STUDY OF DRAG REDUCTION IN TURBULENT FLOW USING HIGH MOLECULAR WEIGHT POLYMERS

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by
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Abstract

Drag reduction has been studied in a build-up closed loop water circulation system using two different types of polymers namely: carboxy methylcellulose CMC and Xanthan Gum, XG of molecular weight $0.4*10^6$ and $5.0*10^6$ g/mol respectively. The turbulent mode was produced via a positive displacement gear pump to avoid mechanical degradation of polymer chain during the experimented period. The effect of polymer concentration was investigated over a range of (up to 300 ppm) at different flow rates up to 6 m^3/h and Reynolds number grater than 33418.71 in a flow pipe diameter 1.25 inches. A gradual increase of drag reduction was achieved by increasing the polymer concentration and water flow rate. The drag reduction effectiveness of the lower molecular weight CMC additive is lower than for XG of higher molecular weight. The maximum percentage drag – reduction values were achieved experimentally at 300 ppm polymer concentration and 6.0 m^3/h flow rate. Those are 16% and 23.3% for CMC and XG, respectively.

The drag reduction performance for mixtures of the two polymers, CMC and XG was also studied during this work. The results show that it is possible to enhance the drag – reduction effectiveness of CMC additive by mixing it with XG of high molecular weight.

Part of the experimental work was devoted to study the performance of CMC and XG solutions as drag – reducers with the existence of small amounts of sodium chloride to reduce the drag forces. The results show that sodium chloride acts as an inhibitor to the effectiveness of such additives, resulting in lower percentage drag – reduction values. This could be attributed to the fact that CMC and XG additives as polyelectrolyte molecules collapse at more compact structure with the addition of sodium chloride as strong ionic salt.

The time dependence of drag – reduction effectiveness undergoes molecular shear degradation during turbulent flow. Thus, the percentage drag – reduction reduces rapidly during the early stages of circulation for both additives. The degradation is more likely to occur at low concentrations.

A simple correlation equation was suggested to predict the effect of flow parameters, additive molecular weight and concentration, flow rate and finally sodium chloride molecular weight and concentration on percentage drag – reduction. The results of the correlation showed satisfactory agreement between observed and predicted values with about 96% correlation coefficient for both CMC and XG additives.

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Variable Notations

Symbols	Description	Unit
C	Polymer concentration	[ppm]
d	Pipe diameter	[m]
L	Testing section length	[m]
L_e	Entrance length	[m]
M_w	Solution molecular weight	[g/mole]
Q	Volumetric flow rate	[m^3/hr]
Re	Reynolds number	[-]
T	Temperature	[°C]
U	Solution velocity	[m/s]
%Dr	Percentage drag reduction	
%TI	Percentage flow increase	

Abbreviations

Abbreviations	**Definition**
CMC	Sodium carboxymethylcellulose
CTAC	Cetyl tri–methyl ammonium chloride
DR	Drag Reduction
DRA	Drag Reduction Agent
NaCl	Sodium Chloride
PAM	Poly acryl amide
PEO	Polyethylene oxide
PIB	Polyisobutylene
STAC	Stearyl tri –methyl ammonium chloride
XG	Xanthan gum

Greek symbols

Symbols	Description	Unit
ΔP	Pressure drop	[N/m^2]
ΔP_s	Pressure drop after adding polymer	[N/m^2]
ΔP	Pressure drop before adding polymer	[N/m^2]
ρ	Fluid density	[kg/m^3]
η	Dynamic viscosity	[poise]
f	Fanning friction factor	
μ	Dynamic viscosity	[Pa.s]
υ	Kinematic viscosity	[c.st]
$[\eta]$	Intrinsic viscosity	[poise]

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Chapter One

Introduction

1- Introduction

A considerable energy may be expanded during the process of transferring fluid through a pipe to overcome friction encountered in movement of the liquid. When a liquid is pumped under pressure, friction pressure is apparent as a pressure drop along the pipe. Such a pressure drop is particularly noticeable under conditions where the velocity of liquid has surpassed the critical limit for laminar flow. Drag is a term used to refer to such frictional pressure drop(1).

Additional energy must be consumed to compensate for the loss of energy due to friction, or to reduce the drag. Many techniques for reducing drag were suggested by many researchers for larger number of applications. One of these techniques depends on suppressing turbulent eddies by using baffles with different heights in turbulent flow region. Other techniques used layers of greasy material or bubble layers to reduce skin friction. One of the modern techniques is the addition of minute quantities of a dilute polymer solution to liquids transported in turbulent flow through pipelines, which can lead to significant drag – reduction (DR). This phenomenon has received much attention, since its discovery more than 50 years ago. Nevertheless, detailed knowledge about the main mechanism for the action of the polymer and its effect on turbulence is not available(1).

Drag reduction phenomena had been well documented in which the fluid that containing these additives requires a lower pressure drop than pure solvent to maintain the same flow rate in a pipe. This behavior can offer large economic advantages and a larger effectiveness of the pipeline transportation(1). High molecular weight polymers were used since the early researches concerned with drag reduction phenomena. The commercial application of polymeric drag reducers were established for crude oil (or water) transportation by many companies like CONOCCO and TAP. These applications showed the high ability of polymers in reducing drag and increasing oil flow rate without the need for any additional any pumping stations or new pipelines. Also, these applications showed many disadvantages of using polymeric drag reducing agents, such as changing the transported liquid properties (especially viscosity) within certain limits of polymers concentration and the polymer stability against high shear forces (shear degradation).(2)

Power saving is the major concern of all the investigation involved in what is called "drag reduction filed". Reducing drag of transported fields through a pipeline caused by friction and turbulence losses have a great benefit from economical point of view. Drag reduction may occure using different technologies with different types of materials.

In liquid transportation through pipelines, the addition of small amounts of chemical additives (generally polymers or surfactants) to the flowing of liquid in turbulent mode, will lead to the reduction in pressure drops which is a clue about the power saving made in the system. Another technique for drag reduction was suggested. Which depends on adding small amounts of solid particles to a flowing liquid in turbulent manner through pipelines. The addition of these particles vanishes one of the major assertions in the drag reduction technique by chemical addition; which is usually a soluble in the transported liquid or have the water, the condition that the drag reducer must be a soluble or at last has the ability to penetrate or its molecules reorient in the transported liquid to be affected. This behavior suggested a new and nearly independent mechanism to explain the behaviors(3).

Polymeric fluids are called viscoelastic fluids. This means that the fluid has both viscous and elastic properties. Maxwell (4)proposed a model that could combine the viscosity and elasticity in to a single constitutive equation. The theoretical basis of the Maxwell fluid assumed that the application of a stress to the fluid causes some ordinary elastic deformation flowed by a Newtonian type of viscous deformation.

Effective polymeric Drag-reducing additives are considered to be flexible, linear with a high molecular weight such as polyisobutylene(5). The dependence of drag reduction efficiency is known to be function of polymer molecular weight; polymer concentration and the degree of turbulence. The additives undergo undesirable mechanical and chemical degradation under turbulent flow and rotation speed. Longer linear molecules are more susceptible to degradation, accompanying more rapid degradation.

The reological characteristics of drag- reducing polymeric solution are not only quite complex, they are generally difficult to evaluate quantitatively because of the low concentration of a polymeric solution. These properties are coupled with the complex system which is virtually difficult to analyze precisely. Consequently, various approximation and simplifying assumptions are necessary in order to obtain a relationship between observable quantities(6).

The current objective of the present investigation is to study the turbulent drag reduction effectiveness of CMC and XG in water flow using a laboratory circulation closed loop system. Furthermore the screening study is to evaluated the additives with respect to their concentrations, degree of turbulence and circulation time.

The main aim of the experimental study is to investigate the effect of presence of salt (i.e NaCl) in the flowing water on the effectiveness of the drag reducers under different concentrations and turbulency.

Chapter two

Literature Survey

2.1 Introduction

The Reynolds number, which is a non–dimensional parameter expressing the ratio of internal forces to viscous forces, is regarded as a general criterion for ascertaining the type of flow as laminar or turbulent. In case of pipe flow, the Reynolds number is defined as

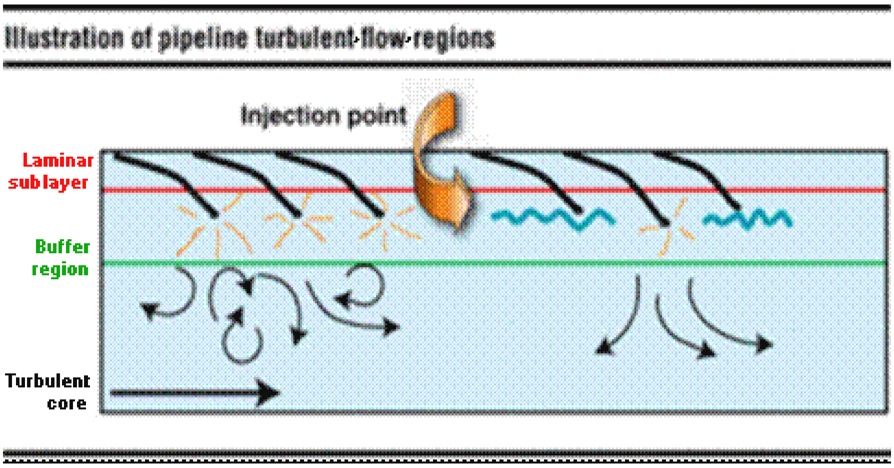
$$Re = \rho U d/\mu \qquad \ldots(2.1)$$

The critical Reynolds number is that value of Reynolds number at which transition is expected to occur. In the fluid flow, three separate regions can be distinguished (7): laminar flow region ($Re < 2000$), transition region ($2000 < Re < 3000$) and turbulent region ($Re > 3000$).

Turbulence is generated in any of the following ways: First, in a flow having abrupt discontinuous velocity distribution. The surface of discontinuity occurs whenever two fluid streams come together in such a way as to cause a sudden jump in velocity between adjacent layers. Secondly, in a flow where velocity gradient occurs without abrupt discontinuity (8).

The pipe fluid flow results in three regions across the pipe diameter : The laminar sub layer , The buffer region and the turbulent core as shown in figure (2.1) . Fluid near the pipe wall (The laminar sub layer) tries to stay stationary while fluid in the center region of the pipe (the turbulent core) is moving quickly . This large difference in fluid velocity between the laminar sub layer and the turbulent core cause turbulent bursts to occur in the buffer region . Turbulent bursts propagate and form turbulent eddies , which cause inefficiencies in the hydraulic energy that drives the fluid down the pipeline.

The net result of using of drag – reducing polymer in turbulent flow is a decrease in the frictional pressure drop in the pipeline . Turbulent and the resulting frictional pressure drop have been show to be reduced by as much as 70% with drag – reducing polymer(9).



Fig(2.1)Drag reduction occurs due to suppression of the energy dissipation by turbulent eddy currents near the pipe wall during turbulent flow

Drag Reduction , as defined by Savins (10) is the increase in pump ability of a fluid caused by the addition of a small amount of an additive to the fluid . The effectiveness of a drag reducer is normally expressed in terms of percent drag reduction

Drag reduction may occur as one of two types ; The extension of laminar behavior to abnormally high Reynolds numbers (turbulent suppression) or the reduction of friction in fully developed turbulence

(wall layer modification) . If the second behavior begins at low Reynolds number it will be difficult to distinguish (indicating the first type of behavior)(11) .

Power saving is the major headline for many investigations that deal with drag reduction. The word "drag" may be defined as the resistance force parallel to the direction of fluid flowing over a solid surface; Drag force may be expressed by two components: "Skin friction component" which is equal to the stream wise component of all shearing stresses over the surface and a "pressure drag component" which is equal to the system wise component of all normal stresses(12).

2.2 Drag Reduction

2.2.1 phenomenon

Drag reduction is a phenomenon in which the friction of a liquid flowing in a pipe in turbulent flow decreases by using small amounts of an additive. This is beneficial because it can decrease pumping energy requirements. The used drag reducing additives are effective because they reduce the turbulent friction of the solution. This results in a decrease in the pressure drop across a length of pipe and likewise reduce the energy required to transport the liquid (13).

The drag reduction was observed by Mysels (14). Mysels compared the pressure drop of gasoline and of gasoline thickened with aluminum disoaps flowing through the same pipe. The first description of drag reduction was given by Tom (15), who studied the effect of flow rate with various concentrations of poly methyl methacrylate in mono–chlorobenzene through two different pipes diameter. The addition of small amounts of polymer will reduce the friction factor of turbulent flow in pipes. Decreasing pipe diameter will increase drag reduction.

The drag reduction phenomenon by polymer additives is very interesting from a fundamental fluid dynamics point of view. The fact that such small changes in the fluid can be so drastically alter the turbulent flow characteristics strongly hints at the existence of a key mechanism of turbulence momentum transport with which the polymer interferes. It means that a study of polymeric drag reduction could help in gaining more knowledge about the turbulence itself(1).

Many techniques for reducing drag were suggested by many researchers for a large number of applications. One of these techniques depends on suppressing turbulent eddies by using baffles with different heights in turbulent flow regions, as in channel flow(16). Other techniques used layer of greasy materials or bubble layer to reduce Skin-friction, as in some marine application in ships(17). One of the modern techniques in drag reduction is by the addition of minute quantities of chemical additives to liquid transported in turbulent flow through pipelines. That in some cases, is necessary to increase the transported liquid flow rate in built pipelines to avoid any extra cost and time spent on building new pipelines to have the same flow improvements needed. So, drag reducers were used to overcome this problem. Polymers and surfactant are the most popular chemical drag reducing agents in commercial applications(18) .

The are several types of additives which cause drag reducing phenomena to occur. These include surfactants, polymers, aluminum disoaps and fibers. Research on polymers was originated with the first appearance of drag reduction phenomena. As drag reducing agents, many researchers used polymers in their studies (19).

The addition of DR additive is done by two different methods, resulting in two different types of drag reduction, homogeneous and heterogeneous(20). Dissolving the polymer in the fluid before the experiments is done in the case of homogeneous DR. The onset shear stress as well as the obtainable magnitude of drag reduction are essentially determined by the molecular parameters of polymer. While, by injection of low concentrated polymer solution in turbulent pipe flow resulted in a heterogeneous DR. The turbulent mixing process as well as the interaction between polymer solution and turbulent flow determine the drag reduction effectiveness.

2.2.2 Applications :

The addition of polymers to systems with turbulent flow for drag reduction purposes require not only the technical benefit of reduced energy consumption, but also economic and environmental benefits.

Many possible applications of drag reduction with polymer additives have been suggested over the last 50 years. Most of these suggestions have remained commercially unexploited because of two reasons. Economies, material costs for polymer additions are too high compared to pumping power savings; plus any polymer addition would require injection equipment and controls that need to be purchased. Performing, the drag reduction effectiveness of polymer additions, is curtailed by rabid shear degradation. With regard to adverse environmental impact, the polymer/additives are relatively innocuous(21).

In spite of the two limitations, cost and degradation, there are commercial applications for polymeric drag reduction agents. Some current applications where drag reduction has been applied include oil transmissions pipelines and district cooling and heating(22).

The application of polyalphaolefins in the Trans-Alaska pipeline result in no adverse environmental impacts. Drag reduction increases oil flow rate of an existing pipeline. But, drag reduction reduces heat transfer rates between the oil and the ambient air. Thus, in the transportation of oil cooling is reduced. The crude oil remains warmer in the pipeline. This fact lowers oil viscosity which result in greater saving in pumping power(23).

The application of polymer additives for crude oil transportation also includes many off-shore pipelines in different parts of the world. For this field, a series of practical articles on the drag reduction was published by Lester in 1985(24, 25).

The use of polymers for drag reduction has been tested in human blood to improve flow during transfusion and in occluded tubes (arteries). Such tests have been conducted since the late 1960s. In the early 1970s the University of Akron had a 5-year program in place on drag reduction in blood flow. One polymer, polyethylene oxide has been tried at low concentrations, between 5 and 100 ppm(21).

Turbulent drag – reduction has also an application in the Fire fighting. One of the first tested concepts for the application of polyethylene oxide for drag reduction was in pampers of New York Fire Department. The use of polyethylene oxide decreased pumping power, increased throw, allowed longer hose lay, and higher delivery rates. The polyethylene oxide also enhanced the coherence of the water jets(21).

Another application of drag – reducers is in hydraulic machines. In the early 1970s, some tests of drag reducing polymers were conducted that indicated: that the performance of centrifugal flow pumps could be increased by 5 to 10 percent using polyacrlamides concentration below 100 ppm(21).

Attempts have been made to reduce the drag on hydrofoil craft by polymer additives. Hydrofoils travel fast and the location of the wake separation is important. This has been shown to be significantly affected by polymer additives(22).

Polymers, such as polyethylene oxide and polyacrylamides have been tried in agriculture to increase water flow rates for irrigation purposes. In some instances a fertilizer has been combined with water. Of course, the environmental impact of the polymers on the crops needs to be ascertained(22).

During rapid water flow, the small turbulent eddies generate noise. This effect can be mitigated by polymer additions. The noise signature of pumps and submarines has been altered by polymer additions. This effect is of possible interest for submersible vessel detection(26).

The transport of ash, coal, sediments, etc. by pipelines can have lower pumping power costs by the use of polymer additives. This application has a potential wide application because of the high tonnage of such solids at many locations worldwide. Several slurry transport studies have been made of the use of polymers during the 1970s and 1980s, including cost estimates(26).

2.2.3 Theories:

Since the discovery of the drag reduction effect, several theories and mechanisms of the phenomena were proposed. All of these are semi empirical or highly speculative, and all have been subjected to criticism. The common theories describing the drag reduction mechanisms are listed below.

1- Wall layer modification hypothesis

Oldryod (27) 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 (28) 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.

Virk et al. (29) described the maximum drag reduction in turbulent pipe flow of dilute polymer solution 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.

Elperin et al. (30) 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.

Fortuna and Hibberd showed that the presence of drag–reducing polymers reduces the frequency and the magnitude of the fluctuations in the velocity gradient at the wall.

Smith et al. (31) 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.

Gustavsson (32) 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 is found that the thickness of this layer grows linearly with wall shear stress from the onset point.

Savins et al. (33) 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.

2- Turbulent suppression hypothesis

Charachafchy (34) 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. 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.

Rodriguez et al. (35) 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.

Lumley (36) 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.

Lumley (37) suggested that the effective viscosity in the buffer zone layer with strong deformation (polymer expand) is the key of drag reduction.

Many researchers (38) 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.

DeGennes (39) 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.

3- Viscosity Gradient Theory

This theory is well defined through the flowing explanation:

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 cross 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.

It was also proposed that the decreased friction factors and sharper velocity profiles, which were measured, could be attributed to the viscosity damping effect But, 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. Example of these solutions are (CMC, and a poly (acid), poly (viny1) alcohol dissolved in water, and polyisobuty in cyclohexane)(40).

4- 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(41).

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(42).

5- Elastic Teroy

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)(41).

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 elogational viscosity near wall is because the extensional strain rates are the highest there, the increased elongational viscosity suppresses turbulent fuctuations, increases the buffer layer thickness and reduces wall friction(43).

2.3 Drag reducing agents

2.3.1 Polymers

Various drag- reducing additives are available, such as flexible long- chain macromolecules, colloidal surfactants and suspension of fine, insoluble fibers or particles(44). Among these, macromolecules, which posses a linear flexible structure and a very high molecular weight, have been widely investigated as drag reducers(10).

Drag reducer polymers are classified into two groups , water – soluble and oil soluble polymers , as listed in table (2.1)(40).

Table 2.1 Drag – reducing polymer additive

Water soluble	Hydrocarbon soluble
Polyacrylamide (PAM)	Polyisobutylene (PIB)
Polyethyleneoxide (PEO)	Polyethyeneoxide (PEO)
Guar gum (GG)	Polymethylmethacrylate (PMMA)
Xanthan gum (XG)	
Soduim carboxymethylcellulose (CMC)	Polydimethylsiloxane (PDMS)
Hydroxyethylecellulose (HEC)	Polycisisoprene (PCIP)
	Polystyrene (PS)

Effective polymeric drag reduction additives are considered to be flexible, linear with high molecular weight (45)such as polyethylene oxide(46), polyacrylamid and polyisobutylene. These polymers are limited because of their susceptibility of flow- induced shear degradation. 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 stresses.

Polyethylene oxide (PEO) has been the most widely studied for both laboratory and commercial applications, including fire fighting and marine propulsion. (PEO) is a linear, flexible molecule which is available commercially in range of molecular weight, Its utility in multiple pass application is limited due to its extreme sensitivity to shear degradation. Drag reduction similar to that obtained in water has been shown for PEO in other solvents such as, sea water, plasma, benzene, dioxane, and chloroform. Mixed (PEO) system, such as (PEO) graft polymer, polymer/soap and polymer/dye mixture, have shown to provide varying levels of drag reduction effectiveness (47).

