THE EFFECT OF SURFACE ACTIVE AGENTS ON FRICTION REDUCTION IN PIPE LIQUID FLOW

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by

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Certification

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Abstract

The turbulent drag-reduction effectiveness of two anionic surfactants, Sodium Dodecy -Benzene Sulfonate (SDBS) and Sodium laureth sulfate (SLES) has been studied in a build –up closed loop water circulation system, the turbulent mode was produced via a positive displacement gear pump to avoid mechanical degradation surfactant molecules during the experimental period. Drag- reduction results were assessed by measuring the pressure drop over 2m test section.

The effect of additive concentration was investigated over a range of 50 to 250ppm by weight in flowing tap-water at flow rates of 2.0 to 6.0 m^3/hr in a 0.0508 m(2 inch) pipe diameter. A gradual increase of percentage drag - reduction and flow capacity (throughput) was achieved by increasing the detergent concentration and water flow rate, reaching up to 38.36% drag-reduction and 30.49% throughput increase. The SDBS detergent gave high drag -reduction values and therefore it's more effective than SLES detergent at the optimum condition. The effectiveness of these anionic surfactants could be attributed to the shear stability of micelles structure as a result of rod – shaped micelles forming.

In order to investigate the performance of the anionic surfactants as drag – reducers in the flowing saline water, the screening studies were carried out in presence of small amounts of sodium chloride or calcium chloride. A gradual decline of detergent effectiveness was noticed by increasing the salt concentration in water. This observation my be due to less shear stability of micelles structure as a result of presence of such strong ionic salts. Calcium chloride caused higher inhibition of drag – reduction effectiveness by the detergents than sodium chloride. Since, calcium chloride forms with the anionic detergent insoluble salts leading to deactivate such drag – reducers.

Friction factor was calculated from experimental data observed at different flowing conditions. For untreated water pipelining friction factors values lies near Blasius asymptotes. While, the increasing the detergent concentrations at high Reynolds number causes decreasing the friction factor values toward Virk asymptote line, which was never reached. The presence of sodium chloride and calcium chloride is small amounts result in values positioned toward Blasius asymptote indicating the less effectiveness detergent additives as drag – reducers.

A simple correlation equation was suggested to predict the effect of flow parameters, detergent molecular weight and concentration, water flow rate and salt concentration on drag – reduction effectiveness of anionic detergents. The results of correlation showed good agreement between the experimentally observed and predicted percentage drag reduction values with a higher than 94.758%.

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Arabic Abstract

Notations

Variable Notations

Symbols	Description	Unit
R^*	Correlation Coefficient	[-]
C	Surfactants concentration	[ppm]
CMC	Critical micelle concentration	[Mol/dm^3]
D	Pipe inside diameter	[m]
%Dr	Percentage drag reduction	[-]
F	Fanning friction factor	[-]
%TI	Percentage flow increase	[-]
h_f	Head loss	[m]
L	Testing section length	[m]
M_w	Molecular weight	[g/ mole]
ΔP	Pressure drop	N/m^2
Q	Volumetric flow rate	[m^3/hr]
Re	Reynolds number	[-]
T	Temperature	[°C]
U	Mean velocity	[m/s]

Abbreviations

Abbreviations	Definition
CTAB	Cetyl tri–methyl ammonium bromide
CTAC	Cetyl tri–methyl ammonium chloride
DRA	Drag Reduction Agent
ETAS	Erucyl tri–methyl ammonium salicylate
GG	Gear Gum
HEC	Hydroxyethylecellulose
M	Inorganic or organic cation
NaSl	Sodium Salicylate
PAM	Poly acryl amide
PCIP	Polycis-isoprene
PDMS	Polydimethylsiloxane
PEO	Polyethylene oxide
PIB	Polyisobutylene
PMMA	Polymethyl methacrylate
PS	Polystyrene
R	Hydrophobic group
SDBS	Sodium dodecyle benzene sulfonate
SLES	Sodium lauryl ether sulfate
STAC	Stearyl tri–methyl ammonium chloride
X	An anion
XG	Xanthan gum

Greek symbols

Symbols	Description	Unit
ΔP	Pressure drop	[N/m^2]
ΔP_a	Pressure drop after adding surfactant	[N/m^2]
ΔP_b	Pressure drop before adding surfactant	[N/m^2]
ρ	Fluid density	[kg/m^3]
τ_w	Wall shear stress	[N/m^2]
f	Fanning friction factor	
μ , η	Dynamic viscosity	[Pa.s] ,[poise]
υ	Kinematicviscosity	[c.st]
ε	Roughness of pipe	[m]

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Chapter One
Introduction

Since Tomes observed the drag reduction phenomenon for the first time in 1948[1], the possibility of obtaining large reductions of the friction and heat transfer in turbulent pipe flows by the use of surfactant and polymer solution have caught the attention of many researches. However, despite five decades of research, a full understanding of the fundamentals of this phenomenon is still far from complete. This lack knowledge is perhaps is not surprising, since the very nature of turbulent flows, as well as the rheolgy of viscoelastic fluid in much simpler flow field, are on going field of research. Nevertheless, as with most of advances in the studies of turbulence of Newtonian fluid. Progress in the drag reduction field has made possible due to the development of smi- empirical models that describe various aspects of the momentum and heat transports. [2]

Power saving is the major concern of all the investigations involved in what is called "Drag Reduction Field". Reducting drag of transport field through pipelines caused by friction and turbulence losses has great benefit from economical point of view. Drag reduction may accrue using different technologies with different type of materials. In liquid transportation through pipelines, the addition of small amount of chemical additions (generally Polymer or Surfactants) to the flowing liquid in turbulent mode, will lead to the reduction in pressure drop which is a clue about the power saving made in the system. Another technique for drag reduction was suggested. This technique depends on adding small amount of solid particles to flowing liquid in turbulent manner

through pipelines. The addition of these particles vanishes one of the major assertions in the drag reduction technique by
chemical addition which is "Solubility of the addition the transported liquid", or have the water, condition that the drag reducer must be soluble or at last has the ability to penetrate or its molecules reorient in the transported liquid to be affected. This behavior suggested new and merely independent mechanism to explain the behavior. [3]

Many techniques for reducing drag were suggested by many researches for large number of applications. One of these techniques depends on suppressing turbulent eddies by using baffles with different heights in turbulent flow region, as in channel flow [4]. The techniques used layer of greasy materials or bubble layers to reduce skin-friction, as in some marine application in ships. One of modern techniques in drag reduction (or friction reduction) is by the addition of minute quantities of chemical additives to liquid transported in turbulent flow through pipelines. That in some cases, it is necessary to increase the transported liquid flow rate in built pipelines to avoid costs and time spent on building new pipelines to have the same flow improvement needed. So, drag reducers were used to overcome this problem[5].

Surfactants were used as drag reducing agents in many studies. The special configuration of the surfactants molecules plus there multiple personality, make it possible to overcome some of the polymers disadvantages. Surfactant molecules have the ability to form certain types of aggregates which are called "micelles". These micelles do have the ability to reform there structure (regain their drag reduction ability) when the fluid enters shear region [4 -5]. Also, surfactant are easier to handle during operation and commercially available. All these advantages made the surfactant to be the preferred on many types of polymers in some commercial application, especially with aqueous media. [6]

The major object of the present work is concerned with studying the effect of Sodium Dodecyl-Benzene Sulfonate(SDBS) and Sodium lauryl ether sulfate (SLES) surfactants on the drag - reduction of turbulent flow. Experiments should be done to investigate the effect of some mineral salts in drag – reduction ability of detergent additives. Sodium chloride and calcium chloride were chosen for this purpose; hence the later affected the hardness of water.

Further aim of the experimental study is to evaluate the effect of bulk velocity, and additives concentrations on the drag - reduction in pipe liquid flow. The information obtained should be of value in themselves and should also assist in the consideration of economic application of friction reducing additives for increasing the capacity of a given pipeline for water transport.

Chapter Two

2.1Friction in Pipe Flow

2.1.1 Fundamentals

When a fluid with uniform flow over the cross-section enters a pipe, the layers of fluid adjacent to the walls are slowed down as on a plane surface and boundary layer forms at the entrance. This build up in thickness as the fluid passes in to the pipe. At the some distance down stream from mouth, the boundary layers reach a thickness equal to the pipe radius and join at the axis, after which condition remain constant and fully developed flow exists. If the flow in the boundary layers is streamline when they meet, laminar flow exists in the pipe. If the transition has already taken place before the meet, turbulent flow will persist in the region of fully developed flow. [7][8]

Stanton and pannel 1945[9] measured the drop in the pressure due to friction for a number of fluid flowing in pipes of various diameter and surface roughness. They expressed their results by using the concept of a friction factor, defined as the dimension less group $R/\rho u^2$, which is plotted as a function of Reynolds number as shown in figure (2.1). ($R=-R_0$) represent resistance to flow per unit area of pipe surface. For a given surface a single curve was found to express the results for all fluids, pipe diameter, and velocities.

At low values of Reynolds number ($Re< 2000$), $R/\rho u^2$ was independent of the roughness, but at high values ($Re>2500$), $R/\rho u^2$ varied with the surface roughness, while at very high Reynolds number the friction factor (f) became independent of Re and it is a function of the surface roughness only. Over the transition region of Re, from 2000 to 2500 $R/\rho u^2$ increase very rapidly. Showing the great increasing in friction as soon as turbulent motion commenced. This problem associated with fluid motion, heat transfer, and mass transfer. Mody 1944[10] worked in terms of a friction factor (here denoted by $f^{\backslash}$) equal to 8 $R/\rho u^2$ and expressed this factor as a functional of two dimension less terms Re and e/d where e is the length representing the magnitude of the surface roughness. These relationships can be seen from dimensional analysis.

The effect of chemical additives on solvent structure on solvent structure may be as important as the effect of solution on additive conformation in drag-reducing solution especially if the solvent is water. Water is a highly ordered liquid due to its polar nature and its propensity to form hydrogen bonds between molecules.   The hydrogen bonds are constantly breaking and reforming, producing transient clusters involving different molecules throughout the fluid. McCormick [11] and Morgan [12] have indicated that structure may be of great importance in the drag reduction phenomenon. They measure the friction factor for a solution of hydrophobically modified acryl amid copolymer (PAAM-35) in which polymer concentration has been held constant but solvent has been varied. Solvent employed were dionized water [13], urea in deionized water NaCl in dionized water. Urea is a water structure breaker, while the additions of NaCl, on the other hand found that enhance intermolecular interaction in this copolymer. DRE is greatly decease by the addition of urea, and enhanced by the addition of NaCl.

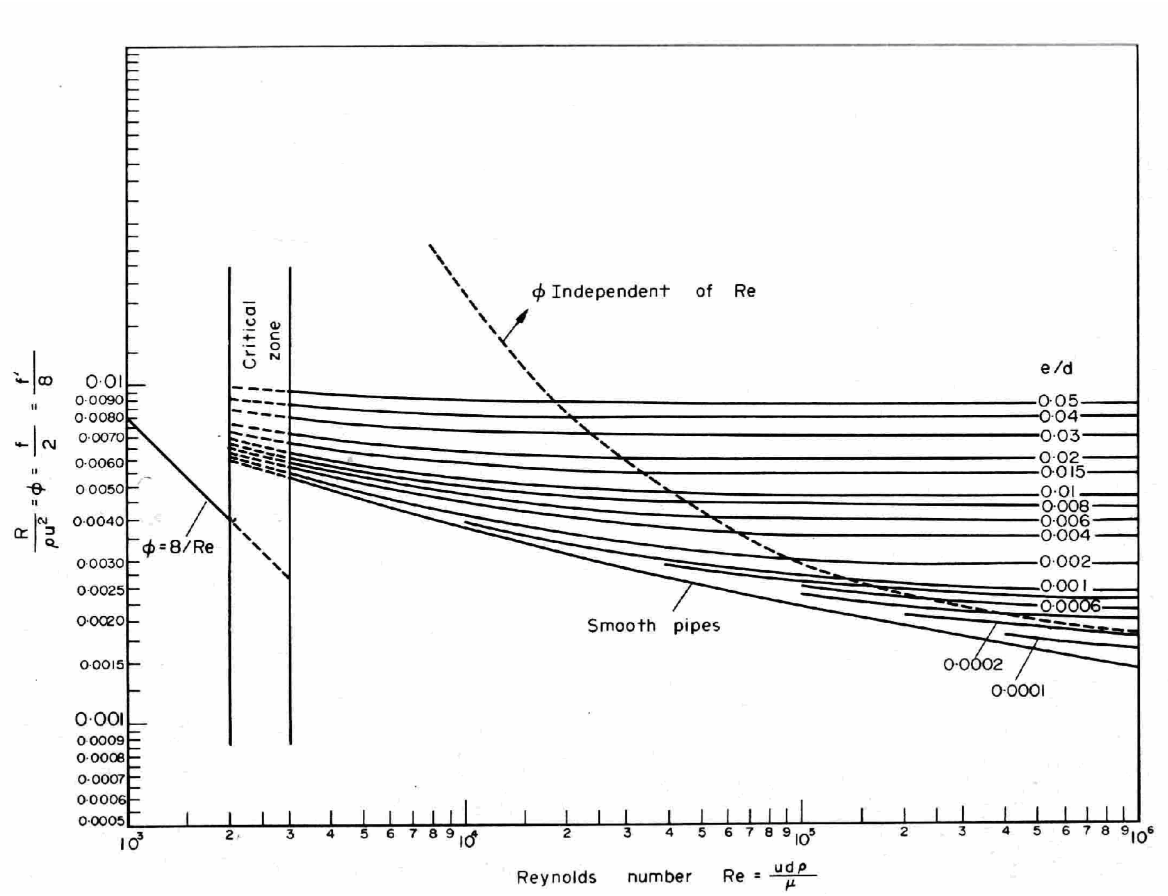


Figure (2.1) Pipe friction chart φ verses Re.

Thus if R is function of u,d, ρ,μ,e

the analysis gives

$$R/\rho u^2 \ = \text{function of } (u\ d\ \rho/\mu) \text{ and } (e/d).$$

Thus a single curve will correlated the fraction factor with the Reynolds number or group for all pipes with the same degree of roughness of e/d. This curve is of very great importance since it not only determines the pressure loss in the flow but can often be related to heat transfer or mass transfer.

Such a series of curves for varying values of e/d is given in Fig.2.1 which shows the values of $R/\rho u^2$ and the values of the moody factor $f^{\backslash}$ related to Reynolds group. Four separate regions can be distinguished:

Region 1: (Re <2000) corresponds to streamline motion and a single curve represent all the data, irrespective of the roughness of the pipe surface. The equation of the curve is: [7]

$$R/\rho u^{2\,=}\varphi = f^{\backslash}/8 = f/2=8/Re \qquad (2.1)$$

$$f = 16/Re \qquad (2.2)$$

Region 2 :(2000<Re <3000) is a transition region between streamline and turbulent flow conditions. Reproducible value of pressure drop can not be obtained in this region, but the value of $R/\rho u^2 = f/2$ is considerably higher than in the streamline region. If an unstable form of streamline flow does persist at Re greater than 2000, the friction force will correspond to that given by the curve $R/\rho u^2 = 8/Re$, extrapolated to values of Re greater than 2000. [7]

Region 3: (Re > 3000) correspond to turbulent region of the fluid and $R/\rho u^2$ is a function of both Re and e/d with rough pipe giving high values of $R/\rho u^2$. For smooth pipe there is a lower limit which $R/\rho u^2$ does not fall for any particular value of Re.

Region 4: rough pipes at high Re. In this region the friction factor becomes independent of Re and depends only on (e/d) as shown below:-[7]

$$e/d=0.05 \qquad Re>1*10^5 \qquad R/\rho u^2 =0.087 \qquad (2.3)$$

$$e/d=0.0075 \qquad Re>1*10^5 \qquad R/\rho u^2 =0.0042 \qquad (2.4)$$

$$e/d=0.001 \qquad Re>1*10^5 \qquad R/\rho u^2 =0.0024 \qquad (2.5)$$

A number of expressions have been proposed for calculating $R/\rho u^2 =\varphi$ in terms of Reynolds number and some of these are given below. [5]

Smooth pipes:

$2.5*10^3 < Re < 10^5$ $\varphi=0.0396\ Re^{-0.25}$ (2.6)

Smooth pipes:

$2.5*10^3 < Re < 10^7$ $\varphi^{-0.5}=2.5\ \ln(Re\varphi^{0.5})+0.3$ (2.7)

Rough pipe:

$\Phi\text{-}0.5=2.5\ln(0.27\ e/d)+0.885Re^{-1}\ \varphi^{-0.5}$ (2.8)

Rough pipe:

$(e/d)\ Re\ \varphi^{0.5} >> 3.2$ $\varphi^{-0.5}=3.2-2.5\ln(e/d)$ (2.9)

Equation 2.6 is due to (Blasius)[14] and the others are derived from considerations of velocity profile. In addition to the moody friction factor $f^{\backslash}=8\ R/\rho u^2$, the fanning or Darcy friction factor $f=2\ R/\rho u^2$ is often used in American texts. It is extremely important therefore to ensure that the precise meaning of the friction factor is clear when using this term in calculating head losses due to friction. [7]

The head loss due to friction is expressed by Darcy's equation as follows:-

$$h_f=8\varphi(L/2d).(u^2/g) \tag{2.10}$$

$$h_f=4\varphi(L/2d).(u^2/g) \quad ,\ \varphi=f \tag{2.11}$$

$$\text{and} \qquad h_f=4f(L/2d).(u^2/g) \tag{2.1 2}$$

and in more conventional pipeline unites, is expressed in term of pressure drop:

$$\Delta p=4f.\ (L/d).\ \rho u^2 \tag{2.13}$$

$$\text{And} \qquad f=(\Delta p.d)/\ (2L\ \rho u^2) \tag{2.14}$$

For turbulent flow and smooth pipe,

$$f=0.04/Re^{0.25} \tag{2.15}$$

Where the Reynolds number:

$$Re=\rho.u.d/\mu \tag{2.16}$$

Equation (2.16) can be written by considering (2.13) and (2.14) as follows:

$$\Delta p/L=16\rho^{0.75}.u^{1.75}.\mu^{0.25}/d^{1.25} \qquad (2.17)$$

The liquid velocity is calculated by equation (2.18)

$$U=Q/A=Q/(\pi/4)d^{2}=1.27*Q/d^{2} \qquad (2.18)$$

Therefore, the pressure drop is estimated by:

$$\Delta p/L=0.244\ Q^{1.75}.\ \mu^{0.25}.\ \rho^{0.75}/d^{4.75} \qquad (2.19)$$

The power required for pumping will be given by the product of the volumetric flow rate and the pressure difference between the pump and the discharge of the pipeline,

$$H_{p}=\Delta p.\ (Q/\eta_{P}) \qquad (2.20)$$

The required horse power is calculated by assuming constant flow rate, as follows:

$$H_{p}=[0.244\ Q^{2.75}L/\ d^{4.75}\ \eta_{P}]\ \rho^{0.75}\ \mu^{0.25} \qquad (2.21)$$

While, the volumetric flow rate is calculated by constant pumping horse power as follows:

$$Q=[d^{4.75}\ \eta_{P}\ H_{p}/0.24\ \mu^{0.25}\ \rho^{0.75}L]^{-0.03637} \qquad (2.22)$$

2.1.2 Friction Factor

Friction factor (also called flow improver) have involved from original ″gel_like″ products to suspension products. Flow improvers were initially limited to conventional applications in the pipeline industry.

The phenomena of friction and drag reduction was first observed more than 60 years ago, it was not until (1979) that friction reduction technology was developed enough to be used on a commercial scale on the

Trans_Alaska pipeline. Initially, the pipeline industry believed only in conventional the industry about the capabilities of flow improvers.

In the process of transferring a Newtonian fluid through a pipeline system, considerable energy may be expanded to over come friction encountered in moment of the liquid. When a liquid is pumped under pressure frictional pressure is apparent as a pressure drop along the pipeline.

The fluid flow through pipes is subjected to resistance due to viscosity, fluid turbulence and roughness of the pipe surface. In order to overcome these resistances, the flow has to expand its energy and consequently, the available energy decrease in the direction of flow resulting in a downward sloping energy line [15].

The basic friction factor in pipe flow can be written in term of fanning friction factor as: [16]

$$f = \frac{\Delta P \cdot D/4L}{\rho v^2/2} \qquad (2.23)$$

According to Reynolds number and properties of the system, some relationships of the friction factor declared by some authors.

For Re < 2100, Poiseuille’s law[17] is applicable.

$$f = \frac{16}{\mathrm{Re}} \qquad (2.\ 24)$$

For Reynolds numbers between 2100 and 4000 Wilson and Azad [18] derived an empirical equation for the central portion of the transition regime.

$$f = 7.1*10^{-10}*\mathrm{Re}^{2} \tag{2. 25}$$

For Reynolds numbers up to 100.000 and smooth cylindrical pipes, Blasius [19] found that the friction factor can be expressed as follow:

$$f = \frac{0.079}{Re^{0.25}} \tag{2.26}$$

Von Karman [19, 20], found an alternative to Blasius equation for the turbulent flow of Newtonian fluids in smooth cylindrical pipes which can be written as follow:

$$\frac{1}{\sqrt{f}} = 4\,log\left(Re\,f^{1/2}\right) - 0.4 \tag{2. 27}$$

Virk [21], represent the greatest possible fall in resistance in which the relation between friction factor (*f*) and ***Re*** does not depend on the nature of the additives or pipe diameter. The formula for Virk is:

$$f = 0.59\,\mathrm{Re}^{-0.58} \tag{2.28}$$

Nikuradse [18] determined asymptotic expression for fully developed turbulent flow in rough pipe as follows:

$$\frac{1}{\sqrt{f}} = 1.737\ln(3.707\frac{D}{\varepsilon}) \tag{2.29}$$

(2.2) Drag reduction

(2.2.1) Drag Reduction Phenomenon

The phenomenon of drag reduction firstly was observed by Mysels [22–24]. Mysels compared the pressure drop of gasoline and of gasoline thickened with aluminum disoaps flow through the same pipe.

The frictional drag of turbulent flow through pipes can be reduced dramatically by adding a minute amount of certain long- chain polymer molecules dissolved in water or in organic solvents. The discovery of this phenomenon of turbulent drag reduction by polymer additives is generally ascribed to Toms [1]. This observation was noticed by chance in the summer of 1946, when he was actually investigating the mechanical degradation of polymer molecules using a simple pipe flow apparatus. Toms observed "the really astounding thing that a polymer solution clearly offered less resistance to flow, under constant pressure, than the solvent itself "[25].

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

2.2.2 Additives

Drag- reducing additives are available, such as flexible long- chain macromolecules, colloidal surfactants and suspension of fine, insoluble fiber or particles [26]. Among these, macromolecules, which posses a linear flexible structure and very high molecular weight, have been widely investigated as drag reducer. [27]

Suspension of insoluble particles such as fine grains or fiber, and polymer solutions mixed with soaps or fibers considered to be also as drag-reducer agents [21]. It has also been found that modified surface such as complaint surfaces, heated surfaces, and surfaces covered with riblets (small triangular ribs) aligned with the flow, can provide drag reduction of varying degree.[13]

In general, the research indicates that any soluble polymer whish is of a high molecular weight (greater than $1*10^{5)}$, will reduce drag in turbulent flow. A partial listing of polymeric drag reducing fluid is found in table (2.1) [21]

Table (2.1) Drag reducing polymer

Water soluble (and brine soluble polymers)	Hydrocarbon soluble
Polyacrylamide(PAM) Polyethyleneoxide(PEO) Guar gum (GGM) Xanthan gum(XG) SoduimCarboxymethylcellulose(CMC) Hydroxyethylecellulose(HEC)	Polyisobutylene(PIB) Polyethylene oxide(PEO) Polymethylmethacrylate(PMMA) Polydimethylsiloxane(PDMS) Polycisisoprene(PCIP) Polystyrene(PS)

One of the most widely used commercial drag reducing biopolymer is guar gum (GG) is a plant polysaccharide with a semi rigid backbone. It has been used for a number of years in oil field application, and in the petroleum industry first discovered its friction reducing effect [28]. The major limitation of guar gum in drag reduction application is its susceptibility to biodegradation. It has been shown that resistance to shear and biodegradation can be increased by grafting acrylamide to guar gum molecules. [29]

Modified cellulose such as Sodium Carboxymethylcellulose (CMC) and Hydroxyethylecellulose (HEC) has been employed commercially and in laboratory studies. CMC was the first water-soluble polymer whose drag reducing was reported in the literature. The most widely used organic polymers are the semi-synthetic gums produced by chemical modification of cellulose. Cellulose comprises the greater part of the cell walls of plants (e.g., cotton fiber is over 90 % cellulose).

Sodium Carboxymethylcellulose is a water-soluble, colorless, odorless and nontoxic powder. Sodium Carboxymethylcellulose is an anionic polymer. Three grades of CMC are available; low viscosity, medium viscosity, and high viscosity.The viscosity of CMC solutions decreases and increases reversibly with raising and lowering of temperature, but no permanent change occurs unless the solutions are kept at high temperature for a considerable length of time. CMC suspensions are shear thinning; they have high apparent viscosity at very low shear rates. [30]

The water-dispersible cellulose polymers are made by chemical modification of water insoluble cellulose, which furnishes the polymeric backbone. Although the basic unmodified cellulose chain is composed of repeating anhydroglucose rings, each of which has three hydroxyl groups capable of substitution fibrous cellulose is a complex structural mixture of crystallites and amorphous material. Consequently, in the preparation of cellulose derivatives, a single cellulose chain will show differences in availability to reaction depending upon the structure, and the substitution will not be uniform. [30]

The other biopolymer which has been widely used as a commercial drag reducer is Xanthan gum (XG).XG is an intracellular polysaccharide produced by the bacteria xanthomnas. XG shows variable Rheological behavior with change in the solvent ionic strength, flow rate, and polymer concentration. Kenis has demonstrated greater shear stability for XG than for a number of other drag reducing molecules [31]. The shear stability, and resistance to shear degradation decreased as follows: PAM>XG>PEO>GG

Composition of XG Polymer 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 $5*10^6$. [30]

Surfactants (Surface-active agents) are chemical compounds known as surfactants, which are, constituted of hydrocarbon portion (tail) and polar (or ionic) portion (head), see Fig. (2.2)[32]. The hydrocarbon portion, which can be linear or branched, interacts very weakly with water molecules in aqueous environment. This chain is usually called hydrophobic group. The polar (or ionic) portion of the molecule, usually called as head-group, interacts strongly with water via dipole-dipole or ion-dipole interactions. Consequently, the head group is said to be hydrophilic group. [33]

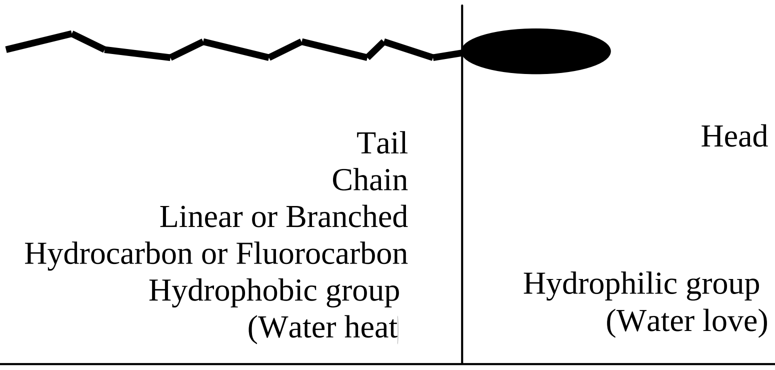


Figure: (2.2). The Basic Chemical Nature of Surface-Active Molecules [32]

Solutions of surfactants with high enough concentrations from aggregates are called micelles. These were observed to cause drag reduction in turbulent flows of liquids, Mysels[34]. Studies of this phenomena have been summarized by Imae et al [35], Ohlendrof et al [36], Ceyr & Bewerdroff[37]. One of the most interested researches in this field are Zakin&Lui[38], and (Zakin&Myska)[39,40].

