | 2.8415           | 1.16454918           | 196.5        | 0.017446  | 2.9945           | 1.227254098          |
| 2.8                           | 230.5           | 0.015787  | 3.7285           | 1.52807377           | 227.5        | 0.016484  | 3.7925           | 1.554303279          |
| 3.2                           | 257             | 0.01509   | 4.4305           | 1.815778689          | 258          | 0.01562   | 4.622            | 1.894262295          |
| 3.6                           | 293.24          | 0.014861  | 5.6805           | 2.32807377           | 294          | 0.014888  | 5.7205           | 2.344467213          |

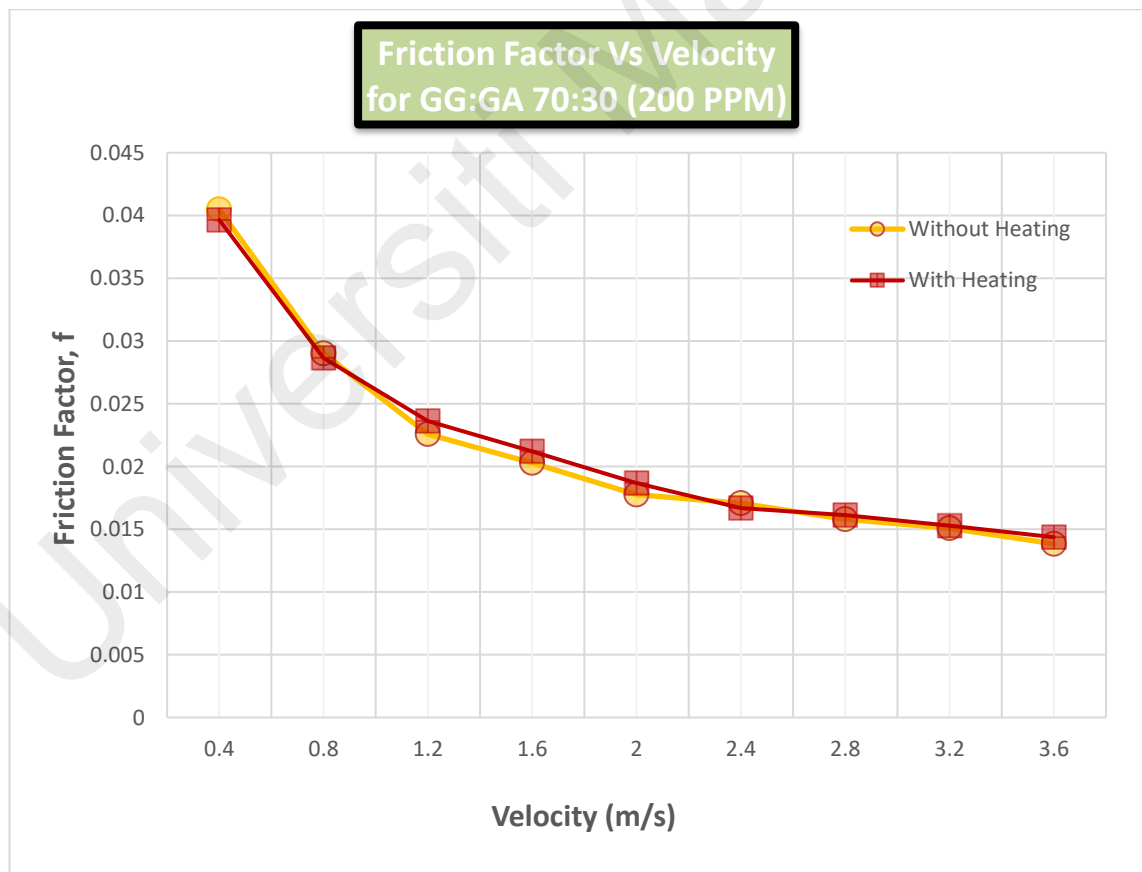


Figure 4.16 GG:GA (70:30 %) 200 PPM Friction Factor Comparison for With and Without Heating

