

INVESTIGATING THE PERFORMANCE OF OKRA - NATURAL MUCILAGE  
COMPOUNDS AS FLOW IMPROVER IN PIPELINES CARRYING  
LIQUID – SOLID SOLUTION

MOHD AZIMIE BIN AHMAD

Thesis submitted in fulfilment of requirements  
for the award of degree of  
Master of Engineering in Chemical Engineering

Faculty of Chemical and Natural Resources Engineering  
UNIVERSITI MALAYSIA PAHANG

DECEMBER 2012

## ABSTRACT

During the transportation of liquids through pipelines, most of the pumping power will be lost or dissipated due to the turbulent mode these liquid are transported within. The addition of viscoelastic polymeric additives to the main flow inside the pipeline was one of the common solutions for such problem. Most of these additives (polymers) are artificial and not environmentally friendly and it can cause dramatic changes in the apparent physical properties of the transported liquid. The present work introduces a new soluble and environmentally friendly drag reducing agent extracted from the okra pods. Also, the present work introduces two, new insoluble drag reducing agents from natural resources (paddy husk and coconut meat husk). In order to achieve the objectives of this study, an experimental rig consists of different pipe diameters at 0.0127, 0.025 and 0.038 m internal diameter (ID) and section length at 0.5, 1.0, 1.5 and 2.0 m of galvanized iron pipes was built as closed loop circulation system. The particle size of suspended fibers (500 and 800  $\mu\text{m}$ ) was prepared using Fritsch Sieve Analysis System technique to enhance the contribution of the findings. The concentrations for suspended fibers are 100, 300 and 500 ppm and okra mucilage concentration at 100, 300, 500, 700 and 1000 ppm. From the drag reduction analysis, the okra-natural mucilage achieved 71 % drag reduction operated at Re equal to 11788 in pipe size equal to 0.0127 m ID at 1.5 m testing length, at 1000 ppm concentration and based on this results, okra-natural mucilage was marked as an efficient drag reducing agent compared to the suspended fibers. Besides, the suspended fibers named paddy husk fibers shows excellent performance as drag reducer which the maximum drag reduction achieved is 32 % operated at Re equal to 35363, particle size at 500  $\mu\text{m}$ , concentration at 500 ppm while coconut meat fibers capable to reduce the drag up to 42 % operated at Re equal to 35363, at the same concentration and particle size of paddy husk fibers. These results take place in pipe diameter of 0.025 m and at 1 m testing length. The combination of okra-natural mucilage at 1000 ppm with paddy husk and coconut meat fibers at the optimum condition (particle size 500  $\mu\text{m}$ , concentration 500 ppm) have produce the 60% and 43% drag reduction at Re equal to 11788 for coconut meat fibers and Re equal to 35363 for coconut meat husk in pipe size equal to 0.0127 m ID at 1.5 m testing length. The highest drag reduction percentage achieved in this research is 71% which means about 71% of power saving could be achieved. The formation of long carbon chain in natural polymers and interaction of fibers suspension among themselves in turbulent flow were identified as sources of drag reduction to occur. The statistical drag reduction correlation was modelled with experimental data using STATISTICA software. As a conclusion, new environmentally friendly drag reducing agents were successfully introduced to replace the existing additives used commercially and its effectiveness was proven in improving the flow.

