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# Experimental Investigation on Drag Reduction Performance of Two Kind of Polymeric Coatings with Rotating Disk Apparatus

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**Abstract:** In the present work, we examined the drag reduction efficiency of two different coatings, i.e., 1) RTV (Room Temperature Vulcanized) Silicon rubber, and 2) PTFE (Poly-tetra fluoro ethylene), using a Rotating Disk Apparatus (RDA). The drag reduction performance of these coatings will be judged by their effect on the resisting torque in the RDA device. The device was fabricated with high accuracy using CNC machine. During the test, the disk was rotated at constant speed using the rotor system. With this rotor system, the rotational speed of the disk could be controlled from 0 up to a maximum of 2000 rpm. In addition, the rotor system was equipped with a torque sensor having a capacity of 200 N.cm and an accuracy of 0.1 N.cm. Tests were performed using water as the fluid surrounding the disk. The device could display the torque applied on the disk by the action of the shear stress at any given rpm. Based on the experimental data obtained in this work, at high enough Reynolds numbers, a drag reduction percentage of 11% and 18% can be achieved with RTV Silicon and PTFE, respectively. It is concluded that in the range of the Reynolds number used in this work PTFE is more efficient than RTV in reducing drag of blunt bodies in external flows.

**Key words:** Drag Reduction-Polymeric Coatings-Rotating Disk Apparatus- Torque Sensor.

## INTRODUCTION

Drag reduction is of crucial in the design of vessels moving in air or water. It has been a topic of great interest in the research community largely because of its relevance to applications such as high speed transportation. Obviously, any reduction in the drag experienced by say, a ship, means less fuel consumption. This is why over the years different techniques have been developed to reduce the drag in internal and external flows (Wells, 1969; Sellin 1989; Hough, 1992; Choi, 1996, Gerhart, 1992). Among current techniques one can mention techniques such as: 1) injection of polymer and surfactant solutions, 2) injection of micro bubbles, 3) using hydrophobic and hydrophilic coatings, 4) using compliant coatings, 5) riblets, 6) plasma gas injection, 7) suction and blowing, 8) boundary layer control with heating and cooling, 9) electromagnetic turbulence control, 10) supercavitation and hybrid methods with more or less success.

Water and wind tunnels have become standard laboratory tools for measuring the drag-reducing capability of the techniques mentioned above. In parallel, one may resort to towing tanks when dealing with ships, boats and the like. In spite of their widespread use, these devices are bulky and needs a large space. Having a drag measuring device which is as accurate but less bulky is of particular interest. Rotating cylinder or rotating disk apparatus (Ge, 2007; Kim, 2001; Choi, 1999; Sohn, 2001; Choi, 2000; Watanabe, 1998; Hong, 2008) appears to be good candidates for this purpose. The present work tries to illustrate the applicability of a rotating disk apparatus in evaluating the drag reduction efficiency of two hydrophobic polymeric coatings.

## NOMENCLATURE

$a$ [m] Disk Radius
$b$ [m] Disk thickness
$c$ [m] Radial gap between disk and enclosure
$s$ [m] Axial gap
$DR$ [%] Drag reduction
Special characters Kinematic Viscosity of water

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*u* [$m^2/s$]
w [rad/s] Angular Velocity
Subscripts
*Al* Aluminium Disk
*P* Polymer coated Disk

***Experimental Procedure:***
***A. Coatings:***

In the present work, we are going to investigate drag-reduction efficiency of two different hydrophobic polymer coatings: i) RTV silicon rubber, and ii) and PTFE Sheets. We have selected these two polymer coatings thanks to their properties such as low surface energy, flexibility, and low coefficient of friction. We coated these polymers on an aluminium disk (see Figure 1 and 2). RTV silicon rubber was coated with spraying and molding method at two different thicknesses of 0.4-mm and 0.1-mm. PTFE sheets thicknesses were 0.4-mm and 0.2-mm thick; they were pasted on one side of the aluminium disk. After applying the coatings, the final thickness of disk was determined to be b = 3mm (see Figure 3).

