

Drag Reduction Using Additives

Subjects: [Engineering](#), [Mechanical](#)

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Reduction of fluid resistance using the rheological characteristics of a polymer-surfactant solvent is research that contains many aspects, such as the theory of the drag reduction process, historical journey, and ongoing current research development. Many studies have been conducted, but it is challenging to know all existing and new research threads. The present investigation was conducted using literature studies regarding drag reducing agents. This research will also discuss the characteristics of flowing fluids and their effects on the velocity profile with friction factor of flowing fluids in smooth circular straight pipe geometries based on experimental, theoretical approaches. It concludes with aspects of research conducted around reducing drag using drag reducing agents, ideas about innovations, structuring overlook in testing, and modification of the fluid flow state.

fluid resistance

rheological characteristics

1. Introduction

1.1. History of Drag Reduction Additives

Turbulence affects the movement of fluid on a wall. The movement of fluid occurs when there is increased turbulence resulting in a loss of adequate energy. Research seeks to reduce the energy loss due to friction generated by turbulent flow in walls. Studies were conducted ^{[1][2][3]} in which the discovery of the mechanism of reducing resistance or turbulent skin friction in moving fluids was made. The discovery involved the existence of different substances that can be used, namely polymer-surfactant agents, bio-biopolymers, and solids such as fibers mixed in the inhibitor reducing solution. However, the initial research did not focus on the solution formed but more on the turbulence mechanism in the fluid when a resistance-reducing solution is added. This research also applies to industries such as the petroleum industry, maritime industry, and shipping. The mechanism referred to in research ^{[1][2][3]} is that the addition of the solution affects the pressure required to decrease the turbulence that occurs in the working fluid in the paper mill when transporting the macerated paper.

Furthermore, Toms ^[4] took a closer look at polymer development by adding it to a Newtonian solution, thereby reducing wall shear stress. This effect is known as the Toms effect. The wall shear stress is reduced by 80% when the polymer solution is injected into a Newtonian turbulent flow resulting in a non-Newtonian solution. However, Toms has not fully explained this effect because he only clarifies the phenomenon that occurs. Oldroyd ^[5] describes the events that occurred very well. The external constraints occur on the pipe wall due to the presence of a laminar sub-layer produced by isotropic matter with a thickness proportional to the molecules' size in the moving fluid.

In the early days of research regarding drag reducing agents, despite the world being affected by a world war, there was a race to find the most effective way to transfer fluid. Weissenberg [6] changed the inner cylinder on a viscometer to produce steady shear, which was continued by Tom's research in 1958 [7], which used a poly(methyl) methacrylate. To produce 3% polymer change, which showed a lower Weissenberg effect, the rheology of the temperature dependence of the polymer was reduced. Toms did this by adjusting the composition of the polymer mixed in a pure solvent using the Weissenberg method. The method was also used by [6], utilizing aluminum surfactant solvent to reduce the resistance flow of pipes for fuel.

At the same time, some studies [8][9] found that there are factors that influence low friction in non-Newtonian flow by using sodium carboxymethyl cellulose in water, which led to the development of biopolymers in this drag reducing agent study. Ten years after the development of this research, there was a development for industrial applications. Some researchers [10][11] started using guar gum, a plant polysaccharide, as a drag reducing agent. A more in-depth investigation of the characteristics of surfactant polymers in turbulent flow in viscoelastic fluids was carried out [9][12][13] with several properties. The reduction of turbulence is strongly influenced by the ratio of elasticity to the viscous force generated by the polymer. In addition to the military industry, the studies of [14][15] were the first to announce that the best polymer used as a drag reducing agent is poly (ethylene oxide). However, several things must be highlighted by further research [9]. References [16][17] examined the characteristics of the drag reducing agent from the aspect of pressure gradient and flow rate resulting from the turbulent flow of different polymers. This is only an initial aspect of the drag reducing agents that require attention. The quantitative theoretical aspects were finally clarified [18], namely polymer molecular weight, polymer concentration, and increased flow rate, increasing the drag reduction effect.

