Indian Journal of Science and Technology, *Vol 10(2), DOI: 10.17485/ijst/2017/v10i2/110369, January 2017* *ISSN (Print) : 0974-6846*
ISSN (Online) : 0974-5645

The Effect of Passive-Active Interaction Method on Drag Reduction Performance in Rotating Disk Apparatus

Hayder A. Abdulbari [1]*, Mohamad Amran Mohd Salleh[2, 3], Musaab K. Rashed[2, 4] and M. Halim Shah Ismail[2]

[1]Center of Excellence for Advanced Research in Fluid Flow, University Malaysia Pahang, Gambang, Kuantan, Pahang, Malaysia; hayder.bari@gmail.com
[2]Department of Chemical and Environmental Engineering, Faculty of Engineering, University Putra Malaysia, UPM Serdang, Selangor, Malaysia; asalleh@upm.edu.my, mshalim@upm.edu.my
[3] Material Processing and Technology Laboratory, Institute of Advanced Technology, University Putra Malaysia, UPM Serdang, Selangor, Malaysia;
[4]Institute of technology, Middle Technical University, Foundation of Technical Education, Baghdad, Iraq; ymkr2016@gmail.com

Abstract

Objectives:Turbulent Drag Reduction (DR) efficacy of diesel fuelin a Rotating Disk Apparatus (RDA) using anionic surfactant of Sodium Lauryl Ether Sulfate (SLES) was investigated with smooth andSV-groove disks(riblets height of 900 and 3100 μm). **Methods:** The DR efficacy indicates how the torque is being reduced with a tiny amount of additives under a turbulent flow at a Reynolds number (Re) range of 302227 to 453341. The effects of different variables such as rotary disk type (smooth or structured), surfactant concentration, and Reynolds number were also studied. **Findings:** SLES shows a good ability to reduce the frictional drag forces with smooth and SV-groove of height 3100μm. In contract, there is no drag reduction can be observed by using this surfactant with SV-groove of height 900 μm. **Application/Improvements:** The passive-active interaction method can be used to improve petroleum liquid flow in pipelines.

Keywords: Drag Reduction, Rotating Disk Apparatus, Passive-Active Interaction, Surfactant

1. Introduction

Drag Reduction (DR) can be defined as the amount of the decrease in the skin frictional drag of fluids by adding a small amount of additives (active means) or by modifying the body surface over which the fluid is flowing (passive means)[1]. Active DR involves the use of minor quantities of Drag Reducing Agents (DRAs), which can be divided into three main groups: long chain polymers, surface active agents (surfactants), and solid particles or fibers[2]. Among all these DRAs, Polymers have been the greatest explored and investigated. Nevertheless, they are prone to the challenge of mechanical degradation, especially under the influence of shear stress or temperature increase, which invariably reduce their efficiency[3]. Another set of material are the surfactants which have been investigated by many authors[4–6], they offer an advantage of self-repair through micelles formation after degradation, but are less effective when compared to the polymers. On the other hand, the five most common methods of passive drag reduction are the using of wavy walls, compliant surfaces, dimples, riblets, and micro-bubbles[7]. Among all passive means, riblets have been shown to be the most effective and interesting DR technique. Unfortunately, the best and maximum flow improvement reported using these riblets was approximately 10% which is not even comparable

**Author for correspondence*

with the active DR efficiencies using viscoelastic additives.

In the present work, a Sodium Lauryl Ether Sulphate (SLES) surfactant was used to study the DR performance of diesel fuel in RDA with smooth and SV-groove disks at a high range of Re (3.23×10^5 - 4.53×10^5). In addition, the influence of different variables on %DR such as surfactant concentration, disk type, riblets height, and Reynolds number were also studied.

2. Materials and Methods

2.1 Experimental Materials

Sodium lauryl ether sulfate (Mw = 288.38 g/mol) used in this work was supplied by Sigma Aldrich, Malaysia and used without further purification. The main fluid was diesel fuel which procured from Shell, Gambang-Kuantan Road, Malaysia.