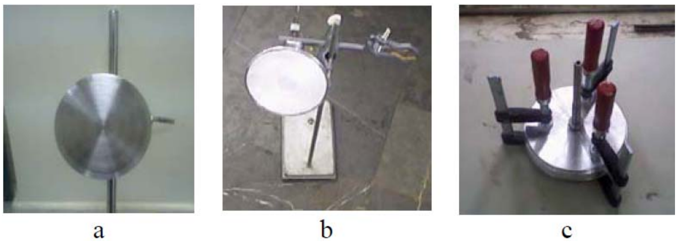


**Fig. 1:** Molding Silicon coating : a- Aluminum Disk, b- Disk covered with Si, c- molding process.

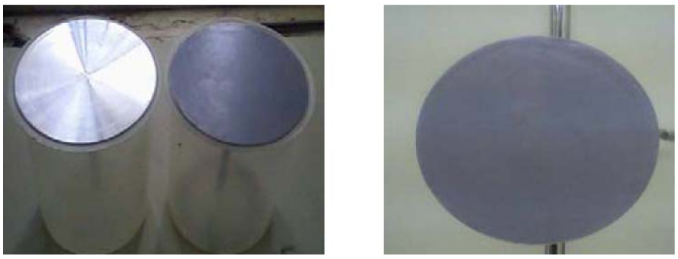

**Fig. 2:** PTFE : Disk Covered by PTFE sheet pasted on Aluminum Disk by pressing.

***B. Apparatus Description:***

To evaluate the drag reduction efficiency of any given coating, a simple disk similar to that described in Ge W., (2007) was fabricated (see Figure 3). The disk was made of Aluminium having a radius of a = 7 cm and a final thickness (without coating and after coating) of b = 0.3 cm. The enclosure in which the disk was rotating had a diameter of 18 cm and a height of 1.9 cm.

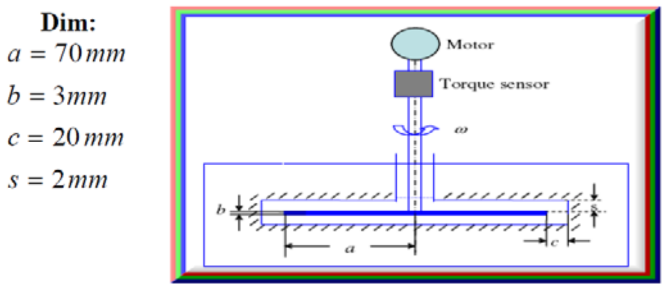


**Fig. 3:** Fabricated rotating Disk dimensional details.

The disk was rotated at constant speed using the rotor system manufactured by Heidolph Company, Model RZR 2102, as shown in Figure 4. With this rotor system, the rotational speed of the disk could be controlled from 0 up to a maximum of 2000 rpm. In practice, however, to have a measurable torque the device was run at a rotational speed in the range of 200 to 2000 rpm.

**Fig. 4:** Rotor system connected to rotating disk apparatus (RDA).

The rotor system shown in Figure 4 was equipped with a torque sensor having a capacity of 2 N.m with an accuracy of 0.00 1 N.m. The device could display the resistive torque applied on the disk at any given rpm by the surrounding fluid.

***C. Governer Equations:***

The drag reduction efficiency of any polymers can be evaluated by comparing the torque experienced by the disk while rotating in the water with and without the coating at the same speed. It is typically defined as:

$$\%DR = \frac{T_{Al} - T_P}{T_{Al}} \times 100 \tag{1}$$

where $T_{Al}$ and $T_p$ are the torques measured on both sides of the disk, rotating at the same rpm in the water without coating and coated with polymers, respectively. The Reynolds number of the disk-induced flow is defined as:

$$\mathrm{Re}_{Disk} = \frac{a^2\omega}{\upsilon} \tag{2}$$

where a is the disk radius, ω is angular velocity, and í is the kinematics viscosity. For the flow induced in the fluid by an enclosed rotating disk, the transitional Re is known to be around $3\times10^5$ (White, 2006). Using this critical Reynolds number as the criterion to ensure that the flow is indeed turbulent, we have reached to the conclusion that the disk should be rotated at rotational speeds above 580 rpm to guarantee that flow is truly turbulent.

