FRICTION REDUCTION CAUSED BY THE ADDITION OF ADDITIVES INTO A TURBUIENT FLOW

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by

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Certification

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Abstract

Carboxy methyl cellulose, two anionic surfactants, Sodium stearate, Sodium lauryl sulfate and suspended clay as drag reducers have been investigated in this work, to reduce the frictional resistance and to save pumping power for turbulent pipe flow. The turbulent mode was produced via a positive displacement gear pump to avoid mechanical degradation of additives chains during the experimental period.

The effect of additives concentration was investigated ranging between (50 – 300 ppm) for polymer and surfactant and (500 – 5000 ppm) for suspended solid in flowing water, at flow rate 3 to 6 m^3 / hr and Reynolds number (20000-70000) in two pipes 1.25 and 2 inch I.D pipe with room temperature .

It is also desired to investigate the effectiveness for both Sodium stearate (SS) and Sodium lauryl sulfate (SLS) surfactants by adding of CMC. It was noticed that a gradual increase in percentage drag reduction was observed by increase the percentage CMC in additive mixture with both SS and SLS surfactants.

Despite the technique was established in two consequence steps which are, the addition of amounts of solid particles that can be suspended in liquid water, these suspension may be used as drag reducing agents. After that the other step is established by the addition of quantities of certain polymer (CMC) with three different concentrations (100,200 and 300 ppm) at the same flowing condition the addition of CMC improve the percentage of drag reduction was suspensions.

A gradual increase of drag reduction and throughput was achieved by increasing the clay concentration and water flow rate and decreasing the pipe diameter.

Friction factors was calculated from experimental data. friction factor values for pure water transported lies near or at Blasuis asymptote. While by introducing the additives, the friction factor values were positioned below Blasuis asymptotes towards Virk maximum drag reduction asymptotes.

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NOTATIONS

Variables Notations

A	Area	[m^2]
C	Additive concentration	[ppm]
d	Pipe diameter	[m]
ID	Inside diameter	[m]
L	Testing section length	[m]
Le	Entrance length	[m]
MW	Molecular weight	[g/g mole]
N	Chain length	[m]
ppm	Part per million	
Q	Volumetric flow rate	[m^3/hr]
Re	Reynolds number ($\rho Vd/\mu$)	
U	Fluid velocity	[m/s]
U*	Friction or shear velocity	[m^2/s]
%DR	Percentage drag reduction	
%TI	Percentage throughput increase	
ΔP	Pressure drop	[N/m^2]

Abbreviations

CDR	Connoco drag reducer
CMC	Carboxymethyl cellulose
CTAC	Cetyl tri-methyl ammonium chloride
DR	Drag reduction
DRA	Drag reduction agent
GG	Guar gum
HEC	Hydroxyethylxcellulose
HP	Horse power
NaSaL	Sodium salicylate
PAA	Polyacrylic acid
PAM	Polyacrylamide
PEO	Polyethylene oxide
SLSC	Sodium lauryl sulfate
SS	Sodium stearate
STAC	Stearyltrimthyl Ammonium Chloride
TAPS	Trans Alaska Pipeline System
XG	Xanthan gum

Greek Letters

$\boldsymbol{\rho}$	Fluid density	[kg/m^3]
$\boldsymbol{\mu}$	Dynamic viscosity	[poise]
$\boldsymbol{\tau}$	Shear stress	[N/m^2]
$\boldsymbol{\nu}$	Kinematic viscosity	[m^2/sec]

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Chapter One
Introduction

1.1 Introduction

In the process of transferring a Newtonian fluid through a pipe, considerable energy may be expanded, 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 term used to refer to such frictional pressure drop(1).

The industrial application of Drag reduction can be found in many areas such as pipelining of crude oil and its fractions, fire – fighting(2) and closed circuit pumping installations, such as central heating systems(3). The first major application of drag reducers in oil pipelines has been in the Trans Alaska oil pipeline system(4). Another major use of such chemicals had been in Iraq in the mid 1980(5). These applications showed the high ability of polymers in reducing drag and increasing oil flow rate without the need for any additional pumping power or new pipelines.

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.

High molecular weight polymers and some surfactants are the most popular chemical drag reducing agents. The dependence of drag reduction efficiency is known to be a function of polymer molecular weight, polymer concentration and the degree of turbulence(6,7).

The phenomenon of Drag reduction by polymer additives is very interesting from fundamental fluid dynamics point of view as well. The fact that such small changes in the fluid can so drastically after 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.

Additive are able to reduce the frictional loss associated with turbulent flow of fluid by lowering the energy loss, those additives allow the pipeline fluid to move faster at any working pressure(8).

The use of polymer additives to reduce drag , and consequently pumping costs, has to be carefully with its degradation rate and the consequent rate of polymer renewal, the investment on injection mechanisms and quantity of polymer necessary to achieve drag reduction intensity, which may preclude its use in normal operating condition, but not in special occasions such as maintenance of equipment.

Hence, polymeric drag reduction is interesting in many ways and this is reflected in virtual explosion of research and development work in many countries during the last four decades. A large amount of publications had been appeared. Some of the publications are theoretical reflections, and also a respectable number of survey articles have been published. Despite this wealth of information, it cannot be said that the phenomenon is well understand. The physical mechanism responsible for the drag reduction remains largely unclear. This is caused by the fact that not only it is necessary to consider the turbulence processes that are present in the flow , but also the influence of the rheological properties of the fluid.

The main object of this work is to select the surfactant type and concentration that gives the highest percentage drag – reduction, polymer concentration, suspended solid, concentration and to study the effects of pipe diameter, flow rate on drag – reduction , percentage throughput increase and friction factor.

Chapter Two
Literature Survey

2.1 Drag Reduction Phenomena

Turbulent drag reduction which is a drastic reduction of frictional resistance can be easily observed by injection a minute amount of polymeric additives in turbulent flow[9], polymer solutions undergoing a turbulent flow in a pipe there by require a lower pressure drop to maintain the same volumetric flow rate . The addition of small amounts of additives to the flowing fluids can show significant effect on a lot of flow types, including the stability of laminar flow, transition to turbulence, vortex formation and break – up[10].

Drag reduction in fluid flow is an interesting phenomenon and has widely attention from theoretical as well as practical point of view. Liquids are mostly transported through pipes, and drag reduction by adding small amount of additives can offer large economic advantages and more effectiveness of flow capacities. Consideration of throughput increase to meet increased and which can be either being permanent or seasonal Drag reduction offer the best quick temporary solution to such problem. Its main advantage is that no capital investment is required[11].

Drag reduction phenomenon exhibited by many Newtonian and pseudoplastic solutions, gells and suspensions, and it can be considered as a departure from their "normal" viscous behavior in general some, high molecular weights polymers and detergent solutions particular some cationic surfactants are used as drag reducer, the use of polymers are limited gradually, due to their toxicity and higher costs[12].

The addition of drag reducing additive is done by two different methods resulting in two different types of drag reduction, homogenous and heterogeneous[13].

The first type is the homogenous drag reduction which dissolving the polymer in fluid before the experiment take place, and the second is the heterogeneous drag reduction which occur by injection of concentrated polymer into turbulent pipe flow[13].

2.2 Fluid Flow Concepts in Drag Reduction

A fluid is classified by the manner in which its viscosity changes with shear rate Newtonian fluids followed the Newton's law of viscosity, which is typical for small molecules such as water. The viscosity of the fluid is independent of the shear rate, as shown in equation (2.1) .

$$\tau = \mu * \frac{du}{dy} \qquad ...(2.1)$$

In a non – Newtonian fluid, the viscosity is often a strong function of shear rate. This is referred to as an apparent viscosity and is defined in equation (2.2) :

$$\tau = \mu_{app} * \frac{du}{dy} \qquad ... (2.2)$$

Additive solutions with drag reducing ability have apparent viscosities that decrease as shear rate is increased. These are called shear thinning fluids, and many equations can be used to fit the apparent viscosity as a function of shear rate(14).

In pipe flow, shear stresses are highest at the wall, the main drag reduction is given as in equation (2.3)(4) .

$$\%DR = \frac{(\Delta Ps - \Delta Pp) * 100}{\Delta Ps} \qquad \text{... (2.3)}$$

Where ΔPs is the pressure drop in a given length of tube for a pure solvent and ΔPp is the pressure drop for drag reducing solution with the same flow rate of liquid.

The pressure loss in a pipe is due to fluid – frictional resistance, broadly classed in terms of laminar and turbulent flows by the fluid Reynolds number, given in equation (2.4) .

$$Re = \frac{\rho V D}{\mu} \qquad \text{... (2.4)}$$

where, ρ is the fluid density, V is the fluid velocity, D is the inner diameter of the pipe, and μ is the solvent viscosity.

The friction factor of the solution with additive is determined using equation (2.5)(15).

$$f = \frac{D * \Delta P}{2 L \rho V^2} \qquad \text{... (2.5)}$$

where , ΔP is the pressure drop, L is the length of the test section, and V is the velocity obtained from flow rate measurements and cross sectional area of the tube.

The friction factor of the solvent can be accurately estimated from the Von Karman equation[16], as given in equation (2.6), for turbulent flow.

$$\sqrt{\frac{1}{f_s}} = 4 * \log(Re * \sqrt{f_s}) - 0.4 \qquad \text{... (2.6)}$$

and in equation (2.7) for laminar regime.

$$f = \frac{64}{Re} \qquad \text{... (2.7)}$$

2.3 Theory

Various approaches to an explanation of drag reduction have been taken, such as reduced energy[17], modified transient shear response[18], boundary layer thickness[19], and resistance to extensional flow[20]. The approaches range from purely hypothetical to essentially rearrangement of turbulent flow data. However non of them have resulted in a method of qualitatively predicting the pressure drop for a given solution from fundamental measurable physical properties of these solutions.

Astarita[21] suggested the turbulence in viscoelastic fluids which is less dissipative and offered some order of magnitude calculations to support his proposal.

Hershey and Zakin[22] proposed the turbulence suppression begins at a critical Reynolds number which is reached when a characteristic time of the flow is of the same order as the longest relaxation time of polymer solution.

Theory of Zimm[23] used relaxation time estimated from a modification, and reciprocals of the shear rate at the wall as a measure of the characteristic flow time. They obtained good predictions of the start of turbulence suppression in their experimental pipe flow data. At about the same time Fabula, Lumely, and Taylor[24] offered a similar proposal. Elata et al.[25,26], had used a similar approach.

Lee, Vaseleski and Metzner[27] reported that Viscoelastic property of the dilute polymer and surfactant solutions may be shown to reduce the radial transport rat in eddies near the wall.

Darby and Chang suggested viscoelastic properties influence the rate of energy dissipation in turbulent eddies[28]. Elperin et al.[29] suggested that an adsorbed layer of polymer molecules could exist at the pipe wall during the flow and this could lower the viscosity, create a slip, damp turbulence and prevent any initiation of vortices at the wall. However, from later experiments it had become clear that the adsorption of the additives on surface could in fact be an experimental artifact, but it cannot be the reason for drag reducing effect.

The structure of turbulence during drag reduction had been studied to the extent of a few turbulent intensity profiles and kinetic energy spectra[19,30,31]. Berretz, Doppev, Horton and Husen[32] show that Drag reducer does not treat or coat the pipe wall or change the bulk hydrocarbon fluid properties but only change the hydraulisc of the flow stream. Lester[7] show that these agents work by absorbing and later returning to the flowing stream energy which comprise turbulence. Lumely[33] had calculated the characteristic time scale of the turbulent flow field, υ/υ^{*2}, is of the order of the molecular relaxation time of a monodesperse polymer sample.

McComb and Rabic[34] observed a thickening of the elastic sub layer, an enlargement of integral scale of autocorrelation a decrease of high – frequency energy spectra and an increase of bursting time. The same observations have also been reported for the premixed drag reducing flow. The difference in turbulence structure between polymer injection and premixed drag – reducing system had not been clarified.

Tabor and de Genne[35], thought that the elastic energy stored in polymer molecules causes drag reduction (elastic theory). That is, the polymer molecules absorb the small scale turbulence energy by prohibiting the turbulent cascade, which results in drag reduction. Following that's the kinetic and elastic energy transport equation were derived in order to investigate the effect of elasticity on drag reduction. It was shown that the polymer stores the elastic energy from the flow in the sub layer and then releases it again in the sub layer when the relaxation time is short (no drag reduction). However, when the relaxation time is long enough (drag reduction), the elastic energy is transported to and released in the buffer layer. Therefore the drag reduction occurs when the turbulent velocity scale is larger than the characteristic velocity scale of the polymer solution[36].

Savins[37], observed drag reducer solutions having elastic deformations which would modify the type of turbulence, where found CMC (polymer) and polyisobutylence solutions have swelling of a liquid jet emerging from a capillary. There was also some evidence of the presence of low level of elasticity in a poly acid. They suggested also the existence of abnormally mobile laminar sub – layer whose thickness is comparable to polymer type and its properties, which cause apparent slip at the wall. It is noted that the viscosity in a boundary layer at the wall is several times higher than in the bulk of the fluid and this tendency is increased with increase in chain in length of polymer. These observations lead to conclude that fluid friction reduction is the results of boundary sub layer modification, and this effect persists even in the fully developed turbulent flow.

Ron Darby et. al.,[28] used the generalized friction factor for drag reducing polymer solutions of three different concentrations both freshly prepared and shear degraded, in a wide range of tube sizes, then to be reduced to the usual friction factor VS. solvent Reynolds number correlation for Newtonian fluids in smooth tubes. They suggested that, the viscous and elastic (time constant) parameter of the solutions which are required for the generalized correlation can be obtained directly from a knowledge of the apparent viscosity function of the solution.

The examination of the drag reduction phenomena in details with the role of molecular parameters on the onset and flow rate dependence has been investigate[24]. The researcher concluded that the experimental studies of drag reduction using "nearly monodisperese" poly styrene samples and gel penetration chromatography analysis have shown details of the relationship between molecular weight distribution of the polymer and the experimentally measured drag reduction onset behavior and flow rate dependence[38].

Ting[39] observed that the onset data for drag reduction shows a qualitative correlation between the parameters describing the polymer and the flow conditions at onset. Achia et al.[40] had measured axial and transverse length scales of the near wall region and found them to be significantly increasing with drag reduction.

2.4 Flow Improver Additives

2.4.1 General

Flow improvers (drag reducers) were first observed in 1945. Drag reduction has been defined as the increase in pump ability of a fluid caused by the addition of small amounts of an additive to the fluid[32].

To compensate for the loss of energy due to friction pressure, additional energy must be consumed consequently, a decrease in friction loss would allow lower energy consumption or alternatively an increased flow rate under the original pumping conditions. Thus, friction loss in the flow of liquids can be appreciably reduced is desirable. Also it is economically profitable to industrial organizations engaged in movement of large volumes of liquid at high flow rates for considerable distance.

Flow improvers do not treat or coat the pipe wall or change the bulk hydrocarbon properties but only change the hydraulics of the flowing stream[32].

The use of chemical additives known as drag – reducing agents to liquid transported in turbulent flow through pipelines which is one of popular method to reduce the friction and to increase the flow capacity.

Furthermore, suppressing turbulent eddies can be a chivied by using baffles with different heights[41], Heating the liquid for viscosity reduction, connecting the pumps in series or in parallel as required, connecting re – enforcement and stand by pumping stations.

2.4.2 Surfactant

Surfactants are surface – active agents, which consist of polar Hydrophilic head and non polar, hydrophobic tail. Surfactants were used as drag reducing agents in many commercial applications. Surfactant molecules have the ability to form certain types of aggregates which are called "micelles". These micelles have the ability to reform there structure and region there drag reducing ability, when the fluid enters lower shear regions[42,43].

Surfactant were discovered as an efficient drag reducer in the early forties. During world war II, Mysels observed a similar drag reduction effect for gasoline with an anionic surfactant, i.e. aluminum soaps. The findings of the work were first patented much later in 1949[44].

Ten years later, knowledge of additives to reduce drag was further advanced by the work of Dodge and Metzner[41], and Shaver and Merrill[45]. Both noticed unusually low friction factors for certain non-Newtonian solutions those of sodium carboxy methylcellulose in water.

The surfactants can be classified according hydrophilic groups as anionic, nonionic and cationic types(46).

Anionic Surfactants

Following the pioneering work of Mysels(44) in non – aqueous systems, Savins(47,48) carried out extensive work on anionic surfactants as drag reducers in aqueous solutions.

Anionic surfactants are negatively charged, which allows them to interact with any positive ions present in solution, such as calcium and magnesium ions in tap water.

Savins(47) observed an interesting stress controlled DR effect in the soap solutions. The DR increased with increasing shear stress up to a critical value. Beyond the critical value, the DR of the soap solution became indistinguishable from that of the soap – free solution. This indicates that the network of micelles collapses if the shear stress exceeds critical shear stress. This occurs because of a temporary disentanglement of the network induced by turbulent vortices and eddies in fully developed flow. If the wall shear stress is reduced from above to below the critical value, then the Network bonds reform and the reducing ability of the solution is restored.

This type indeed preferred due to easy manufacture, primary substance and have strong to clean. Although these conventional soaps are relatively inexpensive and mechanically stable, they have limited applicability as they are precipitated out by interaction with calcium and other ions that are generally present in tap and sea water[49].

Nonionic Surfactants

The studies anon ionic surfactants as drag reducers have been reported only by Zakin and Charg[50,51]. The critical shear stress for mechanical degradation in the case of nonionic surfactant is dependent on the surfactant concentration, electrolyte type and concentration and on the temperature[50,51].

Nonionic surfactants don't have any charges and are less affected by ions. In solutions containing non-ionic surfactant. The temperature at which the maximum drag reducing ability is observed is close to the cloud point, or coacervation temperature, of the surfactant solution.

Nonionic surfactants have an advantage over the anionic and cationic counterparts because they are both mechanically and chemically stable. They do not precipitate out in the presence of calcium and magnesium ions and therefore can be used in hard waters, sea water or concentrated brine solutions[49].

Cationic Surfactants

Drag reduction by cationic surfactants has been considered the most effective way to increase the pump ability of fluid and reduce costs in closed – loop district heating and cooling systems[52,53]. It is known that quaternary ammonium salt cationic surfactants from rod – like micelles in the presence of a suitable counter-ion[54,55]. Surfactant solutions with rod-like micelles show remarkable viscoelasticity , and the effective drag reduction in a turbulent pipe flow has been reported by many investigators[56,57] .

Among the cationic surfactants used for drag reduction, cethyltrimethyl ammonium chloride (CTAC), and stearytrimethyl ammonium chloride (STAC), have been most widely used as the drag – reduction additive. Sodium salicylate (NaSal) was added as a counter – ion, The amount of NaSal was adjusted to the same wt% as that of the surfactant additive, resulting in a molar ratio of CTAC to NaSal of approximately 1.2[58] Gadd[59] suggested the possibility of using the cetryltrimethyl ammonium bromide (CTAB) – naphthol mixture to reduce turbulent friction, because the mixture showed shear – thinning characteristics similar to anionic surfactant solutions, the drag reducing ability of the CTAB – naphtol solution terminated at some upper Reynolds number corresponding a critical shear stress where there was a scission of the micelles. Cationic surfactants are positively charged and typically are effective drag reducers, but are not very biodegradable.

Cationic surfactants are mechanically stable, and thermally instable and thus limited in practical applications[49].

2.4.3 Micelle

A micelle is an aggregate of surfactant molecules dispersed in a liquid colloid. A typical micelle in aqueous solution forms an aggregate with the hydrophilic "head" regions in contact with surrounding solvent, sequestering the hydrophobic tail regions in the micelle centre this type of micelle in know as normal phase micelle (oil – in water micelle). Micelles are approximately spherical in shape. Other phases, including shapes such as ellipsoids, cylinders, and bilayers are also possible.

The shape and size of a micelle is a function of the molecular geometry of its surfactant molecules and solution conditions such as surfactant concentration, temperature, pH, and ionic strength. The process of forming micellae is known as micellisation and forms part of the phase behaviour of many lipids according to their polymorphism[60].

A micelle may take several forms, depending on the conditions and composition of the system, such as distorted spheres, disks, or rods as shown in figure 2.1. Micelles do have the ability to reform their structure (regain their drag reducing ability when the fluid enters lower shear regions[60].

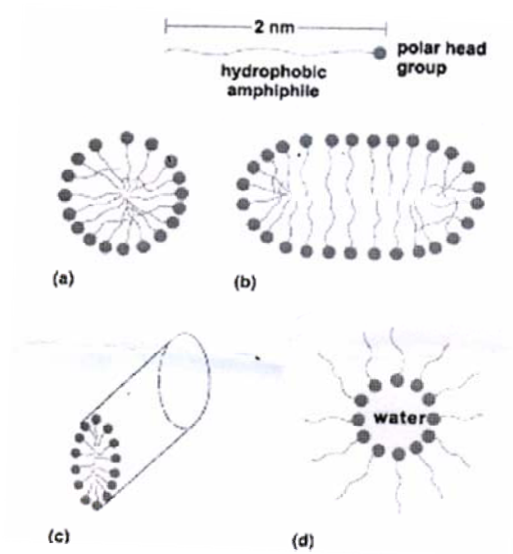

Fig.2.1 Shapes of Micelles: (a) Spherical , (b) Disk , (c) Rod , (d) Reversed

Individual surfactant molecules that are in the system but are not part of a micelle are called "monomers". In water, the hydrophilic "head" of surfactant molecules are always in contact with solvent, regardless of whether the surfactant exist as monomers or as part of micelle. However, the lipophilic "tails" of surfactant molecules have less contact with water when they are part of micelle – this being the basis for the energetic drive for micelle formation.

In a micelle, the hydrophobic tails of several surfactant molecules assemble into an oil – like core the most stable from of which has not contact with water. By contrast, surfactant monomers are surrounded by water molecules that create a "cage" of molecules connected by hydrogen bonds[60].

When surfactants are present above the critical micelle concentration, they can act as emulsifiers that will allow a compound normally insoluble in the solvent being used. By dissolving the insoluble species can be incorporated into the micelle core, which is itself solubilized in the bulk solvent by virtue of the head group favorable interaction with solvent species. The most common example of this phenomenon is detergents, which clean poorly soluble lipophilic material (such as oils and waxes) that can not be removed by water alone.

Detergents also clean by lowering the surface tension of water, making it easier to remove material from a surface. The emulsifying property of surfactants is also the basis for emulsion polymerization.

Micelle formation is essential for the absorption of fat soluble vitamins and complicated lipids within the human body. Bile salts formed in the liver and secreted by the gall bladder allow micelles of fatty acids to form. This allows the absorption of complicated lipids (i.e., lecithin and lipid soluble vitamins (A , D , E and K) by the small intestine within the micelle[60].

2.4.4 Polymers

the drag reduction effect of polymer has been known for almost half a century, a generally accepted explanation of the mechanism that causes this drag reduction is still not available. During the past five decades, a vast number papers have appeared on polymeric drag reduction, which can be roughly divided into three categories[61]. The first category includes studies on drag reduction from a molecular perspective. The behaviour of polymer molecules in various model flows (e.g. simple shear, pure strain, etc.) was examined. One of the most through literature reviews of the dynamics of polymer molecules in turbulent flow was written by Lumley[33]. A recent theoretical study was conducted by Rabin and Zielinska[62]. The examined the effect of polymer molecules on the vorticity distribution in elongational flows and argued that there will be a shift in the turbulent energy from high down to low wave numbers.