Poly(acrylamide) (PAM) is the other synthetic water soluble that differs from PEO in that it has a side chain and is less susceptible to shear degradation. The related polymer poly(acrylic 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 larger body of previously reported experiments describing their solution behavior available in the literature(48).

Polyisobutylenes (PIB) are highly olefinic hydrocarbon polymers, composed of long, straight chain macromolecules containing only chain-end olefin bonds. This molecular structure leads to chemical inertness and resistance to chemical or oxidative attack, and solubility in hydrocarbon solvents. All grades of polyisobutylene are mixtures of molecules of varies sizes (48).

2.3.2 Surfactants :

Surfactants are surface active agents which are the main constituent in soaps and detergents. Apart from the classical soaps, which are the alkaline salts of higher fat acids, new surfactants have been synthesized over the years, which also consist of a polar (hydrophilic) head and nonpolar (hydrophobic) tail. Depending on the electrical charge of the head group, the surfactants can be classified as anionic, cationic and nonionic. When the concentration of a surfactant solution exceeds a critical value, the surfactant molecules start to form aggregate, ie. Micelles. The association of the molecules to micelles is reversible (49).

When the concentration is below the critical value the micelles will dissociate into molecules again. 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(50).

Although the effect of surfactant solution on DR was conducted by Mysels as early as 1949(51), 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(52) ,and Shaver and Merril (53). Surfactant solution have 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. Shenoy reviewed the use of surfactant systems for DR. The study compares the DR effectiveness and outlines the morphological differences of micelles and polymeric solution(22).

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 (54).

The most effective way to reduce costs in closed – loop district heating and cooling systems is by using quaternary ammonium salt cationic surfactants, as drag reducer (55).

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.(56)

The disadvantage of this type of additives is that, the surfactant drag reducing additives require higher concentration (i.e. 2000 ppm), if it is compared with high molecular weight polymeric additives (about 50 ppm) this will lead to higher economic cost.(57)

2.4 Factors affecting the Drag Reduction

2.4.1 Drag reducer concentration

The effect of polymer concentration on drag reduction is shown in Fig. (2.3), which displays data taken in the same pipe for solution of the same polymer ranging in concentration from 50 to 1000 w ppm. 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(58).

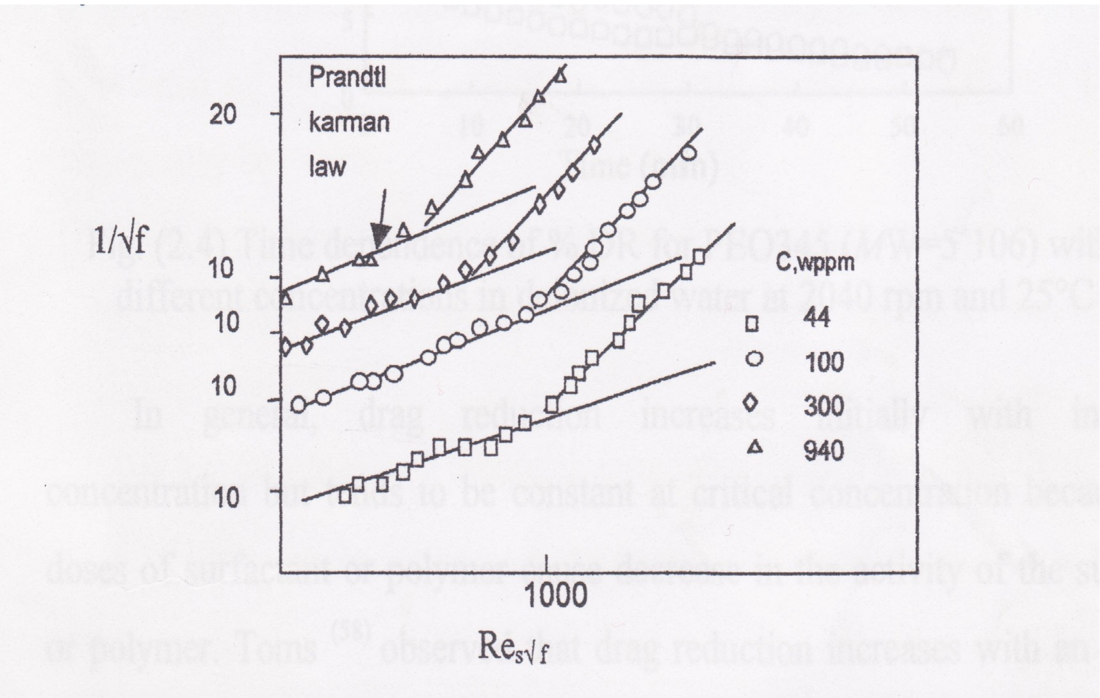


Fig (2.2) Aspects of the polymeric regime. At different concentrations, pipe I.D. 8.46 mm temperature 25C?, solvent distilled water, polymer PEO, M=0.57*10$^{6(58).}$

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, exists concentration at which the drag reduction is maximized.

In general, drag reduction increases initially with increasing concentration but tends to be constant at critical concentration because high doses of surfactant or polymer cause decrease in the activity of the surfactant or polymer. Toms (59)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(60). Using a rotating disk apparatus(61) or a rotating cylinder (62)DR induced by water and solvent-soluble polymers (polyisobutylene) showed similar results to the experiments performed with a small tube, in circulation loop.

2.4.2 Effect of Flow Rate

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. This is that is postulated by the other working parameters in this field as shown in figures (2.5). The causes may be:

1. At high flow rate degradation may occur in drag reducer(63).
2. At high flow rates through high rough by pipe decrease in drag reduction is expected (63).
3. According to elastic theory, drag reducer doesn't stretch fully at high flow rates (64).

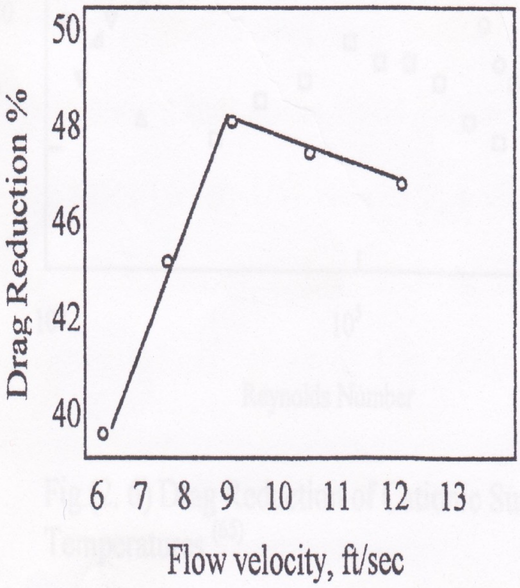


Fig (2.3) flow velocity. Vs. drag reduction%(63).

2.4.3 Effect of Pipe Diameter and Pipe Roughness

Investigators differed in determining the effect of pipe diameter. Some Investigators explained that drag reduction increases with decrease in tube diameter when Reynolds number is held constant(65), as shown in figures(2.4). 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 pip diameter.

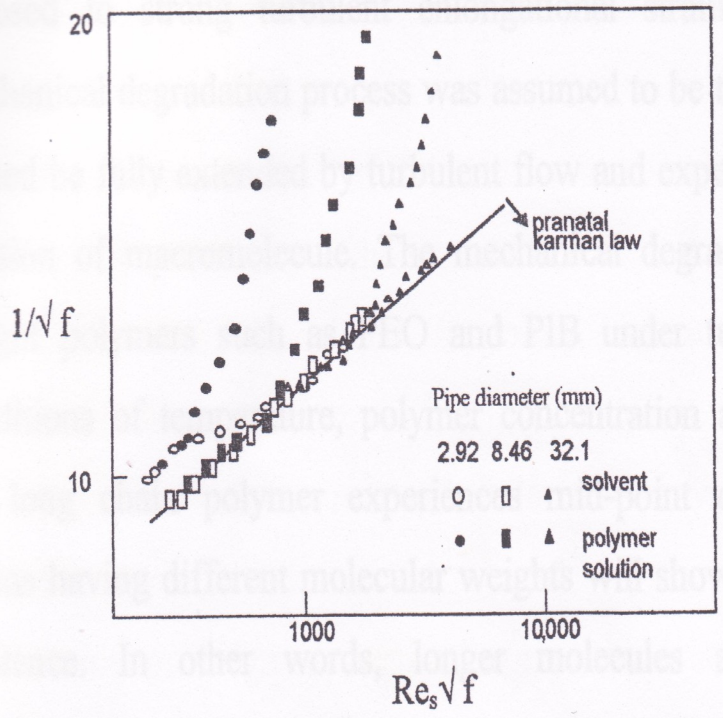


Fig (2.4) Effect of pipe diameter. Pipe I.D. 2.92, 8.46, and 32.1 mm, temperature 25 C?, solvent water, polymer solution PEO(65).

From experiments in a 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 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(66).

2.4.4 Effect of Temperature and Viscosity

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(67). The effect of temperature on drag reduction is shown in figure (2.6). 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(68).

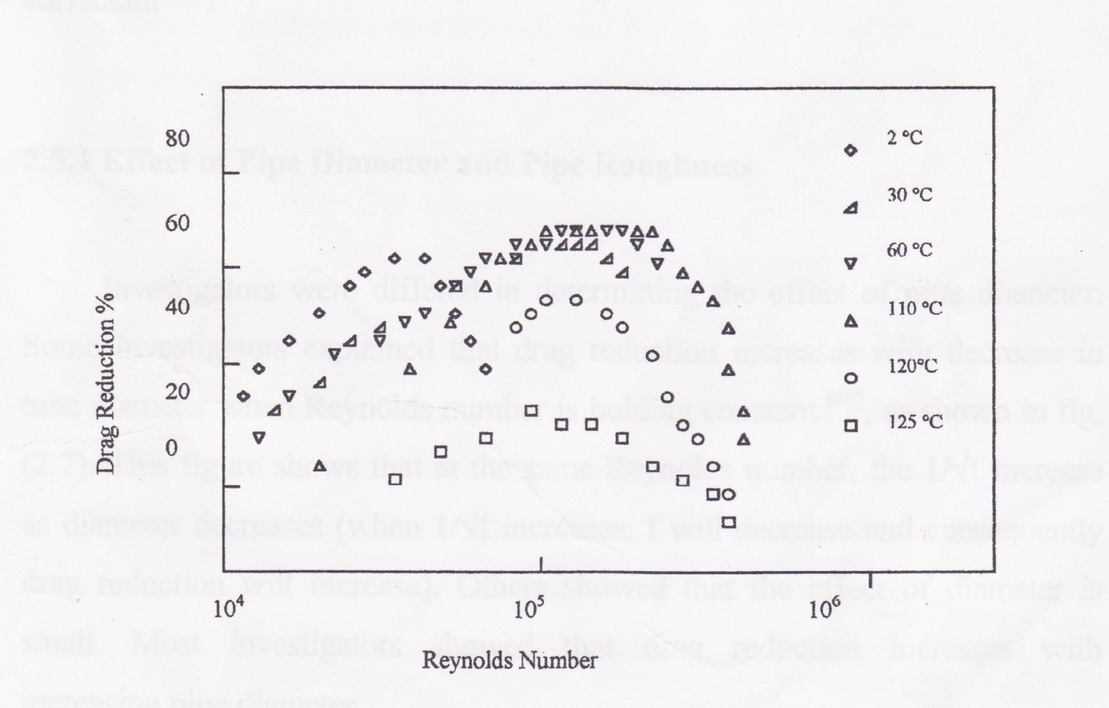


Fig (2.5) Drag Reduction of Cationic surfactant with Different Temperatures(67).

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(69) 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(68).

2.4.5 stability

The drag-reducing additives demonstrate a 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 elongational strain and shear stress. 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.

The stability of some drag-reducer additives such as polyethylene oxide, acrylamide, sodiumacrylate and polyvinyl pyrrolidones in water and polyisobutylene in mineral oil was studied . From the investigation on bent tubes of various geometries it can be concluded that the efficiency of the polymers is strongly dependant on their mechanical degradation(70).

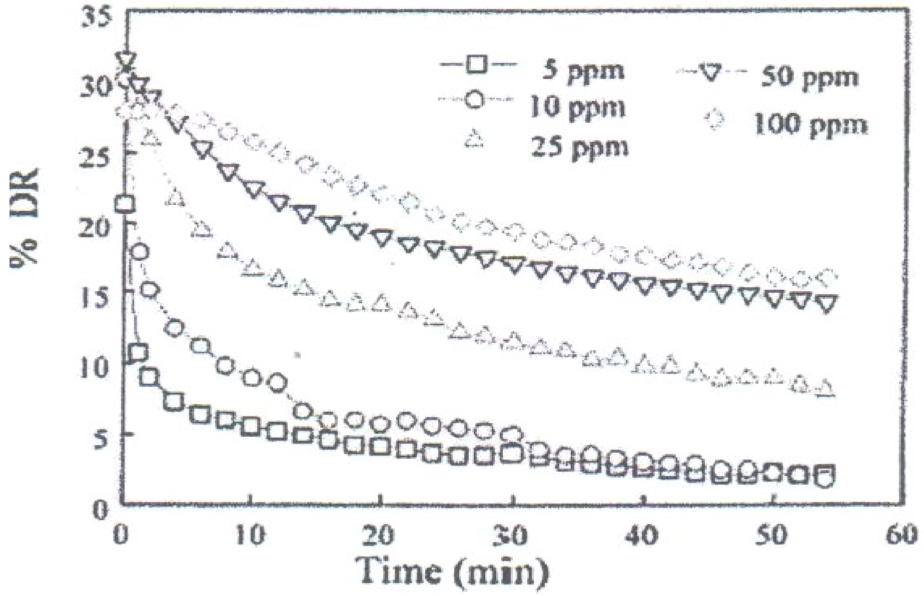


Fig (2.6) Time dependence of %Dr for PEO345(MW=5*10^{6}) with five different concentrations in deionized water at 2040rpm and 25 C?$^{(70)}$.

Figure (2.6) shows some results of time dependence of drag reduction by using polyethylene oxide at different concentrations. The decrease of drag – reduction efficiency with time is clear.

2.5 Properties of CMC and XG

2.5.1 Carboxymethyl cellulose (CMC)

Sodium carboxymethly cellulose is a water – soluble an ionic linear polymer. Purified sodium CMC (which is cellulose gum) is a white to buff – colored, tasteless, odorless and free – flowing powder. Sodium CMC is probably used in more varied applications world wide than any other water soluble polymer today. CMC is used widely in the production of detergents, drilling fluids, paper, textiles, food, coating and cosmetics$^{(71)}$.

The growth of CMC was accelerated by the world conflict in the early 1940s when faty acids usage was drastically shifted from civilian soap manufacture to wartime manufacture of explosives. The major growth in the use of CMC began after it was discovered that it improved the efficiency of synthetic detergents for Anti – Soil Redeposion. With the end of the world conflict in 1945 and with huge demands for consumer products. CMC, backed with several years of laboratory studies, began finding uses in all types of areas requiring water control in systems with various levels of soluble and in soluble solids. The main properties and characteristics CMC are mentioned as follows(71).

a- Chemical Nature of CMC

Cellulose is a linear polymer of 3- anhydrogloucose units. Each anhydroglucose unit contains three hydroxyls groups. CMC is prepared by the reaction of the cellulose hydroxyls with sodium monochlor oacetate as follows:

$OH + NaOH + ClCH_2\ COONa \rightarrow ROCH_2COONa + NaCl + H_2O$

R: cellulose unit

The extent of the reaction of cellulose hydroxyls to form derivative called the degree of substitution (DS) and defined as the average number of three hydroxyl groups in the an hydro glucose unit which have reacted. Thus, if only one of the three hydroxyl, groups has been carboxy methylated the DS is 1.0(71).

Commercial product have DS values ranging from 0.4 to 1.4. The most common grade has a DS of 0.7 to 0.8 CMC is commercially available in several different viscosity grades ranging from 4.5 pa.s (4500 cp) in 1% solution to 0.010 pa.s (10 cp) in 2% solution. The various viscosity grades corresponding to products having molecular weights from about

40000 to 1.000000. CMC which is used as polymer additive in this present investigation has the following specifications:

DS = 0.7

MW = 4000000

μ = 4000 cp

CMC is a salt of a carboxylic acid having approximately the same strength as acetic acid. A dilute solution of CMC has a P_H of about 7 and the over 99% of the carboxylic acid groups in the sodium salt form and only very few in the free acid form. CMC forms soluble salts with alkali metel and ammonium ions. Calcium ion present in concentrations normally found in hard water prevent CMC from developing its full viscosity, and thus its dispersion is hazy. At much higher concentrations, calcium ions, precipitate CMC from the solution(71).

b- physical properties

CMC is very hydrophilic polymer whose equilibrium moisture increases with DS. ie the equilibrium moisture content for product of DS 0.4, 0.7 and 1.2 increases rapidly with relative humidity of the weather.

The molecular weight could be calculated from the intrinsic viscosity measurement in 0.1% NaCl at $25C^?$ using the relationship

$$(\eta) = 2.9 * 10^{-2}\, Mw^{0.78} \qquad \ldots\ldots(2\text{-}1)$$

Where (Mw) is the weight average molecular weight.

Table (2-1) below shows the molecular weight form some commercial types of CMC(71).

Table (2-2) Molecular weight and solution of viscosity of CMC of DS 0.9

Commercial grad	Conc.%	Viscosity		Molecular weight
		Pa.s	cp	
7H	1	1.5-25	1500-2500	70000
7M	2	0.3-0.6	300-600	520000
7L	2	0.025-0.05	25-50	10000
7LZ	2	0.018 or less	18 or less	50000

The only good common solvent for CMC is water. The degree of dispersion in water varies with the DS and molecular weight. CMC with DS of 0.7 may dissolve in glycerin, particularly in the presence of slight amount of water. Table (2-2) shows some of the physical and mechanical properties of CMC(71)

Table (2-3) Typical physical and mechanical properties of CMC at DS 0.7

Specific gravity. 2% sol. at 25C?	1.0068
P_H 2% sol.	7.0
Surface tension. 1% sol. at 25C?	71 dyn/cm
Refractive index, 25 C?	1.515
Elongation% at break	14.3
Tensile strength (mpa)	103.42

c- Rheology

probably the most useful property of CMC is its ability to impart viscosity and other special rheological properties to its aqueous solution to exhibit many typical rheological properties of linear polymers. Most solutions of CMC are pseudo plastic, that is, the measured viscosity decreases with the increase in shear rate. The viscosity not only depends on the shear history, but also on the time after shearing when the viscosity is measured.

The viscosity of CMC in a glycerin – water mixture is greater than the viscosity in pure water; the viscosity in the two solvents appear to be proportional to the viscosities of the solvents(71).

2.5.2 Xanthan Gum (XG)

Xanthan gum is a higher molecular weight natural carbohydrate rate. Its polysaccharide produced in a pure culture fermentation, by the microorganism xanthomonas compactors. The chemical structure of xanthan gum is based on the most recent experimental evidence. The molecular weight is of the order of one million. Xanthan gum contains three different monosaccharide: mannose, glucose, and glucuronic acid (as a mixed potassium, sodium, and calcium salts).

Table (2-4) shows some physical properties of the XG:

Table (2-4) physical properties of XG

Specific gravity	1.6
Bulk density, kg/m^3	839
P_H	7.0
Surface tension, dyn/cm	75
1% viscosity, pa. sec	0.85

Xanthan Gum solution has apparent high viscosity at low solid concentrations and a shear rate of 11 s^{-1}. The effect of salt on the viscosity of xanthan gum solution depend upon the solution concentration of xanthan gum. At low gum concentration below 25% the addition of salt (sodium chloride) causes a slight increase in the viscosity. But at higher concentration , the salt will increase solution viscosity. 0.08% concentration of salt in the solution will yield an ultimate solution viscosity after which the addition of more salt will have no effect on viscosity(71).

An important property of xanthan gum is the control of aqueous rheological properties. Water solution of xanthan gum are extremely pseudo plastic. When shear stress is applied the viscosity is reduced in proportion to the amount of shear. When the shear is released, total viscosity recovery occurs almost instantly.

Xanthan gum, solution are usually more resistant to degradation. A (1%) xanthan gum solution that was sheared at 46000 s^{-1} exhibited on viscosity loss after one hour.

Xanthan gum is usually used as a thickening agent such as in paints paper coating, and in Textile printing and surfactant(71)

Chapter Three

Experimental Work

3.1 Materials

The drag-reduction polymers were carboxymethyle cellulose and xanthan gum of molecular weight of $0.4*10^6$ and $5.0*10^6$ g/mol respectively which were supplied by the general company of vegetable oil industries, Baghdad. A tap water was used as flowing fluid. The analysis of tap water was done in laboratory of Environmental ministry, Baghdad. The average results are shown in table (3.1)

Table (3.1) Salt Analysis of Tap Water

Salts	*(Mg / L)*
Calcium	**48**
Magnesium	**37**
Chloride	**43**
Total dissolved salts	**394**
Total hardness as $CaCo_3$	**272**
pH	**7.5**

3.2 Preparation of polymeric Solution

The method of solution preparation adapted here was to make 3% by weight concentration in a separate container. Thus 10.82 g of corresponding polymer is mixed with 350 ml tap water at laboratory temperature. The container was placed in an electrical shaker, type KOTTERMANN 4040, GERMANY,100 rpm as shown in fig (3.1). The shaker was used instead of mechanical stirrer to avoid any polymer degradation; hence the shaker has no sharp edge that could expose to high shear force. The shaking was started at 40 rpm and increased with 10 rpm after every 24 hours. A homogenous solution was obtained, after 3 days for CMC, and 5 days for XG (6).The solution is allowed to stand for 24 hours at room temperature prior to its use.