## ABSTRAK

Semasa bendalir diangkut di dalam sistem perpaipan, kebanyakan tenaga mengepam akan hilang kerana gelora apabila bendalir mengalir. Penambahan bahan polimerik elastik ke dalam bendalir mengalir menjadi amalan biasa. Kebanyakan polimer ini tidak mesra alam dan semulajadi dan boleh mengubah sifat fizikal bendalir. Kajian semasa ini mengetengahkan satu bahan terlarut dan mesra alam terbaru diekstrak dari buah okra. Kajian ini juga memperkenalkan dua bahan tidak terlarut baru dari sumber semulajadi (hampas padi dan isi kelapa). Bagi mencapai objektif utama kajian ini, sebuah sistem rangkaian paip galvani tertutup didirikan terdiri dari tiga saiz paip yang berbeza iaitu pada 0.0127, 0.025 and 0.038 m diameter dalam (ID) pada panjang paip terdiri dari 0.5, 1.0, 1.5 dan 2.0 meter. Bagi memastikan saiz partikulat yang tepat (500 and 800  $\mu\text{m}$ ), teknik ayakan automatik menggunakan "Fritsch Sieve Analysis System" telah dijalankan. Kepekatan bahan terampai digunakan adalah 100, 300 dan 500 ppm manakala untuk lendir okra kepekatan bahan adalah 100, 300, 500, 700 dan 1000 ppm. Dari keputusan analisis pengurangan seretan bendalir okra semulajadi berjaya mengurangkan seretan sehingga 71% pada Re nombor bendalir bersamaan 11788 pada paip saiz 0.0127 meter diameter dalam dan panjang paip pada 1.5 meter pada kepekatan 1000 ppm, bendalir okra semulajadi jelas adalah DRA yang paling efisien dibandingkan dengan bahan uji yang lain. Di samping itu fiber yang terampai dikenali sebagai hampas padi menunjukkan prestasi bagi mengurangkan seretan dalam paip. Pengurangan maksimum seretan dicatatkan 32% pada ketika Re bersamaan 35363, saiz partikulat 500  $\mu\text{m}$ , kepekatan 500 ppm dan juga serbuk isi kelapa turut berpotensi mengurangkan seretan sehingga 42 % pada Re bersamaan 35363 pada kepekatan dan saiz partikulat sama dengan ujikaji hampas padi. Kedua-dua keputusan ini direkodkan pada paip saiz 0.025 meter dan panjang paip pada 1 meter. Hasil campuran antara bendalir okra semulajadi pada kepekatan optimum 1000 ppm dengan serbuk hampas padi dan isi kelapa (500  $\mu\text{m}$ , 500 ppm) telah memperolehi keputusan pengurangan seretan sebanyak 60 % pada Re 11788, 43 % pada Re 35363 pada paip saiz 0.0127 meter diameter dalam dan panjang paip pada 1.5 meter. Peratus pengurangan seretan yang tertinggi adalah 71% bermaksud sebanyak 71% penjimatan tenaga dapat dijana. Pembentukan rantaian molekul kimia bagi bahan polimer semulajadi okra dan juga interaksi antara fiber di dalam paip telah dikenal pasti sebagai punca pengurangan seretan. Kolerasi statistik pengurangan seretan telah dimodelkan menggunakan perisian "STATISTICA" dengan data-data dari eksperimen. Kesimpulannya, ejen-ejen mengurangkan seretan yang baru dan mesra alam telah berjaya diperkenalkan untuk menggantikan bahan tambah yang sedia ada dan digunakan secara komersil disamping keberkesananannya untuk meningkatkan aliran telah dibuktikan melalui eksperimen ini.

**TABLE OF CONTENTS**

	<b>Page</b>
<b>SUPERVISOR'S DECLARATION</b>	ii
<b>STUDENT'S DECLARATION</b>	iii
<b>DEDICATION</b>	iv
<b>ACKNOWLEDGEMENTS</b>	v
<b>ABSTRACT</b>	vi
<b>ABSTRAK</b>	vii
<b>TABLE OF CONTENTS</b>	viii
<b>LIST OF TABLES</b>	xiii
<b>LIST OF FIGURES</b>	xiv
<b>LIST OF SYMBOLS</b>	xix
<b>LIST OF ABBREVIATIONS</b>	xx
<b>CHAPTER 1 INTRODUCTION</b>	
1.1 Background	1
1.2 Problem Statement	2
1.3 Research Objectives	3
1.4 Scopes of Research	4
1.5 Thesis Outline	5

## **CHAPTER 2      LITERATURE REVIEW**

2.1	Introduction	6
2.2	Liquids Flow In Pipelines	7
2.3	Energy Dissipation In Pipelines	9
2.4	Turbulent Eddies	10
2.5	Drag Reduction	12
2.6	Viscoelasticity	14
2.7	Drag Reducing Agents	15
	2.7.1 Polymeric Drag Reducing Agents	15
	2.7.2 Surfactant Drag Reducing Agents	19
	2.7.3 Drag reduction with Fiber Particles	24
2.8	Drag Reduction Mechanism	29
	2.8.1 Lumley Theory	29
	2.8.2 Hinch Theory	30
	2.8.3 Landahl Theory	31
	2.8.4 Yo – Yo Theory	32
	2.8.5 De Gennes Theory	32
	2.8.6 Bewersdorff Theory	33
2.9	Commercial Applications	34

