FLOW ENHANCEMENT USING STRUCTURED PHYSICAL-CHEMICALLY INTERACTED POLYMER SURFACTANT COMPLEX

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We hereby declare that we have checked this thesis and, in our opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Doctor of Philosophy in Chemical Engineering.

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I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at University Malaysia Pahang or any other institutions.

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DEDICATION

In the name of Allah, The Most Gracious and The Most Merciful

I humbly dedicated this thesis to

My dear father; May Allah have mercy on him

My dear mother; God bless you

My dear wife; Hind

My lovely daughters; Sarah, Razan, and Farah;

My dear brother and my dear sister;

My remarkable family members,

My friends,

Who gave me everlasting inspiration, never ending encouragements, priceless support and pray without ceasing.

Thank you very much

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LIST OF SYMBOLS

^0C	Celsius
R^2	Coefficient of determination
C	Concentration
Ku	Cooperative binding constant
CAC	Critical aggregation concentration
ρ	Density
D	Diameter
ω	Disk rotational speed
y	Distance from the wall
D_w	Distilled water
DR	Drag reduction
ν	Dynamic viscosities
t_p	Flow time of the test solution through the capillary
t_w	Flow time of water through the capillary
U	Flow velocity
C_f	Friction coefficient
Hp	Hours power
ν	Kinematic viscosity
LEBD	Large eddy breakup devices
L	Length
ζ	Linear charge density factor
U	Local mean velocity
MDR	Maximum drag reduction
PH	Measure of hydrogen ion concentration
MSE	Measurement Science Enterprise
mg	Milligrams
mL	Millilitres
µm	Millimeter
Nm	Newton. Meter
ppm	Part per million
Cp	Polymer concentration

PSP	Polymer saturation point
ΔP	Pressure drop
DPT	Pressure drop measurement
η_r	Relative viscosity
rpm	Revolutions per minute
Re	Reynolds number
S	Standard deviation
Cs	Surfactant concentration
t	Time
T_d	Torque in the distilled water
T_s	Torque in the solution
τ_w	Wall shear stress

LIST OF ABBREVIATIONS

AMPS	2-Acrylamido-2-Methylpropane Sulfonic acid
NH4Cl	Ammonium chloride
BTAB	Benzyl trimethyl ammonium bromide
CMCp	Carboxymethylcellulose
CTAC	Cetyltrimethylammonium chloride
CAC	Critical aggregation concentration
CMC	Critical micelle concentration
AOT	Diethyl hexyl sulfosuccinate
DNS	Direct numerical simulations
DoP	Dodecyl pyridinium chloride
DTAB	Dodecyl trimethyl ammonium bromide
DRA	Drag reducer agent
DR	Drag reduction
ESR	Electron spin resonance
HTR	Heat transfer reduction
HTAC	Hexadecyl trimethyl ammonium chloride
CTAB	Hexadecyl trimethylammonium bromide
LEBD	Large eddy breakup devices
LDV	Laser Doppler velocimetry
MDR	Maximum drag reduction
MLDV	MicroPro laser doppler velocimetry
MW	Molecular weight
OTAC	Octadecyl Trimethyl Ammonium Chloride
ppm	Part per million
PIV	Particle image velocimetry
PLIF	Planar Laser Induced Fluorescence
PAA	Polyacrylic acid
PGAs	Polyethylene glycol
PEO	Polyethylene oxide
PIB	Polyisobutylene
PAM	Polyacrylamide

PSP	Polymer saturation point
PS	Polystyrene
PVP	Poly vinyl pyrrolidone
KCl	Potassium chloride
KNO3	Potassium nitrate
RDA	Rotating disk apparatus
SANS	Small-angle-neutron scattering
NaAc	Sodium acrylate
NaBr	Sodium bromide
Na2CO3	Sodium carbonate
NaCMC	Sodium Carboxymethylcellulose
NaCl	Sodium chloride
NaDxS	Sodium dextran sulfate
SDBS	Sodium dodecyl benzene sulfonate
SDS	Sodium Dodecyl Sulfate
NaOH	Sodium hydroxide
C17H33COONa	Sodium oleat
NaOA	Sodium oleate
NaPAsp	Sodium poly aspartate
NaPS	Sodium polystyrene sulfonate
NaSal	Sodium salicylate
TeP	Tetradecyl pyridinium chloride
TTAB	Tetradecyl trimethyl ammonium chloride
CARIFF	The Centre of Excellence for Advanced Research in Fluid Flow
Rh	The hydrodynamic radius
Rg	The radius of gyration
2D	Two dimensions
UDV	Ultrasound Doppler velocimetry
XG	Xanthan gum

