THE EFFECTIVENESS OF DRAG REDUCER AGENTS IN TURBULENT TWO PHASE FLOW

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by

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ABSTRACT

It is well known that the addition of small amount of polymer to a turbulent newtonian fluid flow can result in reduction of drag forces, which has received considerable attention in a number of liquid flow fields. Although, the drag-reduction effect of polymers have been well investigated in single liquid turbulent flow, while little works are done concerning the reduction of drag forces in two-phase liquid-gas flows.

The present work represents an experimental study of drag-reduction performance of the water soluble XG as polysaccharide polymer in both water as single phase as well as in two-phase, water-air turbulent flows. The test section used consisted of a 1.2 m length perspex tube to visualize the type of flow. Various concentrations of XG additive up to 100 ppm, at 40- 160 L/min water and 10- 20 L/min air flow rates were considered, the investigation.

The results show that the drag reduction with XG additive in two-phase flow are significantly higher than in single phase in a whole liquid flow rates. Thus, drag-reduction increases as air flow rate increase reaching a maximum value at 15 L/min air flow. While at 20 L/min air flow rate results a low drag-reduction effectiveness. The drag-reduction ability in air-water, two-phase turbulent flow was noticeable even though in absence of polymeric additive.

The drag-reduction ability in two-phase flow could be attributed to the formation of microbubbles, which reduce significantly the drag forces in turbulent flow. At 20 L/min air flow, the flow regime approaches bubble-plug flow by damping the formation of microbubbles as it was visible through the perspex tube.

Experimental work was devoted to investigate the performance of XG as drag reducer agent in air-water flow with existence of small amounts, up to 2.0 wt % of sodium chloride in water. The presence of up to 2.0 wt % NaCl in two phase flow enhances the drag-reduction behavior at low degree of turbulence, 40 -80 L/min liquid flow rates, leading to an increase of percentage drag-reduction. It was noticed that the presence of salt cause to high degree of foaming which was easy noted through the perspex tube. These micro foams enhance the drag-reduction performance. While, at water flow rates above 100 L/min less foaming was noted. Thus, the drag-reduction decreases gradually with increasing of the concentration of salt.

XG additive demonstrate desirably high drag-reduction efficiency in air-water two-phase turbulent flow, while undesirable mechanical molecular degradation progressed occurs as circulation time.

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Abbreviations

DR	Drag-Reduction
PEO	Polyethylene oxide
PAM	Polyacrylamide
GG	Guar Gum
XG	Xanthan Gum
CMC	Carboxyl Methyl Cellulose
PIB	Polyisobutylene
PMMA	Polymethyl Metharcylate
CDR	Conoco Drag Reducer
HEC	Hydroxyl Ethyl Cellulose
STAC	Stearyltri Methyl Ammonium Chloride
%DR	Percent Drag Reduction
%TI	Percent Through Put
MPPGL	Multiphase Pug and Pay Gas-Lift

NOTATIONS

Symbols	Description	Units
Le	The entrance length	m
d	The diameter of the pipe	m
Q	Volumetric liquid flow rate	m^3/Sec
U	Liquid velocity	m/Sec
P	Pressure	Pa
A	Area of Pipe	m^2
μ	Viscosity	Pa.Sec
ρ	Density	Kg/m^3
f	Fraction factor	

CHAPTER ONE

1.1 Introduction

It is well known that more than 80% of liquids are transported by pipelines in field applications. The fractional losses involved in transporting oil in pipes consumed large amounts of pump energy. Thus coming up with any method to minimize those energy losses is vital to increase the amount of pumped liquids in a certain pipe transport system [1].

One of the methods that are used to increase the efficiency of piping systems is called "drag reduction technique". The term "drag" comes from pulling of an object through water. In the early 1960s the term "drag reduction" was coined. It has been used ever since as descriptor for friction energy losses in turbulent non-Newtonian flow [2].

Drag reduction can be defined as the increase in the pumpability of a fluid, which is caused by addition of small amount of chemical additives. Therefore, during drag reduction and a given bulk mean velocity the fluid with additive requires a lower pressure gradient to move than the fluid without additives [3].

The industrial applications of drag reduction can be found in many areas such as pipelining of crude oil and its fractions, fire fighting to increase the system capacity, and closed circuit piping insulations such as central heating systems. The first major applications of such drag reduction in oil pipelines has been in the train Alaska oil pipe line systems(when as a result the flow rate has been increased by 32000 m^3/day) [4], another major use of such chemicals has been in Iraq in the mid 1980s [5].

The drag reduction studies that followed its discovery by Toms [6] concentrated on single phase systems, while little works were done for multi-phase flows, due to the difficulty of studying the two phase flow systems for drag reduction directly. Many researchers came with alternatives some of those researchers chose study drag reduction in single phase and then include the necessary corrections for the case of two phase flows. Other conducted direct studies of two phase flow systems but confined their selves in to a single kind of this flow [7]. Furthermore, some researchers found that the few grams that are added from those chemical additives may change the flow system from one kind to another [8].

1.2 Aim of The present Work

1- Investigate the effects of changing the percentage of the gas phase with respect to the liquid phase on the drag reduction values.
2- The performance of xanthan gum was investigated as drag reducing agent.
3- Evaluate the effect of the polymer concentrations, solvent, Reynolds number and the presence of sodium chloride on the performance of drag-reduction in a two-phase flow system.

CHAPTER TWO

Literature Survey

2.1 Gas-Liquid Two-Phase Flow

2.1.1 Introduction

The flow of gas-liquid mixtures in pipes and other items of process equipment are common and extremely important. In some cases the quality, that is the mass fraction of gas in the two-phase flow, will vary very little over a large distance. An example of this is the flow in many gas-oil pipelines. In other cases, boiling or condensation occurs and the quality may change very significantly although the total mass flow rate remains constant.

It is important to appreciate that different flow regimes occur at different gas and liquid flow rates and differences also occur for different materials. In order to, have any confidence when calculating pressure losses in two-phase flow, it is necessary to be able to predict the flow regime and then to use an appropriate pressure drop calculation procedure [9].

For two-phase flows, the respective distribution of the liquid and vapor phases in the flow channel is an important aspect of their description. Their respective distributions take on some commonly observed flow structures, which are defined as two phase flow patterns that have particular identifying characteristics. Heat transfer coefficient and pressure drops are closely related to the local two-phase flow structure of the fluid, and thus two phase flow pattern prediction is an important aspect of modeling evaporation and condensation. In fact, recent heat transfer models for predicting in tube boiling and condensation are based on the local flow pattern and hence, by necessity, require reliable flow pattern maps to identify what type of flow pattern exists at the local flow conditions. Analogous to predicting the transition from laminar to turbulent flow in single-phase flows, two-phase flow pattern maps are used for predicting the transition from one type of two-phase flow pattern to another [10].

2.1.2 Vertical Flow Pattern

The flow regimes that are obtained in vertical, upward, co-current flow at different gas and liquid flow rates are shown in figure 2.1. The sequence shown was that which would normally be seen as the ratio increasing of gas to liquid flow rates. In the bubbly regime there was a distribution of bubbles of various sizes throughout the liquid. As the gas flow rate increases, the average bubble size increases. The next regime occurs when the gas flow rate was increased to the point when many bubbles coalesce to produce slugs of gas. The gas slugs have spherical noses and occupy almost the entire cross section of the tube, being separated from the wall by a thin liquid film. Between slugs of gas there are slugs of liquid in which there may be small bubbles entrained in the wakes of the gas slugs. This well-defined flow pattern was destroyed at higher flow rates and a chaotic type of flow, generally known as ***chum flow*** was established.

Over most of the cross section there was a churning motion of irregularly shaped portions of gas and liquid. Further increase in the gas flow rate causes a degree of separation of the phases, the liquid flowing mainly on the wall of the tube and the gas in the core. Liquid drops or droplets are carried in the core: it is the competing tendencies for drops to impinge on the liquid film and for droplets to be entrained in the core by break-up of waves on the surface of the film that determine the flow regime.

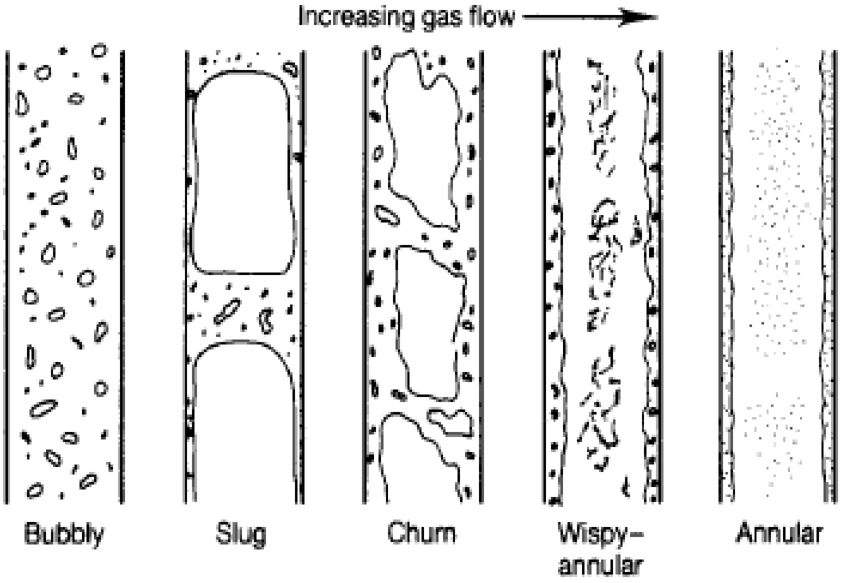

Figure 2.1: flow regimes in vertical gas-liquid flow [10].

The main differences between the ***wispy-annular*** and the ***annular*** flow regimes are that in the former the entrained liquid was presented as relatively large drops and the liquid film contains gas bubbles, while in the annular flow regime the entrained droplets do not coalesce to form larger drops [9].

2.1.3 Horizontal Flow Pattern

Co-current gas-liquid flow in horizontal pipes displays similar patterns to those for vertical flow. However, asymmetry was caused by the effect of gravity, which was most significant at low flow rates, the sequence of flow regimes, as shown in figure 2.2. In the ***bubbly*** regime the bubbles are confined to a region near the top of the pipe. Increasing the gas flow rate, the bubbles become larger and coalesce to form long bubbles giving what was known as the ***plug*** flow regime. At still higher gas flow rates the gas plugs join to form a continuous gas layer in the upper part of the pipe. This type of flow, in which the interface between the gas and the liquid was smooth, and known as the ***stratified*** flow regime. Owing to the lower viscosity and lower density of the gas it will flow faster than the liquid.

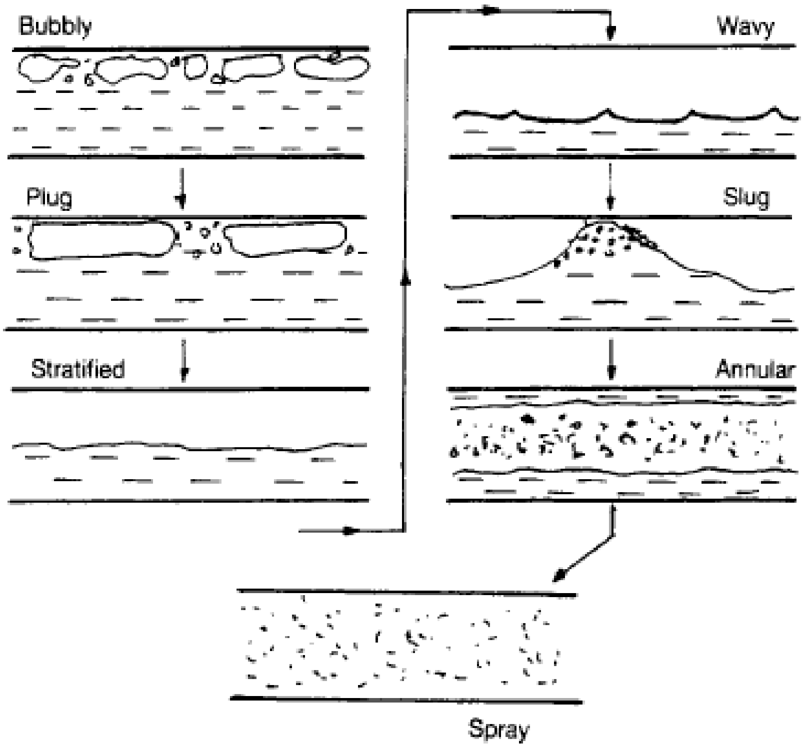

Figure 2.2: flow regimes in horizontal gas-liquid flow [10].

As the gas flow rate was increased further, the interfacial shear stress becomes sufficient to generate waves on the surface of the liquid producing the ***wavy*** flow regime. As the gas flow rate continues to rise, the waves, which travel in the direction of flow, grow until their crests approach the top of the pipe. The gas breaks through; liquid is distributed over the wall of the pipe. This is known as the ***slug*** regime and should not be confused with the regime of the same name for vertical flow.

At higher gas flow rates an ***annular*** regime was found as in vertical flow. A very high flow rates the liquid film may be very thin, the majority of the liquid being dispersed as droplets in the gas core. This type of flow may be called ***spray*** or ***mist*** flow regime. It may be noted that similar flow regimes can be seen with immiscible liquid systems. If the densities of the two liquids are close the flow regimes for horizontal flow will more nearly resemble those for vertical flow [9].

2.1.4 Flow Regime Maps

The prediction of the flow regime in gas-liquid two-phase flow is rather uncertain partly because the transitions between the flow regimes are gradual and the classification of a particular flow is subjective. There are various flow regime maps in the literature, two of which are given in Figures 2.3 and 2.4. For vertical flow of low pressure air-water and high pressure steam-water mixtures, Hewitt and Roberts have determined a flow regime map shown in Figure 2.3.

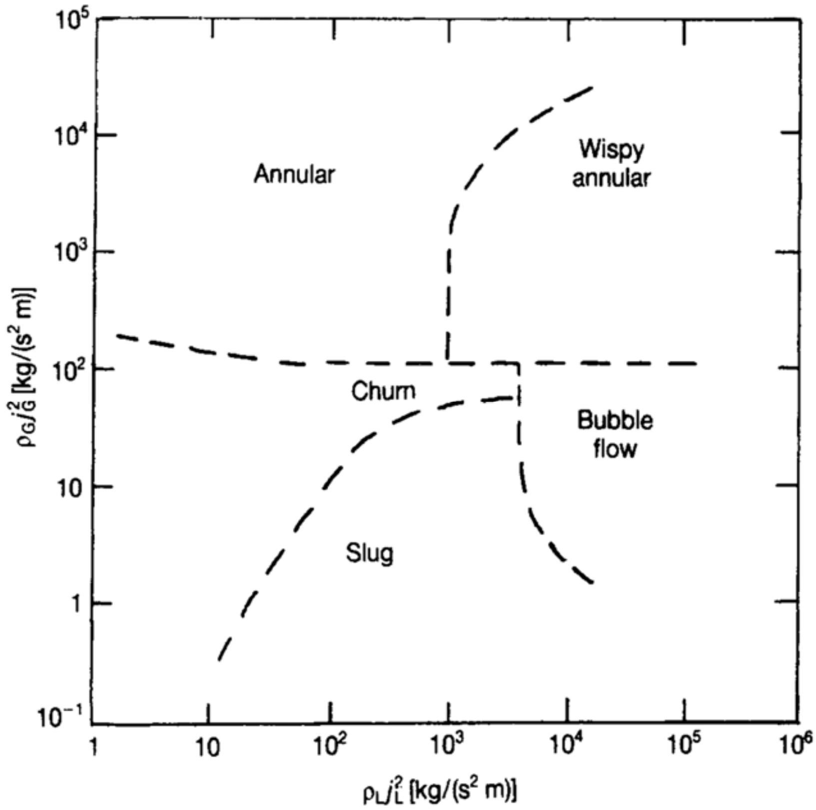

Figure 2.3: Flow regime map for vertical gas-liquid flow [11].

Here, ***jG*** and ***jL*** denote the volumetric fluxes of the gas and liquid. For the gas
jc* = *QdS

and for the liquid

jL* = *QLIS

Where **QG, *QL*** are the volumetric flow rates of the gas and the liquid, and ***S*** is the cross-sectional area of the pipe. The axes of Figure 2.3 represent the superficial momentum fluxes of the gas and liquid. (The volumetric flux is the same as the superficial velocity.) In addition to allowing the flow regime for a specified combination of gas and liquid flow rates to be determined, the diagram shows how changes of operating conditions change the flow regime. In particular it can be seen that the sequence of flow regimes described above is produced by increasing the gas momentum flux and/or reducing the liquid momentum flux [12].

The best known flow regime map for horizontal gas-liquid flow was given by Baker and is shown in Figure 2.4.

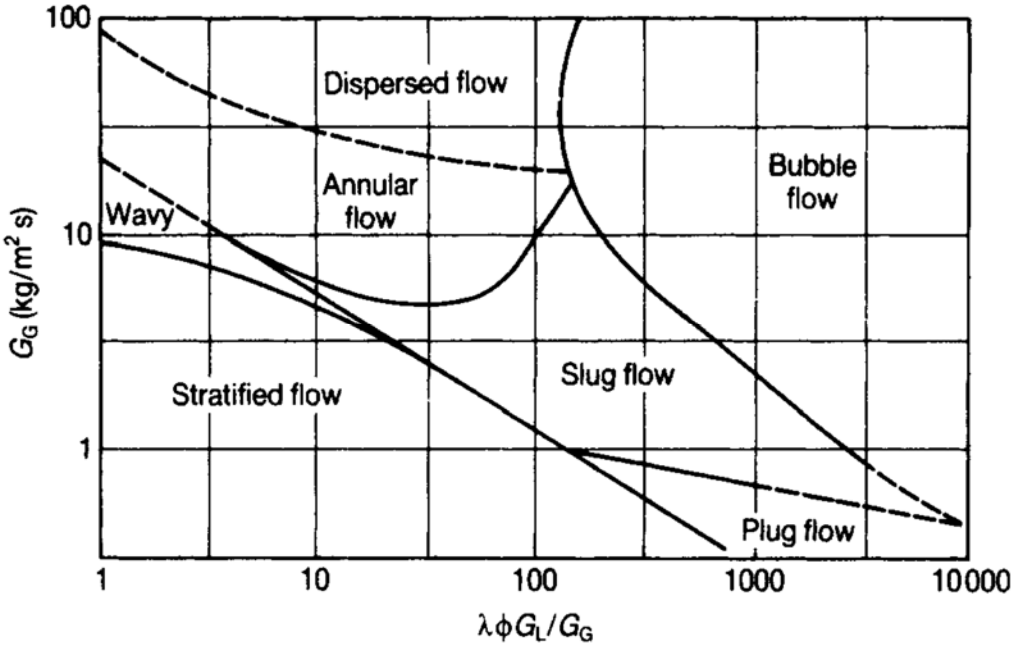

Figure 2.4: Flow regime map for horizontal gas-liquid flow [13].

Here ***GG, GL*** denote the superficial **mass** fluxes of the gas and the liquid. For the gas

GG = MJS =]GpG

and for the liquid

GL = MLIS = jLpL

The quantities **λ** and **Φ** are physical property correction factors defined by the expressions

$$\lambda = \left(\frac{\rho_G}{\rho_A} \cdot \frac{\rho_L}{\rho_W}\right)^{1/2} \qquad \text{and} \qquad \Phi = \frac{\sigma_W}{\sigma_L}\left[\frac{\mu_L}{\mu_W}\left(\frac{\rho_W}{\rho_L}\right)^2\right]^{1/3}$$

The subscripts A and W indicate the values for air and water at 20 ˚**C** and a pressure of 1 atmosphere; consequently **λ** and **Φ** have the value unity for the air-water system under these conditions. One of the problems with two-phase flow is that a significant distance may be required for the flow regime to become established and the flow regime may be changed by flow through pipe fittings and bends. When a change of phase occurs several different flow regimes may be obtained in a short distance as demonstrated by the schematic representation of flow in an evaporator tube [12].

2.2.1 Drag Reduction

In the process of transferring a newtonian fluid through pipelining systems, considerable energy may be expanded to overcome friction encountered in movement of the liquid. When a liquid is pumped under pressure a frictional pressure is apparent as a pressure drop along the pipeline

[14]. Such pressure drops are particularly noticeable under conditions where the velocity of liquid has surpassed the critical limit for laminar flow. To compensate for the loss of energy due to friction pressure, additional energy must be consumed.

Consequently, a decrease in frictional loss would allow lower energy consumption or alternatively an increased flow rate under the original pumping conditions. Thus, a method where by friction loss in the flow of liquids can be appreciably reduced is desirable. Also, it is economically profitable to industrial organizations engaged in movement of large volumes of liquid at high flow rates for considerable distance as in hydraulic fracturing of oil and gas wells [15].

A large amount of energy loss due to friction occurs in many cases of turbulent flow, generally. However, it is well known that turbulent drag reduction (DR) which is a drastic reduction of frictional resistance can be easily observed by injecting a minute amount of polymeric additives in a turbulent flow Polymer solutions undergoing a turbulent flow in a pipe thereby require a lower pressure drop to maintain the same volumetric flow rate[2]. The addition of small amounts of additives to the flowing fluids can show significant effects on a lot of flow types, including the stability of laminar flow, transition to turbulence, vortex formation and break-up [16].

The phenomenon in which drag of a dilute polymer solution is drastically reduced in turbulent flow by minute amount of suitable additives has been well documented [17].This implies that fluid containing these additives requires a lower pressure drop than pure solvent to maintain the same flow rate in a pipe [18, 19].

High molecular weight polymers and some surfactants are the most popular chemical drag reducing agents. The dependence of drag reduction efficiency is known to be a function of polymer molecular weight, polymer concentration and the degree of turbulence [20, 21].

The addition of drag-reduction additive is done by two different methods, resulting in two different types of drag reduction, homogeneous and heterogeneous [22]. Dissolving the polymer in the fluid before the experiments takes place is in the case of homogeneous drag-reduction. The onset shear stress as well as the obtainable magnitude of drag reduction is essentially determined by the molecular parameters of the polymer. While, by injection of moderately concentrated polymer solution into turbulent pipe flow resulted in a heterogeneous drag-reduction, the turbulent mixing process as well as the interaction between polymer solution and turbulent flow determines the drag reduction effectiveness.

2.2.2 Drag Reduction Applications

The industrial application of drag reduction can be found in many areas such as transport of crude oil’ sewage systems to prevent overflowing after heavy rain [23], closed -circuit pumping installations such as central-heating systems, fire- fighting to increase the range of water jets, and water supply and irrigation systems [24]. The first account of field trails was published by Bord and Rossi [25]. They were concerned with the use of drag reducing additives in the pipeline transportation of waxy crude, and they found that there is no unexpected side-effect of these additives that would militate against their commercial use.

Hydro transport of solid such as clay, and gravel, coal, iron ore, sewage slug and pulverized fly ash using drag reducer agents has been studied extensively. Polymer solution may be also be employed for reducing friction in enclosed , high friction system such as hydraulic machinery , motor, gear cases, propellers and bearing.

Intensive research on DR using several techniques in the past several decades has been paid off with several successes. For example, reduced drag can provide increased range or increased speed in nearly any transportation system or can result in fuel savings [26]. Water-soluble polymers, surfactants microbubbles have been tested on ship hull with success.

Latorre could achieve 10 – 15 % DR for ship movement [27]. Greater DR can be reached with a system developed by Mitsui Engineering and Shipbuilding Co. In this system, the bottom of the ship is coated with a highly water-repellent paint and air is supplied by a compressor Figure 2.5[27]. These DR methods have been applied to submarines and torpedoes. However, due to the secret nature of the work there are few results in the open literature. A general description of the work on submarines can found in popular scientific magazine.

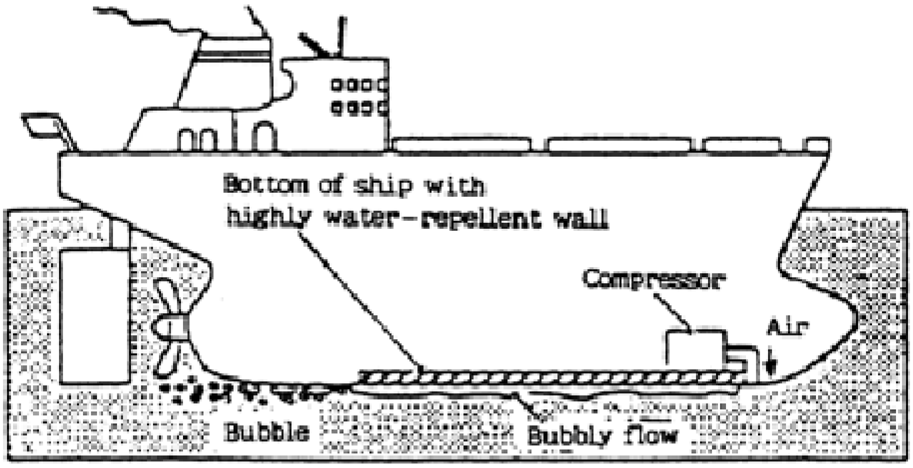

Figure 2.5: Model of drag reduction systems for a ship [27].

Biomedical studies of drag reducing polymers have been conducted for the past twenty years, the possibility of improving blood flow in partially blocked arteries, and thus treating or preventing circulatory disease [1].

Another commercial application of surfactants was the ability to lower the surface tension of a liquid by aggregating at the interface between a liquid and gas, they also capable of lowering interfacial tension by aggregating at the interfaces between two immiscible liquids. Also, surfactants are widely used in many aspects of petroleum industry, such as: demulsifies, acid retreads, and foaming agents, cleaning agents, enhanced recovery agents, corrosion inhibitors, clay stabilizers and surface tension reducers [28, 29].

Iraq is considered of the main countries exporting oil through a large network of pipeline. Consideration of throughput increased demand, which can either, be permanent or seasonal. Drag reducing additives are the best quick, temporary solution of such problem. Its main advantages are that capital investment is not involved. Some research works were carried out locally in Iraq in order to gain experiences and laboratory know how in measuring and comparing the performance of drag reducing chemical additives on Iraqi crud oil and some petroleum fractions. The information obtained should be of values in themselves and should also assist in the consideration of economic application of drag reducing additives for increasing the capacity for a given pipeline for increasing the capacity for a given pipeline for crude oil and fractions. Due to that this techniques was used in Iraq in the first one in the mid 1980[5].

2.2.3 Drag Reduction Mechanism

Drag reduction was discovered almost half a century ago, the physical mechanisms responsible for the phenomena of drag reduction are not completely understood and remain a subject of debate. Nevertheless, it is generally accepted that both the viscoelastic property including elastic behavior and energy dissipation phenomena of chemical additives solutions and the interaction between polymer molecules and turbulence generate the drag reduction phenomena. The role of stress anisotropy due to polymer extension verses elasticity is also still an ongoing subject of controversy in the drag reduction mechanism [30].

The mechanisms of drag reduction are not known exactly, however, the following five types of mechanisms are proposed**.**

2.2.3.1 Wall Layer Modification Hypothesis

Oldryod [31] offered a wall effect hypothesis for Tom's data. He proposed the existence of an abnormally mobile laminar sub layer whose thickness was comparable to molecular dimensions and which caused apparent slip at the wall.

Zakin and Hershy [32] proposed that drag reduction occurs when time scale of the turbulent fluctuations is of the same order of magnitude as the relaxation time of the solution.

Smith et al. [33] proposed a hypothesis based on the assumption that wall effect is significantly altered. The researchers studied the flow on fluid in a horizontal tube by using flow visualization technique. The formation of a more mobile wall layer by the presence of additive is either by physical adsorption to provide a more resilient wall layer or by the orientation of the molecules close to the wall. Both will be explained on the basis of a slip mechanism.

Virk et al. [34] described the maximum drag reduction in turbulent pipe flow of dilute polymer solutions which is ultimately limited by a unique asymptote. During high drag reduction, the mean velocity profile has three zones: viscous sub layer, interactive zone and turbulent core.

Gustavsson [35] assumed a new sub layer portion of the velocity profile of the same form as that proposed by Virk's elastic sub layer model. It was found that the thickness of this layer grows linearly with wall shear stress from the onset point.

Savins et al. [36] showed that the flow of energy from the mean flow to the turbulent motion is a maximum inside the sub layer. Not only does a high rate of dissipation occur here but a high rate of turbulence production exists here as well.