Notably, research on drag reducing agents has been discussed by several sources. A summary of the progress of these studies can be seen in **Table 1**. However, several reviews of drag reducing additives do not adequately specify the developments in the last decade. This study aims to develop and examine further developments and possible innovations that can be implemented in the next few years regarding drag reducing additives. The improvements can occur by innovating the solvent's chemical composition or the percentage of the solution. In addition, we examine the mechanism for reducing the resistance that occurs, which is useful for supporting the reduction of barriers, and suggestions for industries that can implement inventions and innovations in the world of chemical and mechanical engineering. This paper aims for completeness and specificity in its review. The definition of one additive with another is a significant factor because many reviews are still wrong in defining these additives. Then, we examine experimental research on smooth circular pipes; some studies have been excluded as they explore other factors such as duct or bend pipes, sometimes using simulations. These studies are nonetheless mentioned in **Table 1**. Finally, this study focuses on drag reduction caused by wall shear stress based on the difference in pressure gradient in the pipe. We address the final drag reduction result as the main concern is the final effect of the additives.

Table 1. Different review papers covering drag reducing additives.

Reference	Additive Drag Reduction Techniques
Lumley [19]	Polymer and solvent additions
Patterson et al. [20]	Polymer solutions, soap solutions, solid particle suspensions, straight pipeline
Hoyt [21]	Polymer additive, rotating disk, straight pipeline, flat plate
Virk [22]	Polymer additions, straight pipeline
White and Hemmings [23]	Polymer additions, straight pipeline
Shenoy [24]	Polymer additive, solid suspensions solutions, biological additives, surfactant solutions, micellar system, polymeric system
Berman [25]	Polymer and solvent additions, straight pipeline
Hoyt [26]	Polymer and surfactant additions
Zakin et al. [27]	Anionic soap solution, non-ionic solutions, zwitterionic surfactant solution, cationic surfactant solution, straight pipeline
Nadolink and Haigh [28]	Bibliography of polymer additions, pipes/tubes, ducts, channels, flat plates, asymmetrical, axisymmetric bodies
Manfield et al. [29]	Surfactant additions, straight pipeline
Graham [30]	Dilute polymer solutions, FENE spring model, spatial discretization
White and Mungal [31]	Polymer solutions, straight pipeline, channels
Al Sharkhi et al. [32]	Polymer injection, straight pipeline
Wang et al. [33]	Fiber suspensions, polymer solutions, surfactant solutions, straight pipeline
Abdulbari et al. [34]	Bio-polymer solutions, polymer injection
Nesyn et al. [35]	Polymer injection, rotating disk, slurry polymerization, surfactants solutions
Xi [36]	FENE-P, Oldroyd-B, Giesekus models, polymer solutions
Soares [37]	Polymer solutions
Ayegba et al. [38]	Polymer solutions, curved pipes, coiled pipes, ionic surfactants, non-ionic surfactants
Broniarz-Press et al. [39]	Drag reduction and heat transfer in turbulent flow, straight tubes, falling films, coils, polymer-surfactant drag reduction
Boffetta et al. [40]	Dilute polymer solutions, viscoelastic fluid model, numerical analysis Kolmogorov flow

-reducing agents research is conducted, will be explained; we also highlight several aspects of drag-reducing additive research, including variables, straight piping configurations, fluid characteristics that flow, type of fluids, and chemical and mechanical degradation. Different polymers, surfactants, and suspensions will be examined in terms of advantages and disadvantages. Lastly, we distinguish and discuss experimental approaches by debating the

effectiveness of each approach, optimization, and suggestions for research that can be developed in the coming years.

2. Straight Smooth Circular Pipes—Drag Reduction Additives

2.1. Solid Suspension Drag Reduction

The solid suspension is based on the granular size of the smooth, straight, circular pipe, which is a good reference for the research carried out by Watanabe [41]. Experiments were carried out on several types of solid suspension, namely, carbon, SiO₂, and kaolin in a laminar and turbulent flow. The research is supported by the equations formulated by Metzner [42], which are the same derivatives of Poiseuille's equation and the Kármán equation, which are distinguished based on the flow velocity. Based on research [41], the reduction in resistance can only be seen based on the flow characteristics, which are influenced by the rheological properties of the suspension used. The difficulty that is still being experienced is in determining the relationship between the differences in particle shape, given that the carbon suspension is black and difficult to study. If the liquid has a nanosized microstructure, the suspension will be transparent and easier to examine. **Figure 1** shows the results of research on solid suspensions.