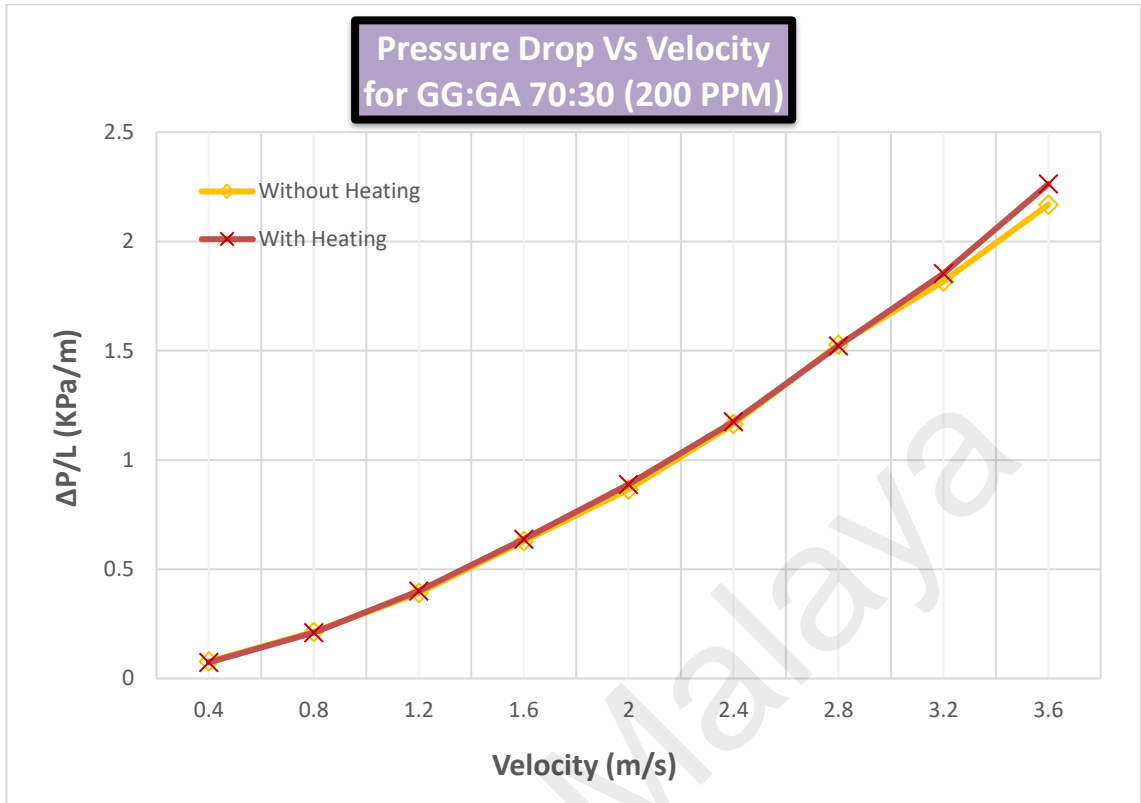


Figure 4.17 GG:GA (70:30 %) 200 PPM Pressure Drop Comparison for Without and With Heating