The mechanism of drag- reduction by surfactant additives is still not well understood, but is generally accepted that drag reduction is associated with network structures called micelles, in the surfactant solution. These network structure show elasticity and prevent the generation of turbulence and thus reduce frictional drag.

Zakin [38] investigated the effects of surfactant structure, temperature, surfactant concentration and mechanical degradation on drag reduction for several polyoxyethylene alcohol nonionic surfactants in aqueous solution. Through studying the effect of surfactant concentration, as illustrated in figure (2.3), it is known that, at low Reynolds number, the 1.0 percent Alfonic 1214 solution with 0.4 NaSO$_4$ at 30^{0}C has high relative viscosity. As a result, the laminar data for this solution lie above those of the 0.5 percent solution. As Reynolds number increases, the friction factor for the two concentrations approach each other. At about 8,000 Reynolds number, the 0.5 percent solution is subjected to shear forces which are large enough to break up the agglomerates. Rapid loss of drag reduction is seen at Reynolds number above 8,000. The percent solution shows no break- up to a Reynolds number of about 10^4.

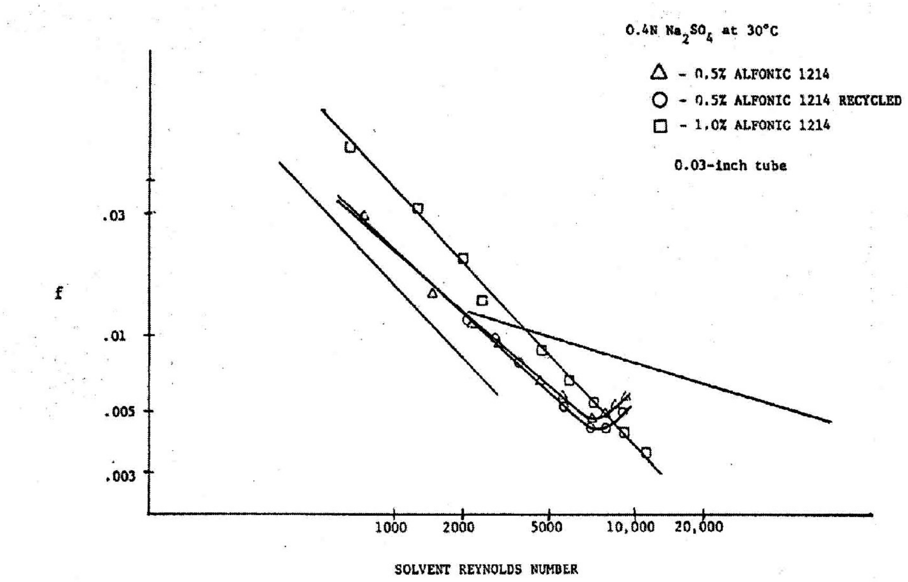


Figure (2.3) Effect of concentration on drag reduction for Alfonic 1214.

Drag reduction by surfactant additives has been considered the most effective way to lower the pumping energy requirements [40, 41, 42] in closed-loop direct heating and cooling systems.

Among the surfactants used for drag reduction, cationic surfactants such as cethyltrimethylammomium chloride (CTAC), $CH_3(CH_2)_{15}N(CH_3)_3Cl$, and stearyltri methylammomium chloride (STAC), $CH_3(CH_2)_{17}N(CH_3)_3Cl$, and sodium salicylate (NaSl) have been mot widely used as the drag- reducing additives.

Under the suitable conditions of surfactant/counterion chemical structure, ratio, concentrations and temperature, they form rod-like micelles. The resulting microstructure imparts viscoelasticity to the solution. The microstructure is mechanically degraded when passing through a high shear pump such as a centrifugal pump. [40]

The advantages of this type of additives are that, the surfactant drag reducing additives require higher concentration (i.e. 200 ppm), if it is compared with high molecular weight polymeric additives (about 50ppm) this will lead to higher economic cost.

2.2.3 Factors Affecting

The effect of chemical additives concentration on drag reduction have been studied by Kim [43] at a constant rotational speed, and found that this effect related to two competitive mechanisms. Initially, drag reduction increases as the concentration increases in the number of available drag reducers. However, as the additives concentration increases further, the solution viscosity drastically increases, leading to a decrease in the turbulent strength, i.e., reduction of Reynolds number and an increase in the frictional drag. Therefore, one anticipates that there exists a critical concentration at which the drag reduction is maximized. The same anticipation was found by Virk[44], who demonstrated that the drag reduction increases initially with increasing concentration but tends to a constant, maximum value of drag reduction at high concentration. To illustrate this point, figure (2.4) shows %Dr of PEO as a function of polymer concentration at 2040rpm.

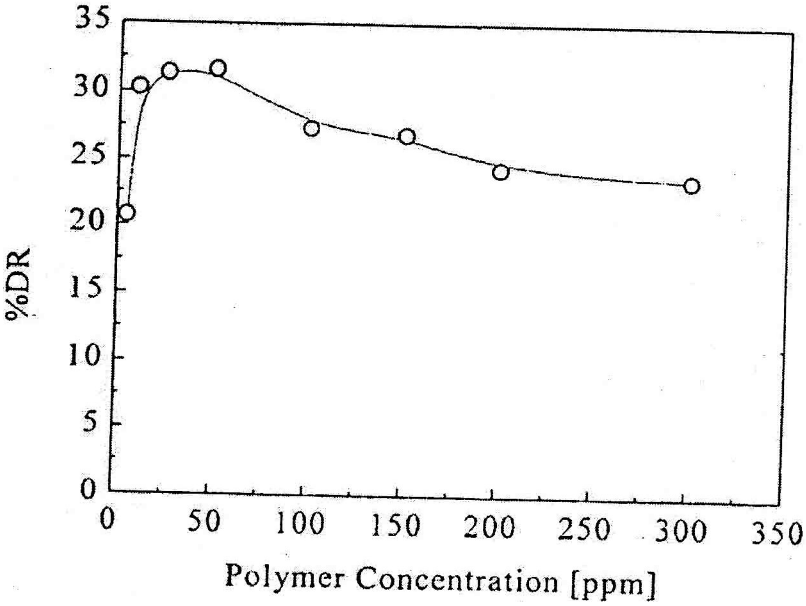


Figure (2.4): %Dr of PEO345 vs. polymer concentration at 2040rpm and 25^0C

In general, drag reduction is increased, as the fluid flow rate increased. Because increasing the fluid velocity means increasing the degree of turbulence inside the pipe, this will provide a better media to the drag reducer to be more effective but it is not a continuously increasing. This is postulated by the other working in this field as shown in figures (2.5). The causes may be, at high flow rate degradation may occur in drag reducer. [45], at high flow rate through high rough by pipe decrease in drag reduction are expected [45] and according to elastic theory, drag reducer doesn't stretch fully at high flow rate. [30]

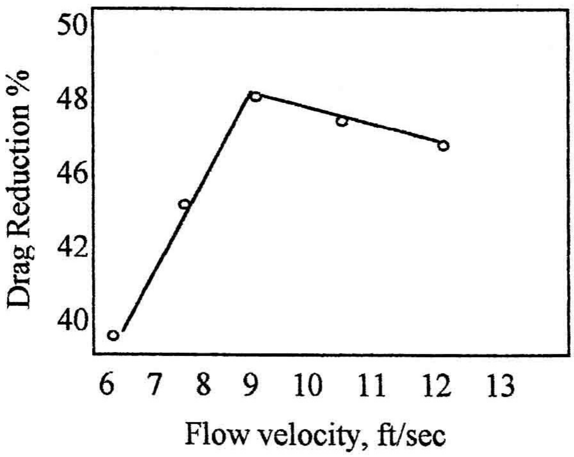


Figure (2.5) flow velocity .Vs. drag reduction [62]

Drag reduction by surfactant increases when temperature is increased because the length of rod-like micelles (collection of micelles) becomes longer. Above some critical temperature, the length of the rod-like micelles will decrease and drag reduction is decreased [46]. The effect of temperature on drag reduction is also shown in figure (2.6) when the surfactant has long chain alkyl groups it will be more effective in drag reduction at high temperature as compared with short chain surfactant, on the other hand short chain surfactant will be more effective at low temperature as compared with long chain surfactant. [47]

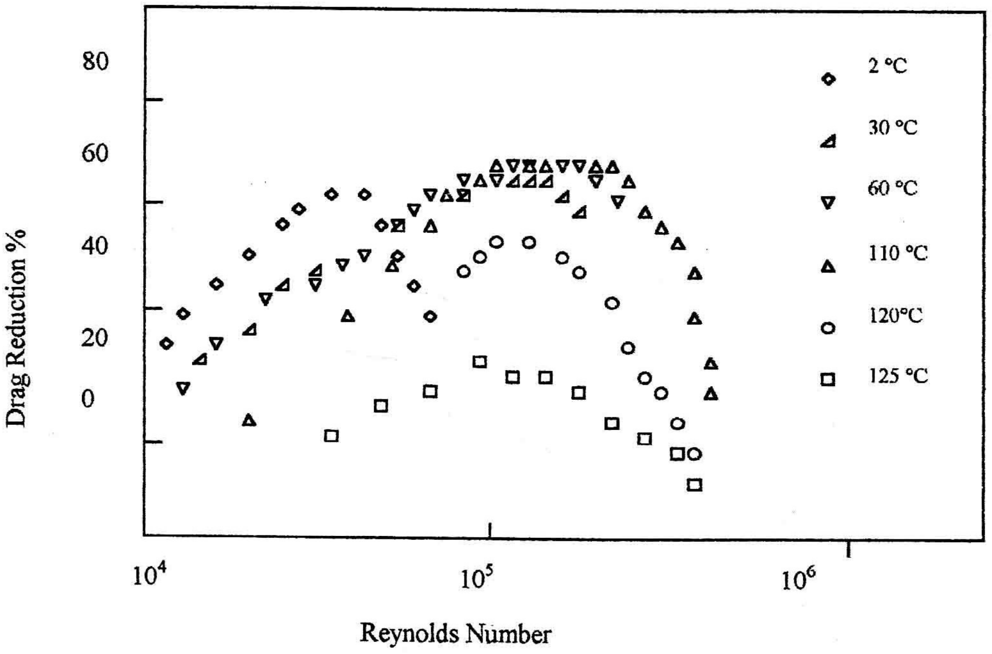


Figure (2.6) Drag Reduction of Cationic Surfactant with Different Temperature.

Polymers more efficient drag reducer in a good solvent then in a poor solvent. Addition of monovalent salt to aqueous (PAA) solution decreases DRE. Addition of ions of higher valence such as (Fe^{2+}, Mg^{2+},Ca^{2+}, and Al^{2+}) leads to more drastic inhibition of drag reduction due to additive flocculation. Solvent nature also effects polymer shear stability, with higher levels of shear degradation reported in poor than in good solvents [11].

2.2.4 Applications

The drag reduction effect is extremely interesting from a practical point of view. Liquid are mostly transported through pipes and a drag reduction, by adding a small amount of chemical additives, can offer large economic advantages and a larger effectiveness of this transportation. The first account of field trails was published by Bord&Rossi in 1971[48]. They were concerned with the use of drag reducing additives in the pipeline transportation of waxy crude, and they found that there is no unexpected side-effect of these additives that would militate against their commercial use.

The first major application of drag reducer in oil pipelines has been in the TAPS, another reported major use of such chemicals has been in Iraq in mid 1982[49].

The industrial application of drag reduction can be found in many areas such as transport of crude oil' sewage systems to prevent overflowing after heavy rain [26], closed -circuit pumping installations such as central-heating systems , fire- fighting to increase the range of water jets, and water supply and irrigation systems [50].

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

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

Another commercial application of surfactants was the ability to lower the surface tension of a liquid by aggregating at the interface between a liquid and gas. They also capable of lowering interfacial tension by aggregating at the interfaces between two immiscible liquids. Also, surfactants are widely used in many aspects of petroleum industry, such as: demulsifiers, acid retarders, foaming agents, cleaning agents, enhanced recovery agents, corrosion inhibitors, clay stabilizers and surface tension reducers [51-52].

2.3 Drag Reduction Mechanisms

Drag reduction was discovered almost half a century ago, the physical mechanisms responsible for the phenomena of drag reduction are not completely understood and remain a subject of debate. Nevertheless, it is generally accepted that both the viscoelastic property including elastic behavior and energy dissipation phenomena of chemical additives solutions and the interaction between polymer molecules and turbulence generate the drag reduction phenomena. The role of stress anisotropy due to polymer extension verses elasticity is also still an ongoing subject of controversy in the drag reduction mechanism [53].

The mechanisms of drag reduction are not known exactly, however, the following two types of mechanisms are proposed;

2.3.1 Wall layer modification hypothesis

Oldryod [54] offered a wall effect hypothesis for Tom's data. He proposed the existence of an abnormally mobile laminar sub layer whose thickness was comparable to molecular dimensions and which caused apparent slip at the wall.

Zakin and Hershy [55, 56] proposed that drag reduction occurs when time scale of the turbulent fluctuations is of the same order of magnitude as the relaxation time of the solution.

Virk et al. [44, 57, 58] described the maximum drag reduction in turbulent pipe flow of dilute polymer solution is ultimately limited by a unique asymptote. During high drag reduction, the mean velocity profile has three zones: viscous sub layer, interactive zone and turbulent core.

Elperin et al. [59] suggested that the existing of adsorbed layer of polymer molecules at the wall pipe during flow will act to reduce the viscosity, create a slip, damp turbulence and prevent any initiation of vortices at the wall.

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

Smith et al. [60] proposed a hypothesis based on the assumption that wall effect is significantly altered. The researchers studied the flow on fluid in a horizontal tube by using flow visualization technique. The formation of more mobile wall layer by the presence of additive either by physical adsorption to provide a more resilient wall layer or by the orientation of the molecules close to the wall, will explained on the basis of a slip mechanism.

Gustavsson [61] assumed a new sub layer portion of the velocity profile of the same form as that proposed by Virk's [21] elastic sub layer model. It is found that the thickness of this layer grows linearly with wall shear stress from the onset point.

Savins et al. [62] showed that the flow of energy from the mean flow to the turbulent motion is a maximum inside the sub layer. Not only does a high rate of dissipation occur here but a high rate of turbulence production exists here as well.

(2.3.2) Turbulent suppression hypothesis

Charachafchy [63] explained that when the drag reducer is mixed with crude oil or refined petroleum products in pipelines, it changes the flow characteristic and reduced the turbulence in the pipeline. A number of turbulent bursts originating at the pipe wall and the strength of the turbulent eddies are reduced by the addition of drag reducers. He believed that the drag reducer absorb part of the turbulent energy and return it to the flowing stream. By lowering the energy loss (or drag), the drag reducer allows the pipeline fluid to move faster at any working pressure.

Rodriguez et al. [64] explained that in the viscoelastic fluid, the stress is dependent on both the amount of strain (elastic response) and the rate of strain (viscous response). If the time scale of the experiment is of the order or shorter than its relaxation time (measure of the relative amounts of viscous and elastic response), any fluid will exhibit elastic as well as viscous properties.

Lumley [65] stated that the stretching of randomly coiled polymers increase the effective viscosity, by consequence, small eddies are damped which leads to a thickening of the viscous sub layer and thus drag reduction.

Lumley [66, 67] suggested that the effective viscosity in the buffer zone layer with strong deformation (polymer expand) is the key of drag reduction.

Many of researchers [68, 69-71] explained that the friction reduction occurs when the relaxation time of the viscoelastic drag reducer molecules in solution is equal or larger than a certain "characteristic flow time". The characteristic flow time has been taken as the reciprocal of the shear rate at the wall and the relaxation time.

DeGennes [72] proposed a new theory which argues that drag reduction is caused by elastic properties rather than viscous. He came to this hypothesis by observing drag reduction in experiments where polymers were active at the centre of the pipe, where viscous forces do not play a role. DeGennes arguments that the elastic properties of polymers cause shear waves to prevent the production of turbulent velocity fluctuations at the small scales.

2.4 Surfactants

2.4.1 Characterizations

The term surfactant is a contraction of the phrase surface-active agent, i.e. a substance whose effect is at an interface between two phases. Surfactant is an organic compound whose molecular structure is made of two dissimilar groups having opposing solubility tendencies (hydrophilic vs. hydrophobic) [73]. Surfactants have the ability to lower the surface tension of a liquid by aggregating at the interface between a liquid and gas. They also capable of lowering interfacial tension by aggregating at the interfaces between two immiscible liquids [74, 75].

Surfactants are organic molecules which are composed of water soluble group (Hydrophilic group) and an oil soluble group (Hydrophilic group) as shown in figure (2.7). The surfactant molecules are thus partially soluble in both water and oil. Surfactants can be classified into oil soluble and water soluble according to their stronger affinity to oil and water respectively [74, 75] .

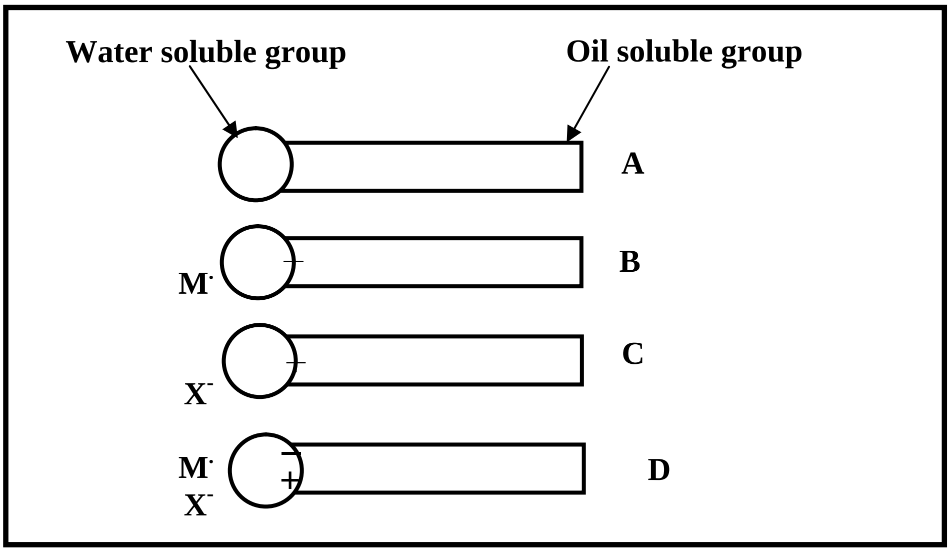


Figure (2.7) models of the various types of surfactants include (A). Nonionic, (B). Anionic, (C). Cationic and (D). Amphoteric[74, 75]

Surfactants tend to aggregate at the air/water interface when it is dissolved in water. This adsorption results in a greater concentration at the interface than in the bulk solution [76]. Surfactants molecules form micelles above a critical concentration as shown in figure (2.8). This characteristic concentration is called the critical micelle concentrating (CMC). Micelles are spherical aggregates of surfactant molecules containing 20 to 100 molecules per micelle. Below CMC, many properties of the system are concentration dependent. Some of these properties are surface tension, interfacial tension, foam stability and emulsion tendencies [75]. By using nonionic and ionic surfactant, one can produce mixed micelles which are often larger in size and in the number of molecules per micelle.

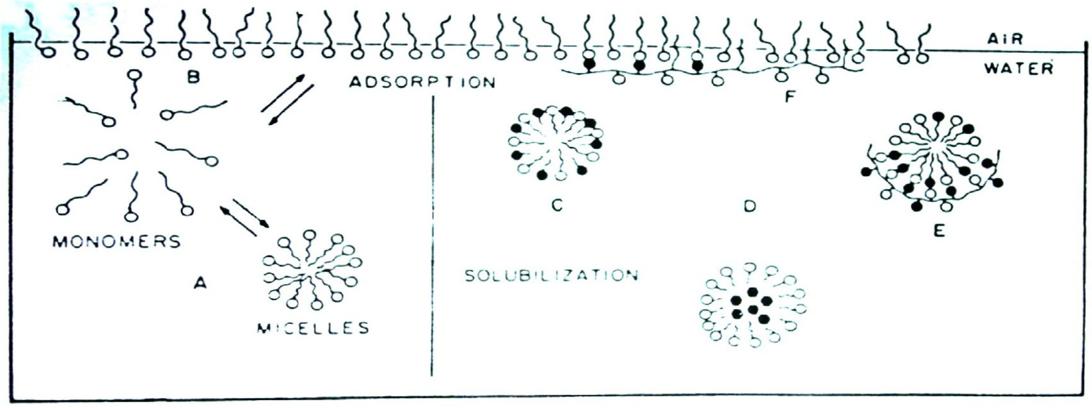


Figure (2.8) A schematic presentation for micelle formation (A), adsorption (B), mixed micelle formation (C),Solubilization of oil in micelles (D), polymer-micelle interaction (E), and surfactant – polymer mixed film at interfaces (F), surfactant solutions(75).

The surfactants have the superiority as drag reducer because critical processing problems, which occur when using polymer, could be eliminated.

Hydrophile, from the Greek (*hydros*) "water" and (philia) "friendship," refers to a physical property of a molecule that can transiently bond with water

(H_2O) through hydrogen bonding. This is thermodynamically favorable, and makes these molecules soluble not only in water, but also in other polar solvents. A hydrophilic molecule or portion of a molecule is one that is typically charge-polarized and capable of hydrogen bonding, enabling it to dissolve more readily in water than in oil or other hydrophobic solvents [77]. The most common hydrophilic group surfactants are given in table (2.2). [78]

Table (2.2) the most commonly hydrophilic groups in commercial surfactant [78].

Group name	**Chemical formula**
Sulfonate	$O_3{}^-M^+$
Sulfate	$R\text{-}SO_4{}^-M^+$
Carboxylate	$R\text{-}COO^-M^+$
Phosphate	$R\text{-}PO_4{}^-M^+$
Ammonium	$R_xH_y N^+X^-$ (x=1-3,y=1-3)
Quaternary	$R_4N^+X^-$
Betaines	$RN^+(CH_3)_2CH_2COO^-$
Sulfobetaines	$RN^+(CH_3)_2CH_2CH_2SO_3{}^-$
Polyoxyethylene(POE)	$R\text{-}OCH_2CH_2(OCH_2CH_2)_nOH$
Sucrose	$R\text{-}O\text{-}C_6H_7O(OH)_3\text{-}O\text{-}C_6H_7O(OH)_4$

Where :

R=Hydrophobic group

M=inorganic or organic cation

X=An anion (halide,acetate….etc.)

Hydrophobe (from the Greek *(hydros)* "water" and *(phobos)* "fear") in chemistry refers to the physical property of a molecule that is repelled by water. Hydrophobic molecules tend to be nonpolar and thus prefer other neutral molecules and nonpolar solvents. Hydrophobic molecules in water often cluster together. Water on hydrophobic surfaces will exhibit a high contact angle.

Hydrophilic and hydrophobic molecules are also known as polar molecules and nonpolar molecules, respectively .Examples of hydrophobic molecules include the alkanes, oils, fats and greasy substances in general. Hydrophobic materials are used for oil removal from water, the management of oil spills, and chemical separation processes to remove non-polar from polar compounds. [77]

2.4.2 Micellization

Where surfactants are dissolved in water at low concentrations, physical properties of the solutions such as surface tension, conductance, vapor pressure, turbidity…etc. indicates that little or no aggregation of surfactant occurs. However, as the concentration is increased, the behavior of such properties and that of many others changes dramatically over a relatively narrow range of concentration. Some examples are shown in Fig. (2.9).

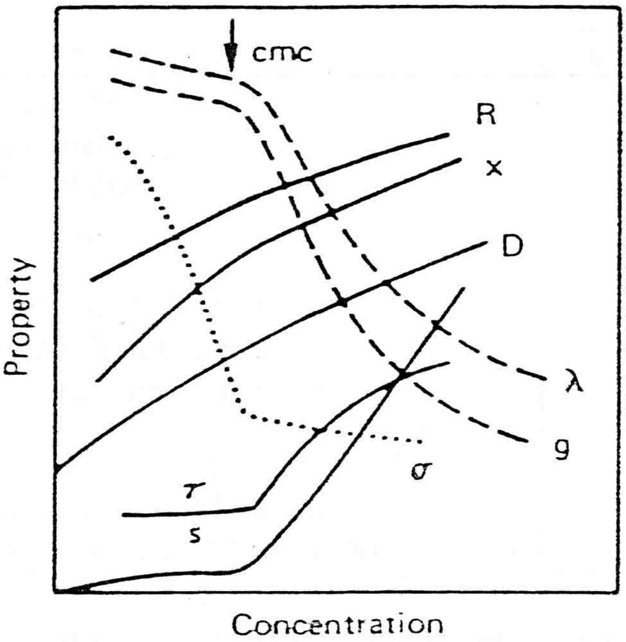


Figure (2.9): Typical curves showing how physical properties of Surfactant solutions depend on concentrations[79].

R: Relative index; D: Density; X: Specific conductance.

τ: Turbidity ;g: osmotic coefficient.

λ: Equivalent conductance, (against √c).

δ: Surface tension (against log c).

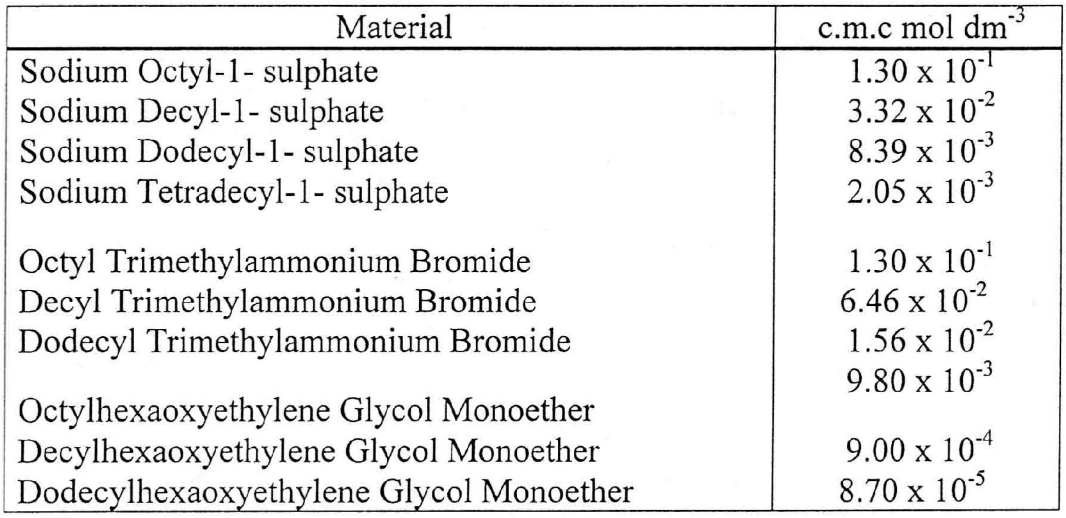
S: Solubility of water- insoluble dye.