## **CHAPTER 3      METHODOLOGY**

3.1	Introduction	37
3.2	Liquid Circulation System	38
3.3	Materials Investigated	44
	3.3.1 Okra-Natural mucilage	44
	3.3.2 Paddy Husk Fiber	49
	3.3.3 Coconut Meat Fiber	52

3.4	Transported Liquid	54
3.5	Solution Preparation	54
3.6	Experimental Variables	55
3.7	Experimental Procedure	56
3.8	Experimental Calculations	60

## **CHAPTER 4 RESULTS AND DISCUSSION**

4.1	Circulation System Verification	62
4.2	Drag Reduction Ability of Natural Mucilage	64
	4.2.1 Effects of Re Numbers on Percentage of Drag Reduction	64
	4.2.2 Effects of Addition Concentrations on Percentage of Drag Reduction	68
	4.2.3 Effect of Pipe Diameter to Percentage of Drag Reduction	71
	4.2.4 Effects of Pipe Length on the Percentage of Drag Reduction	73
4.3	Drag Reduction Ability of Suspended Fibers	76
	4.3.1 Effect of Reynolds Number (Re) on Percentage of Drag Reduction (%Dr) of Paddy Husk and Coconut Meat Husk	76
	4.3.2 Effects of Additive Concentrations on Percentage of Drag Reduction of Paddy Husk and Coconut Meat Husk	82
	4.3.3 Effects of Fiber Sizes on Percentage of Drag Reduction of Paddy Husk and Coconut Meat Husk	87
4.4	Comparison of Drag Reduction Performance	92
4.5	Numerical Model (Correlation by Statistica)	100
4.6	Mechanism	107

## CHAPTER 5 CONCLUSION AND RECOMMENDATIONS

5.1	Drag Reducing Agent (DRA) Performance	109
5.2	Recommendations	110

<b>REFERENCES</b>		111
-------------------	--	-----

### APPENDICES

A1	Weight and concentration of okra-natural mucilage for experiment	116
A2	Weight and concentration of fiber suspension for experiment	117
A3	Weight and concentration of fibers and okra-natural mucilage mixture	118
B1	Back view of experimental rig	119
B2	Isometric view of experimental rig	120
C1	Pressure drop reading and experimental system verification for pipe scale (L/D) equal to 118	121
C2	Pressure drop reading and experimental system verification for pipe scale (L/D) equal to 60	123
C3	Pressure drop reading and experimental system verification for pipe scale (L/D) equal to 39	125
D1	Pressure drop obtained using okra-natural mucilage	127
D2	Drag reduction percentage obtained using okra-natural mucilage	128
E1	Pressure drop obtained using paddy husk fibers	130
E2	Drag reduction percentage obtained using paddy husk fibers	131
F1	Pressure drop obtained using coconut meat fibers	132
F2	Drag reduction percentage obtained using coconut meat fibers	133
G1	Drag reduction percentage obtained using mixture solution (paddy husk + okra-natural mucilage)	134
G2	Drag reduction percentage obtained using mixture solution (coconut meat husk + okra-natural mucilage)	135
H1	Drag reduction percentage comparison of okra-natural mucilage, paddy husk, coconut meat husk and mixture solution at pipe diameter equal to 0.0127 m and testing section length at 1.5 m	136
H2	Drag reduction percentage comparison of okra-natural mucilage, paddy husk, coconut meat husk and mixture solution at pipe diameter equal to 0.025 m and testing section length at 1.0 m	137

H3	Drag reduction percentage comparison of okra-natural mucilage, paddy husk, coconut meat husk and mixture solution at pipe diameter equal to 0.025 m and testing section length at 1.5 m	138
H4	Drag reduction percentage comparison of okra-natural mucilage, paddy husk, coconut meat husk and mixture solution at pipe diameter equal to 0.038 m and testing section length at 1.5 m	139
I1	Steps for statistical correlation estimation	140
J1	List of publications and achievements	144