Elperin et al. [37] suggested that the existing of adsorbed layer of polymer molecules at the wall pipe during flow will act to reduce the viscosity, create a slip, damp turbulence and prevent any initiation of vortices at the wall.

2.2.3.2 Viscosity Gradient Theory

This theory is well defined through the following explanation [38]:

On injection of a dye into a CMC (polymer) solution in turbulent motion, it was observed that fluid layers adjacent to the wall were much thicker than in the flow of water under turbulent conditions. Further, vortices leaving the layer were relatively few in number. The damping effect was attributed to a positive gradient of viscosity for a non–newtonian flowing, the viscosity is generally at a minimum at the boundary and a maximum in the region remote from the wall, owing to the distribution of shearing stress across the tube section encountered by the vortices on forming at the wall and moving toward the region remote from the boundary. It was concluded that the lower energy dissipation resulted from a repressing effect by the viscosity on the formation of the vortices [39].

It was also proposed that the decreased friction factors and sharper velocity profiles, which were measured, could be attributed to the viscosity damping effect. However, this is only partly correct, because there are typical non-Newtonian solutions which exhibit the viscosity gradient effect and yet some of them exhibit drag reduction properties. Examples of these solutions are CMC and a poly (acid), poly (viny1) alcohols dissolved in water, and polyisobutylene in cyclohexane.

2.2.3.3 Turbulent Suppression Hypothesis

Charachafchy explained that when the drag reducer is mixed with crude oil or refined petroleum products in pipelines, it changes the flow characteristics and reduces the turbulence in the pipeline [39]. A number of turbulent bursts originating at the pipe wall and the strength of the turbulent eddies are reduced by the addition of drag reducers. He believed that the drag reducer absorbs part of the turbulent energy and returns it to the flowing stream. By lowering the energy loss (or drag), the drag reducer allows the pipeline fluid to move faster at any working pressure [39].

Rodriguez et al. [39] explained that in the viscoelastic fluid, the stress is dependent on both the amount of strain (elastic response) and the rate of strain (viscous response). If the time scale of the experiment is of the order or shorter than its relaxation time (measure of the relative amounts of viscous and elastic response), then any fluid will exhibit elastic as well as viscous properties.

Many researchers explained that the friction reduction occurs when the relaxation time of the viscoelastic drag reducer molecules in solution is equal or larger than a certain "characteristic flow time". The characteristic flow time has been taken as the reciprocal of the shear rate at the wall and the relaxation time [40].

Lumley [41] stated that the stretching of randomly coiled polymers increase the effective viscosity. By consequence, small eddies are damped which leads to a thickening of the viscous sub layer and thus drag reduction. And he suggested that the effective viscosity in the buffer zone layer with strong deformation (polymer expand) is the key of drag reduction [42].

DeGennes [43] proposed a new theory which argues that drag reduction is caused by elastic properties rather than viscous. He came to this hypothesis by observing drag reduction in experiments where polymers were active at the centre of the pipe, where viscous forces do not play a role. DeGennes argues that the elastic properties of polymers cause shear waves to prevent the production of turbulent velocity fluctuations at the small scales.

2.2.3.4 Elastic Theory

A drag reducer solution with elastic deformations might, occur which would modify the type of turbulence, CMC and polyisobutylene solutions were found to have swelling of a liquid jet emerging from a capillary. There was also some evidence of the presence of low level of elasticity in poly (acids) [44].

At turbulent flow, eddies will strike the elastic material. Strike energy will be stored as strain in the elastic material (polymer coil and micelles surfactant) and return to flow stream.

Some solution might not exhibit much elastic deformation under ordinary conditions; it is possible that elastic behavior might be of importance under turbulent flow conditions. Drag reducing polymer molecules in turbulent boundary layers are stretched by the flow, resulting in an increase in the total increase in the local fluid viscosity, in this extended state, the elongational viscosity increases by a factor of the order of ten thousands. This phenomenal increase in elongational viscosity near wall is because the extensional strain rates are the highest there, the increased elongational viscosity suppresses turbulent fluctuations, increases the buffer layer thickness and reduces wall friction [45].

2.2.3.5 Viscoelasticity

One of the important factors that made the drag-reducing additive to be functional is "viscoelasticity". The term viscoelastic came from the dual action of such additives that it is elastic material keeping the stress when it is under constant strain, and also it is a viscous material that dissipated the stress immediately after the strain action. In other words, when a stress is applied to any material, it will deform. The extent of deformation relative to the original dimension of the material is defined as strain. If the deformation is recovered on the removal of stress then the material is elastic. However, if the components of the material have been able to diffuse a sufficient distance during the experiment to relieve at least part of applied stress then viscous flow will have occurred resulting in a permanent deformation [44].

The term "relaxation time" is one of the characteristics, especially in polymers, that give a close picture of the viscoelastic property of the additive. It is defined as the mean time needed to remove most of the stress when the drag reducing additives molecules are under a constant strain [46].

2.3 Drag-Reduction Agents

The additives cause drag-reduction is divers and include linear flexible polymers [4].solutions of thread-like micelles [29] and rigid-like fibers [47] or rod- like polymers. Therefore, the additives can be divided in four main groups, as follow,

1. Polymers.
2. Surfactants.
3. Fibers
4. Suspended particles.

The linear flexible, high molecular weight polymers and cationic surfactants are considered to the most used and effective drag-reduction agents.

2.3.1 Types of Drag Reducers

Drag-reduction by additives is a flow phenomenon in which small amount of an additive in a fluid cause a reduction in the turbulent friction compared which that of the pure fluid at the same flow rate. Since Toms [11] reported turbulent drag-reduction by polymer additives, there have been many studies on this field, including searches for effective agents.

It is well known that the presence of suspended particles modifies the turbulent structure of the flow [47]. The combination of general factors, such as sediment concentration, specific weight of solid and fluid, particle size and shape and others, can produce sub stationary changes in the behavior of the flow. The most interesting case is that of a drag reduction which can occur in pipes when the combinations of factors produce a decrease of turbulent intensity. The mechanisms which produce these changes in the turbulent structure could be various; depending upon the particle and flow characteristics and the overall effect could also vary for each particular case.

A. and K. Zaqustin [47] presented an analysis of a mechanism in which gravity is considered as the only factor involved in the turbulence. The same approach was obtained a few years later by Mahmood [48].

2.3.2 Polymers

The main properties of the polymer that should be found to be a drag reducer are linear flexible structure and a very high molecular weight. Drag reducer polymers are classified into two groups, water soluble and oil soluble polymers as shown in the list below.

Table (2-1) drags reduction polymers [49].

Water soluble polymers		Hydrocarbon soluble polymers	
Polyethylene oxide	PEO	Polyisobutylene	PIB
Polyacrylamide	PAM	Polystyrene	
Guar gum	GG	Polymethyl metharcylate	PMMA
Xanthan gum	XG	Polydimethyl siloxane	
Carboxymethyl cellulose	CMC	Poly cis isoprene	
Hydroxyethyl cellulose		Conoco drag reducer	CDR

The polymer additives, which cause drag reduction, have a size which is much smaller than the smallest length scale of the turbulence. A well known effect is the increase of the shear viscosity of a fluid due to polymers, which gives reason to suspect that polymers can at the most effect the microscales of the turbulence. That polymer affects the macrostructure of the turbulence, which is responsible for the transport of the momentums that resulting in drag seems unlikely. However, Polymers are primarily active on the microscale of the turbulence but also influence the macroscales of the turbulence [50].

The addition of polymer is possible by two different ways these resulting two different types of drag reduction [51]. Homogeneous drag-reduction is carried out usually by dissolving the polymer in the fluid before the experiment takes place. The onset shear stress as wall as the obtainable magnitude of drag reduction are essentially determined by the molecular parameters of the polymer. The experimental work of the present thesis is of this type. Heterogeneous drag reduction occurs by injection of moderately concentrated polymer solution into turbulent pipe flow. The turbulent mixing process as well as the interaction between polymer solution and turbulent flow determines the drag reduction effectiveness [51].

Many polymers are used to obtain drag reduction in practice; the following properties influence the performance of the polymer; as drag reducer [52].

- High molecular weight (M> 10^6 g/mol)
- Shear degradation resistance.
- Quick solubility in the pipeline fluid.
- Heat, light, chemical, biological degradation resistant.

In present investigation, water was chosen as flowing liquid. Therefore, it is necessary to give a brief description on the main water-soluble drag reducer agents Polyethylene oxide (PEO) has been the most widely studied for both laboratory and commercial applications, including fire fighting and marine propulsion. PEO is linear, flexible molecules which are available commercially in range of molecular weight; its utility in multiple pass application is limited due to its extremes sensitivity [54].

Drag reduction similar to that obtain in water has been shown for PEO in other solvents such as sea water, plasma, petroleum fractions, dioxin, and chloroform. Mixed PEO system, such as PEO graft polymer, polymer/soap and polymer/dye mixtures, have shown to provide varying levels of drag reduction effectiveness [55].

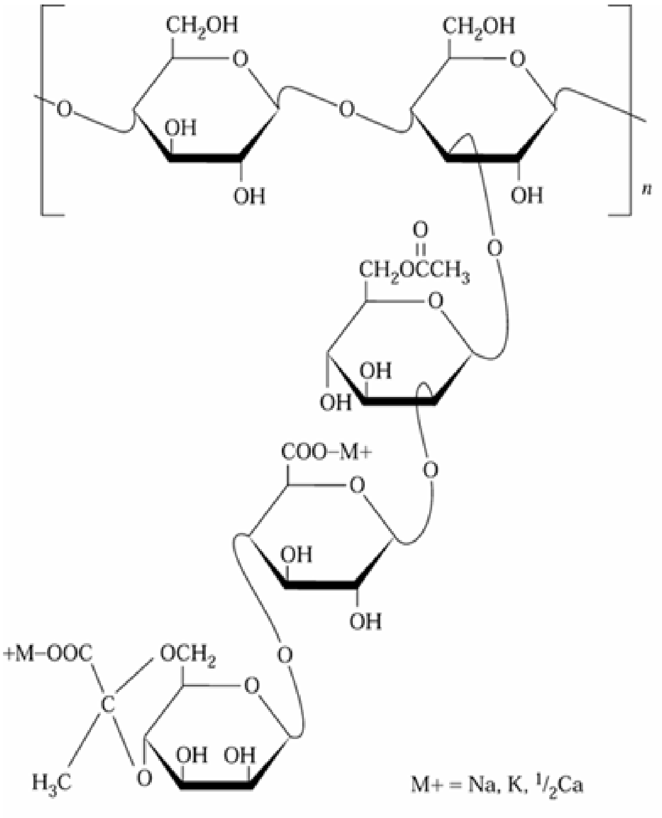

Figure 2.6: Chemical structure of the xanthan gum repeating [53].

Polyacrylamide (PAM) is the other synthetic water soluble polymer which is differ from PEO in that it has a side chain and is less susceptible to shear degradation. The related polymer polyacrylic acid (PAA) can be formed by hydrolysis of PAM. Most of the laboratory and commercial studies, however, have focused on PEO and PAM due to their availability, their relatively low cost, and the large body of previously reported experiments describing their solution behavior available in the literature [56].

One of the most widely used commercial drag reduction biopolymer is Guar Gum (GG). GG is a plant polysaccharide with a semi rigid backbone. The major limitation of guar gum in drag reduction application is its susceptibility to biodegradation. It has been shown that resistance to shear and biodegradation can be increased by grafting acrylamind to guar gum molecules [57].

Modified cellulose such as Carboxymethyl cellulose (CMC) and hydroxyl ethyl cellulose (HEC) have been employed and in laboratory studies.

The other biopolymer which has been widely used as a commercial drag reducer is xanthan gum (XG). Xanthan gum is an extra cellular polysaccharide produced by the bacteria xanthomnas. Xanthan gum is a long-chain synthetic polymer that acts as a strengthening agent, biding soil particles together [58]. A chemical structure of Xanthan gum is shown in Figure 2.6.

XG shows variable rheological behavior with change in solvent ionic strength, flow rate and polymer concentration [59]. The shear stability, and resistance to shear degradation for some water soluble polymers decreased as follow:
PAM>XG>PEO>GG.

2.3.3 Surfactants

The effect of surfactant solution on DR was conducted by Mysels [60], the research has not been as exhaustive and has received less attention than polymer solution. It was not until 10 years later that the interest in DR by surfactants was revived by the work of Dodge and Metzner [61], and Shaver and Merril [62]. Surfactant solution has become a favorite drag reducer owing to their chemical and mechanical stability that is an important requirement for a practical application. Also, development of surfactant systems exhibiting drag reduction at concentrations similar to dilute polymer solutions (<100 ppm) disclosed in number of recent patents.

When the concentration of a surfactant solution exceeds a critical value, the surfactant molecules start to form aggregates, i.e. Micelles. The association of the molecules to micelles is reversible [63]. The micelles are always in thermodynamic equilibrium with the molecules, and are of the size of about 20 to 1000 surfactant molecules. Depending on the molecular structure, concentration, type of solvent, three geometrical types of micelles can be distinguished: spheres, rods, and discs. Furthermore, by adding some salts (ie. Electrolytes), the electrolytic repulsion forces of the head groups can be suppressed, the molecules can be packed more densely facilitating the formation of disc-like or rod-like micelles. The drag reducing ability of a surfactant solution depends strongly on the shape of these micelles [64].

Among the surfactants used for drag reduction cationic surfactants such as cethyltri methyl ammonium chloride (CTAC), $CH_3(CH_2)_{15}\,N(CH_3)_3$ CL, and stearyltri methyl ammonium chloride (STAC), have been most widely used. Sodium salicylate is the most counter – ion [65].

Under the suitable conditions of surfactant /counter ion chemical structures, ratios, concentrations and temperature, they form rod – like micelles. The resulting microstructure imparts viscoelasticity to the solution. The microstructure is mechanically degraded when passing through a high shear pump such as a centrifugal pump [66].

The disadvantage of this type of additives is that, the surfactant drag reducing additives require higher concentration (ie. 2000 ppm), if it is compared with high molecular weight polymeric additives (about 50 ppm) this will lead to higher economic cost.

2.3.4 Suspended Particles

It is well known that the presence of suspended particles modifies the turbulent structure of the flow [47].The combination of general factors, such as sediment concentration, specific weight of solid and fluid, particle size and shape and others, can produce sub stationary changes in the behavior of the flow. The most interesting case is that of a drag reduction which can occur in pipes when the combination of factors produces a decrease of turbulent intensity. The mechanisms which produce these changes in the turbulent structure could be various, depending upon the particle and flow characteristics, and the overall effect could also vary for each particular case.

A. and K. Zaqustin [47].presented and analysis of a mechanism in which gravity is considered as the only factor involved in the turbulence. The same approach was obtained a few years later by Mahmood [48].

2.4 Microbubbles

Microbubble-modified boundary layer and associated skin friction reduction have been an active area of research for ship hull in recent years because of its energy saving potential. The DR in a turbulent boundary layer on a smooth wall can be realized by reducing the skin friction under suitable conditions when small gas bubbles are injected into the flow from an upstream position. The injection of gas into a liquid turbulent boundary layer to form bubbles reduces skin friction drag locally by as much as 80 %. Although it has long been know that a layer of air next to a surface in water reduces turbulent skin friction, the concept of the microbubbles-modified boundary layer came into existence in its present form from the pioneering work of McCormick and Bhattacharyya [67]. They used a copper wire wound around a towed body of revolution to produce hydrogen bubbles by electrolysis. Their experiments showed that microbubbles could reduce total drag and that the DR increased with increasing gas generation rate and decreasing rate. The results, however, were limited to Reynolds numbers between 0.3 and 1.8 million. Subsequently, several experiments conducted in the former Soviet Union reported significant drag reduction in water tunnel boundary layers by injection of air bubbles through flush-mounted porous plates [68, 69] in 1980s, through a series of systematic studies in water tunnels the drag reducing effects on flat wall by microbubbles generated by porous plates and on axisymmetric body by circumferential porous rings was observed.

Recently, Kato et al [70] carried out several experiments with microbubbles in a flat plate boundary layer. In order to overcome the practical limitations of conventional porous plates, such as high injection energy and marine biofouling when used below a ship hull, a new injection method using a slit was devised [71].

Although the effectiveness of microbubbles has been demonstrated and the bubble sizes have been found to be one of the important factors affecting the DR, the over all mechanism that leads to this reduction is only poorly understood. In particular, the interaction between the bubbles and the boundary layer has not been studied extensively [72].

Guin et al [73] investigated the DR effects due to the introduction of microbubbles into a two-dimensional water channel. The study established a relationship between the DR effectiveness and the near-wall bubble concentration. Pal et al [74] found that the bubbles were effective for drag reduction if they are located beyond a certain distance from the wall. The data of Guin et al [73] not only support their finding, but also provide some quantitative relation between drag reduction and near wall void fraction. Numerical investigations into the mechanisms of microbubble drag reduction have been conducted by Madavan et al [75]. The action of the bubbles is simulated by allowing the viscosity and density to vary locally as a function of a prescribed bubble concentration profile. The results of the model show that substantial skin friction reductions can be obtained when microbubbles are present, thus supporting the idea that microbubbles can act not only as an agent to reduce skin friction, but also to reduce overall drag Madavan et al [75, 76] compared the mechanism for microbubble drag reduction to that for polymer reduction. They showed that microbubbles can interact with the turbulent flow in the buffer layer to cause changes in the order of unity in the skin friction. In this respect their effect seems to be closely related to that achieved by polymer additives. Like polymer solutions, microbubbles appear to destroy the energy producing fluctuations near the buffer region. The resulting growth of the sublayer thickness is a manifestation of the drag reduction [75]. Both polymer solutions and microbubbles appear to have very strong effects on dynamics of turbulence for drag reductions greater than about 40 % [75].

Application of air injection along the along the bottom of the hull to reduce the skin friction was proposed as early as the beginning of this century. River barges and ship fitted with an air injection system showed 10 – 15 % reduction in skin friction [27].

2.5 Variables Affecting the Drag Reduction

2.5.1 Drag Reducer Concentration Effect

The effect of polymer concentration on drag reduction is shown in Figure 2.7 which displays data taken in the same pipe for solution of the same polymer ranging in concentration from 50 to 1000 ppm by using polyethylene oxide as agent. This figure shows that at the same Reynolds number, 1/√f increases as concentration is increased. It is necessary to mention here that as the value of 1/√f increases, the value of f is decreased, therefore, the drag reduction is increased. Also it is noted that as concentration of polymer or surfactant increases, the critical solution Reynolds number is decreased [3, 77].

It was found that initially, % DR increases as the concentration increases due to an increase in the number available drag reducers. However, as the polymer concentration increases further, the solution viscosity drastically increases, leading to a decrease in the turbulent strength. Therefore, exist concentration at which the drag reduction is maximized.

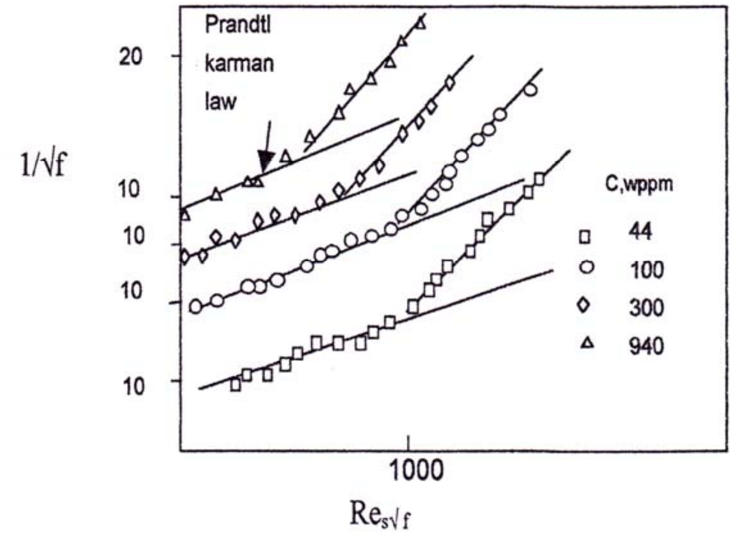

Figure 2.7: Aspects of the polymeric regime. At different concentrations, pipe I.D. 8.46 mm temperature 25C^{o}, solvent distilled water, polymer PEO, M=0.57*10^{6} [77].

In general, drag reduction increases initially with increasing concentration but tends to be constant at critical concentration because high doses of additive cause decrease in there activity. Toms [78] observed that drag reduction increases with an increase in the concentration, beyond which, due to the increased viscosity of the solutions, the drag reduction decreases with an increase in concentration.

A remarkable aspect of polymers as a drag reducer is that DR occurs at very low concentration in the ppm range. Increasing the concentration beyond 30 – 40 ppm lowers DR for PEO in small tube owing to the increase of the viscosity with increasing concentration. Interestingly, DR can be observed in concentrations as low as 0.02 ppm [79]. Using a rotating disk apparatus or a rotating cylinder DR induced by water and solvent-soluble polymers (polyisobutylene) showed similar results to the experiments performed with a small tube, in circulation loop.

2.5.2 Flow Rate Effect

Drag reduction increases, as the fluid flow rate increases. Because increasing the fluid velocity means increasing the degree of turbulence inside the pipe. This will provide a better media to the drag reducer to be more effective, but it is not continuously increasing, as shown in figure 2.8.The causes may furthermore, the following phenomena are noticed[80, 81].

1. At high flow rate degradation may occur in drag reducer.
2. At high flow rates through high rough by pipe decrease in drag reduction is expected.
3. According to elastic theory, drag reducer doesn't stretch fully at high flow rates.

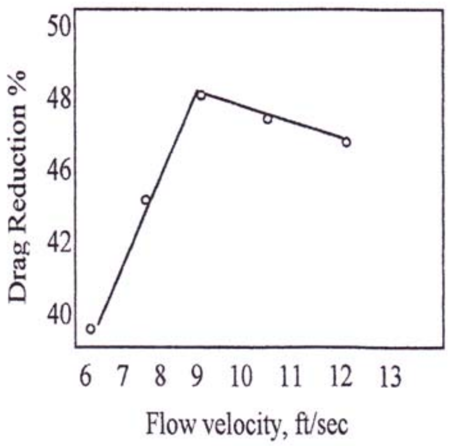

Figure 2.8: flow velocity percentage drag reduction [80].

2.5.3 Pipe Diameter and Roughness Effect

Some Investigators explained that drag reduction increases with decrease in pipe diameter when Reynolds number is held constant [82], as shown in figures 2.9. This figure shows that at the same Reynolds number, the 1/√f increase as diameter decreases (when 1/√f increases, f will decrease and consequently drag reduction will increase). Others showed that the effect of diameter is small. Most investigators showed that drag reduction increases with increasing pipe diameter.

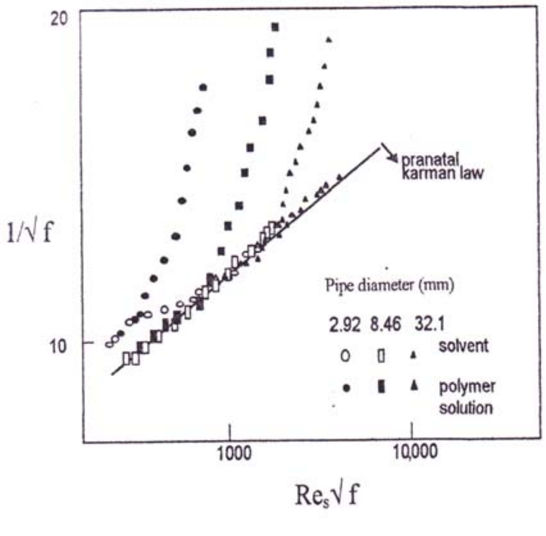

Figure 2-9: Effect of pipe diameter, Pipe I.D. 2.92, 8.46, and 32.1 mm, temperature 25 C^o, solvent water, polymer solution PEO [80].

From experiments in smooth and highly rough pipes of nearly the same inside diameters and polymer type, there was a significant drag reduction in smooth pipe, while rough pipe did not show any drag reduction with increasing flow rate. The drag reduction observed in the rough pipe is increased to a maximum, and then decreased and almost disappeared. This decrease was not attributed to polymer degradation but was caused by rough pipe, since the tested polymer structure did not show any degradation [83].

2.5.4 Temperature and Viscosity Effect

Drag reduction by surfactant increases when the temperature is increased because the length of rod-like micelles (collection of micelles) becomes longer. Above some critical temperature, the length of the rod-like micelles will decrease and drag reduction is decreased [84]. The effect of temperature on drag reduction is shown in figure 2-10. When the surfactant has long chain alkyl groups it will be more effective in drag reduction at high temperatures as compared with the more effective in drag reduction at high temperature as compared with short chain surfactant. On the other hand short chain surfactant will be more effective at low temperatures as compared with long chain surfactant [85].

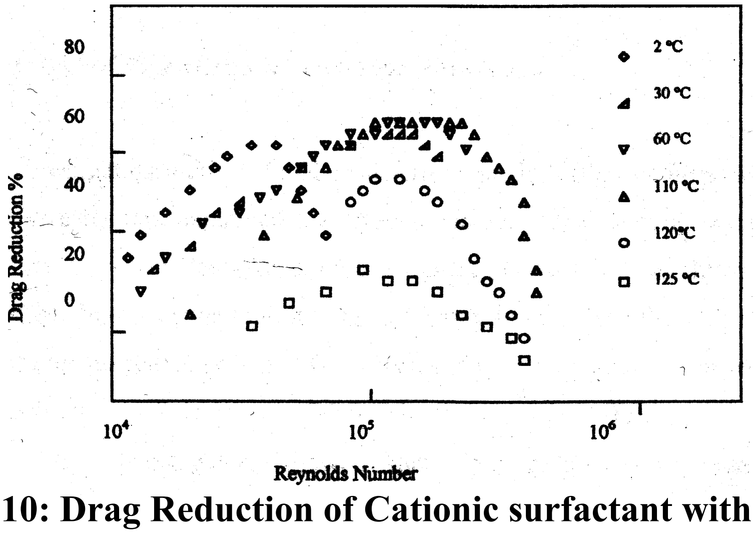

Figure 2-10: Drag Reduction of Cationic surfactant with Different Temperatures [85].

The apparent viscosity of drag reduction solutions changes with temperature and concentration. Viscosity may reveal the existence of structures in the solution and even though it dose not directly predict the drag reduction ability. It can help in the characterization of some processes, which take place in the solution. The concentration of the polymer and surfactant in a drag reduction solution is usually low and viscosity measurements of such systems are often problematic because of low instrument sensitivity; some references revealed that the drag reduction increases with an increase in the concentration, beyond which, due to the increased viscosity of the solutions, the drag reduction decrease with an increase in concentration [86]. Tap water or the presence of different ions in the water decreases the viscosity of drag reducing surfactant in comparison to the distilled water solution of that surfactant [85].

2.6 Degradation of Polymer

Drag-reducing additives demonstrate desirably high drag reduction efficiency while so undesirable mechanical degradation under turbulent flow occurs. Therefore molecular degradation is one of the major defects in the drag reduction application, since the polymeric additives are exposed to strong turbulent elongation strain and shear stress [87]. The mechanical degradation process was assumed to be that the polymer chain can indeed be fully extended by turbulent flow and experience the chain midpoint scission of macromolecule. Therefore the polymer chains having different molecular weights will show different time dependent existence. In other words, longer molecules are more susceptible to mechanical degradation, accompanying more rapid degradation [88, 89 and 90].

The mechanical degradation of polymer solutions has been discussed in a number of reports [91]. Mechanical degradation of polymer is a process the mechanical action in the polymer chain (due to flows forces) exceeds the chemical activation energy in the polymer chain and bond rupture occurs. In the numerous investigations some of the results are in conflict. Apparently, the polymer scissions tend to occur around the chain midpoint.

The mechanism for degradation is beginning to be understood [92]. There exists an enormous amount of degradation literature [91, 93]. These studies attempt to relate molecular properties with time-dependent friction losses of flow systems. Additional theoretical studies are needed to eliminate degradation effects as constrain to polymer usage for drag reduction applications.

The enzymatic degradation of natural water-soluble polymers has recently been investigated using guar galactomannan as a surrogate. This study helps to predict guar gum solution viscosity. A unique correlation was developed between molecular weight, viscosity and degradation time. Degradation is also related to polymer extensional flow behavior [94].