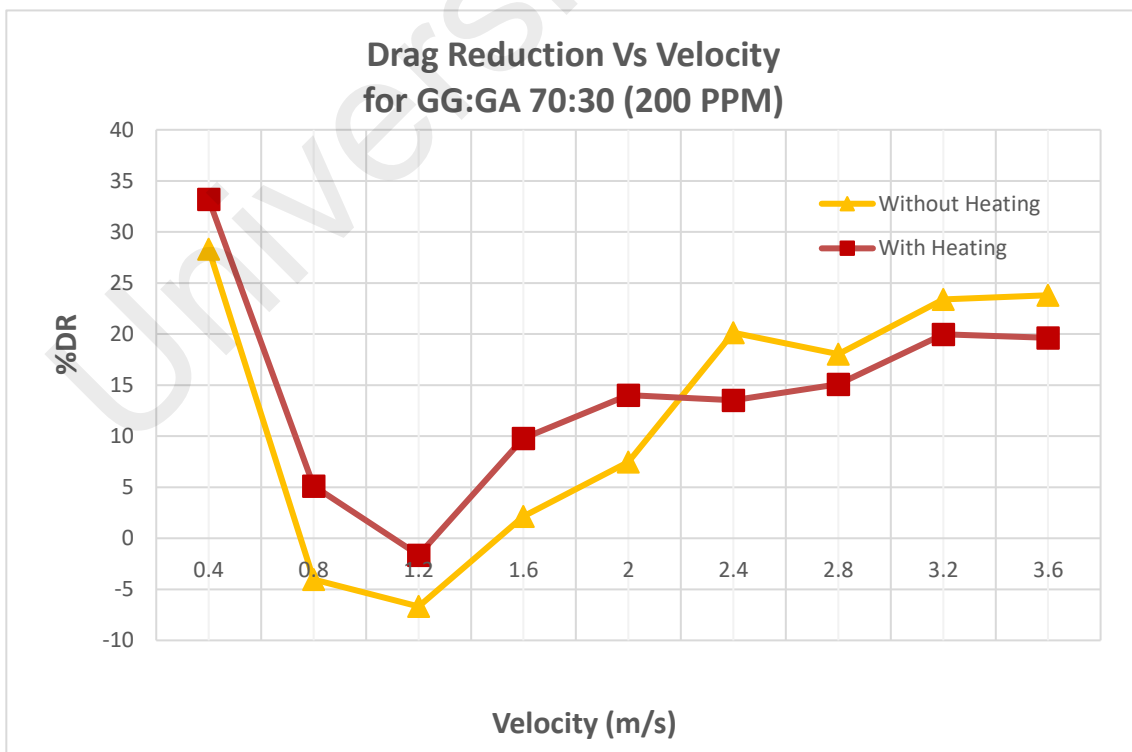
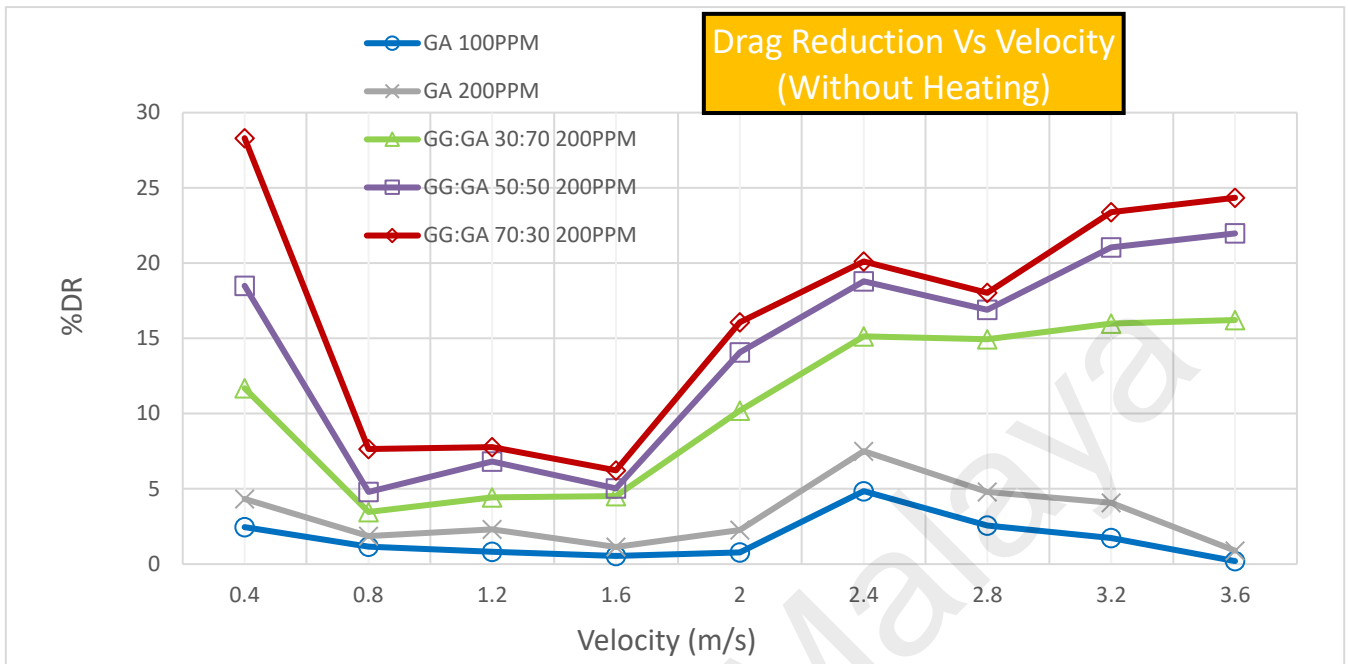