**LIST OF TABLES**

<b>Table No.</b>	<b>Title</b>	<b>Page</b>
Table 2.1	Drag Reducing Polymer Solutions	15
Table 3.1	Experimental flow system symbols description	39
Table 3.2	Physical properties of Okra-Natural Mucilage	49
Table 3.3	Physical properties of paddy husk fibers	52
Table 3.4	Physical properties of coconut meat fiber	53
Table 3.5	Physical properties of water	54
Table 4.1	Drag reduction percentage comparison of DRA at pipe diameter equal to 0.0127 m and testing section length at 1.5 m	94
Table 4.2	Drag reduction percentage comparison of DRA at pipe diameter equal to 0.025 m and testing section length at 1.0 m	97
Table 4.3	Drag reduction percentage comparison of DRA at pipe diameter equal to 0.038 m and testing section length at 1.5 m	99
Table 4.4	The correlation parameter for selected samples of the experimental data	101

## LIST OF FIGURES

<b>Figure No.</b>	<b>Title</b>	<b>Page</b>
Figure 2.1	Laminar flow pattern in a straight pipeline	7
Figure 2.2	Turbulent flow in a straight pipeline	8
Figure 2.3	Random velocity fluctuation at a point in turbulent flow	10
Figure 2.4	Velocity distribution in laminar and turbulent flows in pipelines	12
Figure 2.5	Schematic view of cis and trans forms of hydrocarbon chains	20
Figure 3.1	The schematic diagram of the pipeline system	38
Figure 3.2	Drag reduction experimental rig in the Common Laboratory (UMP)	39
Figure 3.3	A schematic diagram of the test section	41
Figure 3.4	An Ultraflux Portable Flow Meter Minisonic P	42
Figure 3.5	A 0.25 bar Baumer differential pressure gauge	43
Figure 3.6	A 0.16 bar Baumer differential pressure gauge	44
Figure 3.7	Okra-Natural Mucilage Preparation	45
Figure 3.8	Chemical structure of polysaccharide of Okra – Natural Mucilage	46
Figure 3.9	Micromeritics AccuPyc II 1340	47
Figure 3.10	Brookfield DV-III Ultra Programmable Rheometer	48
Figure 3.11	Fritsch Sieve Analysis system	50
Figure 3.12	Paddy Husk Fiber (a) 500 $\mu\text{m}$ (b) 800 $\mu\text{m}$	51
Figure 3.13	Coconut Meat Fiber (a) 500 $\mu\text{m}$ (b) 800 $\mu\text{m}$	53

Figure 3.14	Flow diagram of the experimental work with the investigated okra –natural mucilage	57
Figure 3.15	Flow diagram of the experimental work with the investigated fibers	58
Figure 3.16	Flow diagram of the experimental work with the investigated mixture of okra-natural mucilage with fibers	59
Figure 4.1	Friction factor of fluid flow in experimental system	63
Figure 4.2	Effect of Reynolds number on percentage drag reduction for Okra-Natural Mucilage with different concentrations flowing through pipe size of 0.0127 m at 1.5 testing section length	66
Figure 4.3	Effect of Reynolds number on percentage drag reduction for Okra-Natural Mucilage with different concentrations flowing through pipe size of 0.025 m at 1.5 testing section length	67
Figure 4.4	Effect of Reynolds number on percentage drag reduction for Okra-Natural Mucilage with different concentrations flowing through pipe size of 0.038 m at 1.5 testing section length	67
Figure 4.5	Effect of concentration on percentage drag reduction for Okra-Natural Mucilage dissolved in water flowing through pipe diameter of 0.0127 m ID at 1.5 m testing length with different Re number	69
Figure 4.6	Effect of concentration on percentage drag reduction for Okra-Natural Mucilage dissolved in water flowing through pipe diameter of 0.025 m ID at 1.5 m testing length with different Re number	70
Figure 4.7	Effect of concentration on percentage drag reduction for Okra-Natural Mucilage dissolved in water flowing through pipe diameter of 0.038 m at 1.5 m testing length with different Re number	70
Figure 4.8	Effect of pipe diameter on percentage Drag Reduction at different Reynolds Number, with 300 ppm concentration of Okra-Natural Mucilage dissolved in water at 0.5 m testing length	72
Figure 4.9	Effect of pipe diameter on percentage Drag Reduction at different Reynolds Number, with 300 ppm concentration of	73