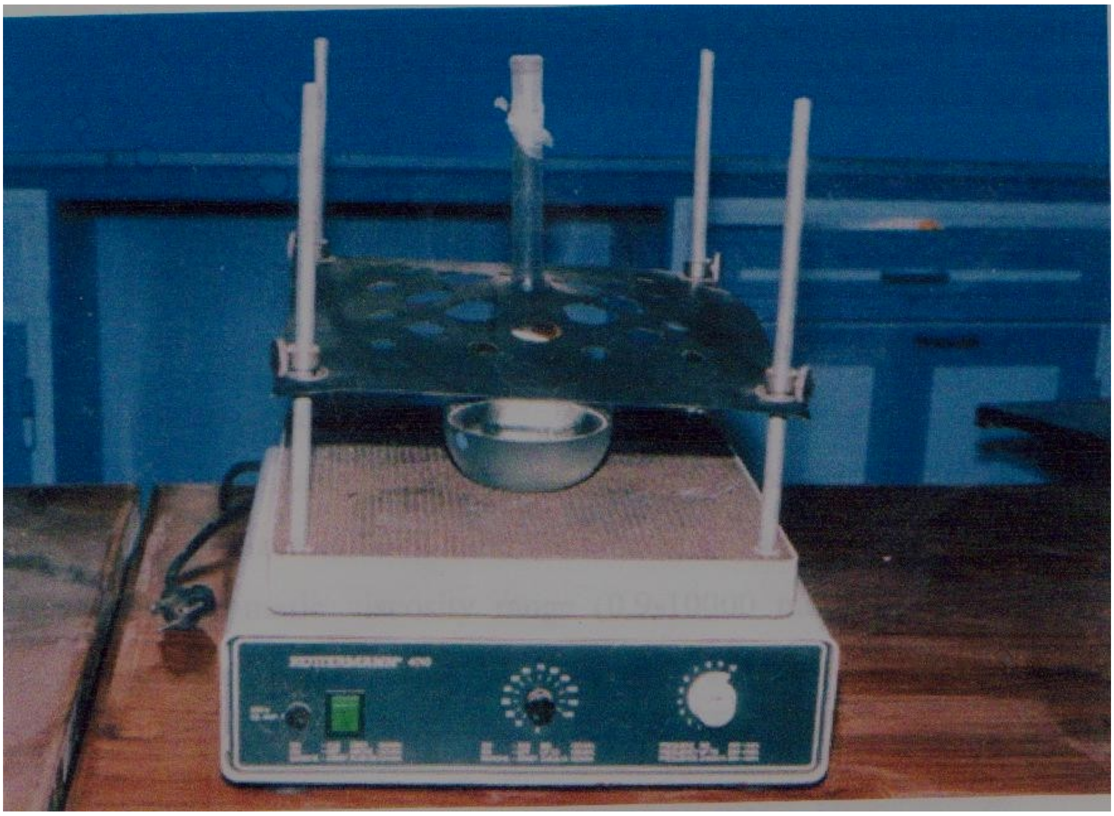


Fig. (3.1) Shaker machine

3.3 Drag Reduction Measurements

3.3.1 Flow loop

The performance of the drag reducing additives was evaluated in a laboratory scale circulation loop(1). The schematic diagram of the experimental set up is shown in figure(3.2).

The fluid container of about 0.49 m^3 capacity was fitted with a positive displacement gear pump of 50.8 mm diameter and 1440 rpm. This type of pump was used to avoid polymer mechanical degradation, which reduced usually the drag-reducing efficiency. Galvanized pipe of 0.03175m inside diameter was used to perform the flow measurements. The 2m long test section was located away from the entrance to get fully developed region . The fluid flow was controlled by means of ball valves; the pressure drop in test section was measured by U- tube manometer filled with water.

The water flow rates were measured with a float flow meter, of 50.8 mm diameter and flow indicating range between 10-100 lit./min.. Figure (3.3) shows the calibration of flow meter.

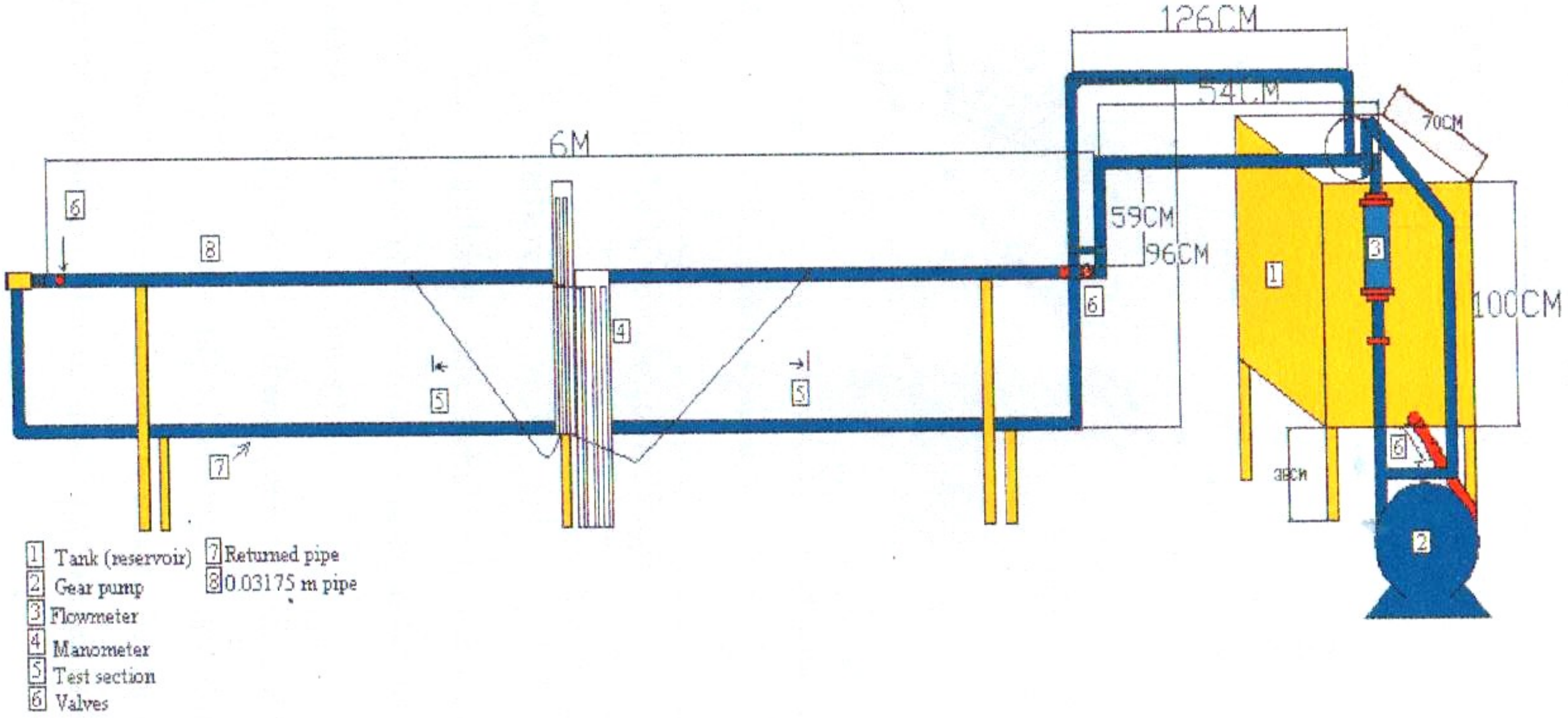


Fig. (3.2) Schematic diagram for the rig

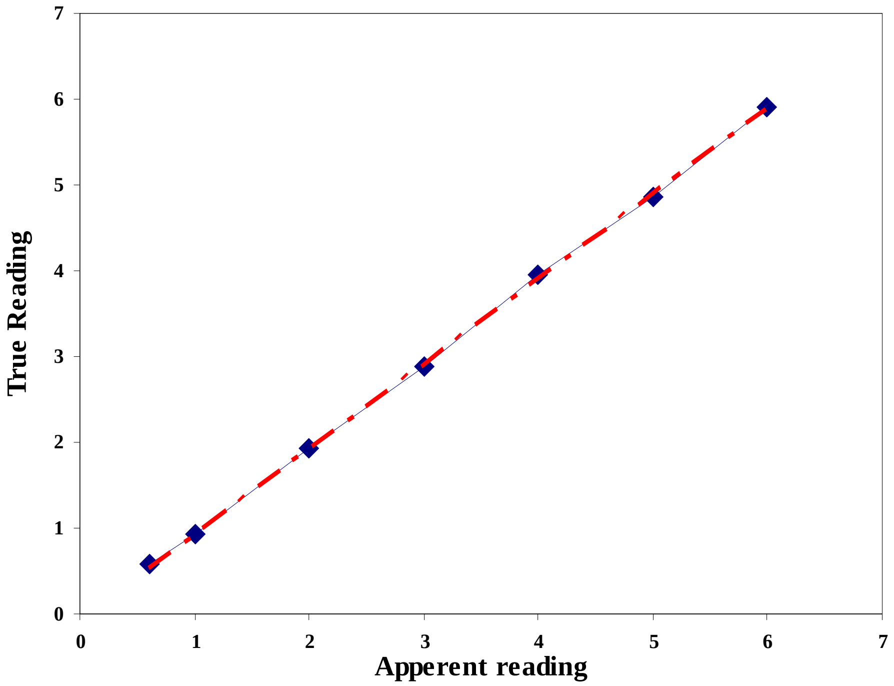


Fig.(3.3) Calibration of flow meter

3.4 Experimental Procedure:

At start an experiment, the reservoir was filled about 150 liters water. After operating the pump the fluid is allowed to flow through only one of the three pipe sizes by closing the other valves. Then connect each tube end of the pressure taps in the upstream and down stream with U-tube manometer, and allow the bubbles in the connecting viny1 tubes to flow away, to avoid any error in the reading. Then open the by- pass valve and closed pipe valve to check the manometer so when the level of the water in manometer is the same level that indicate the reading is right (no bubbles in viny1 tubes).

Then add the required concentration prepared in one liter water allow to mix with water for about 30 min. circulation the open the pipe valves and record the flow rate Q in (m^3/hr) and the pressure drop for each flow rate in (mmH_2O). The same procedure is repeated in order to obtain more data at various concentration of CMC and XG polymers.

The test sections of 2 m long were placed away from the entrance length required, the diameter is 0.03175 m and the minimum entrance length is 1.5875 m .

The minimum entrance length required for a fully developed velocity profile in turbulent flow was calculated from the relationship suggested by Desissler(72).

$$L_e = 50D \qquad \text{….(3.1)}$$

Where:

L_e= entrance length, m

D = pipe diameter, m

the pressure drop reading in the test section was taken using U- tube manometers filled with water

3.5 Calculations

The weight of polymer required to prepare (x) ppm in 150 liter of water is obtained from the following equation

$$ppm = \frac{\rho_{water} * 150 * x}{10^6} \qquad \text{…..(3.2)}$$

Where ρ_{water} = density of water

For example to obtain 50 ppm:

$$\text{ppm} = \frac{1000*150*50}{10^6} = 6.5 \quad \text{g polymer}$$

For 3% polymer solution

$$=\frac{6.5*100}{3} = 216.67 \text{ g solution}$$

Percentage drag reduction, %DR is calculated by using pressure drap measurements in the test section for untreated ΔP and with polymer treated water, ΔP_s (73), as follows

$$\%D.R=\frac{\Delta P-\Delta P_s}{\Delta P}*100 \qquad \text{…..(3.3)}$$

Percentage , throughput increase, %TI is estimated from the obtained percentage drag reduction(74), as in equ. (3.4)

$$\%TI=\left[\frac{1}{(1-\frac{\%Dr}{100})^{0.55}}-1\right]*100 \qquad \text{…..(3.4)}$$

This equation assumes that pressure drop for both the treated and untreated fluid is proportional to flow rate rise.

Fanning friction factor was calculated by using the following equation(75).

$$f = \frac{\Delta P . D / 4L}{\rho . U^2 / 2} \qquad \text{……(3.5)}$$

Where:

f = fanning friction factor.

D = pipe inside diameter, m

L = distance between the pressure taps, m

U = Solution velocity

Chapter Four
Result and Discussion

4.1 Introduction

Two bio- cellylose polymers, namely carboxymethyl cellylose, CMC and xanthan Gum XG were tested in water flow loop at different concentrations and different flow rates in a 1.25 inch pipe diameter. The testing section was 3 m long and it was away from the entrance length as it was calculated by using Desiler equation (72),as given in equ. 3.1 to restrict the pressure drop measurements in fully developed region .

$$L_e = 50D \qquad \ldots (3.1)$$

A once – through flow system was employed (except, the degradation experiments) to minimize the mechanical degradation of additives. Since turbulent flow is necessary for drag – reduction to occur. The system was operated for Reynolds number grater than 33418.71. The laboratory experiments on drag – reduction had been conducted for homogenously premixed dilute polymer solutions.

Drag – reduction characteristics were examined by measuring the pressure drop at different conditions. The percent drag – reduction is determined by measuring the corresponding pressure drop, ΔP_s of treated water compared with pressure drop, ΔP of untreated solvent at the same condition, as given in equation 3.3(73).

$$\%D.R = \frac{\Delta P - \Delta P_s}{\Delta P} * 100 \qquad \ldots .(3.3)$$

Percentage flow increase (Throughput), %TI which is more practical term than the percentage drag – reduction for a given pipeline, can be estimated by equ. (3.4)

$$\%TI = \left[\frac{1}{(1 - \frac{\%Dr}{100})^{0.55}} - 1 \right] * 100 \qquad \text{….(3.4)}$$

This equation assumes that pressure drops for both the treated and untreated fluid proportional to flow rate rise (74).The equation was used successfully to estimate the flow increase (%TI) when the flow rate is kept constant before and after the addition.

Furthermore, it is worthy to demonstrate the measured pressure drop data in the form of fanning friction factor, using equation 3.5(75).

$$f = \frac{\Delta P.D/4L}{\rho.U^2/2} \qquad \text{….(3.5)}$$

Where ΔP represent, the drop between the upstream and downstream points in the test section, and ρ is the water density.

The calibration of flowing system was done with untreated tap-water prior to testing experiments. Figure (4.1) shows the pressure drops date for the 1.25 inch (0.03175 m) pipe diameter used at laboratory temperature.

As illustrated in fig.4.1, gradual increase of pressure drop is observed with increasing the bulk velocity.

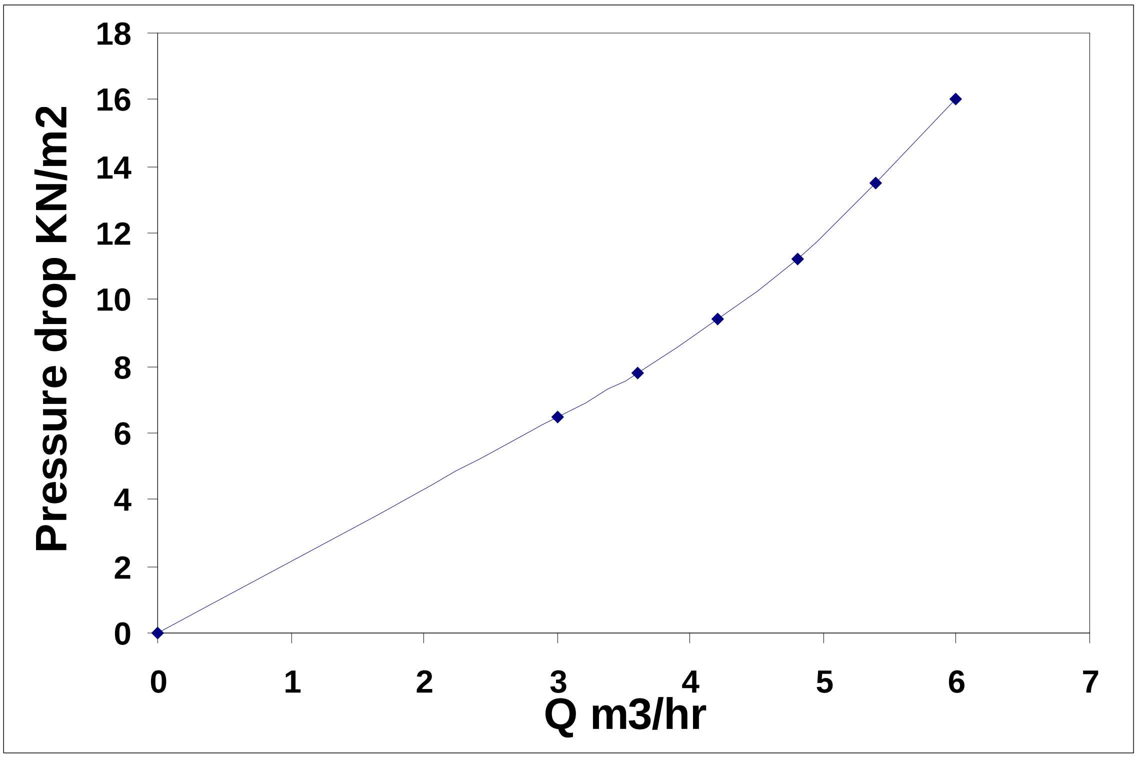


Fig.(2) pressure drop Vs. flow rate of water without treatment

4.2 Testing of CMC as Drag – Reducer

4.2.1 Effect of concentration.

Carboxy methylcellulous. (CMC) of molecular weight $0.4*10^6$ g/mol, was tested in tap-water flow loop at different concentration. Figure (4.2) illustrate the effect of (CMC) concentration, while figure (4.3) show the resulted throughput (%TI) increase. It can be observed that the (CMC) concentration enhances both the percentage drag reduction and throughput increase. The phenomenon can be explained by the elastic – sub layer model theory of virk (58).This sub layer starts to grow with increasing additive concentration.

Polymer concentration was varied from 50 up to 300 ppm CMC. This might have been economically feasible for commercial applications. Furthermore, within concentrations used, Newtonian behavior was observed for all polymer solutions.

Figure 4.2 shows clearly that the drag – reduction increase gradually as polymer concentration increases for all flow rates studied. The data for 6 m^3/h flow rate indicate, that abut 8% drag reduction is achieved by addition of 50 ppm CMC, while about 16% is obtainad for 300 ppm additive.

The primary end use of drag reducers is usually to increase the flow rate or throughput increase without exceeding the safe pressure limits within the flow system. The results in Fig. 4.3 show the ability of CMC additive in increasing water throughput without the need for any additional pumping power or new pipelines. Since, power saving is the major headline for many investigations that deals with drag – reduction(12).