The second category included studies on the effects of polymer on the time – averaged turbulence statistics. One of the best examples of this type of research was done by Virk[30]. They measured stream wise velocity in a drag reduction pipe flow with different molecular weight polymers and different solvents. This work produced the well known "Virk asymptote" for drag reduction as a function of polymer concentration with advances in instrumentation and visualization techniques.

The third category arose, in which changes in coherent turbulent structure due to polymers are examined.

The chemical nature of polymer is important in terms of its relation to other drag reduction parameters. The molecular linkage in the polymer backbone affect shear stability, obtained flexibility inter molecular association and polymer / solvent interaction, which in turn affect drag – reduction elfictimes. Polymer molecular composition and architecture can be tailored to provide desired combination of the both properties[(63)].

The longer polymer chain provides more chance for entanglement and interaction with the flow. It has been confirmed that the extension of the polymer chain is critical for drag reduction. The most effective drag reduction polymers are essentially in linear structure with maximum extensivity for a given molecular weight. Polyethylene oxide, polyisobutylene and polyacrylamide are typical examples of linear polymers. Polymers lacking linear structure, such as gum arabic and the dextrans, are ineffective for drag reduction[(16)]. Polymer as drag reducers are classified in water soluble and hydrocarbons soluble types, as follows :

Water-soluble	**Hydrocarbons-soluble**
Polyethylene oxide, PEO	Polyisobutylene
Polyacrylamide, PAM	Polystyrene
Guar gum, GE	Poly(methyl methacrylate)
Xanthan gum, XG	Polydimethyl siloxane
Carboxy methyl cellulose, CMC	Poly (Cis-isoprene)
Hydroxyethyl cellulose, HEC	Conoco drag reducer , CDR

Polyethylene Oxide is linear, flexible molecular which is available commercially in a range of molecular weights, its utility in multiple pass application is limited due to its extreme sensitivity to shear degradation[63].

A remarkable aspect of polymers, as a drag reducer that DR occurs at very low concentration in the ppm region. Increasing the concentration beyond 30-40 ppm lowers DR for PEO in a small tube owing to increase of the viscosity with increasing concentration.

Interestingly, DR can be observed in concentration as low as 0.02 ppm[64]. Using a rotating disk apparatus[65] or a rotating cylinder[66], DR induced by water – soluble polymers (PEO , guar gum) and Hydrocarbons – soluble polymers (Polyisobutylene) showed similar result to the experiments performed with small tube.

Polyacrylamide (PAM) is the other synthetic water soluble additive which differs from (PEO) is that it has a side chain and is less susceptible to shear degradation[63]. The related polymer, polyacrylic acid can be formed by hydrolysis of PAM.

Most of laboratory and commercial studies, however, have focused on PEO and PAM due to their availability, their relatively low cost, and the large body of previously reported experiments describing their solution behavior available in the literature[63].

Guar gum, is a plant polysaccharide with semi – rigid backbone. It has been used for a number of years in oil field application, and in the petroleum industry[67]. The major limitation of guar gum in drag reduction application is it susceptibility to biodegradation.

The first commercial use of flow improvers occurred in the summer of 1979 when the injection of DR flow improver began in Trans Alaska Pipeline System (TAPS)[67]. Modified cellulose such as carboxy methyl cellulose (CMC) and Hydroxyethyl cellulose (HEC) have been employed commercially and in laboratory studies. CMC was the first water – soluble polymer whose drag reducing properties were reported in the literature[68]. It is colorless, odorless and nontoxic powder. It is consider as an anionic polymer.

Xanthan Gum , is an extracellular polysaccharide produced by the bacteria xanthomnas composition of XG polymer shows that the polymer repeats unit contains five D-glucose rings as the polymer backbone and two side chains composed of a total of six member rings. Molecular weight of Xanthan gum is estimated to be about $5 * 10^6$ g / mole[69].

A range of new water – soluble polymers have been synthesized by McCormick and Coworker[70]. They have undertaken extensive analyses of polymers of widely different structures and composition. These polymers, anionic and cationic polyelectrolytes and polyampholyts.

Application of these water – soluble polymers to DR technologies have been investigated[66,70,71]. It has discovered that all copolymers were found to conform a universal curve of DR, when normalized for hydrodynamic volume fraction polymer in solution. This method of plotting allows the comparison of DR efficiencies of polymers of different structures, composition and molecular weight.

Biopolymers such as high molecular weight polysaccharides produced by living organisms comprovide effective drag – reduction[53]. Polysaccharides of several fresh water and marine algae, fish slimes, sea water slime and other fresh water biological growths have been found to be good drag reducers. Interestingly, as mentioned later these biological additives, are also a source of fouling growth which can substantially reduce the DR effectiveness brought about by other drag reduction technologies.

2.4.5 Comparison between polymers and surfactants

Surfactants solutions have become of favorite drag reducer owing to their chemical and mechanical stability that is an important requirement for practical applications. Development of surfactant systems exhibiting DR at concentration similar to dilute polymer solutions (< 100 ppm) have been disclosed in a number of recent patents[65].

When one compares the data for surfactant solutions with that for polymer solution, it becomes obvious that the drag reduction behaviors in these two cases are different. While the soap solution exhibits drag reduction low wall shear stress values, the polymer solutions show relatively small drag reduction at low Reynolds numbers and increasingly large reduction at high Reynolds numbers. These two types of behavior are obviously a consequence of the morphological difference between micelle and polymeric structures[53]. It can be assumed that :

1- The flexible polymer molecule needs to be elongated by a large velocity gradient before its full drag reducing ability is developed.

2- The surfactant particles are oriented much more easily at lower velocity gradients.

In terms of equivalent molecular weight, micelles are known to have larger values than polymers and therefore they would shift the onset of drag reduction to a lower shear stress value(53,64).

2.4.6 Suspended Particles

It is well known that the presence of suspended particles modifies the turbulent structure of the flow(72). The combination of general factors, such as sediment concentration, specific weight of solid and fluid, particle size and shape and others, can produce sub stationary changes in the behavior of the flow. The most interesting case is that of a drag reduction which can occur in pipes when the combination of factors produce a decrease of turbulent intensity. The mechanisms which produce these changes in the turbulent structure could be various depending upon the particle and flow characteristics, and the overall effect could also vary for each particular case.

A and K Zaqustin(72) presented an analysis of mechanism in which gravity is considered as the only factor involved in the turbulence. The same approach was obtained a few years later by Mahmood(73), Wilson suggested that the particles tended to damp the turbulent fluctuation of the velocity, thus decreasing the velocity gradient at the wall.

2.5 Drag Reduction Application

Drag is a term used to refer to the frictional pressure drop per a length of a pipe, which develops when a fluid flows in a pipe line. Drag reduction is the proportional decrease in this frictional pressure drop achieved by the addition of very small amount of drag reducing agent.

The most spectacular success in polymer applications for drag reduction has been use of oil – soluble polymers in the Trans – Alaska pipeline system (TAPS). The use of CONOCO chemical Co. (CDR) drag reducer had proved practical as a temporary replacement for unconstructed pumping stations, where as a result the flow rate had been increased by 32.000 m^3 / day. The polymer, in this case, was injected downstream of the pumping stations, polymer concentrations were of the order of 10 wppm[(67)]. Another reported major use of such chemicals has been in Iraq in themed[(5)]. Hydro transport of solid such as clay sand and gravel, coal iron ore, sewage slug, and pulverized fly ash using drag reducing agents has been studied extensively. Polymer solution friction system such as hydraulic machinery, motor, gear cases, propellers and bearing[(74)].

The addition of low concentrations of polymers might be capable of improving blood flow through stenestic vessels without altering flow through normal vessels, as is suggested by a study by Unthank et al.[(71)].

A military application which has been patented is the reduction of the Drag acting on a torpedo by ejecting a sea – water polymer solution from the torpedo nose[(75)].

In addition to a drag reduction, the polymer also causes a reduction in heat transfer which is advantages in maintaining low oil viscosity[77], also in sewerage pipes and storm – water drains polymers have been used to increase the flow rates so that the peak loads do not result in overflowing, if only relatively infrequent use is required, this can be much cheaper than constructing new pipes[78].

Chapter Three
Experimental Work

3.1 Materials

Sodium stearate (SS), Sodium lauryl sulfate (SLS) and Carboxy methyl cellulose (CMC) were supplied from General Vegetable Oil Interptice.

SS is a white powder with chemical formula $C_{18}H_{35}O_{21}$ it has a molecular weight of 306. SLS is a white powder also, with chemical formula $C_{12}H_{25}NaO_4S$ and molecular weight of 288.9. CMC is colorless, odorless and non toxic powder with a molecular weight $0.4 * 10^6$.

Clay was supplied from fine Arts Institute. The type of clay is kaolinite with a chemical formula $Al_2Si_2O_5(OH)_4$. Tap water was used as flowing fluid.

3.2 Preparation of additives solution

The method of dissolving of additive adapted here was to make 2% by weight additive solution in separate container. Therefore about 15.3 g of additive was mixed with 750 ml of water.

The solution was stirred by a shaker for 1 hour for the surfactants, SS and SLS and about 6 hours for the CMC. The solution allowed to stand for 24 hours at room temperature prior to its uses. And then carefully transferred to the test apparatus. Care was taken also to avoid degradation of polymer during mixing and transfer.

The Shaker was used to avoid additive molecular degradation because the shaker has no blade or sharp edge that could expose the additive to high shear force. Type of Shaker was KOTTGRMANN 4019 GGPMAMY, 100 rpm.

The clay was crushed by hammer and then suspended dissolved in 750 ml of water.

3.3 Flow System

Laboratory circulation loop system(79) consists of a reservoir tank, gear pump, flow meter , manometer , pipes and valves , as shown in figure 3.2.

The capacity of $0.49m^3$ reservoir tank was supported with two pipes of inside diameter of 31.75 and 50.8 mm to perform the flow measurements.

A gear pump of 50.8 mm diameter and 1440 rpm was used to deliver the fluid to the testing sections.

Piping starts from the reservoir tank through the pump, reaching a connection that splits the pipe into two sections. The first section returns back to the tank using a 50.8 mm pipe as by pass and the other splits into three sections with 1.25 and 2 inch pipe diameters (test section).

The test section of 2 m long was placed away from the entrance length required. The minimum entrance length required for a fully developed velocity profile in turbulent flow was calculated from the relationship suggested by Desissler[92].

$$Le = 50\ D \qquad \text{... 3.1}$$

where,

Le = entrance length, m

D = pipe diameter, m

The reason to do this is to restrict the pressure drop measurements in fully developed region.

The minimum entrance length for the pipe used in table 3.1 was as follows:

Table 3.1 Minimum entrance length for the pipe used

Pipe diameter, m	**Minimum entrance length (Le), m**
0.03175	1.5875
0.05080	2.5400

Finally, all pipes return back to the reservoir tank. A flow meter was used to measure the flow rate of solution.

The water flow rate was measured with float flow meter, of 50.8 mm diameter and flow indicating range was between 0.6 – 6.0 m^3/h. Figure 3.2 shows the calibration of flow meter.

A manometer was used to evaluate the pressure measurements in mH_2O.

Fig. 3.1 Calibration of flow meter For water

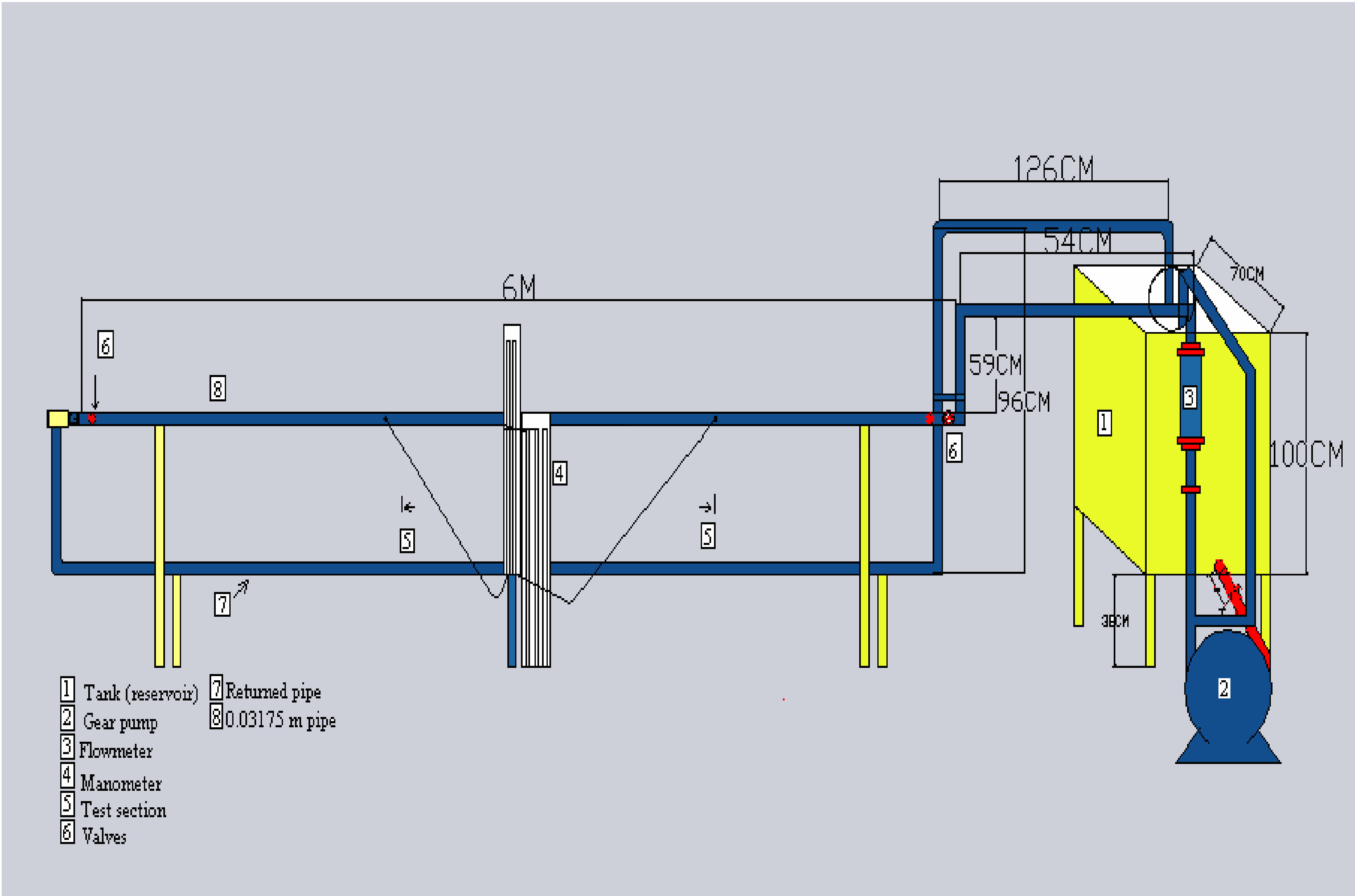

Fig. 3.2 Schematic diagram of experimental rig.

3.4 Experimental Procedure

The experiments were started by cleaning the rig by tap water in the reservoir tank and circulated it in the piping system about 30 min and then discharged out side the flow system. The cleaned reservoir tank was filled with about 150 liters tap-water.

The addition of additive was taken in weight part per million (ppm), this quantity of additives was mixed with about one liter solvent, water and then poured in the solution reservoir tank.

When the pump started delivering the solution through only one of the two pipe sizes by closing the other valves. Then each tube end of the pressure taps was connected in the upstream and down stream with U-tube manometer, and this allowed the bubbles in the connecting Vinyl tubes to flow away, to avoid any error by reading. When the level of the water in manometer is in the same level that indicate the reading of manometer is right.

The solution flow rate was fixed at the certain value by controlling it with the by pass section. Pressure readings were taken for each flow rate, by changing the solution flow rate to another fixed point. Pressure reading were taken for the six desired values of flow rates (3 , 3.6 , 4.2 , 4.8 , 5.4 and 6 m^3 / h).

This procedure was reported for two pipe diameter, surfactant type, surfactant concentration, polymer concentration and particle concentration.

3.5 Calculations

the weight of additive required to prepare (X) ppm in 150 liter of water is obtained from following equation.

$$Weight\ of\ additive = \frac{\rho_{water} * 150 * X}{10^6} \qquad \text{... (3.2)}$$

where,

ρ_{water} = density of water in g / lit.

for example to obtain 100 ppm

$$Weight\ of\ additive = \frac{1000 * 150 * 100}{10^6}$$

= 15 g additive

for 2% additive solution :

$$= \frac{15 * 100}{2}$$

= 750 g additive solution

ΔPs is the pressure drop in a given length of tube for a pure solvent, and ΔPp is the pressure drop for drag reducing solution with the same flow rate of liquid for both. The percentage drag reduction was calculated by equation (3.3)[4].

$$\%DR = \frac{(\Delta Ps - \Delta Pp) * 100}{\Delta Ps} \qquad \text{... (3.3)}$$

The percent throughput increase , TI was estimated by using the following equation[80] .

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

This equation assumed 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[11].

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

Where,

f = fanning friction factor

D = pipe inside diameter / m

L = distance between the pressure taps, m

Chapter Four
Results and Discussion

4.1 Introduction

A large amount of energy loss due to friction occurs in many cases of turbulent flow, generally. However, it is well known that turbulent drag reduction which is drastic reduction of frictional resistance can be easily observed by injection a minute amount of polymeric or surfactant additives in a turbulent flow(9). Treated solutions undergoing a turbulent flow in a pipe thereby required a lower pressure drop to maintain the same volumetric flow rate.

Turbulent drag – reduction efficiency of carboxy methylcellulose, CMC and two different types of surfactants, namely sodium stearate, SS and sodium lauryl sulfate, SLS in addition to clay as suspended agents additive concentration, water flow rate (3 to 6 m^3/hr) in 1.25 and 2.0 inch pipe diameters. The turbulent mode was produced via a positive displacement, gear pump to minimize any mechanical degradation of additive molecules.

The experimental work was evaluated by measuring the pressure drop for treated flowing water. The experimental results are presented as percentage drag reduction, percentage throughput increase and friction factor, and presented figures, and discussed in details. All of experimental data are reported in Appendix A.

4.2 Carboxy Methyl Cellulose Additive

4.2.1 Drag – reduction

Carboxy Methylcellulose, CMC of a molecular weight $0.4 * 10^6$ g/mol was tested as drag – reducer in water flow loop at different concentrations and liquid flow rates. Figure 4.1 and 4.2 illustrate the effect of CMC concentration up to 300 ppm on percentage increase in drag – reduction while figure 4.3 show the effect of water flow rate on the effectiveness of CMC additive as drag reducer furthermore, the screening study were carried out in 1.25 and 2.0 inches pipe diameter, to investigate the effect of pipe diameter on performance of CMC as drag reducer.

Figures 4.1 and 4.2 indicate that a gradual increased percentage drag reduction was observed by increasing the concentration within certain Reynolds number and that means increasing the turbulence spectrums that is under drag reducer effect. The phenomenon can be explained by the elastic _ sub layer model theory of Virk. This sub layer starts to grow with increasing additive concentration.

One of the interesting factors in the study of drag reduction is the effect of flow rate on percent drag reduction and it's relation to the turbulence and the effectiveness of the drag _ reducer polymer.

Figure 4.2 shows that the amount of percentage is about 10.3% in 1.25" pipe. while, by using 300 ppm CMC additive a 16% drag _ reduction was achieved under the same other flowing condition.

The effect of liquid flow rate on drag _ reduction was studied for an additive concentration of 200 ppm as shown in figure 4.3 the results show that the percentage drag _ reduction is increased gradually as superficial velocities of solvent increase, since turbulent flow is necessary for drag _ reduction to occur. This observation is in agreement with the fact, that the polymer thread an interaction with turbulent eddies. Consequently, a remarkable drag _ reduction is observed. This behavior agrees with Berman and his workers(81,82) in which reported that an increase in strain rate and a decrease in the time scale. The effect of turbulency on drag _ reduction is clearly observed by comparison the results for 3.0 and 6.0 m^3/hr flow rates as illustrated in figure 4.3 . Those, 6.8 and 4.3 % drag _ reduction were achieved by 3.0 m^3/hr flow rate in 1.25 and 2 inch diameter. While, by using 6.0 m^3/hr liquid flow rate, 13 and 10.2% percentage drag_ reduction were obtained that means about 100% increase in percentage drag _ reduction is observed when the solvent flow rate increases from 3.0 m^3/hr to 6.0 m^3/hr. This observation supports the predominate effect of turbulency on effectiveness of CMC as drag _ reducer.

Furthermore, the effect of pipe diameter was studied in two different diameters 1.25 and 2 inches. A higher drag _ reduction was observed for small pipe diameters than the large one for a given liquid velocity and additive concentration, as shown in figures 4.1 through 4.3. Considering the fact that for the same bulk mean velocity drag_ reduction decreases with increasing pipe diameter(83).

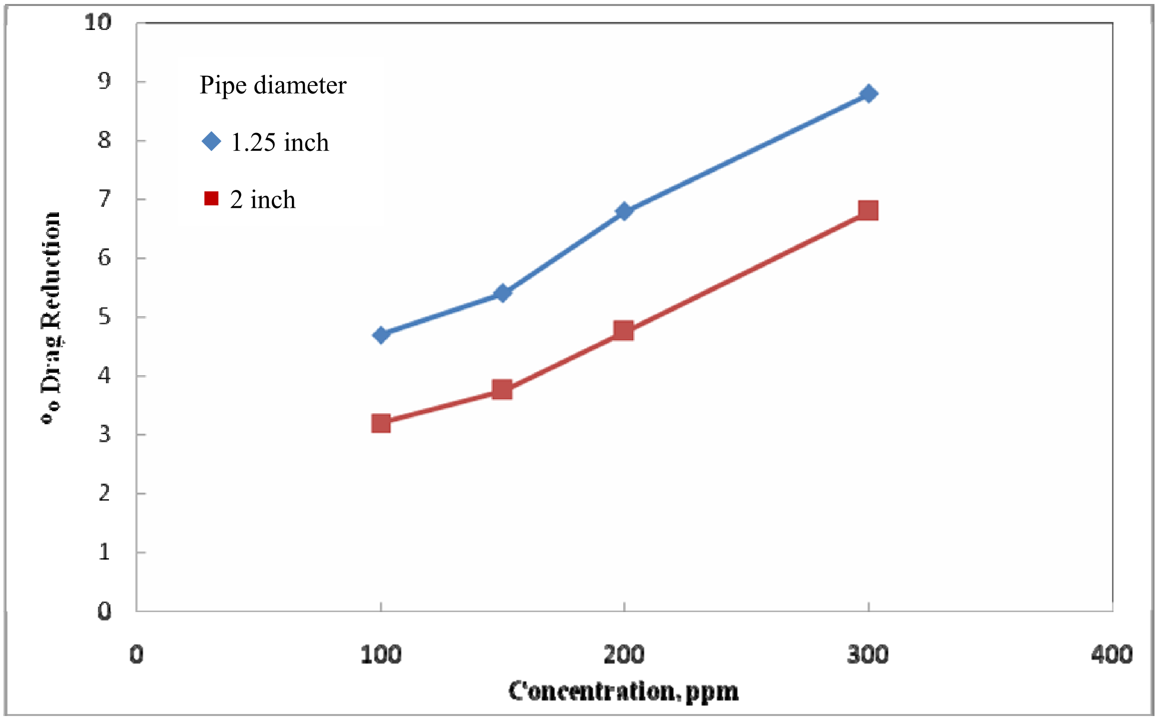

Fig. 4.1 Effect of concentration on percentage drag reduction for CMC of 3 m^3/hr.