	Okra-Natural Mucilage dissolved in water at 2.0 m testing length	
Figure 4.10	Effect of pipe length on percentage Drag Reduction at Reynolds number = 11788, with 500, 700 and 1000 ppm concentration of Okra-Natural Mucilage dissolved in water at 0.0127 m pipe diameter	75
Figure 4.11	Effect of pipe length on percentage Drag Reduction at Reynolds number = 47151, with 500, 700 and 1000 ppm concentration of Okra-Natural Mucilage dissolved in water at 0.0127 m pipe diameter	75
Figure 4.12	Effect of Re on % Dr for transported water with Paddy husk fibers (500 $\mu\text{m}$ ) at different addition concentrations (0.025 m pipe diameter, 1 m testing section length)	78
Figure 4.13	Effect of Re on % Dr for transported water with Paddy husk fibers (800 $\mu\text{m}$ ) at different addition concentrations (0.025 m pipe diameter, 1 m testing section length)	78
Figure 4.14	Effect of Re number on % Dr for transported water with coconut meat fibers (500 $\mu\text{m}$ ) with different addition concentrations (0.025 m pipe diameter, 1 m testing section length)	81
Figure 4.15	Effect of Re number on % Dr for transported water with coconut meat fibers (800 $\mu\text{m}$ ) with different addition concentrations (0.025 m pipe diameter, 1 m testing section length).	81
Figure 4.16	Effect of fibers concentration on % Dr for transported water with Paddy husk fibers (500 $\mu\text{m}$ ) with different flow rates (Re) at (0.025 m pipe diameter, 1 m testing section length)	83
Figure 4.17	Effect of fibers concentration on % Dr for transported water with Paddy husk fibers (800 $\mu\text{m}$ ) with different flowrates (Re) at (0.025 m pipe diameter, 1 m testing section length)	84
Figure 4.18	Effect of fibers concentration on % Dr for transported water with coconut meat fibers (500 $\mu\text{m}$ ) for the solution flowing through 0.025 m pipe diameter and 1 m testing section length	86
Figure 4.19	Effect of fibers concentration on % Dr for transported water with coconut meat fibers (800 $\mu\text{m}$ ) for the solution flowing through 0.025 m pipe diameter and 1 m testing section length	86

Figure 4.20	Effect of the particle diameter (500 and 800 $\mu\text{m}$ ) on the % Dr for transported water with paddy husk fibers with different Re at 500 ppm using (0.0127 m pipe diameter, 1 m testing section length)	88
Figure 4.21	Effect of the particle diameter (500 and 800 $\mu\text{m}$ ) on the % Dr for transported water with paddy husk fibers with different Re at 500 ppm using (0.025 m pipe diameter, 1 m testing section length)	88
Figure 4.22	Effect of the particle diameter (500 and 800 $\mu\text{m}$ ) on the % Dr for transported water with paddy husk fibers with different Re at 500 ppm using (0.038 m pipe diameter, 1 m testing section length)	89
Figure 4.23	Effect of the particle diameter (500 and 800 $\mu\text{m}$ ) on the % Dr for transported water with coconut meat fibers with different Re at 500 ppm using (0.0127 m pipe diameter, 1 m testing section length)	90
Figure 4.24	Effect of the particle diameter (500 and 800 $\mu\text{m}$ ) on the % Dr for transported water with coconut meat fibers with different Re at 500 ppm using (0.025 m pipe diameter, 1 m testing section length).	91
Figure 4.25	Effect of the particle diameter (500 and 800 $\mu\text{m}$ ) on the % Dr for transported water with coconut meat fibers with different Re at 500 ppm using (0.038 m pipe diameter, 1 m testing section length)	91
Figure 4.26	Drag reduction performance by multiple drag reducing agent in pipe diameter equal to 0.0127 m and testing section length at 1.5 m	94
Figure 4.27	Drag reduction performance by multiple drag reducing agent in pipe diameter equal to 0.025 m and testing section length at 1 m.	97
Figure 4.28	Drag reduction performance by multiple drag reducing agent in pipe diameter equal to 0.038 m and testing section length at 1.5 m	99
Figure 4.29	Predicted versus observed values for the 100 ppm okra-natural mucilage flowing through 0.0127 m I.D pipe diameter and 1.0 m testing section length	102