2.2 Surfactant Solutions Preparation

Surfactant solutions were prepared by dissolving the required weight of SLES in 4.5 L of diesel fuel using a hot plate stirrer. Mechanical degradation induced by stirring was reduced by applying mild agitation. The solutions used were prepared in different surfactant concentrations (200, 400, 600, 800 and 1000 ppm).

2.3 Apparatus and Disks

In the present work, the rotating disk apparatus utilized is the same as the one designed and constructed earlier by [5, 6, 8, 9]. The percent drag reduction can be determined from the following formula:

$$\%DR = \frac{T_s - T_a}{T_a} \times 100 \qquad (1)$$

And the rotational Reynolds number is calculated by:

$$\mathrm{Re} = \frac{\rho \omega r^2}{\mu} \qquad (2)$$

Where, ρ is the fluid density, μ is the fluid viscosity, and r is the radius of the disk. The critical Reynolds above which the flow transfers from laminar to turbulent is 3×10^5.

Aluminium alloy was used to fabricate the smooth and SV-groove disks. Three disks were fabricated, one smooth disk and SV-groove disks withtwo different height (H=900 and 3100 μm), which shown in Figure 1.

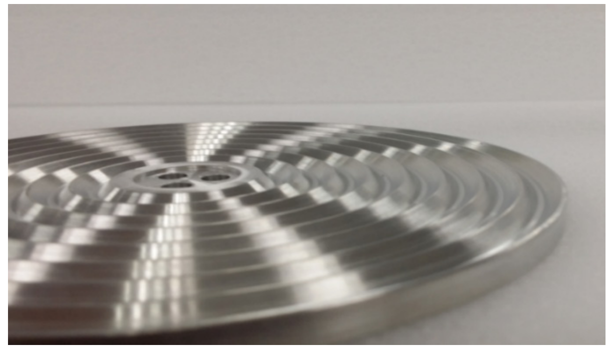

Figure 1. Photograph Pictures of SV-groove Disk.

2.4 Experimental Procedure

Surfactant solutions with varying concentration (200, 400, 600, 800 and 1000ppm) were diluted in 4.5 L of diesel fuel respectively. To ensure the even distribution of the surfactant in diesel, the sample was stirred for 24 hours before being tested on the constructed rotating disk apparatus. Firstly, the fluid container was filled with pure diesel and the smooth aluminium disk was used. The torque values for rational disk speed ranges from 2000 to 3000 rpm were measured. The procedure is repeated with SV-groove 900 and SV-groove 3100. Next, the pure diesel solution was changed with surfactant solutions with varying concentration (200, 400, 600, 800 and 1000 ppm). Measurements were taken again respective to the varying concentration and types of disks used. As a result, three variables were tested in this work which are:

- Disk types (smooth and SV- groove).
- Surfactant concentrations (200, 400, 600, 800, and 1000 ppm)
- Rotational disk velocity (2000 – 3000 rpm) or Re of (3.23×10^5 – 4.53×10^5).

3. Results and Discussions

3.1Passive Drag Reduction

Torque results of the three types of disks (Smooth, SV-groove 900, and SV-groove 3100) which obtained for Re range from 3.23×10^5 to 4.53×10^5 using pure solvent are shown in Figure 2. As shown, torque is increasing with increasing Re for all disks. The minimum torque value indicates a higher DR performance depending on the

DR calculation equation (Eq. 1). It can be observed from Figure2 that the torque values of SV-groove with H=900 µm are less than its value for smooth disk and SV-groove 3100. In contrast, the torque values of SV-groove with H=3100 µm are higher than smooth disk and SV-groove 900. That means the drag reduction efficiency of SV-groove 900 is better than the other two disks. The same results can be observed in Figure 3, which represent the %DR as a function of Re for SV-groove 900 and 3100. All %DR values of SV-groove 900 are positive while it's negative for SV-groove 3100. The negative drag reduction is due to the relation between the degree of turbulence and the drag reduction effect of the proposed structures. It is well known that the drag reduction (active or passive) occurs when an external or additional effect (additives in the case of active DR or structures in the case of passive DR) take action within the flow media, and that result will change the flow behaviour and degree of turbulence in a way that can reduce the power dissipation. All those happen when the external effect balances or overcomes the internal effect (turbulence). In many cases, the drag reduction technique fails to act because this balancing effect is not reached, where in many cases; the degree of turbulence plays the significant role in controlling the DR performance. It is believed that the structure, size, type and design of the riblets interacts efficiently with the flow conditions of the liquids, their viscosity and other apparent physical properties to give a clear positive of negative drag reduction performance. The negative results are expected because the balance between all the mentioned factors was disturbed by increasing the groove height. Such increment did change the flow behaviour and the local turbulence incubated by the grooves that might be capturing and localizing larger eddies and that will create, what is believed to be, complete internal flow surfaces that create larger eddies and that will increase the friction factor of the whole flow system.