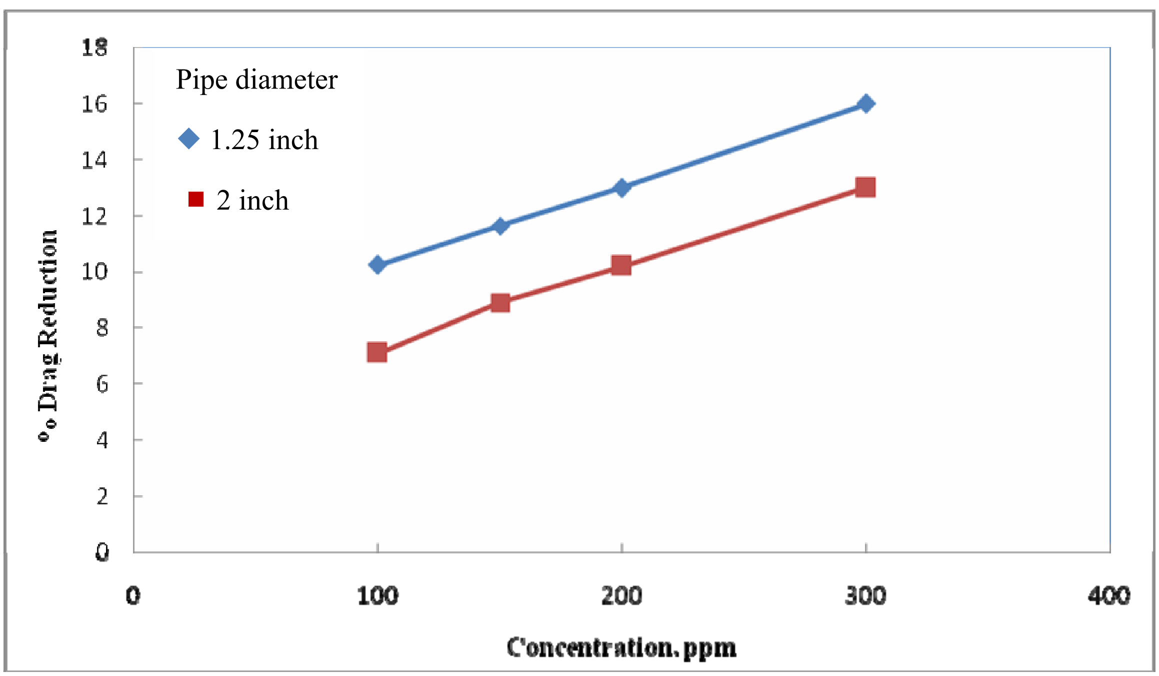

Fig. 4.2 Effect of concentration on percentage drag reduction for CMC at 6 m^3/hr.

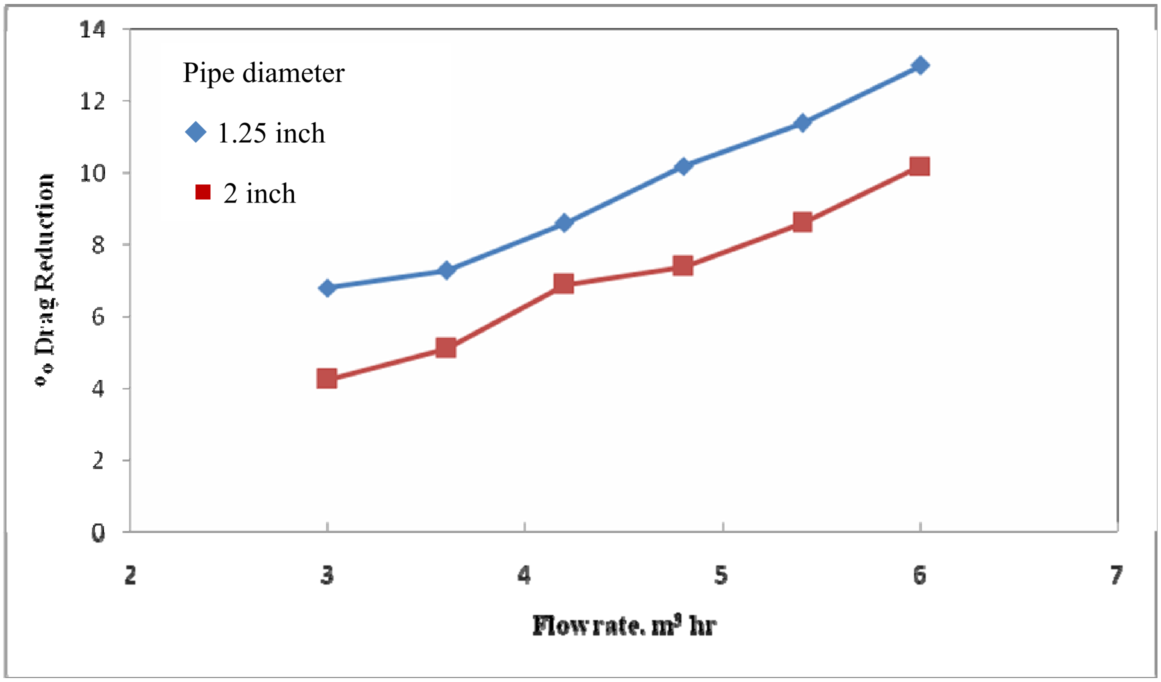

Fig. 4.3 Effect of flow rate on percentage drag reduction for CMC in a 200 ppm.

4.2.2 Throughput Increase

It is believed that the use of additive drag _ reduction could be economic for increasing flow rate capacity at the working pipe lines, in particular for some finite time of applications. The primary and – use of drag reducers is usually to increase the flow rate a capacity or throughput increase without exceeding the safe pressure limits within the flow system.

The increase in throughput which is more practical term than percentage drag _ reduction for a given pipeline can be estimated by equation 3.4, while the calculated results are illustrated in figures 4.4,4.5,4.6. A noticeable increase in throughput was achieved by increasing the polymer concentration and water flow rate. The increase of the pump ability of treated water is higher in small pipe diameter, of 1.25 inch than the large one of 2.0 inch.

Figure 4.5 shows that as much as 10.06% throughput increase was obtained with 300 ppm CMC additive concentration at 6.0 m^3/hr liquid flow rate in 1.25 inch pipe diameter. The results in figures 4.5 and 4.6 indicate clearly the predominate effect of flow rate on throughput increase of pipelining of fluid.

The results of diameter effect on throughput increase is useful for the purpose of scale – up for the fully developed turbulent flow. It is importance lies in the capability of maximizing flow rate of pumping fluids inside pipes or minimizing the pumping casts.

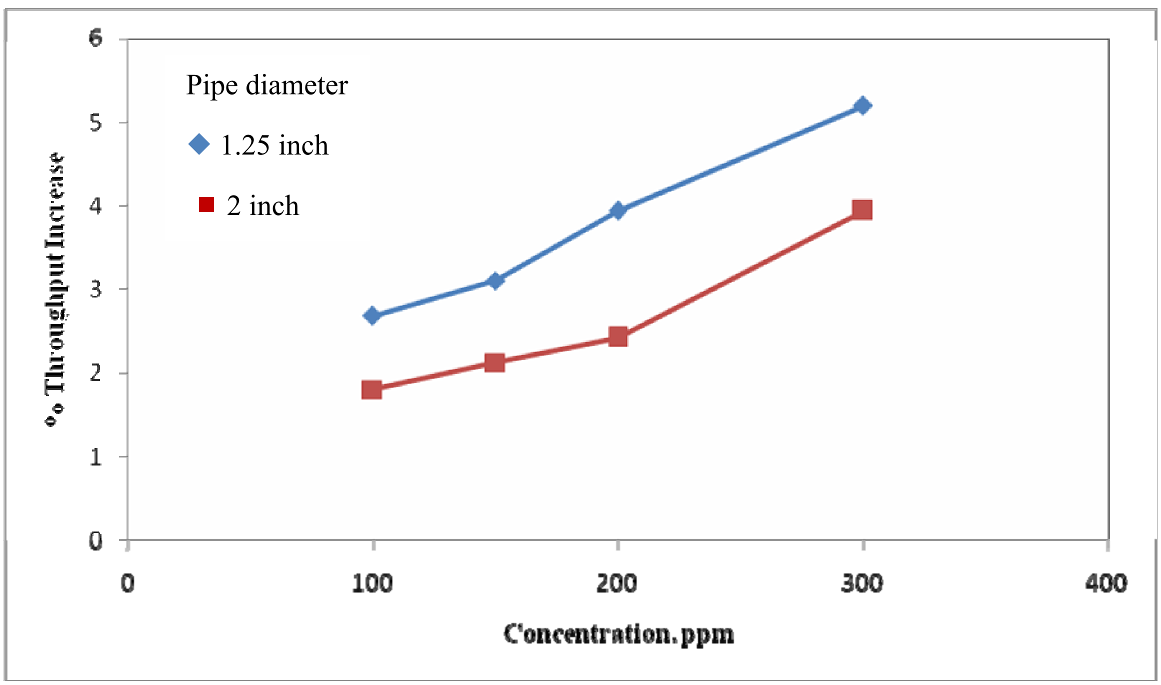

Fig. 4.4 Effect of concentration on percentage throughput increase for CMC of 3 m^3/hr .

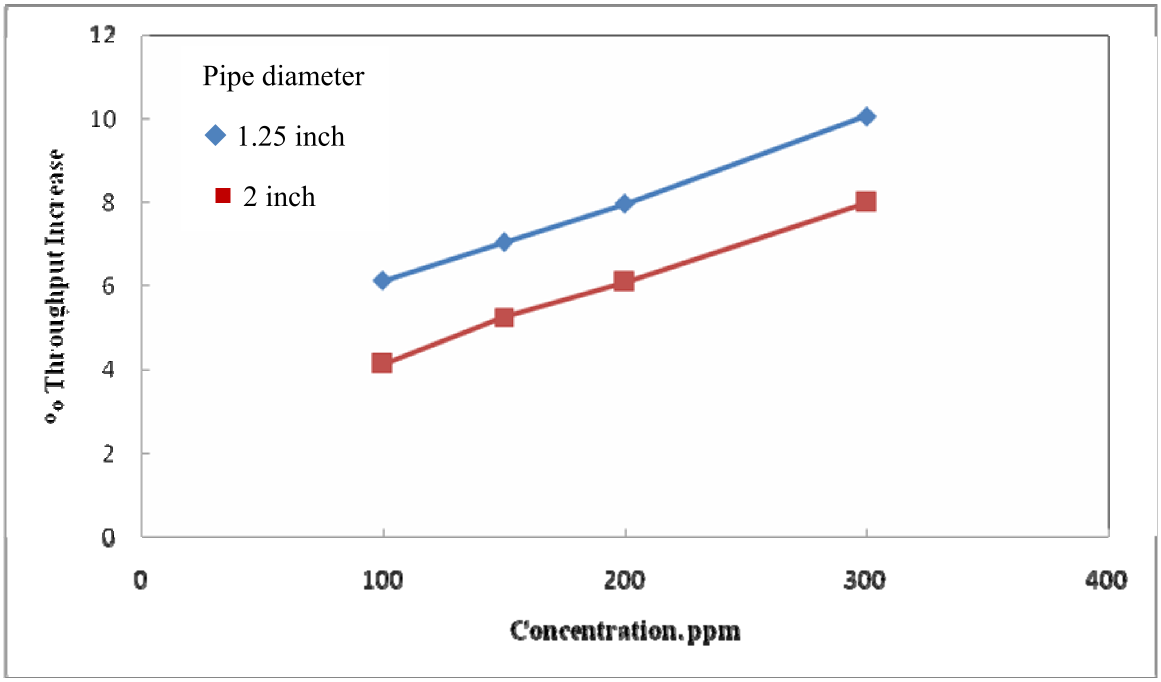

Fig. 4.5 Effect of concentration on percentage throughput increase for CMC at 6 m^3/hr.

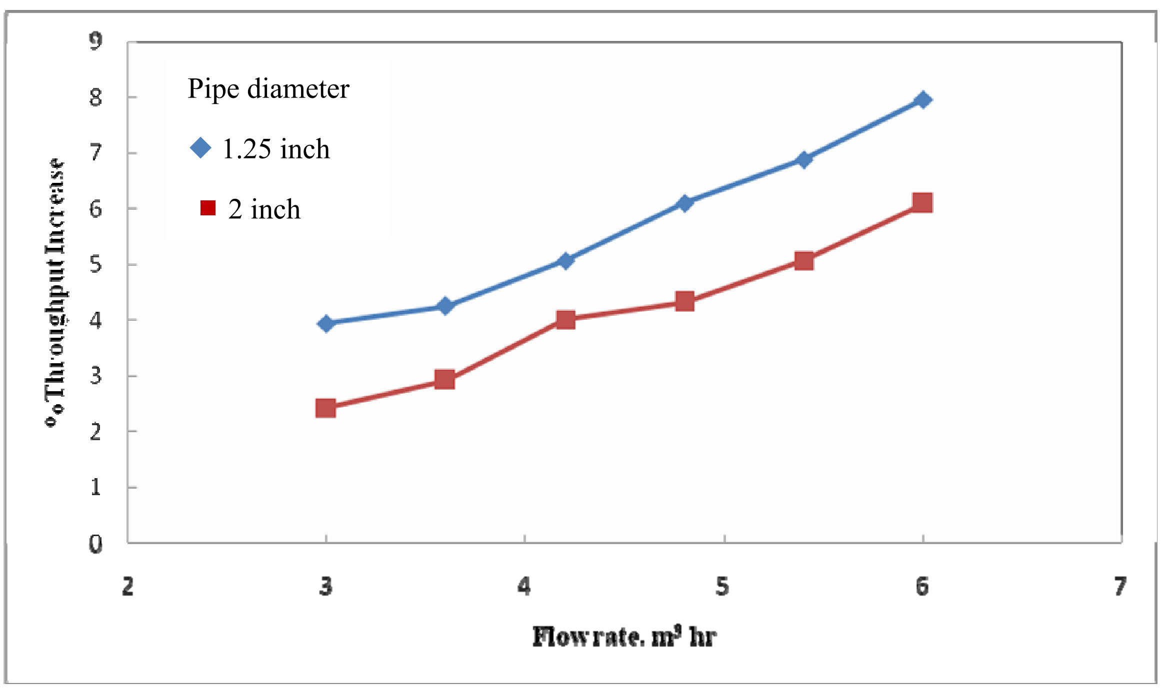

Fig. 4.6 Effect of flow rate on percentage throughput increase for CMC in a 200 ppm.

4.3 Surfactants Additive

4.3.1 concentration Effect

Drag – reduction efficiency of two surfactant types had been studied in water turbulent flow as function of additive concentration. The considered surfactants are Anionic types, sodium stearate, SS of a molecular weight of 306 g/mol, and sodium lauryl sulfate, SLS of a molecular weight of 288.9 g/mol. Four concentration in the range 50 – 300 ppm were tested by using two pipe nominal diameters. These concentrations might have been economically feasible for commercial applications [84].

Figures 4.7 through 4.8 show that percentage drag – reduction increases gradually as detergent concentration increases for both pipe sizes. This means increasing the number of surfactant molecules involved in the drag – reduction process. In another, words, within certain Reynolds number increasing the surfactant concentration means increasing the turbulence spectrum that is under the drag reducer effect.

Maximum percentage drag – reduction of 10.2 and about 7.9 for SS and SLS respectively was observed by addition of 300 ppm additive concentration, in the 1.25 inch pipe at 6.0 m^3/hr flow rate, as shown in figures 4.8 and 4.10. The same figures show clearly, that at 50 ppm additive concentration, about 4.5% and 2.8% drag – reduction were established for SS and SLS surfactant respectively at the same flowing conditions. Those indicating the predomenant effect of additive concentration on there drag – reduction effectiveness .

The effectiveness of SS and SLS anionic surfactants as drag – reducers could be attributed to the shear stability of micelles structure as a result of rod –

shaped micelles forming. The drag reduction properties could be explained by the interaction of surfactant micelles with water, which allows the turbulence to be suppressed.

Furthermore, figures 4.11 and 4.12summarize the effect of detergent concentration on percentage throughput increase at 6.0 m^3/hr flow rate. The additive concentration effect is initial for increasing flow rate capacity. The tread of concentration effect on throughput increase is approximately similar to its' effect on percentage drag – reduction.

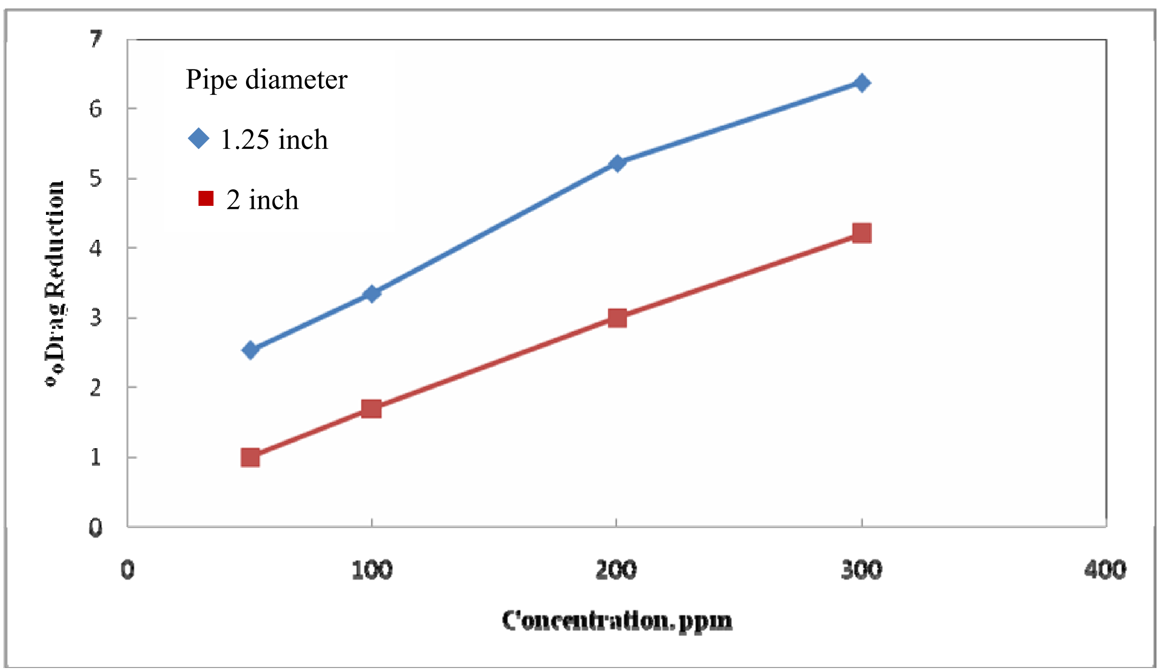

Fig. 4.7 Effect of concentration on percentage drag reduction for SS at 3m^3/hr.

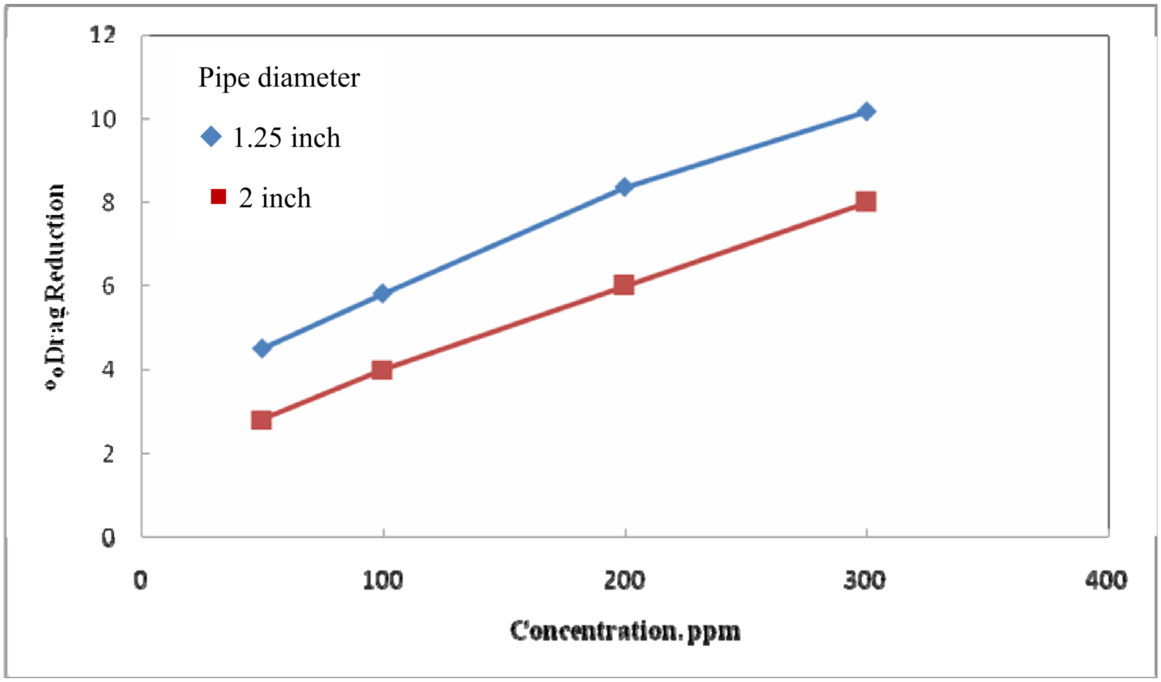

Fig. 4.8 Effect of concentration on percentage drag reduction for SS at $6m^3$/hr.

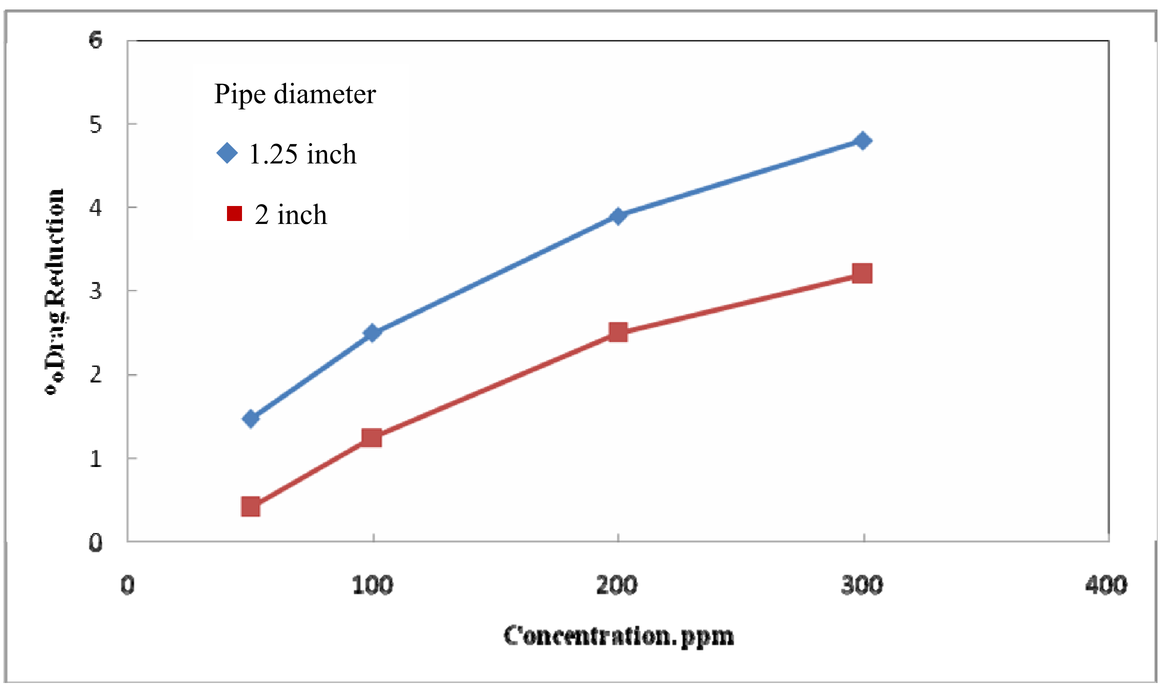

Fig. 4.9 Effect of concentration on percentage drag reduction for SLS at $3m^3$/hr.