Figure 4.30	versus observed values for the 700 ppm okra- natural mucilage flowing through 0.025 m I.D pipe diameter and 1.5 m testing section length	102
Figure 4.31	Predicted versus observed values for the 100 ppm okra- natural mucilage flowing through 0.0381 m I.D pipe diameter and 1.5 m testing section length	103
Figure 4.32	Predicted versus observed values for the 300 ppm okra- natural mucilage flowing through 0.0381 m I.D pipe diameter and 1.5 m testing section length	103
Figure 4.33	Predicted versus observed values for the 500 ppm okra- natural mucilage flowing through 0.0381 m I.D pipe diameter and 1.5 m testing section length	104
Figure 4.34	Predicted versus observed values for the 1000 ppm okra- natural mucilage flowing through 0.0254 m I.D pipe diameter and 1.5 m testing section length	104
Figure 4.35	Predicted versus observed values for the 100 ppm of 500 $\mu$ m paddy husk fiber flowing through 0.0381 m I.D pipe diameter and 0.5 m testing section length	105
Figure 4.36	Predicted versus observed values for the 300 ppm of 500 $\mu$ m paddy husk fiber flowing through 0.0127 m I.D pipe diameter and 1.5 m testing section length	105
Figure 4.37	Predicted versus observed values for the 100 ppm of 500 $\mu$ m coconut meat fibers flowing through 0.0381 m I.D pipe diameter and 1.5 m testing section length	106

**LIST OF SYMBOLS**

$a_r$	constant
$b$	constant
%Dr	Percentage of drag reduction
A	Pipe cross section area ( $m^2$ )
C	Concentration (ppm)
$f$	Friction factor
L	Length (m)
Q	Volumetric flow rate ( $m^3 \cdot s^{-1}$ )
$v$	Average velocity ( $m \cdot s^{-1}$ )
P	Pressure drop (Bar)
$\mu$	Viscosity ( $kg \cdot m^{-1} \cdot s^{-1}$ )
	Density ( $kg \cdot m^{-3}$ )
ppm	part per million
D	Diameter
Re	Reynold number

**LIST OF ABBREVIATIONS**

DR	Drag Reduction
DRA	Drag Reduction Agent
PAA	Poly(Acrylic) Acid
PEO	Poly(Ethylene Oxide)
MW	Molecular Weight
DRP	Drag Reducing Polymer
PNVF	Poly(N-Ninylformamide)
PDRA	Polymer Drag Reducing Agent
CTAB	Cetyltrimethylammonium Bromide
ODEAO	Oleyldihydroxyethylamineoxide
TTAB	n-tetradecyltrimethylammoniumbromide
SANS	Small – Angle – Neutron - Scattering
TME	Trimethylolethane
SDS	Sodium Dodecyl Sulfate
CTAC	hexadecyltrimethylammonium chloride
NaSal	sodium salicylate
APG	Alkyl Polyglucoside
SIS	Shear-Induced Structure
PTEN	PT Exspan Nusantara



## **CHAPTER 1**

### **INTRODUCTION**

#### **1.1 BACKGROUND**

Installations of supporting pumping stations along the piping network have been the existing method used to overcome the pumping power dissipation during the transportation of liquids, gases and multi-phase systems. Such solution did overcome the existing problem, but in the same time, it adds a new problem to the industrial application such as the cost of operation, maintenance and the shutdown of the whole pipelines when any problem in any of the supporting pumping stations occur. Another more practical solution was needed.

Since the early forties of the past century, it was discovered that the addition of minute amounts of additives such as polymers, surfactants or rigid flexible particles can result in important drag reduction effects in many types of flows. This was considered the best available solution for the pumping power dissipation in pipelines. Artificial polymeric additives were the most famous drag reducing agents (DRA) introduced to the industry due to its high viscoelastic properties.

Natural polymers were introduced rarely by few authors and they were not applied seriously in any industrial application. Even though the drag reduction phenomena have been extensively documented, the exact physical mechanisms are still not clearly understood.

In the present work, natural and biodegradable DRA driven from natural polymer extracted from okra and suspended fibers that produced from paddy husk and coconut meat husk are introduced. All materials were chosen because of commercially feasible and environment friendly compared to the other types of DRA that are mostly artificial. An experimental rig was built to investigate the performance of these DRA towards the parameters that have clear effects toward drag reduction performance..

## **1.2 PROBLEM STATEMENT**

Fluids are part of almost every engineering system such as power plants, jet engines, air conditioner, heat exchanger and pipelines flow. In designing such systems, the amount of energy required to drive fluid must necessarily be taken into consideration. This driving power encountered dissipation cause by turbulent flows. This drastic decrease in flow efficiency upon transition to turbulence is known as turbulent drag due to velocity difference between the laminar sub layer and the core of the turbulent flow system, eddies are formed resulting the turbulence due to large inertia force compared to viscous force.

