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MEASUREMENT OF LIQUID FILM THICKNESS ON THE HYDROPHOBIC SURFACES AT THE ROTATING VERTICALLY DISC CONTACTOR

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ABSTRACT

Experimentally, the research on the flow of liquid film of viscous liquid on vertically rotating flat disc partially immersed in a liquid bath has been investigated and modellelled by many researchers. The difference, in this research, the liquid being used is tap water. Meanwhile, the characteristic of disk surface chosen was hydrophobic one. The reason for this choice was due to the fact that the material being used to sell for public had hydrophobic characteristics. Therefore, for the disk material, the researcher used the material from acrylic and novotex that had hydrophobic characteristics on its surface. In addition to the disk material, also investigated the influence of surface topography, by doing three variations of topography. Furthermore, this research was conducted experimentally to see the flow characteristics of liquid film at the rotating vertically disk, especially at the low rotational speed around 1-20 rpm. The other parameter affected to the thickness characteristics of liquid film dealing with the disk depth to the water surface was also considered. Finally, the research result showed that hydrophobic surface had an effect to the flow profile and its depth of liquid film. However, liquid film was not capable of sticking very well especially at the low rotational speed of 1-7.5 rpm. Besides, the thickness profile of liquid film was not always equally the same and was not capable of achieving to the top of disk when it was rotating up.

Keywords: hydrophobic surface, topographical surface, liquid film, rotating disc, fluid slip.

1. INTRODUCTION

For many applications in microfluidic technology and almost all situations in the biological domain, the behavior of interfacial water is of prime importance. The geometric constraint of a solid surface, as well as the interactions between water molecules and the substrate, lead to structural changes of water compared to its bulk properties [18]. In macro, the surfaces characteristics were classified as hydrophilic and hydrophobic, depended by the contact angle made by the water droplets. The hydrophobic surface tended to caused slip of the water, meanwhile the hydrophilic surface did not. The flat surface that was classified as hydrophobic was happened when the water droplets produced the contact angle more than 90º [5, 6, 14], meanwhile in hydrophilic surface the contact angle was less than 90º [19]. In 2008, Granick and Bae [10], initiated the scientific discussion to identify the characteristic of the hydrophilic surface molecule versus hydro phobic's which purposed to characterize the hydrophobic surface, mainly for the practical application. Liquid slip seems to appear when a fluid does not wet a surface [1, 9]. Because the extent of slip varies systematically with the contact angle [12], in the case of water.

The study of liquid film that has same average flow direction with the direction activator was interesting to be discussed. If a rough surface is put in contact with a wetting liquid, the roughness may be spontaneously in vaded depending on the surface pattern and the wetting properties of the liquid. The wetting properties of the surface can be predicted and tuned by the design of a solid texture. In this paper, we analyzed the thickness and the profile of liquid film that was dragged upside by the cause of the disc rotation out of water. The material used for the disk was hydrophobic, with the material kind that has different hydrophobicity value. Moreover, the disk topography was modified with U form, where the width of mound and groove was set in particular measurement, referred to Jimenez et al., 2004 [13], that explained about the flow types caused by the roughness, the roughness type D and type K, which is made by Perry et al., 1969 [16] at the first time. Jimenez studied the boundary layer that was passing through rough surface area, was gained a result that the effective roughness factor depended by the roughness and the thickness of the boundary layer as it was showed at Figure-1.
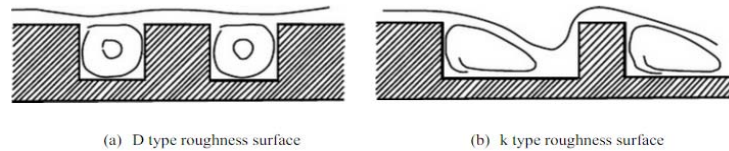
(a) D type roughness surface   (b) k type roughness surface

Figure-1. The surface types contoured to the water flow (Perry *et al.,* 1969).

Explained by Jimenez *et al.*, 2004 [13] the water flow types that were flowing horizontally passed through the box form, will have the different vortex flow and different liquid film thickness. This study's focus, was analyzing the liquid film flow on the topographic surface that has vertical rotation direction.