3.2 Active Drag Reduction

The results for percentage of drag reduction (%DR) as a function of Re and SLES concentrations as well as smooth disk are shown in Figure 4. From this figure, %DR increases with the surfactant concentration. Similar observation have as well been reported by[10], while working with four types of surfactant in a closed pipelines system. The authors claimed that the %DR increased with surfactant concentrations and Re for all types. The surfactant working mechanism could be based on the increase in drag reducer molecules, which is favoured by the increase in their respective concentrations. In addition, the %DR increased with increasing of Re. This quality could be attributed to the capability of the surfactant to self-repair (micelles formation) and return to its original form after passing through the high shear stress regions. The average distance between micelles is substantially small and difficult to break by strong turbulence eddies and shear stress. The maximum %DR of 13.8% was obtained at a surfactant concentration of 1000 ppm and Re = 453341.

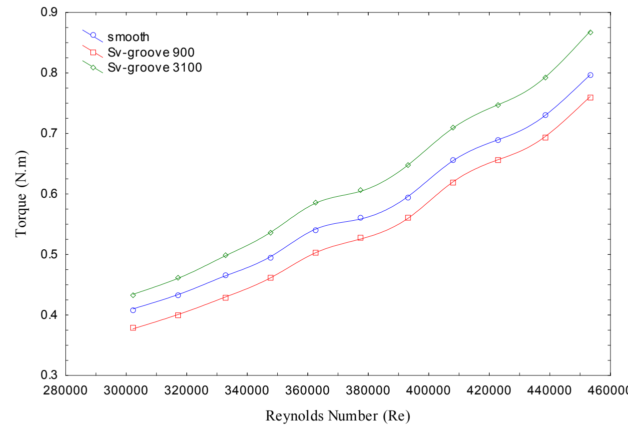

Figure 2. Effects of Re on Torque Values of Three Disk Types.

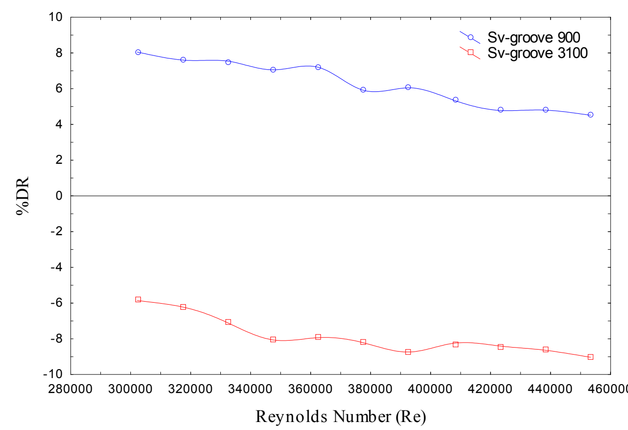

Figure 3. Effects of Re on DR Performance of SV-groove with H=900 and 3100 µm.