During the transportation of liquids through pipelines, energy is absorbed from the main flow by eddies to complete its shape while continue growing up with more swirling movement. This phenomenon will lead to losses in the pumping power. Besides of the installation of pump station, common practice is applied by the addition of commercial soluble chemicals to enhance the flow inside the pipelines. The viscoelastic properties of the chemicals are interfered with the turbulent structures on the pipeline wall and suppress it and that will improve the flow inside pipelines.

Synthetic drag reducing agents are designed to be soluble in the transported media. All these polymers are toxic, not environmentally friendly and not biodegradable and that raise a serious problem with the modern industrial regulations. This is why a biodegradable and environmentally friendly additive is needed.

The solubility in the transported media condition for any additive to be classified as drag reducing agent is considered as one of the major problems facing this industry. And that also led to increase the cost of these additives. Suspended solids drag reducing agents can be considered as a solution for such problem because it is insoluble in aqueous or hydrocarbon Medias and can act efficiently as flow improver. There is a need to introduce a new novel drag reducer agent that can improve the flow into the pipelines without changing any properties of product.

### **1.3 RESEARCH OBJECTIVES**

The aims of this investigation are:

1. To investigate the drag reduction performance of two suspended solid drag reducing agents.
2. To investigate the performance of the okra-natural Mucilage on improving the flow in pipelines.
3. To investigate the effect of the okra-natural solution effect on the drag reduction performance of selected solid additives (paddy husk and coconut meat husk).

## 1.4 SCOPES OF RESEARCH

The scopes of this research are described below:

- (i) Using two types of suspended fibers which are paddy husk fiber and coconut meat fiber. These suspended solids have different properties such as density.
- (ii) Using natural polymer as drag reducing agent which are okra mucilage. The purpose of choosing the additive is the viscoelastic effect that reduce drag, cheap resources also it is natural material that biodegradable so that environmental effect towards it usage can easily contained.
- (iii) Using three different suspended solid concentrations during investigation which are 100, 300 and 500 ppm.
- (iv) Using two different particle sizes for suspended solids investigated which are 500 and 800  $\mu\text{m}$ .
- (v) Using five different addition concentrations for the polymer additive effect towards drag reduction from okra mucilage which the concentrations are 100, 300, 500, 700 and 1000 ppm.
- (vi) The effect of galvanized pipe scale (L/D) was investigated by applying three different pipe diameters, which are 0.0127, 0.025 and 0.038 m inside diameter (ID) with four different testing sections lengths start from 0.5, 1.0, 1.5 and 2.0 m.
- (vii) Using six different solution flow rates represented by the Reynolds number (Re) that apply water as transporting fluid in pipes.

## **1.5 THESIS OUTLINE**

This thesis is divided into five chapters, including the current one which presents the background of research, problem statement, research objectives, scope of study and thesis outline. Chapter 2 presents the literature survey that was done at the earlier stage of the study such as drag reduction technology, types of drag reduction and the application of drag reduction. Chapter 3 presents the research methodology for this study including the system that has been used and the experimental equipments. Chapter 4 presents the experimental results and the analysis with appropriate discussion. Finally, Chapter 5 consists the summary of works and contributions made in this thesis. It also included with the future works that can be further from this field.

## **CHAPTER 2**

### **LITERATURE REVIEW**

Literature review of the existing research and studies in the drag reduction field will be summarised in this chapter, also the types of flow which is laminar and turbulent as an introduction to study the phenomena of drag reduction in turbulent flow. Later, discussion on the types of drag reduction agents from surfactants, suspended fibers and polymers, also the mechanism and theory of the drag reduction and the last part is the commercial application in the drag reduction field.

#### **2.1 INTRODUCTION**

Transportation of liquid in pipeline is exposed to a friction force from the pipe wall that reduces the pressure required to transfer the flow from one station to another station. Currently, industries require installing supporting pumping station in order to maintain the flow rate of transported liquid. Installation and maintenance of the pump station will increase the cost of the transportation. In order to solve this problem, different types of drag reducing agents are introduced as a solution for the pumping power dissipation problem.