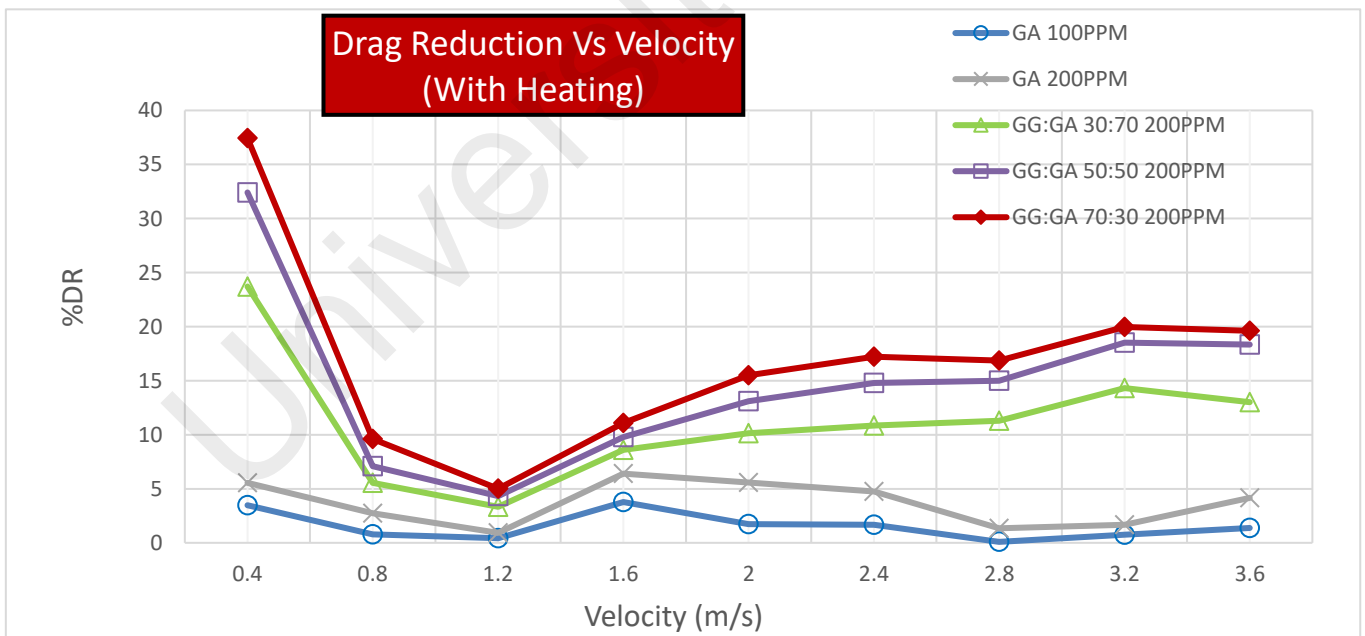
Figure 4.18 GG:GA (70:30 %) 200 PPM Drag Reduction Comparison for Without and With Heating

### 4.3 Overall Results Comparison

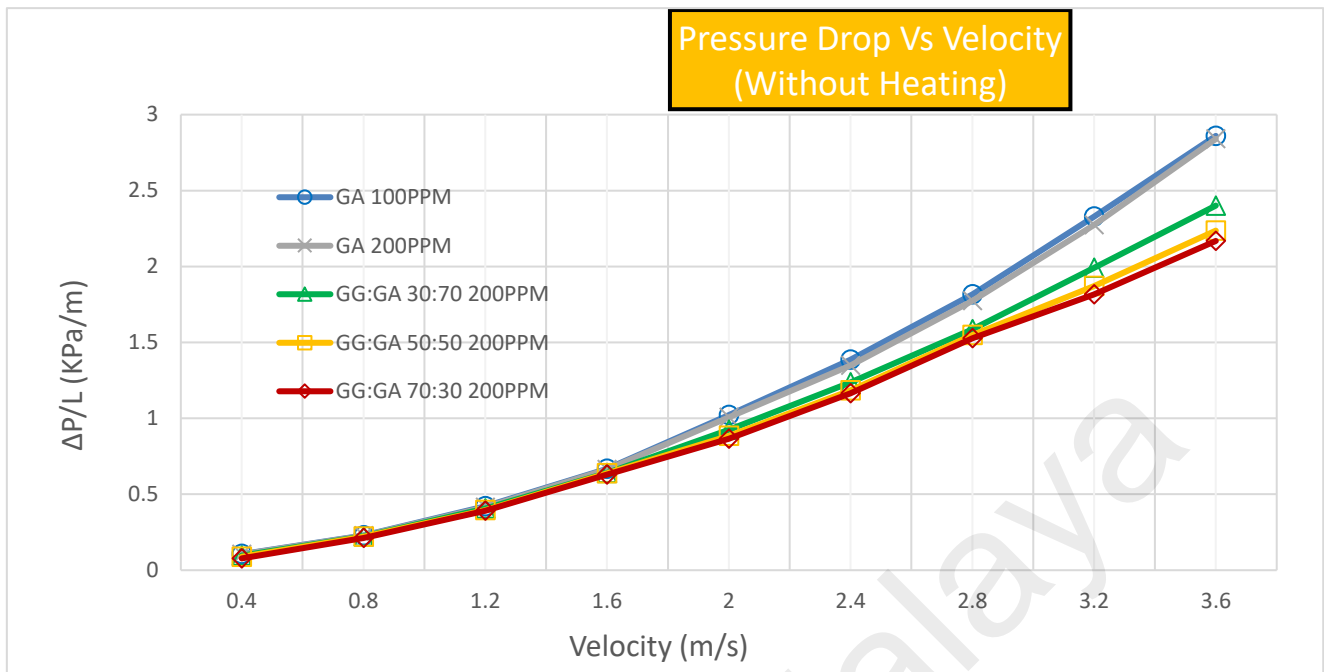
#### 4.3.1 Drag Reduction for overall results (Without Heating)