## RESULTS AND DISCUSSIONS

The drag reduction percentage for PTFE is shown in Figure 5 as a function of the Reynolds number. As can be seen in this figure, the two graphs for the 0.2-mm and 0.4-mm coatings have a drag reduction efficiency of roughly 70% in the laminar flow regime. At Reynolds numbers above Re ≈ $2\times10^5$, however, the drag reduction efficiency of this coating decreases so that at Re ≈ $9.7\times10^5$ it is roughly just 18%.

Figure 6 shows the drag reduction percentage versus the Reynolds number for a 0.4-mm thick RTV-Si rubber coating. As can be seen in Figure 6, at this thickness, the sprayed coating is more efficient than the molded coating in reducing the drag and this is particularly so at low Reynolds numbers. For example, at Re ≈ $3\times10^5$ the maximum drag reduction for the sprayed coating is roughly 50% whereas for the molded coating it is roughly 24%. At higher Reynolds numbers, however, the two curves approach each other (see Fig. 6). And, at Reynolds number above Re ≈ 106 there appears to be no significant drag-reduction capability left in this coating.

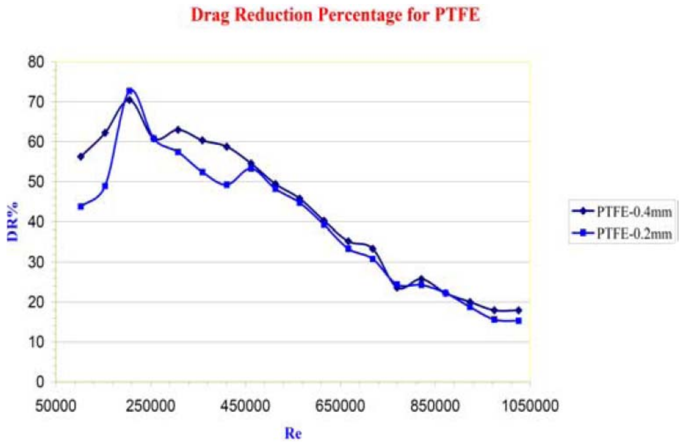


**Fig. 5:** Drag reduction percentage of PTFE with two thickness versus Reynolds number.

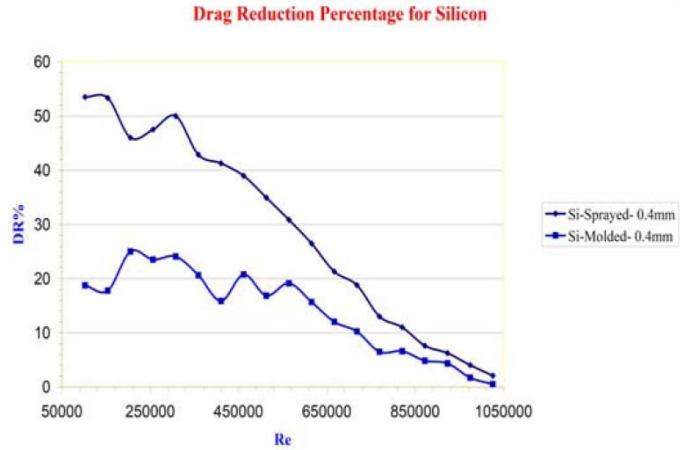


**Fig. 6:** Drag reduction percentage of sprayed and molded RTV Si rubber with 0.4mm thickness versus Reynolds number.

Figure 7 shows that for a thickness of 0.1 mm the two graphs (corresponding to sprayed and molded coating) are virtually the same. At low Reynolds numbers (less than the critical Re) the drag reduction efficiency for both of them is about 40%. Again by an increase in the Re, their drag-reducing efficiency is dropped such that at Re ≈ 106 the drag reduction percentage is roughly 11% for both of them. Having said, it is interesting to note that after $Re \approx 7\times10^5$, the drag reduction percentage of the 0.1-mm thick rubber coating is more than that of the 0.4-mm thick coating. This is perhaps due to the difference in the morphology and roughness structure of the final coated layer when different thickness and method of implementations are used.