The key changes to the application of the DRA is that the understanding of the mechanism of drag reduction and the turbulent structure. There are several types of DRA such as polymer, surfactant and suspended fiber that have received considerable attention. The behaviour and physical properties of each of DRA make it unique from each others. The brief description of various drag reduction mechanism is given in the following section.

## 2.2 LIQUIDS FLOW IN PIPELINES

Liquid flow is categorised into two types of flow regime which known as laminar flow and turbulent flow. It is important to know the type of liquid flow in order to design an operation involving liquid circulation system. Each flow has its own characteristics and thus possesses different drag effects. The factors that determines which types of flow is present is the ratio of inertia forces to viscous forces within the fluid, expressed by the non-dimensional Reynolds number (Re) as shown in Equation (2.1) below:

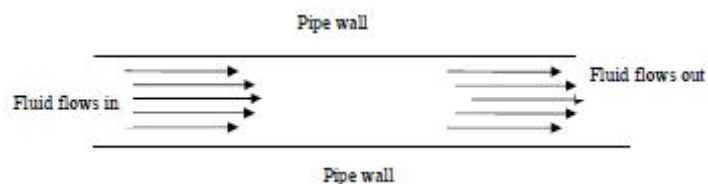
$$Re = \frac{\rho \cdot V \cdot D}{\mu} \quad (2.1)$$

Where  $\rho$  is the density of fluid,  $v$  is the velocity of fluid,  $D$  is the diameter of pipe and  $\mu$  is the viscosity of fluid (Lim, 2009).

As conclusion, liquid flow can be either laminar or turbulent.

### (i) Laminar flow

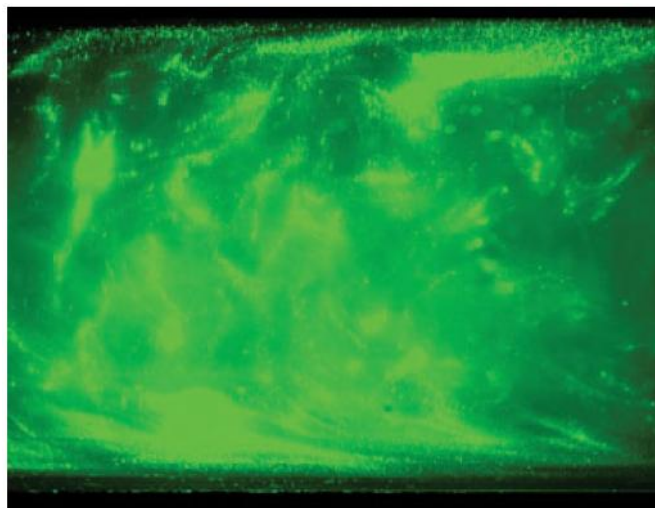
Laminar flow also known as streamline flow occurs when the fluid flows in parallel layers (as shown in Figure 2.1). There is no disruption between the layers, thus no energy losses to the surrounding and the flow's velocity is constant. In order for laminar flow to be permissible, the viscous stresses must dominate over the fluid inertia stresses. Liquid flows are laminar for Reynolds number up to 2000 (Lim, 2009).



**Figure 2.1:** Laminar flow pattern in a straight pipeline

(ii) Turbulent flow

Turbulent flow occurs when there is a friction on the wall of the pipe. It's a flow field that cannot be described with streamlines in the absolute sense. However, time-average streamlines can be describing the average behaviour of the flow. In turbulent flow, the inertia stresses dominate over the viscous stresses, leading to small scale chaotic behaviour in the fluid motion. Figure 2.2 below shown pipe turbulence at  $Re=5000$  using microscopic crystalline platelets illuminated with a sheet of laser light. The platelets align with shear flow, and changes seen across the flow indicates turbulent fluctuations (Lathrop, 2006).



**Figure 2.2:** Turbulent flow in a straight pipeline

Turbulent flow is typified by a flow with  $Re$  above 4000. Energy losses when the flows intercept themselves, and hence slowing down the fluid flow. This phenomenon is attributed to drag effect (Lim, 2009). The turbulent flows are inherently unsteady. The presence of such unsteadiness in a flow can significantly alter the behaviour of important parameters such as the Reynolds stress, turbulent kinetic energy and dissipation rate. The popular way to distinguish laminar and turbulent flow is through calculation of Reynolds Number ( $Re$ ) and was introduced by Osborne Reynolds in 1880s.