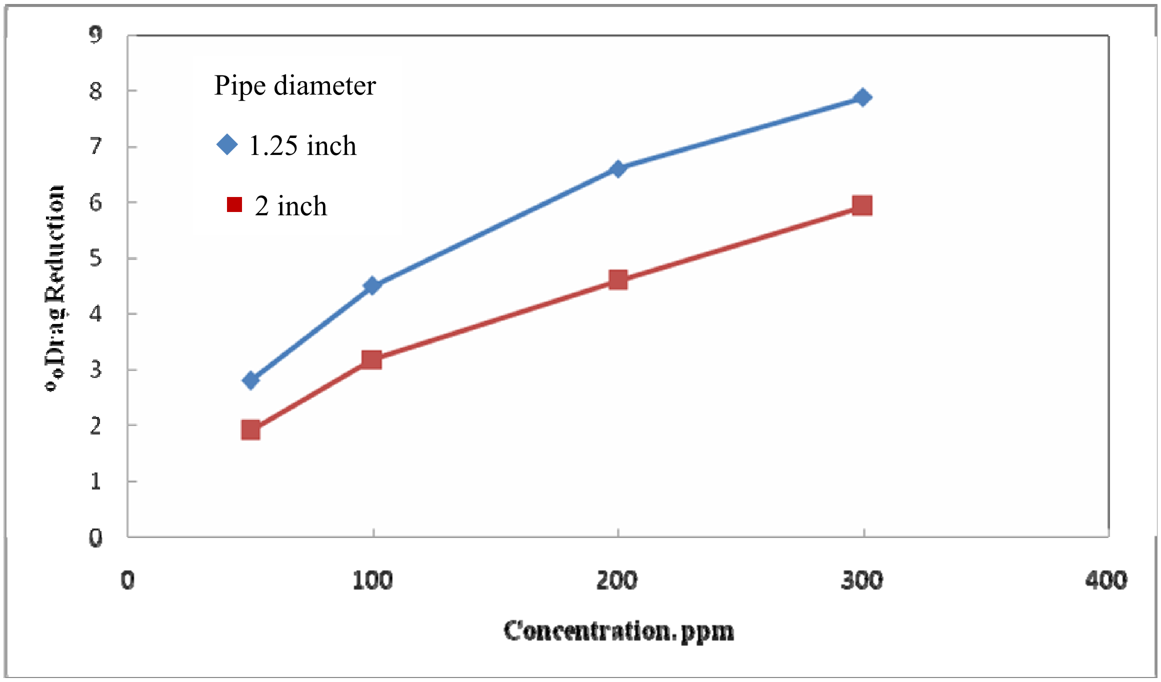

Fig. 4.10 Effect of concentration on percentage drag reduction for SLS at $6m^3/hr$.

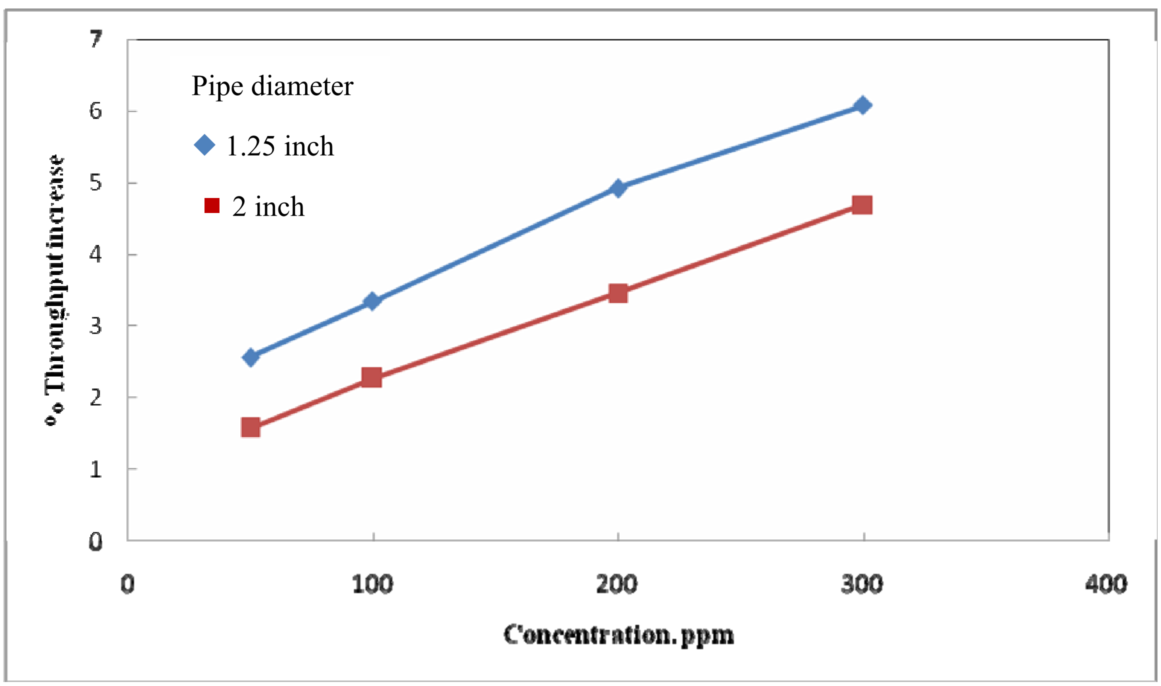

Fig. 4.11 Effect of concentration on percentage throughput increase for SS at $6m^3/hr$.

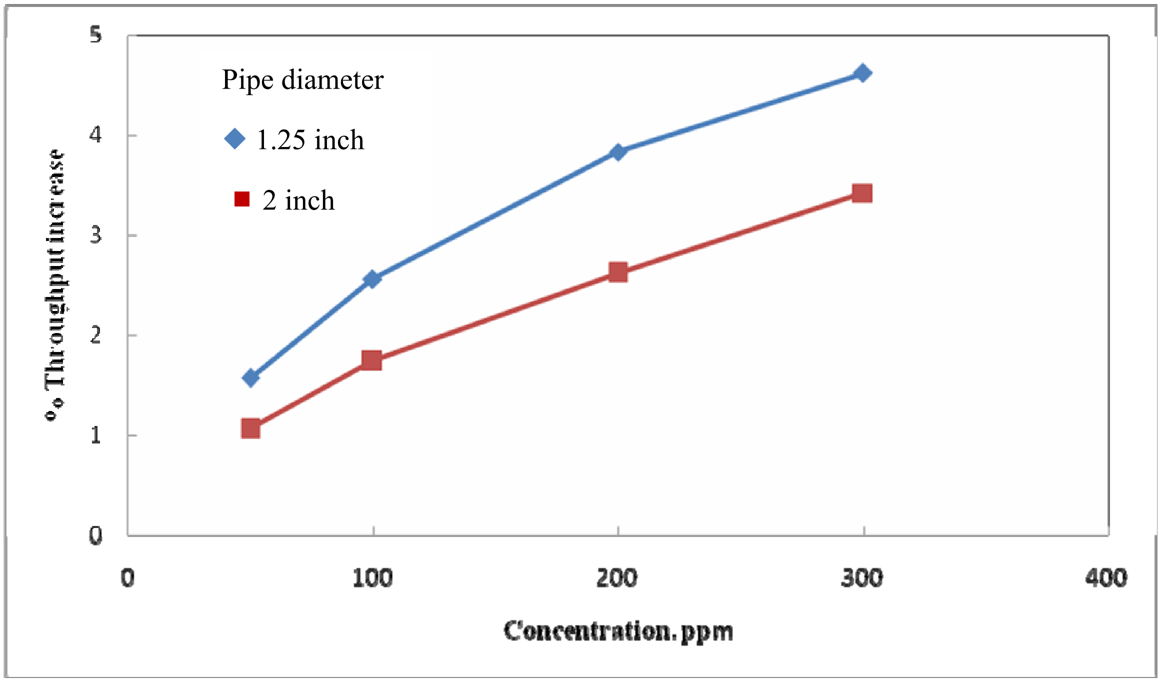

Fig. 4.12 Effect of concentration on percentage throughput increase for SLS at $6 m^3/hr$.

4.3.2 Flow Rate Effect

It is well – known, that the drag – reduction phenomenon acts in turbulence flow [85]. Therefore the degree of turbulence has a predominant effect on its' effectiveness. Different flow rates, in the range 3.0 – 6.0 m^3/hr were chosen to study the effect of turbulency by adding 200 ppm to the following water. Figures 4.13 and 4.14 show the percentage drag – reduction as function of flow rate for SS and SLS surfactant respectively for the two pipe diameters. While, figures 4.15 and 4.16 show the variation of percentage flow increase, (%TI) with flow rate for both surfactant types mentioned above.

It can be noticed from figures 4.13 and 4.14, that the percentage drag – reduction increases gradually by increasing the flow rate through the test section.

This behavior may be explained due to relation between degree of turbulence controlled by the solution flow rate and additive effectiveness. This behavior agrees with Barman and his workers [81] in which they reported that an increase in Reynolds number leads to an increase in the strain rate and a 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.

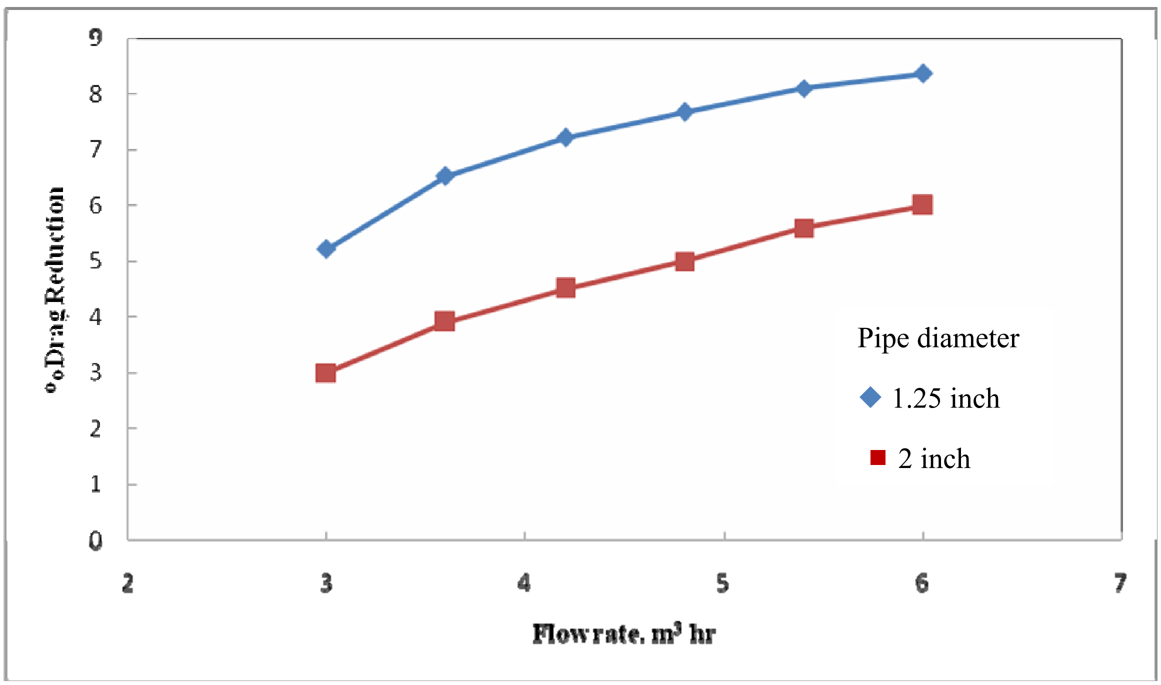

Fig. 4.13 Effect of flow rate on percentage drag reduction for SS in a 200 ppm.

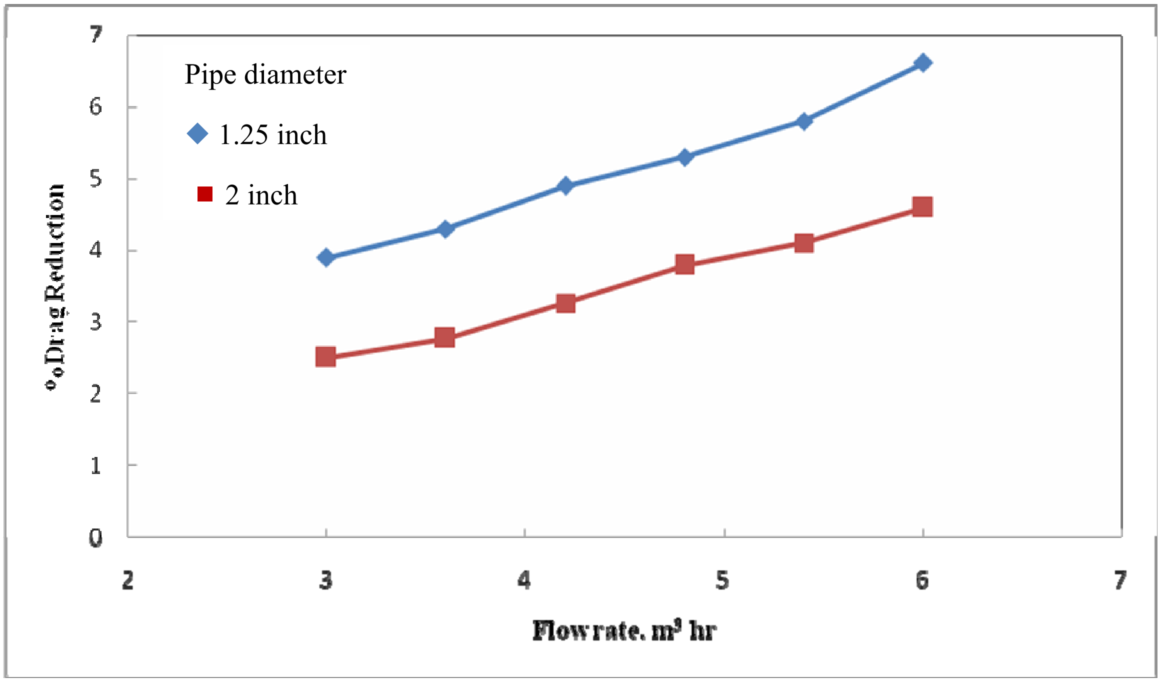

Fig. 4.14 Effect of flow rate on percentage drag reduction for SLS in a 200 ppm.

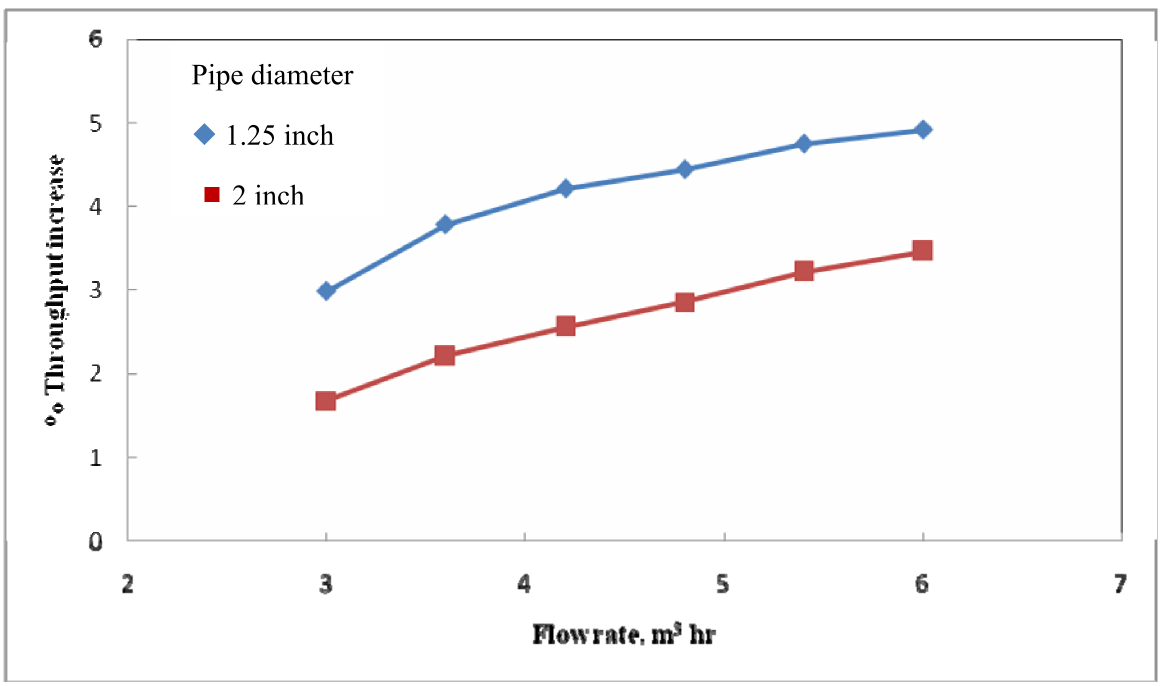

Fig. 4.15 Effect of flow rate on percentage throughput increase for SS in a 200 ppm.

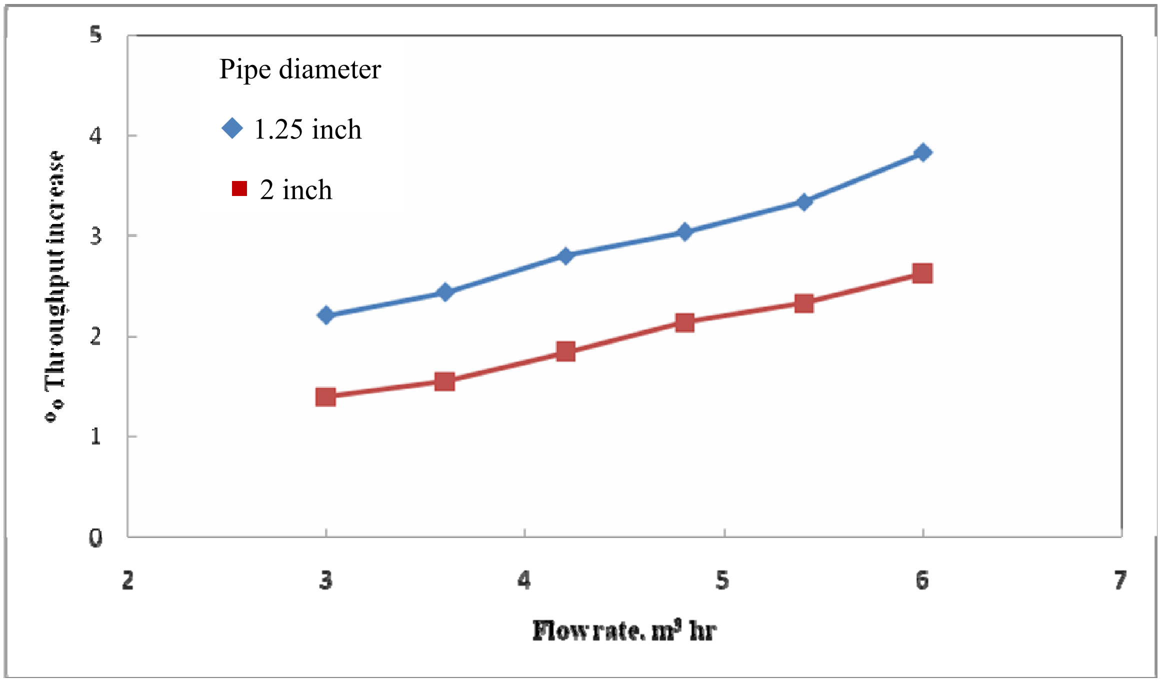

Fig. 4.16 Effect of flow rate on percentage throughput increase for SLS in a 200 ppm.

4.3.3 Effect of Pipe Diameter

Two pipe diameters, 1.25 and 2.0 inch were investigated in the present work to show their effect on percentage drag – reduction and throughput increase. Samples of experimental for both surfactant types, SS and SLS using different concentrations and solution flow rates. The results show that within certain surfactant concentration, percentage drag – reduction and % TI, increase by decreasing the pipe diameter.

Decreasing the pipe diameter means increasing the velocity inside the pipe leading to increase turbulence. All though the energy absorbed by the eddies from the main turbulence flow is higher for smaller pipe than that for large one. Therefore the degree of turbulence becomes higher and more collisions will be done between the eddies producing smaller eddies, which give better media for drag reduction to occur[86].

Furthermore, at a certain Reynolds number value, the smaller diameter gives higher friction factor values, which it means that they give higher values for pressure drops due to the friction. Consequently, with the larger inside pipe diameter[83,87].

The results of diameter effect is useful for the purpose of scal – up for the fully developed turbulent flow. It is importance lies in the capability of maximizing flow rate of pumping fluids inside pipes or minimizing the pumping costs.

4.3.4 Comparison

A comparative study between sodium stearate, SS and sodium lauryl sulfate, SLS surfactants and carboxy methyl cellulose, CMC was done to show there drag – reduction effectiveness in turbulent pipe flow of water. The results are illustrated in figures 4.17 and 4.18 for percentage drag – reduction in 1.25 inch pipe diameters and in figure 4.19 for throughput increase.

From these results, it is clear that SS which is anionic surfactant gives higher drag – reduction and flow capacity values and therefore is more effective than SLS. These results may by attributed to molecular weight variations, which are 306 and 288 g/mol for SS and SLS respectively. It is well know that the higher molecular weight additives are more efficient as drag reducers. Also, it may by due to more shear stability of micelles structure SS surfactant, as a result of rod – shaped micelles forming. CMC is more effective than surfactants.