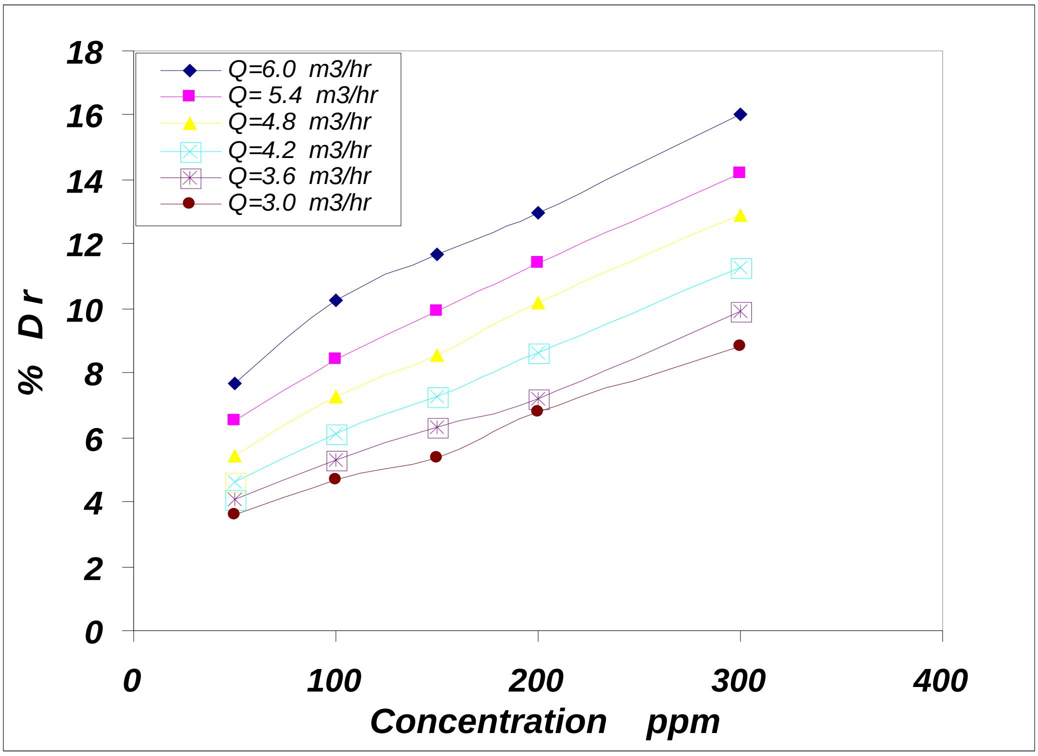


Fig. (4.2) percent drag reduction Vs. concentration of CMC for different flow rate of water

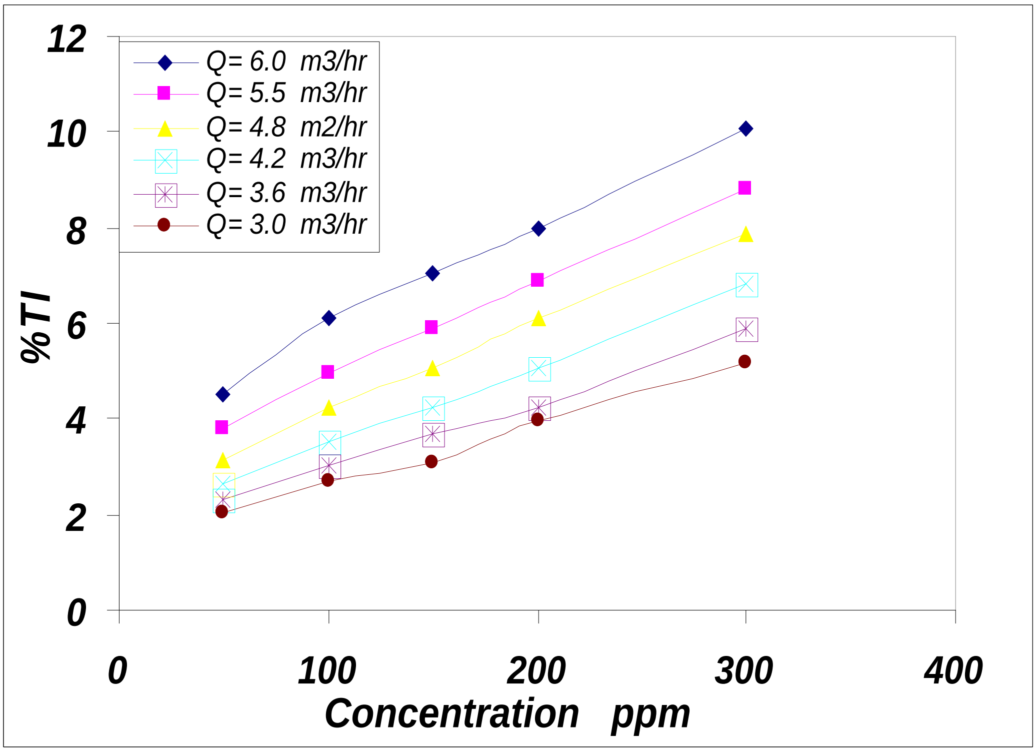
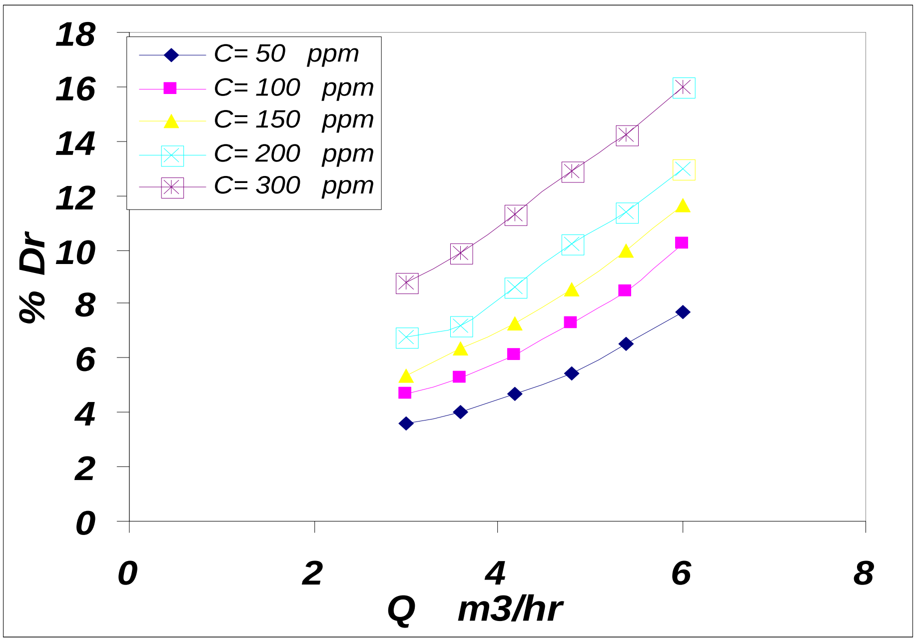


Fig. (4.3) percent throughput Vs. concentration of CMC for different flow rate of water

4.2.2 Effect of flow rate

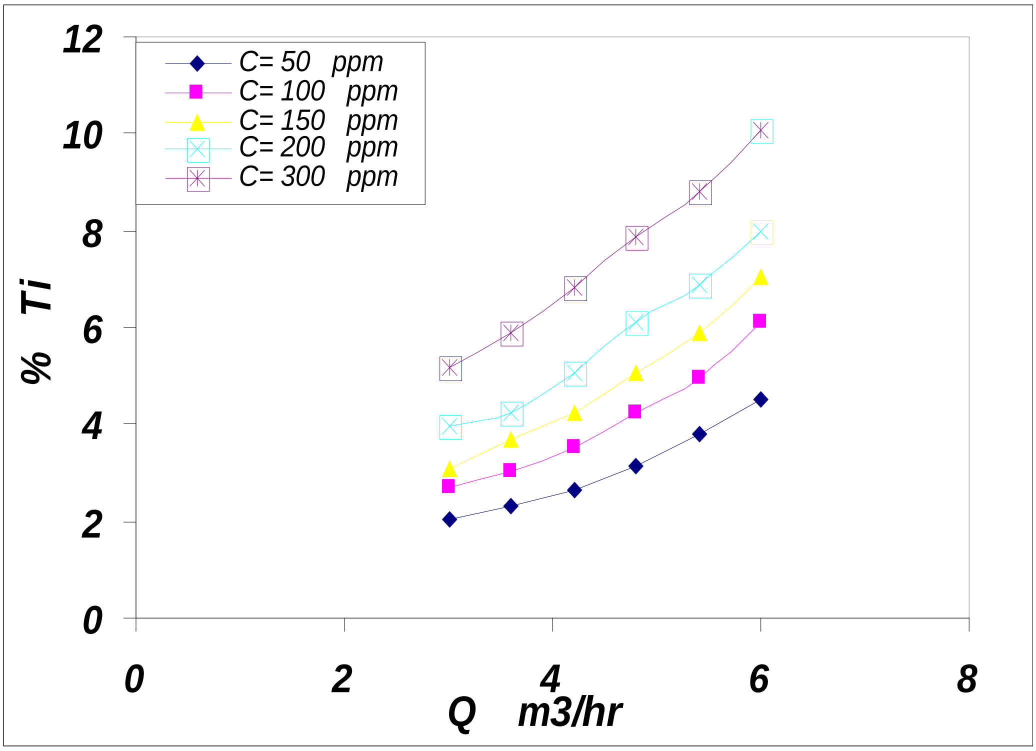
The effect of liquid (Tap- water) flow rate on performance of (CMC) as drag reducer was conducted for six different vol.flow rates (3.0, 3.6, 4.2, 4.8, 5.4, and 6) m^3/hr, as illustrated in figure (4.4) and figure (4.5) for percentage drag reduction (%Dr) and throughput increase (%TI) respectively. The results indicated that increase of flow rate perform the effectiveness of CMC is noticeable. This observation is in agreement with the fact that polymer drag reduction is efficient in turbulent flow (76).This polymer thread have high viscoelasticity and it may cause on interaction with turbulent eddies. Consequently, a remarkable drag – reduction is observed.



Fig(4.4) percent drag reduction Vs. flow rate of water for different concentration of CMC

Furthermore, the variation of Drag – reduction with the solution flow rate agrees with Berman and his workers (77) in which they reported that an increase in the Reynolds number leads to an increase in the strain rate and decrease in the time scale. Then the elongation reaches a constant level for a given solution and pipe diameter when no other limits are present.

As shown in Fig. 4.4, about 100% increase in percentage drag – reduction was observed when the solvent flow rate increases from 3.0 m^3/h to 6.0 m^3/h at 300 ppm CMC addition. This observation supports the predominate effect of turbulency on effectiveness of CMC as drag – reducer agent. Similar observation was noticed for throughput increase, as shown in Fig. 4.5 .



Fig(4.5) percent throughput increase Vs. flow rate of water for different concentration of CMC

4.3 Testing of XG as Reducer:

4.3.1 Effect of concentration:

An other biopolymer which has been widely used as a commercial drag reducer is xanthan gum (XG). XG is an extracellular polysaccharide produced by the bacteria xanthomnas. XG shows variable rheological behavior with changes in solvent ionic strength, flow rate, and polymer concentration which demonstrated a greater shear stability for XG as agent as drag – reducer.

Figure (4.6) illustrates the effect of (XG) concentration (50-300) ppm on percentage increase of drag reduction, while figure (4.7) shows the results of throughput (%TI) increase. It can be observed that the increase of XG concentration enhances both the percentage drag reduction and throughput increase. The phenomenon of concentration effect on drag – reduction by using XG agent is similar as was mentioned previously for CMC, and as was illustrated in section 4.2.1.

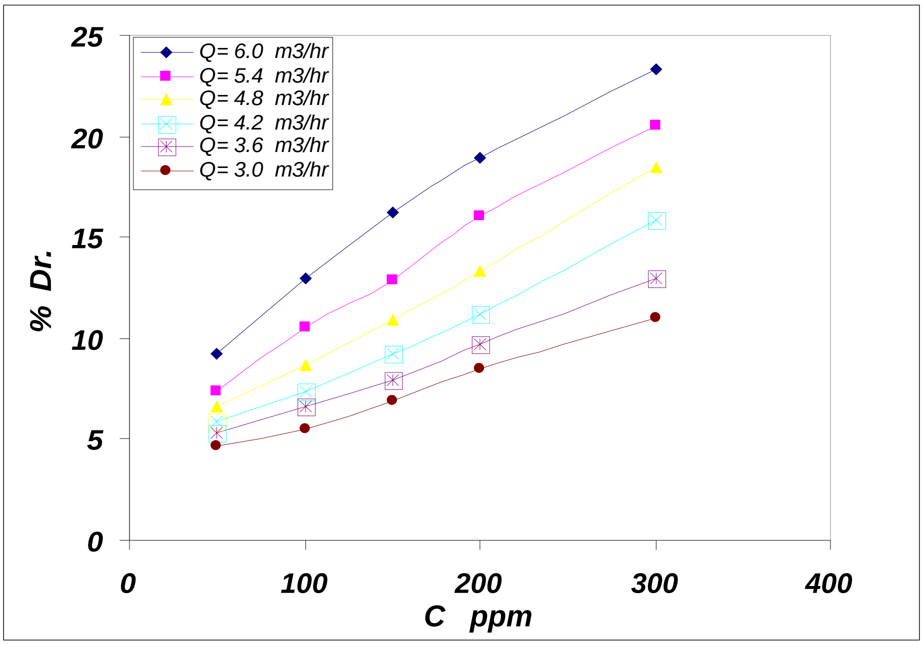


Fig. (4.6) percent drag reduction Vs. concentration of XG for different flow rate of water

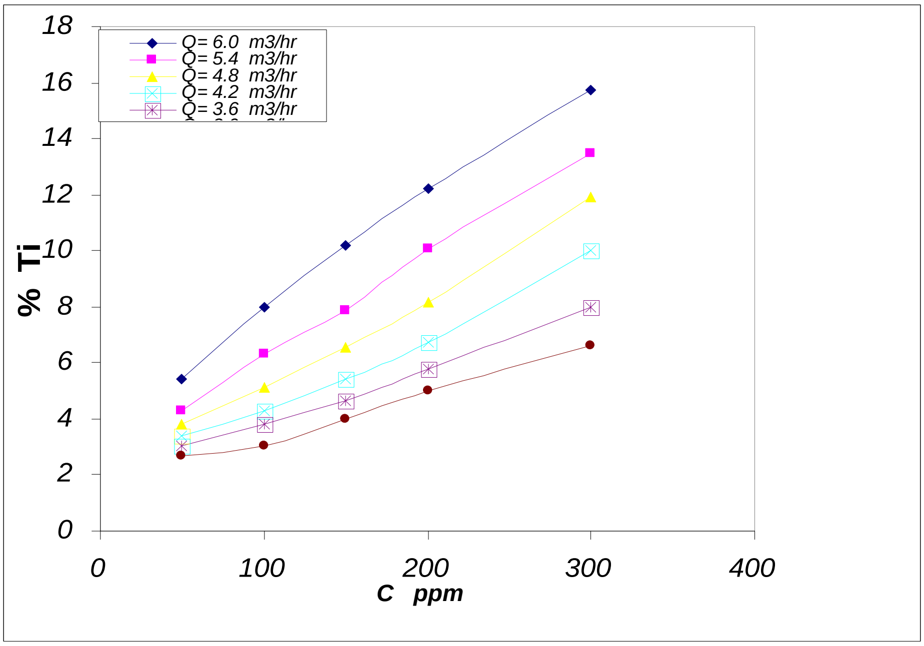


Fig. (4.7) percent throughput increase Vs. concentration of XG for different flow rate of water

It is worthily noticed that XG is more efficient as drag – reducing agent than CMC, as shown in Fig. 4.8. This Figure shows a comparison between both additives as drag reducers at selected flow rates 3.0 m^3/h and 6.0 m^3/h as minimum

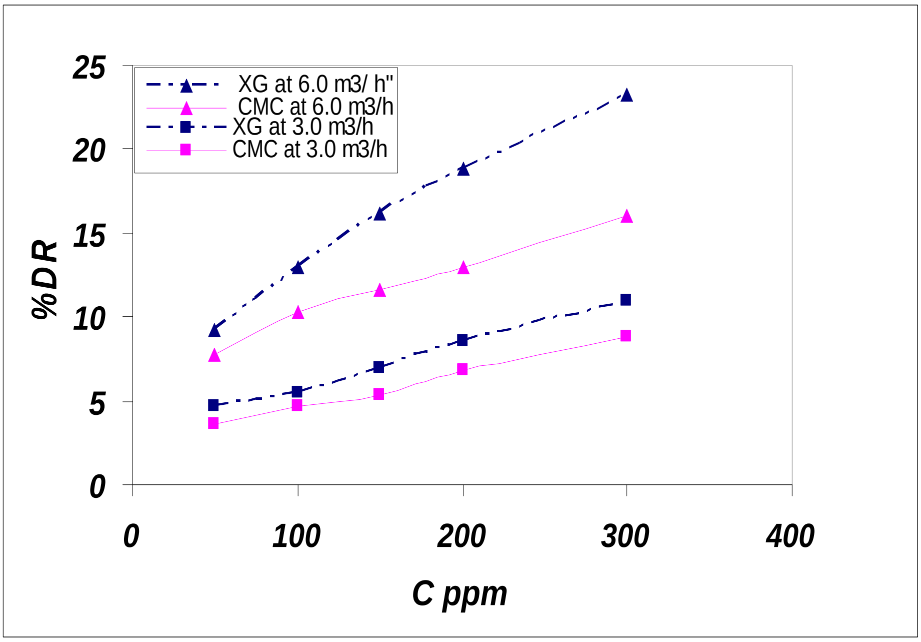


Fig (4.8) Effectiveness of CMC and XG as drag – reducer agent at different concentration

As shown in fig 4.8, XG gives 11% drag – reduction for compared with 8.8% drag – reduction for CMC agent at 300 ppm concentration and 3.0 m^3/h flow rate. The data for 6.0 m^3/h flow rate are 23.3% for XG and 16% for CMC using 300 ppm concentration. The achieved throuput increase is also higher for XG than CMC additives as illustrated in fig 4.9.

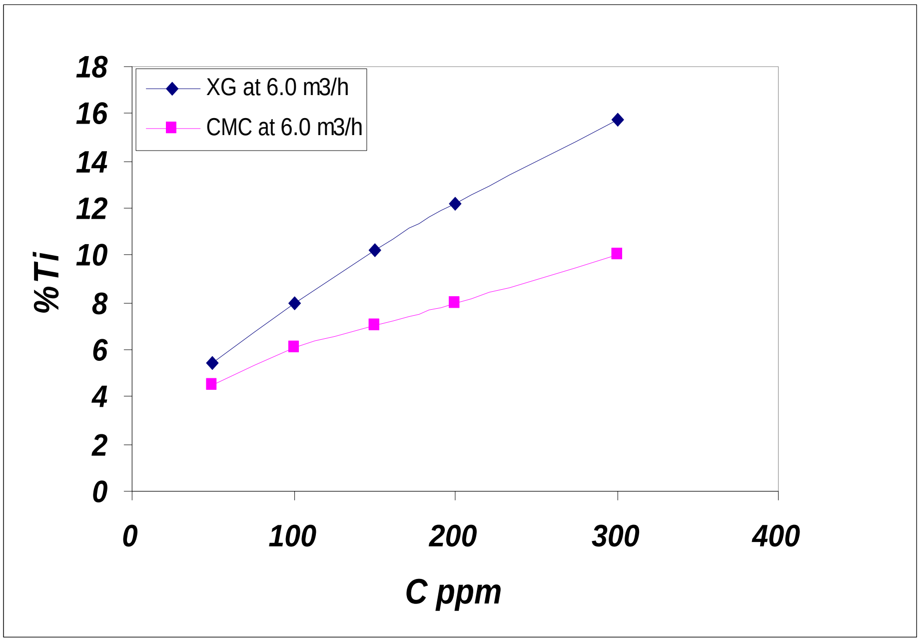
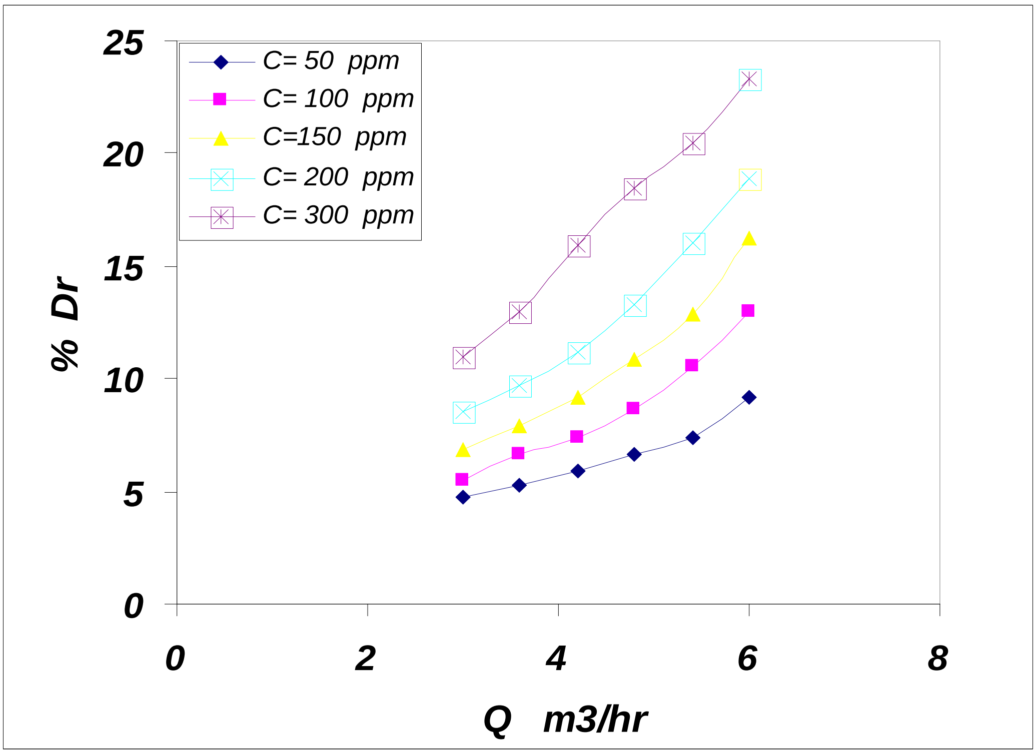


Fig (4.9) Effectiveness of CMC and XG as percent throughput agent at different concentration

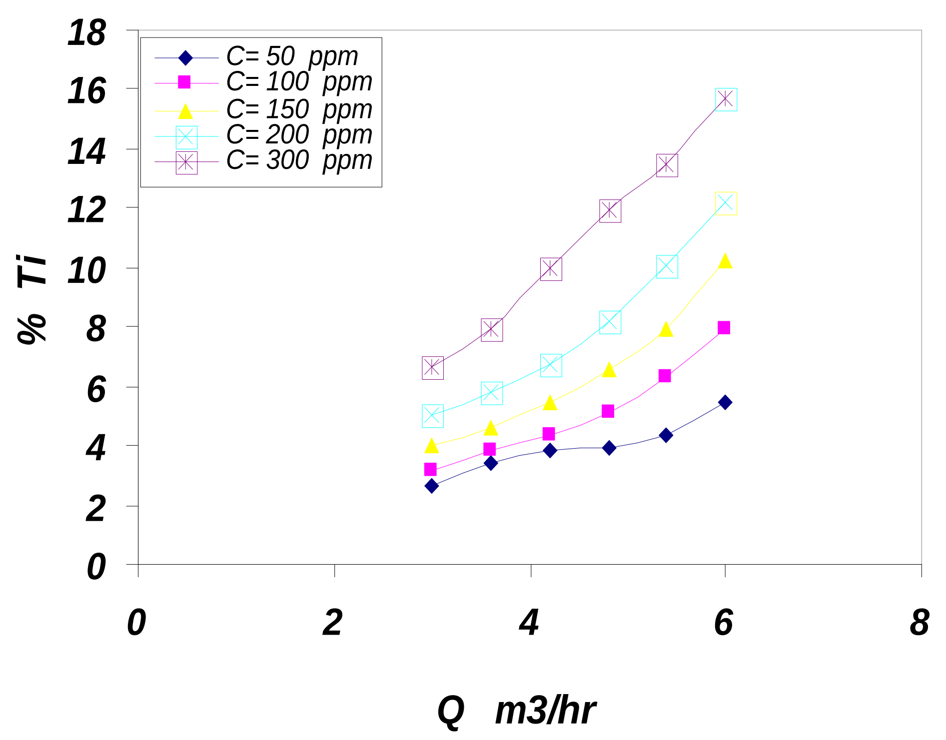
4.3.2 Effect of flow rate:

The effect of liquid flow rate on performance of XG as drag reducer is illusteated in figures (4.10) and (4.11) for percentage drag reduction (%Dr) and throughput (%TI) increase respectively.