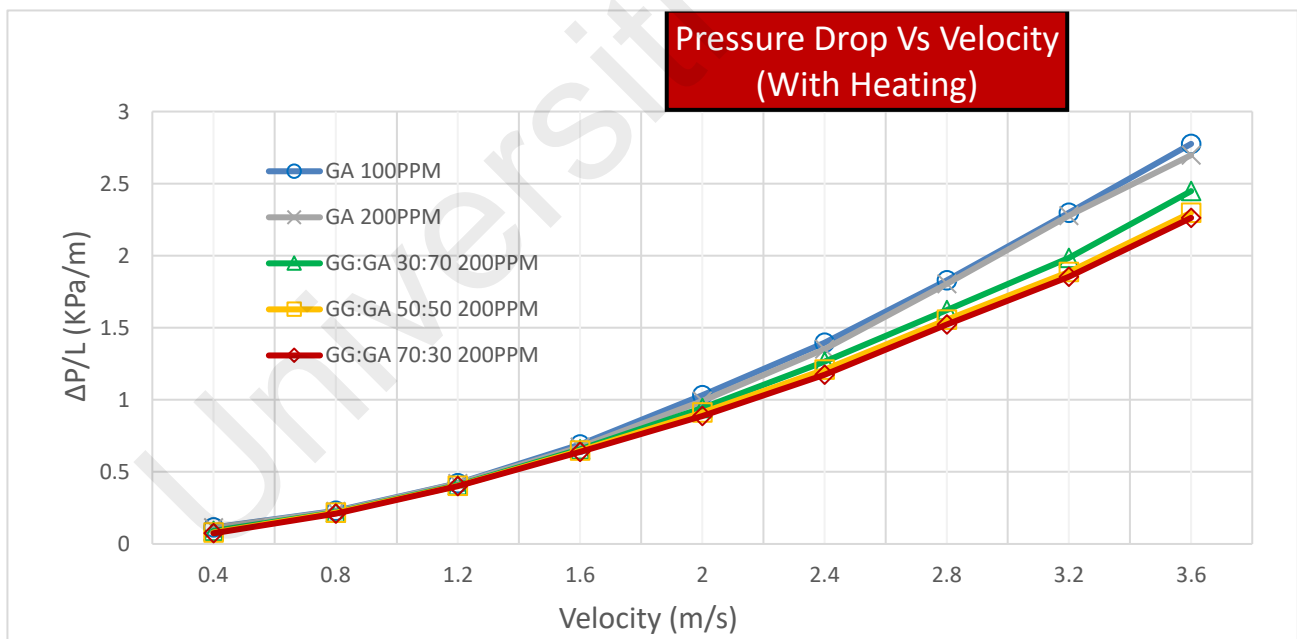
#### 4.3.2 Drag Reduction for overall results (With Heating)



### 4.3.3 Pressure Drop for overall results (Without Heating)



### 4.3.4 Pressure Drop for overall results (With Heating)



This chapter reviewed the acquired data and used it to look at drag reduction. In addition to being familiar with the test equipment, you must know where to execute the test as well. This was done as well as comparing the pressure's effect on data loss, friction factor, and drag reduction %. The figures in the table below demonstrate that, at 100ppm,

the pressure is greater, while at 200ppm, the pressure is slightly lower for Gum Arabic solution. On the other hand, in addition of Gum Guar, the pressure dropped drastically as the ratio of GG is increased. Frictional data reveals that all concentration data and trends are in a fairly tight range. In many runs comparison, the 200ppm concentration with ratio of GG:GA 70:30 had a superior drag reduction % than pure water. While data collecting was taking place, numerous issues were found and discussed.