2.7 Factors Affecting the Degradation

2.7.1 Solvent Type

The type of solvent used to dissolve the polymer is important in degradation kinetics. The degree of mechanical degradation has been reported to be higher in poor solvents than those in good solvents [95]. In a good solvent, the polymer chain prefers interactions with the solvent to those with other polymer molecules, thus it extends in solution to maximum solvent polymer interaction. In poor solvents, the polymer chain coils upon itself to minimize solvent-polymer interaction. Since polymers remain more tightly coiled in poor solvents, the subsequence degradation under shear stress is lower than that for polymers in good solvents.

Kim, et al. [96] demonstrated the above phenomenon by examining the degradation of polystyrene dissolved in benzene, chloroform and toluene, with benzene being the best solvent and toluene being the worst. Figure 2-11, shows that polymeric degradation which is much smaller for benzene than for toluene, as indicated by molecular weight measurements. Both chloroform and toluene show intermediate degradation.

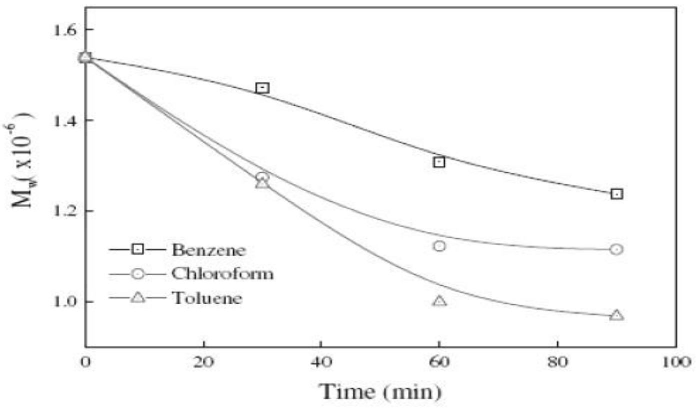

Figure 2-11: change in molecular weight of polystyrene dissolved in various solvents undergoing shear stress as a function of time [96].

2.7.2 Mechanical Configuration

Pipes configuration varies from straight line to inclined line and/or right angle and others. The best shape to reduce the degradation of high molecular weight polymer is the straight line shape. Therefore the pipeline operating system prefers this shape through the pipelining, unless the geography of the area obliges them to use other shapes. Figure 2-12 illustrates the effectiveness of mechanical configuration on drag reduction [97].

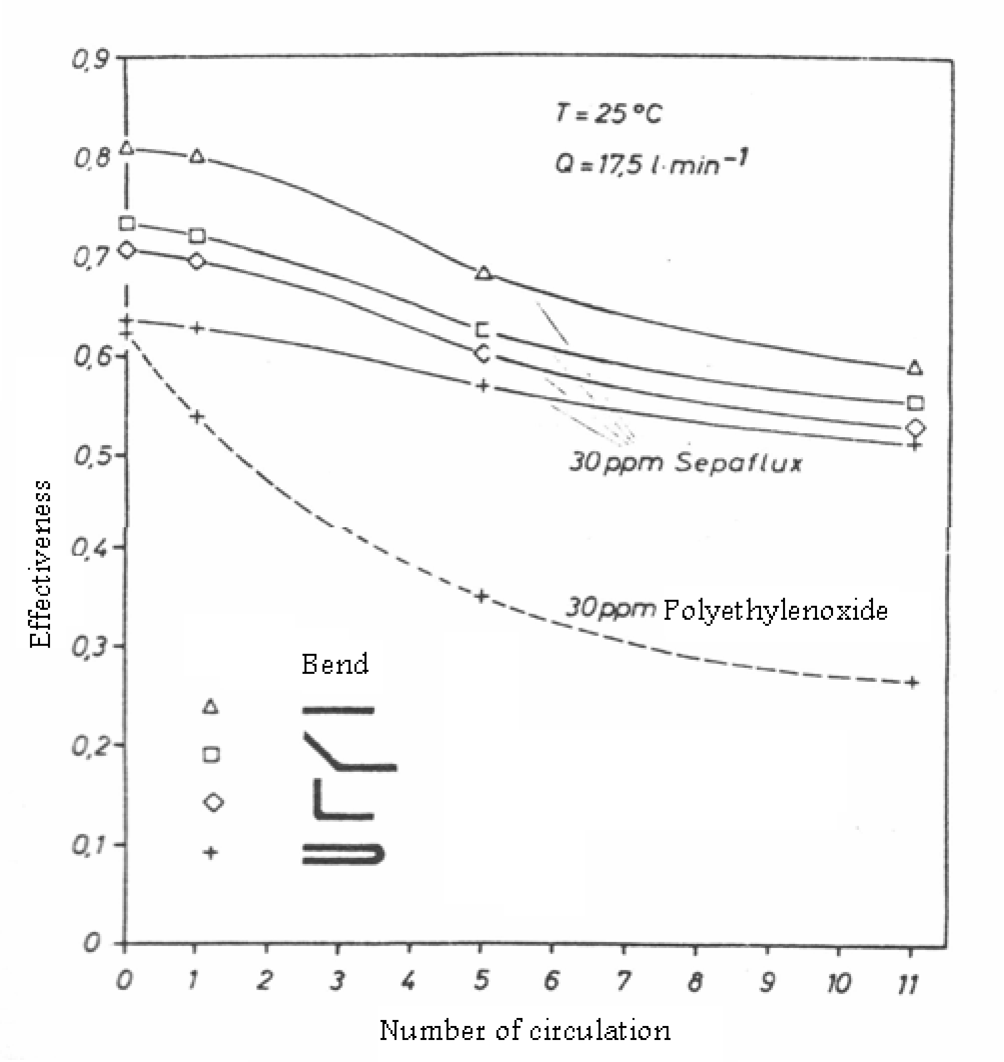

Figure 2-12: Effect of mechanical configuration of polymeric additive effectiveness [97]

2.7.3 Thermal and Radiation

The effect of the thermal degradation on turbulent drag reduction efficiency was studied, for water soluble polyethylene oxide (PEO) with two different molecular weights. It was found that the susceptibility of PEO to degradation increases dramatically with increasing temperature. Figure 2-13 shows the effect of temperature on percent drag reduction, (%DR) examined with 50 ppm PEO at three different temperatures (25؛C, 40؛C, 60؛C). The initial drag reduction efficiency value was 29.39% at 25؛C, 26.7% at 40؛C and 25.3% 60

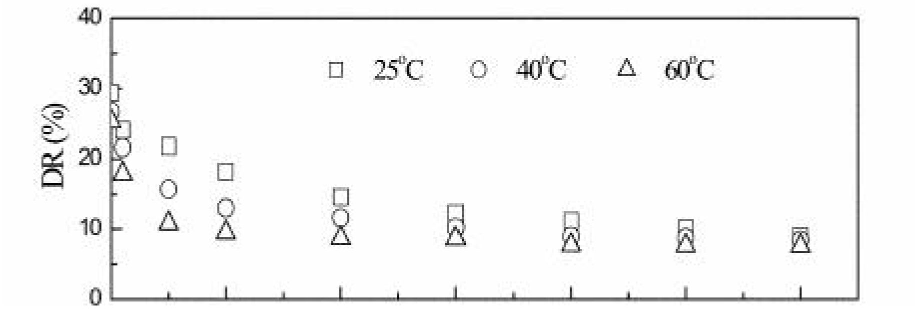

Figure 2-13: effect of temperature on %DR [98].

The same effect had been obtained by Kim [99] in his experimental investigation for PEO (344) at different temperatures, and was found that the %DR of the PEO solution decreases with temperature increase. Radiation had been demonstrated through an experiment. Samples of guar gum solution left for three days, out of strong light, gave the same results as samples tested with 1hr of mixing, but a sample which had been exposed to sunlight over a period of 3 days showed considerable degradation Evidently, the sun light has some action on the guar gum molecules, either a direct photochemical one, or by promoting bacterial action [100].

2.7.4 Aging

All materials are subjected to aging, process of long-term degradation, but not at the same rate or affected on the same manner. The wide variation in susceptibility (or resistance) of polymers to degradation by aging, depends on their chemical composition and structure. Many investigators have studied this field, but recently Jovanovich et al. [101] prepared a solution of 10 wppm of a FORTUM polymer, mixed with diesel. As shown in figure 2-14 drag reduction decreased fast within the first 2 hours. With an additional of 10 wppm polymer a maximum drag reduction percent, (%DR) of 70 % could be observed. The effect had completely vanished after continuous operation for 7.5% hour. The highest value of percent drag reduction, (%DR) with a 5 wppm polymer concentration was around 50%. For this concentration of polymer, the effect had disappeared 4 hour after the beginning of the measurement.

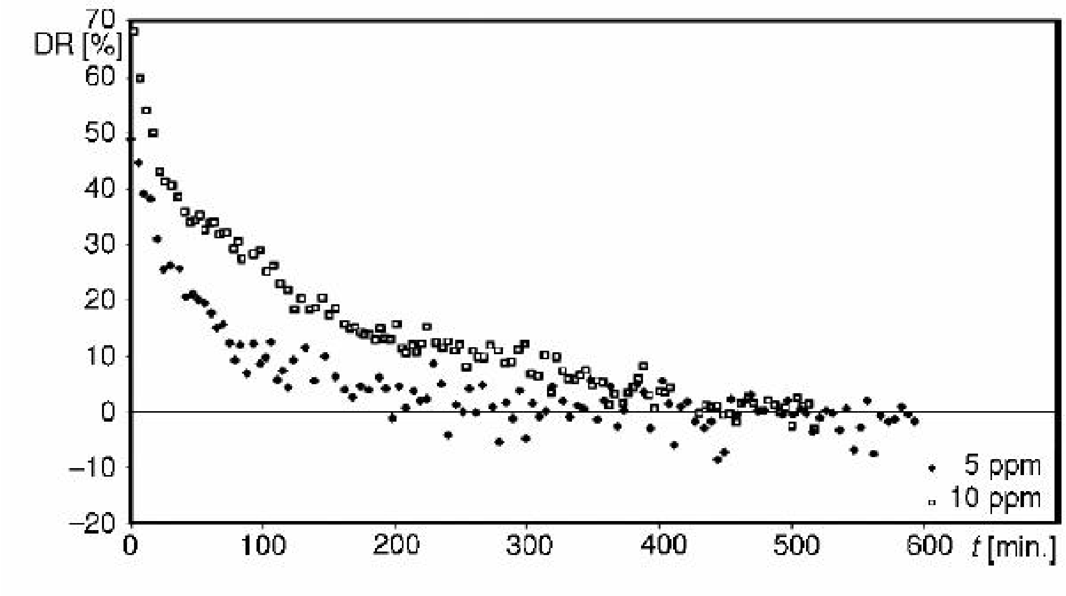

Figure 2-14: DR for different concentration of FORTUM polymer [101].

2.7.5 Types of Pump

There are many types of the pumps that used to transport the liquids in the pipes and that found for every type of this pump advantages and disadvantages and the pumps can be divided in to two types;

As volute pump in this kind the liquid enter in near of the high speed impeller and pushed to the out side toward the radios of the shall that expanded gradually, it conceder a low cost and operate for long time and used to transport the low viscosity liquids where its effected on changing in the viscosity that lead to lowering in the pressure gradient.

That can be subdivided in to two kinds rotary and vibrated, these types of pumps used to avoid the mechanical degradation of the polymer which causes the loss of drag reduction effectiveness during use. The rotary positive displacement pump (gear pump), this pump consist from two gear wheels operate inside a casing, one of the gear wheels is driven and the other rotates in mesh with it. The liquid is carried round in the space between consecutive teeth and the casing and is then ejected as the teeth come in to mesh Figure 2.15 .and the vibrated positive displacement pump that used to injected the solution of the additives to the crude oil where it's no affected by the stresses. The positive displacement pump will handle liquids of very high viscosities [102].

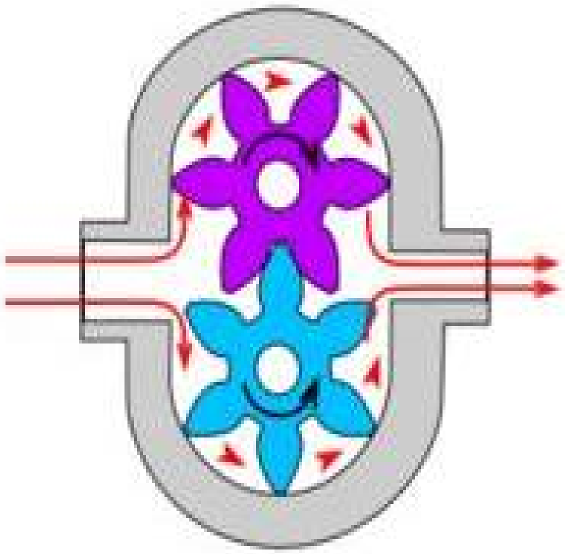

Figure 2-15: Gear pump [102].

2.8 Literature Review

The drag reduction additive in single-phase flow is well documented phenomenon. The publications on this field are quite large. Therefore, the drag reduction and degradation characteristic of polymeric additives under single-phase liquid flow conditions will be reviewed in many investigations briefly. While, there are quite little work were done concerning the drag reduction in multi-phase flow. The most available published works in two-phase (gas-liquid) flow with polymeric additives dissolved in liquid-phase will be here reviewed, in present study. The purpose of this literature review is to summarize the previous work related to the present study. The drag reduction characteristics of polymeric additives under two-phase flow (gas-liquid) systems will be reviewed briefly since many recent and excellent reviews are available. Furthermore, some works on effect of micro-bubbles as well as polymeric degradation are also considered in this chapter.

2.8.1 Two-Phase (Gas-Liquid) System

Rosehart, et.al. [103] investigated the measurements of the void fraction, slug velocity and slug frequency for slug flow of highly viscous non-Newtonian fluids (aqueous polymers solutions) and air at low pressure. The experimental work was performed in a horizontal plastic pipe 2.54cm diameter and 10.67m length. The polymers used were CMC 7H3S, Carbopl 941, and Polyhall 295. A broad range of polymer concentrations was studied and each of the solutions highly viscous and non-Newtonian. The primary purpose of the work was to investigate the effects of liquid phase non-Newtonian characteristics on the behavior of gas-liquid slug flow. The average slug velocities and the liquid slug frequencies were determined visually. The void fraction measurements were made with a specially constructed electrically resonating void fraction meter operating in a capacitive mode.

AL-Sarkhi and Hanratty [104] studied the effect of drag-reducing polymers on annular gas-liquid flow in a horizontal pipe. Measurements of drag reduction were presented for air and water flowing in a horizontal 0.0953m pipe. The fluids had an annular configuration. The injection of polymer solution produced drag reductions of about 48% with concentrations of only 10ppm to 15ppm in the liquid. The effectiveness of the drag reducing polymer was sensitive to the method of injection and the concentration of the polymer solution that was injected.

Soleimani, et.al. [105] described the effect of drag reducing polymers on pseudo-slug interfacial and transition drag to slug flow. Drag reducing polymers were added to air and water flowing in a stratified configuration in a horizontal 2.54 cm pipe. The interface was covered with large amplitude roll waves that have been called pseudo-slug, over a range of flow conditions. The damping of small wave length waves causes a large decrease in the interfacial stress and therefore an increase in the liquid hold up. At superficial gas velocities greater than 4m/s the transition to slug flow is delayed in that it occurs at large liquid holdups. The pressure drop can increase or decrease when polymers are added. The increase in hold up is accompanied by an increase in gas velocity, which causes an increase in the pressure drop. The decrease in the interfacial stress has the opposite effect.

Nieuwenhuys [106] investigated the effect of drag reducing polymers on a vertical multiphase flow. The objective was to reduce the frictional pressure drop in oil and gas wells. The pressure drop in a vertical flow is due to hydrostatic and frictional effects. A vertical Perspex pipe with a length of 18m and diameter of 72mm was used at first. In this set-up the pressure drop was dominated by the hydrostatic head due to low flow rates. The Multiphase Pug and Pay Gas-Lift (MPPGL) set up were constructed during this investigation to test vertical multiphase drag reduction for flows where frictional pressure drop dominates. The set-up consists of a vertical Perspex pipe with a length of 3m and diameter of 40mm, high flow rates were obtained with mixture Reynolds numbers up to 500000. The flow patterns during the experiments were bubbly and slug flow. Thus it has been found that polymers have a negative effect on the hydrostatic pressure drop. The effect of the polymers on the frictional pressure drop remains unknown and should be subject to further investigation.

2.8.2 Microbubbles

It is well known that when a gas injected into the near-wall region of a liquid, turbulent boundary layer, produces skin, friction reductions as much as 40—50%[75]. Practical application of these techniques has hinged on decreasing the amount of injectant required to produce a given level of drag reduction. Micro bubble drag reduction may prove to be the more accessible of the two for ship applications; it avoids the issues of on-board storage and (more importantly) mixing. In general, microbubble drag reduction depends on the coupled interaction among the flow (Turbulence) and bubble characteristics (size, concentration, location, and, dynamics such as deformation, splitting, and coalescence). In some instances, buoyancy may also play an important role. It is not surprising then, that most of the work reported over the last 30 years has been experimental. Some promising computational work hits recently appeared [107], although many aspects of the bubble dynamics have yet to be captured.

Merkle and Deutsch [108] indicated that the size of the bubbles was clearly a parameter of importance. The diameters of the bubbles affect their trajectories and thus their concentration and location in the boundary layer. Measurements of bubble sizes indicate that the bubble size decreases when free stream speed was increased and increases when airflow rate is increased, but appears to show a little dependence on the injection procedure. The bubble sizes in a micro bubble cloud are subject to any of three competing mechanisms: the initial formation at the wall; bubble splitting by turbulence action and bubble coalescence upon collision. The most significant characteristic of the bubble sizes was their diameter in comparison to the boundary layer scales.

Dentsh, et.al.[109] described the micro bubble, drag reduction in rough walled turbulent boundary layers. Experiments were conducted in 12inch diameter tunnel at the Applied Research Laboratory, Pennsylvania state university using the tunnel wall boundary layer to determine the influence of surface roughness on micro bubble drag reduction. To accomplish this, carbon dioxide was injected through a slot at rates of $0.001m^3/s$ to $0.011m^3/s$ and resulting skin friction drag measured on a 317.5mm long by 152.4mm span balance. In addition to the hydro-dynamically smooth balance plate, additional plates were covered with roughly 75,150 and 300 micron grits. Over the speed range tested of 7.6m/s, 10.7m/s and 13.7m/s, the roughness ranged from smooth to fully rough. Comparison against results of a polymer drag reduction experiment using the same facility is made. Finally a measure of the expected persistence of the phenomena is given.

Murai, et.al.[110] studied the mechanism of frictional drag reduction using bubbles in three different cases. According to a series of turbulent channel flow experiments, they obtained the following conclusions:

1. Large bubbles reduce the wall friction if a large void fraction is provided in the flow. To the contrary, a bubble which has about the channel half height in diameter generates the largest wall shear stress.
2. The local wall shear stress is reduced in the near part of individual bubbles in the case of large bubbles.
3. There is a significant correlation for the three terms of two-phase turbulent shear stress.
4. Micro bubbles less than 0.1mm in average diameter undoubtedly reduce the drag and its sensitivity reaches up to 10^{-3}.

2.8.3 Degradation

Choi and Kasza [111] studied experimentally the long-term degradation behavior of 200wppm polyacrylamide solution in a closed re-circulatory flow loop at temperatures of 7.2, 25 and 87.8°C. The degradation behavior was found to be strongly dependent on temperature. The results indicate that, with flow shear similar to that encountered in particle district heating and cooling pipe flow, polyacrylamide solutions are highly effective friction reduction agents and have a reasonable lifetime at a water temperature of 7.2 ° C.

Kim, et.al.[112] presented the degradation of high molecular weight polystyrene under turbulent flow using a rotating disk apparatus for three different solvent systems at a maximum polymer concentration of 150ppm by weight. The drag reduction efficiency decreases with time due to the mechanical degradation of polymer molecules, and extent of the degradation was found to be a function of the solubility parameter of the solvents. A theoretical model for molecular degradation provides excellent agreement with our experimental data.

Sung, et.al.[113] described the turbulent drag reduction efficiency of water soluble polyethylene oxide (PEO) with two different molecular weights as a function of polymer concentration and temperature in turbulent flow produced via a rotating disk system. The mechanical degradation behavior was a function of time in a turbulent flow and is they used in their both a simple exponential decay function and a fractional exponential decay equation. The fractional exponential decay equation was found to fit the experimental data better than the simple exponential decay function. Its thermal degradation further exhibited that the susceptibility of (PEO) to degradation increases dramatically with increasing temperature.

Brazin, et.al.[114] studied the better characterized effect of pipeline diameter on polymer degradation on a laboratory scale, add polyethylene oxide of molecular weight 8×10^6g/mol to water in turbulent pipe flow and compare the extent of drag reduction and polymer degradation between 2 and 4inch ID pipes. Assess drag reduction by measuring pressure drops over various regions of the pipe and thereby calculate reductions in the wall shear stress.

CHAPTER THREE
Experimental Work

3.1 Preparation of Polymer Solution

The water soluble xanthan gum polymer (XG) of a molecular weight of 5×10^6 g/mol was used as drag-reducing agent. It was supplied from local market in Baghdad. Tap water was used for dissolving of XG polymer and for investigating its drag reduction effectiveness.

The dissolving of XG was carried out in a shaking machine at temperature of 30°C very carefully .The shaker has a rotation motor with a power of 1.5 KW and 1500 rpm. These conditions were used to avoid any polymer molecular degradation, since the stirring device has no blade or sharp edge that could expose the polymer to high shear force.

A concentration of 1% by weight of solution in a separate container was prepared. Thus, 20 grams of XG was placed in two-litter conical flask and mixed with 2000 grams tap water. The container was placed in the electrical shaker. A homogenous solution was obtained in about one day shaking. The solution was allowed to stand about 24 hour prior to further investigation.

The desired polymer concentration for drag reduction investigations is obtained by mixing the mother solution with the water in the reservoir according to the following equations [30].

$$\begin{pmatrix}\text{Quantity added}\\ \text{from mother solution}\end{pmatrix}=\left(\frac{\text{Fluid mass in the tank}\times\text{Desired concentration}}{\text{Concentration of mother solution}}\right)\quad \text{.... (3.1)}$$

For example to obtain 25 ppm in 300 L solution (water) in the reservoir tank:

$$\frac{300000 * 0.000025}{0.01} = 750 \ \text{cm}^3$$

Hence, 750 cm^3 should be added from mother solution into 300 L water to reach 25 ppm solution.

3.2 Flow Loop

An available closed circulation loop system was re-construction to ensure studying the drag reduction performance of xanthan gum polymer, in both liquid-phase flows. The flow loop system consists from the following main parts, as shown in figure 3-4.

3.2.1 Fluid Reservoir

The water reservoir has a capacity of 1000 litters, with dimensions 1m, 0.8 m, and 1.25 m as figure 3-4, which is considered as feed tank for the solvent for the whole loop-the reservoir is made of carbon steel. The inside wall of the tank was painted to a void any affects of tap water on this material. The temperature of the fluid in the reservoir was measured by a thermometer.

3.2.2 External Gear Pump

The pump was selected from company certified ISO Gool Pompetravaini (type: PMPATIPO). This pump has a maximum capacity of 10

m^3/hr. A motor from ASINCRONG-IEC (type: FELM) 3-phase and 1500 rpm drive the pump. This type of pump was used to avoid polymer mechanical degradation which reduced the drag-reducing capability.

3.2.3 Liquid Flow Meter

To record the liquid flow rate a standard water flow meter was used Rotameter type 0422-31-7368 of a range of 20 – 200 L/min water at 20°C. The liquid flow meter was calibrated by measuring actual flow rate using stopwatch and volumetric flask at each point of interest allowing a calibration curve represented in figure 2 in appendix B.

3.2.4 Air Compressor

Air was used as the gas phase which has physical properties as listed in table 3-1. The air was provided using a compressor followed by an accumulator tank in order to have a steady flow of air during the run. The compressor was designed from company Ingersoll-Rand type (WELDED AIR RECIVER-BS 5169 IIIE). This compressor is a positive displacement machine, where air pressure is increased by reducing the size of the space that contains the air. Reciprocating compressors resemble small automotive engines and have a crankshaft, a connecting rod and piston, a cylinder and a valve head. In operation, air flows into the cylinder where the piston compresses discharges it. The small engine is driven by motor type (HOLEC HH) with power at 2.2Kw and 2820rpm. The compressor has a 150 L/sec maximum flow rate, 16.5bar maximum pressure and operates at 10 to 120^{o}C. The compressor is shown in figure 3-4.

The experimental equipment used in the two-phase feasibility study is shown in figure 3-4. The air supply was provided by compressor and was stored in tank 150 L/sec capacity maintained at 11bar.

Table (3-1) Physical properties of air

Specific gravity	1.0
Specific weight at 25^{o}C and 1.013 bar	1.1847 kg/m^{3}
Hydrostatic pressure gradient	1.01325bar
Average Molecular weight	28.96
Viscosity 25 ^{o}C and 1.013 bar	0.894*10^{-3} kg/m.s

3.2.5 Rotameter

A standard air flow meter was used to record the air flow meter range 0.3 – 33.0 L/min of air at 20 ̊C and 1 atm its kind universal 77-3626 Levego". The gas flow meter was calibrated by measuring pressure difference through the orifice and then calculates the velocity before and after the orifice figure 1 in appendix B represents the gas flow meter calibration.

3.2.6 Mixing Device

Many of researches that deals with the two phase flow found problems in the point of mixing of the two phase due to the kind of mixing, mixing zone determined and the different of the pressures of the phases. Diyaiy [115] used a U shape of 0.2 m long. The liquid and gas flow smoothly and separately to be mixed with each other at the end of U shape in a horizontal pipe of 0.25 m long with inside diameter of 0.024 m (with total length of 0.45 m) this section was located before the test section , as shown in figure 3-3.

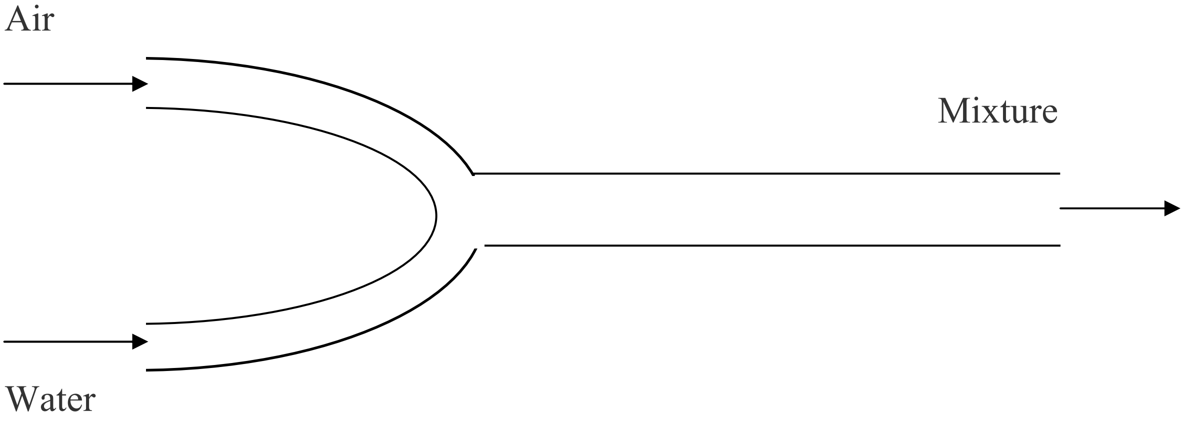

Figure 3-1: Mixing device [114]

At the beginning of the work the air enter with sudden enlargement and 15° angle with horizontal to make a good mixing between the two phases (water ,air) All tubing following the mixing cylinder are 76mm inlet diameter, made of stainless steel and was mounted in the same horizontal plane. The mixing reservoir is located upstream the test section of all pipes diameter [116].

But after many experiments and by looking to the flow through the Perspex pipe the babble flow wasn't happened because at this point was changed. The air entered to the flow system before the liquid pump and calculates the effect of the air flow on water flow meter and treated with this effect. After this change the babble flow was happened and noticed it through the Perspex section from the test section.