A gradual increase in both percentage drag – reduction and percentage throughput was observed by increasing the solvent flow rate. Here again The degree of turbulency is predominate for polymeric drag reduction explained in chapter 4.2.2 previously. The obtained data for XG are also higher than by using CMC as drag – reducers. Fig 4.12 supports this observation, by comparing the effect of flow rate on drag reduction obtained for 300 ppm XG and CMC.



Fig(4.10) percent drag reduction Vs. flow rate of water for different concentration of XG



Fig(4.11) percent throughput increase Vs. flow rate of water for different concentration XG

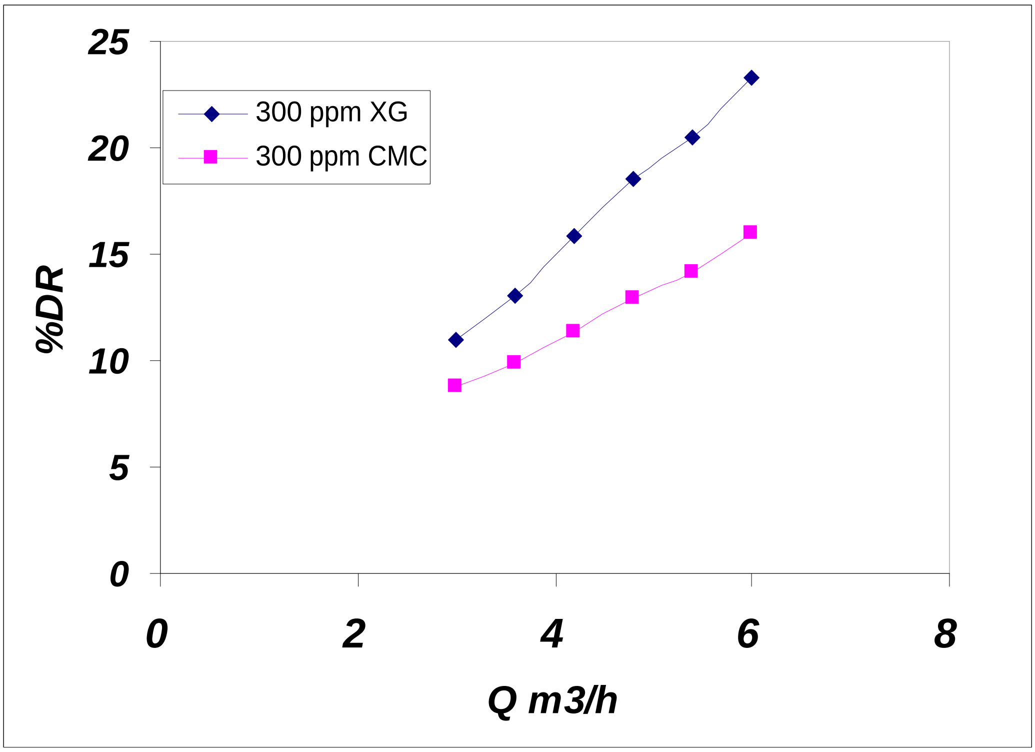


Fig (4.12) Effectiveness of CMC and XG as drag Reducers at different flow rates, 300 ppm concentration

4.4 Mixed Polymer additives

It was observed in section 4.3, Figure 4.8, that CMC is less effective turbulent drag – reducer than Xanthan Gum. In this section, an attempt was made to use mixtures of CMC and XG as mixed additives to investigate their effectiveness and in order to enhance the drag – reduction ability of CMC agent. The results are illustrated in figure 4.13 for different concentrations of mixed polymers.

The results in Figure 4.13 indicate a gradual increase of percent drag – reduction as percentage increase of XG in mixed additive at all concentrations studied. It is clear to show that the drag – reduction effectiveness for carboxy methylcellulose additive will be improved by addition of Xanthan Gum. Those, the percentage drag – reduction at 50% XG in mixed additive are about 17.1 to 13 times higher than by using CMC alone.

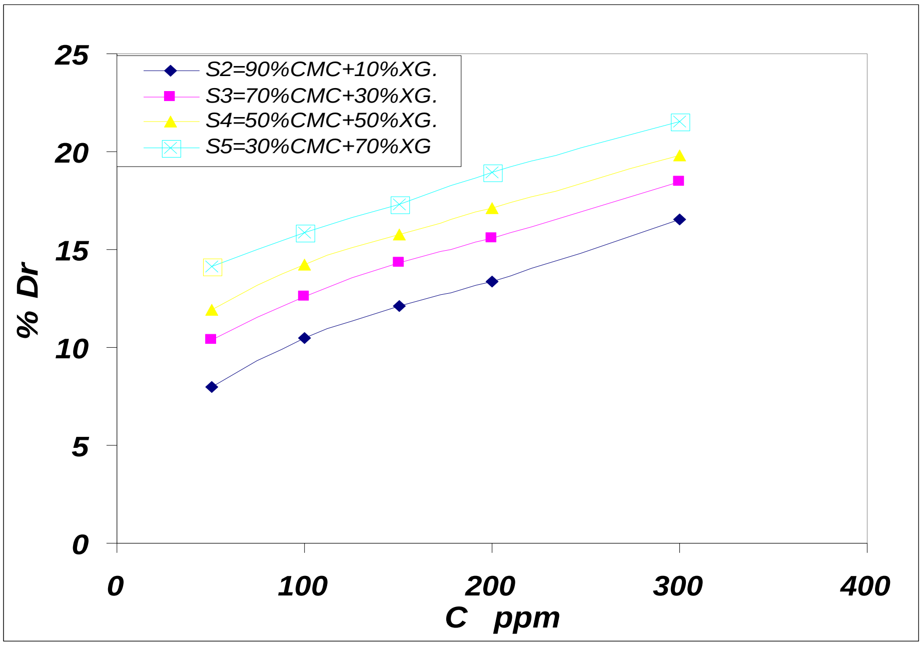


Fig (4.13) percent drag reduction vs. concentration of polymer for four samples from CMC and XG Mixture for flow rate 6.0 m^3/h of water

The effectiveness of mixed additives as drag – reducer compared with single polymer additives are shown in Figure 4.14, five samples of additives were prepared for this investigation as follows.

SAMPLE NO.	% CMC	%XG
1	100	0
2	90	10
3	70	30
4	50	50
5	30	70

The results of this investigation are presented in Figure 4.14. It is clear to show that the drag – reduction effectiveness for sample No.2 with 10% XG is close to that of pure CMC alone. While DRE for sample No.4 with 50% XG is about 31 % higher as that of CMC alone at 200 ppm additive concentration, as an example. The higher improvement in the DRE is observed in sample No.5 because it contains a higher percent of XG, about 70% which is considered as a good drag reducer. Furthermore the results show no synergistic effect for use of polymeric mixtures.

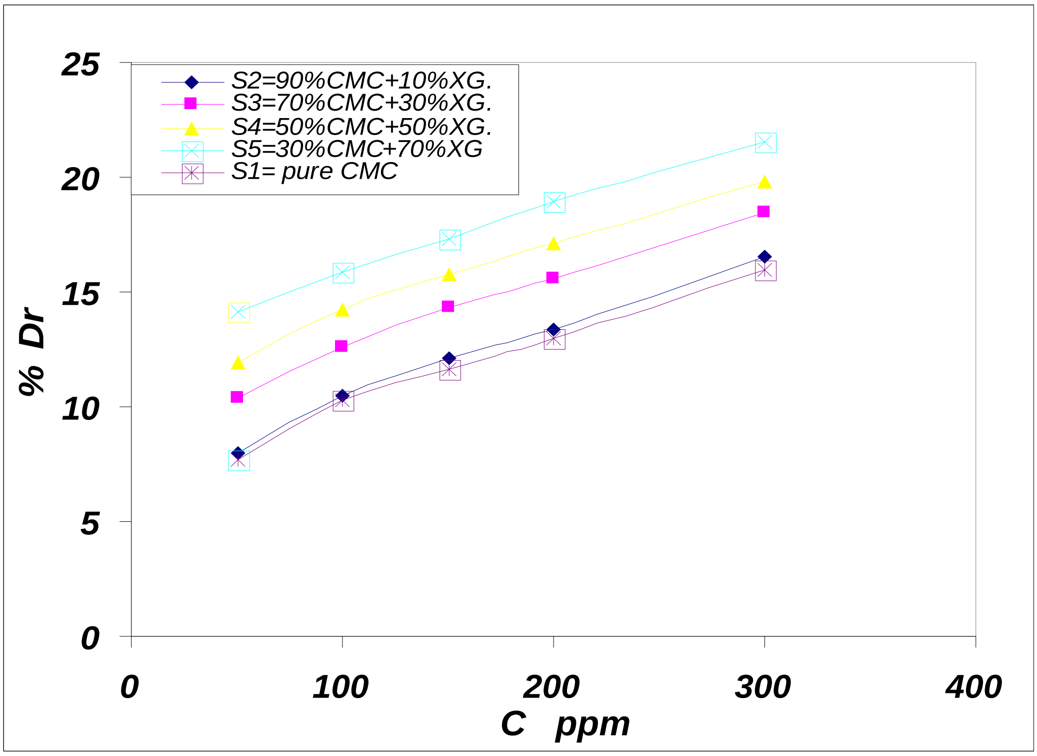


Fig (4.14) Drag reduction as function of polymer Concentration of mixed XG and CMC, at flow rate 6 m^3/h

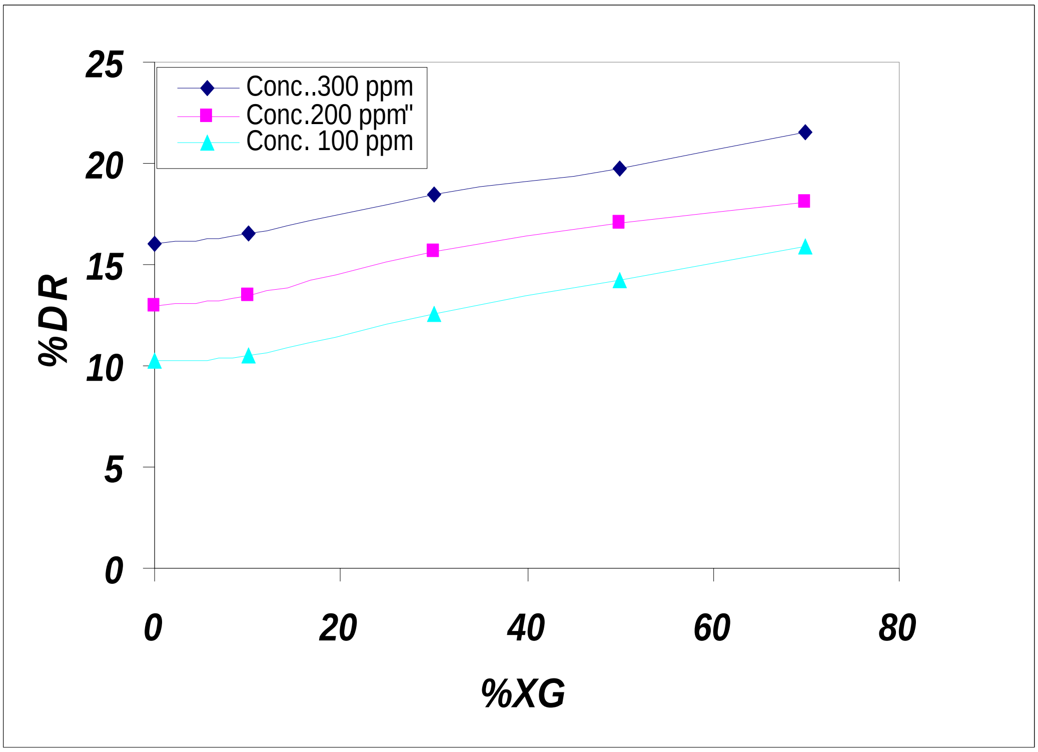


Fig (4.15) percent drag reduction vs. percent XG in mixture CMC and XG addition at different concentration of polymer at flow rate 6 m^3/h

4.5 Effect of Salt

Drainage as well as sea water and some times raw water contain usually inorganic salts, mainly as sodium chloride. Therefore , it is worthily to study the performance of polymer additives with the existence of such salts to reduce the drag forces in flowing water. Furthermore, such studies are usefully to investigate the effect of sprinkler irrigation systems as well as to increase the throughput area of converge.

The experiments were performed to study the effect of adding sodium chloride in different concentrations on drag reduction effectiveness of CMC and XG in turbulent circulation of tap water. The considered concentrations were in the range of 400 – 1000 ppm NaCl at 3.0 – 6.0 m^3/h flow rates.

Figures 4.16 and 4.17 show the concentration dependence of sodium chloride on effectiveness of CMC and XG respectively as drag reducer agents at a selected circulation rate of 6.0 m^3/h. While Figures 4.18 and 4.19 illustrate the combined effect of salinity and polymer concentrations on percentage drag reduction of CMC and XG respectively, compared with performance of pure polymeric additives (without salt addition).

As shown in figures 4.16 and 4.17, the percentage drag reduction decreases proportionally with the increase of salinity. Those, the percentage drag reduction at selected CMC concentration of 200 ppm is 13% drops to about 11% in presence of 400 ppm NaCl and to about 8.5% with 1000 ppm salt. While the corresponding values for XG are 18.9% for pure polymer and 17.4% and 14.7%by addition of 400 ppm and 1000 ppm salt respectively .

It can be concluded, that sodium chloride acts as inhibitor to the performance of such polymers as drag reducers (78).Therefore the drag – reduction effectiveness for CMC and XG in the drainage waters is lower than of tap water. The result is in agreement with the observation von Ali(79).

As a polyelectrolyte molecules, CMC and XG are highly extended in low salt contain and collapse at a 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 that influences the viscosity of polymer solution(79). Furthermore, Rochefort and Middemann (78)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.

Further more results of drag – reduction effectiveness of CMC and XG in presence of sodium chloride are illustrated in figures 4.20 and 4.21 respectively, at different flow rates of water circulation and different polymer concentrations. These results support the inhabited effect of salt on drag reduction effectiveness.

The throughput is also affected by presence of salt in flowing water as shown in figures 4.22 and 4.23 for CMC and XG agents respectively. There again the salinity is in throughput.

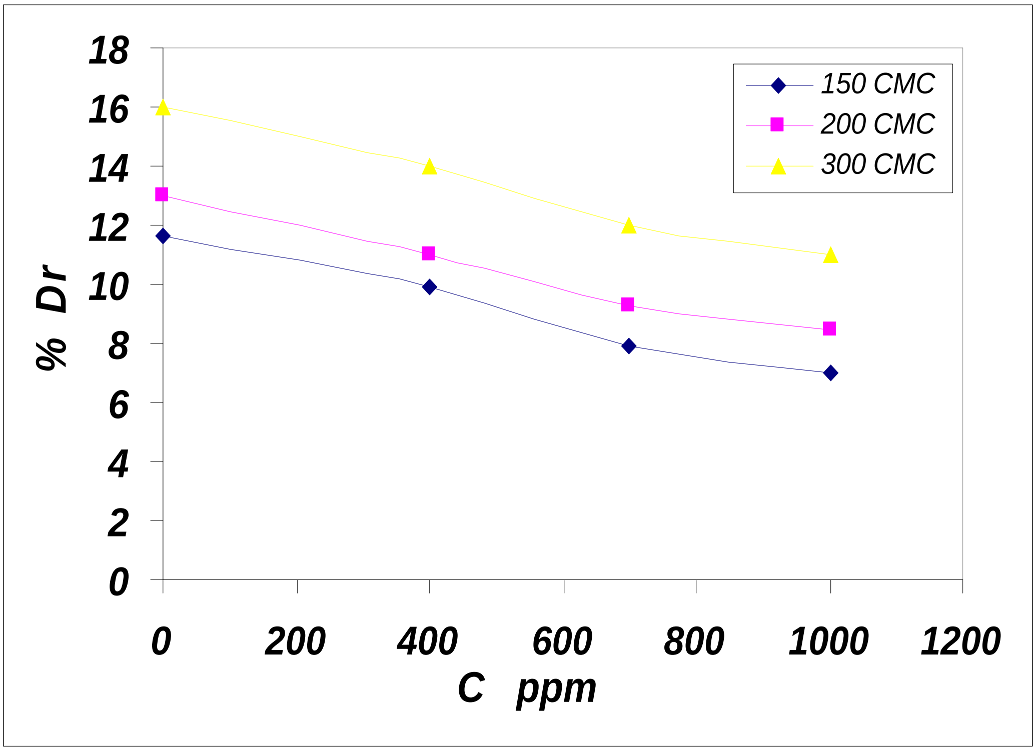


Fig (4.16) percent drag reduction vs. concentration of NaCl salt addition for different concentration of CMC at 6.0m^3/hflow rate water

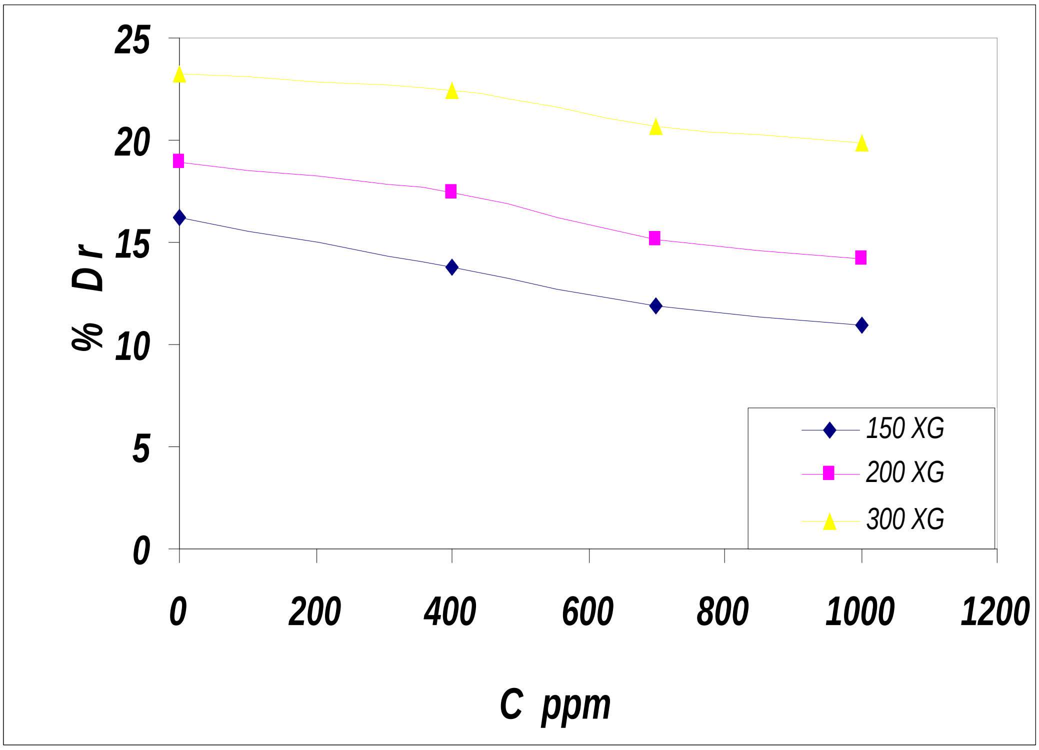


Fig (4.17) percent drag reduction vs. concentration of NaCl salt addition for different concentration of XG at 6.0m^3/h flow rate water