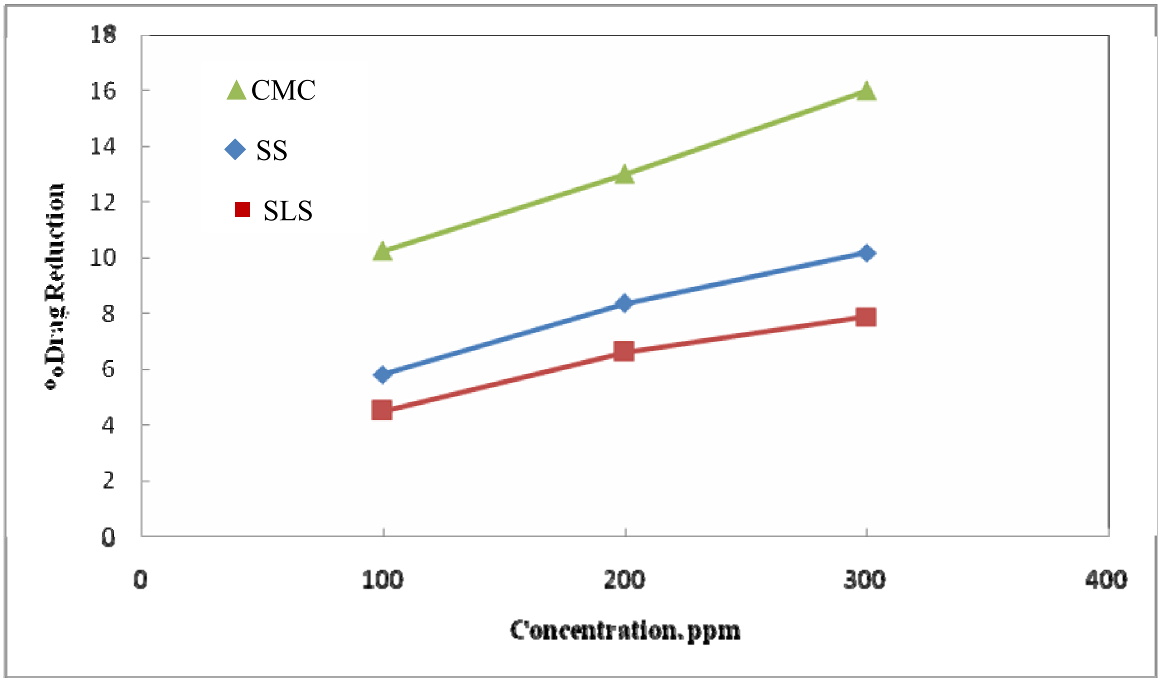

Fig. 4.17 Effect of concentration on percentage drag reduction for SS , SLS surfactants and CMC polymer at 6.0 m^3/hr through 1.25 inch I.D pipe.

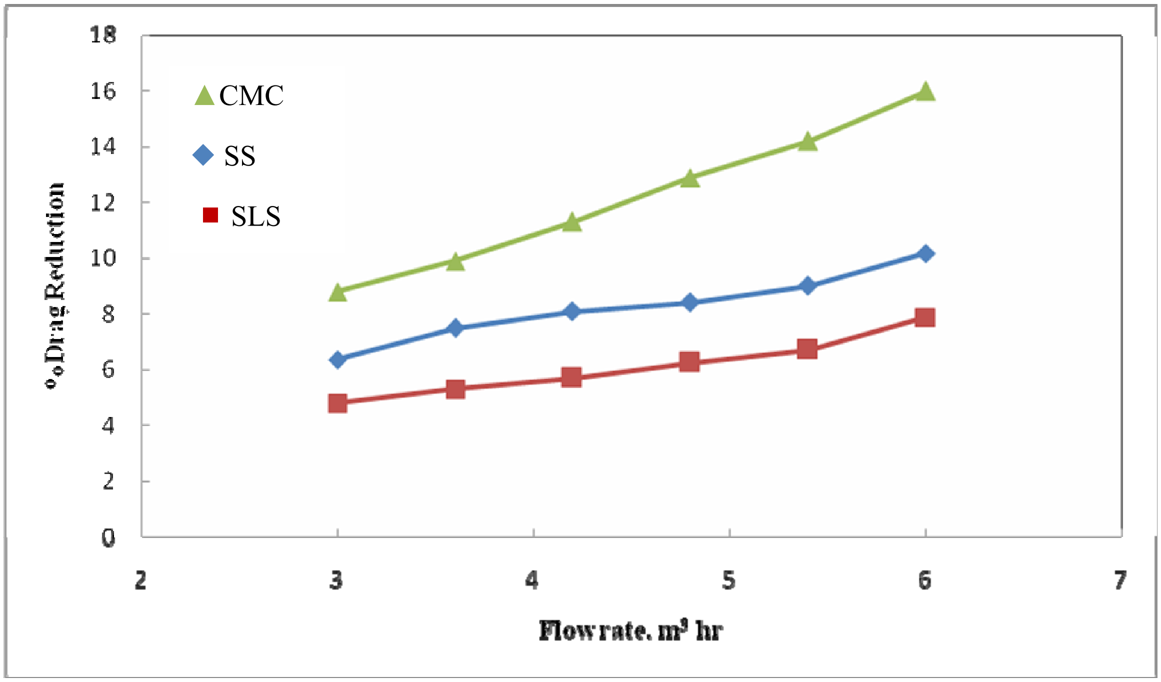

Fig. 4.18 Effect of flow rate on percentage drag reduction for SS , SLS surfactants and CMC polymer at 300 ppm through 1.25 inch I.D pipe.

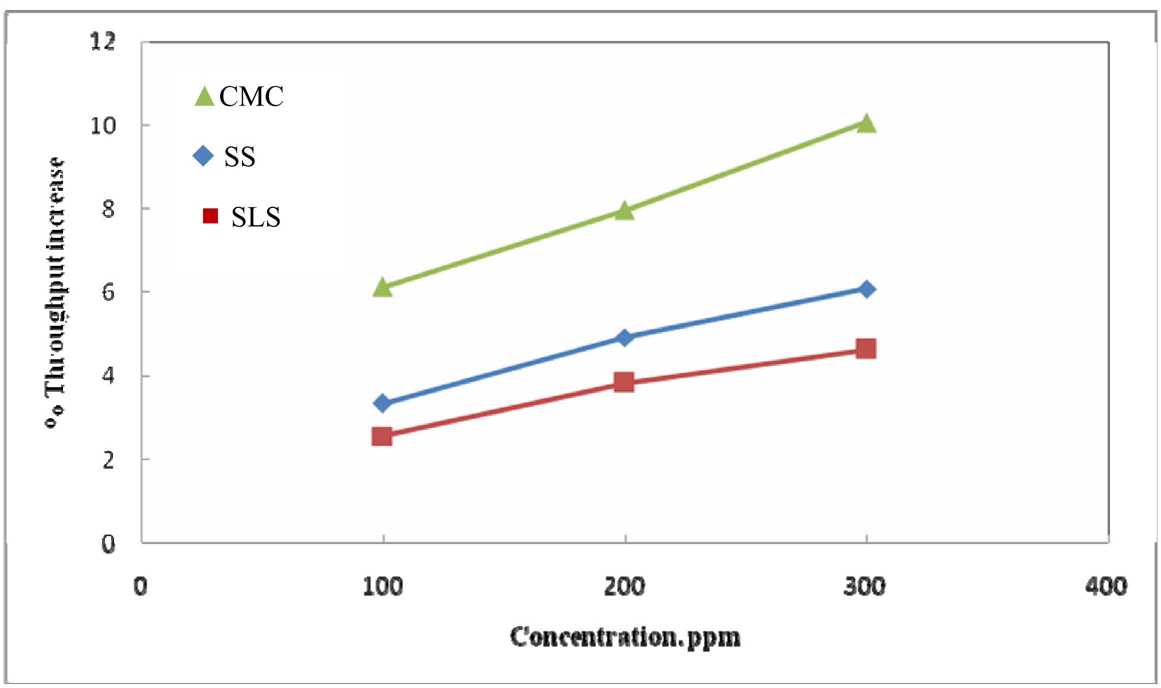

Fig. 4.19 Effect of concentration on percentage throughput increase for SS , SLS surfactants and CMC polymer at 6.0 m^3/hr through 1.25 inch I.D pipe.

4.4 Mixed CMC with Surfactant as Additive

As it was observed in section 4.3, that the considered two surfactant types, SS and SLS are less effective drag – reducers than carboxy methyl cellulose, CMC. Therefore, an attempt was made to mix CMC and SS or SLS surfactant in order to enhance the drag – reduction effectiveness of surfactant types.

It is clear to show that the drag – reduction effectiveness for both SS and SLS surfactant will be improved by addition of CMC, as illustrated in figures (4.20) and (4.21) for SS and SLS additives respectively. These figures show, that a gradually increase in percentage drag – reduction was observed by increase the percentage CMC in additive mixture with both SS and SLS surfactants. The percentage drag – reduction of CMC/ SS mixture was increased from about 10% for pure SS (no CMC presence) to about 17% by mix of about 67% CMC in the 300 ppm total additive mixture. The later value is a little higher than those for pure CMC, which lie about 16% the ratio of about 2:1 CMC to SS could be considered as optimum composition of additive to get high percentage drag – reduction for SS mixed with CMC as additive.

Figure(4.21) show that the drag – reduction effectiveness of mixed additive with SLS surfactant increases gradually with increase the CMC values, reaching about 16% for pure CMC in 1.25" pipe at 6.0 m^3/hr flow rate . While at 67% CMC in additive mixture gives about 14.8% DR which is 1.2% lower than for pure CMC. Therefore it can be concluded that 67% CMC in mixtures of both type of surfactant is an optimum value. The same observation was observed for throughput increase with mixed additives as show in figure(4.23).

Furthermore, figure(4.22) shows that the mixed surfactant/ CMC additive resulted in similar drag reduction effectiveness behavior in 1.25 and 2.0 inch pipe diameters. As it is expected the smaller pipe diameter gives higher percentage drag reduction values than the large one for all additive mixtures used.

At concentration of 67% SS with CMC mixture shows a certain synergistic effect. Those the achieved percentage drag reduction is higher than for pure CMC additive.

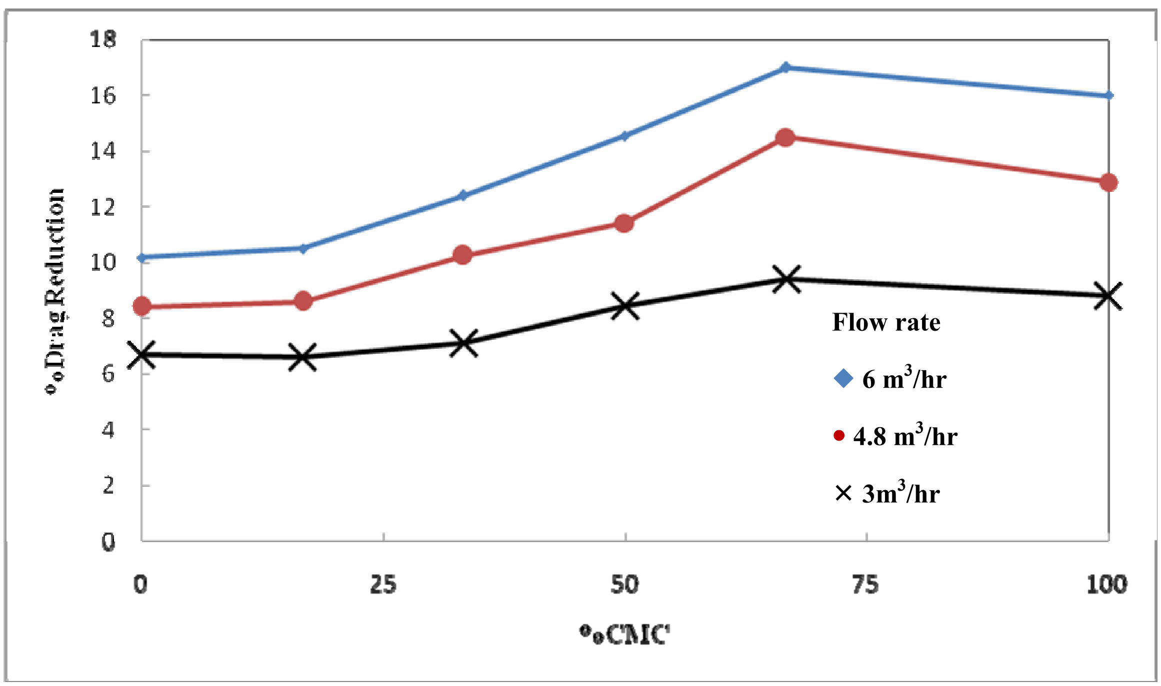

Fig. 4.20 Effect of %CMC mixture with SS at 300 ppm percentage drag reduction through 1.25 inch I.D pipe.

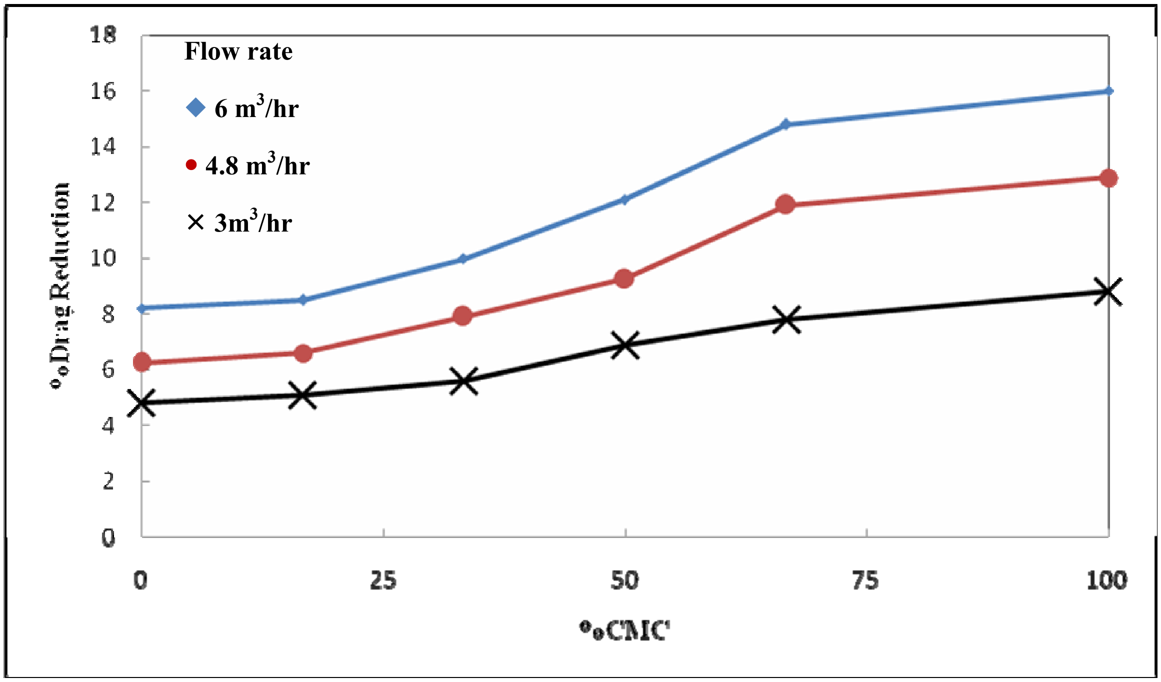

Fig. 4.21 Effect of %CMC mixture with SLS at 300 ppm percentage drag reduction through 1.25 inch I.D pipe.

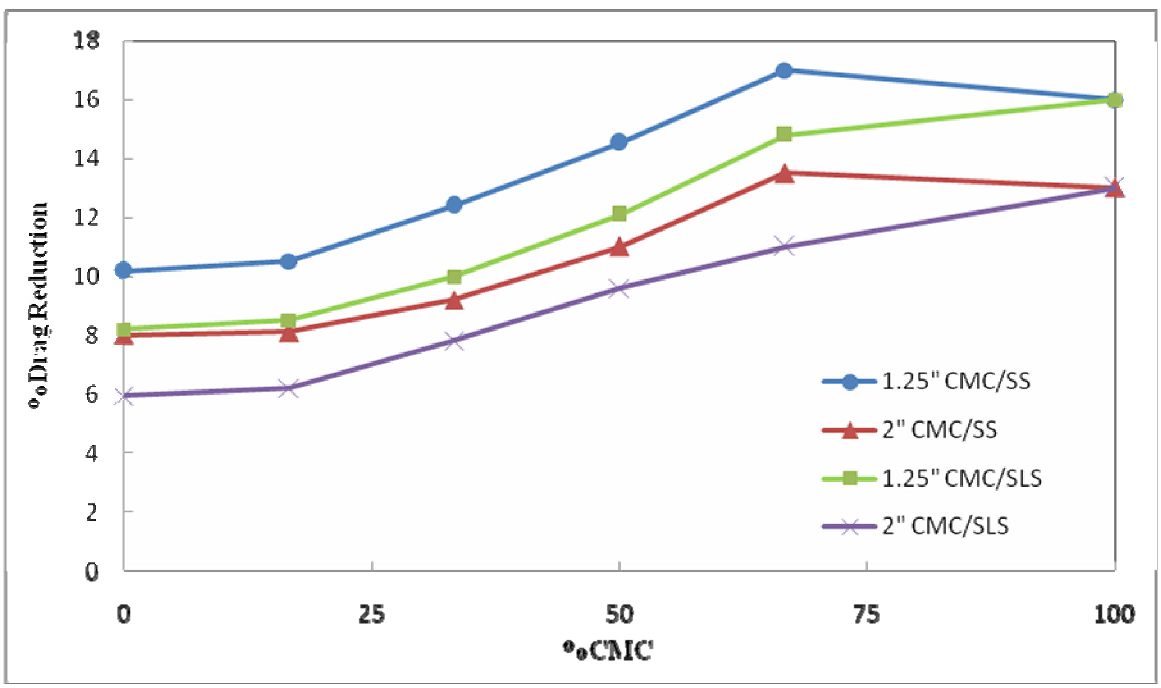

Fig. 4.22 Effect of %CMC mixture with surfactant at 300 ppm on percentage drag reduction for two pipe at $6m^3/hr$.

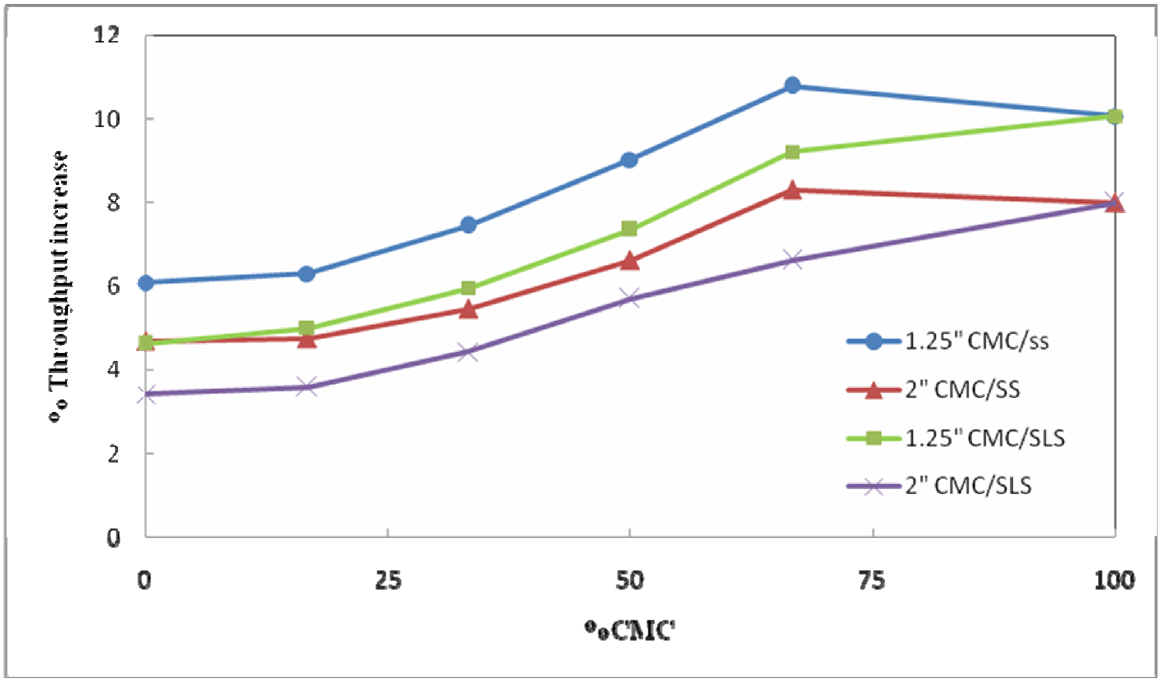

Fig. 4.23 Effect of %CMC mixture with surfactants at 300ppm on percentage throughput increase for two pipe at 6m^3/hr.

4.5 Clay Additive

The screening study was performed to evaluate the drag reduction effectiveness or of a certain of type of natural clay additive. The effect of additive concentration and degree of turbulence were investigated in 1.25 and 2.0 inch inside pipe diameters using tap water. Since river water contains usually various amount of natural mud according to the season. The study aimed also to investigate the effect of minor amounts of clay as additive in reducing the energy requirement for discharge of river water and in possible sprinkler irrigation system as well as to increase the throughout area of converge.

The results of effectiveness of clay on percentage drag reduction are plotted in figure 4.24, for additive concentration ranging from 500 – 5000 ppm, which may by present in river water in different seasons. It is clear that clay acts as efficient drag reducer for flowing water. A gradually increase of percent drag reduction drag reduction is observed as clay additive concentration increases. It is possible that the presence of non – settling slurries (turbidity) aqueous solution of clay influence the viscosity of flowing water. Therefore, the increasing in the drag reduction effectiveness in existing of clay is consistent with the observed changes in solution viscosity[(88)]. Furthermore, clay acts to form rod like micelles, as in case of surfactants. The drag reduction properties could by explained by the interaction of clay micelles with the water, which allows the turbulence to be suppressed. Figure 4.24 show that, the concentration has a primary effect on drag reduction in presence of clay additive.

Those about 3.6% drag reduction was achieved with 500 ppm clay addition, while at 5000 ppm, the percentage drag reduction value increase to 21.8% for 1.25 inch pipe diameter.

Also, figure 4.25 and 4.26 show the percentage throughput increase by increasing the concentration because it is direct function of percentage drag reduction.

One of the interesting factors in the study of drag reduction is the effect of flow rate on percent drag reduction and it’s relation to the turbulence and the effectiveness of the drag reducer additive. Three different flow rates of 3, 4.8 and 6m^3/hr where chosen to study this effect for clay additive at different concentrations. The results are represented in figures 4.27 and 4.28. Increasing the flow rate means increasing the velocity which was represented by the dimensionless from of Reynolds number (Re) that means increasing the degree of turbulence inside the pipe, this will provide a better media to the drag reducer (suspended solid) to be more effective.

However, it is well known that the dependence of drag reduction efficiency to by a function of the degree of turbulence.

It is well known that the drag reduction effectiveness of suspended solid additive is influenced largely by pipe diameter[89], where as a satisfactory quantitative explanation of this is still lacking.

Figure 4.29 illustrate the dependence of diameter on percentage drag reduction for pipes with I.D 31.75 and 50.8mm at optimum ($6.0 m^3/hr$) and lower ($3.0 m^3/hr$) flow rates. Therefore the maximum drag reduction achieved are, 21.8% and 17.7% at flow rate $6.0 m^3/hr$ for two pipe and 5000 ppm concentration.