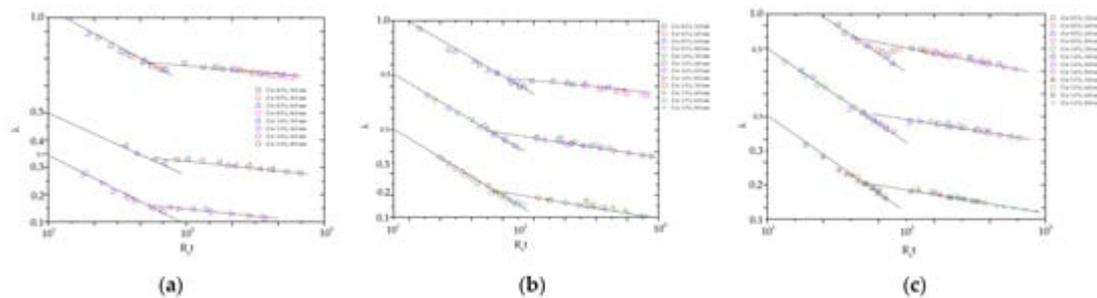


Figure 1. Comparison of friction factor to Reynolds number of three kinds of solid suspension: (a) carbon; (b) SiO₂; and (c) kaolin with different granular size.

2.2. Surfactant Drag Reduction

Surfactants can be divided into two types, namely ionic and non-ionic surfactants. Among several sources, there are two good references in representing the results of experimental research on the use of surfactants. Representing studies on ionic surfactants, reference [43] researched two cationic surfactants, namely Ethoquad O/13 (oleyl tris(hydroxyethyl) ammonium acetate) and Ethoquad O/12 (oleyl bis(hydroxyethyl) methylammonium chloride). In the study, it was found that the drag reduction effect appears to decrease with the rising temperature surfactant, as can be seen in **Figure 2**. The addition of surfactants also causes the effect to reduce and destroys the previously formed micelles.

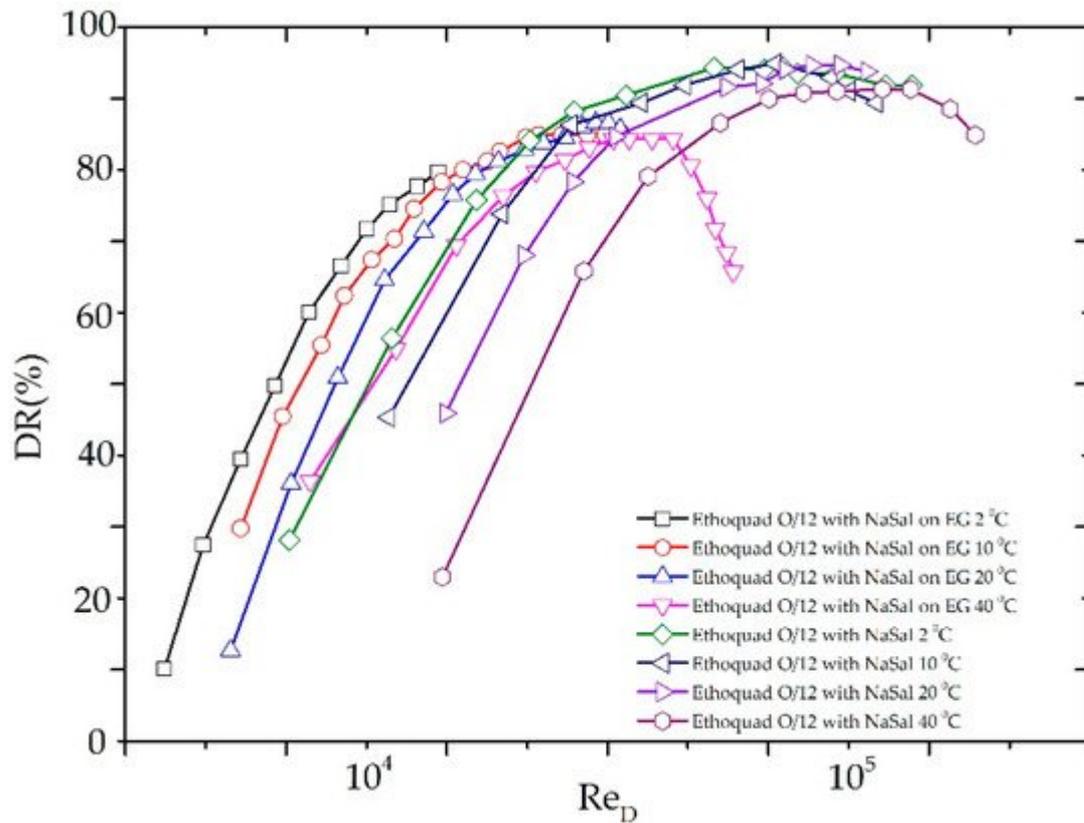


Figure 2. Drag reduction effect of Ethoquad O/12 with NaSal (sodium salicylate) in water and drag reduction effect of Ethoquad O/12 with NaSal on EG (ethylene glycol) with water at different temperatures.