3.2.7 Pipes

A galvanized pipe of 0.032 m (1.25 inch) inside diameter and 6 m length was used to perform the flow measurements. A piece of Perspex tube of 1.2 m length was used to recognize the type of flow. The perspex tube was located after 2 m of the entrance length, and it was considered as the test section

3.2.8 Test Section

The boundary layer forms in the inlet of the pipe and grows in thickness until it fills the flow area, or until it extends to the center of the pipe .The velocity profile will not change down stream from this point and the flow is said to be fully developed. The distance down stream from the pipe entrance to point where the flow becomes fully developed is called the entrance length.

The Desissler eq. was used to determine the entrance length, which was about 1.53 m.

The Desissler equation $Le = 50 \times d$ …………………………… (3.2)

Where Le= the entrance length in meter.

d= the diameter of the pipe in meter.

The test section is 1.2 m long and it's placed after 2 m from starting point, which is away from the entrance according the pipe diameter.

3.2.9 Accessories

1. U tube manometer was used to measure the pressure drop between the two points of test section. The U- tube manometer was filled with mercury and has ringed up to 300 mm Hg.

2. A regulator valve was used at outlet of the compressor to control the flow rate of air into the pipeline. It consists of two pressure gauges with maximum inlet pressure and outlet pressure of 150 bars and 16 bar respectively, it was delivered by S.A. White Martins.

3. Orifice a standard designed orifice was used to calibrate the gas flow meter. It is located in the half of the straight pipe due the recommended installation for concentric, thin-plate orifice. It has an inlet diameter of 14 mm and outlet diameter of 45 mm.

4. Three standard sets of pressure tap locations were used as follows:

Both pressure taps are installed in the flanges. The inlet pressure tap is located one pipe diameter upstream and the outlet pressure tap is located one-half diameter downstream of the orifice as measured from the upstream face of the orifice as shown in figure 3-5. The orifice was designed by Abeed [116], assuming the airflow is incompressible fluid and after applying Bernoulli's equation for two points, to get the theoretical discharge from orifice reported by Holman [117] as:

$$Q_{theory} = U_2 A_2 = \frac{A_2}{\sqrt{1 - \frac{A_2}{A_1}}} \sqrt{\frac{2(\Delta P)_g}{\rho_g}} \qquad \text{…. (3.3)}$$

The discharge is a function of several variables (A, P andρ) and may be calculated after derivative discharge and each subject to an uncertainty. Then, the uncertainty in the discharge measurement is (±2.3 percent)

5. **Air filter** was used to obtain clean air with low humidity. Therefore, it was put in the exit of compressor as shown in figure 3-4. The used filter is type (NORGREN) with maximum pressure 10bar and maximum temperature 50^{o}C.

3.3 Experimental Procedure

The drag-reducing ability of additive under turbulent flow conditions were evaluated by measuring the pressure flow rate relationship when the test fluid was forced to flow in the circulation flow system. The experiments were carried out in pipes with nominal diameters of 1.25 inch. The polymer solutions tested were 0, 25, 50, 75 and 100 ppm. All runs were conducted at temperature about 30^{o}C to 40^{o}C.

The liquid reservoir was filled with 300 litters of water. The appropriate amount of the prepared XG polymer solution was added carefully into the tank. Typically 30 minutes circulation was performed before pressure drop reading to ensure homogeneous mixture. The fluid was allowed to flow through the pipe. The flow rate was maintained constant by means the corresponding valves. The experiment was stopped after obtaining a stabilized pressure drop reading. The calibration of the laboratory test loop was performed with untreated fluid prior to testing of drag reduction additives, as shown in figure 3-4.

In case of two-phase air-water system, the experimental runs were started by passing a given flow rate of water through the system to check the consistency of the pressure which were recalibrated before every run. Air at a given flow rate was then admitted to the system through the mixing device. The pressure drop measurements were done mentioned above for different flowing conditions.

The time-dependence drag-reduction experiments were evaluated by circulation the solution in flow system for different time.

3.4 Calculation

To satisfied the liquid flowing lies in turbulence region the Reynolds number should be calculated

$$\mathrm{Re}=\frac{\rho U d}{\mu} \qquad \text{……….} \ (3.4)$$

The water temperature =30˚C

$\rho = 995.607$ Kg/m^3

$\mu = 7.974*10^{-4}$ Pa.s

d = $32*10^{-3}$ m

$$\mathrm{A}=\frac{\pi * d^2}{4}=8.04*10^{-4}\ \mathrm{m}^2$$

$$\mathrm{U}=\frac{\dot{m}}{A}=\frac{m^3/s}{m^2}=\frac{m}{s}$$

Table (3-2): Liquid flow rates and its corresponding velocities and Reynolds numbers

Liquid flow rate L/min	Liquid velocity m/sec	Reynolds number
40	0.829	33122
60	1.24	49543
80	1.66	66324
100	2.07	82705
120	2.49	99486
140	2.90	115867
160	3.32	132648

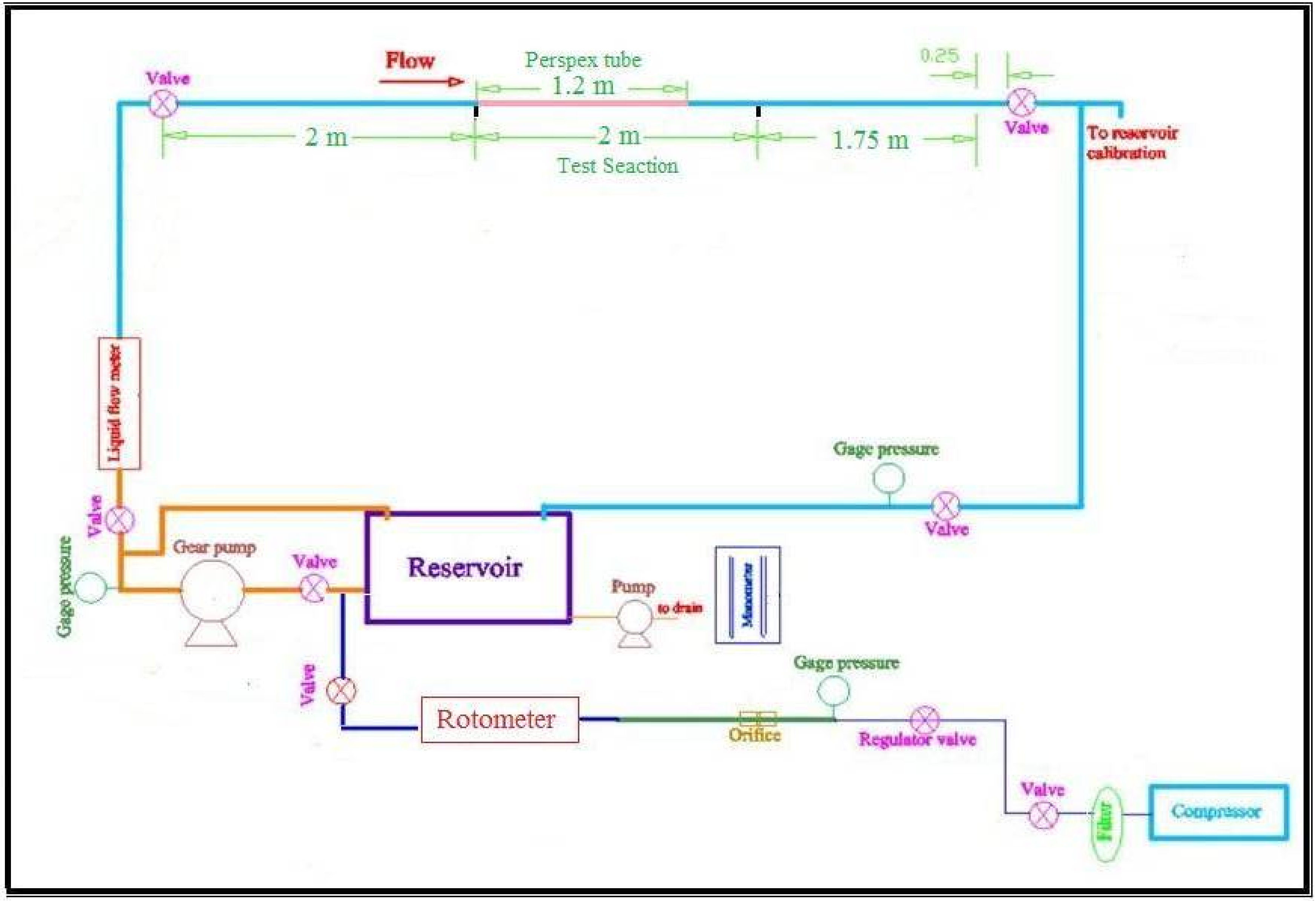

Figure (3-1) Schematic Diagram of Experimental Approach

CHAPTER FOUR
Results and Discussion

4.1 Drag-Reduction with XG Additives

The turbulent drag-reduction efficiency of xanthan gum (XG) was studied in a build-up closed loop water circulation system. The turbulent mode was produced via a gear pump to a void any mechanical degradation of polymer chain during the pumping stage, since such pump expensing low shear force on the fluid. Figure 4-1 represents the dependence of drag-reduction efficiency on polymer concentration and solution flowrate for XG additive. As can be seen in figure 4-1 the percentage drag reduction is induced by viscoelastic behavior contributions from the individual polymer concentration increases the drag reduction capability [113].

The percentage drag reduction achieved with XG additive was in the range from 2.3 to 4.9 % which is significantly low probably due to the low molecular weight of xanthan gum used [99], Deshmukh [118] have shown greater DRE and shear stability for (PAM) grafted to xanthan gum and guar gum and the low roughness of the test section (Perspex tube) [85].

Furthermore, XG as a rigid polysaccharide additive has relatively low drag reduction effectiveness compared with the flexible, linear and high molecular weight such as polyisobutylene [119].It is well-known. That the drag-reduction phenomenon works in turbulent mode [32]. Therefore, the degree of turbulence has a predominant effect on its effectiveness, as shown in figure 4-1. The results show generally, that the percentage drag reduction increases with Reynolds number increase, due to the increasing the viscoelastic polymer threads and turbulent eddies [120]. The gradual increase of the percentage drag-reduction with Reynolds number increase is clear for Re 3830-7660, while for high Reynolds numbers is not well clear, as shown in figure 4-1.

The drag reduction behavior in turbulent flow is appeared to be related with elongation straining as well as shearing force, in which these cause the breakage of main chain of the polymer by the mechanical forces. Probably, the high turbulence affects the scission of polymer chain leading to variation in drag reduction.

Percentage drag reduction, %DR is calculated by using pressure drop measurements in the test section for untreated ΔP and with polymer treated water, ΔP_s [121] as follows:

$$\%D.R = \frac{\Delta P - \Delta P_s}{\Delta P} * 100 \qquad \text{..... (4.1)}$$

The primary end-use of drag reducers is usually to increase the flowrate (through put TI) without exceeding the safe pressure limits within the flow system. TI can be estimated by equation:

$$\% TI = \left[\frac{1}{(1 - \frac{\% Dr}{100})^{0.55}} - 1 \right] * 100 \qquad \text{....................... (4-2)}$$

An increase of TI was achieved by increase the polymer concentration and Reynolds number of solution, as illustrated in figure 4-2, which shows the same behavior as that observed for percentage drag-reduction in figure 4-1.

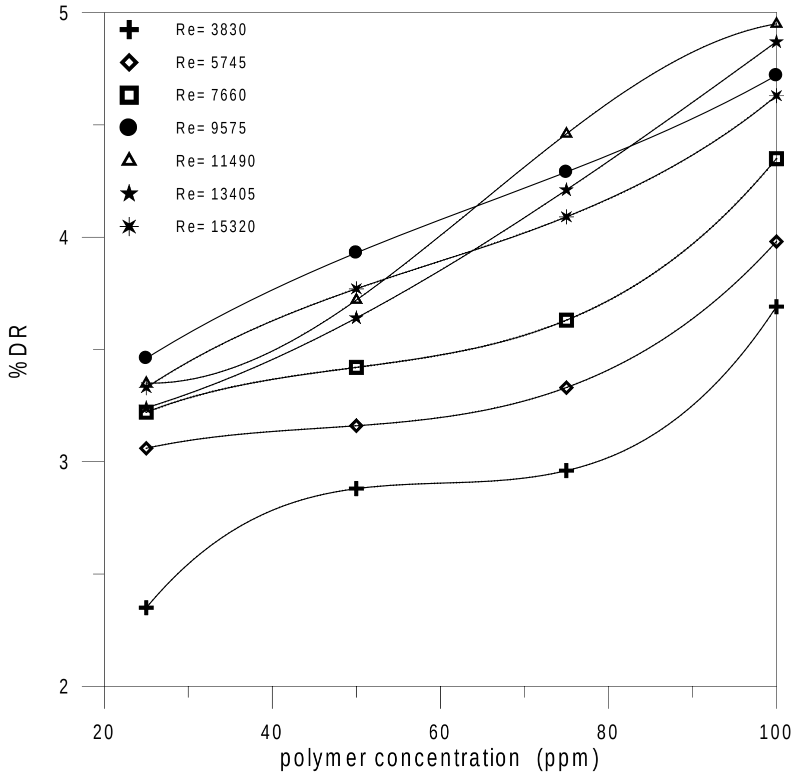

Figure 4-1: polymer conc. vs. %DR for different Re

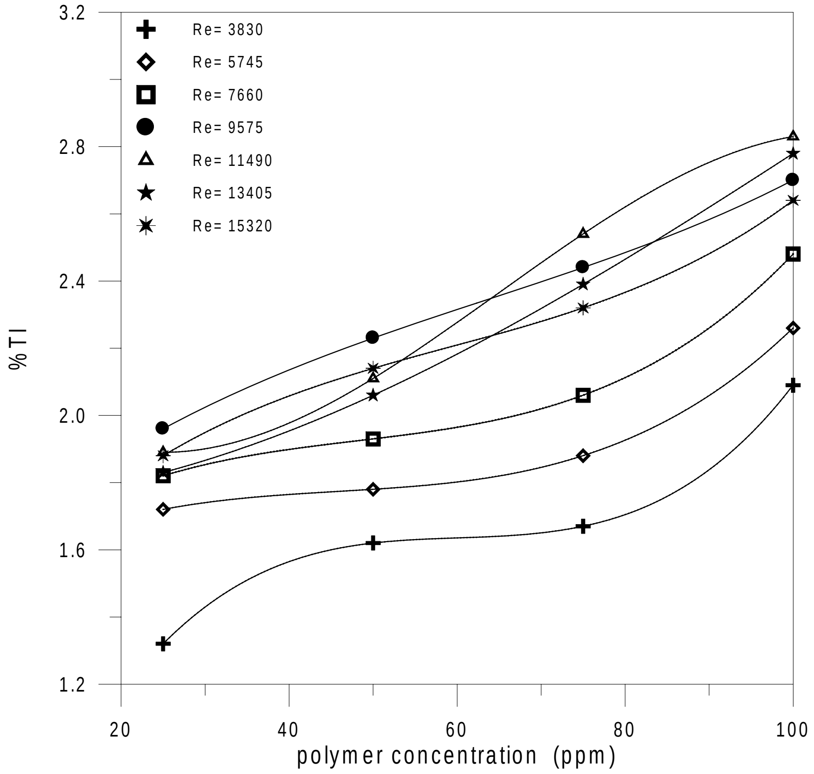

Figure 4-2: polymer conc. vs. %TI for different Re

4.2 Drag-Reduction in Presence of Air

Air was used in turbulent piping of water, in order to investigate its effect on reduction of frictional drag. Three different air flow rates, namely, 10, 15 and 20 L/min were used at different water flow rates. Figure 4-3 represents the dependence of air on percentage drag-reduction.

The results show that the presence of air acts as efficient drag-reducer agent. Thus, more than 16 % drag-reduction was achieved, without using any conventional drag-reducer agent at different liquid and air flow rates.

The presence of air in flowing water changes usually the flow to bubbly type, forming microbubbles. It is well known that the microbubbles reduce the frictional drag leading to increase the percentage drag-reduction [108, 109 and 110].

At 10 and 15 L/min air flow rates, the percentage drag-reduction increases gradually by increasing the liquid flow rate until about 100 L/min water flow rate, the maximum percentage drag-reduction values at 100 L/min liquid flow rate are 23 and 26 % for 10 and 15 L/min air flow respectively as shown in figure 4-3. At liquid flow rate above 100 L/min start the drag-reduction values to drop, due to decrease the air bubbles at high liquid flow rates.

In case of using relatively high air flow rate, such as 20 L/min, the percentages drag reduction decrease as liquid flow rate increases. These could be attributed to the fact that by increasing the liquid flow rate, the flow changed from bubbly flow to plug flow, which reduces the drag-reduction performance.

At liquid flow above 100 L/min starts the drag-reduction to increase, due to change the flow to bubbly type, which enhances the drag-reduction ability.

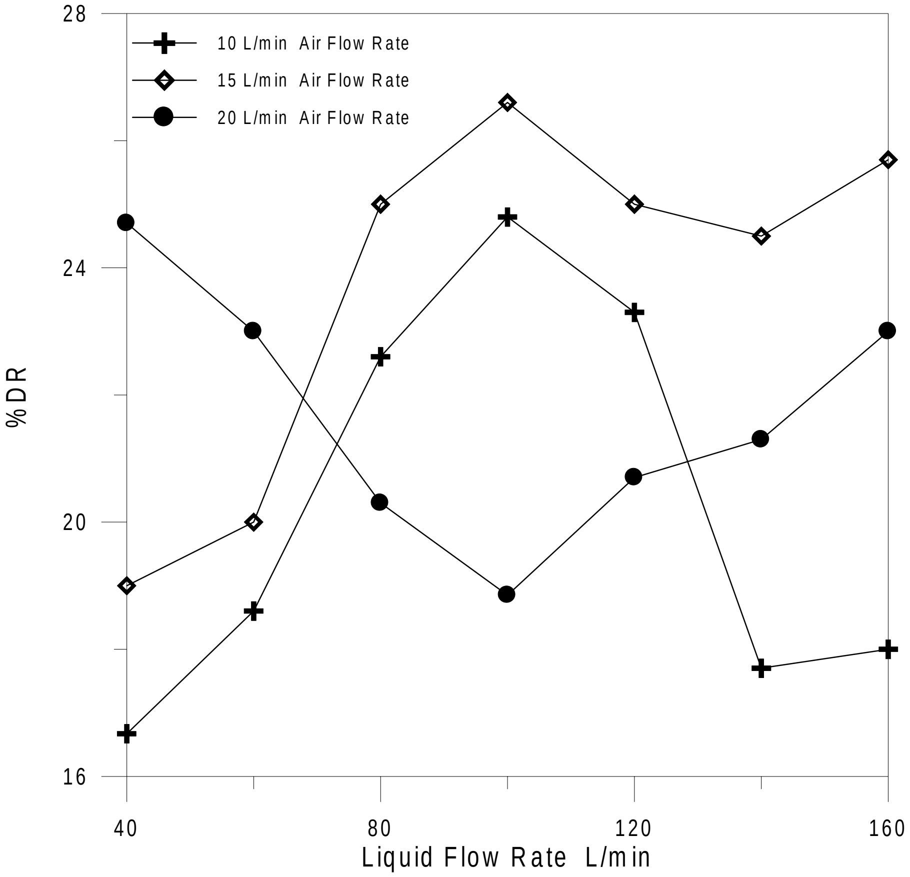

Figure 4-3: effect of air flow rate on %DR without polymer

4.3 Drag-Reduction by XG in Two-Phase Flow

4.3.1 Air Effect

The drag-reduction effectiveness of xanthan gum in two-phase water-air turbulent flow was studied in this part of the work. Three air flow rates, 10, 15 and 20 L/min were used with different water flow rates as liquid-phase. Figure 4-4 summarizes the drag-reduction results for 50 ppm additive concentration for both single and two-phase flow.

The results show that the drag-reduction in two-phase system is significantly higher than in single phase flow. The effect of air flow rate on drag-reduction performance is as it was observed previously in part 4.2. The presence of air in flowing water changes usually the flow to bubbly type, forming microbubbles. It is well known that the microbubbles reduce the frictional drag leading to increase the percentage drag-reduction [108].

Figure 4-4 show, with all selected water flow rates, the increasing air percent in water flow up to 15 % lead to increasing in drag-reduction percent. The increasing air percent more than 15 % to 20 %, this increasing would decrease drag-reduction due to changing the type of two phase flow from bubbly to plug.

The three percentage of air were used in the investigation, namely 10, 15 and 20 Vol. %, for three selected water flow rates. The presence of air in water flow causes significant increase in percentage drag-reduction for all liquid flow rates studied. The results are illustrated in figure 4-5. Those, for 160 L/min water flow rate, about 20% drag-reduction is achieved with 10% air in water flow and about 25 and 23 % drag-reductions with 15 and 20% air flow respectively.

For 100 L/min water flow rate, about 24.5% drag-reduction is achieved with 10 % air in water flow, about 26.8%drag-reduction is achieved with 15 % air in water flow, and the drag-reduction percent decrease to 18.6 % with increase the air percent in water to 20%. For 40 L/min water flow rate, about 16.8 % drag-reduction is achieved with 10 % air in water flow; about 19 and 24.6 % drag-reductions are achieved with 15 and 20 % air flow respectively.

These showed the increasing in turbulence degree (water flow rate) means increase in the drag-reduction percent with a certain limits [80, 81].

Figure 4-6, 4-7 show more details for the effect of gas flow rate with respect to liquid flow rate on percentage drag-reduction for two selected additive concentrations, 50 and 100 ppm respectively.

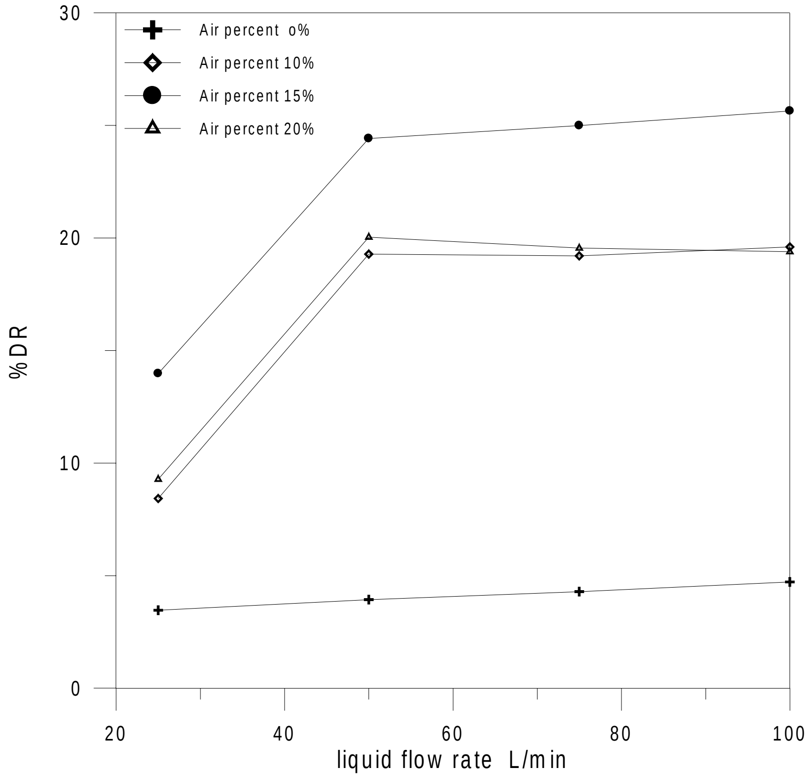

Figure 4-4: percentage drag-reduction in two-phase flow for 50 ppm XG and different air and water flow rates

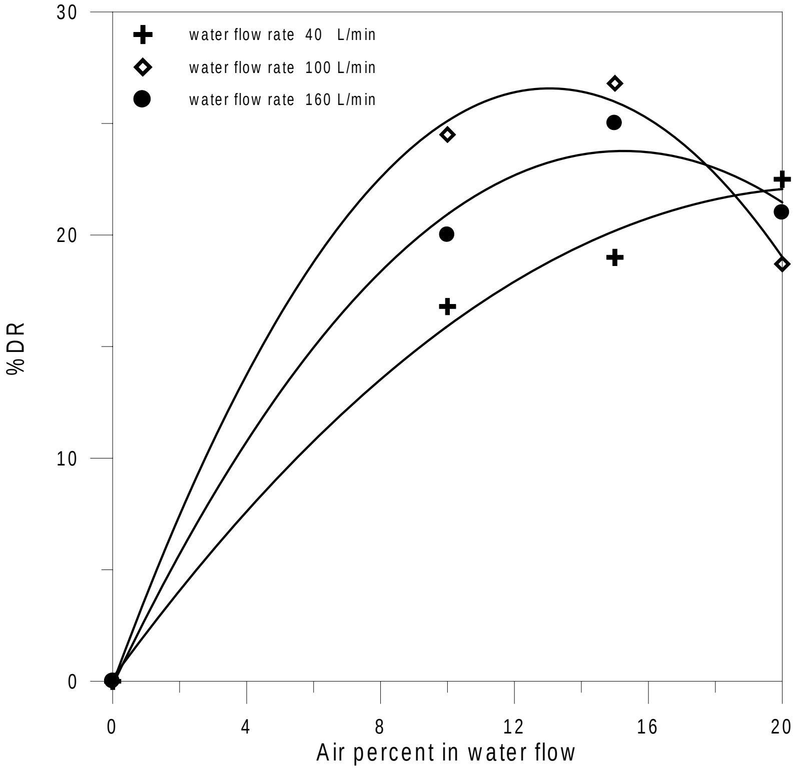

Figure 4-5: Air % in water vs. %DR for three selected water flow rates without polymer

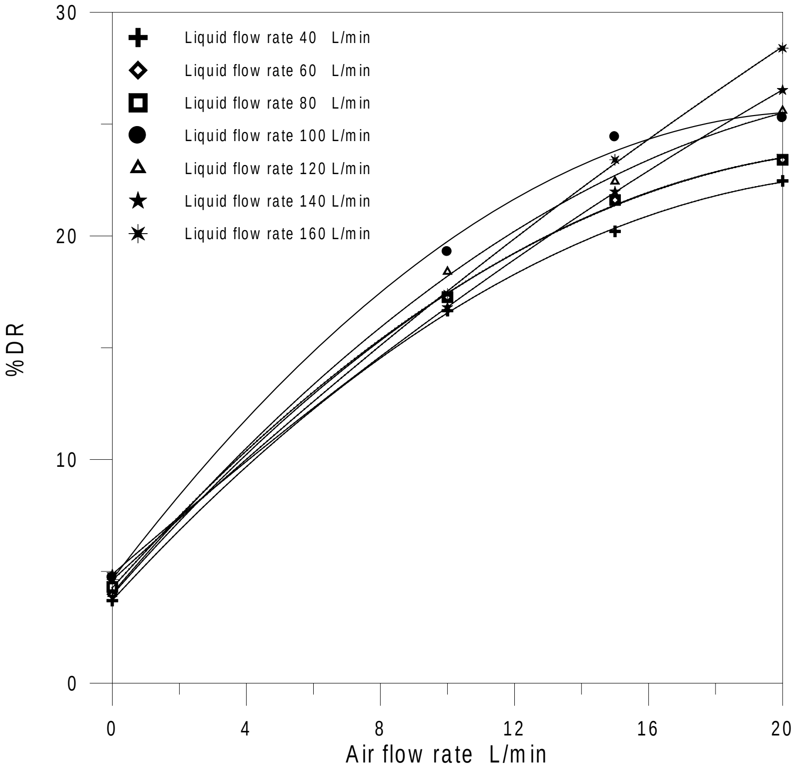

Figure 4-6: air flow vs. %DR for different liquid flow rate and 50 ppm XG

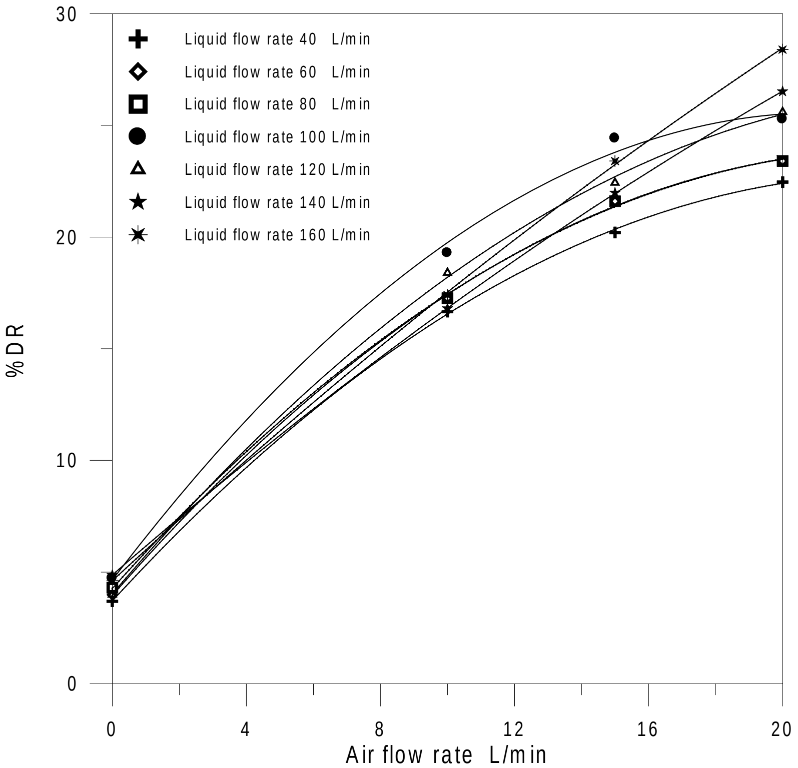

Figure 4-7: air flow rate vs. %DR for different Liquid flow rate and 100 ppm XG

4.3.2 Concentration Effect

As it was observed previously, that the drag-reduction ability of xanthan gum agent in single phase (liquid phase) is noticeable low, while the presence of micro air bubbles cause significant increase the drag-reduction in turbulent flow. Thus, the addition of xanthan gum agent to bubbly flow resulted in noticeable improves of its drag-reduction effectiveness.