Such changes are attributed the sudden onset of molecular aggregation (micelliation). The range of concentrations within which this occurs may be termed as the critical micelle region. It is common practice to critical micelle concentrations.

Many (C_{12}) ionic surfactants have a critical micelle concentrating (CMC) value of approximately (10^{-2}) mol/dm^3, and the addition of two –CH_2- groups lowers the value to approximately (10^{-3}) mol/dm^3.

The critical micelle concentrating (CMC) values of non- ionic surfactants usually lower than those of corresponding chain length ionic materials [79]. Each surfactant at a given temperature and electrolyte concentration has a characteristic (CMC) value. Some (CMC) values for different materials are listed in Table (2.3).

Table (2.3): Critical Micelle Concentration (CMC) **for Some Surfactants in water at 25C^0.**



Material	c.m.c mol dm^{-3}
Sodium Octyl-1- sulphate	1.30×10^{-1}
Sodium Decyl-1- sulphate	3.32×10^{-2}
Sodium Dodecyl-1- sulphate	8.39×10^{-3}
Sodium Tetradecyl-1- sulphate	2.05×10^{-3}
Octyl Trimethylammonium Bromide	1.30×10^{-1}
Decyl Trimethylammonium Bromide	6.46×10^{-2}
Dodecyl Trimethylammonium Bromide	1.56×10^{-2}
Octylhexaoxyethylene Glycol Monoether	9.80×10^{-3}
Decylhexaoxyethylene Glycol Monoether	9.00×10^{-4}
Dodecylhexaoxyethylene Glycol Monoether	8.70×10^{-5}

When the variation of (CMC) with temperature is plotted on the same curve, it becomes clear that at a particular temperature the concentration of the dissolved materials becomes equal to the (CMC). The temperature at which this intersection occurs is known as a Krafft temperature or (krafft point). That is the temperature at which the solubility becomes equal to (CMC). As illustrated in Fig. (2.10).

In order to explain the drop in molar conductance which has also observed two types of micelles have been suggested [79], spherical ionic micelles and lamellar neutral micelles, as schematically shown in Fig. (2.11).

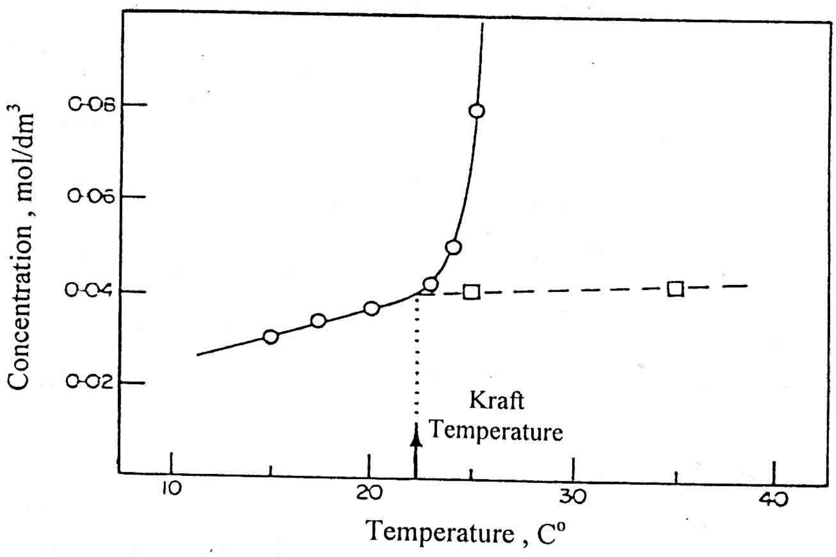


Figure (2.10): Solubility vs. Temperature for Sodium Decylsulfonate in Water, Showing Location of Krafft Point[79].

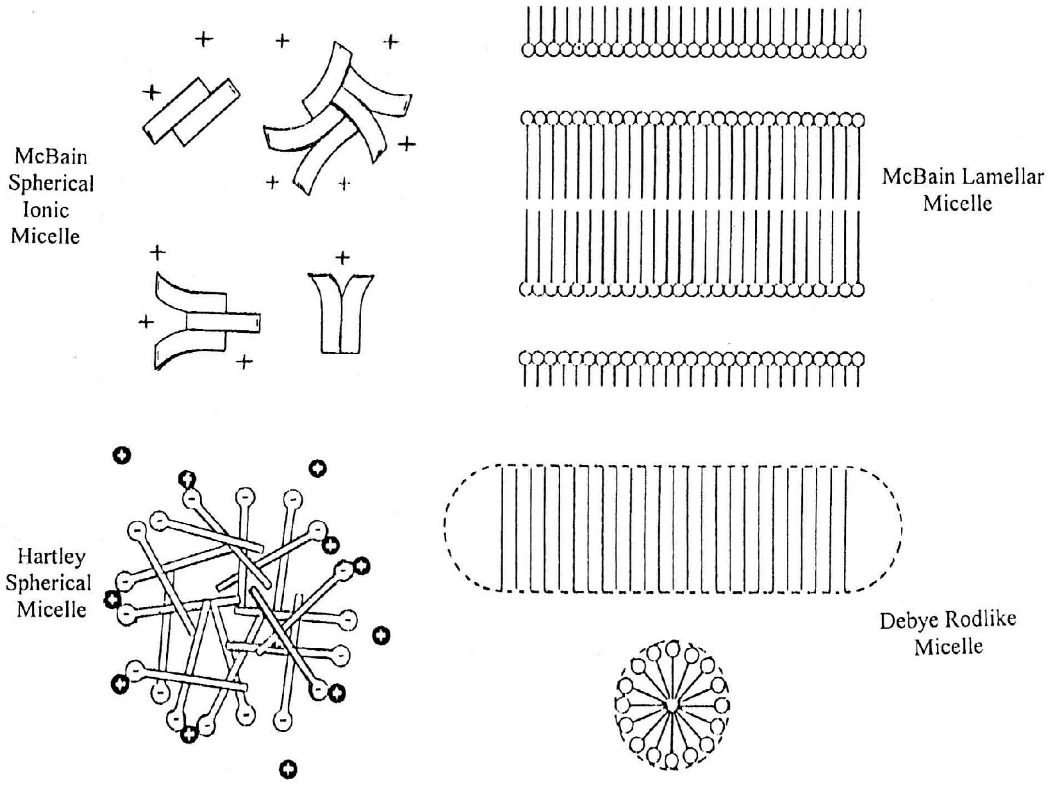


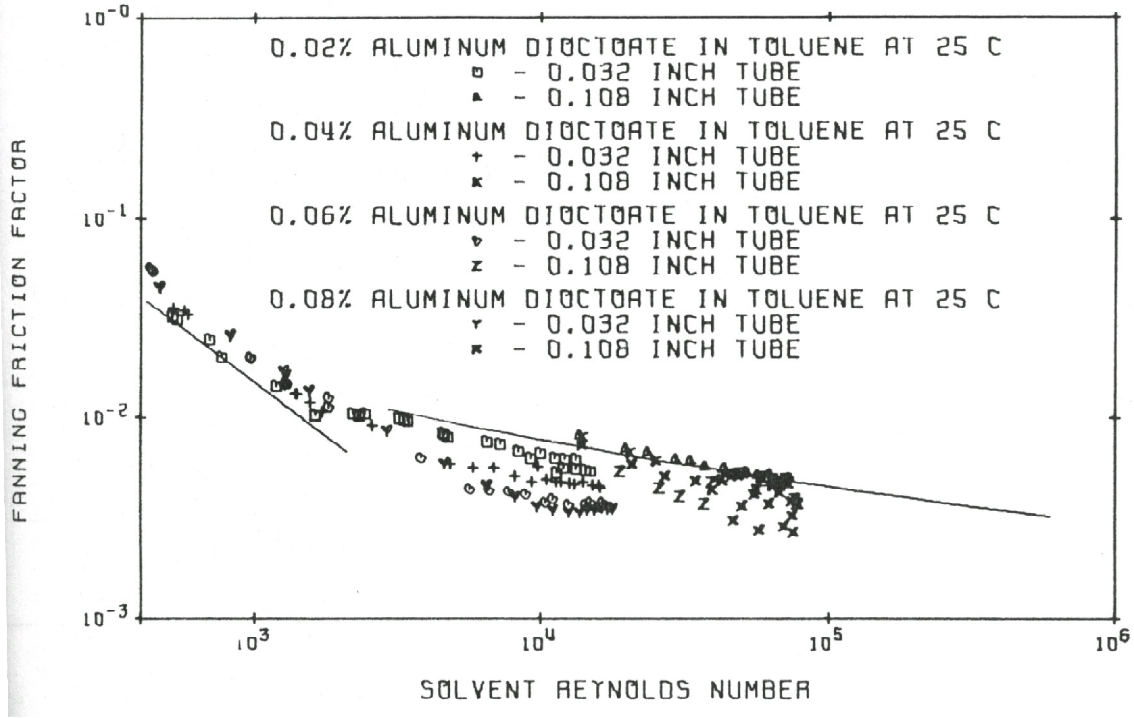
Figure (2.11): Various Models of Micelle Structure, McBain Spherical Ionic Micelles, McBain Lamellar Micelle, Hartley Spherical Micelle, and Dobye Cylindrica[79].

2.5 Drag –Reducer Agents

White [51] (1967)concluded that the drag reduction increases with increasing pipe diameter, and it terminates at a limiting value of the flow of Reynolds number because of the degradation that occurred as a result of oxidation after a period of several days. In the experimental work, a dilute solution of 508 ppm of cetyl tri methyl ammonium bromide (CTAB) used in water in order to increase its flow rate.

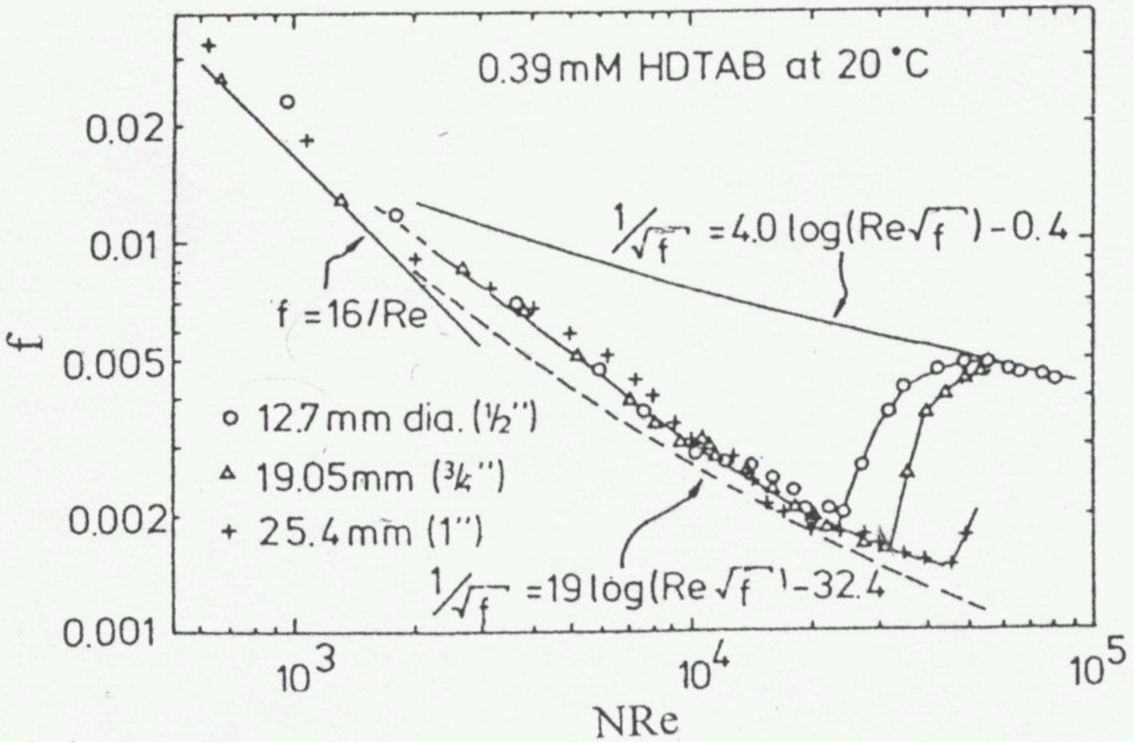
Michael et al. [52] (1971) studied the drag reduction in pipe flow using aluminum disoap in toluene. The method of preparation of disoap solutions affects strongly the laminar and turbulent flow behavior. The structure will be a meat stable in solution if the concentration below the minimum, otherwise the solution structure is stable, although the solution structure may temporarily be broken down by high shear. Finally, the aluminum dioctoate appears to be an effectively drag–reducing agent and the friction losses will be lower with increasing aluminum dioctoate concentration as shown in Figure, (2.12).

Zakin [38] (1983) used large number of non–ionic surfactants to study the effect of surfactant structure, concentration, temperature and mechanical degradation on drag reduction. This was carried by using number of linear primary alcohol lethoxylate–surfactant in aqueous solution. The Brij 96 ($C_{18}H_{35}$–$(OCH_2$–$CH_2)_{10}$–OH) surfactant was more active than others. The used surfactant had the ability to self repair when it reaches a region of lower shear forces. Finally, showed that drag reduction increases with decreasing pipe diameter.



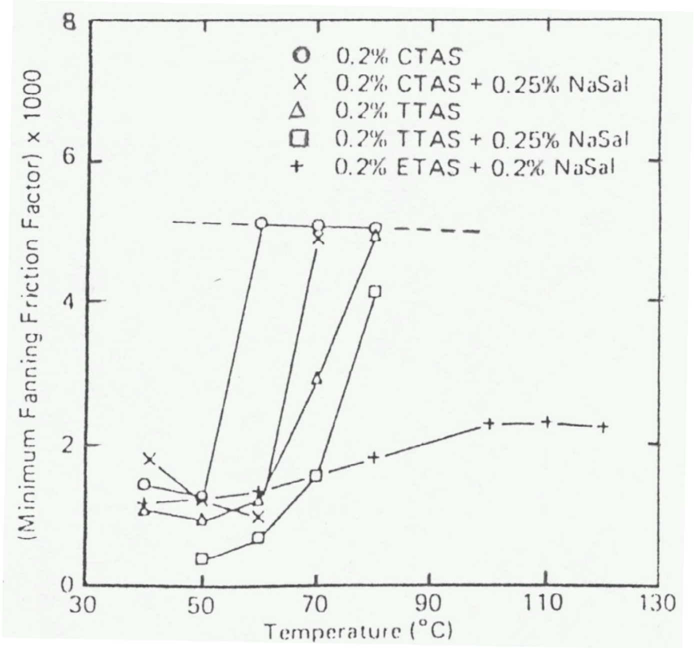
Figure, 2.12Concentration and diameter effect for aluminum dioctoate in toluene

Elson et al. [80] (1983) used alkyl tri methyl ammonium halides with 1–naphthol as a drag reducing agent in aqueous solution to study the effect of solution concentration soap–naphthol ratio, soap molecular weight, and temperature of solution on drag reduction. The results showed that friction losses increases with increasing pipe diameter as show in Figure, (2.13), also concluded that maximum drag reduction required low soap concentration.



Figure, 2.13 Effect of pipe diameter on friction factors of equimolar HDTAB, 1 – Naphthol solution

Rose et al. [41] (1984) presented experimental work to measure the heat transfer coefficients and drag reduction activity of aqueous solution of typical cationic surfactant (cethyl tri methyl–ammonium chloride, CTAC, tallow tri methyl ammonium salicylate, TTAS and Erucyl tri methyl ammonium salicylate, ETAS) as a function of temperature. The results indicated that the surfactant have a critical temperature and Reynolds number above which the heat transfer coefficients and pipe flow friction return to that of the water without additives as shown in Figure, (2.14). The surfactants have been shown to simultaneously lower the pipe flow friction and individual heat transfer coefficient from that of pure water.



Figure, 2.14 Effect of surfactant composition on drag reduction in aqueous solution

Mansour et al. [81] (1988) used a soapy industrial cleaner as a drag reducing agents in turbulent flow of crude oil in different pipes sizes to study the effect of additives on reducing skin friction. A concentration of only 2 ppm of the chemical additive injected into the crude oil line causes an appreciable amount of drag reduction in different pipes. The researchers concluded that drag reduction increases with increasing pipe diameter.

Zakin et al. [82] (1993) used cationic Habon G surfactant $(C_{16}H_{33}N(CH_3)_2C_2H_4OH)^+$ which consisted of 53.3% active surfactant, 10.2% iso propanol and 36.3% water flowing through section test of 4 cm. inside diameter pipe. The researchers concluded that surfactant solutions in water can reduced turbulent friction losses more than predicted by the Virk maximum drag reduction asymptote (MDRA). Elastic sub layer which means velocity profile in highly drag reducing surfactant solutions is steeper than that profile proposed by Virk as the (MDRA) for polymer solutions. Finally, Zakin et al. concluded that turbulence intensities for drag reducing surfactant systems are reduced from 20 to 35% of those for water at all locations in the tube.

Zakin and Hetsron [83] (1997) investigated experimentally the effect of surfactant drag–reducing additive (530 ppm Habon G solution) on the structure of wall turbulence, in water flowing through pipe. Real time infrared thermography was used for flow visualization and measurements of span wise spacing between the thermal streaks. Drag reduction of 82%-85% was achieved in a tube flow, well below the predictions of the Virk maximum drag reduction asymptote proposed for high polymers. The results of span wise streak spacing indicate that wall shear velocity may be an appropriate parameter for describing non dimensional streak spacing behavior in drag reducing flows.

Line.et.al [46] (2000) investigated one –to-one molar ratio sodium salicylate (5mM)/ Arqui 5-50 (5 mM) solution, in comparison to sodium salicylate (12.5 mM)/ Arqui 5-50 (5 mM) or 2.5: 1 solution. Results showed a dramatic influence of the counter ion to the surfactant concentration ratio on the Viscoelasticity of the surfactant drag reducing systems. The 1:1 solution has normal surfactant drag reducer characteristics such as viscoelastic properties and thread- like micellar networks and branches.

Beris [84] (2000) developed of a theoretical quantitative understanding of the dynamic of high Reynolds number free surface flows under large free surface deformations in the presence of on or multiple surfactants on turbulence, waves, slick formation, and mass transfer through the free surface.

Lin et.al [47] (2001) compared the effect of concentration of the counter ion and its ratio to surfactant concentration on drag reduction, Rheological behavior, and microstructures. They found Arquad 16-50 (commercial CTAC, cetyltrimethylammonium chloride) (5mM) with the counter-ion 3,4-dichlorobenzcate (5 and 10 mM), 3,4-dimethylbenzcate (5 and 10 mM) solutions are good drag reducers at different temperature ranges.

Myska and et.al [85] (2001) studied the properties of many cationic and zwitter ionic surfactants. They hydrodynamic radius of the micelles, the shear and a extensional viscosity of the solutions at concentrations appropriate for drag reduction were investigated. They concluded that zwitter ionic surfactant and a mixture of cationic CTAC with Nasal are excellent drag reducers with the ability to decrease friction losses by more than 90%.

Wilkens et al. [86] (2003) studied the flow pattern suppression in gas–liquid PVC pipe flow of 2 in. in diameter by means of surfactants (SDS and LAS) additive. Both hard water (10 gpg municipal supply) and soft water (zero gpg de–ionized) were used in there experiments. The addition of the surfactant to gas–liquid flow significantly reduces the occurrence of slug flow. The slug flow regime is largely replaced by a new stratified flow pattern at high liquid flow rates. These stratified have a layer of bubbles that appear to dampen wave growth and stabilize the interface.

Katie and Zakin [87] (2005) studied number of Zwitterionic and cationic surfactants to determine the rheological properties of surfactant solutions and compare with their drag reducing properties. The rheological properties include shear viscosity, shear–induced structure and shear stress.

Al-Qamaje[89] (2006) ,studied the effect of molecular weight performance of drag reduction by using polyisobutylene in piping of gas oil. Three molecular weight $2.9*10^6$, $4.1*10^6$, and $5.9*10^6$ g/mole were tested the highest molecular weight polyisobutylene treated gas oil show the greatest degree of flow capacity increase, approaching the maximum drag- reduction asymptote of Virk.

Chapter Three

3.1 Materials

Sodium Dodecy -Benzene Sulfonate (SDBS) and Sodium lauryl ether sulfate (SLES) were used as friction reduction agent, which were supplied by the general Company of Vegetable Oil Industries, Baghdad. SDBS of General formula ($C_{12}H_{25}C_6H_4SO_3^{-}Na$) is a brawny paste material with molecular weight of 420 g/gmol and active substance concentration of 93.4 % , while the general formula of SLES ($CH_3(CH_2)_{10}CH_2(OCH_2CH_2)_3OSO_3^{-}Na$) is a white gel material with a molecular weight of 372 g/gmol with an active material of 76% .

Annular Sodium Chloride and Calcium Chloride were uses to show its effect on drag reduction performance. They were supplied by local market.

Tap water was used as following fluid. Its analysis done at laboratory of Environmental Ministry of Baghdad, as listed in table (3.1)

Table (3.1) Salt Analysis of Tap Water

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

3.2 Preparation of Surfactant Solution

The method of additive solution preparation adapted in this study was to make 5% by weight concentration in a separate container. Thus, 10 gram of SDBS and SLES surfactant type were placed in a one litter conical flask and mixed with 250 ml of water at room temperature(25-30C^0), in an electrical shaker type KOTTERMAN 4010, GERMANY, about one hour at 8 rpm was required to get a homogenous solution.

3.3 Flow System

The drag reduction experiments were carried out in the laboratory circulation loop [88], as shown in Figure (3.1). It consists of reservoir tank as feed tank of water with dimensions 100*70*70cm and a capacity of 0.49 m^3. The reservoir tank was supported with Galvanized steel pipes of inside diameter 50.8mm to perform the flow measurement. A gear pump of 50.8mm diameter, 1440 rpm and total head of 6m was used to deliver the fluid at high turbulence. Gear pump was used to avoid surfactant mechanical degradation and thus reduce the drag – reducing effectiveness.

The test section of 2m long and located away from the entrance to get fully developed region. The fluid flow was adjusted of ball valves; the pressure drop in test section was measured by U- tube manometer filled with water.

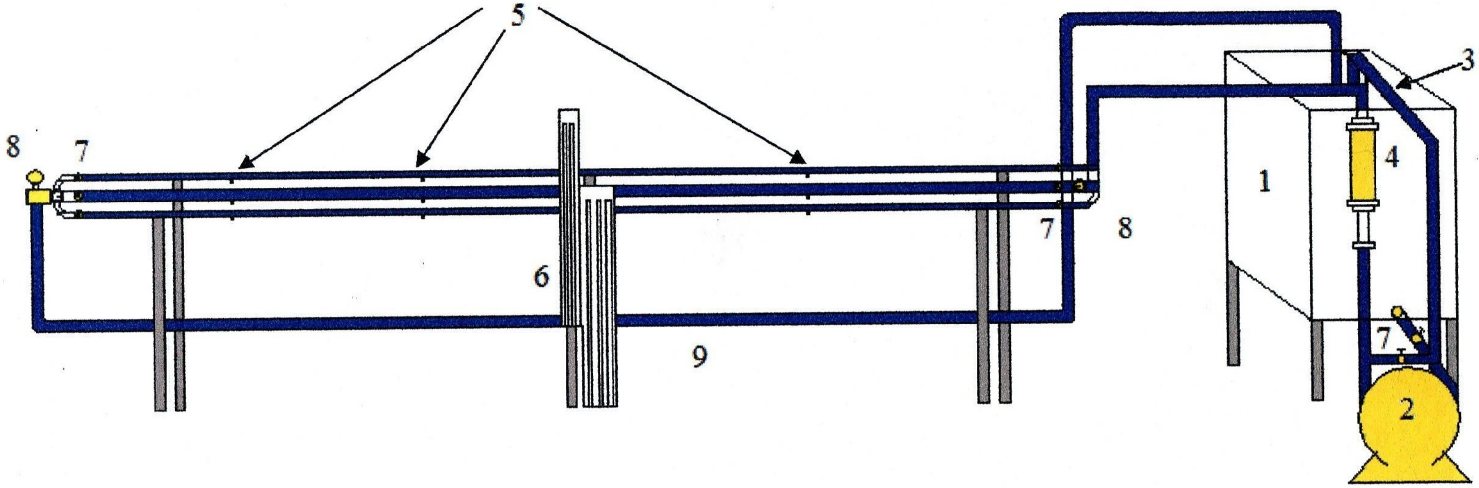


Figure 3.1: Schematic diagram of experimental rig

Schematic diagram details

No.	Item	No.	Item
1	Reservoir	6	U-tube manometers
2	External gear pump	7	Ball type valves
3	By-pass	8	Gauge pressure
4	Float flow meter	9	Recycle
5	Test Sections		

3. 4 Experimental Procedure

The drag reduction effect of surfactant additives under turbulent flow conditions were evaluated by measuring the pressure drop –flow rate relationship when the test fluid was forced to flow in circulating flow loop.

The reservoir tank was filled initially with 130 liters tap water .Water was allowed to flow through the pipe by operating the gear pump. The flow rate was maintained constant by means the corresponding valves. The experiment was stopped after obtaining a stabilized pressure drop reading.

The same procedure was done to measure the pressure drop-flow rate for treated water. In order to insure a homogenous mixture, it was decided to dilute the drag – reducing additive prior to add to the feed tank. The appropriate amount of concentrated additive solution was diluted by about 250 ml of tap water and mixed by hand- shaking. The homogenous additive solution was added into the feed tank. About 30 minutes of mixing by operating the pump were allowed prior to performing the test.

3.5 Calculation

The flow rate was read directly from the flow meter in (m^3/hr), and the volumetric average velocity for each pipe was calculated by dividing the volumetric flow rate by the flow area (*A*) :-

$$u = \frac{Q}{A} = \frac{Q}{\frac{\pi}{4} D^2 3600} \qquad (3.1)$$

Where: *u* in m/sec, and Q in m^3/hr and D in m.