According to the data, drag reduction % increases tremendous at speed of 0.4 m/s and reduces drastically when the velocity increased to 1.2 m/s. Again increase from 1.2 m/s to 1.6 m/s where all the solution shows almost the same reading. The DR continuous increase for solution mixed with GG and shows decrement for solution GA alone.

As the system speed increases, there is a rise in friction, which causes a rise in temperature and necessitates the use of a lower-temperature recirculating cooler to keep the bulk temperature at 35°C. As the velocity becomes higher, the additives in transportation energy start interacting with the turbulent eddies, causing the frictional loss to be reduced, unless the additives are mixed in and dispersed in the water at the higher velocity.

## REFERENCES

- Bridson, J. H., Kaur, J., Zhang, Z., Donaldson, L., Fernyhough, A. J. P. D., & Stability. (2015). Polymeric flavonoids processed with co-polymers as UV and thermal stabilisers for polyethylene films. *122*, 18-24.
- Campbell, S. E., & Jovancicevic, V. (2001). *Performance improvements from chemical drag reducers*. Paper presented at the SPE International Symposium on Oilfield Chemistry.
- Cheng, N.-S. J. J. o. h. e. (1997). Simplified settling velocity formula for sediment particle. *123*(2), 149-152.
- Daily, J. W., & Bugliarello, G. (1958). *The effects of fibers on velocity distribution, turbulence and flow resistance of dilute suspensions*: Hydrodynamics Laboratory, Department of Civil and Sanitary Engineering ....
- Dasman, A., Othman, N. A., Ahmad, S., Yacob, N. A., & Ishak, A. (2014). *Mixed convection boundary-layer flow near the stagnation-point on a vertical surface in a nanofluid*. Paper presented at the AIP Conference Proceedings.
- Demirci, Z. O., Yilmaz, I., Demirci, A. Ş. J. J. o. f. s., & technology. (2014). Effects of xanthan, guar, carrageenan and locust bean gum addition on physical, chemical and sensory properties of meatballs. *51*(5), 936-942.
- Dror, Y., Cohen, Y., & Yerushalmi-Rozen, R. J. J. o. P. S. P. B. P. P. (2006). Structure of gum arabic in aqueous solution. *44*(22), 3265-3271.
- Duffy, G. G., Moller, K., & Titchener, A. J. N. Z. E. (1972). A study of the flow properties of New Zealand wood pulp suspensions. *27*(9), 273-279.
- Edomwonyi-Otu, L., Simeoni, M., Angeli, P., & Campolo, M. J. N. J. o. E. (2016). Synergistic effects of drag reducing agents in pipes of different diameters. *22*(2), 1-5.
- Forgacs, O., & Mason, S. J. J. o. c. s. (1959). Particle motions in sheared suspensions: IX. Spin and deformation of threadlike particles. *14*(5), 457-472.
- Haaland, S. E. (1983). Simple and explicit formulas for the friction factor in turbulent pipe flow.
- Han, L., Xu, J., Lu, X., Gan, D., Wang, Z., Wang, K., . . . Weng, J. J. J. o. M. C. B. (2017). Biohybrid methacrylated gelatin/polyacrylamide hydrogels for cartilage repair. *5*(4), 731-741.
- Han, W. J., Dong, Y. Z., & Choi, H. J. J. P. (2017). Applications of water-soluble polymers in turbulent drag reduction. *5*(2), 24.
- Hasan, M. L. B., & Khalid, M. N. B. M. (2017). *Preparation of Nano-Scale Biopolymer Extracted from Coconut Residue and Its Performance as Drag Reducing Agent (DRA)*. Paper presented at the MATEC Web of Conferences.