3.3 Passive – Active Interaction

Figures 5 and 6 show the effects of SLES concentration on DR performance using SV-groove 900 and SV-groove 3100, respectively. The drag reduction behaviour portrayed in both figures is approximately same of each

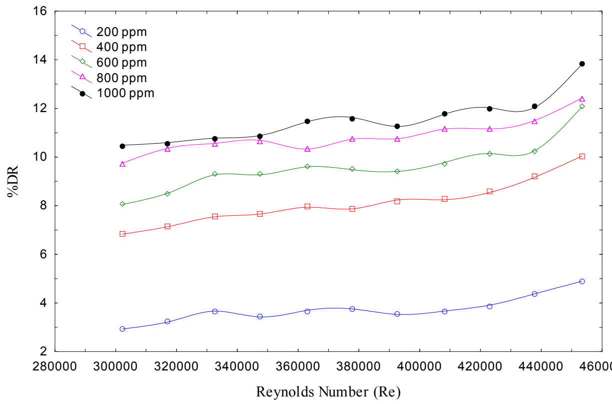

Figure 4. Effects of SLES Concentrations on DR Performance for Different Re Using Smooth Disk.

other. In Figure5, SV-groove 900 data show negative values of the %DR for all surfactant concentration and Re range. If these results compared with the passive results of SV-groove 900 (free additives), they show an opposite DR values. Where all passive DR values for SV-groove 900 were positive and they changed to negative values when the surfactant added to the main fluid. That means the DR performance of passive SV-groove 900 is better than that of surfactant solutions. Although the negative values of DR with surfactant solutions, the %DR increased with SLES concentration and Re (as shown in Figure5). In contract, Figure6 detected a different behaviour of DR with SV-groove 3100. There was no drag reduction can be observed for SV-groove 3100 with pure solvent (free additives) and the passive %DR is less than that with surfactant additives for SV-groove 3100. The addition of surfactant additives to SV-groove 3100 shows clear improvement to the passive DR performance. In addition, for a comparison between SV-groove 900 (Figure 5) and SV-groove 3100 (Figure6), it can be observed that firstly the passive %DR of SV-900 is higher than that of SV-3100. However, after the surfactant additives added to the pure solvent, the DR behaviour in both cases converted and the %DR of surfactant solutions with SV-3100 becomes higher than that of SV-900. In addition, the %DR increased with surfactant concentration and Re, as shown in Figure6. As mentioned above in the passive part, the main role of the riblets to increase the DR performance is to move up the turbulence eddies on the riblets tips only and prevent their formation inside the riblets valley. For the low dimensions of riblets (900 μm), it could be opined that the addition of surfactant additives to the main fluid will leads to generate micelles inside the riblets valley.

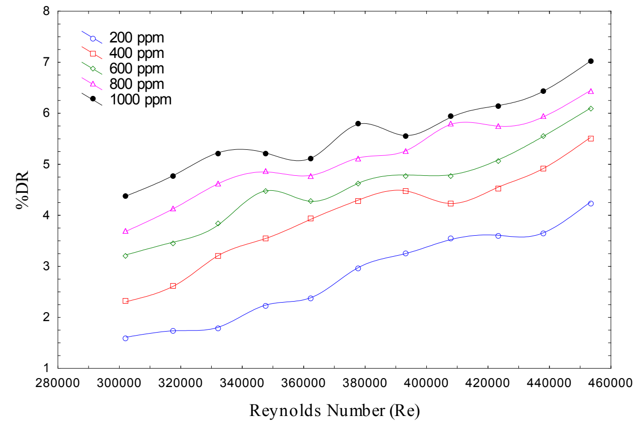

Figure 5. Effects of SLES Concentrations on DR Performance for Different Re Using SV-groove with H 900 μm.

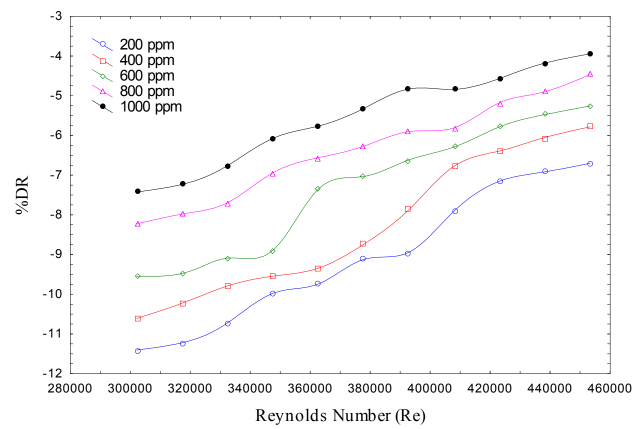

Figure 6. Effects of SLES Concentrations on DR Performance for Different Re Using SV-groove with H= 3100 μm.

