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

MOHD AZIMIE BIN AHMAD

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Faculty of Chemical and Natural Resources Engineering
UNIVERSITI MALAYSIA PAHANG

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## 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 µm) 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 µm, 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 µm, 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 µm), 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 µm, kepekatan 500 ppm dan juga serbuk isi kelapa turut berpotensi mengurangkan seretan sehingg 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 csmpuran antara bendalir okra semulajadi pada kepekatan optimum 1000 ppm dengan serbuk hampas padi dan isi kelapa (500 µm, 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 keberkesanannya untuk meningkatkan aliran telah dibuktikan melalui eksperimen ini.

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# 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 ($m^3.s^{-1}$) |
| *v* | Average velocity ($m.s^{-1}$) |
| ΔP | Pressure drop (Bar) |
| µ | Viscosity ($kg.m^{-1}.s^{-1}$) |
| *P* | Density ($kg.m^{-3}$) |
| 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 | Cetryltrimethylammonium 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 µm.

(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:

$$\mathrm{Re} = \frac{\rho . V . D}{\mu} \qquad (2.1)$$

Where ρ 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).

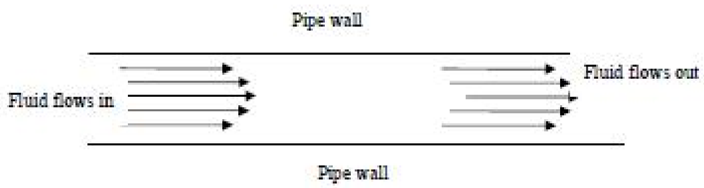


**Figure 2.1**: Laminar flow pattern in a straight pipeline

(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).

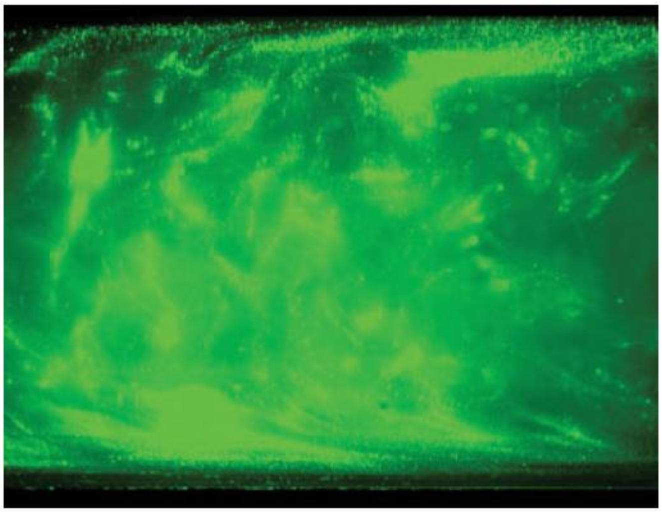

**Figure 2.2**: Turbulent flow in a straight pipeline

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.