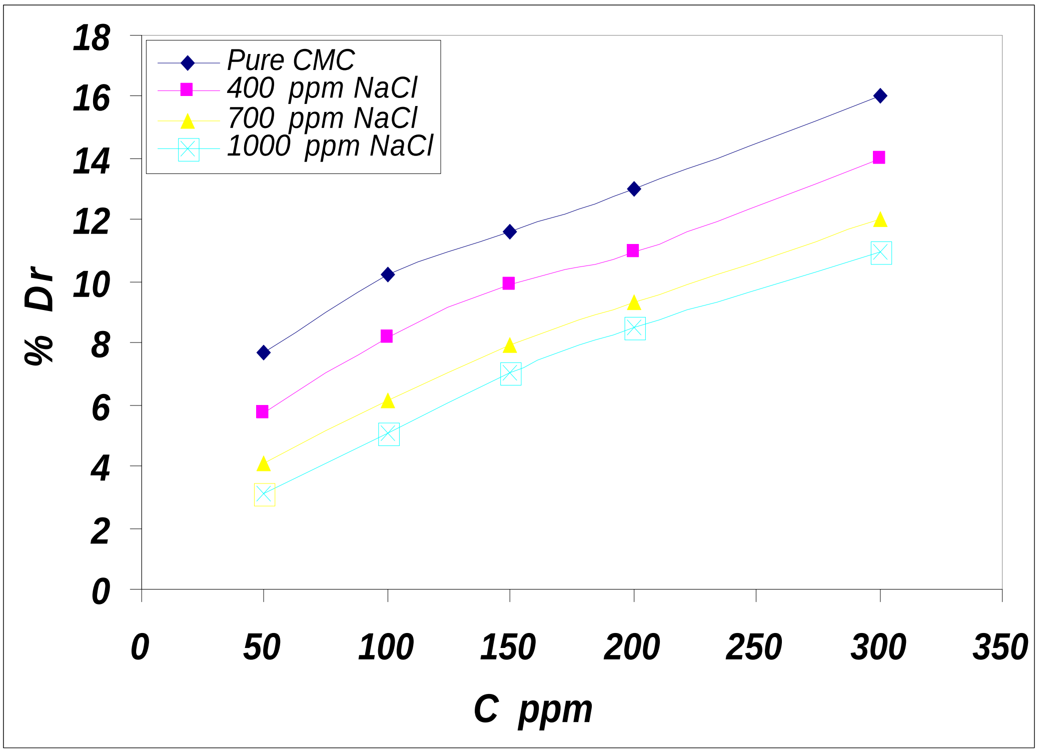


Fig (4.18) percent drag reduction as function of concentrations of CMC and NaCl at 6.0m^3/h flow rate of water

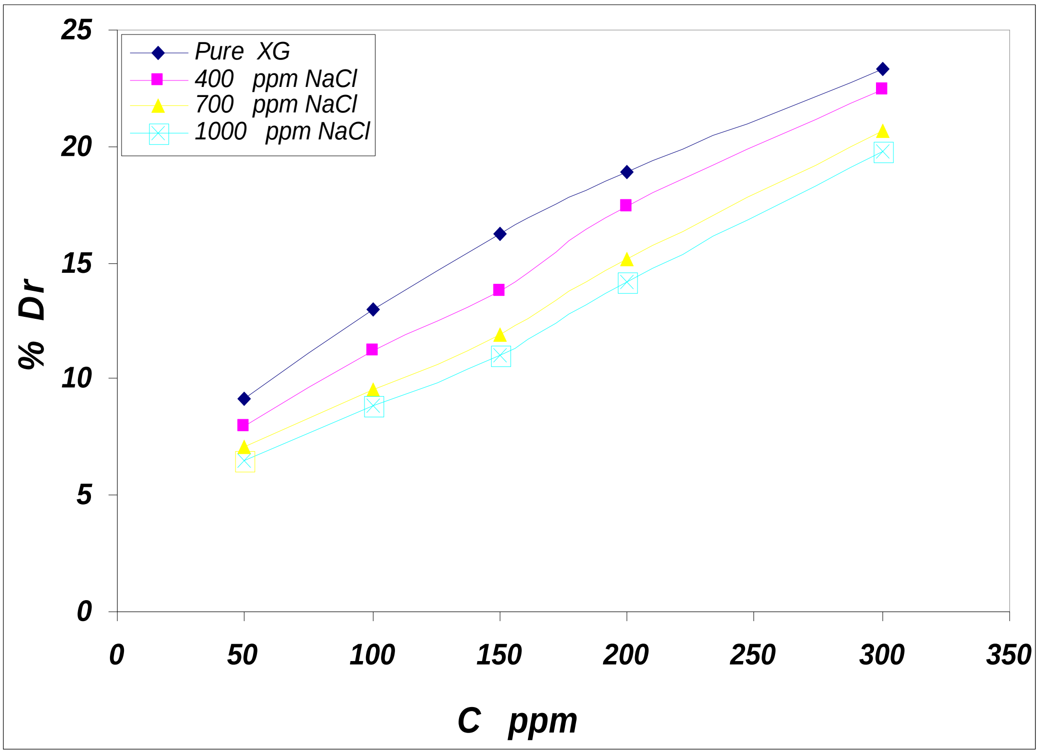


Fig (4.19) percent drag reduction as function of concentrations of XG and NaCl at 6.0m^3/h flow rate of water

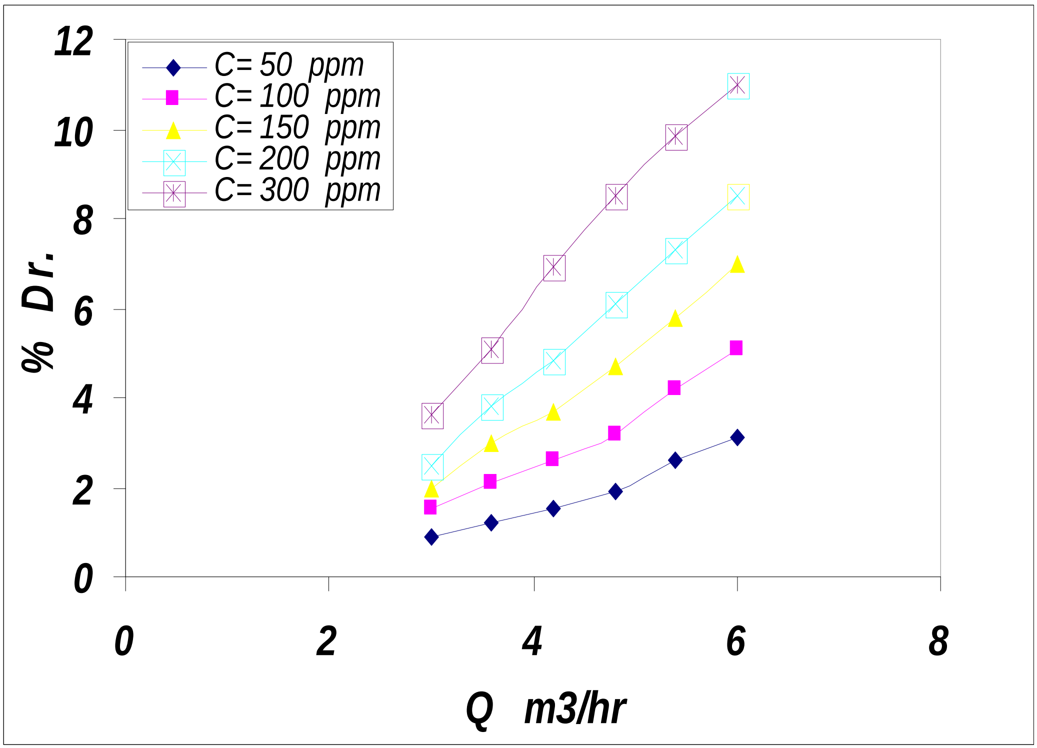


Fig. (4.20) Effect of water flow rate and CMC concentration on drag reduction adding of 1000 ppm NaCl

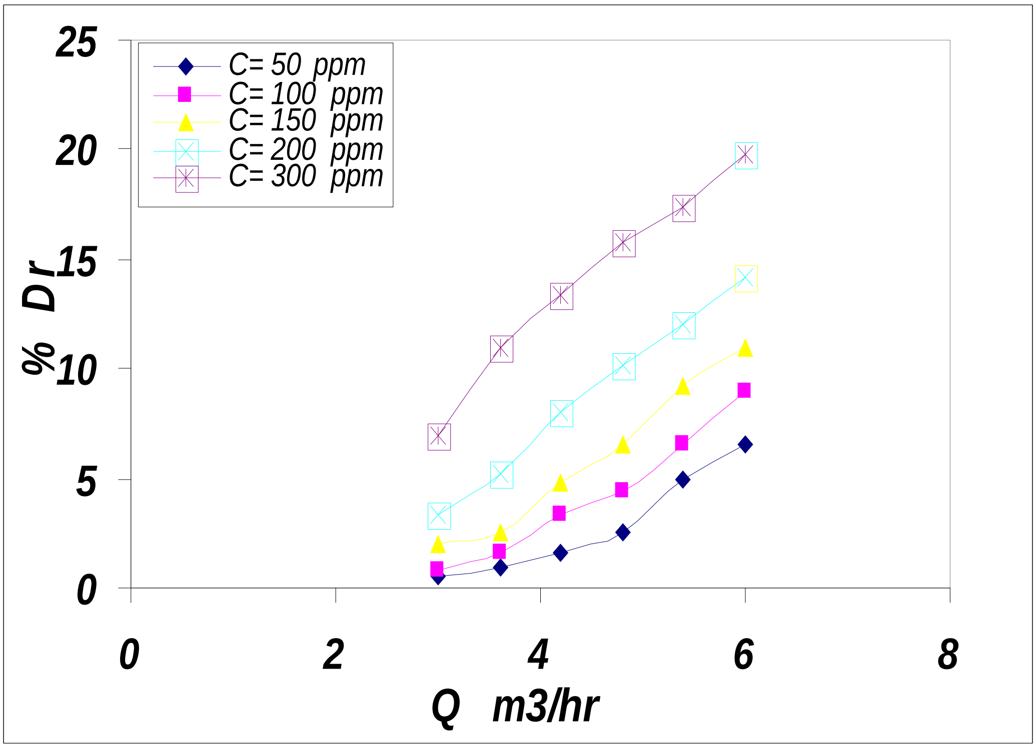


Fig. (4.21) Effect of water flow rate and XG concentration on drag reduction adding of 1000 ppm NaCl

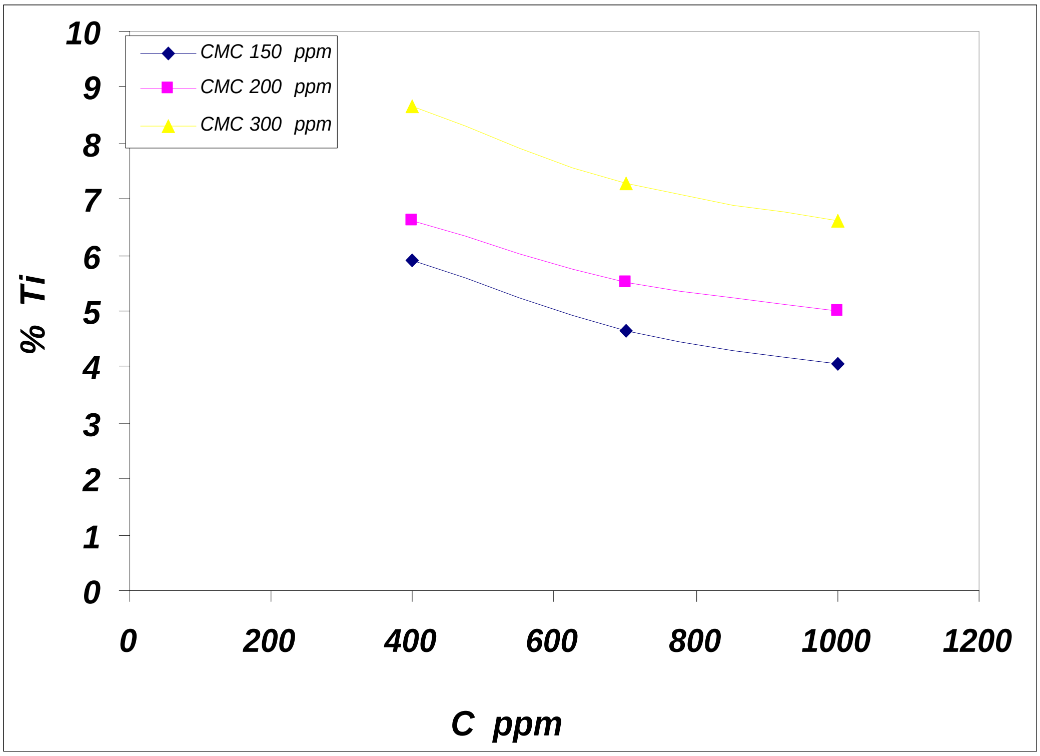


Fig (4.22) percent throughput increase vs. concentrations of NaCl salt addition for different concentrations of CMC at 6.0 m^3/h flow rate of water

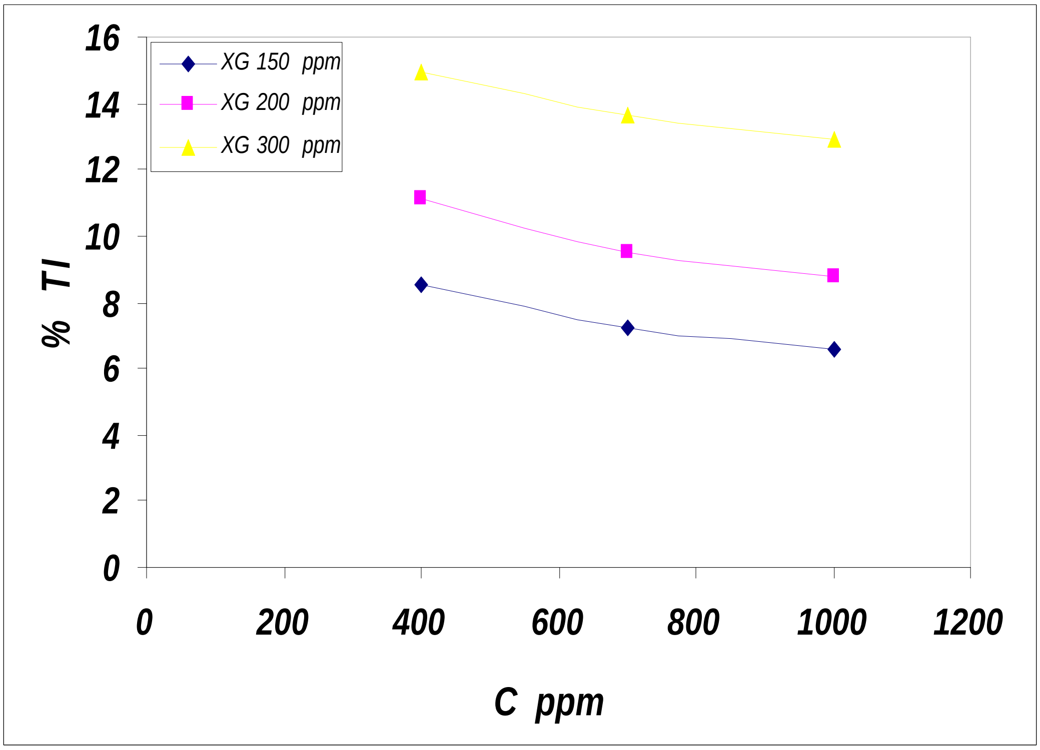


Fig (4.23) percent throughput increase vs. concentrations of NaCl salt addition for different concentrations of XG at 6.0 m^3/h flow rate of water

4.6 Time Dependence

The effectiveness of polymeric drag – reduction additives is usually limited because of their susceptibility to flow – inducted shear degradation (80). Degradation happens due to the input of mechanical energy into the polymer solution which causes the scission of molecular weight distribution. Therefore, the time dependence of Drag – reduction efficiency was studied in order to investigate the possible degradation of polymer additives due to mechanical effects during the circulation.

The degrading of Xanthan Gum and carboxy methycellulose was investigated in this work by measuring changes in drag – reduction as function of time at solvent flow rate 6 m^3/h as shown in figure 4.24. The results indicate that the drag – reduction decreases with time due to possible degradation of the additive molecules under turbulent flow. The different values of percent drag – reduction efficiency are due to the difference in polymer – solvent interaction(81).

It can be concluded from figure 4.24 that the polymer degraded rapidly during the early stages of circulation for both polymeric additives. The percentage drag – reduction for Xanthan Gum drops from about 13% to about 6.5% at 100 ppm concentration during the first 25 hours. This means that DRE will be reduced by about 50% of its initial value. Similar behavior can be observed for carboxy methyl cellulose additive, as shown in figure 4.24 Moreover, the drag – reduction drops for carboxy methylcellulose and Xanthan Gum after 50 hrs circulation at about 75% and 70% respectively, for 100 ppm concentration, reaching 2.5% and 4% drag – reduction for CMC and XG. The initial values are 10% and 13% respectively.

The effectiveness of Xanthan Gum and carboxy methylcellulose as drag – reducer agents with time can be clearly recognized by measurement of pressure drop during the circulation, as illustrated in figure 4.25. This figure shows that the pressure drop increases from initial values of 2402.28 pa and 2329.49pa for CMC and XG respectively to arrive at a plateau value of 2567.35pa and 2506.56pa at the first 25 hours of circulation time. All these experiments were conducted at constant flow rate with Reynolds number of 66837.41.

For the sake of easily recognizing the effect of concentration on degradation, the results of Xanthan Gum at two different concentrations, 100 and 300 pm are plotted in figure 4.1 at a flow rate of 6.0 m^3/h, taking the time zero for maximum drag – reduction. The figure indicates clearly, that low concentration will be degraded quickly compared with high concentration. This is in agreement with finding of sellin(82), who found that degradation is more likely to occur at low concentration. Therefore, the percentage drag – reduction decreases rapidly from 10% to about 4% after 25 hours circulation for 100 ppm XG concentration. While at 300 ppm concentration there is still enough undegraded polymer until 50 hours experimental time is elapsed.