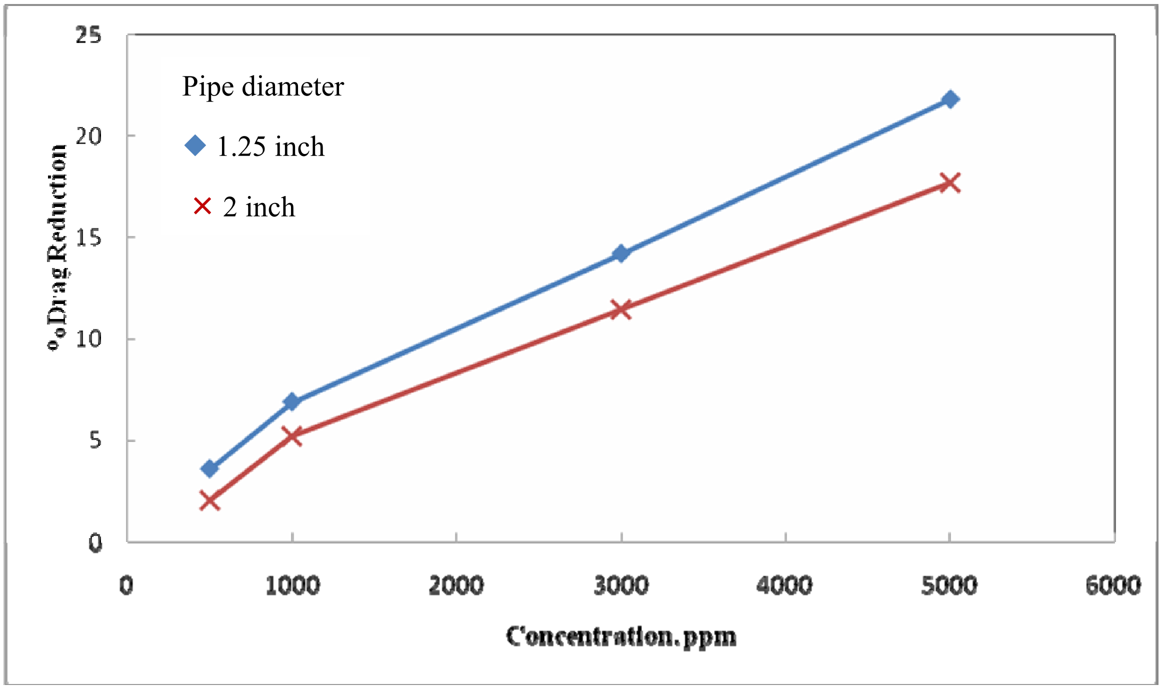

Fig. 4.24 Effect of concentration on percentage drag reduction for transported water with clay as suspended solid at $6m^3/hr$.

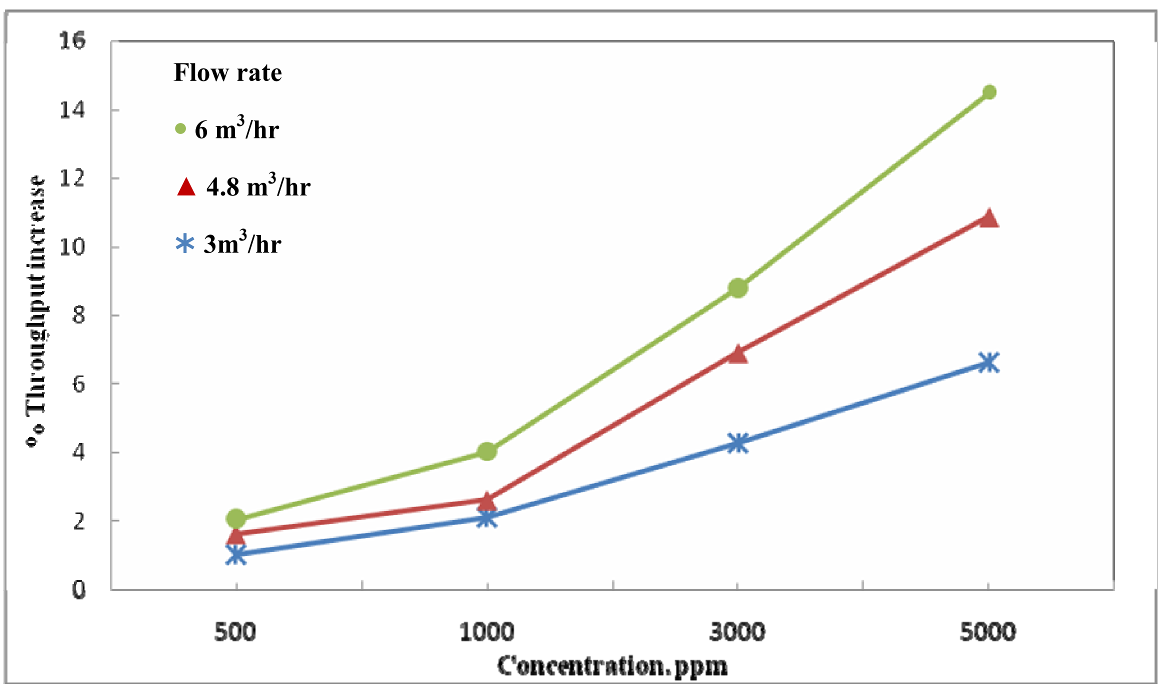

Fig. 4.25 Effect of concentration on percentage throughput increase for transported water with clay as suspended through 1.25 inch.

Fig. 4.26 Effect of concentration on percentage throughput increase for transported water with clay as suspended solid 2inch.

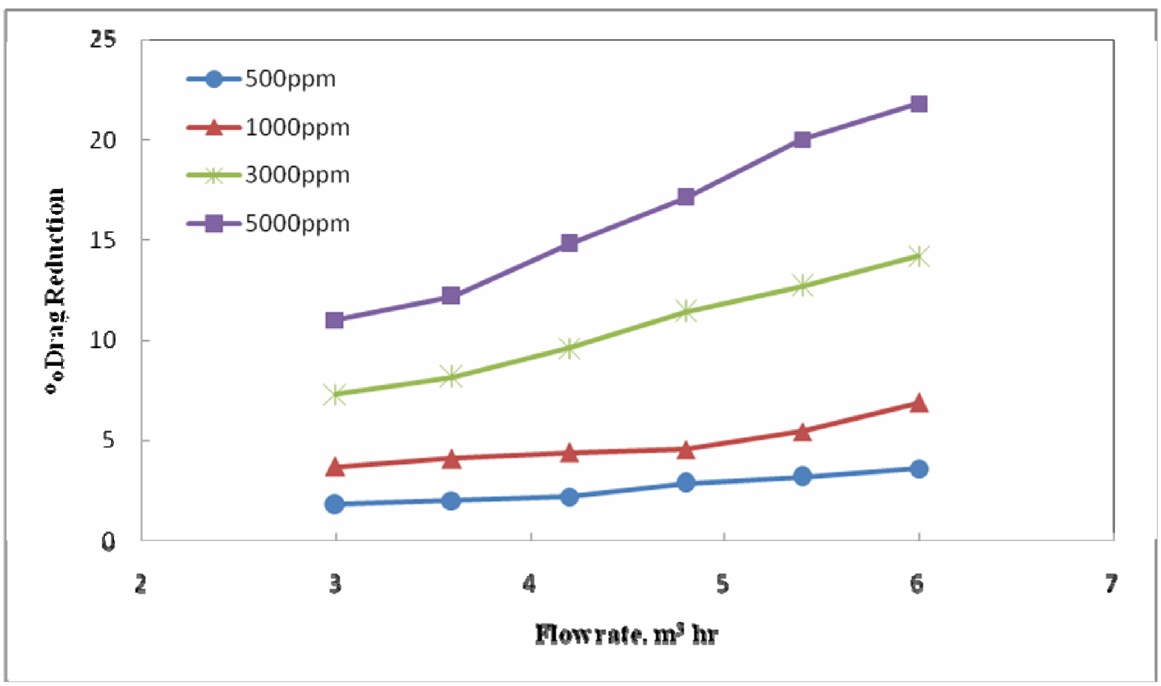

Fig. 4.27 Effect of flow rate on percentage drag reduction for transported water with clay as suspended solid through 1.25inch.

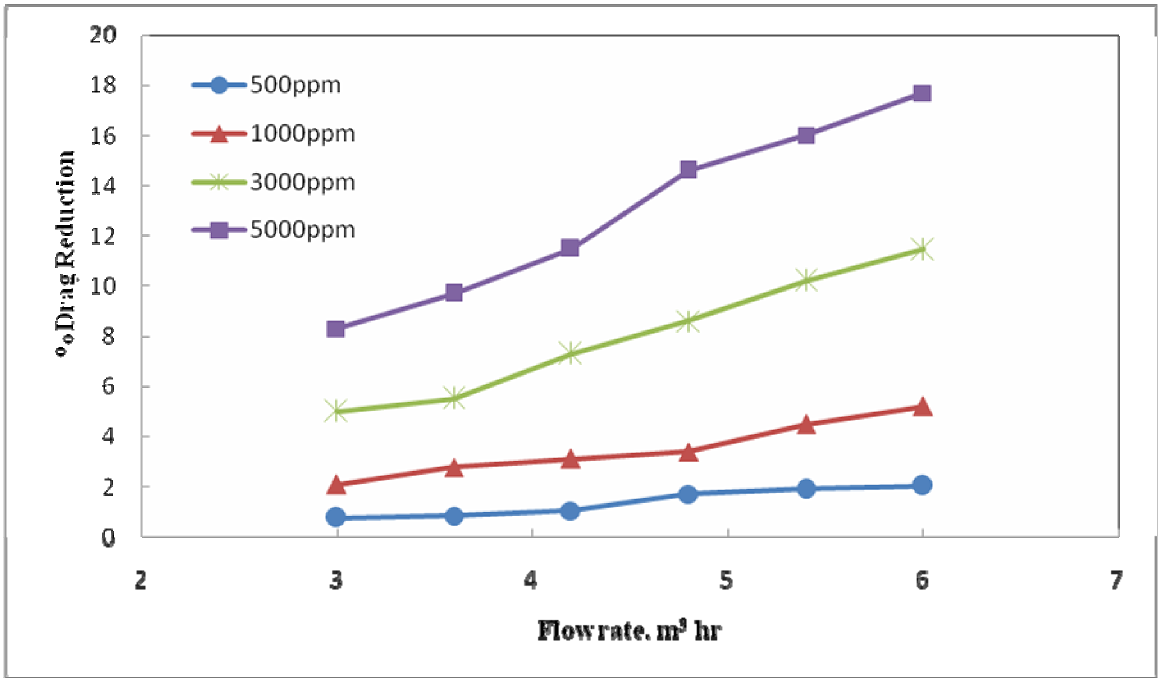

Fig. 4.28 Effect of flow rate on percentage drag reduction for transported water with clay as suspended solid through 2inch.

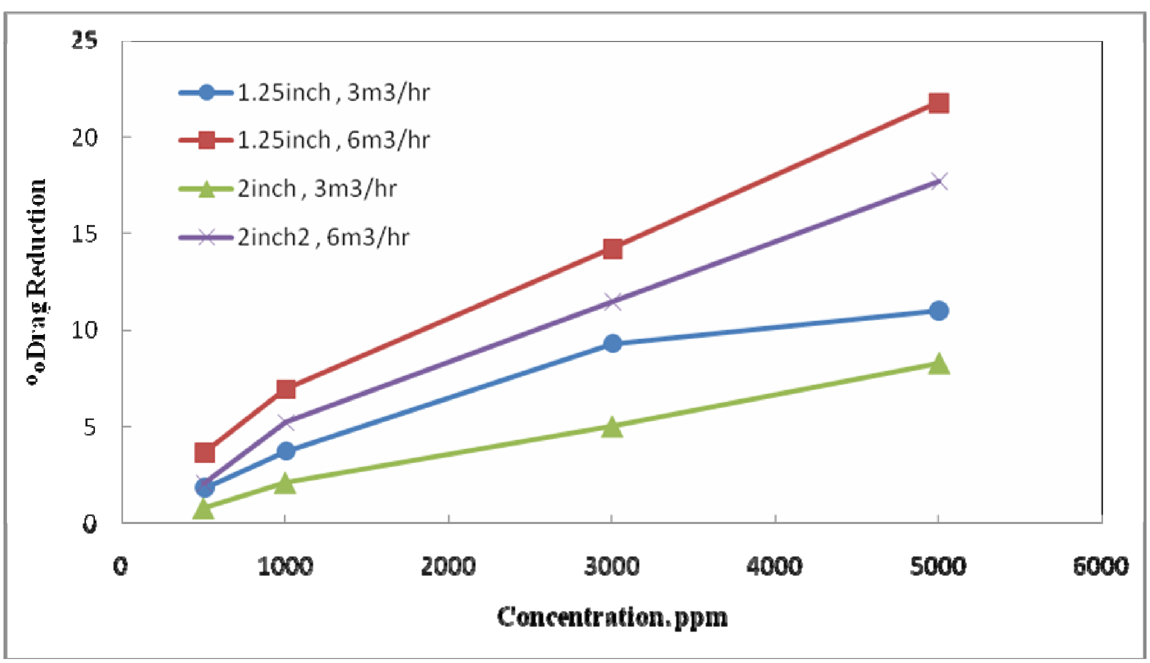

Fig. 4.29 Effect of pipe diameter on percentage drag reduction with different concentration of clay.

4.6 Combined Effect of CMC and Clay Additive

Carboxy methyl cellulose was added in different concentrations to turbulent water flow treated with 5000 ppm clay to examine it's effect on improving the drag reduction effectiveness. Figures 4.30 and 4.31 show the effect of adding this polymer (CMC) on the %DR by using 1.25 and 2.0 inch pipe diameter respectively. It is clear that the addition of CMC improves the percentage drag reduction was suspensions. Also, percentage drag reduction of the flowing shown to increase by increasing the polymer concentration reaching maximum values of 32% with concentration 300ppm of polymer in water clay suspension. This shows an increase about 10.2% when compared with 21.8% maximum percentage drag reduction of the same suspension within the same flowing conditions but without the polymer addition.

The same behavior was observed with 2insh pipe diameter, that a 9.4% increase in maximum percentage drag reduction of 27.1% was reported using 300ppm of CMC with an 9.4% increase in percentage drag reduction compared with the same percentage but without the polymer addition 17.7% as shown in figure 4.31.

Figure 4.32 show that drag reduction percentage increase as pipe diameter decreases for different flow rate. Therefore a maximum drag reduction percentage is obtained in the 1.25inch pipe. This amount of drag reduction seems to be promising for practical applications.

This phenomenon can be interpreted by turbulent or molecular interactions as follows: DR can be decreased when pipe diameter is increased when pipe diameter is increased if the persistence time of larger eddies that is proportional to D/U is important. This persistence time related to the length of time the molecules are stretched in the relatively rotation – free, high strain – rate areas of turbulent flow, and the mean distance between two molecules is less than the size of an elongated molecule.

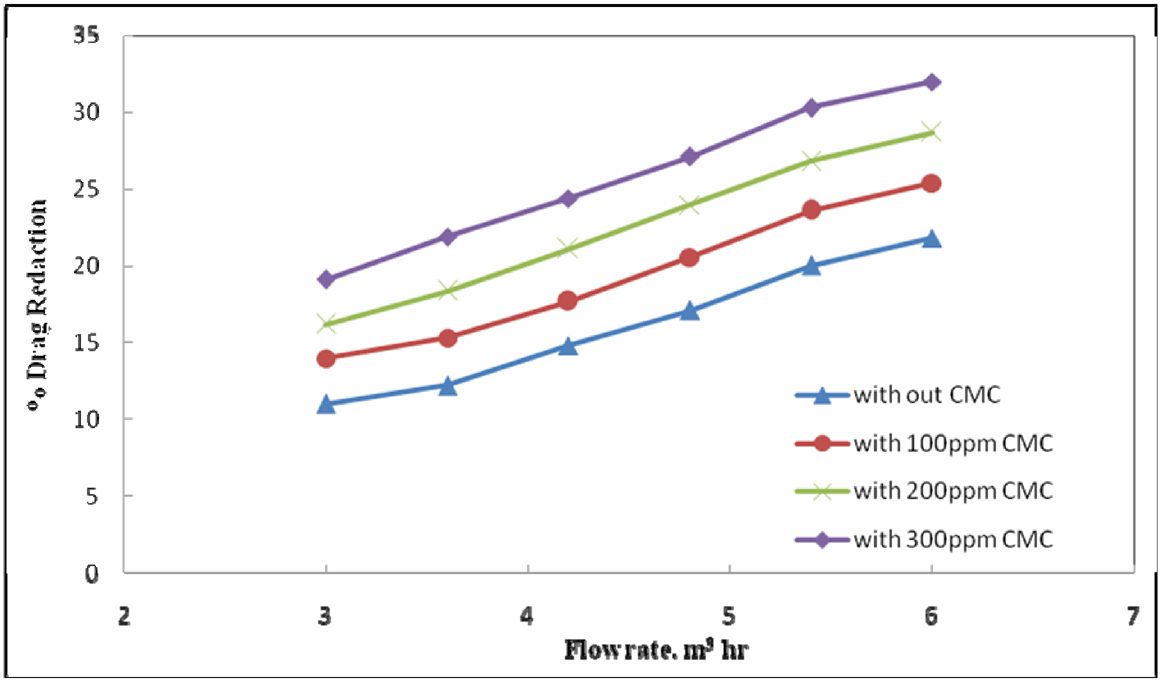

Fig. 4.30 Effect of adding CMC on percentage drag reduction for water – clay suspension with solid concentration of 5000ppm through 1.25inch I.D pipe

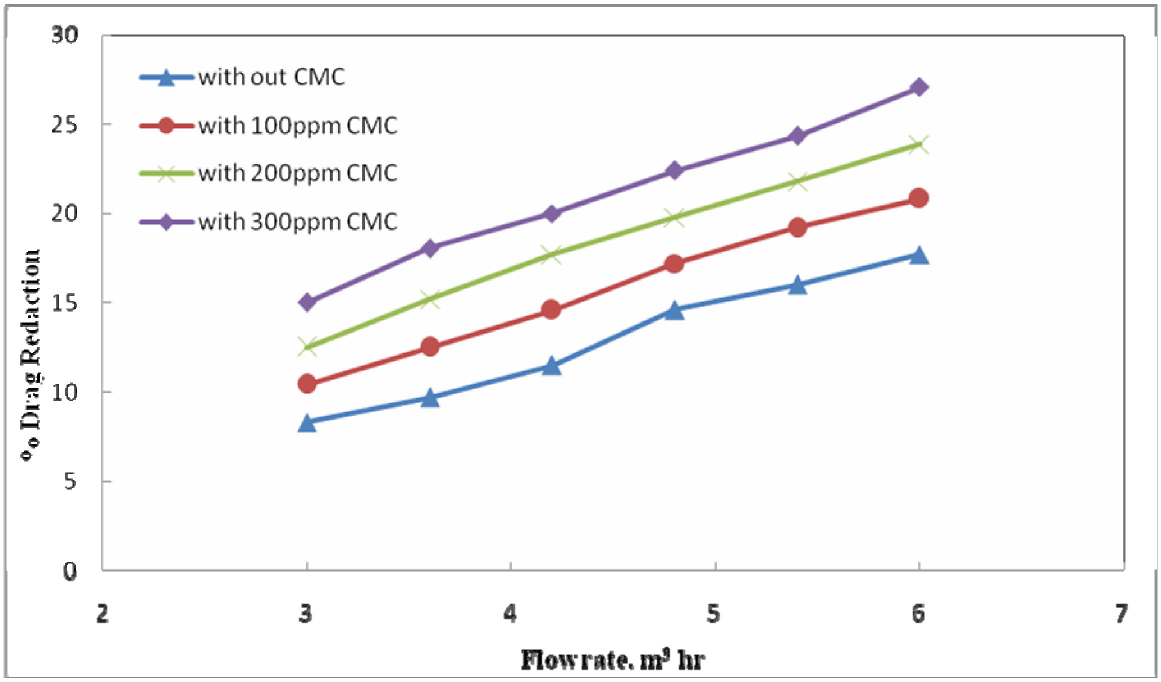

Fig. 4.31 Effect of adding CMC on percentage drag reduction for water – clay suspension with solid concentration of 5000ppm through 2inch I.D pipe

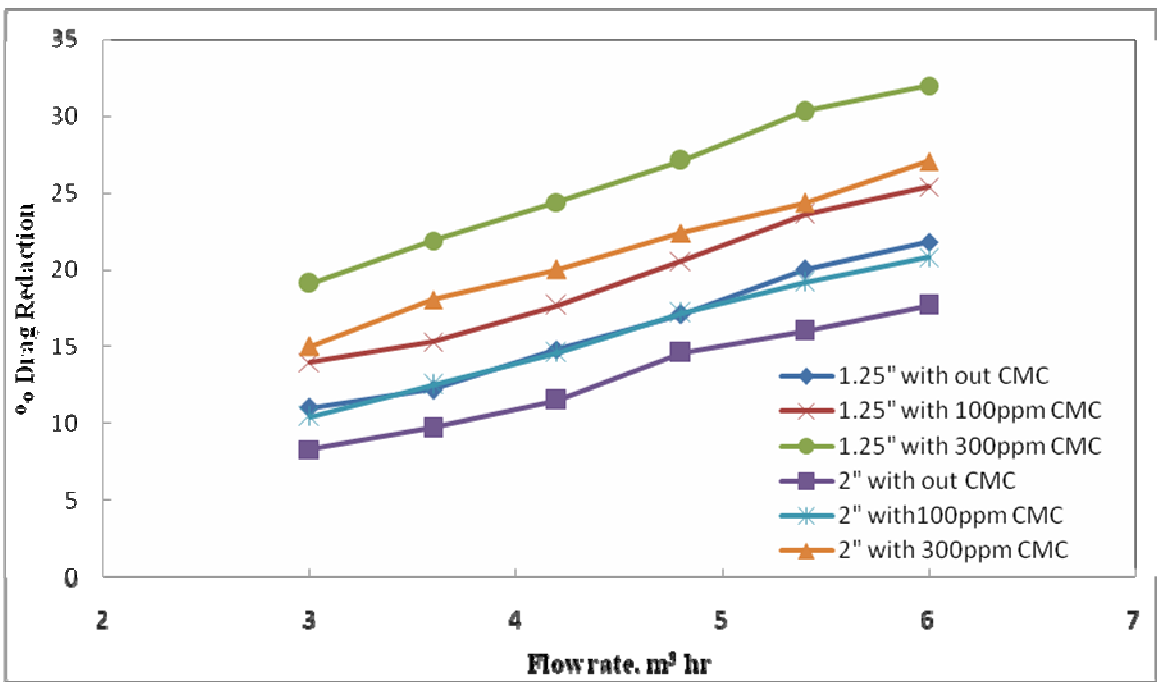

Fig. 4.32 Effect of pipe diameter on effectiveness of CMC/clay additive as drag – reducer/ 5000ppm clay

The effect of combined CMC and clay additive on throughput increase was studied at different CMC concentrations and flow rates. The result illustrated in figures 4.33 and 4.34 for the three concentrations polymers at select two pipe diameter. This show clear, that the addition of CMC polymers improves the throughput of the flowing water – clay suspension.

A linear increase of percentage throughput with flow rate increase was observed. The maximum values were 23.6% and 18.9% for 1.25 and 2inch pipe diameter at 6.0m^3/hr flow rate.