The Reynolds number was calculated by using equation (3.2) with kinematic viscosity of flowing liquid, for each run as follows

$$\mathrm{Re} = \frac{uD}{\upsilon} \qquad (2.16)$$

Where υ is in m^2/sec and $\upsilon = \frac{\mu}{\rho}$ (3.2)

Pressure drop readings through testing sections before and after drag reducer addition, were needed to calculate the percentage drag reduction %Dr as follows: [26]

$$\%Dr = \frac{\Delta P_b - \Delta P_a}{\Delta P_b} \qquad (3.3)$$

where: ΔP_b = Pressure drop before addition of additives.

ΔP_a = Pressure drop after addition of additives.

Percentage flow increase can be calculated as follow [88]:

$$\%TI = \left(\frac{1}{\left(1 - \frac{\%Dr}{100}\right)^{0.55}} - 1 \right) \times 100 \qquad (3.4)$$

Friction factor in term of fanning friction factor can be calculated as follow [16]:

$$f = \frac{\Delta P \cdot D/4L}{\rho \cdot v^2 / 2} \qquad (2.23)$$

Where:

f = fanning friction factor.

D= pipe inside diameter, m.,

L= distance between the pressure taps, m.

Chapter Four

4.1 Scope of Investigation

Drag reduction is a Phenomenon exhibited by many Newtonian and psedoplastic solutions, gells and suspensions and it can be considerable as a departure from their normal viscous behavior. In general, Polymers and surface active solutions are used as drag reducer. Recently more attention were taken for surface active agents than high molecular weight polymers due to the toxicity and highly cost of the later.

The screening study was designed to evaluate the drag – reduction effectiveness of two type's surfactants additives. Those are Sodium Dodecy -Benzene Sulfonate (SDBS) and Sodium lauryl ether sulfate (SLES). The effect of additive concentration and degree of turbulence was investigated in a laboratory circulation loop using tap water. Since turbulent flow is necessary for drag reduction to occur, the system was operated for Reynolds number running 10,000- 50,000, which produced by a positive displacement gear pump, to avoid any mechanical degradation of surfactant chains.

Furthermore, we will focus our attention on the role of material salts, such as sodium chloride and calcium chloride. Since drainage water as sea water contains salts, mainly as sodium chloride. These for some experiments had been done during the present work on turbulent flow of water containing different concentrations of sodium chloride and calcium chloride.

Calibration of the pipeline in the laboratory test loop was performed with untreated water prior to testing the drag- reduction additives. Figure (4.1) shows the calibration pressure drop data for the test loop. As illustration in figure (4.1), a general increase of pressure drop is observed with increasing the flow rate of solvent.

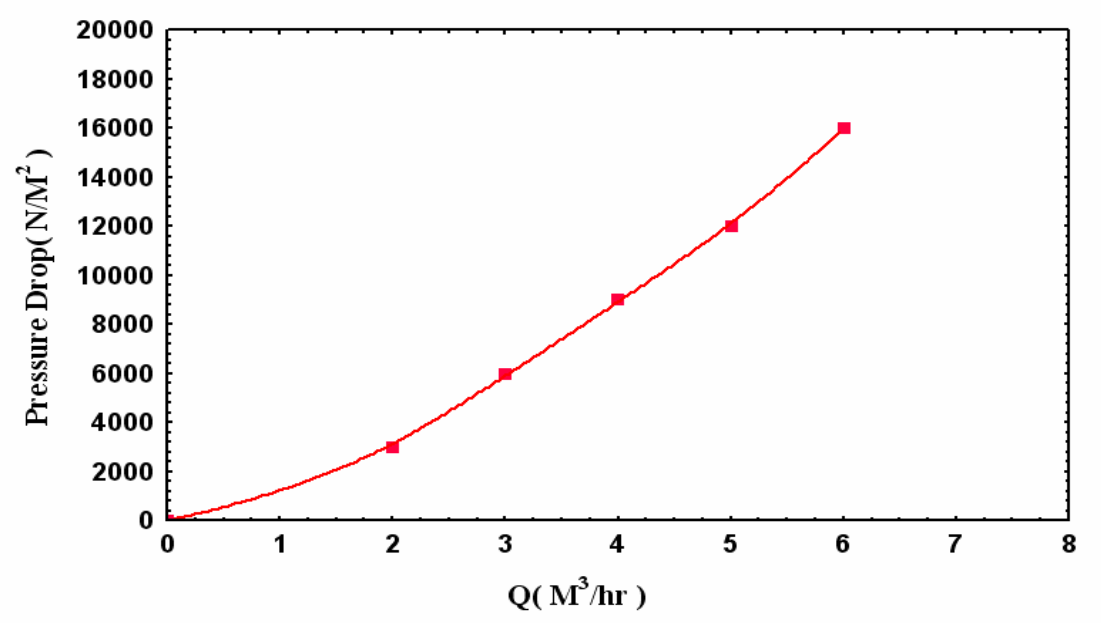


Figure (4.1) Laboratory Test Loop Calibration Data.

Percentage drag-reduction was calculated based on pressure drop data as given in equation [26]:

$$\%Dr = \frac{\Delta P_b - \Delta P_a}{\Delta P_b} \tag{3.3}$$

The effectiveness of surfactants was presented as percentage drag reduction as well as throughput increase, calculated by equation [88]:

$$\%TI = \left(\frac{1}{\left(1 - \frac{\%Dr}{100}\right)^{0.55}} - 1 \right) \times 100 \tag{3.4}$$

And friction factor calculated by equation [16]:

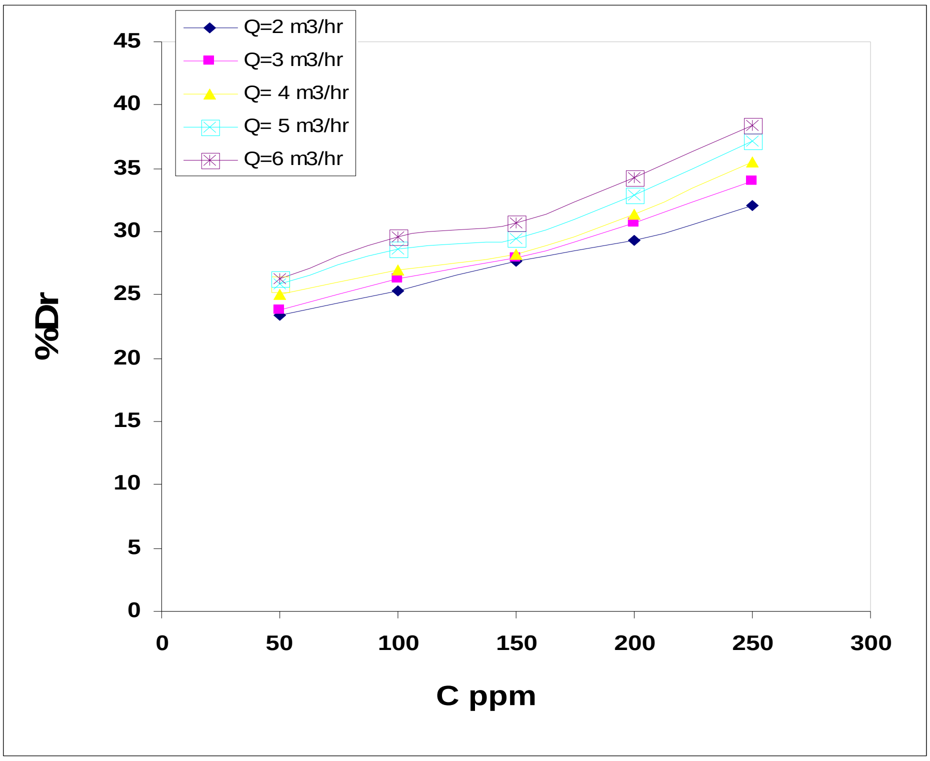
$$f = \frac{\Delta P \cdot D/4L}{\rho \cdot v^2/2} \tag{2.23}$$

4.2 Drag Reduction

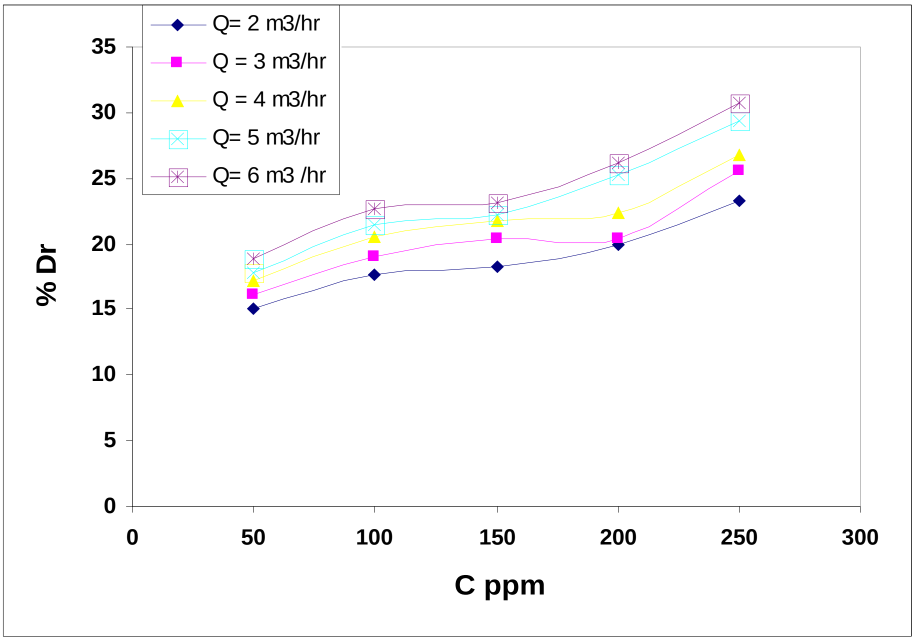
4.2.1 Effect of Concentration

Drag – reduction efficiency of surfactants, type SDBS and SLES dissolved in water had been studied in tap water turbulent flow as function of additive concentration. This concentration ranged from 50ppm up to 250ppm, which might have been economically possible for commercial applications [26]. Furthermore, the uses of highest surfactant concentrations were limited due to high foaming problems during the circulation. Within the concentrations used, Newtonian behavior was observed for all surfactant solutions.

The results of the additive concentrations on percentage drag – reduction are plotted in figures (4.2) and (4.3) for SDBS and SLES surfactant respectively, at different solution flow rates. It is clear that the addition of surfactants within the considered concentrations improves the percentage drag- reduction of the flowing water. This may be attributed to the formation of rod-like micelles which increases as concentration increases to some extent. The surfactants act to reduce the surface tension. Above CMC, The surfactants act to reduce the surface tension. Above CMC, the surfactant begins to form micelle structures in the liquid. These structures may have different shapes. In single-phase flow, surfactant drag reduction occurs if the micelle structures formed are rod-like. The benefit of these self-assembling structures is that they break a part when subjected to conditions of high shear but then reassemble through fast self-assembly kinetics down stream [88].



Figure, (4.2) Effect of concentration on percentage drag reduction for SDBS dissolved in water flowing through 0.0508 m I.D. pipe



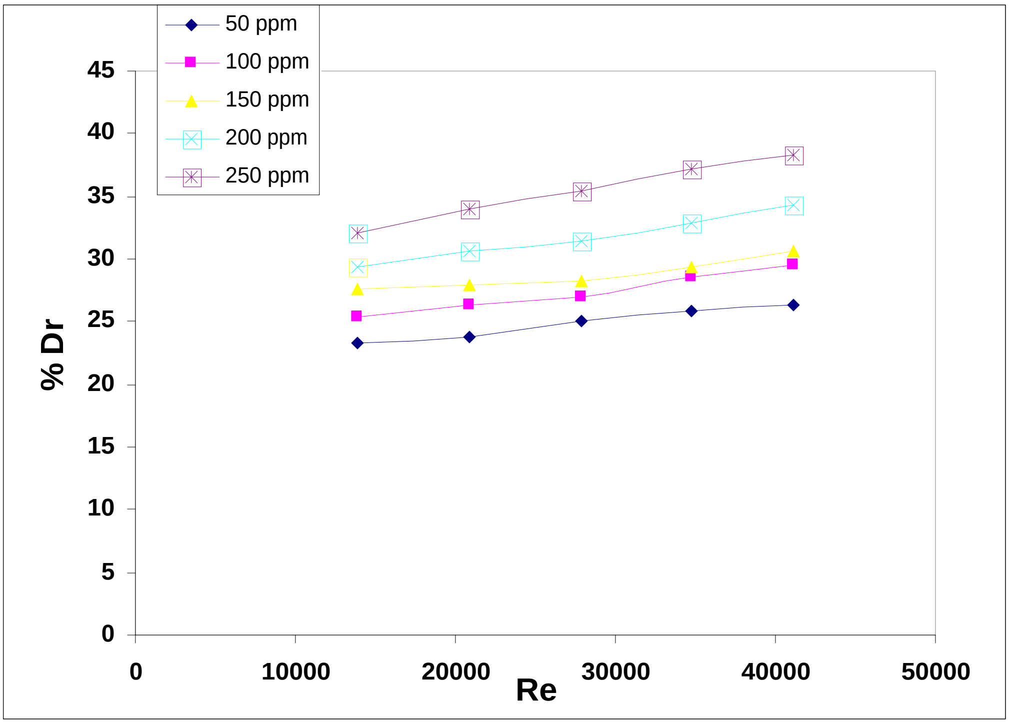
Figure, (4.3) Effect of concentration on percentage drag reduction for SLES dissolved in water flowing through 0.0508m I.D. pipe

As shown in figures (4.2) and (4.3) the drag reduction efficiency of SDBS is little larger than that of SLES in a whole surfactants concentrations range up to 250ppm at different flow rates. Those about 26.31% and about 38.36% drag reduction were obtained for SDBS at 50 and 250ppm SDBS concentrations respectively at 6.0 m^3/hr solvent flow rate. The corresponding values for SLES are about 18.92% and 30.77 at the same conditions, probably due to difference in there chemical compositions leading variable drag reducing efficiency.

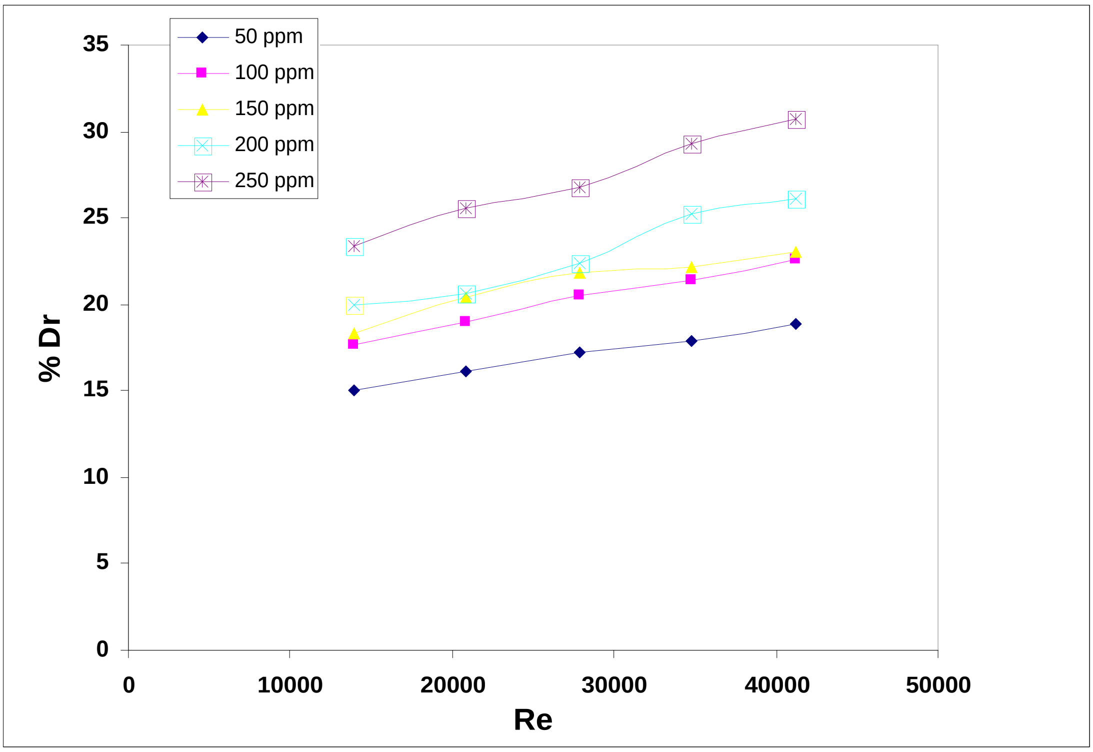
4.2.2 Effect of Fluid Velocity

Figures (4.4) and (4.5) show the effect of solution velocity on the percentage drag reduction. The velocity component is represented by dimensionless form of Reynolds number (Re). These figures show selected samples from the experimental data. Figure (4.4) show the effect of Reynolds number on %Dr for SDBS surfactant dissolved in water flowing through 0.0508 m pipe diameter while figure (4.5) show this effect with SLES surfactant. From these figures it can be noticed that, the percentage drag reduction increases generally by increasing Re (fluid velocity) through the testing section. Increasing the fluid velocity means increasing the degree of turbulence inside the pipe, this will provide a better media to the drag reduced (surfactant) to be more effective. This behavior may be explained due to relation between degree of turbulence controlled by the solution velocity and additive effectiveness.

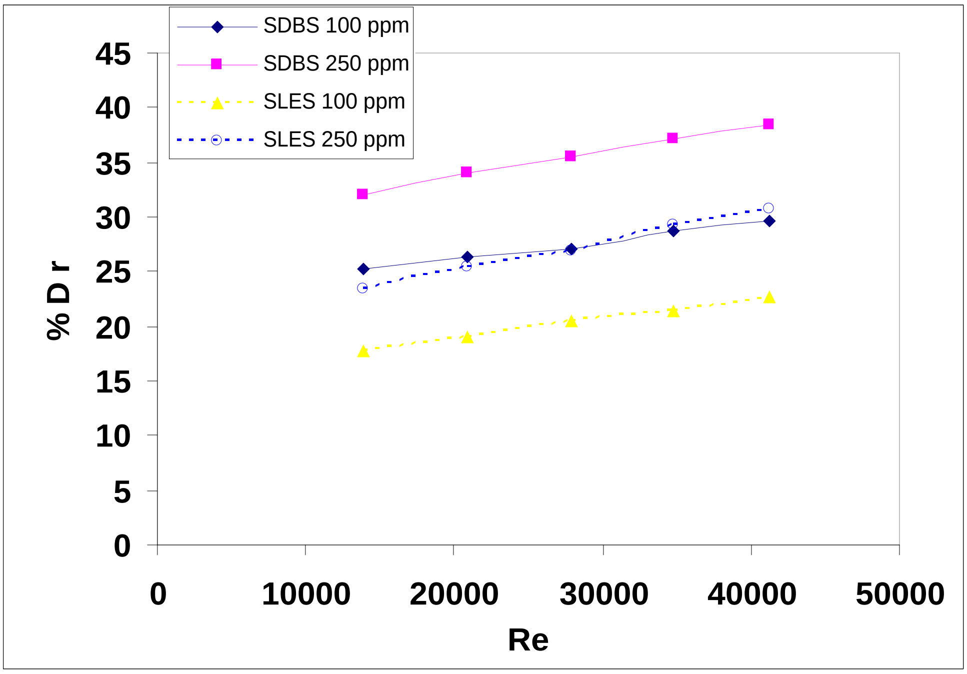
The experimental results indicated here again that SDBS is more efficient as drag reducer than SLES as illustrated in figure (4.6). This is attributed to the ability of surfactants to self repair and return to their original form after passing through the high shear stress regions. The clearly the effect of Reynolds number performance of both surfactant types as drag reducer. The minimum and maximum Reynolds number, 10000 and 50000 at 250ppm concentration are chosen for this comparison. Those, the percentage drag- reduction values obtained for SDBS agent at low and high Reynolds number are about 32 and 38.36 respectively. While the corresponding data with SLES agent are 23.33 and 30.77 for lowest and highest Reynolds number respectively at the same concentration of 250ppm. The results indicate, that the effect of liquid velocity is relatively low in increase of drag-reducers efficiency, when compared with polymeric additives, i.e., oppanol B-250 which gives more than 10% increase in drag reduction when the Reynolds number increase from 10000 to 50000[89] .



Figure,(4.4) Effect of Reynolds number on percentage drag reduction for SDBS within different concentrations in 0.0508 m I.D. pipe



Figure, (4.5) Effect of Reynolds number on percentage drag reduction for SLES within different concentration in 0.0508 m I.D. pipe



Figure, (4.6) Comparison the effectiveness of SDBS and SLES as Drag-reducing Agents at different Reynolds number.

4.3 Effect of Salt Additive

4.3.1 Sodium Chloride

The experiments were performed to study the effect of sodium chloride on performance of ionic surfactants as drag-reducers. Since drainage water as well as sea waters contain various amounts of salts, mainly as sodium chloride. The study aimed also to investigate the effect of surfactants as drag reducers in reducing the energy requirement for discharge of salt water and in possible sprinkler irrigation system as well as to increase the throughout area of converge.

Figures 4.7(a-c), 4.8 (a-c), 4.9(a-d) and 4.10(a-d) illustrate the effect of sodium chloride concentration on effectiveness of SDBS and SLES drag reducer respectively at different surfactant concentration and different water flow rates. These figures show a decrease in the drag –

reduction as the salt concentration increase. It can be concluded, that sodium chloride acts as an inhibitor to performance of such detergents as drag reducer.

The inhibition effect of water salinity may be attributed to the shear stability of micelles structure or the shape of the micelles. Sodium chloride as strong ionic salt gives the surfactants lower stabilities against shear forces as a resulted of rod-shaped micelles forming. Furthermore, the ionic strength as function of salt concentration influence the viscosity of surfactant solutions, similar effect is observed for polymeric drag reducer in presence of salts [90].

Table (4.1) shows comparative study of salt effect on drag-reduction effectiveness of two types of surfactants, SDBS and SLES at two selected additive concentrations, 100 and 250 ppm, two different salt concentrations, 500 and 1500ppm and 6.0 m^3/hr flow rate.

Table (4.1) Comparison the performance of SDBS and SLES Surfactants in presence of Sodium Chloride at Different Concentration at 6.0 m^3/hr solvent flow rate

Detergent ppm	***NaCl ppm***	***SDBS***		***SLES***	
		% Dr	***%decrease in Dr***	***%Dr***	***%decrease in Dr***
100	-	29.6	-	22.6	-
100	500	23.3	21.0	19.2	15.0
100	1500	17.4	41.0	15.6	31.0
250	-	38.4	-	30.8	-
250	500	32.2	16.0	28.9	6.0
250	1500	26.0	32.0	23.4	24.0

As seen in table (4.1) as well as in figures (4.7) and (4.8), that the performance of surfactant as drag reducer is well inhibited with increasing the salt concentration. Furthermore, it can be seen that the SDBS surfactants is more affected by presence of salt as SLES surfactants. The declines of percentage drag reduction are 20% and 41% at NaCl concentrations 500 and 1500 ppm respectively for SDBS detergent. While the corresponding values for SLES detergent, are 9.7% and 31% respectively at the same operating other conditions. These results may be attributed to molecular weight variation between SDBS and SLES. Also, it may be due to the difference effect of both surfactants to the shear stability of micelles structure.

It is worthily to analyze the inhibited effect of sodium chloride on drag reduction effectiveness of the two surfactant types at different ratio of surfactant to salt, as illustrated in table (4.2). Since the drag reduction experiments were carried out at different detergent concentrations.

Table (4.2): Effect of Sodium Chloride to Surfactant ratio on decrease of Drag –Reduction, at 6.0 m^3/hr flow rate.

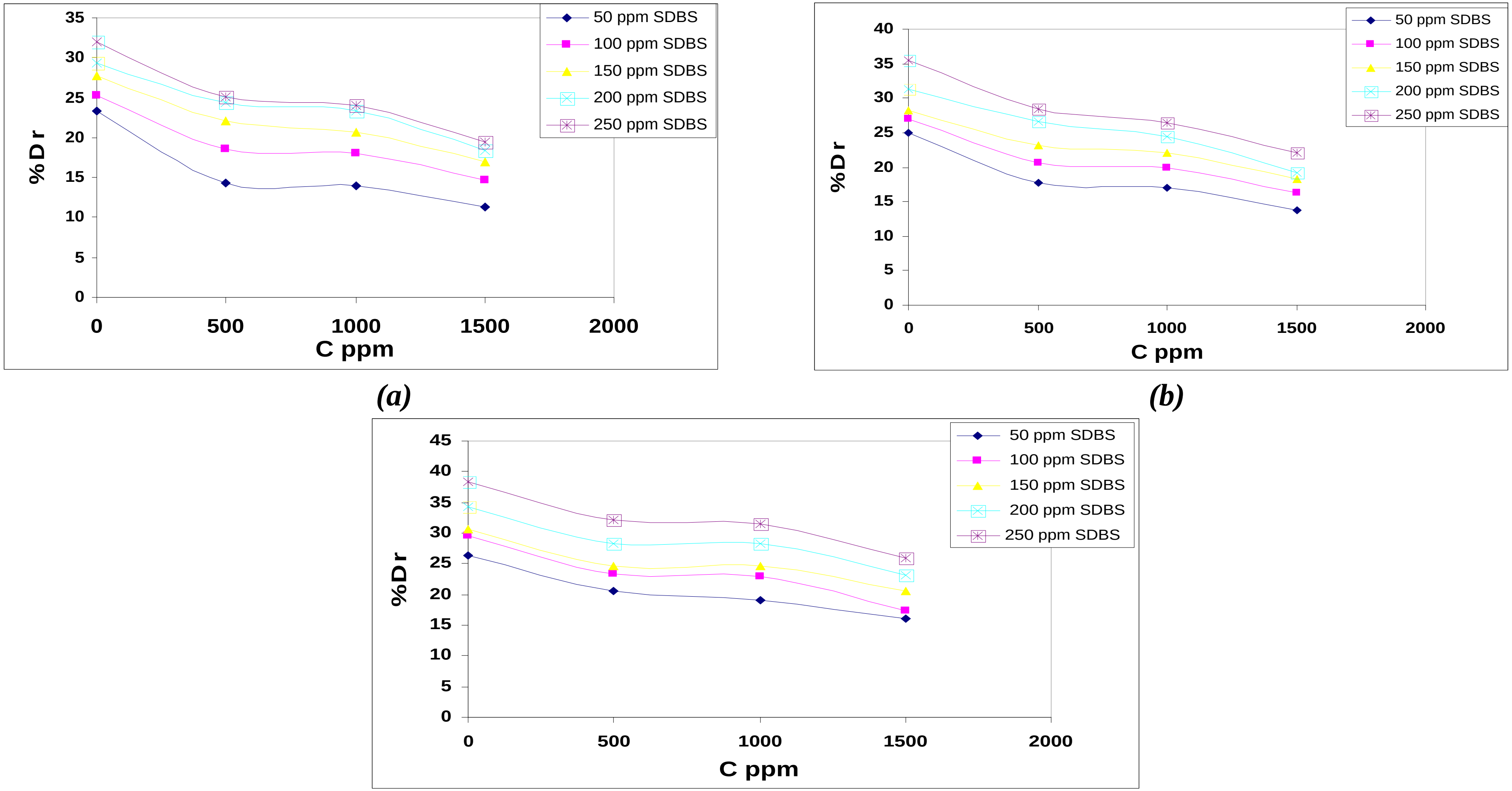
Ratio Salt to Detergent	***%Decrease in Drag Reduction***	
	SDBS	***SLES***
2:1	15.5	6.2
5:1	20.0	15.0
6:1	32.0	24.0
15:1	41.0	31.0

Table (4.2) shows again the inhabited effect of sodium chloride on percentage drag reduction by increasing the salt to detergent ratios. Those, 52% reduction are observed for SDBS by increasing the salt ratio from 2 to 15. The corresponding values for SLES are 58.7% at similar operating conditions. This indicates a little more inhibited effect of increasing the salt ratio foe SLES compared with SDBS detergents. Furthermore, the effect of solvent flow rate on performance of surfactants as drag reducers in presence of salt was also analyzed in table (4.3).