Figure 4-8 through 4-11 represents the variation of percentage drag-reduction with concentration of xanthan gum additive ranging between 25 and 100 ppm in air-water flows. As it's expected a gradual increase of percentage drag-reduction is noticed, generally, by increasing the concentration within the Reynolds number studied for three gas flow rates, 10, 15 and 20 L/min, indicating a good interaction between xanthan gum agent and microbubbles as drag reducers. It is also observed that the drag-reduction values at high additive concentration, 100 ppm are about the same or little lower than the values for 80 ppm concentration. It could be concluded that 80 ppm is the best additive concentration for efficient drag-reduction with the condition applied.

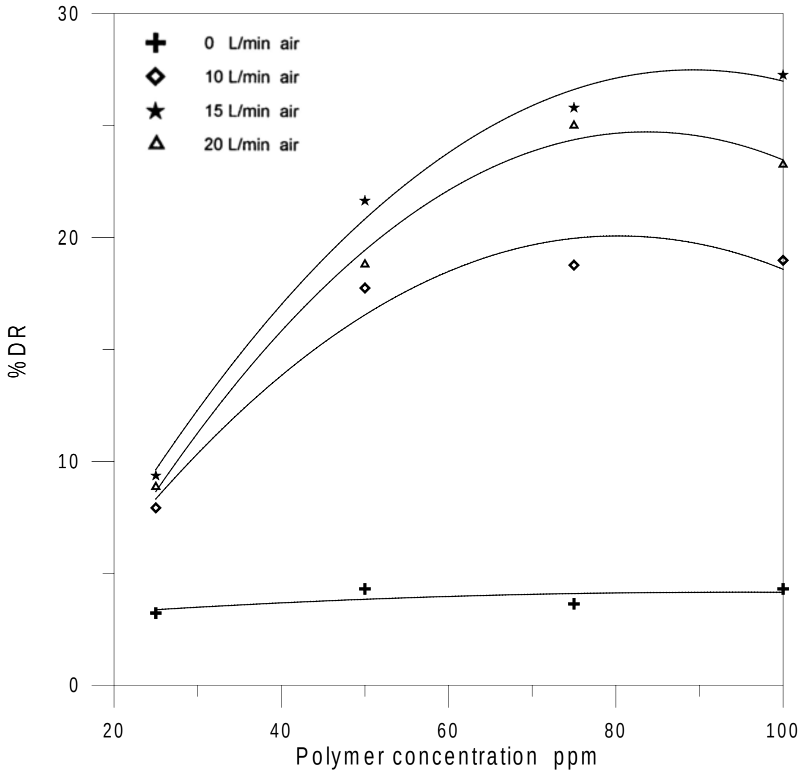

Figure 4-8: Polymer concentration vs. %DR for different air flow at liquid flow rate 80 L/min

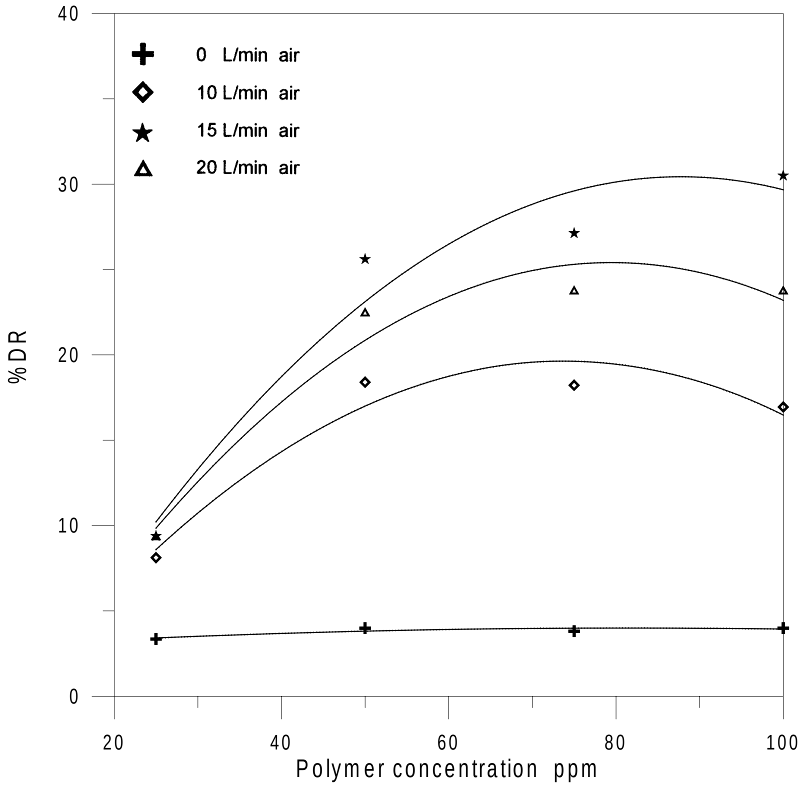

Figure 4-9: Polymer concentration vs. %DR for different air flow at liquid flow rate 120 L/min

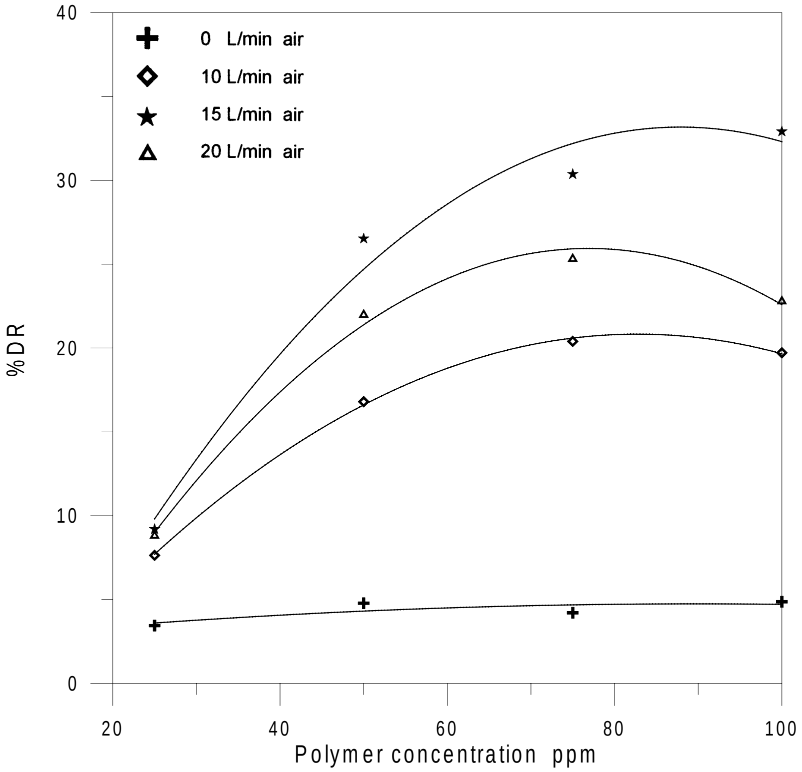

Figure 4-10: Polymer concentration vs. %DR for different air flow at liquid flow rate 140 L/min

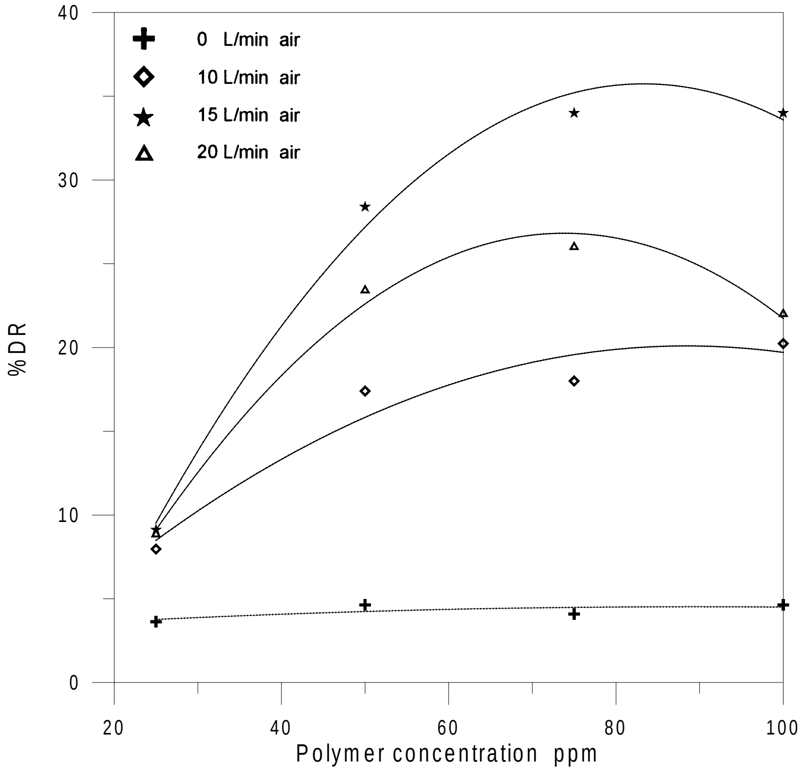

Figure 4-11: Polymer concentration vs. %DR for different air flow at liquid flow rate 160 L/min

4.3.3 Flowrate Effect

It is worthily to evaluate the percentage drag-reduction ability in two-phase flow by combination of various air-water flow rates for different xanthan gum concentrations, as illustrated in figures 4-12 through 4-15. The results show the following observation.

- The drag-reduction increase with xanthan gum concentrations, up to 75 ppm due to polymeric effect. 100 ppm additive shows lower percentage drag-reduction probably due to hindering the microbubbles, as shown in figure 4-15.
- Increases of water flow rate have a little effect on drag-reduction increase for specified additive concentration and gas flow rate. Thus, at 75 ppm XG

concentration, as an example, and at 10 L/min air flow, about 17, 18 and 20 % drag-reduction were achieved for 60, 100 and 140 L/min water flow respectively, as shown in figure 4-14. The corresponding values for 15 L/min air flow are about 19, 24 and 26 percentage drag-reduction respectively. While the percentage drag-reduction for 20 L/min air flow rate are 22, 20 and 24. All these results indicate that liquid flow rates have low effect on the performance of drag-reduction in two-phase flow, since the used liquid flow rates are within the turbulent region which is suitable to develop a bubbly flow in presence of air. Furthermore, it was observed that high air flow rate; 20 L/min resulted in lower and instable percentage drag-reduction values than by bubbly to plug flow form, as shown in figures 4-12 to 4-15.

- Finally, it can be concluded that the choice of suitable air and water flow rates in addition to additive concentration is predominant microbubbles which are efficient drag reducers.

The primary end-use of drag reducers is usually to increase the flow rate or throughput increase through put increase without exceeding the safe pressure limits within the flow system [2]. The figure 4-16 shows a noticeable increase of the throughput by increasing the air flow rate up to 15 L/min in two-phase flow system with xanthan gum additive.

The maximum %TI within the conditions studied was 18% at 75 ppm XG concentration and 15 L/min air flow rate and 160 L/min water flow rate as shown in figure 4-16.

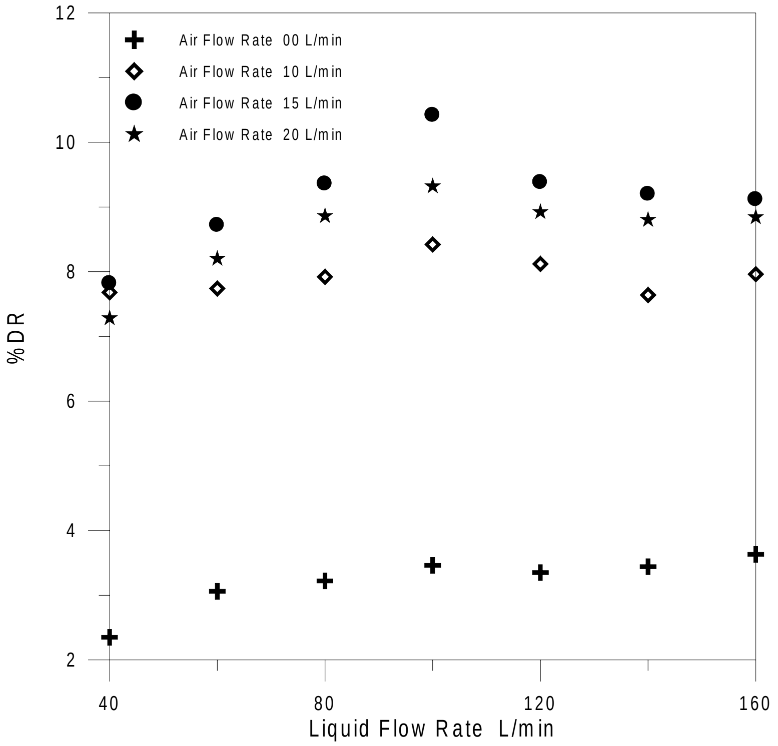

Figure 4-12: Effect of liquid flow rate on %DR of 25 ppm XG additive in two-phase flow

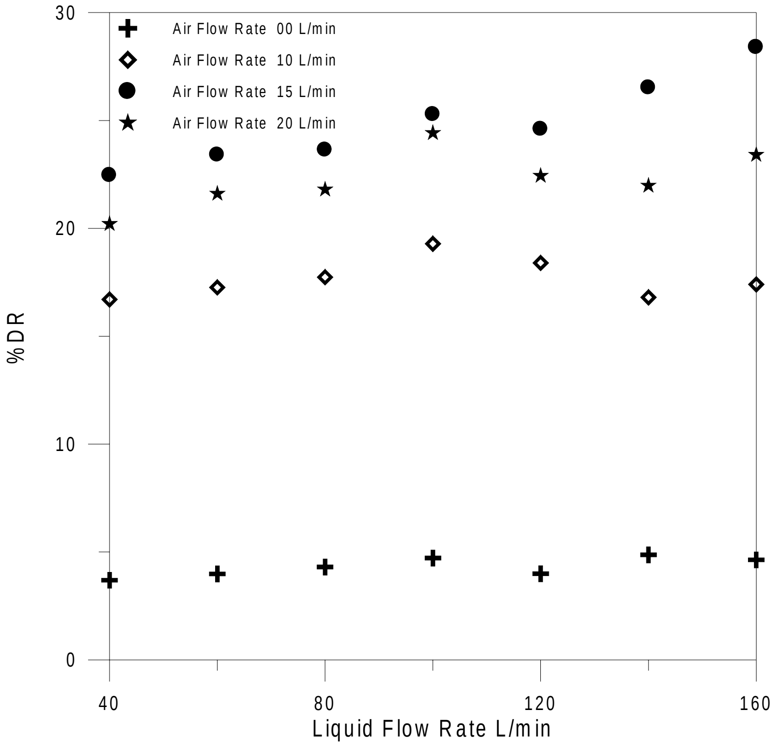

Figure 4-13: Effect of liquid flow rate on %DR of 50 ppm XG additive in two-phase flow

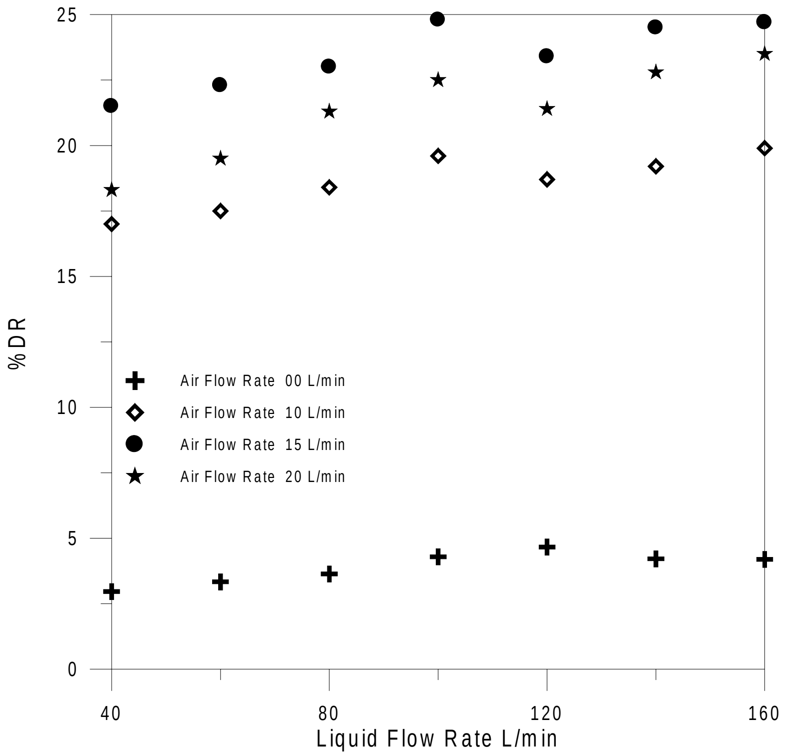

Figure 4-14: Effect of liquid flow rate on %DR of 75 ppm XG additive in two-phase flow

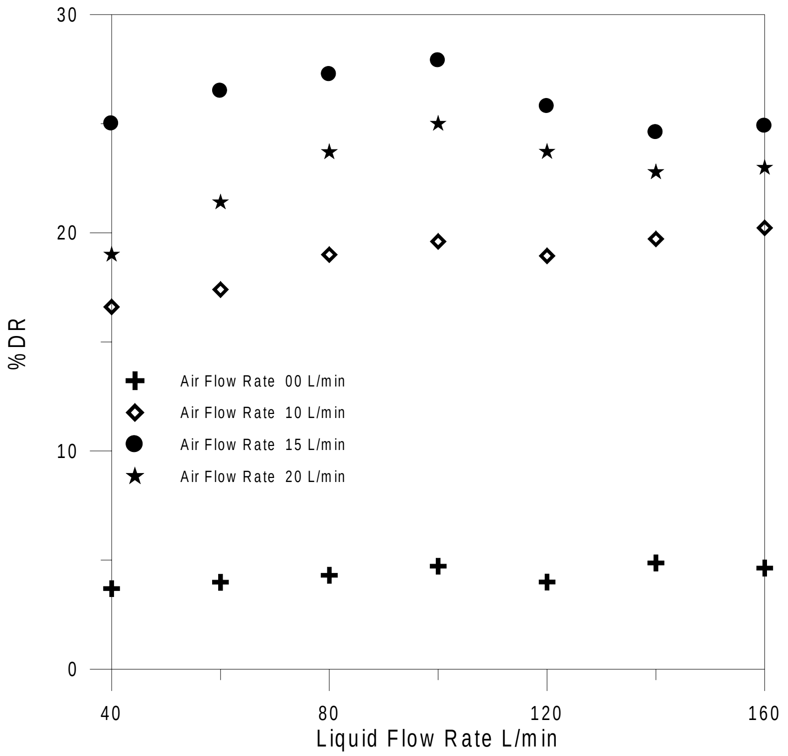

Figure 4-15: Effect of liquid flow rate on %DR of 100 ppm XG additive in two-phase flow

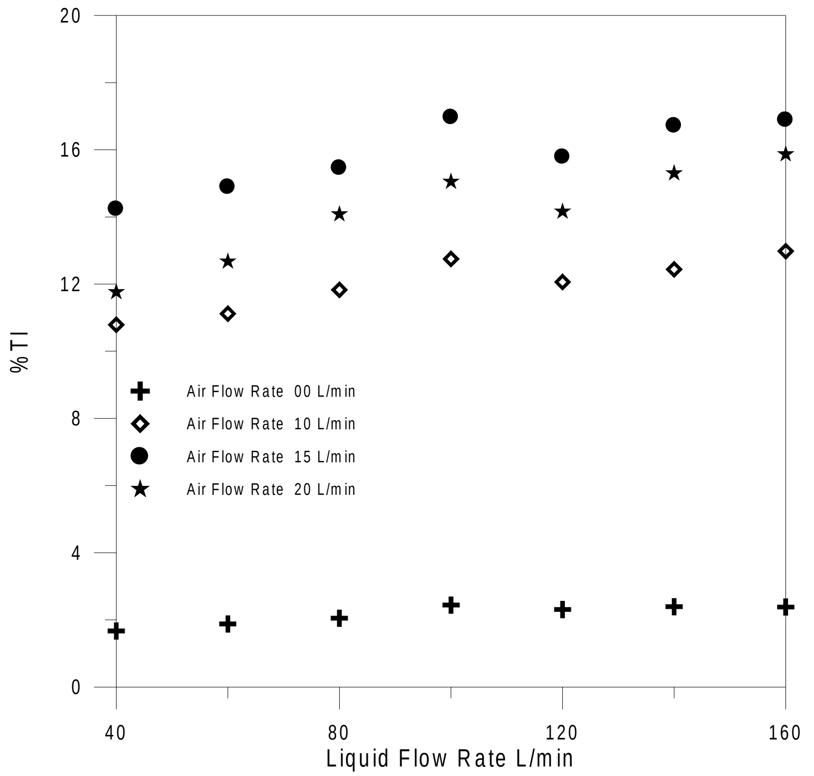

Figure 4-16: Combined effect of water and air flow rates on throughput increase in two-phase flow at 75 ppm XG concentration.

4.4 Effect of Sodium Chloride in Two-Phase Flow

It is well known that sea water as well as drainage and some times river water contain inorganic salts, mainly as sodium chloride. Therefore, it is useful to investigate the performance of xanthan gum agent with existence of sodium chloride to reduce the drag forces in two-phase, water-air turbulent flow. Salt concentrations in the range of 0.5 – 2.0 % was considered in present works, since sea water and some drainage water contain usually above 0.5 % salts.

The experimental results with saline water in two-phase flow showed different drag reduction behavior according the turbulence of flow. At low liquid flow rates, in the range of 40 -80 L/min act the presence of sodium chloride as activator for the drag reduction ability, as illustrated in figures 4-17, 4-18 and 4-19. Thus the drag-reduction increase significantly with increasing the salt contain in water, mainly at 2.0 % NaCl, as shown in table 4-1. The drag-reduction ability of salt is more efficient in high gas flow rate, 20 L/min, and low liquid flow rate, 40 L/min. Thus, the percentage drag-reduction in two phase flow without salt addition at 40 L/min liquid flow and 10 L/min air flow is about 16 % increase to 34 % with 2.0 % sodium chloride. The corresponding value at 15 L/min air flow rate is about 20 % without salt addition and reaching to 40 % in presence of 2.0 % NaCl. While drag-reduction values 20 L/min air flow are about 22 % for water without salt and 43 % in case of 2.0 % salt addition. 43 % drag-reduction is considered the highest value achieved in the present investigation.

The addition of sodium chloride to two-phase turbulent flow causes a noticeable foam formation as microbubbles, which were easy noted through the perspex tube. Therefore, the activated effect of salt on performance of drag-reduction could be attributed to the degree and size of foaming. While, with increasing the turbulent degree this effect will be damped. Furthermore, it is well known that the surfactants which usually formed foam are efficient drag-reductions [109,110].

Table 4-1: Effect of sodium chloride on %DR at 40, 60 and 80 L/min liquid flow rate and 10 L/min air flow rate for 50 ppm XG.

%NaCl	Liquid flow rate 40 L/min	Liquid flow rate 60 L/min	Liquid flow rate 80 L/min
0.0	16	17.3	17.8
0.5	16	17.3	18.2
1.0	16	17.3	18
2.0	34	24.8	22.8

Table 4-2: Effect of sodium chloride on %DR at 40, 60 and 80 L/min liquid flow rate and 15 L/min air flow rate for 50 ppm XG.

%NaCl	Liquid flow rate 40 L/min	Liquid flow rate 60 L/min	Liquid flow rate 80 L/min
0.0	20	23.8	23.5
0.5	26	24.8	24.8
1.0	33	25	26
2.0	40	35	35

Table 4-3: Effect of sodium chloride on %DR at 40, 60 and 80 L/min liquid flow rate and 20 L/min air flow rate for 50 ppm XG.

%NaCl	Liquid flow rate 40 L/min	Liquid flow rate 60 L/min	Liquid flow rate 80 L/min
0.0	22	12.3	18.8
0.5	34	22.2	19
1.0	28	23.5	20.2
2.0	43	24.8	22.8

The experimental results of drag-reduction performance in two-phase flow shown an inhibited effect for sodium chloride addition at high liquid flow rates, 100-160 L/min, as illustrated in figures 4-20 through 4-23. In other words, the drag-reduction efficiency decreases proportionally with the increase of salinity. Furthermore, drag-reduction decreases slightly with increase of liquid flow rate within the range 100-160 L/min for all studied gas flow rates.

The inhibited behavior of drag reduction in saline water could be attributed to the decrease of foam formation at high turbulence compared with lower turbulence, as it was noted through the perspex tube.

Table 4-2 summarizes the drag-reduction values, which were observed in two-phase flow without and in presence of selected concentrations of sodium chloride at different gas flow rates. As illustrated in table 4-4, the percentage drag-reduction values at 100 L/min water flow rate are about 19.4, 24.5 and 25.7 for in absent of salt, drop to about 14, 16.8 and 16 respectively in present of 2.0 % sodium chloride. The corresponding data for 160 L/min water flow rate are 17.5, 28.5 and 23 at 10, 15 and 20 L/min air flow respectively in absence of NaCl drop to about 6, 14.5 and 10 respectively by addition of 2.0 % NaCl, which indicate more inhibition at 160 L/min water flow compared with 100 L/min water flow rate.

It has been observed that the addition of small amount of sodium chloride in single liquid-phase act as inhibitor to the performance of polymeric turbulence drag-reduction [30, 122 and 123].

As polyelectrolyte molecules, xanthan gum are highly extended in low salt contained and collapses at more compact structure with the addition of sodium chloride. The change from an extended to a collapsed state as a function of solution ionic strength influences the viscosity of polymer solution [124]. Furthermore, note Rochefort and Middemann. Nada [125] conducted experiments to study the influence of salt additives on the performance of xanthan gum. They observed a similar effect in molecular configuration with solution ionic strength of XG.

Table 4-4: Effect of sodium chloride on %DR at 100, 140 and 160 L/min liquid flow rate and 10 L/min air flow rate for 50 ppm XG.

%NaCl	Liquid flow rate 100 L/min	Liquid flow rate 140 L/min	Liquid flow rate 160 L/min
0.0	19.4	16.5	17.5
0.5	17.2	13.2	13.75
1.0	16.6	12	10
2.0	14	10	6

Table 4-5: Effect of sodium chloride on %DR at 100, 140 and 160 L/min liquid flow rate and 15 L/min air flow rate for 50 ppm XG.