- Hawege, E. F., & Abushina, A. A. (2019). Study Influence of adding Surfactant to polymers in Reduce Friction in Pipelines.
- Henaut, I., Darbouret, M., Palermo, T., Glenat, P., & Hurtevent, C. (2009). *Experimental Methodology To Evaluate DRAs: Effect of Water Content and Waxes on Their Efficiency*. Paper presented at the SPE International Symposium on Oilfield Chemistry.
- Hosseini-pour, A., Japper-Jaafar, A. B., & Yusup, S. (2018). Calculation of wax appearance temperature directly from hydrocarbon compositions of crude oil.
- Ibrahim, J. U., & Braimoh, L. A. (2005). *Drag Reducing Agent Test Result for ChevronTexaco, Eastern Operations, Nigeria*. Paper presented at the Nigeria Annual International Conference and Exhibition.
- Ikoku, C. U. (1984). Natural gas reservoir engineering.
- Jainuddin, M. N. R. (2015). *Experimental Study on the Effect of Different Injection Rates of Biopolymer Extracted from Natural Waste Material (Coconut Residue) as Drag Reducing Agent (DRA) in Water Injection Well: Formation Permeability Reduction*.
- Kang, C., Vedapuri, D., & Jepson, W. (2000). *The Performance of Drag Reducing Agent in Three Phase Slug Flow and Annular Flow*. Paper presented at the International Pipeline Conference.
- Karp-Boss, L., Jumars, P. A. J. L., & Oceanography. (1998). Motion of diatom chains in steady shear flow. *43*(8), 1767-1773.
- Kazi, M. S. N., Duffy, G. G., & Chen, X. D. J. C. E. J. (1999). Heat transfer in the drag reducing regime of wood pulp fibre suspensions. *73*(3), 247-253.
- Kim, C., Lim, S., Choi, H., Sohn, J. I., & Jhon, M. J. J. o. a. p. s. (2002). Characterization of drag reducing guar gum in a rotating disk flow. *83*(13), 2938-2944.
- Kühnen, J., Song, B., Scarselli, D., Budanur, N. B., Riedl, M., Willis, A. P., . . . Hof, B. J. N. p. (2018). Destabilizing turbulence in pipe flow. *14*(4), 386-390.
- Kumar, N., Kaur, P., Bhatia, S. J. N., & Science, F. (2017). Advances in bio-nanocomposite materials for food packaging: a review.
- Lee, P. F., & Duffy, G. G. J. A. J. (1976). Relationships between velocity profiles and drag reduction in turbulent fiber suspension flow. *22*(4), 750-753.
- Li, Y., Dai, C., Zhou, H., Wang, X., Lv, W., Wu, Y., . . . Research, E. C. (2017). A novel nanofluid based on fluorescent carbon nanoparticles for enhanced oil recovery. *56*(44), 12464-12470.
- Ling, F. W., Abdulbari, H. A., Kadhum, W. A., & Heng, J. J. C. E. C. (2020). Investigating the flow behavior of dilute aloe vera biopolymer solutions in microchannel. 1-11.