Table (4.3): Effect of Flow Rate on performance of Detergent Drag – Reducers in Saline Water.

Detergent ,ppm	***NaCl ppm***	***Flow Rate , m^3/hr***		
		2.0	***4.0***	***6.0***
SDBS, 100	500	27.0	23.7	20
SLES,100	500	5.6	8.0	7.5
SDBS,250	500	21.0	19.7	15.5
SLES,250	500	7.0	7.5	6.2
SDBS,100	1500	41.5	39.0	41.0
SLES,100	1500	35.0	33.7	31.0
SDBS,250	1500	39.1	38	32.0
SLES,250	1500	21.5	20.7	24.0

As illustrated in table (4.3) the increase in solvent flow rate causes more decrease in drag reduction with increasing the solvent flow rate at low salt concentration 500ppm. The values are 18.5%, 20.59% and 23.33% inhabitation by increasing the flow rate in order 2.0, 4.0, and 6.0 m^3/hr respectively for SDBS detergent. The corresponding values for SLES detergent are16.66%, 18.8%, and 20.92% at the same flow rates respectively. While, there is low effect of flow rate on the inhibition of drag- reduction with high concentration of NaCl, 1500 ppm. This can be attributed to the fact that at high stability, 1500ppm, the more shear stability of micelles structure against the flow rate at high concentration of detergent additive.

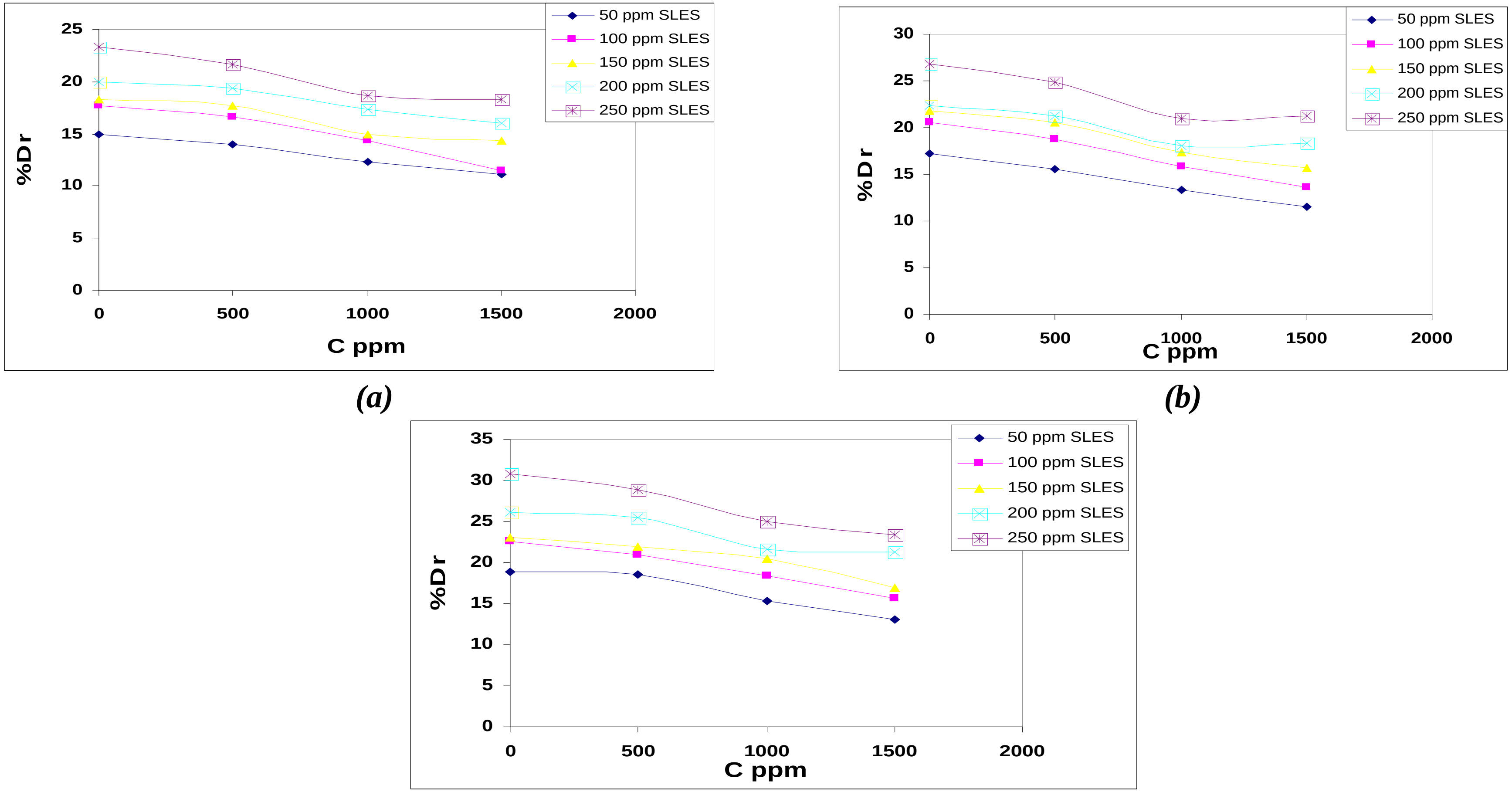


(a)

(b)

(c)

Figure, (4.7) Percent drag reduction vs. concentration of NaCl salt addition for different concentration of SDBS at flow rate of water;
(a):2m3/hr, (b): 4m3/hr and (c): 6 m3/hr

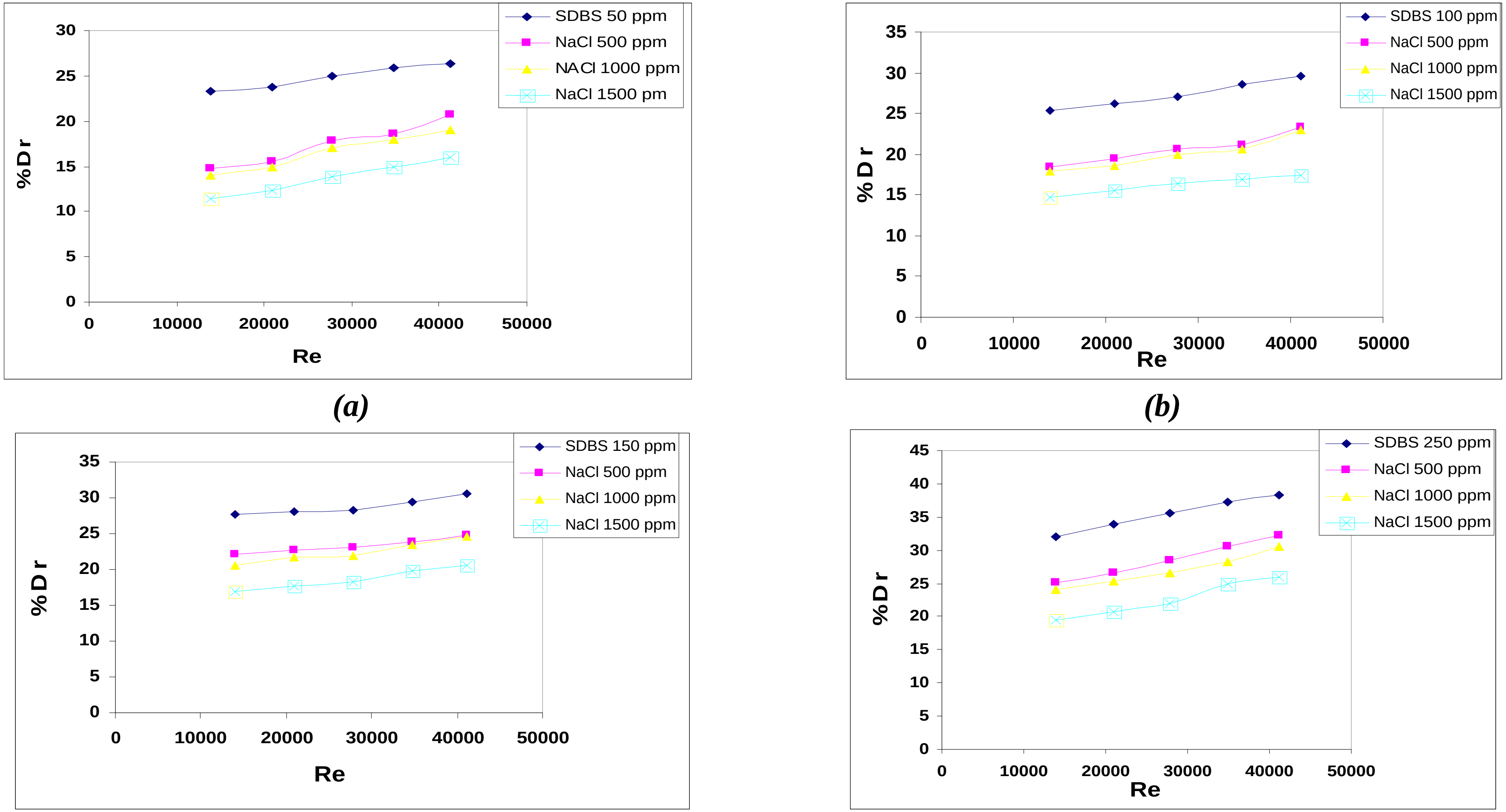


(a)

(b)

(c)

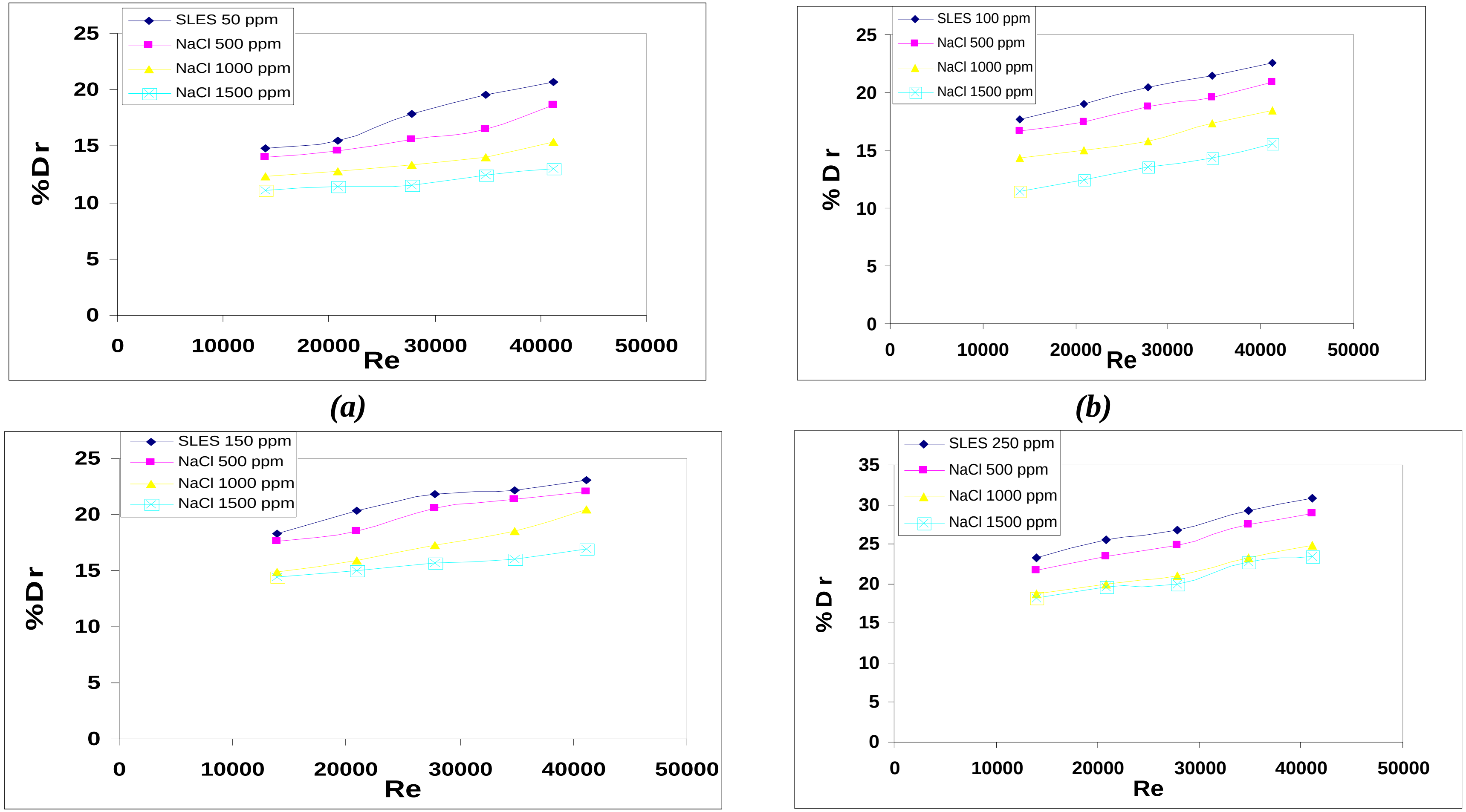
Figure, (4.8) Percent drag reduction vs. concentration of NaCl salt addition for different concentration of SLES at flow rate of water;
(a):2m3/hr, (b): 4m3/hr and (c): 6 m3/hr



(a) *(b)*

(c) *(d)*

Figure (4.9) effect of additive type on %DR at 0.0508m I.D.;
(a): 50 ppm, (b): 100 ppm, (c): 150 ppm and (d): 250 ppm



(a) *(b)*

(c) *(d)*

Figure (4.10) effect of additive type on %DR at 0.0508m I.D.;
(a): 50 ppm, (b): 100 ppm, (c): 150 ppm and (d): 250 ppm

4.3.2 Calcium Chloride

In this section, an attempt was made to investigate the effect of calcium chloride presence in water on drag-reduction performance of detergent additives. The results are illustrated in figures (4.11) through (4.14). While, Table (4.4) shows comparative study of calcium chloride effect on drag-reduction effectiveness of two types of surfactants, SDBS and SLES at two selected additive concentrations, 100 and 250 ppm, two different salt concentrations, 500 and 1500ppm and 6.0 m^3/hr flow rate.

As shown in figures (4.11) and (4.12), percent drag- reduction decrease proportionally with increase of calcium chloride salinity for both SDBS and SLES detergents. The decline in effectiveness of detergent agents as drag –reducers can be attributed also due shear stability of micelles structure, which is affected by presence of calcium chloride, as presented in section 4.3.1 previously. Furthermore, the analysis of the results in table (4.4) and (4.5) indicate clearly that calcium chloride has more inhabited effect on drag – reduction performance of both types than sodium chloride. Those, at 500ppm salt concentration 20% decline of the effectiveness with sodium chloride was achieved, compared with about 53% decrease with calcium chloride for 100ppm SDBS. The corresponding values for 100ppm SLES are 15% decrease with 500ppm sodium chloride and 56.6% decrease of drag – reduction with calcium chloride. This supports the fact that calcium chloride presence in water acts as strong inhibitor for detergent as drag – reducer, mainly at high salts concentration reducing about 59% for SDBS and 67% for SLES at 100ppm concentration and 1500pmm calcium chloride.

The large inhibited effect of calcium chloride on drag – reduction performance of SDBS and SLES detergents can attribute also to the fact that calcium ions make insoluble salts anionic – detergent molecules. Therefore, the insoluble drag- reducers in water flowing, in addition to the reducing the shear stability of micelles structure by calcium ions presence inhibit the drag – reducing effectiveness of detergents progressively. It is well known that the anionic detergents have less detergency in hard water that contains usually calcium and magnesium ions [91].

Table (4.4) Comparison the performance of SDBS and SLES Surfactants in presence of Calcium Chloride at Different Concentration and 6.0 m^3/hr solvent flow rate

Detergent ppm	***CaCl$_2$ ppm***	***SDBS***		***SLES***	
		% Dr	***%decrease in Dr***	***%Dr***	***%decrease in Dr***
100	-	29.6	-	22.6	-
100	500	13. 9	53.0	10.7	52.6
100	1500	12.2	58.8	7.5	66.8
250	-	38.4	-	30.8	-
250	500	27.0	29.7	21.4	30.5
250	1500	19.5	49.2	16.1	47.5

The inhibited effect of calcium chloride on performance of anionic – detergent as drag – reducers is clearly observed by increasing the salt – detergent weight ratio, as shown in table (4.5). These results support the role of calcium chloride as inhibitor for turbulent drag – reduction mainly at high ratios of salt to detergent additives, reaching about 59% and 69% reduction in the original drag – reduction (without salt addition) for SDBS and SLES respectively. The ratio 6:1 in table (4.5), shows a little lower reduction in Dr performance than the ratio 5:1, probably due to the higher detergent concentration of the forms.

Table (4.5): Effect of Calcium Chloride to Surfactant ratio on decrease of Drag –Reduction, at 6.0 m^3/hr flow rate

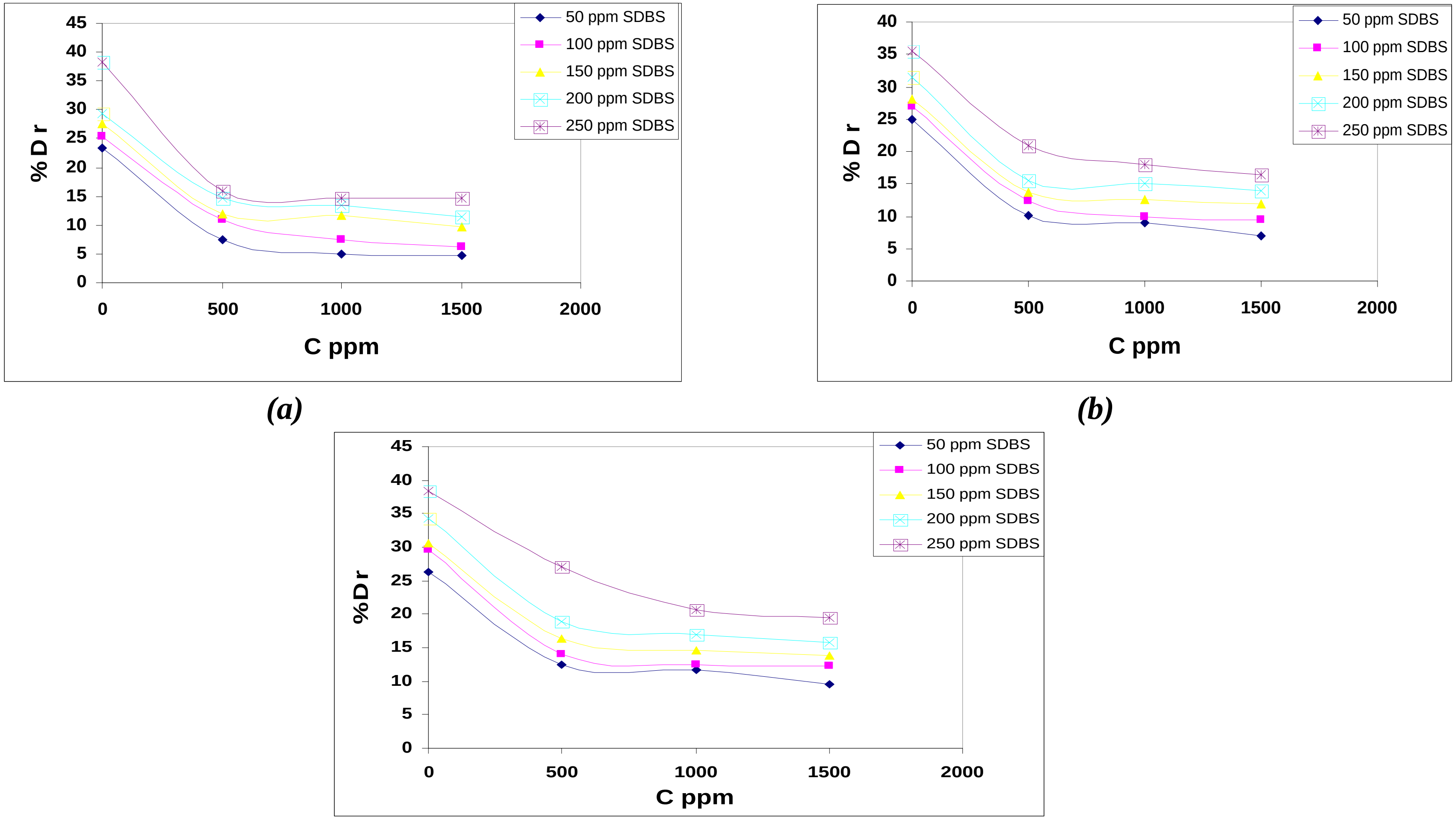
Ratio Salt to Detergent	***%Decrease in Drag Reduction***	
	SDBS	***SLES***
2:1	29.7	30.5
5:1	53.0	52.6
6:1	49.2	47.5
15:1	58.8	66.8

The combined effects of calcium chloride addition and solution flow rate on drag – reduction effectiveness of detergent agents are summarized in table (4.6). It is clearly to see that as the flow rate increases the inhibited effect of calcium chloride on percentage drag reduction decreases for all concentrations used. Table (4.3) shows, as in case of sodium chloride addition, that the increase of the flow rate enhances the inhibition of NaCl on drag – reduction at low detergent concentration.

While the flow rate has approximately, no influences on percentage drag reduction at high concentration.

Table (4.6): Effect of Flow Rate on Percentage Decrease of Drag - Reduction effectiveness of Detergents in Saline Water.

Detergent ,ppm	***$CaCl_2$ ppm***	***Flow Rate , m^3/hr***		
		2.0	***4.0***	***6.0***
SDBS, 100	500	62.5	57.8	53.0
SLES,100	500	72.0	62.4	52.6
SDBS,250	500	58.3	45.3	29.7
SLES,250	500	56.2	43.5	30.5
SDBS,100	1500	78.7	67.9	58.8
SLES,100	1500	85.4	74.8	66.8
SDBS,250	1500	61.5	57.3	49.2
SLES,250	1500	67.5	57.8	47.5

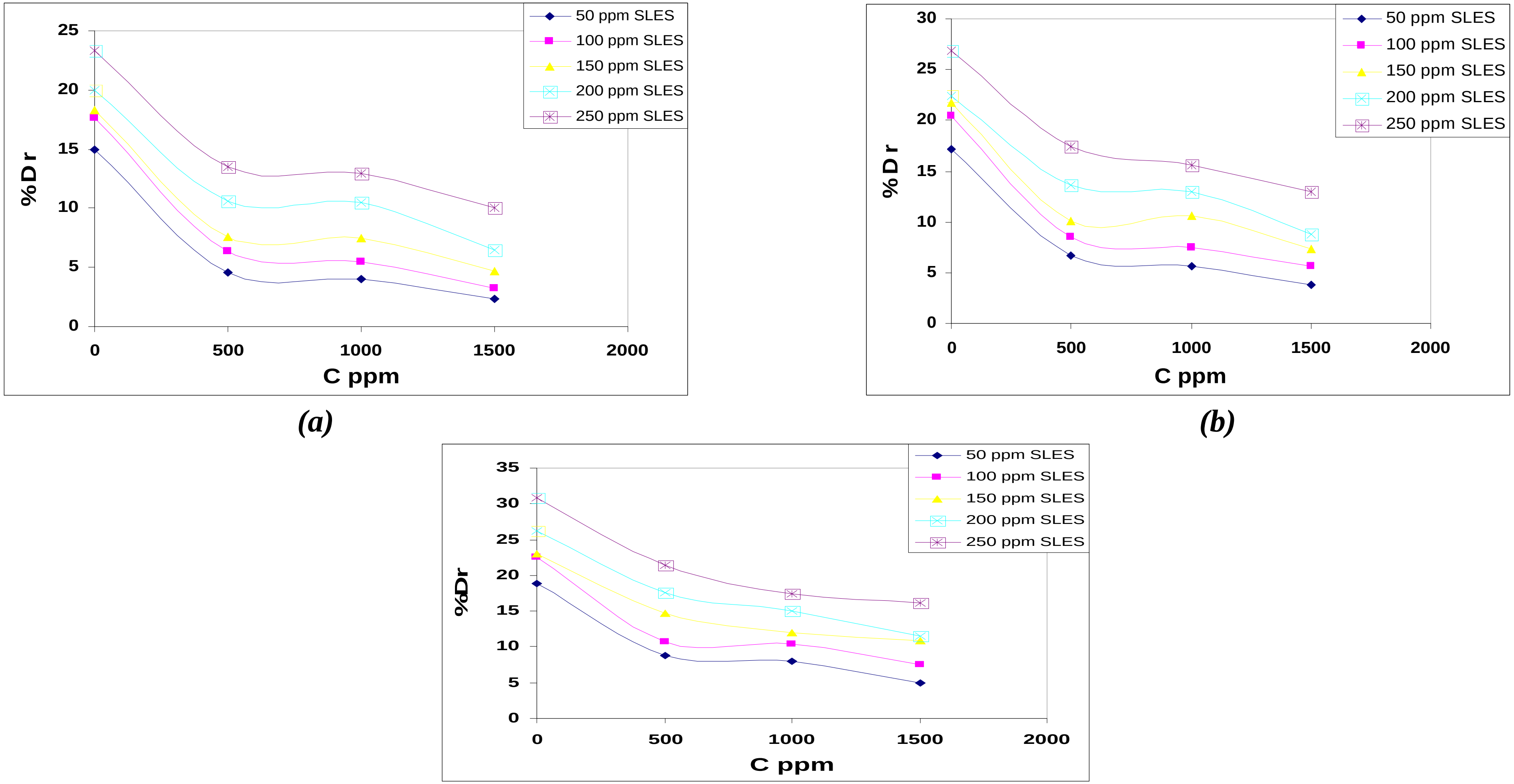


(a)

(b)

(c)