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ABSTRAK

Dalam kajian ini, DR untuk kompleks surfaktan-polimer yang mempunyai caj dan kepekatan yang sama dan berbeza dikaji di dalam sistem akueus di bawah aliran gelora. ‘Co-polimer’ akrilamida dan natrium acrylate (PAM) yang merupakan polimer anionik dan polietilena oksida (PEO) yang merupakan polimer bukan ionik telah digunakan dalam kajian ini. Surfaktan yang digunakan dalam kajian ini adalah hexadecyl trimethyl ammonium klorida (HTAC) yang merupakan surfaktan kationik dan sodium dodecyl benzena sulfonate (SDBS) yang merupakan surfaktan anionik. Kesan gabungan kompleks mereka (PAM-SDBS, PAM-HTAC, PEO-SDBS dan PEO-HTAC) ke atas DR juga dikaji. Pendekatan baru bagi menentukan tahap DR melalui kawalan ciri-ciri fizikal polimer dan surfaktan dan kompleks mereka telah dijalankan dalam kajian ini. Kajian ini dibahagikan kepada empat fasa eksperimen iaitu: (i) uji kaji ke atas kekonduksian elektrik untuk menentukan julat interaksi dan kelikatan kinematik untuk menilai kemampuan interaksi polimer dan surfaktan yang ditambah; (ii) eksperimen menggunakan alat cakera yang berputar (RDA) untuk menilai kecekapan bahan tambahan dan kestabilan masing-masing di bawah kadar ricih dalam aplikasi DR; (iii) uji kaji untuk menguji prestasi peningkatan aliran kompleks polimer surfactant dari segi kadar aliran, kepekatan bahan tambahan, kepekatan pembentukan kompleks, kadar ricih, dan taburan halaju dalam aliran paip; (iv) eksperimen menggunakan MicroPro laser Doppler velocimeter MLDV MicroPro teknik untuk mengira halaju aliran dalam paip dan kemudahan aliran mana-mana saiz pada dinding dan (v) data eksperimen telah dilampirkan dalam bentuk ungkapan statistik menggunakan perisian SPSS. Kajian mengenai kekonduksian elektrik dan kelikatan menunjukkan bahawa walaupun interaksi antara polimer dan surfaktan adalah lebih ketara apabila dinilai menggunakan ujian kelikatan, perbezaan yang minimum pada data yang diperolehi dicatat pada kepekatan PEO yang tinggi. Hubungan yang kuat dapat diperhatikan antara kelikatan sistem dan prestasi DR yang dicatat. Secara amnya keputusan RDA dan aliran dalam paip menunjukkan polar yang berbeza berdasarkan kepada parameter polimer surfaktan. Terdapat kesan yang ketara pada kelikatan dan DR pada sistem aliran yang disebabkan oleh interaksi yang kuat antara caj yang bertentangan dengan polimer dan surfaktan. Rintangan degradasi bagi PEO didapati bertambah baik dengan penambahan surfaktan. Hasil kajian menunjukkan polar yang berbeza (kenaikan atau penurunan) dalam DR bergantung kepada pelbagai faktor seperti kepekatan polimer, kepekatan surfaktan, kombinasi kompleks, interaksi antara caj-caj, dan nisbah kepekatan polimer-surfaktan. Jumlah DR yang maksimum iaitu 54% diperoleh pada gabungan 40 ppm PEO dengan 100 ppm HTAC. Dalam interaksi antara kompleks menggunakan PEO dengan surfaktan, pengurangan DR diperhatikan meningkat selepas titik interaksi (CAC). Walau bagaimanapun, peningkatan dalam DR telah menunjukkan penurunan kembali, walaupun kepekatan itu masih di bawah titik SPS (titik akhir interaksi). Kajian MLDV menunjukkan bahawa perubahan dalam struktur bergelora adalah disebabkan oleh pengubahsuaian profil halaju di bahagian yang berhampiran dengan dinding apabila menambah surfaktan ‘micelle’ kepada rantaian polimer seperti yang dinyatakan dalam teori. Menurut imej morfologi menggunakan Cryo-TEM, interaksi antara polimer dan surfaktan pada pembentukan kompleks dapat diperhatikan dengan jelas dan ini menerangkan bagaimana kelakuan aliran dipertingkatkan seperti yang dilaporkan melalui keputusan RDA dan kajian aliran dalam paip. Kesimpulannya, untuk mendapatkan DR yang baik bagi sesuatu sistem aliran bendalir, kepekatan polimer dan surfaktan yang tepat harus dikekalkan apabila gabungan polimer-surfaktan digunakan.