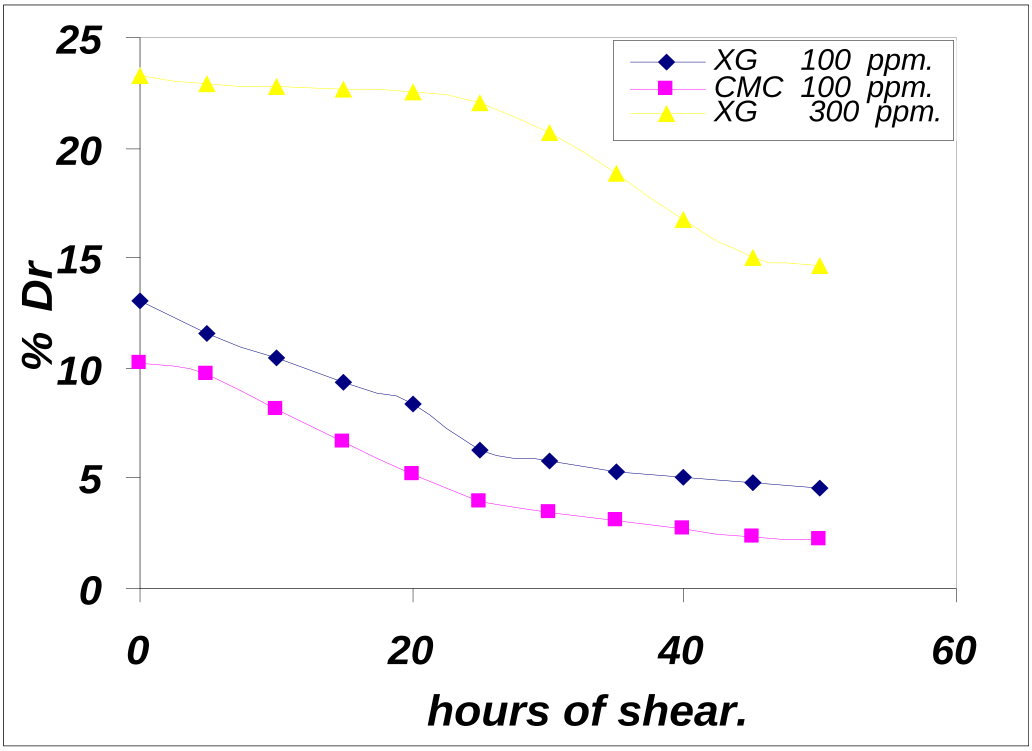


Fig (4.24) percent drag reduction vs. Time for
Selected additive concentration
and 6.0 m^3/h flow rate

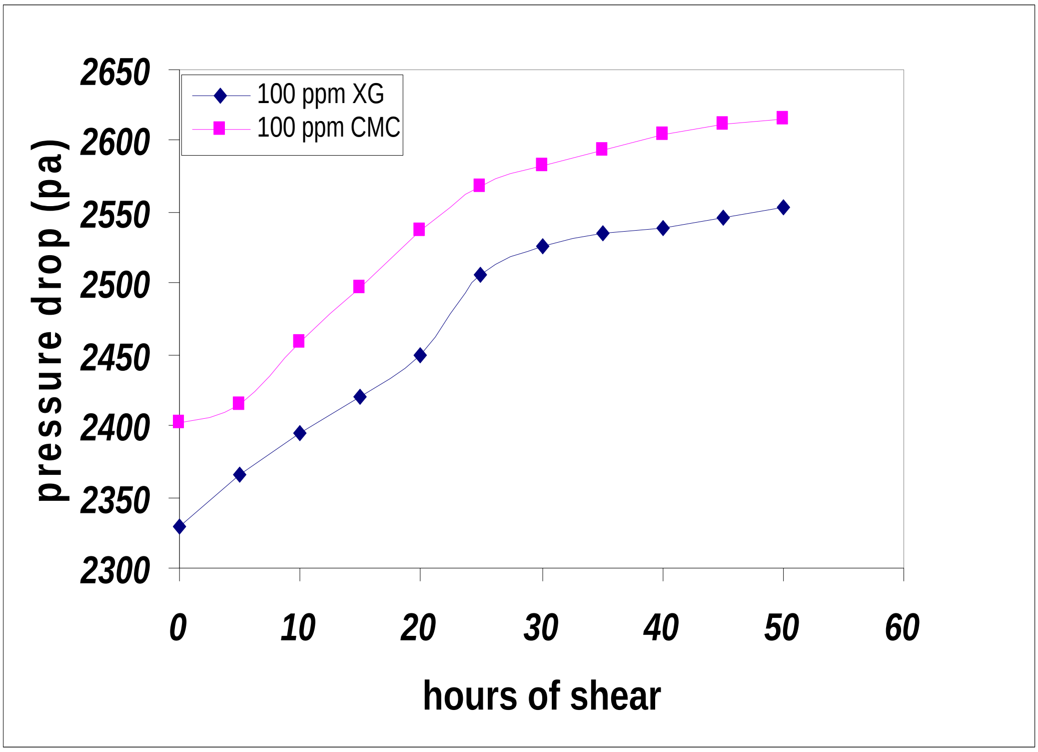


Fig (4.25) Time dependence of pressure drop

6.0m^3/h, 100ppm

4.7 Friction factor

The relationship between friction factor and Reynolds number, is that Re depends primarily on the roughness of the pipe wall and type of flow. Where Reynolds number is less than 2000, the flow is laminar, the friction factor follows Boisuelle's low (83).

$$f = 16/\,\mathrm{Re} \qquad \text{….. (4.1)}$$

At a Reynolds number above 4000, the flow is turbulent. The zone in between is a transition region in which no correlation exists(84).
The friction factor follows Blasius law for turbulent flow(83), as :

$$f = 0.0791\ \mathrm{Re}^{-0.25} \qquad \text{….(4.2)}$$

Another asymptote was suggested by Virk to represent the greatest possible fall in resistance, in which the relation between friction factor and Reynolds number dose not depend on the nature of the additives or pipe diameter(85). The formula for virk line is.

$$f = 0.59\ \mathrm{Re}^{-0.58} \qquad \text{….(4.3)}$$

It is useful to represent the effectiveness of CMC and XG additives as drag – reducers in the form of fanning friction factor, calculated by equation 3.5(75).

$$f = \frac{\Delta P.D/4L}{\rho.U^2/2} \qquad \text{……(3.5)}$$

The drag – reduction properties of solutions are shown in figures 4.26 to 4.29 as the fanning friction factor, f vs. solvent Reynolds number, Re.

The use of Reynolds number based on solvent viscosity provides a direct indication of the degree of drag – reduction.

Figure 4.26 and 4.27 show the relationship between the friction factor and Reynolds number for CMC and XG additives respectively at various concentrations in water flowing using a 0.03175 m pipe diameter. While, figures 4.28 and 4.29 illustrate the friction factor data for CMC and XG treated water, which respectively contain different concentrations of sodium chloride.

As expected for such solutions, the friction factor values for untreated water, or treated with low concentrations of additives line shifts towards Blasius asymptotes. While increasing the concentration of polymeric additives at higher Reynolds number causes decreasing of the friction factor values up to the virk asymptote line. This was never reached, as shown in figures 4.26 and 4.27 for CMC and XG additives respectively. The addition of small amounts of sodium chloride results in friction values towards, Blasius asymptote indicating the inhibited effect of such salt on drag – reduction effectiveness of CMC and XG agents.

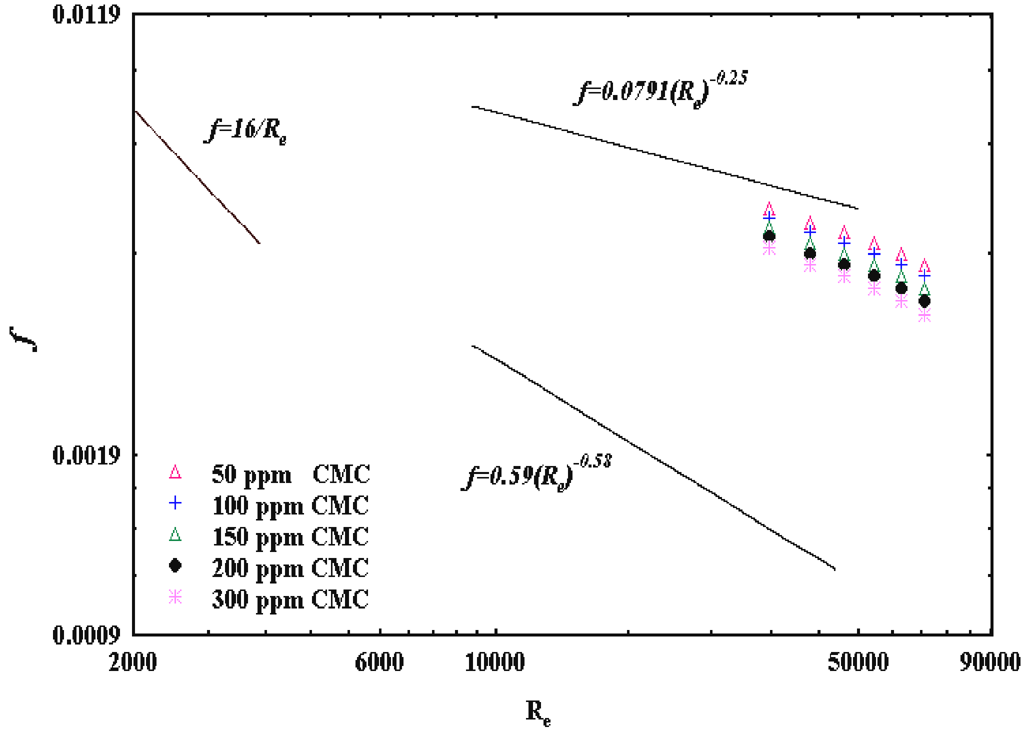


Fig (4.26) The friction factor as function of Reynolds number for CMC

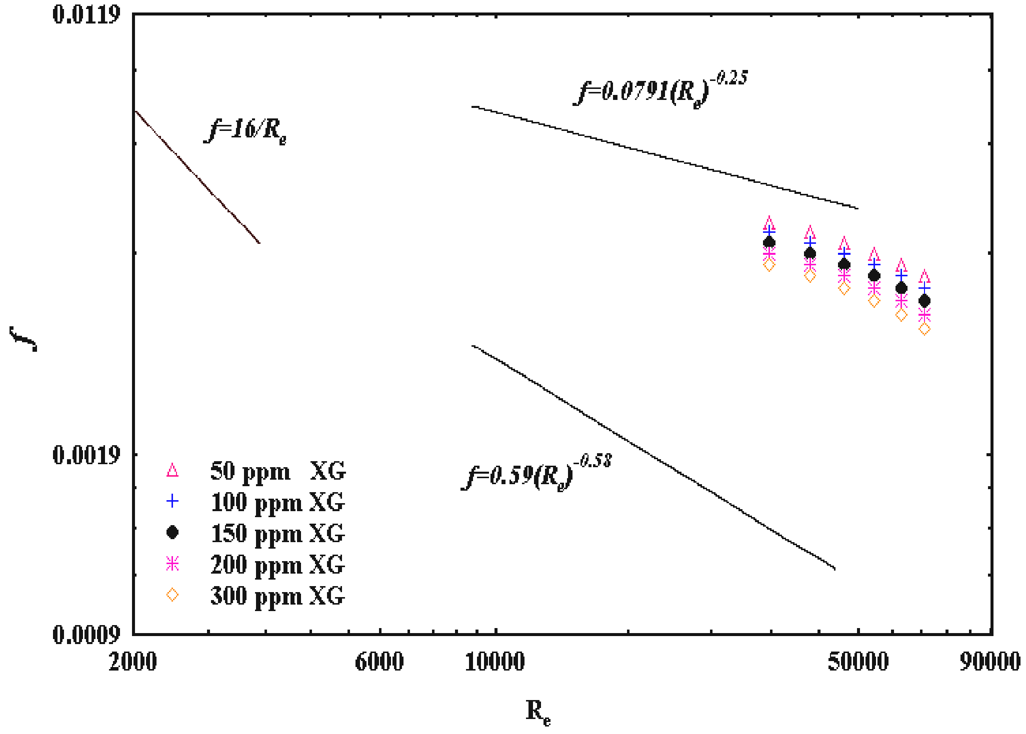


Fig (4.27) The friction factor as function of Reynolds number XG

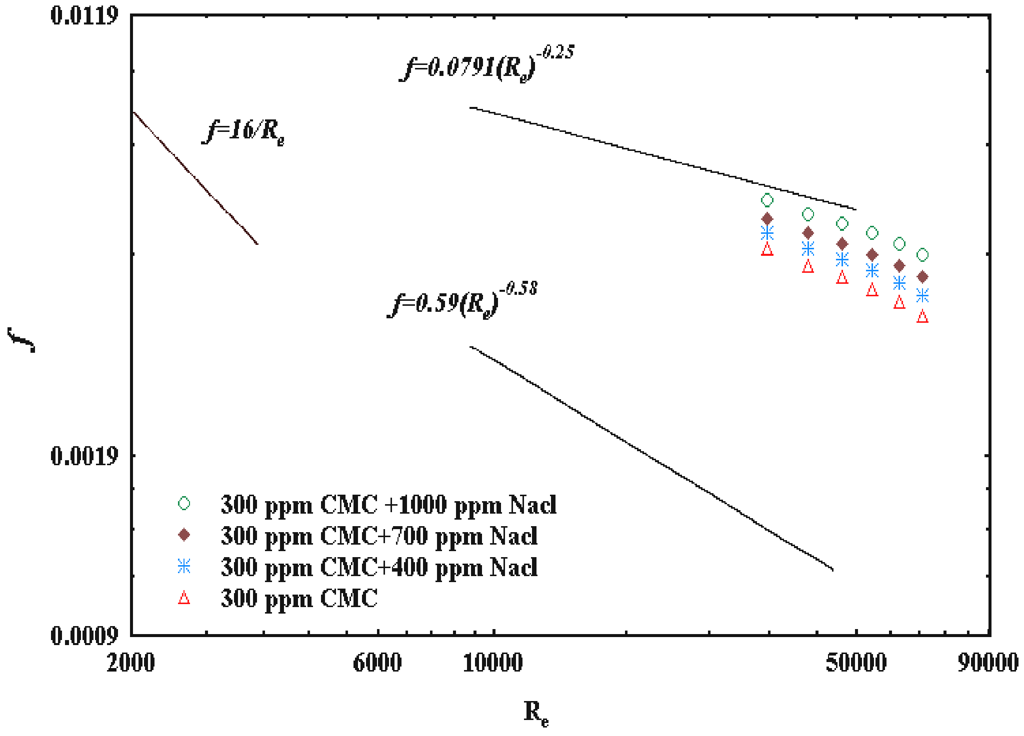


Fig (4.28) The friction factor as a function of Reynolds number for CMC with salt

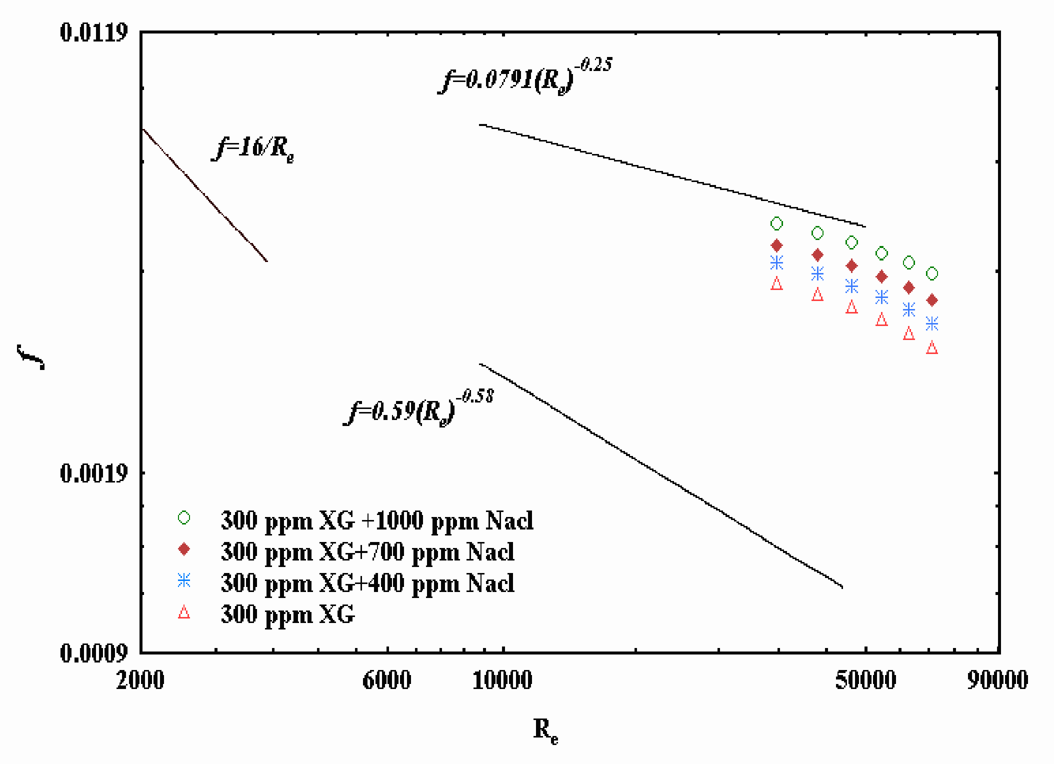


Fig (4.29) The friction factor as Reynolds number for XG with salt

4.8 Correlation

In this work the statistic software is used to obtain a simple correlation that can be used in practice to predict %DR as a function of flowing variables. Such correlations may save money and time. The drag reduction (***%DR***) for a particular polymer type is found to be a function of the variables that have been taken into consideration in the present work, i.e., flow rate (***Q***), additive concentration (C), additive molecular weight (M), salt concentration (***S***), as follows

$$DR = f(Q, C, M, S)\ \% \qquad \text{.....(4.4)}$$

The relationship that has been found to be satisfactory relates the percentage drag – reduction with the operating conditions as follows

$$\%DR = A1 \times Q^2 + A2 \times C + M^{A3} + A4 \times S + A5 \qquad \text{...(4.5)}$$

The correlation coefficients, A, through A5 are evaluated by a least square method. The values are given in table 4.1 for CMC and XG mixed CMC – XG additives. Figure (4.30) displays the relation between the values of ***(%DR)*** taken from experimental data and the predicted values from the mathematical correlation for CMC; while figures 4.31 and 4.32 show such comparison for CMC and mixed CMC/XG additives. It can be noticed from these figures that most of the points lie within ±10% of the unit slope straight line. That means a good agreement between predicted and theoretical data, with correlation coefficient values of 0.9842, 0.9782 and 0.9487 for CMC, XG and mixtures of CMC and XG respectively, as shown in table 4.1. The suggested equation filled the percentage drag – reduction results for CMC and XG, each alone with variances of about 96.867% and 95.69% respectively. This is better than for mixed additives with a variance of about 90%.

Table (4.1) values of the corrleations coefficients

for each additive type.

Additive type	Constants					Variance (*V*%)	Correlation coefficient (*R**)
CMC	**A1**	**A2**	**A3**	**A4**	**A5**		
	0.1857	**0.0258**	**0.3362**	**-0.00402**	**-7.0586**	**96.867**	**0.9842**
XG	**0.3584**	**0.0455**	**0.0913**	**-0.00401**	**-6.1187**	**95.69**	**0.9782**
CMC+XG	**0.2721**	**0.0356**	**0.2096**	**-0.00401**	**-6.4896**	**90.010**	**0.9487**