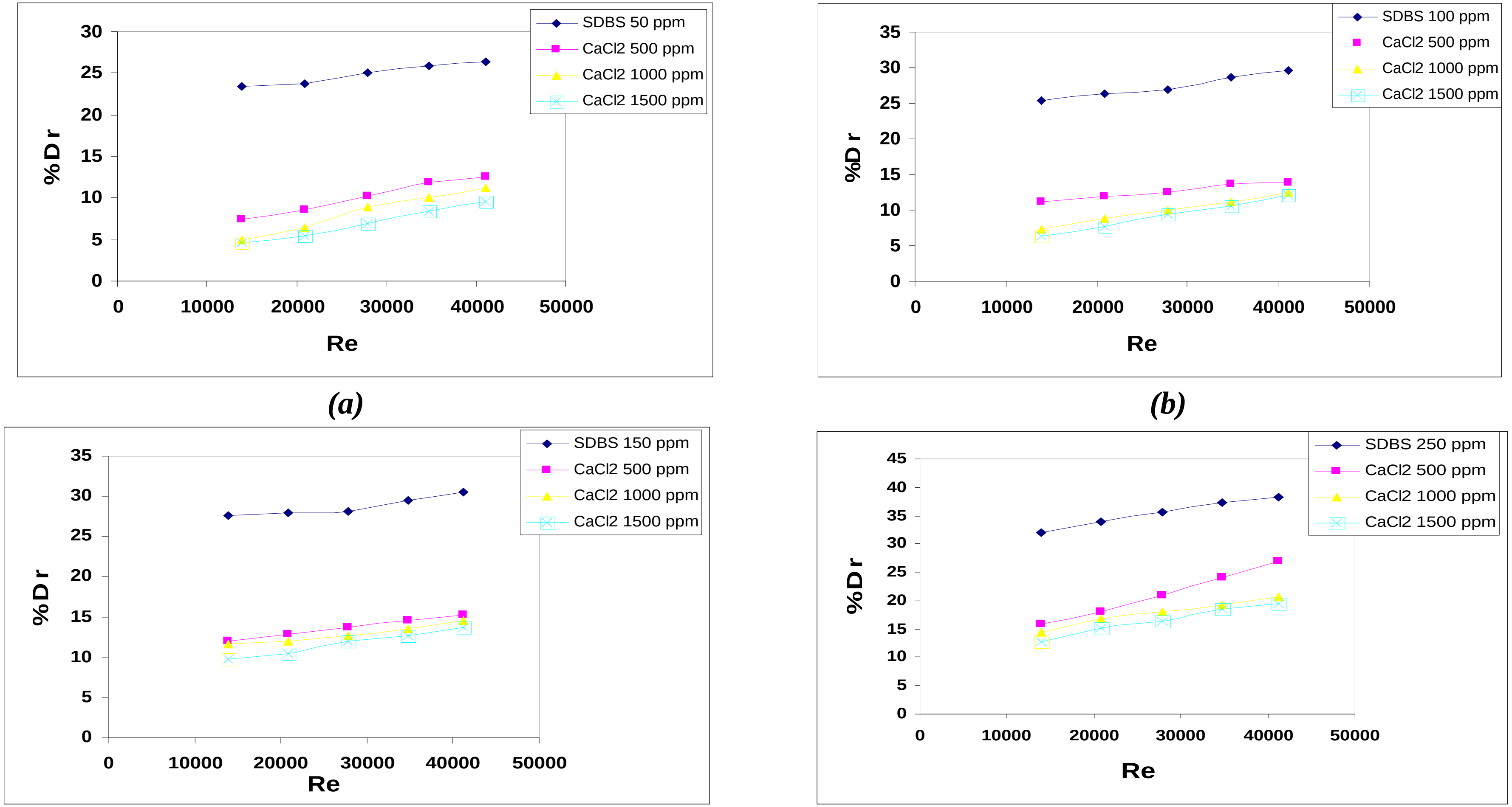
Figure, (4.11) Percent drag reduction vs. concentration of$CaCl_2$ salt addition for different concentration of SDBS at flow rate of water;
(a):2m3/hr, (b): 4m3/hr and (c): 6 m3/hr



(a) *(b)*

(c)

Figure, (4.12) Percent drag reduction vs. concentration of$CaCl_2$ salt addition for different concentration of SLES at flow rate of water;
(a):2m3/hr, (b): 4m3/hr and (c): 6 m3/hr

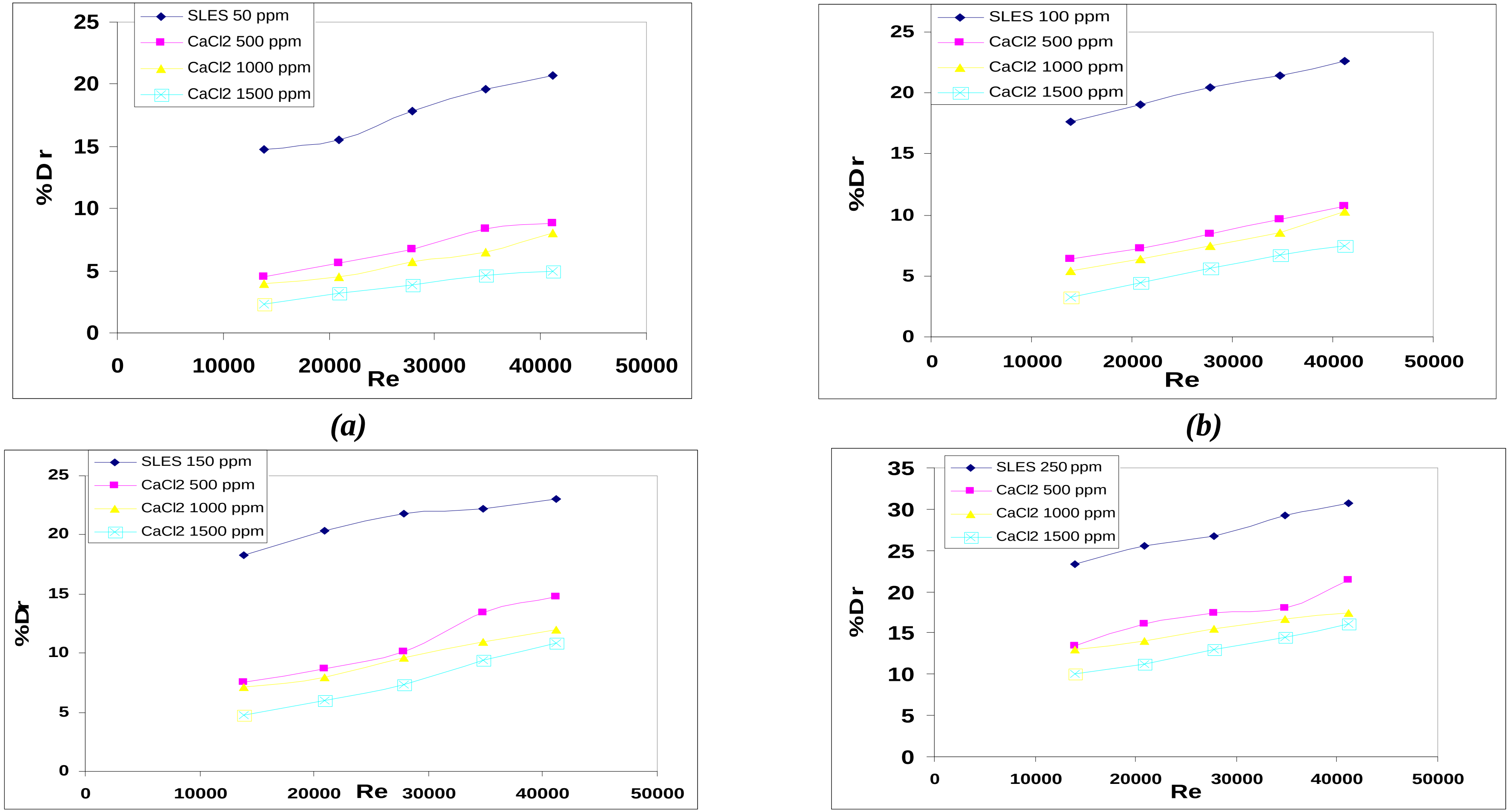


(a) *(b)*

(c) *(d)*

Figure (4.13) effect of additive type on %DR at 0.0508m I.D.;

(a): 50 ppm, (b): 100 ppm, (c): 150 ppm and (d): 250 ppm



(a) *(b)*

(c) *(d)*

Figure (4.14) effect of additive type on %DR at 0.0508m I.D.;
(a): 50 ppm, (b): 100 ppm, (c): 150 ppm and (d): 250 ppm

4.4 Friction Factor

The drag – reduction properties of SDBS and SLES detergents in flowing water could be explained as the Fanning friction factor versus solvent Reynolds number. The use of Reynolds number based on the solvent viscosity and pipe diameter provides a direct indication of the degree of turbulent drag- reduction. The Fanning friction factor was calculated from the experimental data based on pressure drop measurement, as in equation (2.23) [16].

The effect of SDBS and SLES detergents with different concentrations, without and with sodium chloride and calcium chloride addition as function of Reynolds number are represented in figures (4.15-4.24). These figures are divided into three regions, as follows:

1. Laminar region (Re < 2100), where the friction factors follows Poiseuille,s law[17] as in equation

$$f = \frac{16}{\mathrm{Re}} \qquad (2.24)$$

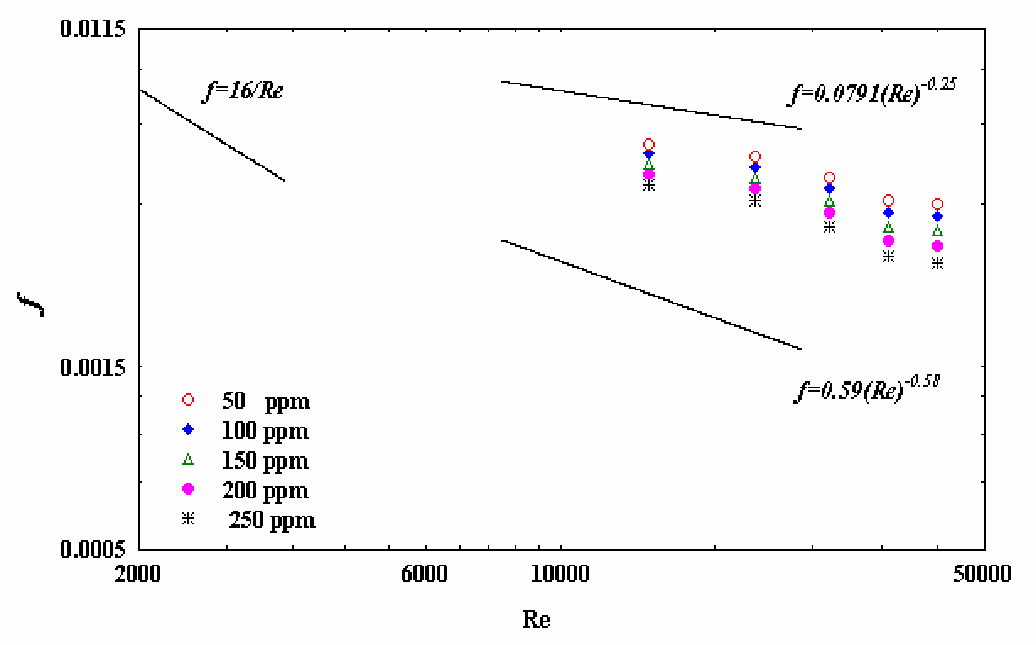
2. Turbulent region (Re>3000), where friction follows Blasius law [19], as in equation

$$f = \frac{0.079}{\mathrm{Re}^{0.25}} \qquad (2.26)$$

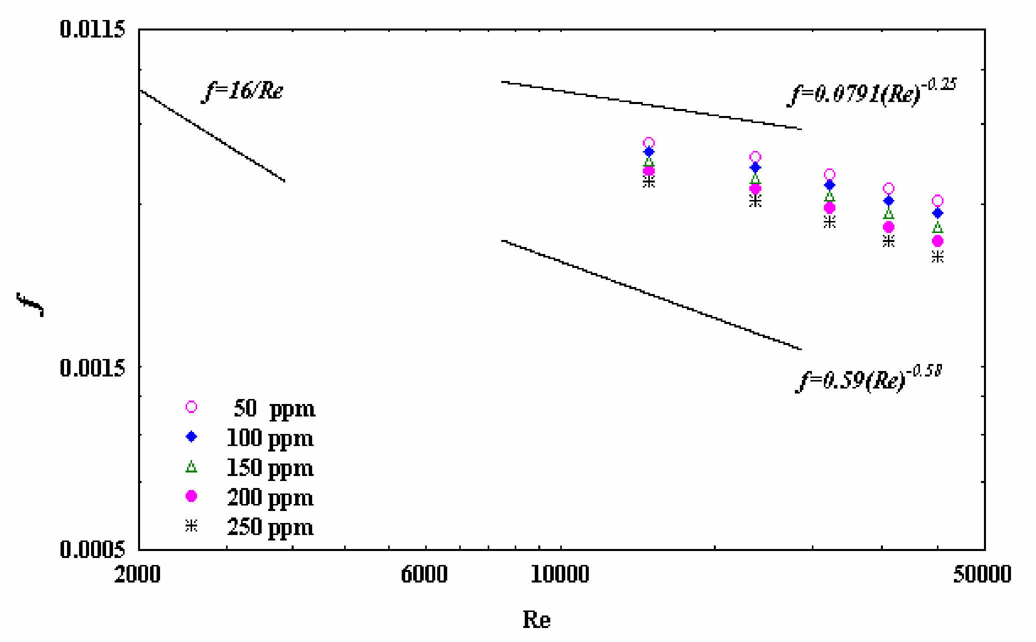
3.Virk asymptote region, suggested by Virk to represent the greatest possible fall in resistance in which the relation between the friction factor (f) and(Re) does not depend on the nature of the additives or pipe diameter. The formula for Virk[21] is:

$$f = 054\,\mathrm{Re}^{-0.58} \qquad (2.28)$$

It can be noticed that, when the surfactant concentration is low, 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 surfactant presented in the flow, the experimental data points are positioned in the direction of lowering friction towards Virk asymptote that represented maximum limits of drag reduction[21], which will give the idea that, to reach such asymptote, higher additive concentration and highest Re are needed furthermore. The fall in resistances is limited or bounded between the Blasius line and Virk asymptote for all treated water.



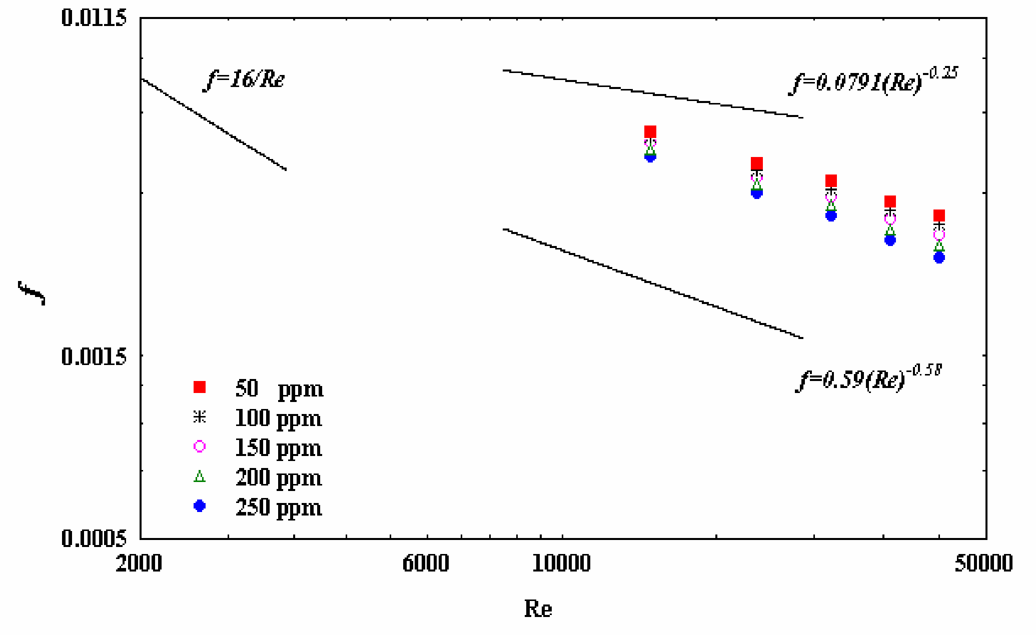
Figure, 4.15 Friction factor versus Reynolds number at different concentration of SDBS surfactant dissolved in water flowing through 0.0508m I.D. pipe.



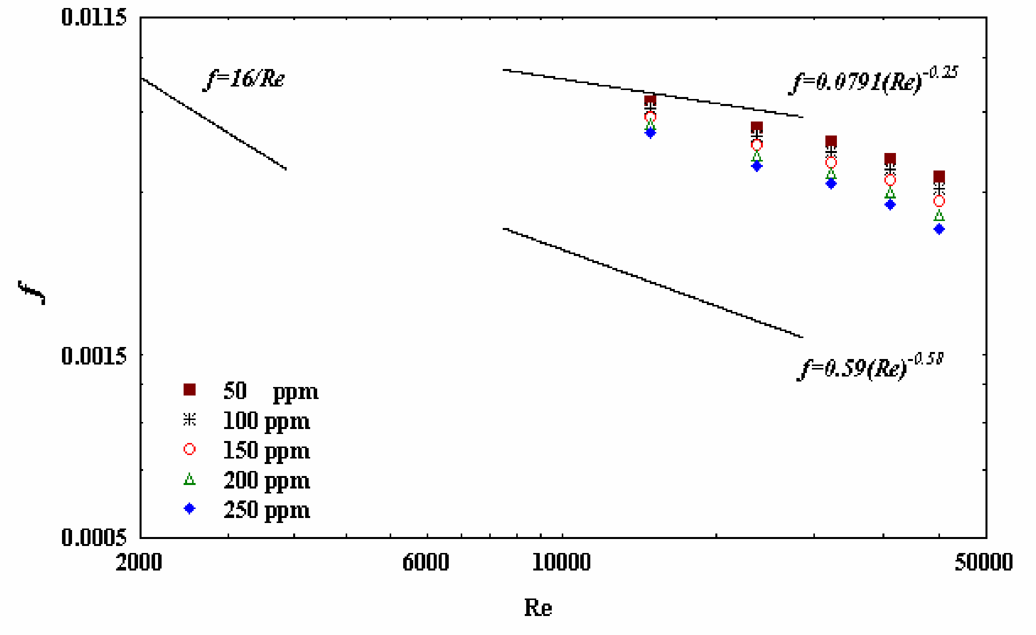
Figure, 4.16 Friction factor versus Reynolds number at different concentration of SLES surfactant dissolved in water flowing through 0.0508m I.D. pipe.

As shown in figures (4.15) and (4.16), that SDBS detergent is more effective for friction reduction as SLES detergents, mainly at high Reynolds number. This represented that SDBS give highest stabilities against shear forces against rod-shaped micelles forming.

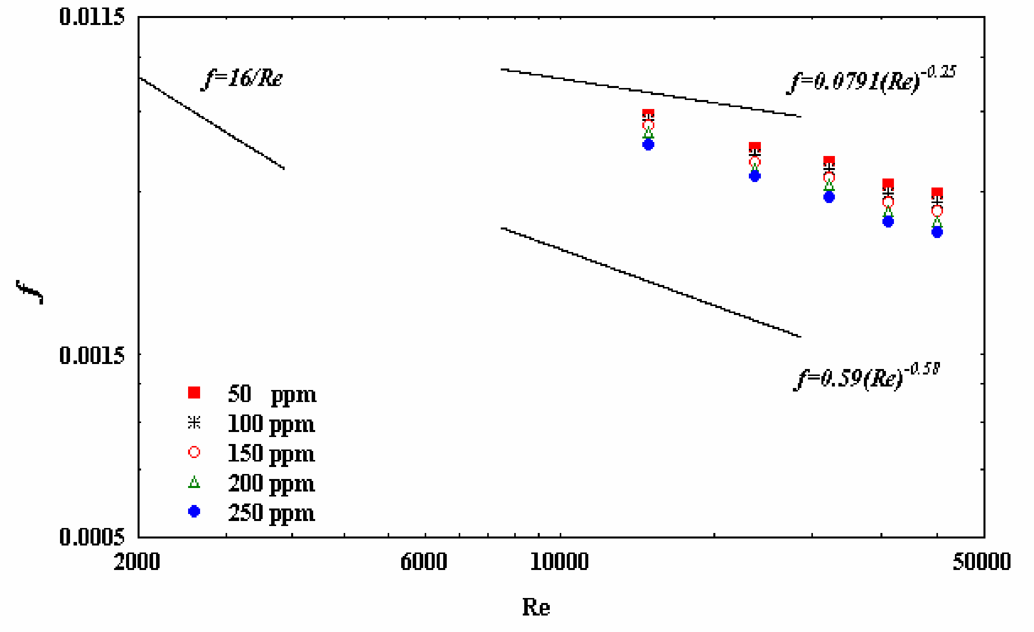
It is clearly that indicated from figures (4.17) and (4.18), that sodium chloride inhibited the friction reduction for both surfactant types. The presence of calcium chloride cause lower friction towards Blasius line, as shown in figures (4.19) and (4.20) for SDBS and SLES detergents respectively.



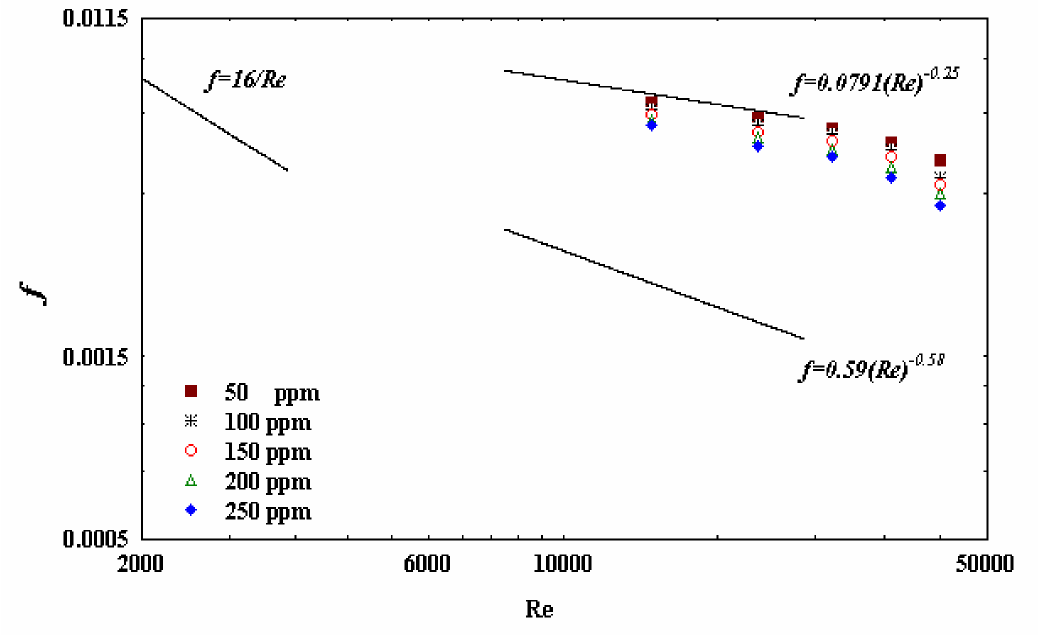
Figure, 4.17Friction factor versus Reynolds number at different concentration of SDBS surfactant and 500ppmNaCl salt addition dissolved in water through 0.0508m I.D. pipe.



Figure, 3.18 Friction factor versus Reynolds number at different concentration of SLES surfactant and 500ppm NaCl salt addition dissolved in water through 0.0508m I.D. pipe.



Figure, 4.19 Friction factor versus Reynolds number at different concentration of SDBS surfactant and 500 ppm $CaCl_2$ salt addition dissolved in water through 0.0508m I.D. pipe.



Figure, 4.20 Friction factor versus Reynolds number at different concentration of SLES surfactant and 500 ppm $CaCl_2$ salt addition dissolved in water flowing through 0.0508m I.D. pipe.

Furthermore, figures (4.21)and (4.22) shows the combined effect additive and salt concentrations on friction factor values for SDBS and SLES treated solutions respectively. While, figures (4.23) and (4.24) represented the combined effect of detergent agent and calcium chloride on friction factor for SDBS and SLES detergents respectively. These figures show the drastic inhibition of sodium chloride and calcium chloride for friction reduction. Calcium chloride acts more as inhibitor than sodium chloride.

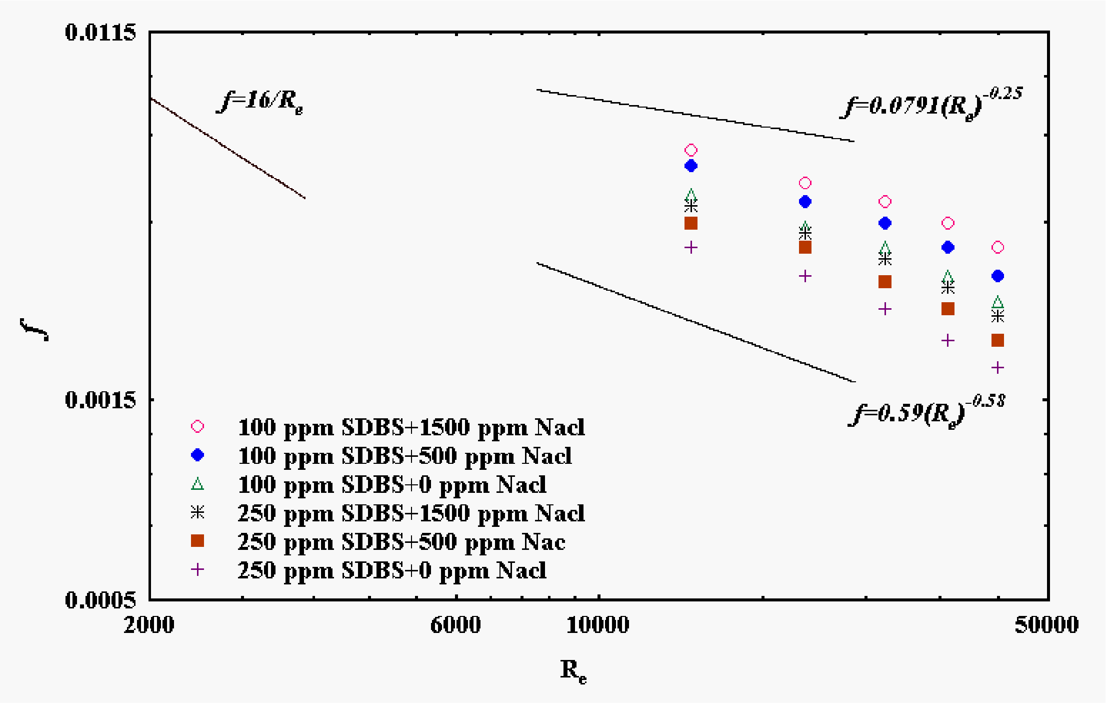
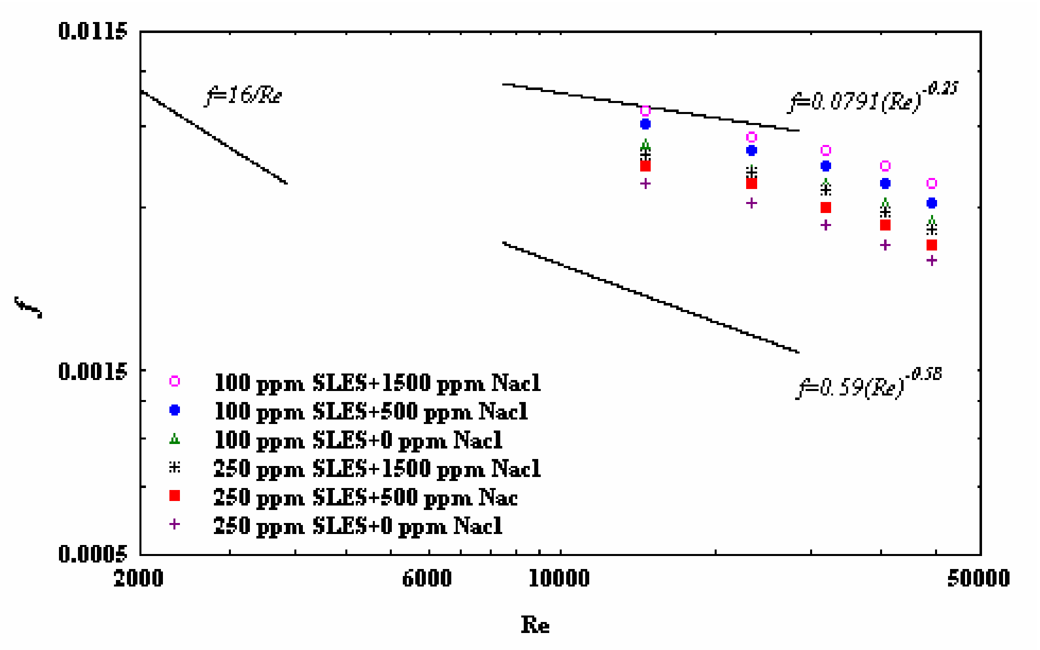


Figure (4.21) The Combined effect of SDBS and NaCl Concentrations on Friction Factor verses Reynolds number.