4. Conclusion

A high precision rotating disk apparatus was used to investigate the effects of rotary disk types (smooth and structured), additive concentrations, and rotational disk speed on drag reduction efficacy of diesel fuel. Anionic surfactant of sodium lauryl ether sulfate was utilized to prepare five different concentrations of surfactant solutions. The structure disk types used in this study were smooth disk, SV-groove 900, and SV-groove 3100. In the passive DR (free additives), the SV-groove 900 showed a higher drag reduction efficiency, while a minimum DR was achieved with SV-groove 3100. The surfactant addition to the main fluid inversed the DR behaviour of these two disks by improving the drag reduction performance of SV-groove 3100 and decreases for SV-groove 900. The

%DR of surfactant solutions with smooth disk was higher than that of both SV-groove 900 and 3100. The maximum %DR of surfactant solutions with smooth disk was 13.8%, while it was -3.94 and 7.02with SV-groove 900 and 3100, respectively. Furthermore, it was clear that the drag reduction performance decreased with increasing Re in the passive method, while it increase with surfactant concentrations and Re in the active and passive – active interaction methods.

5. Acknowledgments

The authors express their profound gratitude to the University Putra Malaysia for funding this research work.

6. References

1. Kim CA, Jhon MS, Choi HJ. Scaling Functions of Polymer-Induced Turbulent Drag Reduction Focusing on the Polymer – Solvent Interaction. Journal of Applied Polymer Science.2002; 88 (7):1836–9.
2. Hak MG. Modern Developments in Flow Control. Applied Mechanics. 1996; 49 (7):365–79.
3. Pereira AS, Andrade RM, Soares EJ. Drag Reduction Induced by Flexible and Rigid Molecules in a Turbulent Flow into a Rotating Cylindrical Double Gap Device. 22nd International Congress of Mechanical Engineering Ribeirao Preto, SP, Brazil: 2013.p.8142–53.
4. Li F, Kawaguchi Y, Yu B, Wei J, Hishida K. Experimental Study of Drag-Reduction Mechanism for a Dilute Surfactant Solution Flow. International Journal of Heat Mass Transfer. 2008; 51(3-4):835–43.
5. Bari HA, Yaacob ZY, Oluwasogaakindoyo E. Effect of SDBS on the Drag Reduction Characteristics of Polyacrylamide in a Rotating Disk Apparatus. International Journal of Basic Applied Science. 2015; 4 (3):326–32.
6. Abdulbari H A, Akindoyo EO, Yousif Z. A Dual Mechanism of the Drag Reduction by Rigid Polymers and Cationic Surfactant: Complex and Nanofluids of Xanthan Gum and Hexadecyl Trimethyl Ammonium Chloride. International Journal of Research Engineering Technology. 2015; 4 (2):84–93.
7. Abdulbari HA, Yunus RM, Abdurahman NH, Charles A. Going Against the Flow-A Review of Non-Additive Means of Drag reduction. Journal of Industrial Engineering Chemistry. 2013; 19 (1):27–36.
8. Rashed M K, Mohd MA, Abdul Bari HA, Halim SI. Investigating the Effects of Surfactants on Drag Reduction Performance of Diesel Fuel in a Rotating Disk Apparatus. Journal of Purity, Utility Reaction and Environment. 2016; 5 (1):18–30.
9. Abdulbari HA, Rashed MK, Amran M, Salleh M, Ismail MHS. A Novel Polymer-Surfactant Complex Mixture to Improve Diesel Fuel Flow. Advanced and Applications in Fluid Mechanics. 2016; 19 (3):669–85.
10. Abdul-hadi AA, Khadom AA. Studying the Effect of Some Surfactants on Drag Reduction of Crude Oil Flow. Chinese Journal of Engineering. 2013; 2013:1–6.