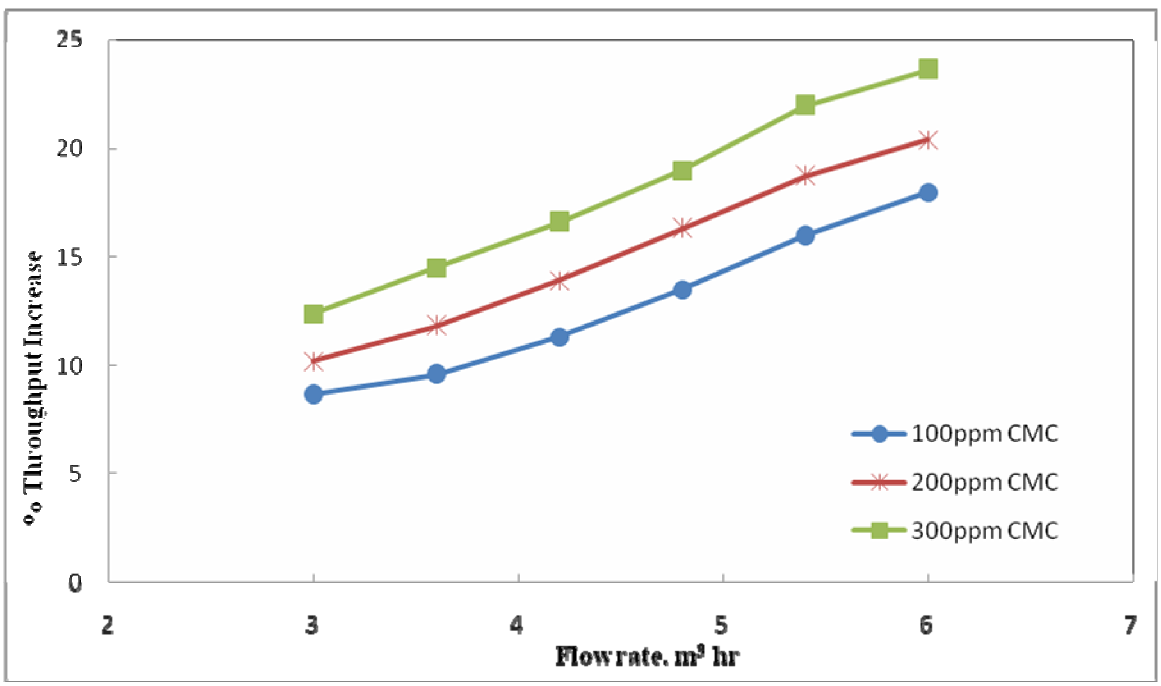

Fig. 4.33 Effect of adding CMC on percentage throughput increase for water – clay suspension with solid concentration of 5000ppm through 1.25inch I.D pipe

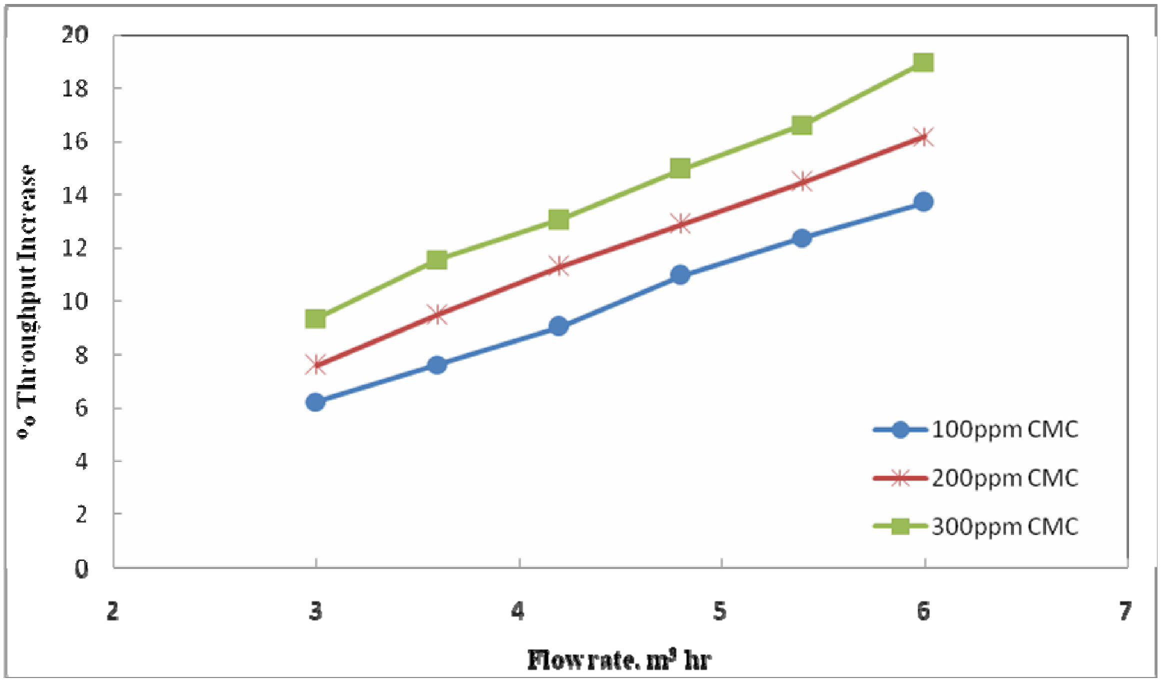

Fig. 4.34 Effect of adding CMC on percentage throughput increase for water – clay suspension with solid concentration of 5000ppm through 2inch I.D pipe.

4.7 Friction Factor

Another representation to the effect of all variable used in the investigation can be seen using friction factor, which calculated from equation 3.5.

Selected samples of the experimental results for fraction factor are shown in figure 4.35 to 4.38 . This figures show friction factor for various Re pipe diameter ,surfactant type, surfactant concentration, polymer concentration and solid particles concentration.

When additives concentrations is zero (pure solvent), most of the experimental data points are located at or close Blasuis asymptote, which give an indication that the starting points of the operation are close to that of the standard operation conditions suggested in the literatures.

When the additives is presented in the flow, the experimental data points are positioned in the direction of lowering friction towards Virk asymptote[90].

Virk asymptote that represent maximum limits of drag reduction, which will give idea that, to reach such an asymptote, higher additive concentration and Re are needed to reach such an asymptote.

These figures are divided in to four regions, These regions are[91]:-

1. laminar flow region Re < 2300, where the friction factor follows Poisuelle's law as follows :

$$f = \frac{16}{Re} \qquad \ldots(4.7.1)$$

2. transition regions Re =2300, where the flow change from laminar to turbulent flow. fraction coefficient rise rapidly.
3. turbulent region (Re >3000), where the friction factor follows Blasius law:

$$f = 0.0791\ Re^{-0.25} \qquad \ldots(4.7.2)$$

Virk asymptote region, which is suggested by Virk to represent the greatest possible fall in resistance in which the relation between friction factor (f) and re dose not depend on the nature of the additives or pipe diameter. The formula for Virk is :

$$f = 0.59\ Re^{-0.58} \qquad \ldots(4.7.3)$$

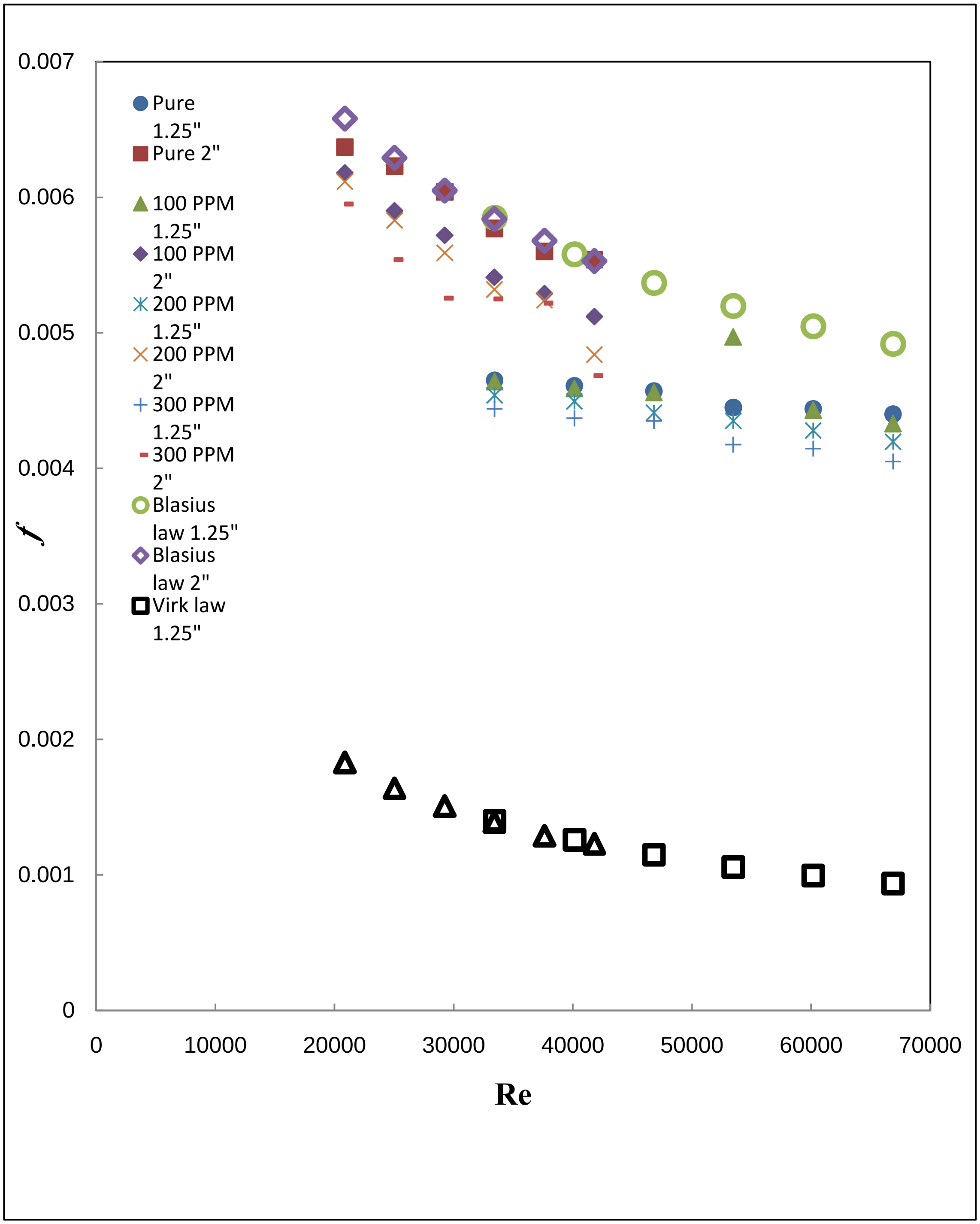

Fig. 4.35 Friction factor as function of Reynolds number for CMC.

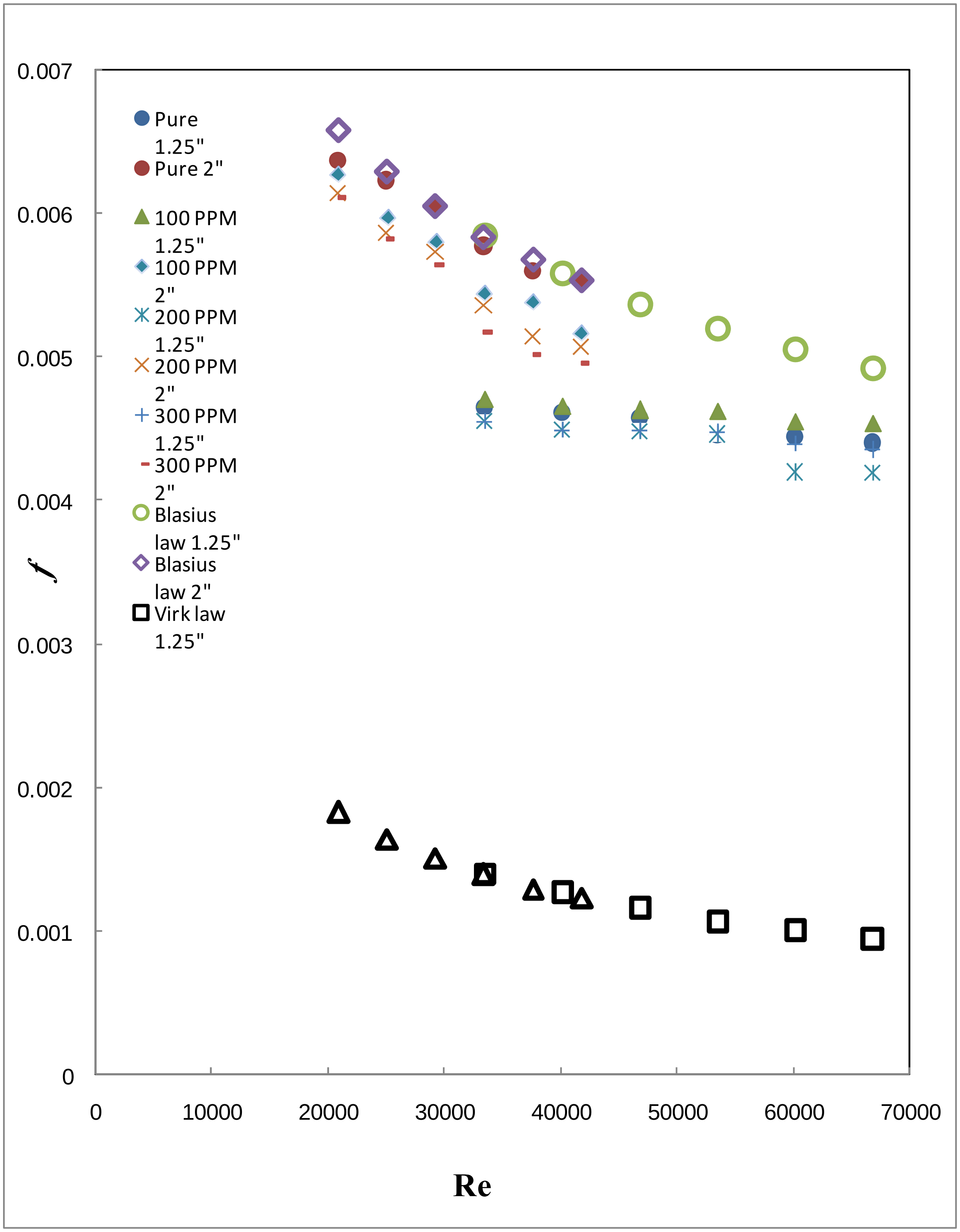

Fig. 4.36 Friction factor as function of Reynolds number for SS.

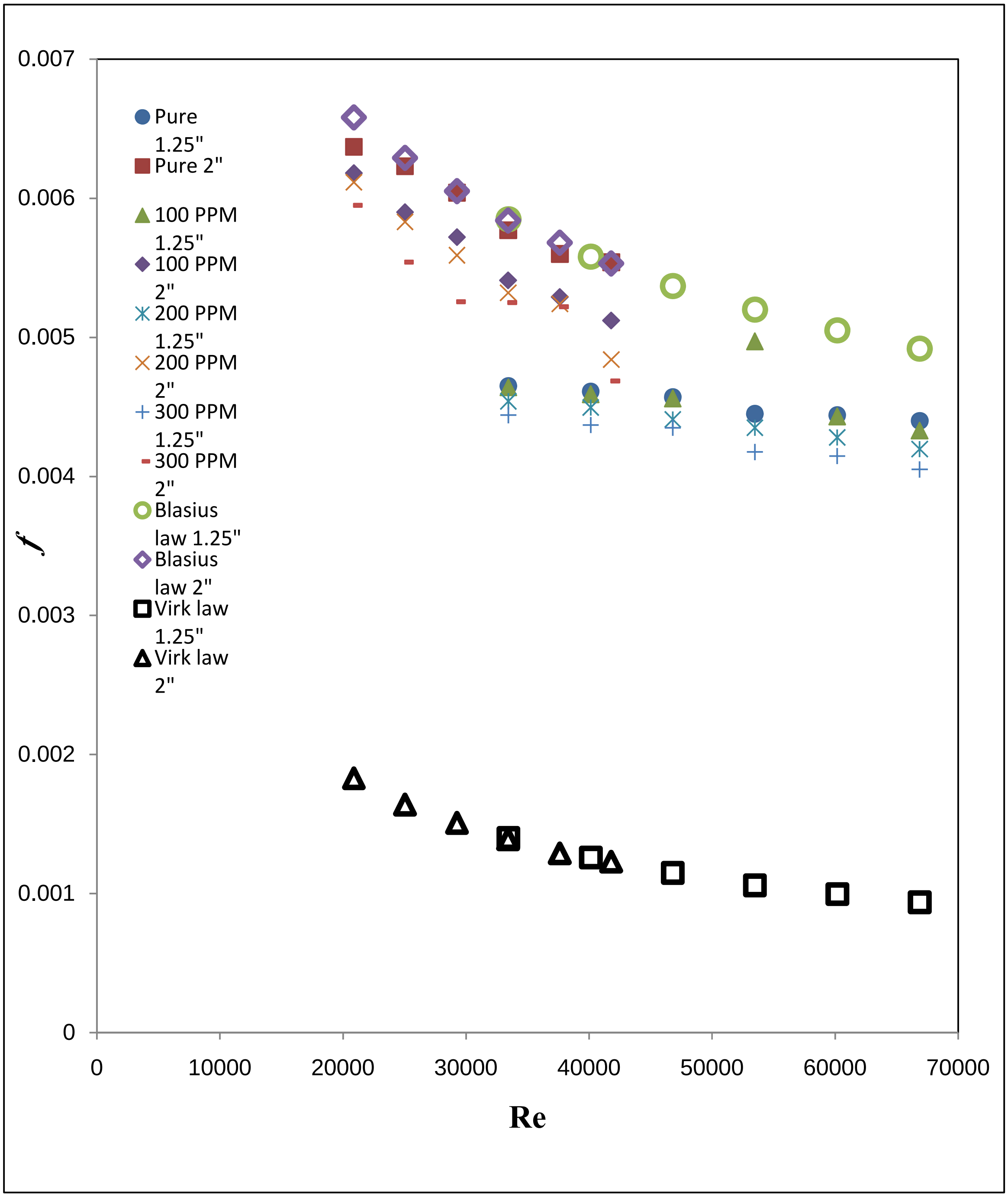

Fig. 4.37 Friction factor as function of Reynolds number for SLS.

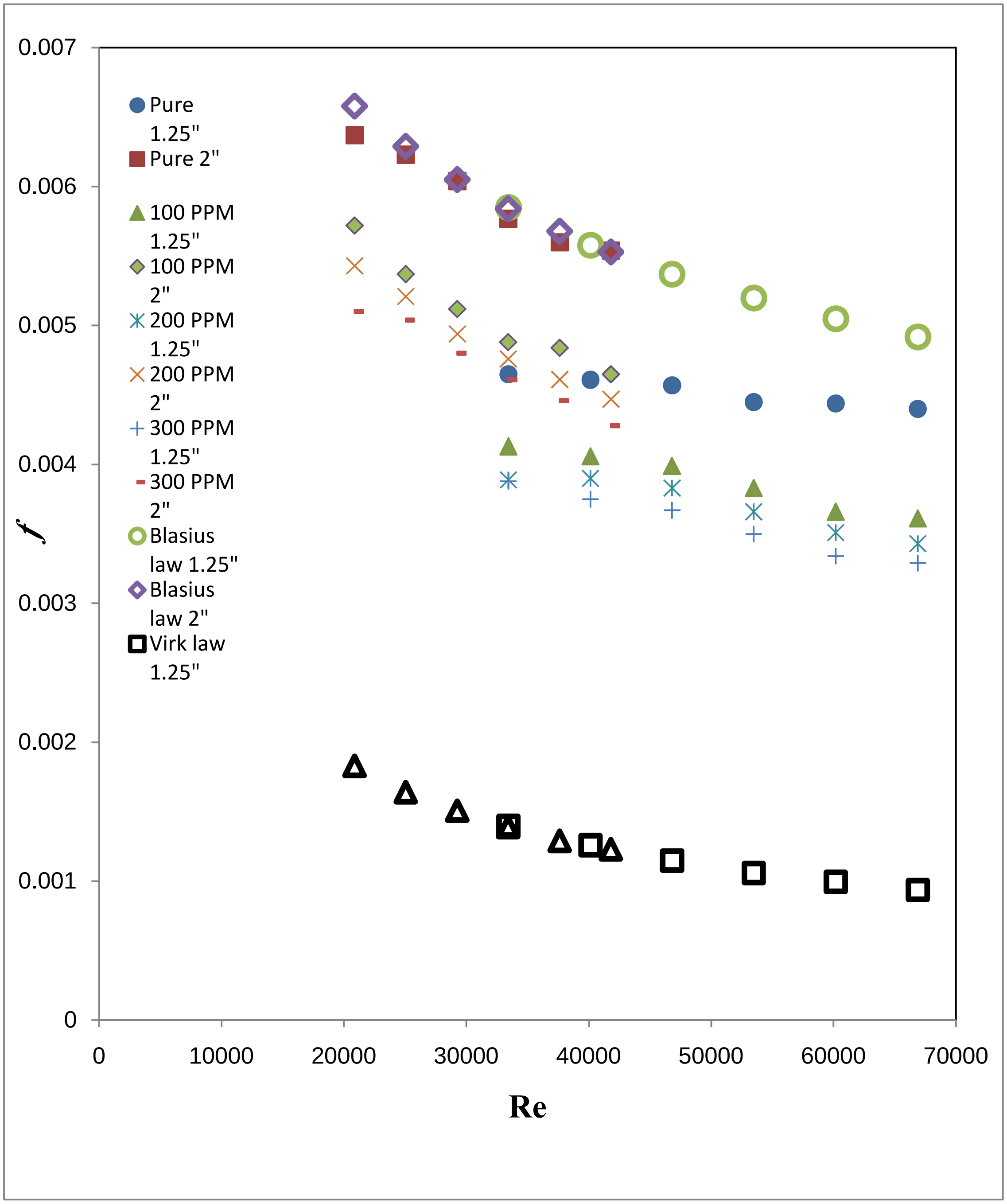

Fig. 4.38 Friction factor as function of Reynolds number for adding CMC in water – clay suspension.

Chapter Five

Conclusions and Recommendations

for Future Work

5.1 Conclusions

1. Carboxy methyl cellulose and Sodium stearate and Sodium lauryl sulfate surfactants were used as drag reducing agents in turbulent water flow. to certain limits of velocity (i.e, the maximum Velocity).

Percentage drag reduction was Found to increase by increasing the additive concentration and Re and by decreasing the pipe diameter.

2. It can be noticed that percentage drag reduction and percentage throughput increase for SS higher than SLS surfactants additive.

3. Surfactant additive (SS and SLS) is a poor drag reducer agents, while its drag reduction effectiveness can be improved by combined mixing with the carboxy methyl cellulose

4. Clay solid particles was found to behave as a good drag reducing agents, percentage drag reduction was found to increase by increasing flow rate, particles concentration. Moreover the drag reduction effectiveness of CMC alone or clay alone were improved noticeably by mixing these additives together as drag reducer agent.

5. Values of calculated fanning fraction factor for CMC, SS, SLS and for adding CMC in water Clay suspension, treated water positioned toward Virk line for

maximum drag reduction, especially for high concentrations and Reynolds numbers in 2 inch ID pipe.

5.2 Recommendations for Future Works

1.Further work can be carried out by using different type of solid particles (i.e. sand) to improve the drag reduction effectiveness of polymers (i.e. Guar gum) or surfactants (i.e. SLES)

2.Studying the time dependence of drag reduction performance of additives in presence of clay addition.