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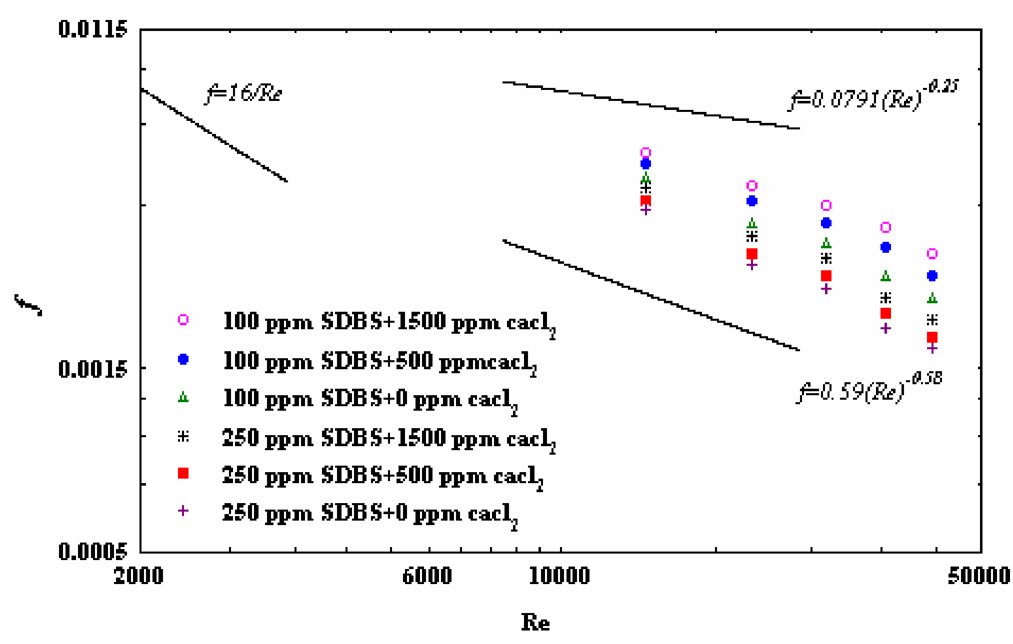

Figure (4.23) The Combined effect of SDBS and $CaCl_2$ Concentrations on Friction Factor verses Reynolds number.

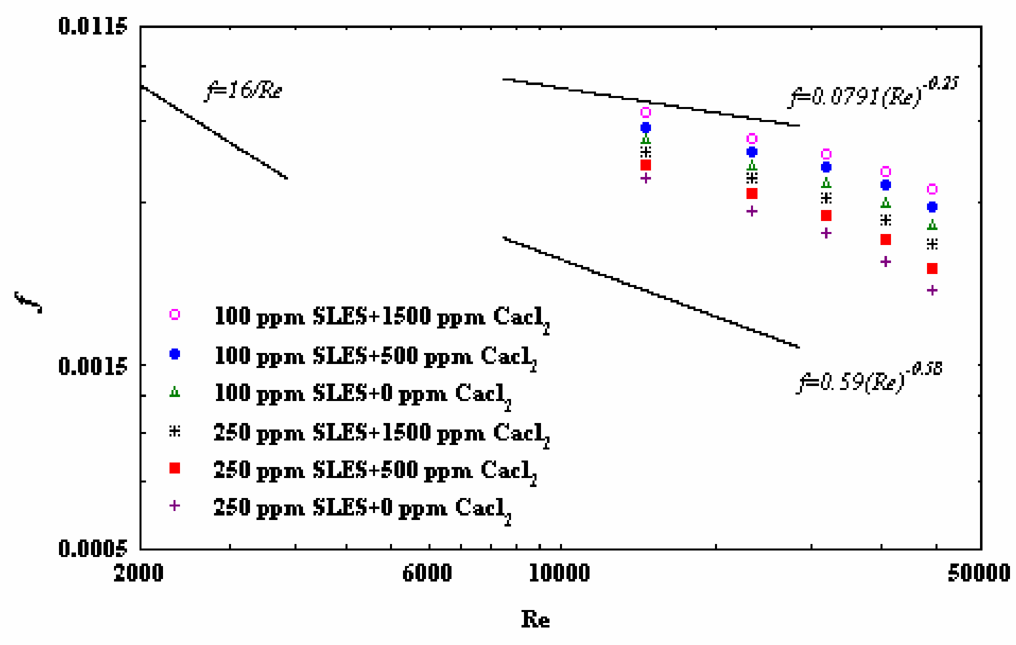

Figure (4.24) The Combined effect of SLES and $CaCl_2$ Concentrations on Friction Factor verses Reynolds number.

4.5 Throughput Increase

The data presented should be useful in the possible application of detergent drag – reducers for flow capacity increase throughput increases for flowing water. It is believed that the use of drag – reducers could be economic for increasing flow rate. Capacity of the working pipelines in particular some finite time of application. The percentage increase in the throughput, %TI, which is more practical term than the percentage drag-reduction for a given pipeline, can be estimated by equation (3.4) [88]:

$$\%TI = \left(\frac{1}{\left(1 - \frac{\%Dr}{100}\right)^{0.55}} - 1 \right) \times 100 \qquad (3.4)$$

The results are illustrated in figures (4.25) and (4.26) for SDBS detergent and SLES detergent at different concentration and flow rates. These show clear that the addition of detergent drag-reducers improves the flow rate capacity of the flowing water. A noticeable increase of throughput was achieved by increasing the surfactants concentration and fluid flow rate. Furthermore the percentage throughput increase values obtained with SDBS are usually higher than those with SLES detergent for all concentrations and flow rates studied. These are due to the fact that SDBS is more effective than SLES as drag – reducers. The maximum throughput increase within the condition studied, were 30.49% and 22.42% for SDBS and SLES detergents respectively , at 250ppm concentration and 6.0 m^3/hr flow rate.

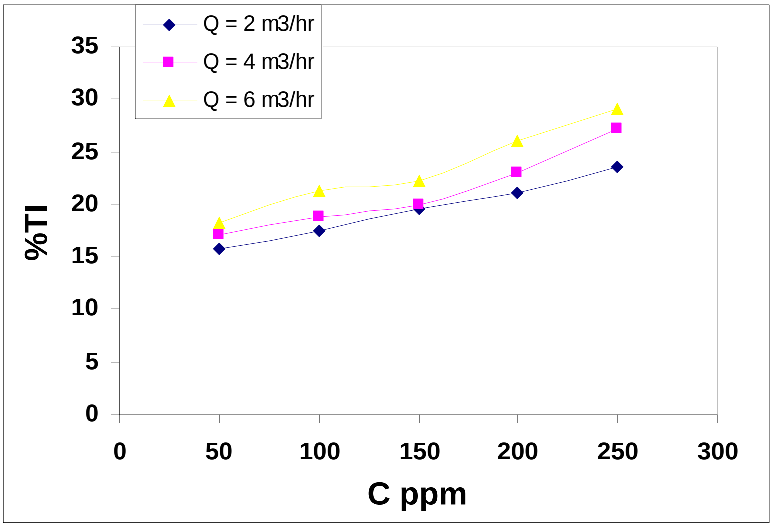

Figure (4.25) Throughput Increase at Different Concentrations and Flow Rates for SDBS Detergents.

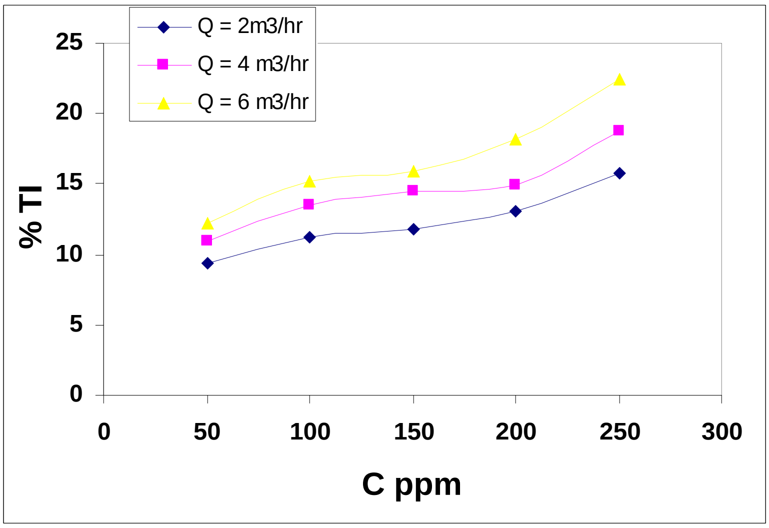

Figure (4.26) Throughput Increase at Different Concentrations and Flow Rates for SLES Detergents.

The flow capacity of saline water was analyzed for both salts, NaCl and $CaCl_2$, as show in figures (4.27) and (4.28) for SDBS and SLES detergent treated fluid. As shown in these figures, percent throughput increase decreases proportionally with increase of salinity. These results may be attributed to inhibition effect and material salts on drag- reduction performance of SDBS and SLES detergents as drag- reducers. It could be observed that calcium chloride is the more effective inhibitors than sodium chloride, mainly at high concentration.

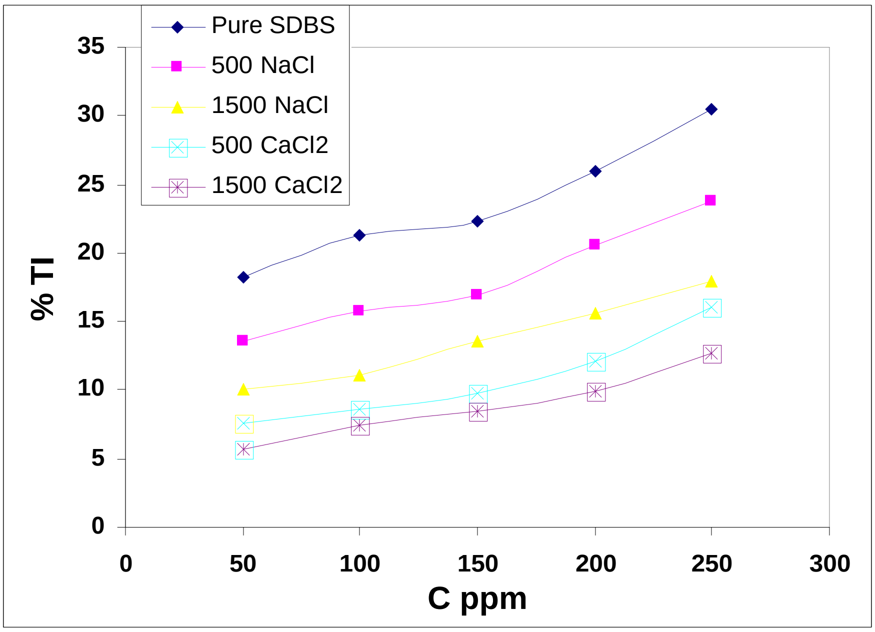

Figure (4.27) Effect of NaCl and $CaCl_2$ addition on Throughput Increase of flowing Water by using SDBS detergent at flow rate 6.0 m^3/hr.

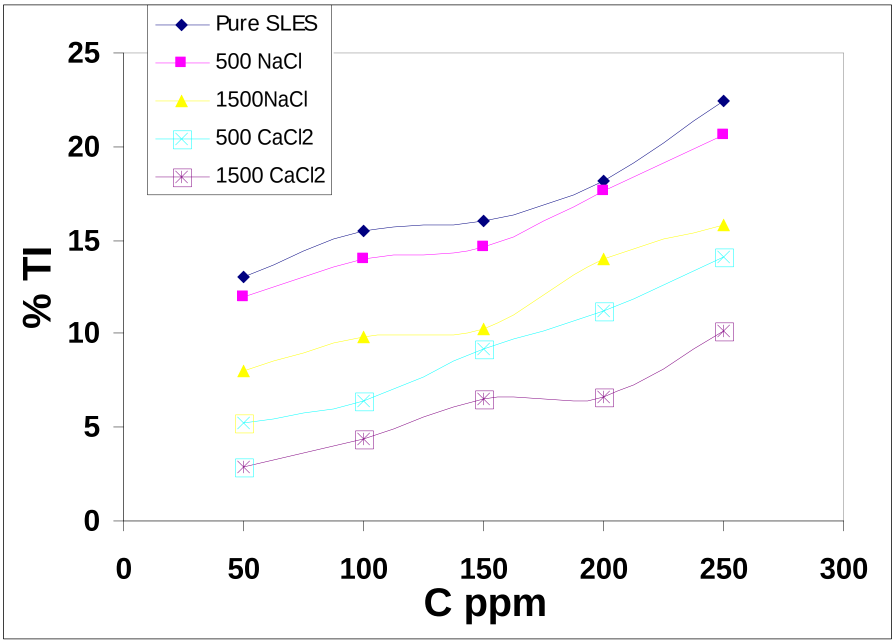

Figure (4.28) Effect of NaCl and $CaCl_2$ addition on Throughput Increase of flowing Water by using SLES detergent at flow rate 6.0 m^3/hr.

4.6 Correlation

The experimental results show, that the drag – reduction efficiency is to be a function of detergent type, detergent concentration and the degree of turbulence (solvent flow rate), while the addition of salt addition has an inverse effect. The primary end use of drag reducers is usually to increase the flow capacity without exceeding the safe pressure limits within the piping systems.

Therefore, it was useful to find a correlation to predict the drag-reduction values based on the above mentioned flow conditions.

A simple relationship that has been found to be satisfactory relates the percentage drag- reduction and the flow conditions, starting with the following functionality:

$$\%DR = f(Q, C) \tag{4.1}$$

Where:

%DR=drag reduction percent, ***Q***=flow rate (m^3/hr), ***C***=additive concentration (ppm). Equation (4.2) for each surfactant (SDBS and SLES).

$$\%DR=A1*Q^{A2}+C\times A3+A4 \tag{4.2}$$

For two types of surfactants it's observed:

$$\%DR = f(Q, C, M) \tag{4.3}$$

Therefore, by applying statistica software (Qusi Newton) method It can be reach to the following equation:

$$\%DR=A1\times Q^{A2}+C\times A3+W\times A4+A5 \tag{4.4}$$

Where:

%DR=drag reduction percent, ***Q***=flow rate (m^3/hr), ***C***=additive concentration (ppm) and M=additive molecular weight (kg/mole).

A computer program was used to find the values of constants ***A1*** through ***A5*** that give the best fitting of the experimental data. The coefficients for each detergent type, SDBS and SLES additives are tabulated in table (4.1).

Table (4.4) values of the corrleations coefficients

Additive type	**Constants**					**Variance (*V* %)**	**Correlation coefficient (*R**)**
SDBS	**A1**	**A2**	**A3**	**A4**	**A5**		
	0.595103	**1.321664**	**0.049959**	**7.655491**		**0.9864**	**96.892**
SLES	**0.675535**	**1.265388**	**0.045648**	**4.18579**		**0.97252**	**98.590**
SDBS+SLES	**0.634001**	**1.293464**	**0.047804**	**-164.486**	**65.1372**	**0.9918**	**97.219**

Figures (29), (4.30), and (4.31) summarized the relation between the values of ***(%DR***) taken from experimental data and the predicted values from the mathematical correlation for SDBS, SLES and all data consequently. It can be noticed that most of the points lie with in ±10%, of the unit slope straight line.

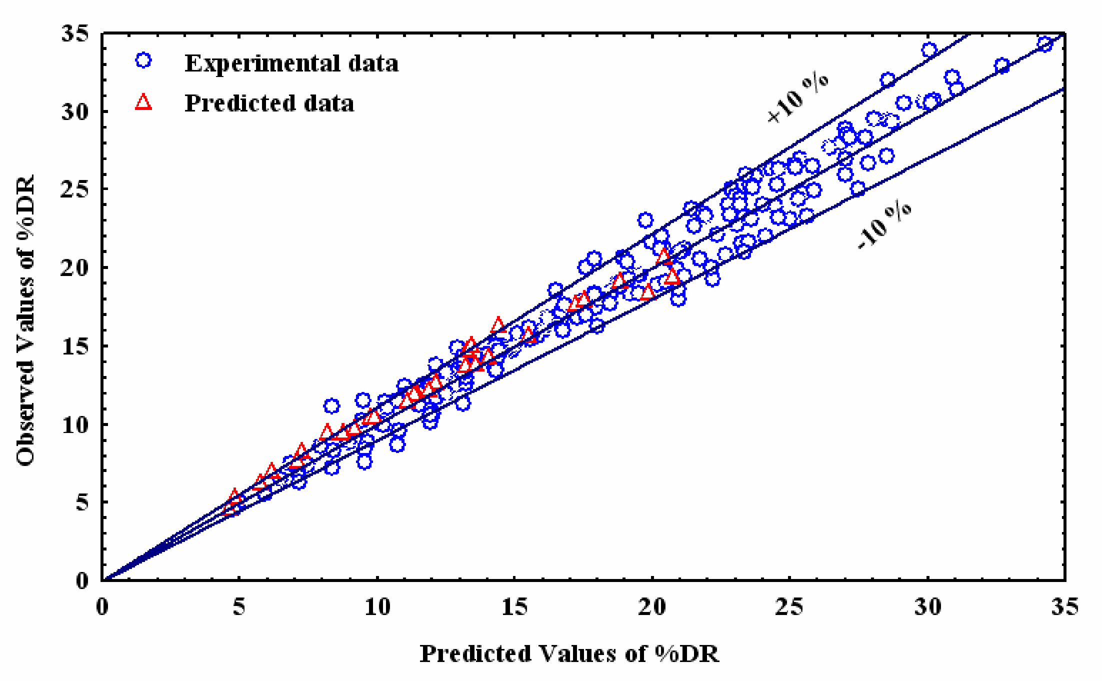

Figure (4.29) Predicted values vs. Observed values of drag reduction for SDBS

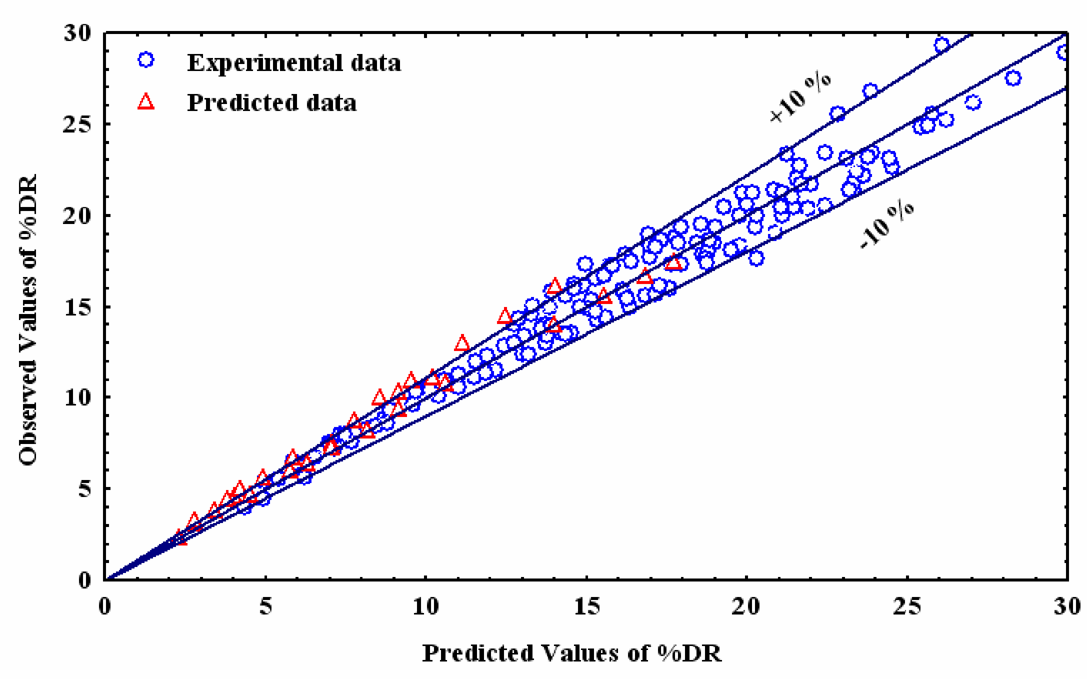

Figure (4.30) Predicted values vs. Observed values of drag reduction for SLES

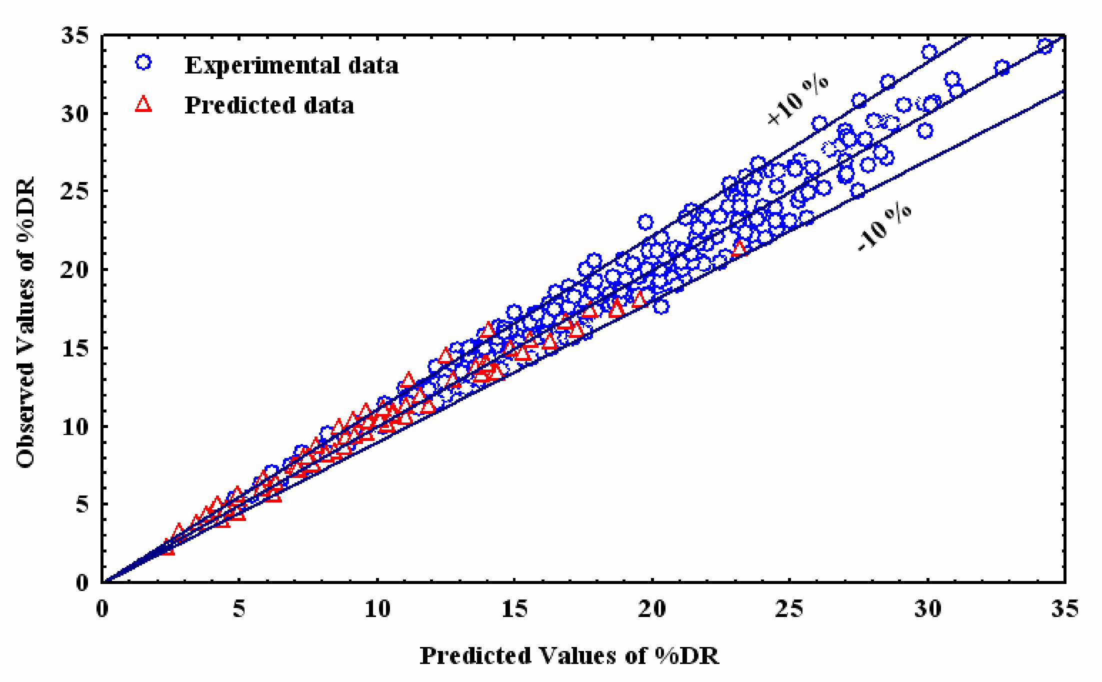

Figure (4.31) Predicted values vs. Observed values of drag reduction for All Experimental values

Chapter Five

5.1 Conclusions

1. The anionic surfactants (SDBS, SLES) are found to be effective drag reducing agent in turbulent water pipelining. SDBS detergent is more efficient than SLES detergent due to the difference in there molecular structure.
2. Percentage drag reduction or percentage flow increase percent are found to increase gradual by increasing the solution velocity represented by Reynolds number.

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

4. By using SDBS anionic surfactant with tap water, the flow rate in pipelines could be increased up to 32% without making any change in the flow system. Therefore, the cost of pumping water could be reduced by in an appreciable percentage.

5. The presence of sodium chloride and calcium chloride is small amount act as detergent as drag – reducers agents, due to the decrease of shear stability of micelles structure.

6. Calcium chloride presence in flowing water cause more inhibition of detergent drag – reducing effectiveness, due also to forming of insoluble salts with anionic detergents.

7. The friction factor values for pure solvents (water) and with sodium chloride and calcium chloride are distributed at or near Blasius asymptote suggested for Newtonian flow. After the addition of small

amount of additives, the friction factor values become lower and positioned toward Virk maximum drag reduction asymptote.

8. A simple correlation was suggested to predict the percentage drag – reduction as function of detergent molecular weight and concentration, salt molecular weight and concentration and water flow rate. The correlation equation results a good agreement between theoretical and experimental data.

5.2 Recommendations for further work

1. An extension of this work would be a comparable study by using different types of surfactants, including anionic – cationic and nonionic surfactants, as drag – reducers agents in flowing water.

2. A further study deals with investigation of surfactants drag – reducers in flowing of crude oils and petroleum fractions.

3. An investigating study would be to investigate the shear stability of surfactants under different flowing conditions.

4. An obvious area for future work is to study the effect of different salts and insoluble matter addition on performance of surfactants as drag – reducers.