%NaCl	Liquid flow rate 100 L/min	Liquid flow rate 140 L/min	Liquid flow rate 160 L/min
0.0	24.5	26.5	28.5
0.5	20.2	23.8	23.5
1.0	19	19.9	18.5
2.0	16.8	15.6	14.5

Table 4-6: Effect of sodium chloride on %DR at 100, 140 and 160 L/min liquid flow rate and 20 L/min air flow rate for 50 ppm XG.

%NaCl	Liquid flow rate 100 L/min	Liquid flow rate 140 L/min	Liquid flow rate 160 L/min
0.0	25.7	22	23
0.5	22.7	18.6	16.8
1.0	18.5	15.3	12
2.0	16	12.4	10

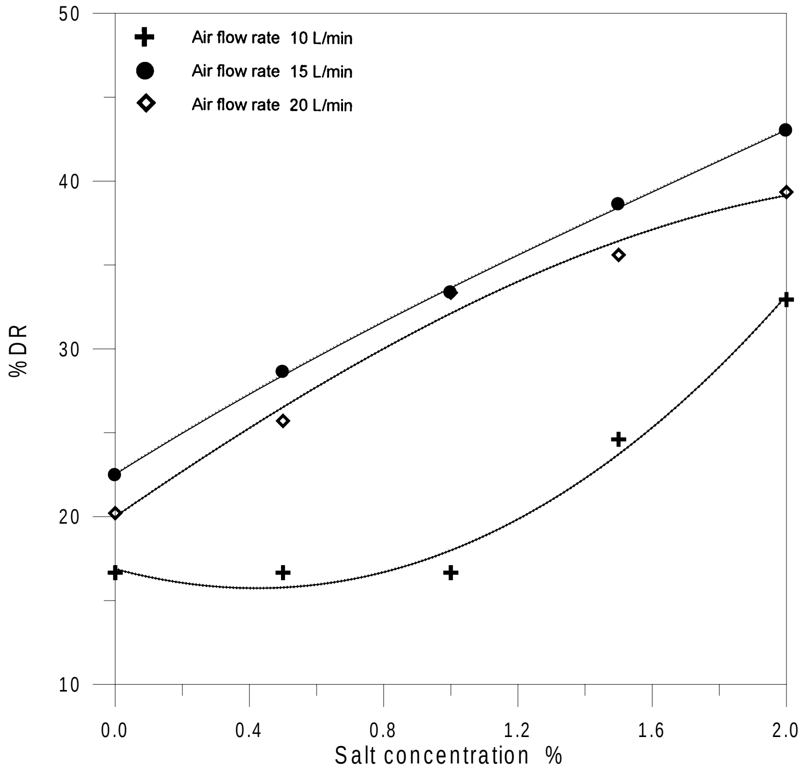

Figure 4-17: Effect of NaCl addition on %DR at 40 L/min water flow rate and 50 ppm XG additive.

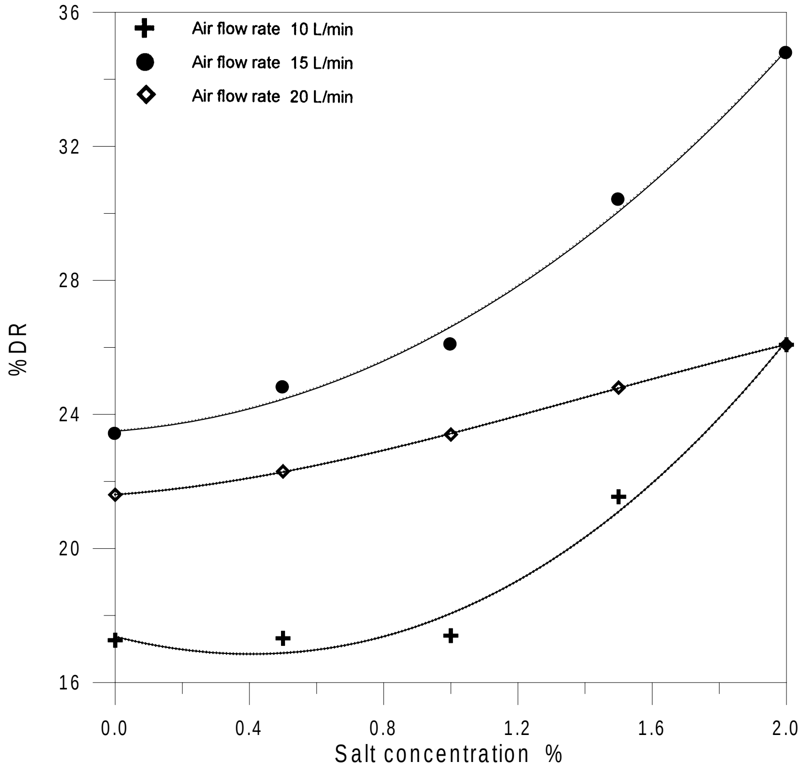

Figure 4-18: Effect of NaCl addition on %DR at 60 L/min water flow rate and 50 ppm XG additive

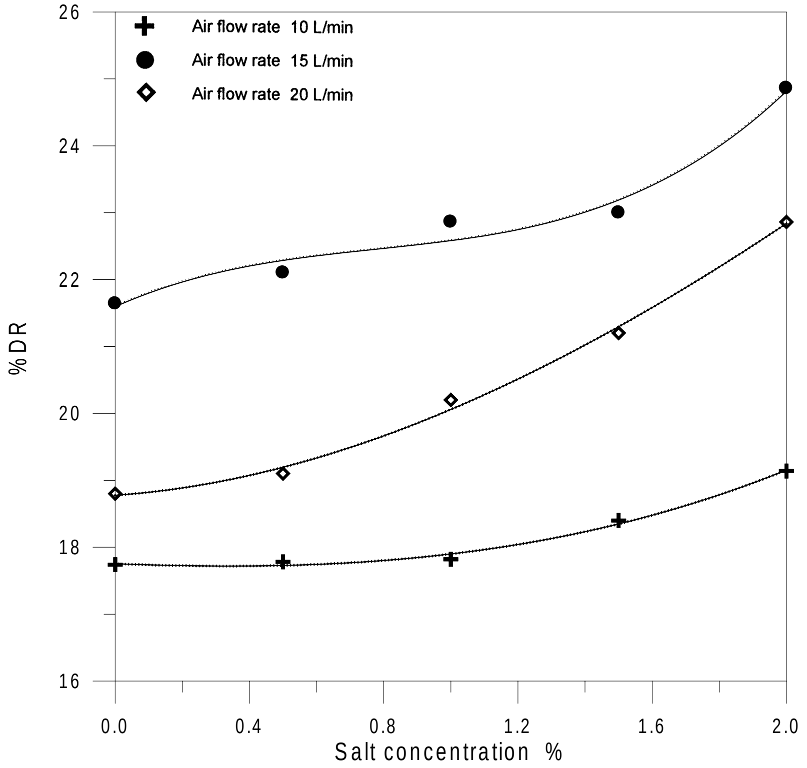

Figure 4-19: Effect of NaCl addition on %DR at 80 L/min water flow rate and 50 ppm XG additive

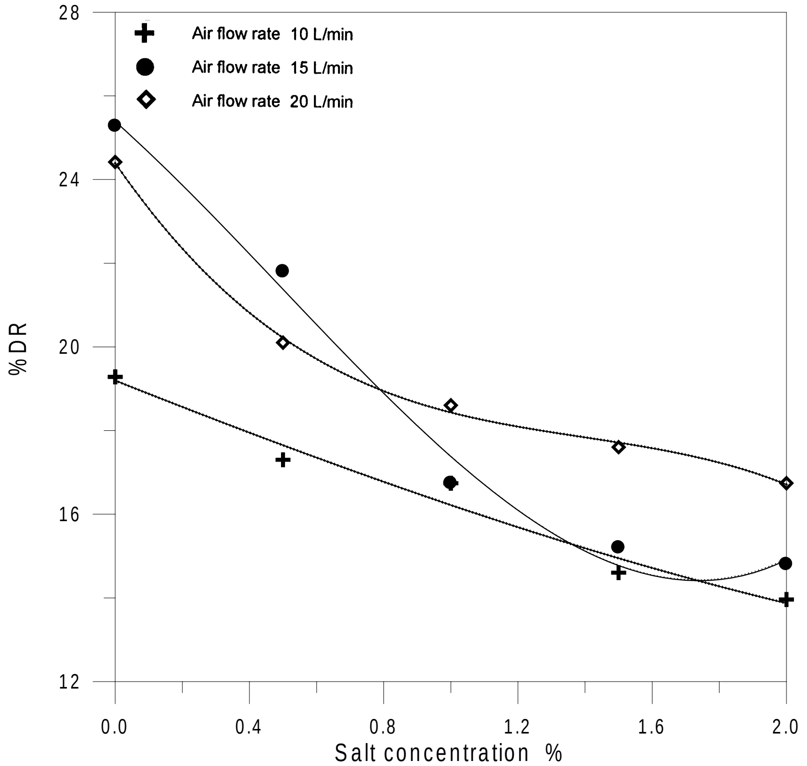

Figure 4-20: Effect of NaCl addition on %DR at 100 L/min water flow rate and 50 ppm XG additive

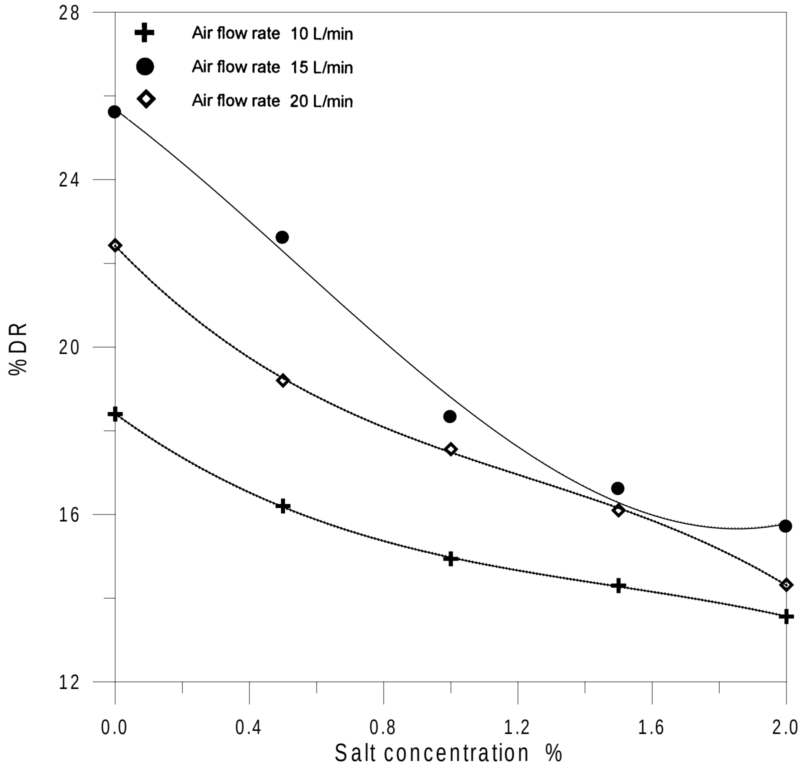

Figure 4-21: Effect of NaCl addition on %DR at 120 L/min water flow rate and 50 ppm XG additive

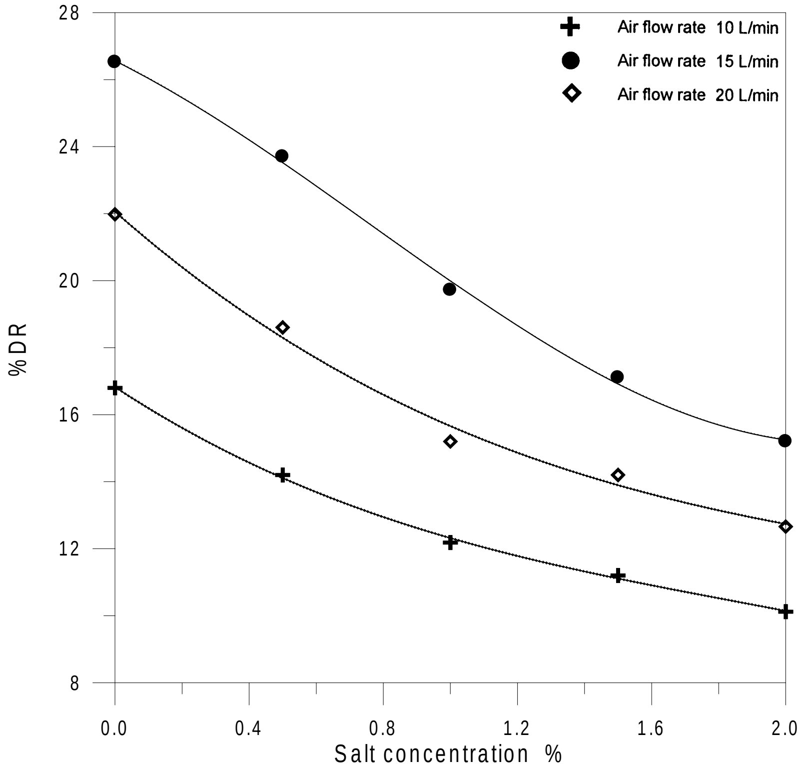

Figure 4-22: Effect of NaCl addition on %DR at 140 L/min water flow rate and 50 ppm XG additive

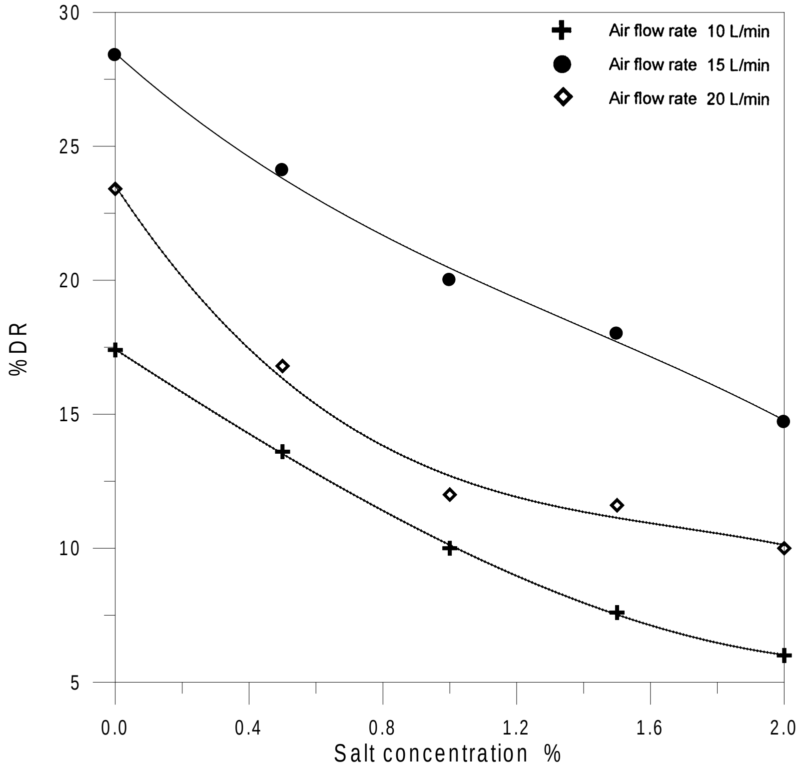

Figure 4-23: Effect of NaCl addition on %DR at 160 L/min water flow rate and 50 ppm XG additive

4.5 Time-Dependence

4.5.1 Single Phase Flow

The time dependence drag-reduction experiments were carried out, in order to study the effect of circulation time on the efficiency of xanthan gum as drag reducer agent in flowing water. The results at different additive concentrations are plotted in figures 4-24, 4-25 and 4-26 for a three selected water flow rates, taking the time zero for maximum drag-reduction.

The figures indicate clearly, that low concentrations will be degraded quickly compared with high concentrations. Further more, the decline in percentage drag-reduction is favored at low liquid flow rate as shown in figure 4-24 for water flow rate 40 L/min compared with figure 4-26 for higher liquid flow rate about 160 L/min.

This observation is in agreement with Sellin [126] who found that polymers degradation is more likely to occur at low liquid flow rates for low concentration [119]. Therefore the percentage drag-reduction decreases rapidly, reaching to about zero after 60 minute circulation for 25 ppm xanthan gum and 40 L/min water flow rate.

The combined effect of circulation time and liquid flow rate on performance of xanthan gum as drag reducer agent is illustrated in figures 4-27 and 4-28 for two selected polymer concentrations, 25 and 75 ppm. As it is expected general that the percentage drag-reduction increase as liquid flow rate increases. The once circulation gives the highest drag-reduction values. While, the pumping of the solution for different time leading to lower drag-reduction efficiency, mainly for 60 minute operation, at which the minimum drag-reduction was achieved, due to degradation of polymeric additive.

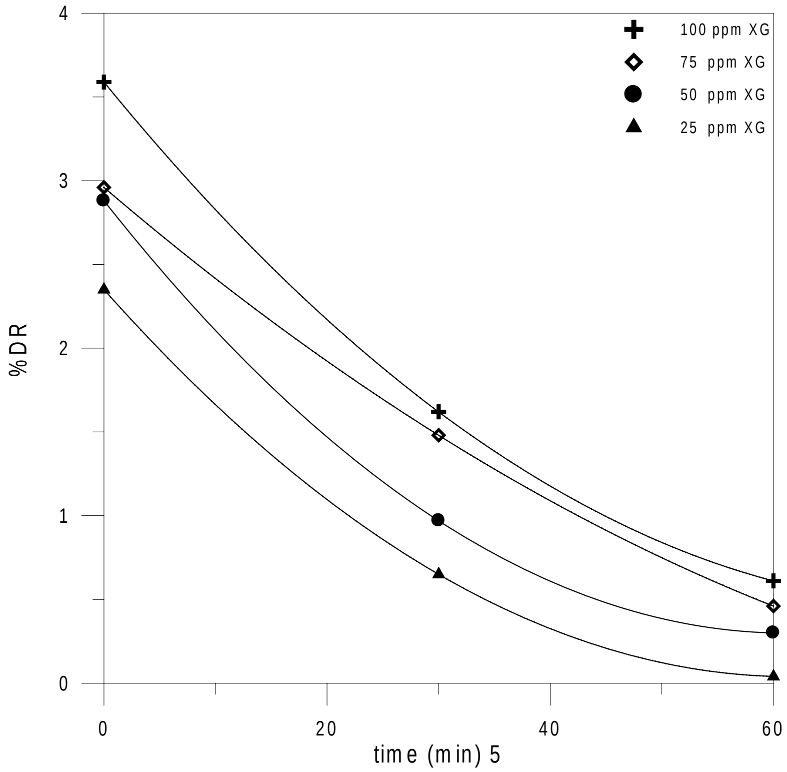

Figure 4-24: Time dependence drag-reduction for different XG concentrations at 40 L/min water low rate

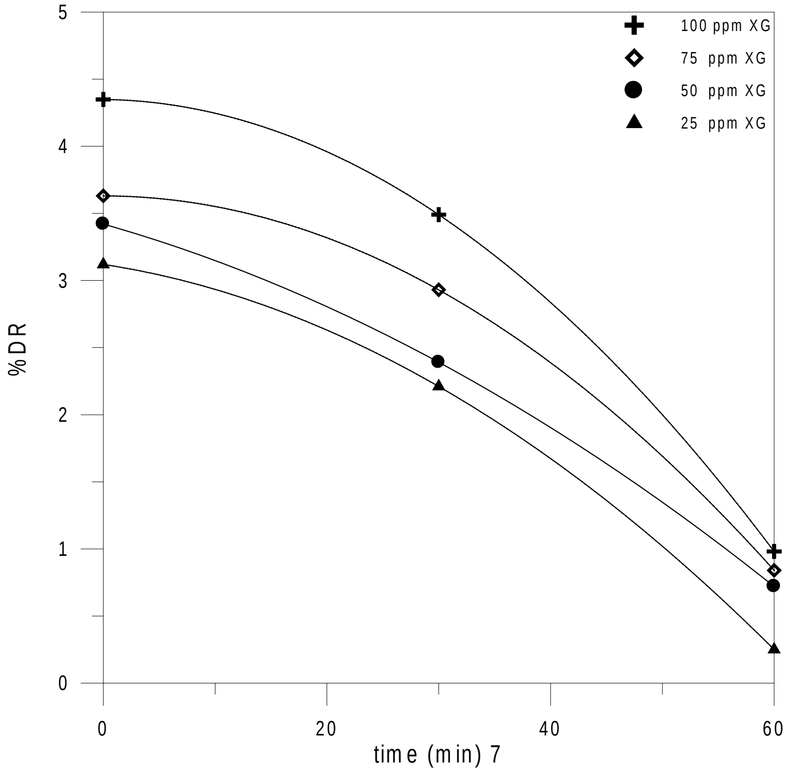

Figure 4-25: Time dependence drag-reduction for different XG concentrations at 80 L/min water low rate

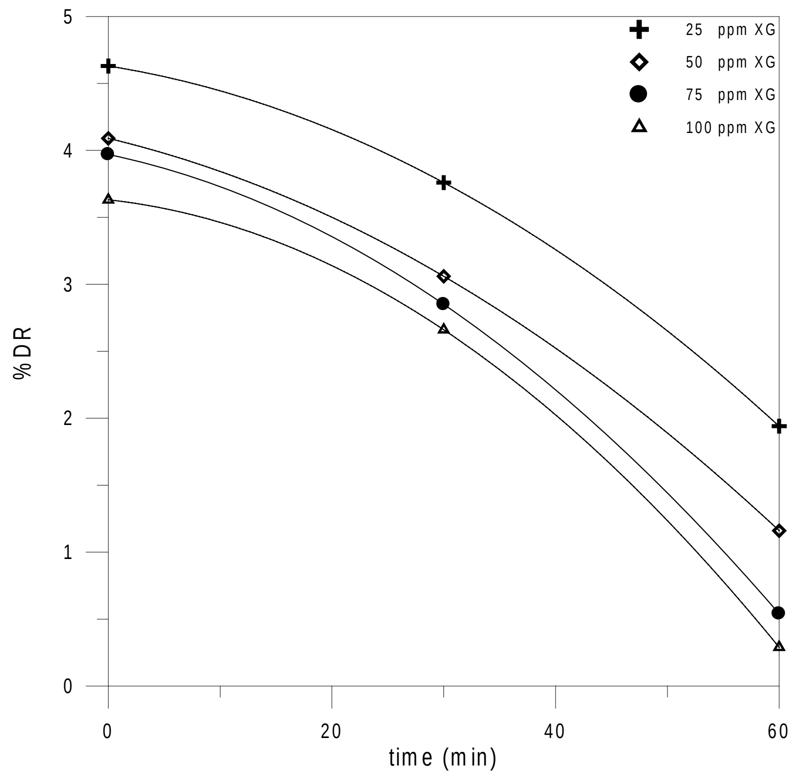

Figure 4-26: Time dependence drag-reduction for different XG concentrations at 160 L/min water low rate

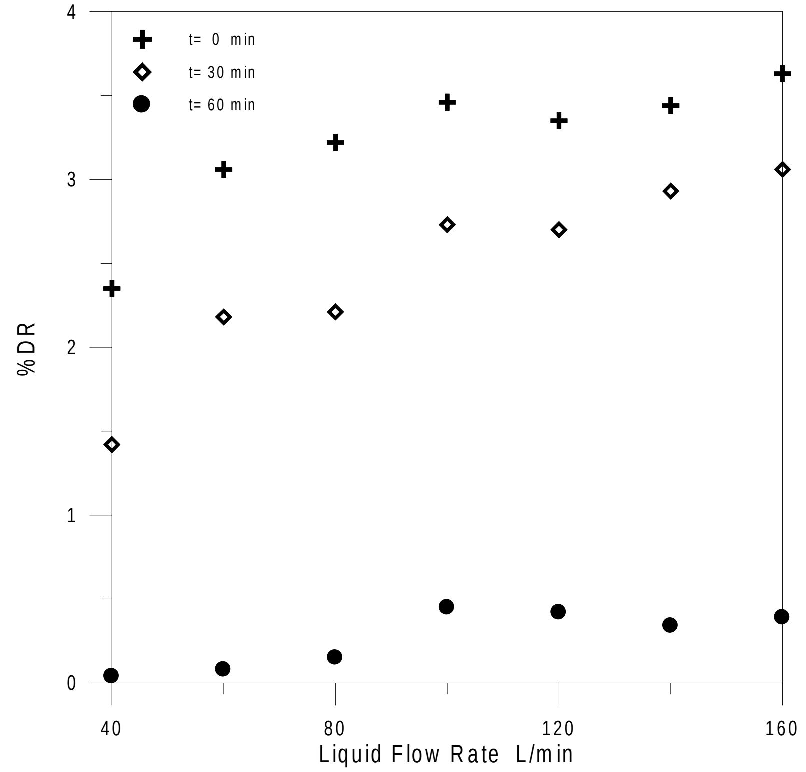

Figure 4-27: Liquid flow rate vs. %DR for different times for 25ppm XG

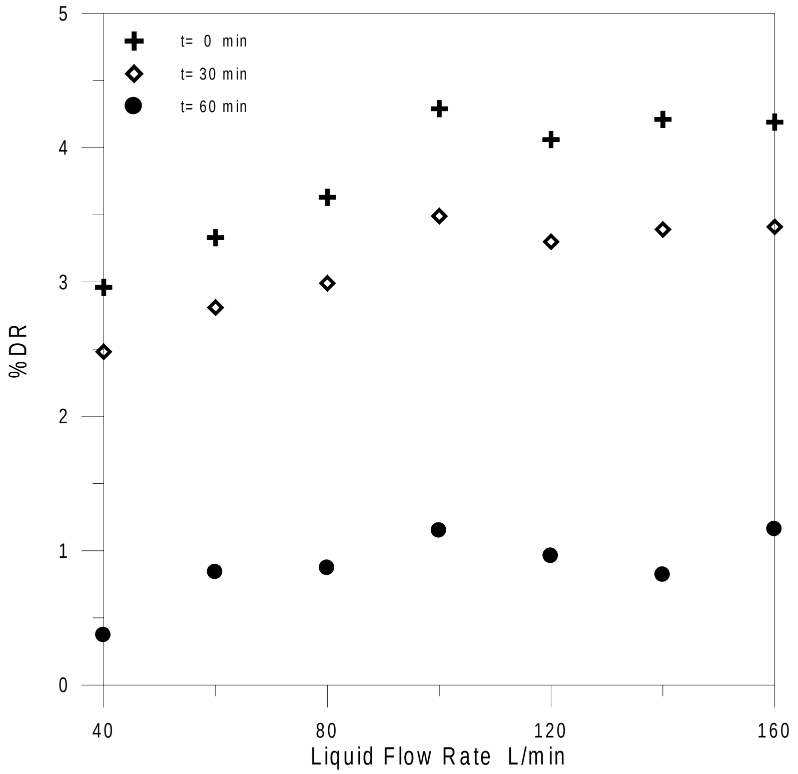

Figure 4-28: Liquid flow rate vs. %DR after deferent times for 75ppm XG

4.5.2 Two-Phase Flow

The time dependence drag-reduction efficiency of xanthan gum additive in two-phase (water-air) flow was investigated in this part of study. Two phase condition that was studied included air and water flow rates as well as additive concentrations. Figures 4-29, 4-30 and 4-31 present the effect of air flow rate on drag-reduction effectiveness with time of 25 ppm XG concentration at liquid flow rates 60, 100 and 160 L/min respectively. Similar, the corresponding results for 50 ppm additive concentration are illustrated in figures 4-32, 4-33 and 4-34 respectively.

As shown in these figures, drag-reduction effectiveness of two-phase flow in noticeable larger than of single-phase, as it was observed previously in part 4.3. Furthermore, the results those show the drag-reduction ability of additive decrease gradually with time due to degradation of the polymer molecules under turbulent flow. Since the mechanical degradation is associated with bond breaking due to chain stretching by the flow.

As illustrated in above mentioned figures, the behavior of decline of drag-reduction performance is seems to be similar in whole considered conditions for single-phase as well as for two-phase flows. In other words the presence of air has no noticeable effect on degradation of polymer molecules.