Non-ionic surfactants have also been studied [44]. In one investigation, the addition of surfactants with the injection method was more effective than those mixed before experimenting. In this study, a comparison of PIV and LDV data collection results was also carried out. The differences found in the results comparing the tools were as follows. A significant function that can be distinguished is that PIV could record the direction of flow before and after the addition surfactants. This effect was seen when the flow was in turbulent flow by reducing turbulence from the interaction between the fluid layer and the pipe wall and reducing shear stress. Other studies that support the statement for the use of non-ionic surfactants include Cai et al. [45] on the use of oleyl di-methyl amine oxide (ODMAO), who found that when the concentration was at 400 ppm and above, there was a drag reduction effect of 70 percent in straight pipes. The study also examined the effect of shear rate on different micelles resulting in different shear characteristics.

Meanwhile, with LDV only the effect on the shear stress of the wall could be observed. This finding is supported by the surfactant injection method [46][47]. The results of study [44] are shown in **Figure 3**. We can see the decrease of shear stress based on the length and the injection method using homogenous and non-homogenous surfactant injections; as a result, the drag is reduced within the range of 11–50%.

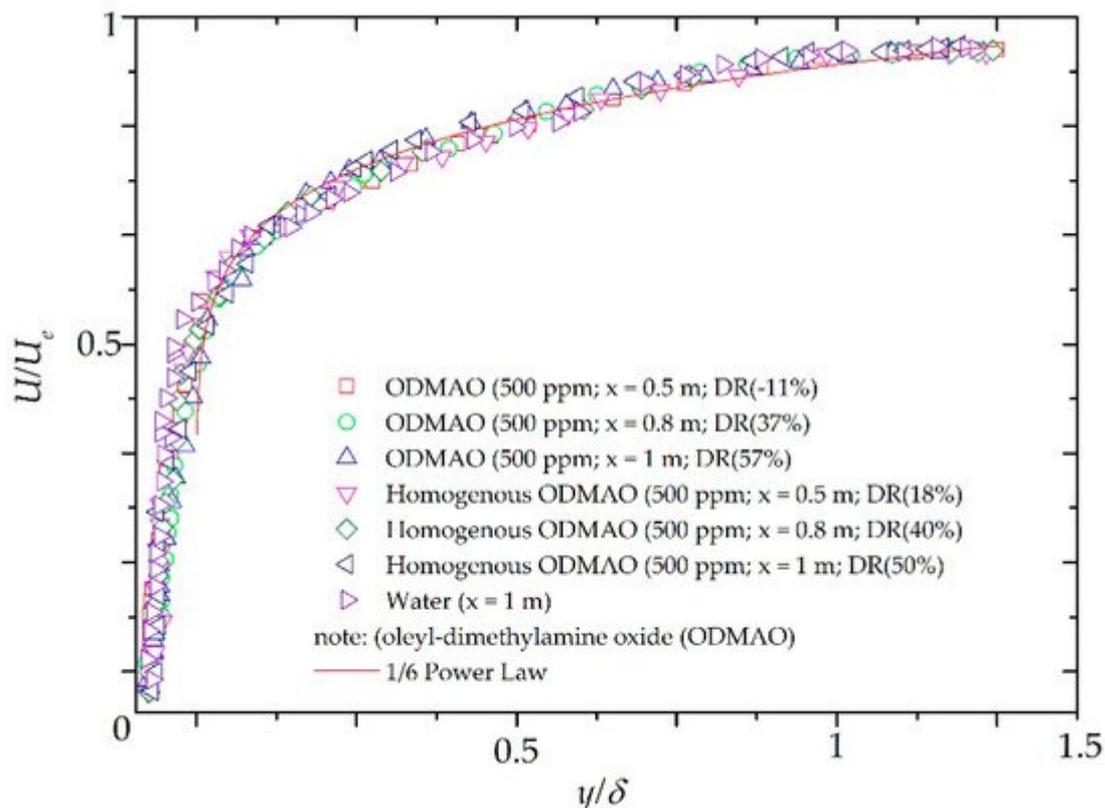


Figure 3. The comparison between homogenous and non-homogenous surfactant injection was affecting the drag reduction property.

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