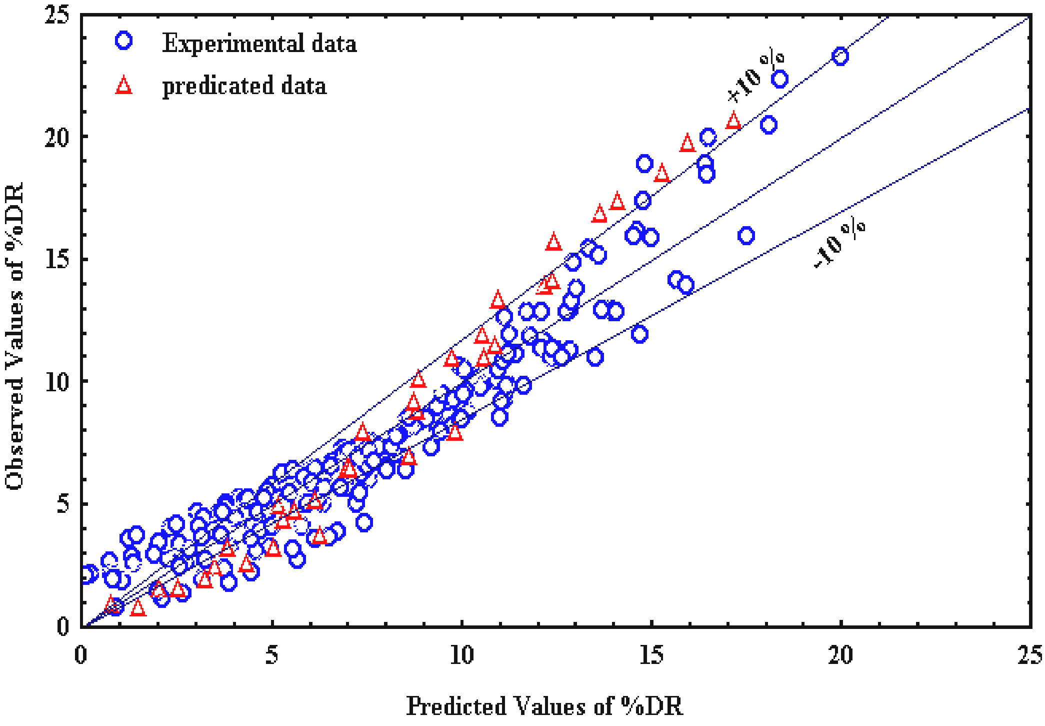


Fig (4.30)   Correlation for all data of CMC

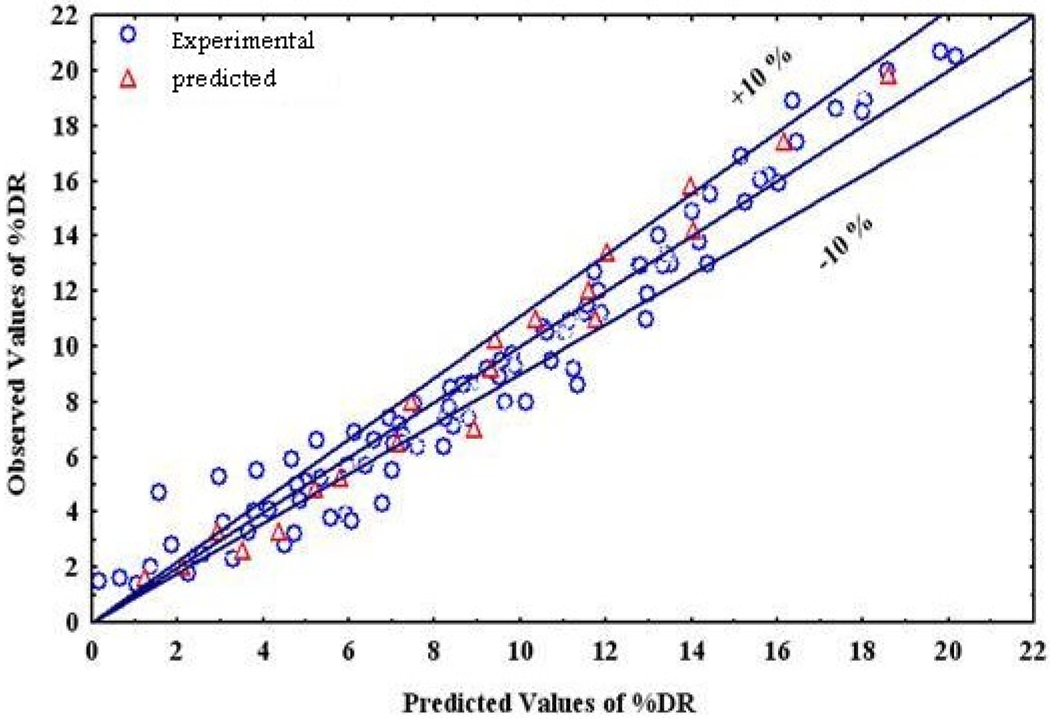


Fig (4.31) Correlation for all data of XG

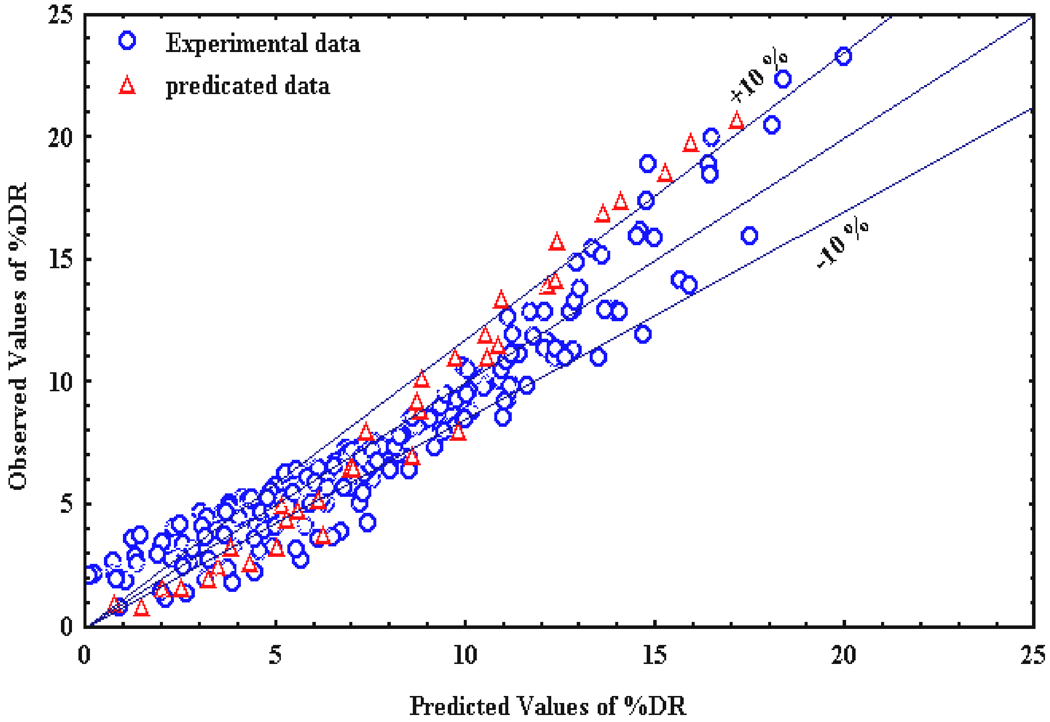


Fig (4.32) Correlation for all data of XG and CMC

Chapter Five
Conclusions and Recommendations

5.1 Conclusions

The following conclusions are drawn from this study:-

1. The effectiveness of carboxy methylcellulose and Xanthan Gum as drag – reducers in turbulent water flow was found to increase by increasing the polymer concentration and solvent flow rate.
2. The higher molecular weight Xanthan Gum treated water shows more effectiveness for increasing the percentage drag – reduction and flow capacity for the low molecular weight CMC additive.
3. Sodiume chloride acts as an inhibitor for drag – reduction performance of both additives, CMC and XG due to the collapse of such molecules to a more compact structure with the existence of such a salt.
4. A gradual decrease of percentage drag – reduction was observed as circulation time progresses, due to mechanical degradation of polymer molecules.
5. It is possible to enhance the drag reduction of any polymer by mixing it with low percent of another polymer of higher molecular weight. An attempt was made to improve the (DRE) of CMC by mixing it with XG and the result was promising .
6. correlation equations were fitted to represent the experimental data mathematically using a computer program (statistica). These correlations show the pressure drop reducing (DR) as a function of additive concentration (C), flow rate (Q), salt molecular weight (M), and salt concentration(S). The results showed a good agreement between the theoretical and experimental data.

5.2 Recommendations

For further work in this area, the following is recommended:-

1. Studying the effect of different salt, such as calcum chloride, Magnesium chloride on effectiveness of CMC and XG as drag – reducer in water flowing. Thermo, investigating the drag – reduction performance of these additives in different sources of water.
2. Investigate, the performance of other water soluble polymers, such as polyethylene oxide and polyacrylamid as drag – reducer in salin water.
3. studying the effect of increasing temperature on the efficiency of polymeric additives and their degradation behavior.
4. studying the effect of pipe diameters and pipe roughnes on effectiveness of polymeric drag – reducers with and without existing of mineral salts in flowing water .

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Appendices

Table (A-1) Experimental Results for CMC as Drag Reducer in water

Conc. ppm	Flow rate m^3/hr	%DR	%TI
50	6.0	7.7	4.5054
	5.4	6.5	3.7961
	4.8	5.4	3.1302
	4.2	4.6	2.6534
	3.6	4.0	2.2991
	3.0	3.6	2.0396
100	6.0	10.2	6.1282
	5.4	8.4	4.9754
	4.8	7.3	4.2572
	4.2	6.1	3.5223
	3.6	5.3	3.0403
	3.0	4.7	2.6830

Table(A-1) continue

Conc. ppm	Flow rate m^3/hr	%DR	%TI
150	6.0	11.6	7.0499
	5.4	9.9	5.9077
	4.8	8.5	5.0386
	4.2	7.3	4.2572
	3.6	6.3	3.6742
	3.0	5.4	3.1002
200	6.0	13.0	7.9603
	5.4	11.4	6.8836
	4.8	10.2	6.0957
	4.2	8.6	5.0702
	3.6	7.2	4.2572
	3.0	6.8	3.9492
300	6.0	16.1	10.0642
	5.4	14.2	8.7882
	4.8	12.9	7.8921
	4.2	11.3	6.8174
	3.6	9.9	5.9013
	3.0	8.7	5.1987

Table (A-2) Experimental Results for XG as Drag Reducer in water

Conc. ppm	Flow rate m^3/hr	%DR	%TI
50	6.0	9.2	5.4515
	5.4	7.4	4.3191
	4.8	6.6	3.8267
	4.2	5.9	3.4012
	3.6	5.3	3.0404
	3.0	4.7	2.6830
100	6.0	13.0	7.9603
	5.4	10.5	6.2912
	4.8	8.7	5.1334
	4.2	7.4	4.3191
	3.6	6.6	3.8267
	3.0	5.5	3.1602

Table(A-2) continue

Conc. ppm	Flow rate m^3/hr	%DR	%TI
150	6.0	16.2	10.2086
	5.4	12.9	7.8921
	4.8	10.8	6.5533
	4.2	9.2	5.4515
	3.6	7.9	4.6302
	3.0	6.8	4.010617671
200	6.0	18.9	12.2118
	5.4	16.0	10.06427892
	4.8	13.3	8.1656
	4.2	11.2	6.7512
	3.6	9.7	5.7722
	3.0	8.5	5.0070
300	6.0	23.3	15.7077
	5.4	20.5	13.4483
	4.8	18.5	11.9085
	4.2	15.9	9.9922
	3.6	13.0	7.9603
	3.0	11.0	6.6192

Table (A-3) Experimental Results for CMC with NaCl at concentration 400 ppm of NaCl as Drag Reducer in water

Conc. ppm	Flow rate m^3/hr	%DR	%TI
50	6.0	5.7	3.2805
	5.4	4.4	2.5057
	4.8	4.0	2.2706
	4.2	3.3	1.8627
	3.6	2.6	1.5168
	3.0	2.0	1.1173
100	6.0	8.2	4.8181
	5.4	7.1	4.1337
	4.8	6.3	3.6437
	4.2	5.1	2.9209
	3.6	4.2	2.3879
	3.0	3.7	2.1536

Table(A-3) continue

Conc. ppm	Flow rate m^3/hr	%DR	%TI
150	6.0	9.9	5.9013
	5.4	8.2	4.8181
	4.8	7.2	4.2263
	4.2	6.4	3.7046
	3.6	4.5	2.9805
	3.0	4.5	2.5647
200	6.0	11.0	6.6192
	5.4	9.7	5.8367
	4.8	9.6	5.0702
	4.2	7.5	4.3811
	3.6	6.3	3.6437
	3.0	5.8	3.3408
300	6.0	14.0	8.6490
	5.4	12.8	7.8921
	4.8	11.4	6.8836
	4.2	10.0	6.0308
	3.6	8.7	5.1334
	3.0	7.5	4.3811

Table (A-4) Experimental Results for CMC with NaCl at concentration 700 ppm of NaCl as Drag Reducer in water

Conc. ppm	Flow rate m^3/hr	%DR	%TI
50	6.0	4.1	2.3292
	5.4	3.3	1.8627
	4.8	2.8	1.5742
	4.2	2.2	1.2310
	3.6	1.7	1.0040
	3.0	1.3	0.7222
100	6.0	6.1	3.5223
	5.4	5.0	2.9209
	4.8	4.5	2.5647
	4.2	3.4	1.9207
	3.6	2.9	1.9317
	3.0	2.2	1.2310

Table(A-4) continue

Conc. ppm	Flow rate m^3/hr	%DR	%TI
150	6.0	7.9	4.6302
	5.4	7.2	4.1954
	4.8	6.1	3.5526
	4.2	5.3	3.0403
	3.6	4.1	2.3292
	3.0	3.5	1.9788
200	6.0	9.2	5.5154
	5.4	8.3	4.9124
	4.8	7.6	4.4432
	4.2	6.5	3.7656
	3.6	5.6	3.2203
	3.0	4.9	2.8017
300	6.0	12.0	7.2838
	5.4	11.3	6.8174
	4.8	9.9	5.9013
	4.2	8.2	4.8181
	3.6	7.4	4.3191
	3.0	6.2	3.5829

Table (A-5) Experimental Results for CMC with NaCl at concentration 1000 ppm of NaCl as Drag Reducer in water

Conc. ppm	Flow rate m^3/hr	%DR	%TI
50	6.0	3.1	1.7470
	5.4	2.6	1.4594
	4.8	1.9	1.0606
	4.2	1.5	0.8347
	3.6	1.2	0.6662
	3.0	0.9	0.4984
100	6.0	5.1	2.9209
	5.4	4.2	2.3879
	4.8	3.2	1.8048
	4.2	2.6	1.4594
	3.6	2.1	1.1741
	3.0	1.5	0.8347

Table(A-5) continue

Conc. ppm	Flow rate m^3/hr	%DR	%TI
150	6.0	7.0	4.0721
	5.4	5.8	3.3408
	4.8	4.7	2.6830
	4.2	3.7	2.0952
	3.6	3.0	1.6893
	3.0	2.0	1.1173
200	6.0	8.5	5.0070
	5.4	7.3	4.2572
	4.8	6.1	3.5223
	4.2	4.8	2.7423
	3.6	3.8	2.1536
	3.0	2.5	1.4022
300	6.0	11.0	6.6192
	5.4	9.85	5.8690
	4.8	8.5	5.0070
	4.2	6.9	4.0106
	3.6	5.1	2.9209
	3.0	3.6	2.0369

Table (A-6) Experimental Results for XG with NaCl at concentration 400 ppm of NaCl as Drag Reducer in water

Conc. ppm	Flow rate m^3/hr	%DR	%TI
50	6.0	8	4.6927
	5.4	7.2	4.1954
	4.8	5.1	2.9209
	4.2	3.6	2.0369
	3.6	2.0	1.1173
	3.0	1.2	0.6662
100	6.0	11.2	6.7512
	5.4	9	5.3239
	4.8	6.8	3.9492
	4.2	5.2	2.9805
	3.6	3.3	1.8627
	3.0	1.8	1.0040

Table(A-6) continue

Conc. ppm	Flow rate m^3/hr	%DR	%TI
150	6.0	13.8	8.5103
	5.4	12.7	7.7561
	4.8	9.5	5.6436
	4.2	6.4	3.7046
	3.6	3.9	2.2120
	3.0	2.8	1.5742
200	6.0	17.4	11.0864
	5.4	14.9	9.2795
	4.8	12.0	7.2838
	4.2	9.3	5.5154
	3.6	6.4	3.7046
	3.0	4.3	2.4468
300	6.0	22.4	14.9677
	5.4	20	13.0577
	4.8	18.9	12.2118
	4.2	14.7	9.1385
	3.6	12.9	7.8921
	3.0	8.6	5.0702

Table (A-7) Experimental Results for XG with NaCl at concentration 700 ppm of NaCl as Drag Reducer in water

Conc. ppm	Flow rate m^3/hr	%DR	%TI
50	6.0	7.1	4.1337
	5.4	5.7	3.2805
	4.8	4.0	2.2706
	4.2	2.8	1.5742
	3.6	1.5	0.8347
	3.0	0.8	0.4427
100	6.0	9.5	5.6436
	5.4	7.4	4.3191
	4.8	3.7	2.0952
	4.2	4.1	2.3294
	3.6	2.4	1.3450
	3.0	1.4	0.7784

Table(A-7) continue

Conc. ppm	Flow rate m^3/hr	%DR	%TI
150	6.0	11.9	7.2169
	5.4	10.7	6.4220
	4.8	7.8	4.5678
	4.2	5.7	3.2805
	3.6	3.2	1.8048
	3.0	2.3	1.2879
200	6.0	15.2	9.4919
	5.4	12.9	7.8921
	4.8	10.5	6.2912
	4.2	8.6	5.0702
	3.6	5.5	3.1602
	3.0	3.8	2.1536
300	6.0	20.7	13.6056
	5.4	18.6	11.9841
	4.8	16.9	10.7183
	4.2	14.0	8.6490
	3.6	11.5	6.9501
	3.0	8.0	4.6927

Table (A-8) Experimental Results for XG with NaCl at concentration 1000 ppm of NaCl as Drag Reducer in water

Conc. ppm	Flow rate m^3/hr	%DR	%TI
50	6.0	6.5	3.765650748
	5.4	5.0	2.8613
	4.8	2.5	1.4022
	4.2	1.6	0.8910
	3.6	1	0.5542
	3.0	0.5	0.2760
100	6.0	8.9	5.2603
	5.4	6.5	3.7656
	4.8	4.4	2.5057
	4.2	3.3	1.8627
	3.6	1.6	0.8910
	3.0	0.8	0.4427

Table(A-8) continue

Conc. ppm	Flow rate m^3/hr	%DR	%TI
150	6.0	11	6.6192
	5.4	9.2	5.4515
	4.8	6.5	3.7656
	4.2	4.8	2.7423
	3.6	2.6	1.4594
	3.0	2	1.1173
200	6.0	14.2	8.7882
	5.4	12	7.2838
	4.8	10.2	6.0957
	4.2	8	4.6927
	3.6	5.2	2.9805
	3.0	3.3	1.8627
300	6.0	19.8	12.9026
	5.4	17.4	11.0864
	4.8	15.8	9.9204
	4.2	13.4	8.2343
	3.6	11	6.6192
	3.0	7	4.0721

الخلاصة

تم دراسة تقليل الاعاقة في الجريان الاضطرابي في نظام لجريان مغلق بوجود نوعين مختلفين من البوليمرات وهما كاربوكسي مثيل سلي لوز والصمغ الزانثان. تم الحصول على الجريان الاضطرابي بواسطة مضخة الازاحه الموجبه لتجنب الانحلال الميكانيكي لسلاسل البوليمر خلال فترة التجربه . تم اختبار تاثير تركيز البوليمرات المضافة بحدود تصل الى 300 جزء من المليون وفي سرع جريان مختلفة تصل الى 6م^3/ ساعة وفي انبوب جريان قطره 1.25 انج .

وتم الحصول على زيادة تدريجيه في تقليل الاعاقة الاضطرابي عي طريق زيادة تركيز البوليمر ومعدل جريان الماء. فعالية تقليل الاعاقة الاضطرابي تقل عند اضافة كاربوكسي مثيل السلي لوز الاقل وزرنا جزئيا منه في حالة استخدام الصمغ الزانثان ذو الوزن الجزيئي الاكبر.

اقصى نسبة لقتليل الاعاقة الاضطرابي تم الحصول عليها تجريبا باستخدام 300 جزء من المليون تركيز البوليمر و6م^3/ساعة سرعة جريان. وهي 16% و 23.3% للكاربوكسي مثيل سلي لوز والصمغ الزانثان وعلى الترتيب.

وتم ايضا خلال العمل دراسة فعالية تقليل الاعاقة عند استخدام خليط البوليمرات كاربوكسي مثيل السلي لوز المضاف مع الصمغ الزانثان ذو وزن جزيئي عالي.

وتم تخصيص جزء من العمل التجريبي لدراسة اداء الكاربوكسي مثيل السلي لوز والصمغ الزانثان وكعوامل تقليل الاعاقة الاضطرابي بوجود كميات صغيرة من كلوريدات الصوديوم لتقليل من قوى الاعاقة. واظهرت النتائج انه كلوريدات الصوديوم تعمل كمثبط لفعالية هذه المواد وبالتالي ينتج عنه قيم نسبة تقليل الاعاقة اقل. ويرجع هذا لحقيقة كون الكاربوكسي مثيل السلي لوز والصمغ الزانثان سلاسل طويلة تتكسر عند اضافة كلوريد الصوديوم وهو ملح ايوني قوي.

باعتماد الوقت ولفعالية تقليل الاعاقة الاضطرابي بانحلال القص الجزيئي خلال الجريان المضطرب ولذلك نسبة تقليل الاعاقة تقل بسرعة كبيرة خلال المراحل المبكرة من الجريان لكلا المواد المضافة. تزداد احتمالية حدوث الانحلال في التراكيزالقليلة.

تم اقتراح معادلة تخمينيه لتقدير تاثير معاملات منظومة الجريان وهي الوزن الجزيئي، التركيز للمواد المضافة، سرعة الجريان واخيرا التركيز والوزن الجزيئي للكلوريد الصوديوم على نسبة تقليل الاعاقة . اظهرت النتائج الافتراضية توافق كبير بين القيم المستحصله عمليا والقيم المحسوبة من المعادلات التخمينيه بسبة 96% لكل من الكاربوكسي مثيل سلي لوز والصمغ الزانثان.

شكر وتقدير

اتقدم بجزيل الشكر والامتنان والتقدير الى الدكتور الفاضل جابر شنشول جمالي لتفضله بالاشراف على هذا العمل لما قدمه لي من اهتمام كبير وتوجيهات قيمة.

الشكر الجزيل الى عميد كلية الهندسة والى اساتذتنا الاعزاء في قسم الهندسة الكيمياوية الذين كانوا شمعة اضاءت لنا دروب العلم .

والشكر الخاص الى عائلتي الكريمة وخاصة إلى والدتي لما قدمته لي من تشجيع ودعم كبيرين.

وأخيرا أود أن أقدم تقديري إلى أصدقائي والى جميع من ساعدني عمليا ومعنويا لأتمام هذا العمل أسال الله تعالى ان يوفق الجميع لخدمة الوطن والإنسانية انه سميع مجيب.

دراسة تقليل الاعاقة في الجريان الاضطرابي باستخدام بوليمرات عالية الوزن الجزيئي

رسالة
مقدمة الى كلية الهندسة في جامعة النهرين
وهي جزء من متطلبات نيل درجة ماجستير علوم

في

الهندسة الكيمياوية

من قبل
هاله جاسم محمد فرحان
بكالوريوس علوم في الهندسة الكيمياوية ٢٠٠٤

ذو الحجة ١٤٢٨
كانون الثاني ٢٠٠٨