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Appendices

Table, A.1 Experimental data for pure SDBS surfactant dissolved in water flowing in 0.0508 m I.D. pipe

Conc.* *ppm	***Re***	***Q* m^3/hr**	***%Dr***	***f***	***%TI***
50	13924.484	2.00	23.33	0.00451	15.73
	20886.727	3.00	23.77	0.00412	16.10
	27848.969	4.00	25.00	0.003511	17.14
	34811.211	5.00	25.83	0.00292	17.86
	41173.4530	6.00	26.31	0.00283	18.28
100	13924.484	2.00	25.33	0.004832	17.43
	20886.727	3.00	26.28	0.00441	18.26
	27848.969	4.00	27.00	0.00382	18.90
	34811.211	5.00	28.64	0.00320	20.39
	41173.4530	6.00	29.54	0.00311	21.24
150	13924.484	2.00	27.67	0.00514	19.5
	20886.727	3.00	28.00	0.00471	19.8
	27848.969	4.00	28.20	0.00414	19.99
	34811.211	5.00	29.43	0.00357	21.13
	41173.4530	6.00	30.62	0.00346	22.27
200	13924.484	2.00	29.33	0.00542	21.04
	20886.727	3.00	30.68	0.0054	22.33
	27848.969	4.00	31.40	0.00443	23.03
	34811.211	5.00	32.86	0.00381	24.50
	41173.4530	6.00	34.31	0.00379	26.00
250	13924.484	2.00	32.00	0.00570	23063
	20886.727	3.00	33.94	0.00534	25.61
	27848.969	4.00	35.50	0.00475	27.27
	34811.211	5.00	37.20	0.00417	29.16
	41173.4530	6.00	38.36	0.0041	30.49

Table, A.2 Experimental data for pure SLES surfactant dissolved in water flowing in 0.0508 m I.D. pipe

Conc. ppm	***Re***	***Q*** **m^3/hr**	***%Dr***	***f***	***%TI***
50	13924.484	2.00	15.00	0.00461	9.35
	20886.727	3.00	16.17	0.00412	10.19
	27848.969	4.00	17.20	0.00363	10.94
	34811.211	5.00	17.84	0.00324	11.41
	41173.4530	6.00	18.92	0.00292	12.23
100	13924.484	2.00	17.66	0.00491	11.28
	20886.727	3.00	19.00	0.00447	12.29
	27848.969	4.00	20.50	0.00395	13.45
	34811.211	5.00	21.40	0.00358	14.16
	41173.4530	6.00	22.60	0.00321	15.13
150	13924.484	2.00	18.33	0.00522	11.78
	20886.727	3.00	20.38	0.00476	13.35
	27848.969	4.00	21.80	0.00427	14.48
	34811.211	5.00	22.19	0.00389	14.80
	41173.4530	6.00	23.08	0.00351	15.53
200	13924.484	2.00	20.00	0.00553	13.06
	20886.727	3.00	20.44	0.0058	13.40
	27848.969	4.00	22.40	0.00452	14.97
	34811.211	5.00	25.21	0.00417	17.32
	41173.4530	6.00	26.15	0.00382	18.14
250	13924.484	2.00	23.33	0.00585	15.73
	20886.727	3.00	25.51	0.00538	17.58
	27848.969	4.00	26.80	0.00489	18.72
	34811.211	5.00	29.31	0.00441	21.02
	41173.4530	6.00	30.77	0.00414	22.42

Table, A.3 Experimental data for SDBS surfactant after 500 ppm of NaCl salt addition dissolved in water flowing in 0.0508 m I.D. pipe

Conc. ppm	***Re***	***Q*** **m^3/hr**	***%Dr***	***f***	***%TI***
50	13924.484	2.00	14.38	0.00511	8.91
	20886.727	3.00	15.51	0.00445	9.71
	27848.969	4.00	17.82	0.00352	11.40
	34811.211	5.00	19.56	0.00356	12.72
	41173.4530	6.00	20.66	0.00275	13.57
100	13924.484	2.00	18.50	0.00528	11.91
	20886.727	3.00	19.52	0.00421	12.69
	27848.969	4.00	20.59	0.00373	13.52
	34811.211	5.00	21.17	0.00324	13.98
	41173.4530	6.00	23.33	0.00296	15.73
150	13924.484	2.00	22.13	0.00549	14.75
	20886.727	3.00	22.72	0.00441	15.23
	27848.969	4.00	23.12	0.00393	15.56
	34811.211	5.00	23.90	0.00345	16.21
	41173.4530	6.00	24.73	0.00317	16.91
200	13924.484	2.00	24.43	0.00563	16.66
	20886.727	3.00	26.00	0.00462	18.01
	27848.969	4.00	26.65	0.00416	18.59
	34811.211	5.00	27.17	0.00367	19.05
	41173.4530	6.00	28.90	0.00331	20.63
250	13924.484	2.00	25.15	0.00581	17.27
	20886.727	3.00	26.60	0.00484	18.54
	27848.969	4.00	28.50	0.00439	21.26
	34811.211	5.00	30.50	0.00382	22.15
	41173.4530	6.00	32.20	0.00355	23.83

Table, A.4 Experimental data for SDBS surfactant after1000 ppm of NaCl salt addition dissolved in water flowing in 0.0508 m I.D. pipe

Conc. ppm	***Re***	***Q*** **m^3/hr**	***%Dr***	***f***	***%TI***
50	13924.484	2.00	14.00	0.005405	8.65
	20886.727	3.00	15.00	0.005183	9.35
	27848.969	4.00	17.00	0.004470	10.79
	34811.211	5.00	17.90	0.004805	11.46
	41173.4530	6.00	19.00	0.003708	12.29
100	13924.484	2.00	17.95	0.0052567	11.49
	20886.727	3.00	18.55	0.0048719	11.95
	27848.969	4.00	20.00	0.004218	13.06
	34811.211	5.00	20.59	0.004516	13.52
	41173.4530	6.00	23.00	0.003444	15.46
150	13924.484	2.00	20.67	0.004943	13.58
	20886.727	3.00	21.68	0.004632	14.39
	27848.969	4.00	22.00	0.003918	14.64
	34811.211	5.00	23.45	0.004386	15.83
	41173.4530	6.00	24.62	0.003240	16.82
200	13924.484	2.00	23.33	0.004702	15.73
	20886.727	3.00	24.08	0.004306	16.36
	27848.969	4.00	24.40	0.037326	16.63
	34811.211	5.00	26.38	0.0032419	18.35
	41173.4530	6.00	28.31	0.0030654	20.09
250	13924.484	2.00	24.00	0.004571	16.29
	20886.727	3.00	25.31	0.004120	17.41
	27848.969	4.00	26.50	0.003590	18.45
	34811.211	5.00	28.31	0.002944	20.09
	41173.4530	6.00	30.56	0.002818	22.21

Table, A.5 Experimental data for SDBS surfactant after1500 ppm of NaCl salt addition dissolved in water flowing in 0.0508 m I.D. pipe

Conc. ppm	***Re***	***Q*** **m^3/hr**	***%Dr***	***f***	***%TI***
50	13924.484	2.00	11.40	0.005289	6.88
	20886.727	3.00	12.40	0.004600	7.55
	27848.969	4.00	13.82	0.003793	8.52
	34811.211	5.00	14.90	0.003288	9.28
	41173.4530	6.00	16.00	0.003141	10.06
100	13924.484	2.00	14.75	0.004980	9.17
	20886.727	3.00	15.60	0.0044541	9.78
	27848.969	4.00	16.35	0.003549	10.32
	34811.211	5.00	16.86	0.002956	10.69
	41173.4530	6.00	17.43	0.002822	11.11
150	13924.484	2.00	17.00	0.004507	10.79
	20886.727	3.00	17.76	0.0042502	11.35
	27848.969	4.00	18.35	0.0033414	11.80
	34811.211	5.00	19.88	0.0027306	12.96
	41173.4530	6.00	20.60	0.0025079	13.53
200	13924.484	2.00	18.38	0.0043662	11.82
	20886.727	3.00	18.94	0.0039480	12.24
	27848.969	4.00	19.12	0.0031401	12.38
	34811.211	5.00	21.61	0.0025278	14.33
	41173.4530	6.00	23.13	0.002345	15.57
250	13924.484	2.00	19.50	0.00413	12.67
	20886.727	3.00	20.81	0.003623	13.69
	27848.969	4.00	22.00	0.002935	14.64
	34811.211	5.00	25.00	0.002336	17.14
	41173.4530	6.00	26.00	0.002019	18.01

Table, A.6 Experimental data for SLES surfactant after 500 ppm of NaCl salt addition dissolved in water flowing in 0.0508 m I.D. pipe

Conc. ppm	***Re***	***Q*** **m^3/hr**	***%Dr***	***f***	***%TI***
50	13924.484	2.00	14.00	0.007653	8.65
	20886.727	3.00	14.54	0.006605	9.03
	27848.969	4.00	15.60	0.0062761	9.78
	34811.211	5.00	16.53	0.005752	10.45
	41173.4530	6.00	18.62	0.004966	12.00
100	13924.484	2.00	16.66	0.007412	10.54
	20886.727	3.00	17.46	0.064533	11.13
	27848.969	4.00	18.80	0.0059240	12.14
	34811.211	5.00	19.54	0.005575	12.70
	41173.4530	6.00	20.92	0.004750	13.78
150	13924.484	2.00	17.67	0.0071217	11.29
	20886.727	3.00	18.51	0.006159	11.92
	27848.969	4.00	20.60	0.0056946	13.53
	34811.211	5.00	21.36	0.005347	14.13
	41173.4530	6.00	22.00	0.004548	14.64
200	13924.484	2.00	19.33	0.006867	12.54
	20886.727	3.00	20.00	0.0059870	13.06
	27848.969	4.00	21.20	0.005348	14.00
	34811.211	5.00	23.12	0.005127	15.56
	41173.4530	6.00	25.54	0.004315	17.61
250	13924.484	2.00	21.67	0.006610	14.38
	20886.727	3.00	23.46	0.005643	15.84
	27848.969	4.00	24.80	0.005162	16.97
	34811.211	5.00	27.48	0.004670	19.33
	41173.4530	6.00	28.92	0.004198	20.65

Table, A.7 Experimental data for SLES surfactant after 1000 ppm of NaCl salt addition dissolved in water flowing in 0.0508 m I.D. pipe

Conc. ppm	***Re***	**Q m^3/hr**	***%Dr***	***f***	***%TI***
50	13924.484	2.00	12.33	0.006707	7.51
	20886.727	3.00	12.81	0.0065746	7.83
	27848.969	4.00	13.40	0.0056120	8.23
	34811.211	5.00	14.01	0.0051768	8.66
	41173.4530	6.00	15.38	0.004572	9.62
100	13924.484	2.00	14.33	0.0065524	8.88
	20886.727	3.00	15.01	0.0063172	9.36
	27848.969	4.00	15.80	0.0054729	9.92
	34811.211	5.00	17.31	0.0047355	11.02
	41173.4530	6.00	18.46	0.004382	11.88
150	13924.484	2.00	14.90	0.006301	9.28
	20886.727	3.00	15.90	0.0061940	9.99
	27848.969	4.00	17.30	0.052484	11.01
	34811.211	5.00	18.50	0.0045206	22.91
	41173.4530	6.00	20.46	0.004193	13.42
200	13924.484	2.00	17.33	0.006150	11.03
	20886.727	3.00	17.90	0.005918	11.46
	27848.969	4.00	18.00	0.004970	11.53
	34811.211	5.00	19.31	0.0043104	12.53
	41173.4530	6.00	21.69	0.0039377	14.39
250	13924.484	2.00	18.67	0.005811	12.04
	20886.727	3.00	20.00	0.00579	13.06
	27848.969	4.00	21.00	0.004656	13.84
	34811.211	5.00	23.21	0.004125	15.63
	41173.4530	6.00	24.92	0.003714	17.07

Table, A.8 Experimental data for SLES surfactant after 1500 ppm of NaCl salt addition dissolved in water flowing in 0.0508 m I.D. pipe

Conc. ppm	***Re***	***Q*** **m^3/hr**	***%Dr***	***f***	***%TI***
50	13924.484	2.00	11.13	0.0064898	6.70
	20886.727	3.00	11.48	0.0059616	6.94
	27848.969	4.00	11.53	0.0054532	6.97
	34811.211	5.00	12.41	0.0047428	7.56
	41173.4530	6.00	13.00	0.0044472	7.96
100	13924.484	2.00	11.50	0.006286	6.95
	20886.727	3.00	12.40	0.005600	7.55
	27848.969	4.00	13.59	0.005297	8.37
	34811.211	5.00	14.28	0.0045398	8.84
	41173.4530	6.00	15.60	0.0042147	9.78
150	13924.484	2.00	14.38	0.0059792	8.91
	20886.727	3.00	15.00	0.005452	9.35
	27848.969	4.00	15.65	0.004961	9.81
	34811.211	5.00	16.00	0.0043770	10.06
	41173.4530	6.00	16.23	0.003938	10.23
200	13924.484	2.00	16.00	0.005739	10.06
	20886.727	3.00	17.21	0.005212	10.95
	27848.969	4.00	18.35	0.004614	11.80
	34811.211	5.00	19.31	0.004116	12.53
	41173.4530	6.00	21.23	0.003770	14.03
250	13924.484	2.00	18.25	0.005581	11.72
	20886.727	3.00	20.41	0.004924	13.38
	27848.969	4.00	21.24	0.004461	14.03
	34811.211	5.00	22.68	0.003904	15.20
	41173.4530	6.00	23.40	0.003512	15.79

Table, A.9 Experimental data for SDBS surfactant after 500 ppm of $CaCl_2$ salt addition dissolved in water flowing in 0.0508 m I.D. pipe

Conc. ppm	*Re*	*Q* m^3/hr	*%Dr*	*f*	*%TI*
50	13924.484	2.00	7.48	0.0063811	4.37
	20886.727	3.00	8.61	0.0051752	5.08
	27848.969	4.00	10.22	0.0047672	6.11
	34811.211	5.00	11.90	0.0041535	7.22
	41173.4530	6.00	12.50	0.0039509	7.62
100	13924.484	2.00	11.06	0.0061702	6.66
	20886.727	3.00	11.86	0.0049689	7.19
	27848.969	4.00	12.45	0.0045630	7.59
	34811.211	5.00	13.56	0.0039506	8.34
	41173.4530	6.00	13.93	0.0037485	8.60
150	13924.484	2.00	12.00	0.0059674	7.28
	20886.727	3.00	12.84	0.0047671	7.85
	27848.969	4.00	13.68	0.0043607	8.43
	34811.211	5.00	14.50	0.0037489	9.00
	41173.4530	6.00	15.32	0.0035461	9.58
200	13924.484	2.00	14.55	0.005696	9.03
	20886.727	3.00	14.91	0.0045631	9.29
	27848.969	4.00	15.41	0.004175	9.64
	34811.211	5.00	16.71	0.0035451	10.58
	41173.4530	6.00	18.81	0.0033401	12.14
250	13924.484	2.00	15.00	0.005320	9.35
	20886.727	3.00	18.00	0.004381	11.53
	27848.969	4.00	21.00	0.003877	13.84
	34811.211	5.00	24.00	0.003334	16.29
	41173.4530	6.00	27.00	0.003121	18.90

Table, A.10 Experimental data for SDBS surfactant after 1000 ppm of $CaCl_2$ salt addition dissolved in water flowing in 0.0508 m I.D. pipe

Conc. ppm	***Re***	***Q*** **m^3/hr**	***%Dr***	***f***	***%TI***
50	13924.484	2.00	5.00	0.002886	2.86
	20886.727	3.00	6.50	0.001792	3.77
	27848.969	4.00	8.90	0.001696	5.26
	34811.211	5.00	10.10	0.001566	6.03
	41173.4530	6.00	11.70	0.001523	7.08
100	13924.484	2.00	7.39	0.002814	4.31
	20886.727	3.00	8.86	0.001747	5.23
	27848.969	4.00	10.00	0.001676	5.79
	34811.211	5.00	11.25	0.001546	6.78
	41173.4530	6.00	12.50	0.001509	7.62
150	13924.484	2.00	11.74	0.005382	7.11
	20886.727	3.00	12.00	0.0045687	7.28
	27848.969	4.00	12.64	0.004127	7.72
	34811.211	5.00	13.58	0.0039505	8.36
	41173.4530	6.00	14.55	0.0031474	9.03
200	13924.484	2.00	13.32	0.005134	8.18
	20886.727	3.00	13.91	0.0043650	8.59
	27848.969	4.00	15.05	0.0038582	9.39
	34811.211	5.00	15.81	0.0037467	9.93
	41173.4530	6.00	16.86	0.0029434	10.69
250	13924.484	2.00	14.55	0.004881	9.03
	20886.727	3.00	17.77	0.004126	11.36
	27848.969	4.00	18.00	0.003648	11.53
	34811.211	5.00	19.21	0.003503	12.45
	41173.4530	6.00	20.73	0.002721	13.63

Table, A.11Experimental data for SDBS surfactant after 1500 ppm of $CaCl_2$ salt addition dissolved in water flowing in 0.0508 m I.D. pipe

Conc. ppm	*Re*	**Q m^3/hr**	*%Dr*	*f*	*%TI*
50	13924.484	2.00	4.68	0.005396	2.67
	20886.727	3.00	5.43	0.0047813	3.12
	27848.969	4.00	7.00	0.0041732	4.07
	34811.211	5.00	8.34	0.0035597	4.91
	41173.4530	6.00	9.50	0.003361	5.64
100	13924.484	2.00	6.30	0.005147	3.64
	20886.727	3.00	7.70	0.0045769	4.51
	27848.969	4.00	9.49	0.0039685	5.64
	34811.211	5.00	10.51	0.0033559	6.30
	41173.4530	6.00	12.20	0.0031515	7.42
150	13924.484	2.00	9.79	0.004941	5.83
	20886.727	3.00	10.50	0.0043715	6.29
	27848.969	4.00	11.96	0.0037639	7.26
	34811.211	5.00	12.68	0.0031521	7.74
	41173.4530	6.00	13.80	0.0028487	8.51
200	13924.484	2.00	11.48	0.004789	6.94
	20886.727	3.00	12.25	0.004182	7.45
	27848.969	4.00	13.93	0.0035603	8.60
	34811.211	5.00	14.34	0.002992	8.89
	41173.4530	6.00	15.76	0.0026453	9.89
250	13924.484	2.00	14.77	0.00452	9.19
	20886.727	3.00	15.11	0.003731	9.43
	27848.969	4.00	16.39	0.003311	10.35
	34811.211	5.00	18.42	0.002734	11.85
	41173.4530	6.00	19.47	0.002451	12.65

Table, A.12 Experimental data for SLES surfactant after 500 ppm of $CaCl_2$ salt addition dissolved in water flowing in 0.0508 m I.D. pipe

Conc. *ppm*	*Re*	*Q* m^3/hr	*%Dr*	*f*	*%TI*
50	13924.484	2.00	4.53	0.00691	2.58
	20886.727	3.00	5.60	0.00632	3.22
	27848.969	4.00	6.70	0.005955	3.89
	34811.211	5.00	8.33	0.005498	4.90
	41173.4530	6.00	8.84	0.004910	5.22
100	13924.484	2.00	6.34	0.006643	3.67
	20886.727	3.00	7.21	0.00668	4.20
	27848.969	4.00	8.45	0.005721	4.98
	34811.211	5.00	9.60	0.005270	5.71
	41173.4530	6.00	10.71	0.004416	6.43
150	13924.484	2.00	7.57	0.006434	4.42
	20886.727	3.00	8.64	0.005881	5.10
	27848.969	4.00	10.13	0.005542	6.05
	34811.211	5.00	13.38	0.00553	8.22
	41173.4530	6.00	14.76	0.004211	9.18
200	13924.484	2.00	10.60	0.006269	6.36
	20886.727	3.00	11.36	0.005637	6.86
	27848.969	4.00	13.56	0.005220	8.34
	34811.211	5.00	15.41	0.004738	9.64
	41173.4530	6.00	17.64	0.00441	11.26
250	13924.484	2.00	13.48	0.00617	8.29
	20886.727	3.00	16.16	0.005381	10.18
	27848.969	4.00	17.43	0.00540	11.11
	34811.211	5.00	18.08	0.00442	11.59
	41173.4530	6.00	21.37	0.003718	14.14

Table, A.13 Experimental data for SLES surfactant after 1000 ppm of $CaCl_2$ salt addition dissolved in water flowing in 0.0508 m I.D. pipe

Conc. ppm	***Re***	***Q*** **m^3/hr**	***%Dr***	***f***	***%TI***
50	13924.484	2.00	4.00	0.004717	2.27
	20886.727	3.00	4.50	0.0041830	2.56
	27848.969	4.00	5.68	0.003556	3.27
	34811.211	5.00	6.50	0.0029629	3.77
	41173.4530	6.00	8.00	0.002787	4.69
100	13924.484	2.00	5.42	0.004574	3.11
	20886.727	3.00	6.43	0.003979	3.72
	27848.969	4.00	7.50	0.00332	4.38
	34811.211	5.00	8.00	0.002703	4.69
	41173.4530	6.00	10.31	0.002547	6.17
150	13924.484	2.00	7.45	0.004312	4.35
	20886.727	3.00	9.34	0.003538	5.54
	27848.969	4.00	10.55	0.003166	6.32
	34811.211	5.00	11.00	0.0025150	6.62
	41173.4530	6.00	11.97	0.002319	7.26
200	13924.484	2.00	10.45	0.004121	6.26
	20886.727	3.00	11.32	0.003300	6.83
	27848.969	4.00	13.00	0.0029620	7.96
	34811.211	5.00	13.80	0.0023502	8.51
	41173.4530	6.00	14.96	0.0021467	9.32
250	13924.484	2.00	13.97	0.003912	8.63
	20886.727	3.00	14.00	0.00310	8.65
	27848.969	4.00	15.57	0.00279	9.76
	34811.211	5.00	16.68	0.00213	10.56
	41173.4530	6.00	17.46	0.001821	11.13

Table, A.14 Experimental data for SLES surfactant after 1500 ppm of $CaCl_2$ salt addition dissolved in water flowing in 0.0508 m I.D. pipe

Conc. ppm	***Re***	***Q*** **m^3/hr**	***%Dr***	***f***	***%TI***
50	13924.484	2.00	2.32	0.0031968	1.30
	20886.727	3.00	3.14	0.0037856	1.77
	27848.969	4.00	3.86	0.003390	2.19
	34811.211	5.00	4.64	0.0027661	2.65
	41173.4530	6.00	5.00	0.0026639	2.86
100	13924.484	2.00	3.26	0.002939	1.84
	20886.727	3.00	4.43	0.0035832	2.52
	27848.969	4.00	5.68	0.003156	3.27
	34811.211	5.00	6.71	0.0025625	3.89
	41173.4530	6.00	7.50	0.0023596	4.38
150	13924.484	2.00	4.71	0.003395	2.69
	20886.727	3.00	6.00	0.0031802	3.46
	27848.969	4.00	7.30	0.0028726	4.26
	34811.211	5.00	9.40	0.0023578	5.58
	41173.4530	6.00	10.82	0.002138	6.50
200	13924.484	2.00	6.42	0.0031843	3.72
	20886.727	3.00	8.25	0.0028758	4.85
	27848.969	4.00	8.76	0.0025699	5.17
	34811.211	5.00	10.38	0.0021561	6.21
	41173.4530	6.00	11.00	0.001935	6.62
250	13924.484	2.00	10.00	0.002812	5.97
	20886.727	3.00	11.15	0.002510	6.72
	27848.969	4.00	13.00	0.00239	7.96
	34811.211	5.00	14.51	0.001913	9.01
	41173.4530	6.00	16.14	0.001621	10.17

الخلاصه

تم دراسه تقليل الاعاقه الاضطرابي في منظومه جريان مغلقة للماء بوجود نوعين من معاملات التوتر السطحي (SDBS) و (SLES) قد تم الحصول علىالجريان الاضطرابي بواسطه مضخه الازاحه الموجيه لتجنب الانحلال الميكانيكي لسلاسل معاملات التوتر السطحي. نتائج تقليل الاعاقة قيمت بقياس هبوط الضغط على ٢ م مقطع اختبار.

تم اختبار تأثير تركيز المنظفات بحدود بين ٥٠ ــ ٢٥٠ جزء بالمليون وزنا في ماء الاساله بسرعه الجريان من ٢ ــ ٦ م^{3}/ ساعة با نبوب جريان ذو قطر ٢ انج. يحصل زيادة مستمرة في تقليل الاعاقه بزياده تركيز المنظف المضاف وسرعة جريان الماء التي تصل الى ٣٨،٣٦ % تقليل اعاقه و ٣٠،٤٩ % طاقه انتاجية. اظهرت النتائج ان منظف SDBS يعطي زياده في قيم تقليل الاعاقه ولذا انها فعاله اكثر منها منظف SLES في الشرط القصوي. فعالية معاملات التوتر السطحي يمكن ان تنسب الى استقرار قص تركيب micelles كنتيجة للقضيب – شكل تشكيل micelles.

من اجل التحقيق في اداء معاملات التوتر السطحي كتقليل الاعاقة في تدفق الماء الملحي ، اجريت دراسات في وجود كميات صغيرة من كلوريد الصوديوم او الكالسيوم. لوحظ هبوط تدريجي من تأثير المنظف بزيادة تركيز الملح في الماء. هذه الملاحظة راجعا الى قله استقرار تركيب micelles كنتيجه لحضور الاملاح الايونية القويه. كلوريد الكالسيوم يسبب انخفاض اعلى على تقليل الاعاقه بتأثير المنظفات من كلوريد الصوديوم.كلوريد الكالسيوم مع المنظف غير ايوني العديم الذوبان يؤدي الى تعطيل تقليل الاعاقة.

تم حساب معامل الاحتكاك من النتائج العملية لتقليل الاعاقة. تقع قيم معامل الاحتكاك للماء الغير معامل باتجاه محاذي بلاسيوس (Blasius asymptotes) . بينما عند زيادة تركيز المنظف بعدد رينولدز عالي يسبب قله معاملات الاحتكاك باتجاه محاذي فيرك (Virk asymptote) والمقترح لاعلى درجات تقليل الاعاقه والذي لم يتم الوصول اليه. ان وجود كلوريد الصوديوم وكلوريد البوتاسيوم بكميات صغيره تظهرقيم باتجاه محاذي بلاسيوس(Blasius asymptotes) وتبين اقل فعاليه من المنظفات المضافة.

تم اقتراح معادلات تخمينية لتقدير تأثير معاملات منظومة الجريان، وهي الوزن الجزيئي للمنظفات المضافة ، التركيز، سرعه جريان الماء واخيرا تركيز الاملاح على تأثير تقليل الاعاقة على المنظفات الايونية. نتائج المعادلات تؤشر الى توافق كبير بين قيم نسبه تقليل الاعاقة المستحصله علميا والمحسوبة من المعادلات التخمينية بنسبه اعلى من ٩٤،٧٥٨ %.

شكر وتقدير

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

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

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

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

تأثير معامل فعالية السطح على معامل الاحتكاك في انبوب تدفق السوائل

رسالة
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في
الهندسة الكيمياوية

من قبل
رنا زهير محمد
بكالوريوس علوم في الهندسة الكيمياوية ٢٠٠٠

محرم ١٤٢٩
كانون الثاني ٢٠٠٨