ABSTRACT

In this study, the DR of surfactant-polymer complex at similar and different charges and concentrations in aqueous systems under turbulent flow was investigated. Copolymer of acrylamide and sodium acrylate (PAM) which are an anionic polymer and non-ionic polyethylene oxide (PEO) were used in this study. The surfactants used in the study are hexadecyl trimethyl ammonium chloride (HTAC) which is a cationic surfactant and sodium dodecyl benzene sulfonate (SDBS) which is an anionic surfactant. The effect of their complexes (PAM-SDBS, PAM-HTAC, PEO-SDBS, and PEO-HTAC) was also investigated for DR effect. A new approach for the determination of the limitations of DR through the control of the physical properties of the polymers and surfactant and their complexes were suggested in this study. This study is partitioned into five experimental phases which are: (i) experiments on the electrical conductivity to determine the interaction range, and the kinematic viscosity to evaluate the interaction behaviour of the additives; (ii) experiments using the rotating disk apparatus (RDA) to evaluate the efficiency of the additives and their respective stabilities under an extended shear rate in DR applications; (iii) experiments on testing the flow enhancement performance of the polymer-surfactant complexes in terms of the flow rate, additives concentrations, complexes formation concentrations, shear rate, and velocity distribution in pipe flow; (iv) experiments using the MicroPro laser Doppler velocimeter (MLDV) technique to calculate the flow velocity in the pipes and flow amenities of any size near to a wall and (v) experimental data were presented in term of statistically expression using statistical package for the social sciences (SPSS) software. The studies on the electrical conductivity and viscosity assessment showed that even though the interaction between the polymer and surfactant was more pronounced when evaluated using viscosity tests, a minimal deviation in the obtained data was observed at higher PEO concentrations. A strong relationship was observed between the viscosity of the system and the recorded DR performance. The results of the RDA and pipeline studies generally showed different patterns based on the polymer-surfactant parameters. There were pronounced effects on the viscosity and DR of the flow system which are mainly due to the strong interaction between the opposite charges of polymers and surfactants. The degradation resistance of PEO was found to improve with the addition of surfactants. The results showed a different trend (increase or decrease) in DR% depending on many parameters such as the polymer concentration, surfactant concentration, complex combination, charge interaction, and polymer-surfactant concentration ratio. A maximum DR of 54% was observed at a combination of 40 ppm of PEO with 100 ppm of HTAC. In the interaction of complexes using PEO with surfactant, the drag reduction was observed to increase after the interaction point critical aggregation concentration (CAC). However, the improvement in DR was noticed to decrease back again even when the concentration was still below the polymer saturation point (PSP). The MLDV studies showed that the change in the turbulent structure was due to the modification of the velocity profile in the region near the wall when adding micelle surfactants to the polymer chain which describes the theory. According to the morphology images using Cryo-Transmission electron microscopy (Cryo-TEM), the results have confirmed the interaction between polymer and surfactant on the formation of the complexes that clearly explains the enhanced flow behaviour reported by the RDA and the pipe studies. This study, concludes that there is a need to maintain the right concentration of the polymer and surfactant in the system for a better DR when using the combined polymer-surfactant approach.

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