Figure 8 shows a comparison between the maximum drag reduction efficiency of the sprayed Si rubber at two different thicknesses with that of a 0.4-mm PTFE coating. As can be seen in this figure, at all range of the Reynolds numbers, the PTFE coating is more efficient than the rubber coating. As a matter of fact, for PTFE coating the maximum drag reduction percentage is about 70% whereas while for the Si-rubber it is about 53%.

***Conclusion:***

It was shown that in the laminar flow regime the coatings have high drag reduction efficiency as compared to the turbulent flow regime. It is also concluded that the drag reduction efficiency of rubber and PTFE coatings is dropped with an increase in the Re number. At high Re numbers (corresponding to fully turbulent flow regime) the drag reduction percentage of Si-rubber and PTFE coatings is about 11% and 18%, respectively. It is also seen that at low Re number, sprayed Si coating has a better performance in comparison with the one applied using the molded method. This appears to have roots in the porosity of the sprayed coating after curing that causes it to be more hydrophobic. In addition it is observed that PTFE is more efficient than the Si rubber in all range of laminar and turbulent flow regimes, induced by rotating disk.

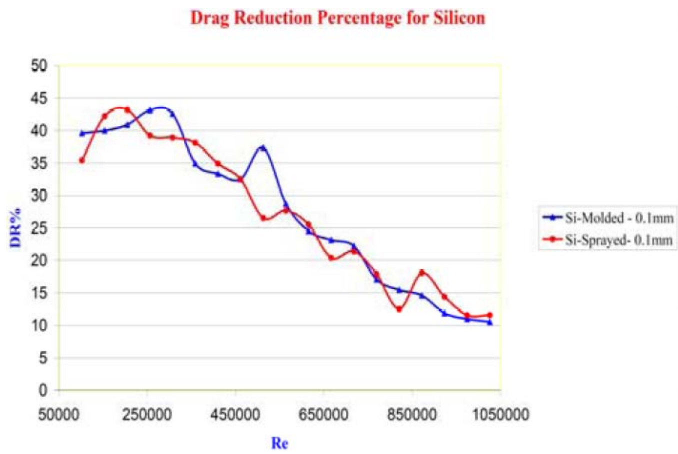


**Fig. 7:** Drag reduction percentage of sprayed and molded RTV Si with 0.1mm thickness versus Reynolds number.

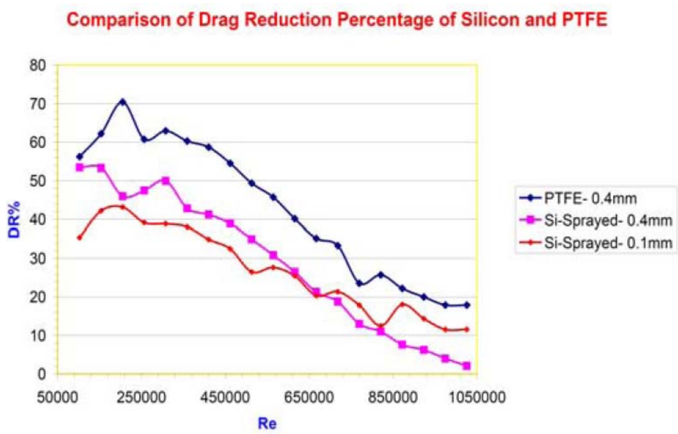


**Fig. 8:** Comparison of drag reduction of PTFE with RTV Si rubber.

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