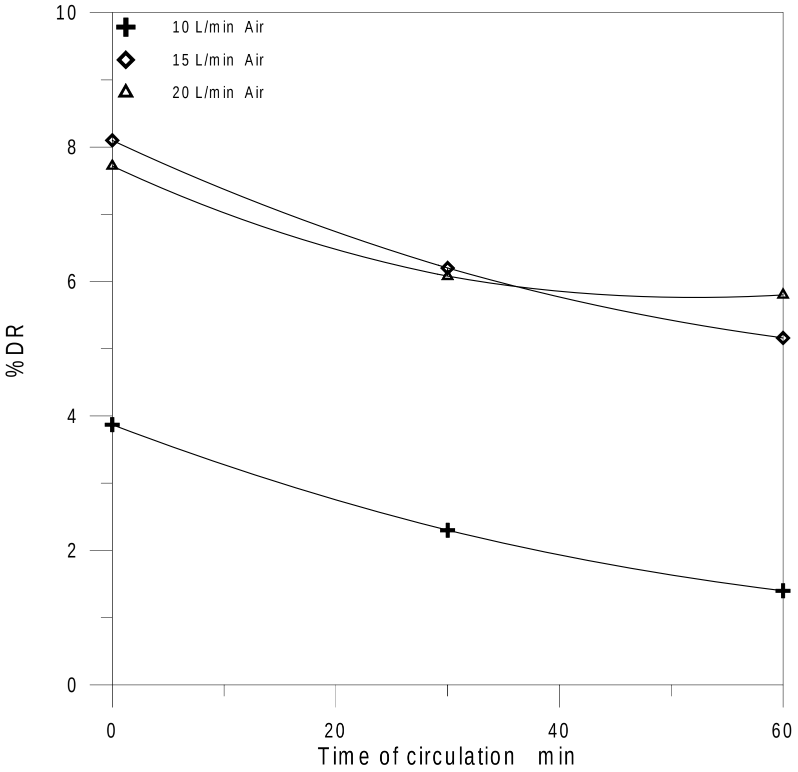

Figure 4-29: %DR vs. time of circulation at 25 ppm XG and 60 L/min water flow rate for different air flow rate.

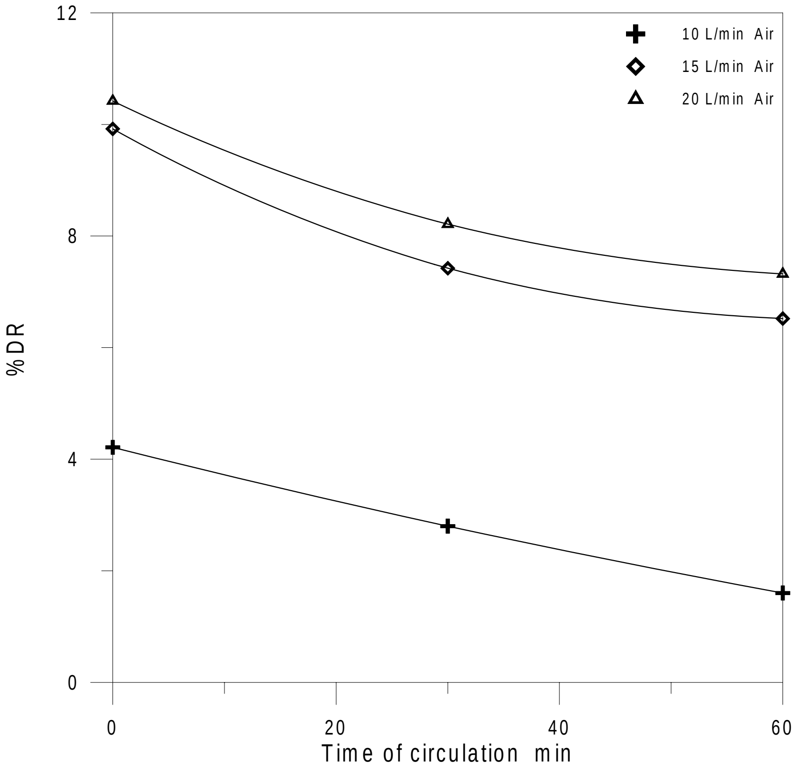

Figure 4-30: %DR vs. time of circulation at 25 ppm XG and 100 L/min water flow rate for different air flow rate.

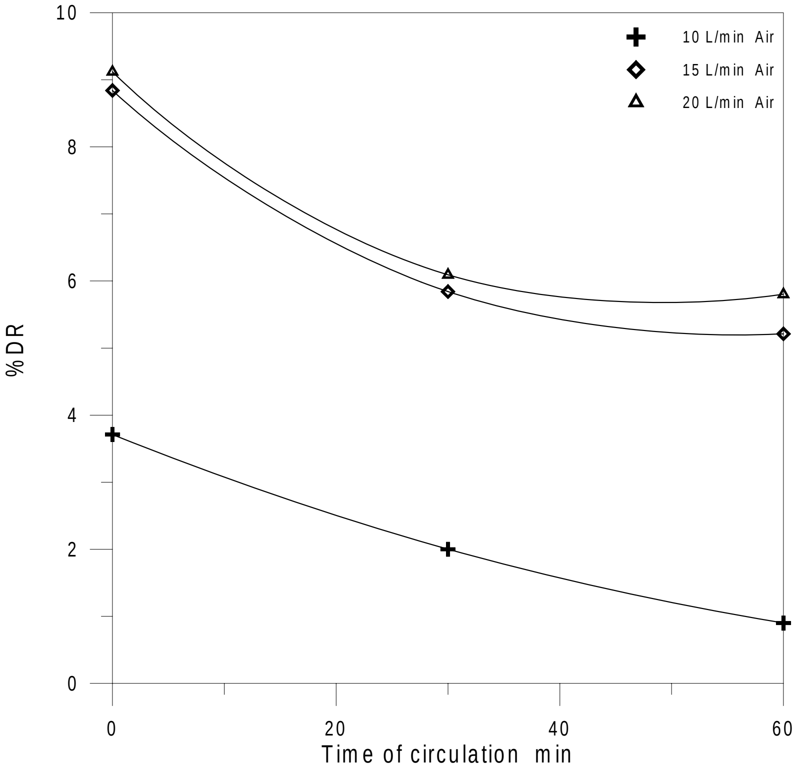

Figure 4-31: %DR vs. time of circulation at 25 ppm XG and 160 L/min water flow rate for different air flow rate.

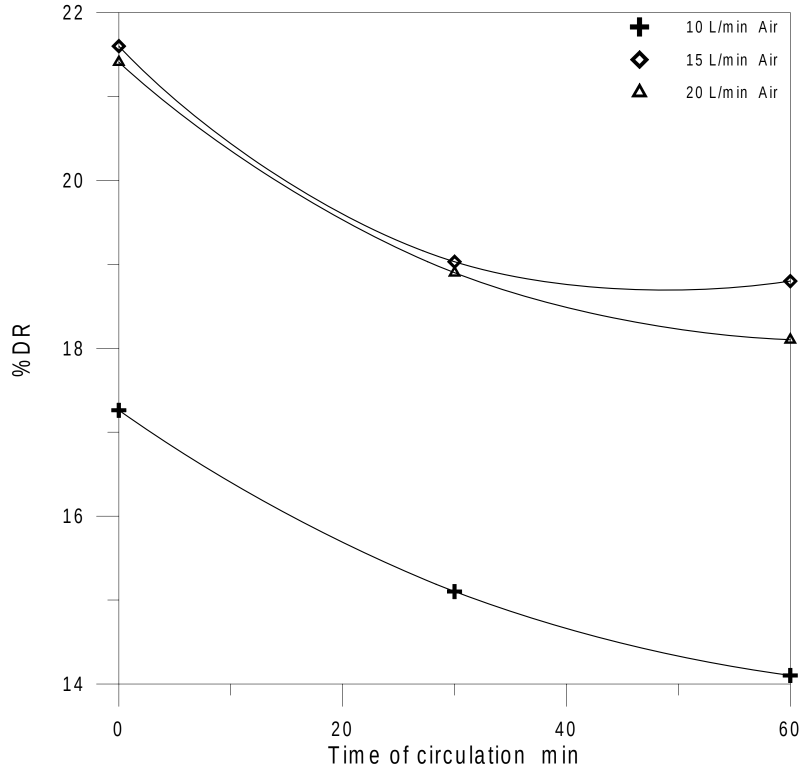

Figure 4-32: %DR vs. time of circulation for 50 ppm XG and 60 L/min water flow rate for different air flow rate.

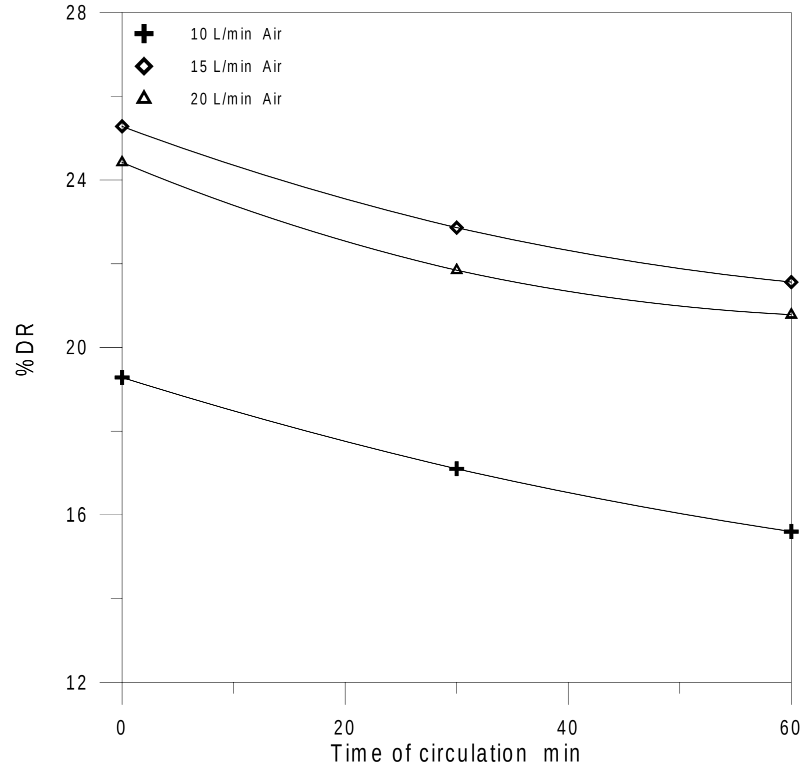

Figure 4-33: %DR vs. time of circulation for 50 ppm XG and 100 L/min water flow rate for different air flow rate.

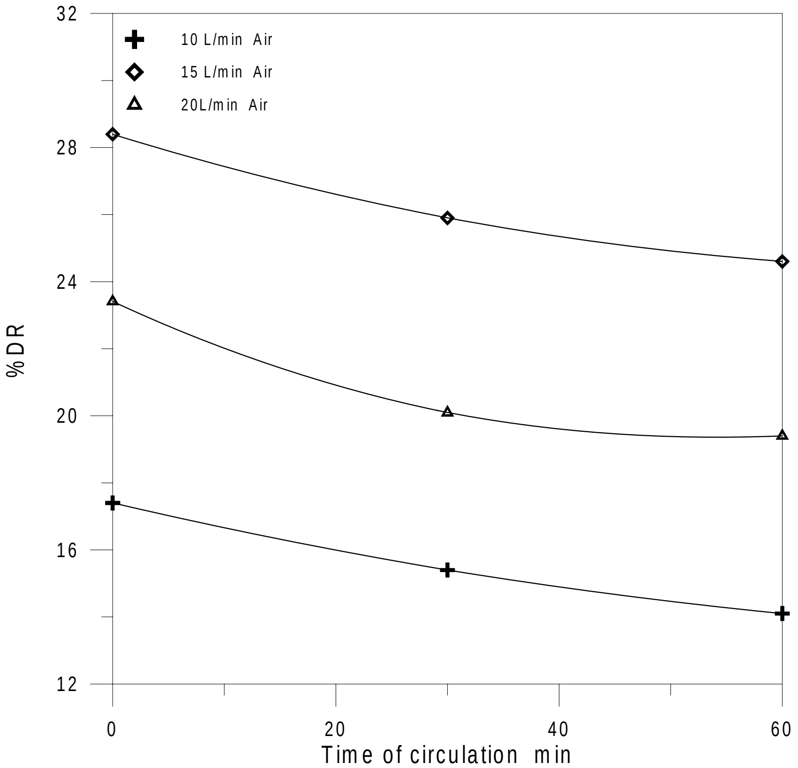

Figure 4-34: %DR vs. time of circulation for 50 ppm XG and 160 L/min water flow rate for different air flow rate

CHAPTER FIVE
Conclusions and Recommendations

5.1 Conclusions

1. Xanthan gum additive as a rigid polysaccharide shows relatively low drag reduction ability in turbulent pipe single water flow. The drag-reduction effectiveness of xanthan gum agent decreases gradually as circulation time progresses, due to mechanical degradation, which is more likely to occur at low additive concentration and low flow rate.
2. The addition of air was effective in reducing drag forces in turbulent water flow in absence of polymeric additive, due to formation of microbubbles which act as effective drag reducer. The drag – reduction effectiveness of microbubbles is a function of gas and liquid flow rates up to 15 L/min and 120 L/min respectively.
3. The drag-reduction with xanthan gum additive is significantly higher in two-phase (air-water) turbulent flow than in single liquid-phase flow could be explained by the interaction of polymeric additive and microbubbles with the water, which allows the turbulent to be suppressed.
4. A noticeable increase of percentage drag-reduction was observed at 2.0 % sodium chloride content of water at low turbulent degree, due to the micro foam formation which enhances the drag-reduction effectiveness of xanthan gum additive in two-phase flow. While at high turbulence acts the sodium chloride as inhibitor for the drag-reduction performance due to less foaming and collapse of xanthan gum additive to a more compact structure with the existence of sodium chloride.

5.2 Recommendations for Future Work

1. Investigate the relation between the gas bubble sizes in liquid with percentage drag reduction by using image processing techniques through Perspex tube.
2. Studying the effect of pipe size and roughens on percentage drag reduction in two-phase flow.
3. Studying the drag-reduction performance in two-phase flow, crude and its fractions with different gases.
4. Details study is required on effect of different salts, such as sodium chloride and calcium drag-reduction behavior of different polymeric additives in two-phase flow.

REFERENCES

[1]. White,A., and Hemmings, J.A.G. "Drag Reduction by Additives – Review and Bibliography." BHRA Fluid Engineering : Bedford, England. (1979).

[2].Munson, R.B., Yong, D.F. and Okilishi, H.T.," fundamental of fluid mechanics "3rd edition update John Whily, New York (1998).

[3]. Shanshool, H.S. Al-Najjar and A.H. Al-Ajeel," determination of drag reduction for Iraqi crude oils" Eng. and Tech., 10(5) (1991).

[4]. Lescarbours, V.A., Culter,J.D.,and Wahl, H.A. J. "Drag Reduction with a polymeric Additives in Crud Oil Pipelines." Soc. Petroleum Engrs. Vol. 11(3):p.p. 229-235. 1971.

[5].GTA-BASF Eng."Drag Reduction Seminor Northern Oil Company (NOC), Kirkuk/Iraq,Feb 1985.

[6].Toms, B.A. "Some Observations of the Flow of Linear Polymer Solutions Through Straight Tubes at Large Reynolds Numbers."Proc. International Rheoogical Congress, Vol. II : 135-141. 1948.

[7]. A. Al-Sarkhi, T.J. Hanratty "Effect of drag-reducing polymers on annular gas-liquid flow in a horizontal pipe" Chemical Eng. Dep. University of Illinois, 2000.

[8].Soleimani, A., Al-Sarkhi, A., and Hanratty, T. J., "Effect of Drag Reducing Polymers on Pseudo Slug Interfacial Drag and Transition to Slug Flow", International Journal of Multiphase Flow, Vol. 28, PP. 1911-1927, 2002.

[9]. Ishii, M. and Hibiki, T. "Thermo fluid dynamics of two phase flow". Springer. 2005.

[10]. G. **F.** Hewitt and D. N. Roberts, Studies of two-phase flow patterns by Simultaneous X-ray and flash photography, Report AERE-M 21 59 (London: HMSO, 1969)

[11]. Holland F.A. and Bragg R. "Fluid Flow For Chemical Engineers" University of Manchester Institute of Science And Technology, Second Edition, 1995.

[12]. Baker 0., Oiland Gas Joumal53, pp. 18595 (26 July, 1954)**.**

[13]..Lauchlan C,S and Escaramea M. et.al. "Air in Pipelines Literature Review " Report SR 649 , 2005.

[14].Oldroyd, J. G.,"A Suggested Method of Deteching Wall Effects inTurbulent Flow Through Pipes," in Proc. 1st Intern. Congr. Rheol., North Holland, **2**, pp 130-134 (1948).

[15]. Marlin, D.Holtmyer and Jiten Chatterji "Study of Oil Soluble Polymers as Drag Reduction", Ducan Oklahoma MID-MAY polymer Engineering and Scince Vol. 20, No. 7 1980.

[16]. Jun Hee Sung, Sung Tack Lim, Chul Am Kim, Heejeong Chung and Hyoung Jin Choi, "Mechanical degradation Kinetics of Poly(ethylene oxide) in a turbulent flow", Korea. Australia Rheology Journal, Vol. 16, No. 2, June 2004.

[17]. Savins, J.G. "Drag Reduction Characteristic of Solutions of Macromolecules in Turbulent Pipe Flow", J. Soc. Pet. Eng. p.p. 203-214, Sep. 1964.

[18]. Tanner, R.I.: "Drag Reduction in a Model of Shear – Flow Turbulence", I. and E.C. Fundamentals, J. Vol. 7, No.1 PP. 32-38, Feb. 1968.

[19]. Smith, C.L.: "Turbulent Drag Reduction by Polyacrylamide and Other Polymers" Soc. Pet. Eng. J., Paper 2405, June 1969.

[20]. Motier, J. F.: "Polymeric Drag Reducers", Pipeline and Gas Journal, vol. 32 p.p. 379, June 1985.

[21]. Lester, C.B.: "The Basic of Drag Reduction", Oil and Gas Journal vol. 5156, Feb. 1985.

[22]. Thiel, H. Turbulent flow of heterogeneous polymer solution in aritically roughed pipe. "drag reduction fluid flow" Editors, R.H.Sellin and R.T. Moses, 1989.

[23]. Burger, E. D. Chorn, L. G. and Perkins, T.K. " Studies of Drag conducted over abroad range of pipeline conditions when flowing pride hoe by crude oil" Journal of Rheology, vol. 24 (5), p.p. 603-629, 1980.

[24]. Sellin, R.H., Hoyt J.W. and Scrivener, O. "The effect of drag reducing additives on liquid flows and their industrial applications" part I: basic aspects, J. Hydraulic Res., vol. 20, p.p. 29-68. 1982.

[25]. Brod, M., B.C. Deane, and F. Rossi, "Field Experience with the Use of Additives in the Pipeline of Waxy Crude's", J. Intst. Petrol, 57(554), pp 110-116, 1971.

[26]. Tsutahara, M. and Sakamoto, M. Trans of the JSME Series B 61, p.p.2088, 1995.

[27]. Watanabe, K. in “Proceedings of the International Symposium on Seawater Drag Reduction”, Newport Rhode Island, p.p. 19, July 1998.

[28]. White A., "Flow characteristics of complex soap systems", Nature, 214, pp. 585–586, 1967.

[29]. Michael M.L., Hershey H.C. and Robert A.B., "Effect of aging, concentration, temperature, method of preparation and other variables on the drag reduction of aluminum di soaps in toluene", Chem. Eng. Prog. Symp. Ser., 67 (111), pp. 27–45, 1971.

[30]. Ali, E. "Prediction of Turbulent Drag Reduction with Polymer Additives". Ph.D. Thesis. University of technology July 1996.

[31]. Oldroyd J.G., "A suggested method of detecting wall affects in turbulent flow through pipes", First Int. Congr. on Rheol. VII, North Holland, Amsterdam, pp. 130–134 (1948).

[32]. Hershey H.C. and Zakin J.L., "Existence of two types of drag reduction in pipes flow of dilute polymer solutions", Ind. Eng. Chem. Fund., 6 (3), Aug., pp. 381–387 (1967).

[33].Smith J.W., Hummel R.L. and Arunachalam V., "Flow visualization studies of a turbulent drag rducing solutions", Can. J. Chem. Eng., 50, pp. 337–343 (1975).

[34].Virk P.S., Mickley H.S. and Smith K.A., "The ultimate asymptote and mean flow structure in Toms phenomemo", ASME J. Appl. Mech., 37, June, pp. 488–493 (1970).

[35]. Gustavsson L.H., "Drag reduction experiments with polystyrene with some implication for the mean velocity profile", Phys. Fluids, 20, 10, II, pp. S120–S123 (1977).

[36].Savins J.G., "Drag reduction characteristic of solutions of macromolecules in turbulent pipe flow", Soc. Pet. Eng. J., Sep., pp. 203–214 (1964).

[37].Elperin I.T., Smolski B.M. and Leventhal S., "Decreasing the hydrodynamic resistance of pipelines", Int. Chem. Eng., **7**, pp. 276–295 (1967).

[38].Lester, C.B.: “The Basic of Drag Reduction”, Oil and Gas Journal 51-56, Feb.4, 1985.

[39]. Charachafchy A.A., "Increasing the pump ability in pipes by using chemical additives", Developments article, article (1-44), Petroleum training institute, Baghdad, May (1989).

[40]. Kim , C.A., J.H. Choi, C.B. Kim, W. Chun and M.S. Jhon, " Drag reduction chatacteristcs of poly(ethyleneoxide) in seawater, J. Chem. Eng. Japan 32, 803-811.

[41]. Sarah E. Morgan," Water Soluble Copolymers Macromolecular Drag Reduction", a review of predictive theory. Prog. Polym sci. Vol.15, p. 507-549, 1990.

[42]. www.exxonmobil.com "Vistanex polyisobutylene Properties and Applications.2005.

[43]. Zakin J.L., "Surfactant drag reduction", Reviews in chemical engineering, pp. 252–320 (1998).

[44]. Charachafchy A.A., "Increasing the pump ability in pipes by using chemical additives", Developments article, article (1-44), Petroleum training institute, Baghdad, May (1989).

[45]. Rodriguez J.M., Zakin J.L. and Patterson G.K., "Correlation of drag reduction with modified Deborah number for dilute polymer solution", Soc. Pet. Eng. J., Sep., pp. 325–332 (1967).

[46]. Lumley J.L., "Drag reduction by additives", Ann. Rev. Fluid Mech., 1, pp. 367–384 (1969).

[47].Zagustin, A., and K. Zagustin, “Mechanics of Turbulent Flow in Sediment Laden Streams,” Inter. Cong. Hydr. Res., Kyoto, Japan, B33, 2, (1969).

[48].Mahmood, K., “Flow in Sand-Bed Channels,” Ph.D. Thesis , Colorado State-University, Feb. 1971.

[49]. Mohammed H. J. "Flow Increase In Turbulent Fluid Flow By Using Drag Reducing Agents" M.Sc, Thesis, Nahrian University, Chemical Engineering, (2007).

[50]. Ptasinki, P.K.; "Turbulent Flow of Polymer Solutions Near Maximum Drag Reduction"; Exeriments Rijswijk, in press, 2003.

[51]. Thiel, H., "Turbulent Flows of Heterogeneous Polymer Solutions in Artificially Roughened Pipes", Drag Reduction Fluid Flow: Techniques for Friction Control, Editors by Sellin and Moses, 1989.

[52] Virk, P.S., "Drag Reduction Fundamentals", Journal of AIChE, Vol. 21, No.4, PP. 625-656, 1975.

[53]. John Wiley & Sons "Encyclopedia of Bioprocess Technology: Fermentation, Biocatalysts, and Bioseparation"1975.

[54]. Tullis, J.P., and Ramu, K.L.V., "Drag Reduction Pipe Flow with Polymer Injection", International Conference on Drag Reduction, 4th-6th September, PP. 31-41, 1974.

[55]. McComb, W.D, Allan, J., and Greated, C.A., "Effect of Polymer Additives on the Small Scale Structure of Grid Generated Turbulence", Physics of Fluids, Vol.20, No.6, PP. 873-879, June, 1977.

[56]. Sarah E. Morgan ,Water soluble copolymers, Macromolecular Drag Reduction , A review of Predictive theory. Prog. Polymer sci. Vol.15, 507-549, 1990.

[57]. Singh R.P., and Kumer A., the influence of polymer additives on velocity and temperature field, p 131, springer verlag Berlin 1980.

[58]. Nieuwenhuys, G.M.H., "Effect of Drag Reducing Polymers on a Vertical Multiphase Flow", Report No. MEAH: 230, 2003

[59]. Ambari A., Desouis C., the influence of polymer additives on velocity and temperature field . IUTAM Sump. Editor B.Gampert p437, 1984.

[60]. Mysels, K.J., “ Flow of thicknend fluids”, U.S. patent no. 2, p. 492-173, 1949.

[61]. Dodge, D.W. and Metzner, A.B.” Turbulent Flow of Non-Newtonian System.” AIChE J. 5:189-204. 1959.

[62].Shaver, R.G. and Merril, E.W. “ Turbulent Flow of Pseudo 66. plastic Polymer Solution in Straight Cylindrical Tubes” AIChE J.5: 181-188. 1959.

[63].Zakin J.L., "Surfactant drag reduction", Reviews in chemical engineering, pp. 252–320 (1998).

[64]. Antonio M.F., Eugenio C. and Athanassios Z.P., "Micellization in model surfactant systems", Langmuir, Aug., pp. 1–30, (1998).

[65]. Shenoy, A.V.: J. colloidand polym sci ; 262,319 (1984).

[66]. Zakin, J.L, Myska, and Z. Chara, "New Limiting Drag Reduction and Velocity Profile Asymptote for Polymeric and Non- Polymeric Additives Systems", AICHE J., 42, pp 3544-3546, (1996).

[67]. ME McCormick and R Bhattacharyya, Nav. Eng. J. 85, 11 (1973).

[68].VG Bodgevich, AR Evseev and AG Malyuga, Second International Conference on Drag Reduction, Cambridge (England), BHRA, P. 25 (1977).

[69]. Merkle CL and Deutsch S, in “Frontiers in experimental fluid mechanics” vol. 46 (M Gad-el-Hak, ed), pp 291 (1989).

[70]. Kato H., Miyanaga M. and Haramoto Y., in “Cavitation and gas-liquid flow in fluid machinery and devices” (TJ O’Hern, JH Kim, WB Morgan eds), FED vol 190, ASME, New York, p. 185 (1994).

[71]. Kato H, Miyanaga M. and Yamaguchi H., in “Advances in multiphase flow” (A Serizawa, T Fukano and J Bataille eds.), Proceedings of the Second International Conference on Multiphase Flow, Kyoto, Elsevier, Amsterdam, p 85 (1995).

[72]. Guin MM, Kato H. and Takahashi, Y. “Proceedings of the International Symposium on Seawater Drag Reduction”, Newport, Rhode Island, pp. 155 (July 1998).

[73]. Guin MM., Kato H. and Yamaguchi H. , M Maeda and Miyanaga, Mar. Sc. Technol. 1, 241 (1996).

[74]. S Pal, CL Merkle and S Deutsch, Phys. Fluids 31, 744 (1988).

[75]. Madavan NK., Merkle CL. and Deutsch S., Trans. Of the ASME, 107, 370 (1985).

[76]. Wells, C.S. JR., “Turbulent heat transfer in drag reduction fluids”, AJCH journal, PP.406-410, MAY 1968.

[77]. Shanshool J., and Al-Qamaje H. M., "Effect of Molecular weight on Turbuant Drag Reduction with Polyisobutylene Additives". M.Sc. Thesis, Nahrain University, Chemical Eng. (2006).

[78]. Oliver and S.I. Bakhtiyarov, J. Non-Newtonian Fluid Mech. 12, 113 (1983).

[79]. Choi HJ .and Jhon MS., Ind. Eng. Chem. Res 35, 2993 (1996).

[80]. Nada, S.: “Thermal stability of Polymer”, M.Sc. Thesis, University of Baghdad, Petroleum of Engineering”

[81]. Lin, Z.; Chou, L.C.; Lu, B.; Zheng, Y.; Davis, H.T.; Scriven, L.E. Talmon, Y.; and Zakin, J.L.: “Experimental Studies on Drag Reduction and Rheology of Mixed Cationic Surfactants With Different Alkyl Chain Lengths”, Rheol. Acta, pp.39, 354-359, 2000.