In a rotating disk contactor, the disc are partially immersed in the water. As a consequence of the rotation, a liquid film is brought upwards over the surface of the discs, thus providing a contact of the film with the gas phase above the water [2, 8, 11]. After moving downwards the liquid film will be taken up again by the bulk of water in the trough. The recirculated water film will be homogeneously mixed with the bulk of the liquid. The thickness of the liquid film on the discs plays an important role, particularly at low rotational speed in mass transfer studies [3, 4, 7, 15] sugested an analogy between the formation of films on rotating discs on the one hand and flat plates withdrawn from a liquid on the other hand. The withdrawal of flat plates from liquids has been examined thoroughly, both experimentally and theoritically, by Zeevalkink *et al.*, 1978 [20]. The flat plate withdrawal theory states that withdrawal of a smooth infinitely long flat plate from a liquid with a velocity results in an adhering film of thickness δ which can be calculated as a function of the effects of gravity, withdrawal velocity and physical properties of the fluid. This may be expressed as follows:

$$\delta = K \left(\frac{\eta \omega R}{\rho g} \right)^{1/2} \qquad (1)$$

Where δ is liquid film thickness (μm), η is dynamic viscosity of liquid (kg.m^{-1}.s^{-1}), ρ is density of water (kg.m^{-3}), g is acceleration due to gravity (kg.m^{-2}), ω is rotational speed (rpm), R is radius of disc (m)

The application from the formula mentioned above, by Zeevalkink *et al*, 1978 [20], that studied about liquid film thickness (δ), in his experiment used volume method meanwhile disc material used was made of polysterene. The way how it worked, some water that carried by the disc when exposed to the air as a result of the rotation, measured with sponge that was pasted on disc (Along the surface that is not submerged with water, was called the area of film ultimate thickness), see Figure-2. So the formula was:

$$\delta = \frac{M}{\text{...}} \qquad (2)$$

Where M is the difference of sponge weight (gram). He related δ to be a function of the rotational speed as well as depth of immersion in addition to the forces of gravity and viscosity.
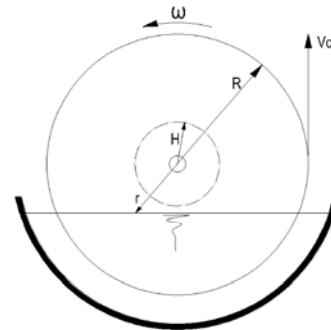

Figure-2. The rotating vertically disc
(Zeevalkink *et al.,* 1978).

The formula above could be concluded that, larger the disc diameter, then the peripheral velocity was larger either, so the liquid film thickness was increased. Sanjay, 2007, who also studied the liquid film profile, used the disc material made of acrylic. He got the different value of liquid film thickness and was not uniformly on the disc surface, so the value of peripheral velocity was also different. The disc material that was used by the previous researchers had many different kinds, so the liquid film thickness profile that gained was different too.

2. MATERIAL AND METHOD

For the experiment use has been made of a laboratory scale rotating disc apparatus (see Figure-2). Do a variation on the type of material for the disk and the disk surface topography. The material types of the disc were novotex and acrylic. The disc surfaces topography was made in three variants. The water basin was formed semi-cylinder and made of acrylic. The depth of immersion of the discs was varied by varying the water level in the trough. For practical reasons only the outer discs were used for the measurements. The water temperature was kept at 26±0.5°C.

There were several methods for measuring the liquid film thickness that patched on the disc surface which was rotating vertically. But in this study, liquid film that patched to the disc while it was out of water, the thickness value was less than 100 μm and the temperature used was 26°C so it was difficult to be detected.

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Table-1. Reactor design and operating parameters for laboratory scale.

Number of disc (no.)	1.0
Material of disc	Acrylic and Novotex
Diameter of disc (cm)	23
Thickness of disc (cm)	1.0
Distance between outer disc and trough (cm)	2.0
Rotational speed (rpm)	1; 3; 5; 7.5; 10; 15; 20
Depth of immersion under from centre of disc (m)	0.025 ; 0.063 ; 0.07
The width of the mound and groove on disk (cm) : - Type 1 - Type 2 - Type 3(the number and width of the hemisphere)	0.9-0.9 1.0-1.5 0.9-0.9 (3- 1.5)
The high of the mound and groove on disc (cm)	0.3-0.3

In this work the amount of water entrained by the discs was measured by holding sponges against one of the discs (in Figure-1, along the line CD which is in the region of ultimate film thickness). After one or two rotations the increase of weight increase M per rotation the mean film thickness was calculated assuming that the water was equally spread over the disc and that the film velocity equals the velocity of the disc, using formula no.2. The formula of the submerged disc area, using total disc extent. At the Figure-3 below, the reactor that was used to measure the liquid film thickness with one disc only.
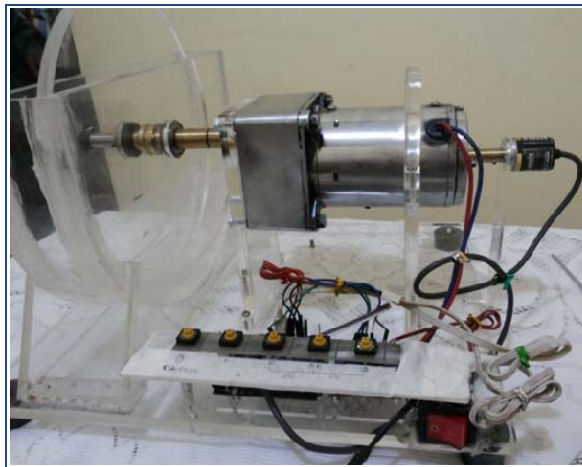
Figure-3. Rotating vertically disc contactor apparatus.