- Ma, H., Zhao, Y., Lu, Z., Xing, R., Yao, X., Jin, Z., . . . Yu, F. J. I. J. o. B. M. (2020). Citral-loaded chitosan/carboxymethyl cellulose copolymer hydrogel microspheres with improved antimicrobial effects for plant protection. *164*, 986-993.
- Montazer, E., Shafii, M. B., Salami, E., Muhamad, M. R., Yarmand, H., Gharekhani, S., . . . Badarudin, A. J. A. P. T. (2020). Heat transfer in turbulent nanofluids: separation flow studies and development of novel correlations. *31*(8), 3120-3133.
- Motta, M. V. L., de Castro, E. V. R., Muri, E. J. B., Loureiro, B. V., Costalonga, M. L., & Filgueiras, P. R. J. I. j. o. b. m. (2019). Thermal and spectroscopic analyses of guar gum degradation submitted to turbulent flow. *131*, 43-49.
- Murali, R., Vidhya, P., & Thanikaivelan, P. J. C. p. (2014). Thermoresponsive magnetic nanoparticle-aminated guar gum hydrogel system for sustained release of doxorubicin hydrochloride. *110*, 440-445.
- Ouwehand, A., Tiihonen, K., Mäkeläinen, H., Rautonen, N., Hasselwander, O., & Sworn, G. (2009). Non-starch polysaccharides in the gastrointestinal tract. In *Designing Functional Foods* (pp. 126-147): Elsevier.
- Padala, S. R., Williams, P. A., Phillips, G. O. J. J. o. A., & Chemistry, F. (2009). Adsorption of gum Arabic, egg white protein, and their mixtures at the oil- water interface in limonene oil-in-water emulsions. *57*(11), 4964-4973.
- Pandey, V. S., Verma, S. K., Yadav, M., & Behari, K. J. C. p. (2014). Guar gum-gN, N'-dimethylacrylamide: Synthesis, characterization and applications. *99*, 284-290.
- Pittendrigh, C., Bruce, V., & Kaus, P. J. P. o. t. N. A. o. S. o. t. U. S. o. A. (1958). On the significance of transients in daily rhythms. *44*(9), 965.
- Qi, C., Wan, Y.-L., Li, C.-Y., Han, D.-T., Rao, Z.-H. J. I. J. o. H., & Transfer, M. (2017). Experimental and numerical research on the flow and heat transfer characteristics of TiO<sub>2</sub>-water nanofluids in a corrugated tube. *115*, 1072-1084.
- Raghem-Moayed, A. (1999). *Characterization of fibre suspension flows at papermaking consistencies*. Citeseer,
- Raghem-Moayed, A., & Dodson, C. J. A. m. l. (1999). Modeling stochastic fibre clumps. *12*(2), 7-11.
- Simeoni, M. (2016). *Experimental evaluation of biopolymer and synthetic polymer drag reduction in industrial scale facilities*. PhD Thesis,
- Sokhal, K. S., Dasaroju, G., & Bulasara, V. K. J. V. (2019). Formation, stability and comparison of water/oil emulsion using gum arabic and guar gum and effect of aging of polymers on drag reduction percentage in water/oil flow. *159*, 247-253.
- Sokhal, K. S., Gangacharyulu, D., & Bulasara, V. K. J. C. p. (2018). Effect of guar gum and salt concentrations on drag reduction and shear degradation properties of turbulent flow of water in a pipe. *181*, 1017-1025.



- Sworn, G. (2021). Xanthan gum. In *Handbook of hydrocolloids* (pp. 833-853): Elsevier.
- Turian, R. M., & Yuan, T. F. J. A. J. (1977). Flow of slurries in pipelines. *23*(3), 232-243.
- Tynell, T., Karppinen, M. J. S. S., & Technology. (2014). Atomic layer deposition of ZnO: a review. *29*(4), 043001.
- Tze-Shyuen, L. W. (2014). Computational Fluid Dynamics Study of Flow within a Double Gap Cylinder.
- Williams, P. A., & Phillips, G. O. (2021). Gum arabic. In *Handbook of hydrocolloids* (pp. 627-652): Elsevier.
- Wole-Osho, I., Okonkwo, E. C., Kavaz, D., & Abbasoğlu, S. J. J. o. E. E. (2021). Energy, Exergy, and Economic Investigation of the Effect of Nanoparticle Mixture Ratios on the Thermal Performance of Flat Plate Collectors Using Al<sub>2</sub>O<sub>3</sub>-ZnO Hybrid Nanofluid. *147*(1), 04020083.
- Xing, L., Ke, Y., Hu, X., Zhao, Y., Peng, F., Bai, C., . . . Aspects, E. (2019). Preparation and properties of amphoteric polyacrylamide/modified montmorillonite nanocomposites and its drag reduction performance. *574*, 94-104.
- Yue, Y., Wang, X., Han, J., Yu, L., Chen, J., Wu, Q., & Jiang, J. J. C. p. (2019). Effects of nanocellulose on sodium alginate/polyacrylamide hydrogel: Mechanical properties and adsorption-desorption capacities. *206*, 289-301.
- Zhang, X., Duan, X., & Muzychka, Y. J. J. o. M. L. (2019). Degradation of flow drag reduction with polymer additives—A new molecular view. *292*, 111360.
- Zhang, X., Duan, X., & Muzychka, Y. J. P. o. F. (2020). Drag reduction by linear flexible polymers and its degradation in turbulent flow: A phenomenological explanation from chemical thermodynamics and kinetics. *32*(1), 013101.
- Zheng, M., You, Q., Lin, Y., Lan, F., Luo, M., Zeng, H., . . . Zhang, Y. J. F. c. (2019). Effect of guar gum on the physicochemical properties and in vitro digestibility of lotus seed starch. *272*, 286-291.