[82]. Lin, Z.; lu, B.; Zakin, J. L.; Talmon, Y.; Zheng, Y.; Ted Devis, H. and Scrivent, L.E.: “Influence of Surfactant Concentration and Counter ion to Surfactant Ratio on Rheology of Wormilike Micelles ”, J. colloid and Interface Science, pp. 239, 543-554, 2001.

[83]. Myska, J. lin, Z.; Stepanek, P.; and Zakin, J.L.: “Influence of Salts on Dynamic Properties of Drag Reducing Surfactants”, J. Non-Newtonian Fluid Mech. pp. 97, 251-266. 2001

[84]. Lester, C.B.: “The Basic of Drag Reduction”, Oil and Gas Journal 51-56, Feb.4, 1985.

[85]. Virk, P.S.: “Drag Reduction in Rough Pipes”, J. Fluid Mich., Vol. 45,Part 2, PP. 225-246, 1971.

[86]. Jun Hee Sung, Sung Taek Lim, Chul Am Kim, Heejeong Chung and

Hyoung Jin Choi, “Mechanical degradation kinetics of poly(ethylene oxide) in a turbulent flow”, Korea-Australia, Rheology Journal, Vol. 16, No. 2, June 2004.

[87]. Mc Cormick C. L., Hester R. D., and Morgen S. E., Macromolecules in press.

[88]. Brostow, W., “Drag Reduction and Mechanical Degradation of Polymer Solutions in Flow”, *Polymer*, 24, pp 631 (1983).

[89]. Brostow, W., H. Ertepinar, and R. P. Singh, “Flow of Dilute Polymer Solutions; Chain Conformations and Degradation of Drag Reducers,”*Macromolecules*, 23, pp 5109-5118 (1990).

[90]. Brostow, W., S. Majumdar, and R. P. Singh, “Drag Reduction and Salvation in Polymer Solutions,” *Macromol Rapid Commun*, 20, pp 144-147 (1999).

[91]. Nguyen, T.Q.and Kausch,H.H. "Mechanochemical Degradation in Transient Elongational flow."Adv. Polym. Sci. 100:217-229. 1992.

[92]. Kulicke,W.M.,Kotter,M. and Grager,H. "Drag Redaction Phenomenon with Special Emphasis on Homogenous Polymer Solutions." Adv. Poly. Sci. 89; 1-68. Springer-Verlag, Berlin. 1989.

[93]. Clay, J.D. and Koelling, K.W. "Molecular Degradation of Concentrated Polystyrene Solutions in a Fast Transient Extensional Flow." Poly. Eng. Sci. 37: pp. 1521-1533. 1997.

[94]. Lee,E.C. and Muller, S.J. "Flow Light Scattering Studies of Polymer Coil Conformation in Solutions in Extensional Flow." Macromolecules 32; pp. 3295-3305. 1999.

[95]. Nakano, A., and Y. Minoura, “Effects of Solvent and Characterization on Scisson of Polymer with High-Speed Stirring,” J. Appl. Polym. Sci., 19, pp 2119-2130, 1975.

[96]. Kim C.A., J.T. Kim, K. Lee, H.J. Choi, and M.S.Jhon, “Mechanical Degradation of Dilute Polymer Solutions under Turbulent Flow”, Polymer J., vol. 41, pp 7611 – 7615, 2000.

[97]. Munstedt, H., Kunststofflaboratorium, BASF Aktiengesellschaft, Ludwigshafen is Rhein, Eingegangen am 18, 1981.

[98].Choi, H. J., Sung, J. H., Lim, S. T., Kim, C. A. and Chung, H. “Mechanical Degradation Kinetics of Polyethylene Oxide in A Turbulent Flow”, J. Korea – Australia Rheology, 16 (2), pp 57-62, 2004.

[99].Kim C.A., Kim, J.T. Lee, K. Choi, H.J. and Jhon, M.S. “A High – PrecisionRotating Disk Apparatus For Drag Reduction Characteristic”,Polymer Testing, 20, pp 43 – 48, 2001.

[100].Gadd, G. E.,“Turbulence Damping and Drag Reduction Produced by Certain Additives in Water,” Nature, 206, pp. 463-467, 1965.

[101]. Jovanovic, J., and Frohnapfel, B. “The Effect of Polymers on the Dynamics of Turbulence in A Drag Reduced Flow”, Thermal Science J., vol. 9(1), pp 31-14, 2005.

[102]. Backurst, J. R. and Harker, J. H. "Chemical engineering vol. I". sex edition, 2005.

[103]. Rosehart, R.G. Scott, D.S., and Rhodes, E., "Gas-Liquid Slug Flow with Drag Reducing Polymer Solutions", Journal of AIChE, Vol. 18, P. 744, 1972.

[104]. AL-Sarkhi, A., and Hanratty, T.J., "Effect of Drag Reducing Polymers on Annular Gas Liquid Flow in a Horizontal Pipe", International Journal of Multiphase Flow, Vol. 27, PP. 1151-1162, 2001.

[105]. Soleimani, A., Al-Sarkhi, A., and Hanratty, T. J., "Effect of Drag Reducing Polymers on Pseudo Slug Interfacial Drag and Transition to Slug Flow", International Journal of Multiphase Flow, Vol. 28, PP. 1911-1927, 2002.

[106]. Nieuwenhuys, G.M.H., "Effect of Drag Reducing Polymers on a Vertical Multiphase Flow", Report No. MEAH: 230, 2003.

[107]. Xu J, Maxey and MR, Karniadakis GE. "Numerical simulations of turbulent drag reduction using micro-bubbles"J. Fluid Mec 468:271-281, 2002.

[108]. Merkle, C.L., and Deutsch, S., "Microbubble Drag Reduction in Liquid Turbulent Boundary Layers", Appl. Mech. Rev., Vol. 45, No. 3, PP. 103-127, 1992.

[109]. Dentsh, S., Money, M., Fontaine, A.A., and Petrie, H., "Microbubble Drag Reduction in Rough Walled Turbulent Boundary Layers with Comparison against Polymer Drag Reduction", Paper No. s00348-004-0863-6, Pennsylvania Stat University, July, 2004.

[110]. Murai, Y., Oishi, Y., Sasaki, T., Kodama, Y., and Yamamoto, F., "Turbulent Shear Stress profile in a Horizontal Bubbly Channel Flow", Paper No. N00014-03-1-0299, National Maritime Research Institute of Japan, 2005.

[111]. Choi, U.S., and Kasza, K.E., "Long Term Degradation of Dilute Polyacrylamide Solutions in Turbulent Pipe Flow", Drag Reduction In Fluid Flows: Techniques for Friction Control, Editors by Sellin and Moses, 1989.

[112]. Kim, C.A., Kim, J.T., Lee, K., Choi, H.J., and Jhon, M.S., "Mechanical Degradation of Dilute Polymer Solutions under Turbulent Flow", Journal of Polymer, Vol. 41, PP. 7611-7615, 2000.

[113]. Sung, J.H., Lim, S. T., Kim, C. A., Chung, H., and Choi, H. J., "Mechanical Degradation Kinetics of Polyethylene Oxide in a Turbulent Flow", Journal of Rheology Korea-Australia, Vol. 16, No. 2, PP. 57-62, June, 2004.

[114]. Brazin, J., Lee, S., and Maurer, S., "The Effect of Diameter on Polyethylene Oxide Degradation during Turbulent Drag Reduction", Paper No.10.26 Team 5, March 2006.

[115]..Diyaiy. S.A. "Effect of Flow Patterns and Physical Properties on Pressure Drop for Gas-Liquid Flow in Horizontal", M.Sc. Thesis, University of Technology, Chemical Engineering (1993)

[116]. Abeed. E.M. "Drag Reduction in Single and Two-Phases Turbulent Pipe Flow Using CMC Polymer". Ph.D., Thesis, University of Technology, Mechanical Engineering, (2006).

[117]. Holman, J.P., and Gajda, W.J., "Experimental Methods for Engineers", McGraw-Hill Book Company, Fourth Edition, 1984.

[118]. Singh R. P., Deshmukh, and Kumer A., the influenece of polymer on velocity and temperature field (B. Gampert. ED), p. 131, springer, Berlin, 1985 Drag Reduction by polymeric solutions.

[119]. Niazzi E.S., "Effectiveness of Polyisobutylene as Drag Reduction Agents in Turbulent Pipe Flow", Ph.D Thesis, Nahrain University, Chemical Engineering, (2007).

[120]. Berman, N. s., andW. K. George, “Onset of Drag Reduction in Dilute Polymer Solutions,” *Phys. Fluids*, **17**, pp 250 (1974).

[121]. Burger E.D, Munk W.R. and Wahi H.A., " flow increase in the trans-alaska pipeline using a polymeric Drag Reducing Adduitives", J. petroleum Tech. Feb. 1982, 377-386

[122]. Mohammed H. J. " Study of Drag Reduction In Turbulent Flow Using High Molecular Weight Polymers", M.Sc. Thesis, Nahrain University, Chemical Engineering, (2007).

[123].. Rochetort W . E and Middeman S., " Relationship between Rheological behaviour and drag reduction for dilute of XG solution " Drag reduction in fluid flow symposiam, 1989.

[124]. Lescarboura, J.A.:" Drag Reduction with a Polymeric Additive in Crude Oil Pipelines", Soc. Pet. Eng., 229-234, (Sep., 1971).

[125]. Nada, S. Al-Z, "Thermal stability of Polymer", M.Sc. Thesis, University of Baghdad, Petroleum of engineering, (1989).

[126]. Sellin, R. H. J." Experimental with polymer additives in long pipeline" Int. Conf. Drag Reduction, Combridge, pp G2, 1974.

APPENDIX A
EXPERIMANTAL RESULTES
Table (A-1): Results of the polymer degradation in single phase

Polymer conc. ppm	Liquid Flow Rate L/min	%DR At t= 0 min	%DR After 30min	%DR After 60min
25	**40**	**2.35**	**1.42**	**0.04**
	60	**3.06**	**2.18**	**0.08**
	80	**3.22**	**2.21**	**0.15**
	100	**3.46**	**2.73**	**0.45**
	120	**3.35**	**2.7**	**0.42**
	140	**3.44**	**2.13**	**0.34**
	160	**3.63**	**3.06**	**0.29**
50	**40**	**2.88**	**0.97**	**0.31**
	60	**3.16**	**1.3**	**0.68**
	80	**3.42**	**1.39**	**0.85**
	100	**3.93**	**1.85**	**0.92**
	120	**3.72**	**1.8**	**0.62**
	140	**3.64**	**1.78**	**0.6**
	160	**3.97**	**1.6**	**0.54**
75	**40**	**2.96**	**2.48**	**0.37**
	60	**3.33**	**2.81**	**0.84**
	80	**3.63**	**2.39**	**0.87**
	100	**4.29**	**3.09**	**0.54**
	120	**4.06**	**3.3**	**0.96**
	140	**4.21**	**3.39**	**0.82**
	160	**4.19**	**3.41**	**1.16**
100	**40**	**3.69**	**1.62**	**0.61**
	60	**3.98**	**1.87**	**0.7**
	80	**4.35**	**2.49**	**0.78**
	100	**4.72**	**2.92**	**0.88**
	120	**4.55**	**3.07**	**0.79**
	140	**4.87**	**2.88**	**0.89**
	160	**4.91**	**3.18**	**0.94**

Table (A-2): Results of the polymer degradation in two-phase with 10 L/min Gas flow rate

Polymer conc. ppm	Liquid Flow Rate L/min	%DR At t= 0 min 10 L/min	%DR After 30min	%DR After 60min
25	**40**	**3.48**	**2.1**	**1.6**
	60	**3.87**	**2.3**	**1.4**
	80	**3.96**	**2.5**	**1.2**
	100	**4.21**	**2.8**	**1.6**
	120	**4.06**	**2.6**	**1.4**
	140	**3.82**	**2.3**	**1.2**
	160	**3.98**	**2.1**	**0.9**
50	**40**	**16.67**	**14.21**	**12.8**
	60	**17.26**	**15.7**	**14.1**
	80	**17.74**	**16.2**	**14.9**
	100	**19.28**	**17.1**	**15.6**
	120	**18.4**	**16.2**	**15.4**
	140	**16.8**	**14.9**	**13.4**
	160	**17.4**	**15.4**	**14.1**
75	**40**	**16**	**14**	**13**
	60	**17.4**	**15.6**	**14.1**
	80	**18.76**	**15.9**	**14.13**
	100	**19.2**	**16.3**	**15.09**
	120	**18.22**	**15.98**	**15.02**
	140	**20.4**	**17.2**	**16.4**
	160	**18**	**15.8**	**14.2**
100	**40**	**16.66**	**13.19**	**12.8**
	60	**17.4**	**14.4**	**14.1**
	80	**18.98**	**15.3**	**15.1**
	100	**19.6**	**15.89**	**15**
	120	**16.94**	**14.02**	**13.43**
	140	**19.72**	**16.08**	**15.4**
	160	**20.23**	**17.3**	**16.6**

Table (A-3): Results of the polymer degradation in two-phase with 15 L/min Gas flow rate

Polymer conc. ppm	Liquid Flow Rate L/min	%DR At t= 0 min 15 L/min	%DR After 30min	%DR After 60min
25	**40**	**7.28**	**5.8**	**4.93**
	60	**8.1**	**6.2**	**5.16**
	80	**8.86**	**6.66**	**5.6**
	100	**9.92**	**7.42**	**6.52**
	120	**9.32**	**6.92**	**8.82**
	140	**8.8**	**5.98**	**5.41**
	160	**8.84**	**5.84**	**5.21**
50	**40**	**20.2**	**18.32**	**17.7**
	60	**21.6**	**19.03**	**18.8**
	80	**22.44**	**20.02**	**19.07**
	100	**24.42**	**21.84**	**20.78**
	120	**22.43**	**20.8**	**19.79**
	140	**21.98**	**19.87**	**18.9**
	160	**23.41**	**20.09**	**19.4**
75	**40**	**19**	**16**	**15**
	60	**19.6**	**17.06**	**16.36**
	80	**25**	**22.2**	**21.4**
	100	**26.1**	**23.4**	**22.8**
	120	**23.72**	**21.02**	**20.21**
	140	**25.32**	**22.21**	**21.13**
	160	**26**	**23.63**	**22.04**
100	**40**	**16.67**	**14.7**	**13.06**
	60	**26.08**	**23.17**	**22.21**
	80	**23.36**	**20.01**	**19.82**
	100	**25**	**21.07**	**20.3**
	120	**23.72**	**20.03**	**19.49**
	140	**22.78**	**18.98**	**18.01**
	160	**22**	**18.06**	**17.19**

Table (A-4): Results of the polymer degradation in two-phase with 20 L/min Gas flow rate

Polymer conc. ppm	Liquid Flow Rate L/min	%DR At t= 0 min 20 L/min	%DR After 30min	%DR After 60min
25	**40**	**7.84**	**5.72**	**5.39**
	60	**8.72**	**6.08**	**5.82**
	80	**9.36**	**6.97**	**6.13**
	100	**10.42**	**8.21**	**7.32**
	120	**9.38**	**7.21**	**6.09**
	140	**9.2**	**7.4**	**5.94**
	160	**9.12**	**6.09**	**5.8**
50	**40**	**22.46**	**21.7**	**20.6**
	60	**21.41**	**20.9**	**20.09**
	80	**23.64**	**20.84**	**19.96**
	100	**25.28**	**22.86**	**21.56**
	120	**25.6**	**22.89**	**21.6**
	140	**26.4**	**23.92**	**22.82**
	160	**28.4**	**25.9**	**24.6**
75	**40**	**24.**	**22**	**21**
	60	**26.08**	**23.7**	**22.9**
	80	**25.8**	**24.6**	**23.46**
	100	**24.8**	**23.9**	**22.89**
	120	**27.12**	**23.29**	**22.6**
	140	**30.38**	**27.5**	**26.2**
	160	**34.2**	**31.6**	**30.8**
100	**40**	**33.32**	**30.26**	**29.8**
	60	**34.78**	**31.8**	**31.**
	80	**27.26**	**24.4**	**23.2**
	100	**27.9**	**23.9**	**23.02**
	120	**30.5**	**27.2**	**26.7**
	140	**32.92**	**29.7**	**28.13**
	160	**34**	**30.8**	**29.6**

Table (A-5): Results of %DR in two-phase with different salt conc.

Gas (Air) Flow Rate L/min	Liquid Flow Rate L/min	%DR with 0.0% NaCl	%DR with 0.5% NaCl	%DR with 1.0% NaCl	%DR with 1.5% NaCl	%DR with 2.0% NaCl
10	**40**	**16.67**	**16.66**	**16.66**	**24.6**	**32.94**
	60	**17.26**	**17.32**	**17.4**	**21.54**	**26.08**
	80	**17.74**	**17.78**	**17.82**	**18.4**	**19.14**
	100	**19.28**	**17.3**	**16.74**	**14.6**	**13.96**
	120	**18.4**	**16.2**	**14.94**	**14.3**	**13.56**
	140	**16.8**	**14.2**	**12.18**	**11.2**	**10.12**
	160	**17.4**	**13.6**	**10.01**	**7.6**	**6.02**
15	**40**	**20.2**	**25.7**	**33.34**	**35.6**	**36.34**
	60	**21.6**	**22.3**	**23.4**	**24.8**	**26.08**
	80	**22.44**	**20.9**	**19.14**	**21.2**	**22.86**
	100	**24.42**	**20.1**	**18.6**	**17.6**	**16.74**
	120	**22.43**	**19.2**	**17.56**	**16.1**	**14.32**
	140	**21.98**	**18.6**	**15.2**	**14.2**	**12.66**
	160	**23.41**	**16.8**	**12.01**	**11.6**	**10.01**
20	**40**	**22.46**	**28.6**	**33.34**	**38.6**	**43**
	60	**23.41**	**24.8**	**26.08**	**30.4**	**34.78**
	80	**21.64**	**22.1**	**22.86**	**23.**	**24.86**
	100	**25.28**	**21.8**	**16.74**	**15.2**	**16.8**
	120	**25.6**	**22.6**	**18.32**	**16.6**	**15.7**
	140	**26.52**	**23.7**	**19.72**	**17.1**	**15.2**
	160	**28.4**	**24.1**	**20**	**18**	**14.7**

Table (A-6): Results of %DR in two-phase with different Liquid flow rate for three selected air flow rate

Liquid Flow Rate L/min	%DR with Gas (Air) Flow Rate 10 L/min	%DR with Gas (Air) Flow Rate 15 L/min	%DR with Gas (Air) Flow Rate 20 L/min
40	**16.67**	**19**	**24.7**
60	**18.6**	**20**	**23**
80	**22.6**	**25**	**20.3**
100	**24.8**	**26.6**	**18.85**
120	**23.3**	**25**	**20.7**
140	**17.7**	**24.5**	**21.3**
160	**18.0**	**25.7**	**23.0**

APPENDIX B
CALEBRATIONS

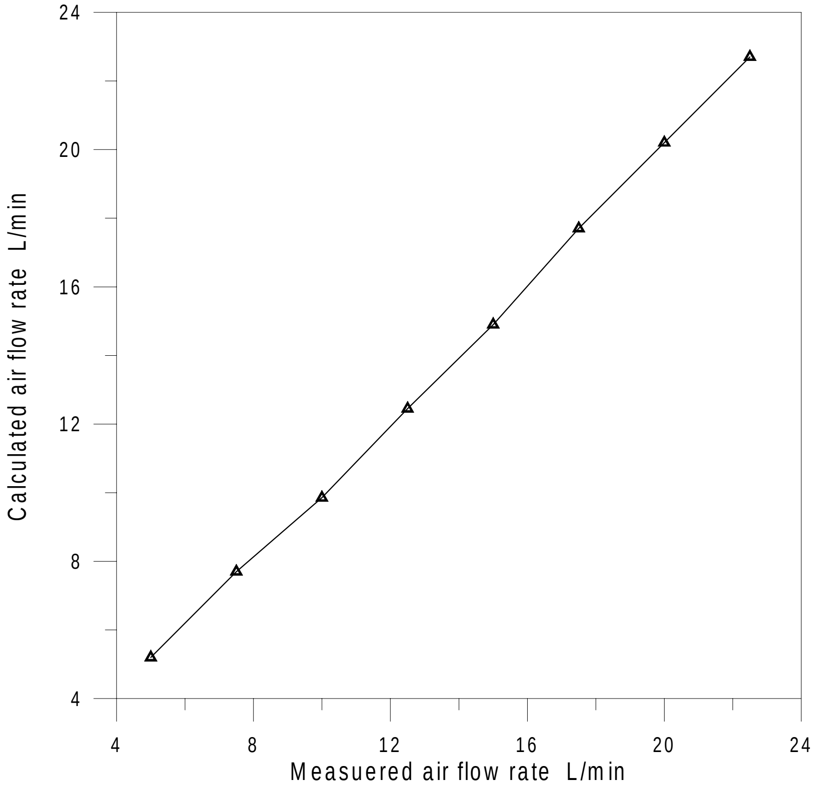

Figure 1: measured air flow rate vs. calculated air flow rate

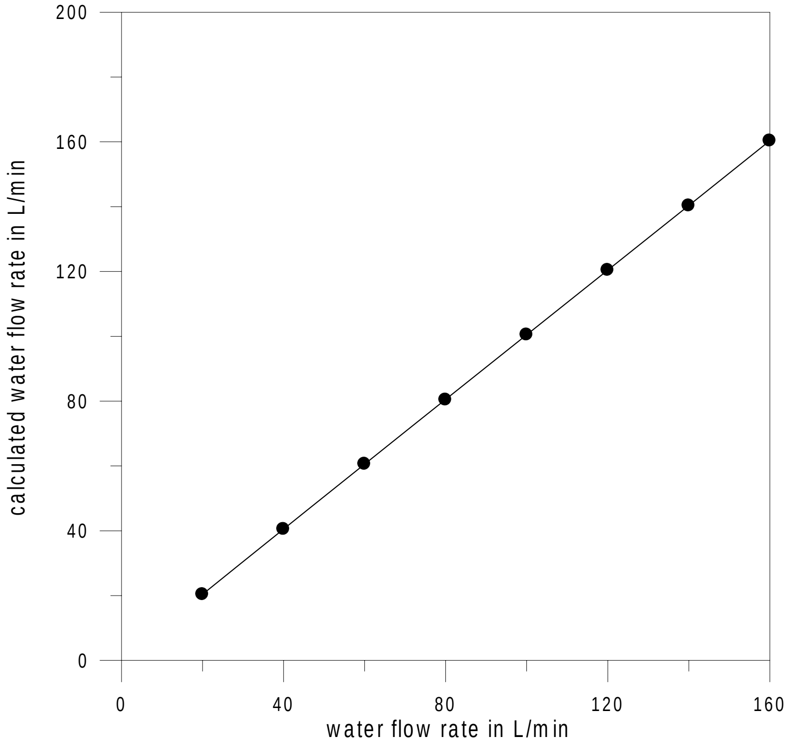

Figure 2: measured water flow rate vs. calculated water flow rate

الخلاصة

من المعروف ان اضافة كمية قليلة من البوليمرات الى سائل نيوتوني ذو جريان أضطرابي ينتج عنه تقليل في قوى الأعاقه والتي تثير كثيراً من الأهتمام في مجالات دراسة جريان الموائع. مع ذلك فأن تأثير تقليل الاعاقه الناتج من اضافة البوليمرات قد تم دراسته في حالة الجريان الأضطرابي للسوائل، وهنالك بعض الدراسات التي تناولت تقليل الأعاقه للجريان ثنائي الطور (غاز- سائل). العمل الحالي يمثل دراسه تجريبيه لتأثير تقليل الأعاقه بواسطة أذابة بوليمرنوع (Xanthan Gum) في الماء وفي حالتي الجريان الأحادي والثنائي الطور(هواء- ماء).

أن مقطع الاختبار يتكون من انبوب بلاستيكي شفاف (Perspex tube) بطول ١.٢ م يسمح برؤية نوع الجريان. عدة تراكيز من البوليمر(Xanthan Gum) ولحد تركيز ١٠٠ جزء بالمليون وبسرع جريان ٨٠-٤٠ لتر/ دقيقه للماء وبسرع جريان ٢٠-١٠ لتر/دقيقه للهواء.

لقد أوضحت النتائج العمليه أن نسب تقليل الأعاقه بأذابة البوليمر(Xanthan Gum) في حالة الجريان ثنائي الطور حققت زيادة ملحوضه عما هي عليه في الجريان أحادي الطور، ولجميع معدلات الجريان المدروسه. أن نسب تقليل الأعاقه تزداد بأزدياد جريان الهواء ولغاية قيمه عليا هي ١٥ لتر/دقيقه. ولكن عند سرعة جريان ٢٠ لتر/دقيقه أنتجت تقليل نسب أعاقة الجريان. أن قدرة تقليل الأعاقه في الجريان ثنائي الطور (هواء- ماء) واضحه حتى في حالة عدم أستخدام مذاب بوليمري.

أن قدرة تقليل الأعاقه في الجريان الأضطرابي ثنائي الطور يمكن أن تعزى الى تكوين فقاعات صغيره جداً والتي تقلل وبشكل واضح قوى الأعاقه في الجريان وفي حالة سرعة جريان الهواء بمعدل ٢٠ لتر/دقيقه حيث نظام الجريان يقترب من التغير من الفقاعات الصغيره (microbubble flow) الى النظام الفقاعي (plug flow) وتقليل تكوين الفقاعات الصغيره الذي كان ملحوظاً من خلال الأنبوب الشفاف.

تم أختيارالتجارب العمليه للتحقق من قدرة البوليمر في تقليل الأعاقه للجريان ثنائي الطور مع وجود كميات قليله من ملح الطعام NaCl وحتى تركيز ٢%، أن وجود هذا التركيز من ملح الطعام في الجريان الأضطرابي ثنائي الطور يزيد من سلوك تقليل الأعاقه في درجات الأضطراب الواطئه (معدلات جريان قليله ٨٠-٤٠ لتر/دقيقه) والذي يؤدي الى زيادة نسبة تقليل الأعاقه.

أن وجود ملح الطعام أدى الى تكوين رغوه وبدرجه عاليه كان من السهل ملاحظتها من خلال الأنبوب الشفاف، والتي زادت من نسبة تقليل الأعاقه. بينما في حالات الجريان الأضطرابي العاليه (معدل جريان أكثرمن ١٠٠ لتر/دقيقه) فأن كمية الرغوه تبدأ بالنقصان مما يخفض نسب تقليل الأعاقه تدريجياً مع أزدياد تركيز الملح.

لقد أظهرت النتائج العمليه أن أضافة البوليمر(Xanthan Gum) يعطي كفاءه تقليل أعاقه مقبوله في حالة الجريان الأضطرابي ثنائي الطور، ولكنه أظهر أضمحلال ميكانيكي للجزيئات غير مرغوب فيه يزداد مع زيادة زمن التدوير.

شكر وتقدير

أقف عاجزاً عن التعبيرعن مدى الشكر والأمتنان الذي أود أن أبديه ألى أستاذيِ الفاضلين الأستاذ الدكتور **جابر شنشول** والأستاذ المساعد الدكتور **عادل عباس** لما بذلاه من جهد وعناء لأخراج هذا الجهد بهذه الحلة الغراء.

واتقدم بالشكر الجزيل الى الاستاذ الدكتور **قاسم جبار سليمان** وجميع الكادر في قسم الهندسه الكيمياويه لما بذلوه في مساعدتي لانجاز هذا العمل.

كما أتقدم بالشكر والأجلال الى والداي الكريمان الذين حفوني بالدموع والدعاء.واشكر عائلتي التي لطالما كابدت عناء البعد والفراق.

وأشكر أخواني وزملائي الذين لم يدخروا جهداً في مساعدتي.

نعيم الحلو

تاثير مضافات تقليل الاعاقة في الجريان الاضطرابي ثنائي الطور

رسالة
مقدمه الى كلية الهندسة في جامعة النهرين وهي جزء من متطلبات نيل درجة
ماجستيرعلوم في الهندسة الكيمياوية

من قبل

نعيم عبد المحسن اسماعيل حسين الحلو
بكالوريوس علوم في الهندسة الكيمياوية ١٩٩٩

ذو الحجة ١٤٢٩
كانون الاول ٢٠٠٨