3. Studying the effectiveness of other types of surfactants, such as catatonics as additive for drag reduction.

4. Performance of a Full – scale tests of drag reduction additives in the field before selecting the finial additive is an important step for an accurate simulation of the whole process of DR.

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Appendices

Table (A-1) Experimental Results for CMC as Drag Reducer in water through 1.25 inch I.D pipe

Flow rate m^3/hr	Conc. ppm	ΔP N/m^2	%DR	%TI	Friction factor
3.0	0	646.8	-	-	0.004656
	100	644.4	4.7	2.68	0.004639
	150	643.4	5.4	3.1	0.004632
	200	630.1	6.8	3.94	0.004536
	300	616.4	8.8	5.19	0.004437
3.6	0	921.2	-	-	0.004605
	100	919.3	5.3	3.04	0.004595
	150	915.3	6.3	3.67	0.004576
	200	899.2	7.89	4.25	0.004495
	300	874.2	9.9	5.90	0.004370
4.2	0	1244.6	-	-	0.004560
	100	1241.6	6.1	10.06	0.004560
	150	1234.3	7.3	8.78	0.004533
	200	1200.5	8.6	7.89	0.004409
	300	1182.4	11.3	6.82	0.004346

Flow rate m^3/hr	Conc. ppm	ΔP N/m^2	%DR	%TI	Friction factor
4.8	0	1617	-	-	0.004454
	100	159	7.30	4.25	0.004447
	150	1566	8.55	5.04	0.004140
	200	1548.9	10.2	6.1	0.004350
	300	1484.7	12.9	7.89	0.004175
5.4	0	1999.2	-	-	0.004442
	100	1991.3	8.45	4.97	0.004425
	150	1976.6	9.95	5.93	-
	200	1927.6	11.4	6.88	0.004280
	300	1865.9	14.2	8.78	0.004146
6	0	2445.9	-	-	0.004377
	100	2418.6	10.25	6.12	0.004328
	150	2370	11.65	7.09	0.004241
	200	2345	13	7.96	0.004196
	300	2263.8	16	10.06	0.004051

Table (A-2) Experimental Results for SS as Drag Reducer in water through 1.25 inch I.D pipe

Flow rate m^3/hr	Conc. ppm	ΔP N/m^2	%DR	%TI	Friction factor
3.0	0	676.1	-	-	0.00486
	50	654.9	2.53	1.25	0.004714
	100	653.6	3.35	1.89	0.004706
	200	631.6	5.22	2.99	0.004547
	300	633	6.37	3.66	0.00455
3.6	0	970.4	-	-	0.004851
	50	943.3	2.77	1.57	0.004716
	100	932.9	3.8	2.15	0.00466
	200	897.68	6.53	3.78	0.004488
	300	897.7	7.5	4.38	0.004488
4.2	0	1318.1	-	-	0.004811
	50	1283.8	2.9	1.67	0.004715
	100	1259	4.1	2.33	0.00463
	200	1227.5	7.22	4.21	0.004484
	300	1225	8.08	4.74	0.004499

Flow rate m^3/hr	Conc. ppm	ΔP N/m^2	%DR	%TI	Friction factor
4.8	0	1724.8	-	-	0.004849
	50	1661	3.14	1.77	0.004672
	100	1643.9	4.68	2.67	0.00462
	200	1592.5	7.67	4.44	0.004457
	300	1587.6	8.4	4.94	0.004465
5.4	0	2156	-	-	0.004834
	50	2099.7	3.49	1.97	0.004665
	100	2048	5	2.86	0.00455
	200	1999	8.1	4.75	0.004419
	300	1979.6	9.0	5.32	0.004398
6.0	0	2695	-	-	0.004820
	50	2595	4.5	2.56	0.004644
	100	2588	5.82	3.34	0.00454
	200	2469	8.36	4.92	0.004419
	300	2420	10.18	6.08	0.004356

Table (A-3) Experimental Results for SLS as Drag Reducer in water through 1.25 inch I.D pipe

Flow rate m^3/hr	**Conc. ppm**	**ΔP N/m^2**	**%DR**	**%TI**	**Friction factor**
3.0	0	676	-	-	0.00486
	50	666	1.47	0.82	0.004797
	100	659.54	2.5	1.40	0.00478
	200	649.7	3.9	2.21	0.004677
	300	643.8	4.8	2.74	0.004645
3.6	0	970	-	-	0.004851
	50	951	2.02	1.13	0.004753
	100	939	3.19	1.79	0.004696
	200	928.5	4.3	2.44	0.00464
	300	919	5.3	3.04	0.004595
4.2	0	1318	-	-	0.004841
	50	1295	2.11	1.18	0.004757
	100	1279	3.35	1.89	0.004697
	200	1254	4.9	2.80	0.004607
	300	1247	5.7	3.28	0.00458

Flow rate m^3/hr	**Conc. ppm**	**ΔP N/m^2**	**%DR**	**%TI**	**Friction factor**
4.8	0	1725	-	-	0.004849
	50	1656	2.31	1.29	0.004657
	100	1646	3.44	1.95	0.00463
	200	1622	5.3	3.04	0.00456
	300	1617	6.25	3.52	0.00454
5.4	0	2156	-	-	0.004834
	50	2092	2.51	1.41	0.004649
	100	2077	3.63	2.06	0.004617
	200	2043	5.8	3.34	0.00454
	300	2029	6.7	3.88	0.004507
6.0	0	2695	-	-	0.00482
	50	2620	2.8	1.57	0.004688
	100	2573	4.5	2.56	0.0046
	200	2526	6.61	3.83	0.00452
	300	2492	7.88	4.62	0.00446

Table (A-4) Experimental Results for CMC/SS as Drag Reducer in water through 1.25 inch I.D pipe

Flow rate m^3/hr	Ratio	ΔP N/m^2	%DR	%TI
3.0	16.7	622	6.62	3.82
	33.3	619	7.1	4.12
	50	610	8.45	4.97
	66.7	600	9.4	5.58
3.6	16.7	892	7.32	4.1
	33.3	884.5	8.2	4.63
	50	869.8	9.44	5.60
	66.7	853	11.2	6.82
4.2	16.7	1215	8.14	4.78
	33.3	1193	9.81	5.84
	50	1181	10.74	6.44
	66.7	1148	13.18	7.43
4.8	16.7	1568	8.6	5.05
	33.3	1539	10.28	6.15
	50	1519	11.43	6.90
	66.7	1470	14.5	8.99
5.4	16.7	1973	9.3	5.33
	33.3	1938	10.9	6.49
	50	1901	12.6	7.69
	66.7	1842	15.32	9.57
6.6	16.7	2411	10.5	6.29
	33.3	2362	12.4	7.45
	50	2303	14.54	9.03
	66.7	2254	17.0	10.79

Table (A-5) Experimental Results for CMC/SLS as Drag Reducer in water through 1.25 inch I.D pipe

Flow rate m^3/hr	Ratio	ΔP N/m^2	%DR	%TI
3.0	16.7	642	5.1	2.98
	33.3	638	5.6	3.20
	50	629	6.9	4.01
	66.7	623	7.8	4.60
3.6	16.7	870	5.5	3.19
	33.3	858	6.8	3.95
	50	852	7.5	4.38
	66.7	846	8.1	4.71
4.2	16.7	1240	5.9	3.41
	33.3	1220	7.4	4.38
	50	1217	7.7	4.49
	66.7	1205	8.6	5.15
4.8	16.7	1611	6.6	3.84
	33.3	1589	7.9	4.63
	50	1565	9.25	5.48
	66.7	1520	11.9	7.23
5.4	16.7	1859	7	4.06
	33.3	1827	8.6	5.07
	50	1795	10.2	6.04
	66.7	1745	12.7	7.76
6.0	16.7	2245	8.2	8.93
	33.3	2202	9.98	5.93
	50	2150	12.1	7.29
	66.7	2084	14.8	9.17

Table (A-6) Experimental Results for clay as Reducer in water through 1.25 inch I.D pipe

Flow rate m^3/hr	Conc. ppm	ΔP N/m^2	%DR	%TI
3.0	0	676	-	-
	500	664	1.8	1.01
	1000	642	3.7	2.1
	3000	617	7.3	4.27
	5000	593	11.0	6.62
3.6	0	970	-	-
	500	951	20	1.14
	1000	921	4.1	2.33
	3000	822	8.16	4.82
	5000	843	12.2	7.42
4.2	0	1318	-	-
	500	1289	2.2	1.23
	1000	1264	4.4	2.5
	3000	1146	14.6	5.7
	5000	1127	14.8	9.22
4.8	0	1725	-	-
	500	1676	2.85	1.61
	1000	1637	4.57	2.6
	3000	1519	11.43	6.9
	5000	1421	17.1	10.87
5.4	0	2156	-	-
	500	2087	3.18	1.80
	1000	2038	5.45	3.2
	3000	1882	12.7	7.75
	5000	1725	20.0	13.05
6.0	0	2695	-	-
	500	2598	3.6	2.04
	1000	2509	6.9	4.01
	3000	2313	14.2	8.79
	5000	2107	21.8	14.48

Table (A-7) Experimental Results for adding CMC in water-clay suspension as Drag Reducer through 1.25 inch I.D pipe

Flow rate m^3/hr	Conc. ppm	ΔP N/m^2	%DR	%TI	Friction factor
3.0	0	676	-	-	0.00486
	100	573	13.97	8.64	0.004127
	200	529	16.2	10.20	0.00381
	300	539	19.1	12.36	0.00388
3.6	0	970	-	-	0.004851
	100	813	15.3	9.56	0.00406
	200	784	18.36	11.80	0.00392
	300	750	21.9	14.5	0.003748
4.2	0	1318	-	-	0.004841
	100	1088	17.7	11.30	0.00399
	200	1044	21.1	13.9	0.00383
	300	999.6	24.4	16.6	0.00367
4.8	0	1725	-	-	0.004849
	100	1362	20.57	13.5	0.00383
	200	1303	24.0	16.29	0.00366
	300	1245	27.1	18.98	0.0035
5.4	0	2156	-	-	0.004834
	100	1647	23.6	15.95	0.003658
	200	1578	26.8	18.7	0.003506
	300	1504	30.3	21.96	0.00334
6.0	0	2695	-	-	0.00482
	100	2019	254	17.48	0.003612
	200	1921	28.7	20.4	0.00343
	300	1833	32.0	23.6	0.003298

Table (A-8) Experimental Results for CMC as Drag Reducer in water through 2 inch I.D pipe

Flow rate m^3/hr	Conc. ppm	ΔP N/m^2	%DR	%TI	Friction factor
3.0	0	127.1	-	-	0.00637
	100	123	3.2	1.80	0.006179
	150	122.6	3.75	2.12	0.006146
	200	122	4.25	2.42	0.006115
	300	189	6.8	3.94	0.00595
3.6	0	179	-	-	0.00623
	100	170	3.9	2.2	0.005905
	150	167.5	4.4	2.5	0.005835
	200	167	5.1	2.92	0.005829
	300	159	7.14	4.15	0.005547
4.2	0	237	-	-	0.00604
	100	224	4.7	2.68	0.005719
	150	221	5	2.86	0.005639
	200	219	6.9	4.01	0.005589
	300	206	8.7	5.13	0.005252
4.8	0	302	-	-	0.00577
	100	277	5.8	3.34	0.00541
	150	275	6.7	3.88	0.005377
	200	272	7.4	4.32	0.00532
	300	269	10.1	6.04	0.00525
5.4	0	382	-	-	0.00564
	100	343	6.6	3.8	0.00529
	150	341	7.7	5.04	0.00527
	200	340	8.6	5.07	0.00524
	300	338	11.54	6.97	0.005217
6.0	0	470	-	-	0.00554
	100	410	7.1	4.13	0.00512
	150	396	8.9	5.26	0.00495
	200	387	10.2	6.09	0.004838
	300	375	13.0	7.99	0.004685

Table (A-9) Experimental Results for SS as Drag Reducer in water through 2 inch I.D pipe

Flow rate m^3/hr	Conc. ppm	ΔP N/m^2	%DR	%TI	Friction factor
3.0	0	127	-	-	0.00637
	50	126	1.0	0.55	0.006315
	100	125	1.7	0.95	0.00627
	200	122.5	3	1.68	0.006139
	300	122	4.2	2.38	0.00611
3.6	0	179	-	-	0.00623
	50	178.6	1.3	0.72	0.006223
	100	171.5	2.7	1.52	0.00597
	200	168	3.9	2.21	0.005866
	300	167	5.26	3.02	0.00582
4.2	0	237	-	-	0.00604
	50	241	1.7	0.947	0.006145
	100	228	3.12	1.75	0.00581
	200	245	4.5	2.56	0.00573
	300	221	6	3.46	0.005637
4.8	0	302	-	-	0.00577
	50	297	2.2	1.23	0.005807
	100	279	3.6	2.03	0.00545
	200	274	5	2.86	0.00536
	300	265	6.89	4.0	0.005174
5.4	0	382	-	-	0.00564
	50	372	2.5	1.4	0.005752
	100	349	3.8	2.15	0.005383
	200	333	5.6	3.22	0.005142
	300	325	7.85	4.59	0.005017
6.0	0	470	-	-	0.00554
	50	457	2.8	1.57	0.00571
	100	414	4.0	2.27	0.005175
	200	405.5	6	3.46	0.0050715
	300	397	8	4.69	0.00496

Table (A-10) Experimental Results for SLS as Drag Reducer in water through 2 inch I.D pipe

Flow rate m^3/hr	Conc. ppm	ΔP N/m^2	%DR	%TI	Friction factor
3.0	0	127	-	-	0.00637
	50	126	0.41	0.22	0.006315
	100	125.7	1.25	0.69	0.0063
	200	124	2.5	1.40	0.006225
	300	123	3.2	1.80	0.006165
3.6	0	179	-	-	0.00623
	50	177	0.69	0.38	0.006165
	100	174	1.83	1.02	0.006032
	200	170	2.77	1.55	0.005974
	300	169.5	3.6	2.03	0.005923
4.2	0	237	-	-	0.00604
	50	231	0.83	0.46	0.005895
	100	230.5	2.1	1.17	0.005877
	200	227	3.26	1.84	0.005802
	300	226	3.75	2.12	0.00577
4.8	0	304	-	-	0.00577
	50	300.6	1.1	0.554	0.005879
	100	279	2.58	1.45	0.005414
	200	275	3.79	2.14	0.005346
	300	273	4.13	2.34	0.005327
5.4	0	382	-	-	0.00564
	50	377	1.28	0.71	0.00583
	100	341	2.8	1.57	0.005293
	200	338	4.1	2.33	0.005217
	300	335	5.1	2.92	0.005164
6.0	0	470	-	-	0.00554
	50	461	1.9	1.06	0.005762
	100	420	3.1	1.74	0.005224
	200	412	4.59	2.62	0.005145
	300	405	5.93	3.42	0.005072

Table (A-11) Experimental Results for CUC/SS as Drag Reducer in water through 2 inch I.D pipe

Flow rate m^3/hr	Ratio	ΔP N/m^2	%DR	%TI
3.0	16.7	121	4.82	2.77
	33.3	120	5.46	3.19
	50	118	6.8	3.95
	66.7	116	8.33	4.93
4.8	16.7	282	7.33	4.28
	33.3	279	8.11	4.71
	50	276	9.37	5.59
	66.7	270	11.29	6.8
6.0	16.7	432	8.15	4.82
	33.3	427	9.2	5.48
	50	418	11.0	6.61
	66.7	407	13.5	8.34

Table (A-12) Experimental Results for CUC/SLS as Drag Reducer in water through 2 inch I.D pipe

Flow rate m^3/hr	Ratio	ΔP N/m^2	%DR	%TI
3.0	16.7	122	3.8	2.15
	33.3	121.5	4.3	2.46
	50	120	5	2.88
	66.7	119	6.25	3.63
4.8	16.7	287	5.7	3.31
	33.3	285	6.4	3.73
	50	282	7.1	4.17
	66.7	277	8.8	5.26
6.0	16.7	441	6.2	3.4
	33.3	433	7.8	4.43
	50	425	9.6	5.70
	66.7	418	11	6.62

Table (A-13) Experimental Results for clay as Drag Reducer in water through 1.25 inch I.D pipe

Flow rate m^3/hr	Conc. ppm	ΔP N/m^2	%DR	%TI
3.0	0	127.4	-	-
	500	126	0.75	0.42
	1000	124.7	2.08	1.16
	3000	121	5.0	2.86
	5000	117	8.3	4.88
3.6	0	181	-	-
	500	175	0.83	0.46
	1000	172	2.77	1.56
	3000	167	5.5	3.16
	5000	150	9.7	5.77
4.2	0	245	-	-
	500	242	1.04	0.58
	1000	237	3.12	1.76
	3000	227	7.29	4.25
	5000	217	11.5	6.95
4.8	0	304	-	-
	500	299	1.7	0.95
	1000	294	3.4	1.92
	3000	278	8.6	5.07
	5000	260	14.6	9.07
5.4	0	382	-	-
	500	375	1.9	1.06
	1000	365	4.5	2.57
	3000	343	10.2	6.10
	5000	321	16.0	10.07
6.0	0	470	-	-
	500	460	2.04	1.14
	1000	446	5.2	2.98
	3000	407	11.45	6.89
	5000	379	17.7	11.31

Table (A-14) Experimental Results for adding CMC in water-clay suspension as Drag Reducer through 2 inch I.D pipe

Flow rate m^3/hr	Conc. ppm	ΔP N/m^2	%DR	%TI	Friction factor
3.0	0	127	-	-	0.00637
	100	114	10.41	6.23	0.00572
	200	108	12.5	7.6	0.00543
	300	100	15	9.35	0.0051
3.6	0	179	-	-	0.00623
	100	154	12.5	7.62	0.005376
	200	150	15.2	9.49	0.005206
	300	144	18.05	11.57	0.005035
4.2	0	237	-	-	0.00604
	100	201	14.58	9.05	0.005127
	200	194	17.7	11.3	0.004939
	300	188	20	13.05	0.004802
4.8	0	302	-	-	0.00577
	100	250	17.2	10.97	0.00488
	200	244	19.8	12.9	0.004762
	300	236	22.4	14.96	0.004609
5.4	0	382	-	-	0.00564
	100	314	19.2	12.4	0.004839
	200	299	21.79	14.48	0.004613
	300	289	24.35	16.63	0.00446
6.0	0	470	-	-	0.00554
	100	372	20.83	13.7	0.004655
	200	358	23.9	16.2	0.004471
	300	343	27.08	18.98	0.004287

Table (A-15) Results of Friction Factor for Blasuis and Virk Asymptotes through 1.25 inch I.D pipe

Re	$f_{Blasuis}$	f_{Virk}
66865	0.00492	0.000938
60166	0.00505	0.000997
53467	0.00520	0.00106
46799	0.00537	0.00115
40132	0.00558	0.00126
33433	0.00585	0.00140

Table (A-16) Results of Friction Factor for Blasuis and Virk Asymptotes through 2 inch I.D pipe

Re	$f_{Blasuis}$	f_{Virk}
41808	0.00553	0.00123
37627	0.00568	0.00129
33426	0.00585	0.00139
29261	0.00605	0.00151
25045	0.00629	0.00164
20879	0.00658	0.00183

الخـلاصــة

في هذا البحث العلمي تمت دراسة فعالية Carboxy methyl cellulose و نوعين من المنظفات (Sodium stearate , Sodium lauryl sulfate) و الطين العالق كمواد مقللة للاعاقة ، لتَخفيض المقاومةِ الإحتكاكيةِ و الإحتِفاظ بضخّ القوَّةِ لتدفق الإنبوبِ المضطرب . النمط المضطرب الناتج عن طريق مضخة الازاحة الموجبة لتفادى انحلال سلاسلِ الإضافاتِ أثناء الفترةِ الضخ .

تأثير تراكيز الإضافاتِ درس بمعدل يتراوح بين (50 - 300) جزء بالمليون بالنسبة للبوليمر و المنظف و(500 - 5000) جزء بالمليون للعوالق الصلبة في الماءِ المُتَدفّق، وبمعدل جريان يتراوح من 3 إلى 6 م^3\ساعة و رقم الرينولد (20000 – 70000) في أنبوبين بأقطار 1.25 و 2 انج وبحرارة الغرفة .

وهو يفضل أيضاً أنْ يَتحرّى التأثيرَ لكلتا SS و SLS المنظفين سوف يتحسنان بإضافة CMC، أنّ الزيادة التدريجية في تخفيضِ عائق النسبة المئويةِ لوحظتْ بالزيادةِ، ويلاحظ ذلك كلما زادت النسبة المئوية CMC في خَلِيْطِ المضافِ بكلا SS و SLS المنظفين .

بالاضافة الى تقنية اخرى أسّستْ في خطوتي إضافة كمياتِ الجزيئاتِ الصلبةِ التي يُمْكِنُ أنْ تُعلّقَ في الماءِ السائلِ، هذه التعليق قدْ يُستَعملُ كعوامل إختزال عائق. بعد تلك الخطوةِ الأخرى مُؤَسَّسةْ بإضافةِ كمياتِ polymer مُتَأكّدة (CMC) بثلاثة تركيز مختلفة (100 ، 200 ,300) ppm بالشرطِ نفسهِ أي اضافة (CMC) تحسن من تقليل الاعاقة في العائق.

أي زيادة تدريجية مِنْ تخفيضِ العائق والطاقة الإنتاجيةِ يُنجز بزيَادَة تركيزِ المضافَ و جريان السائل وبنقصانِ قطرَ الأنبوب.

تم حساب معامل الاحتكاك من المعلومات العملية في البحث حيث اظهرت النتائج ان معاملات الاحتكاك في حالة ضخ الماء النقي خلال الأنابيب تقع بالقرب او على محاذاة Blasuis ، وعند اضافة كل من المضافات الى السائل المدور فان تلك المعاملات سوف تتجه اسفل ذلك المحاذي باتجاه محاذي Virk لاقصى درجات تقليل الاعاقة .

شـــكر و تقديـــر

الحمد لله الذي انعم علينا بتمام الصحة و فضلنا بنعمة العقل وزيننا بتاج العلم

أتقدم بخالص شكري و تقديري و امتناني لكل من آزرني خلال فترة إعدادي للأطروحة ابتداء بأستاذي الفاضل الدكتور **جابر شنشول جمالي** لما ابداه من مساندة و دعم فكان لي نعم المؤازر و الناصح فكان هذا البحث ثمرة من جهده المعطاء .

وكما اعبر عن عميق شكري للأستاذ الدكتور **قاسم جبار سليمان** رئيس قسم الهندسة الكيمياوية و الى جميع أساتذتي و زملائي الكرام في قسم الهندسة الكيمياوية .

كذلك شكري لأفراد عائلتي و زوجي الأعزاء و بالخصوص والدي الغالي لصبرهم ودعمهم الذي قدموه لي خلال فترة حياتي الدراسية .

أسـماء حسـن ضـياء

تقليل الاحتـكاك بواسـطة المحسنات المضـافة
في الجريان المضطرب

رسالة

مقدمة الى كلية الهندسة في جامعة النهرين

وهي جزء من متطلبات نيل درجة ماجستير علوم

في الهندسة الكيمياوية

من قبل

أسـمـاء حسـن ضـياء

(بكالوريوس علوم في الهندسة كيمياوية ٢٠٠٥)

جمادى الآخرة ١٤٢٩ هـ

حزيران ٢٠٠٨ م