3. RESULTS AND DISCUSSIONS

3.1. The influence of hydrophobic surface towards liquid film flow's profile

The relation between disc material and liquid film thickness would be reviewed with looking at the relation of liquid film thickness with disc rotational velocity root. Below the liquid film thickness profile in every materials with doing the variations toward the depth of disk in the water and angular velocity root.

The liquid film thickness value on the flat disc surface would be higher if the disc depth (H) was increased. In this research, the biggest liquid film thickness value was gained by the 39% depth. This liquid film thickness at the angular velocity 0.105 rad/sec (1 rpm) on the hydrophobic surface was very hard to patch so it just formed as the water droplets. On that velocity, the flow profile on the acrylic surface has the liquid film thickness value was under 0.3 μm, meanwhile on the novotex was still around 0.7-2.1 μm. Liquid film thickness value was increased extremely on the angular velocity above 0.785 rad/sec (7.5 rpm).

In this work, obtained that the tendency of liquid film thickness, in acrylic material and novotex 0, based on the relation between δ_{rf} with disc rotational speed, was non linier. If it was plotted with fourth order diffensial equation then coefficient of determination (R^2) more than 99%. That condition valid for the variations of the water depth below and above the axis of the disc, and agreed with the research conducted by Avanasiev et al., 2008. The equation that valid was differential fourth order equation, with the value of R^2 99.8%. Implementation of the fourth order equation, not in accordance with the linear equation used by Bintanja et al., (1975) and Zeevalkink et al., (1978) [3,20]. This is due to the influence of the material characteristics of the disc used.

3.2. Liquid film flow profile on the topographic disc surface
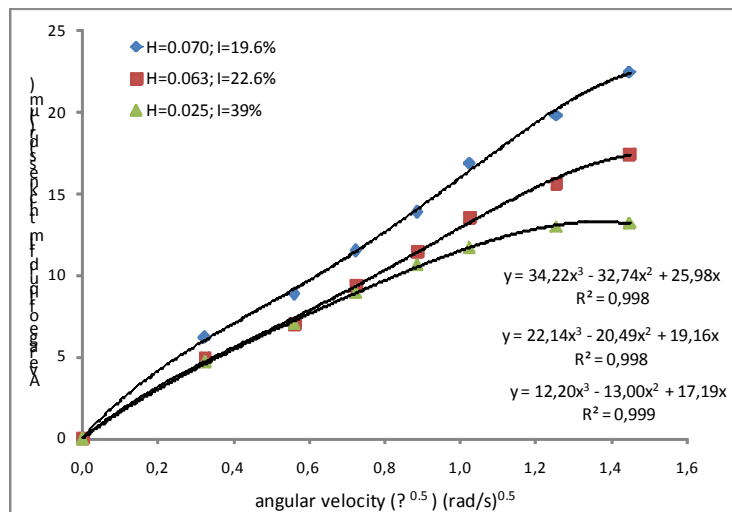
The liquid film thickness profile on the topographic disc surface towards the rotational speed variations was non linier, the differential equation fourth order. That the same phenomena with the flat disc.

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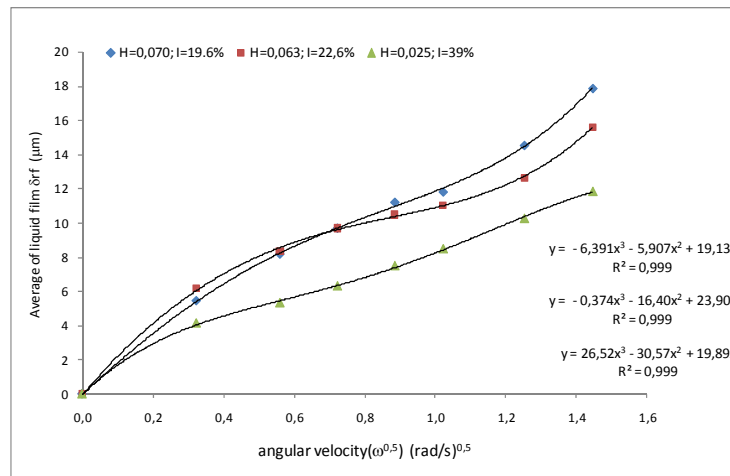
(a)
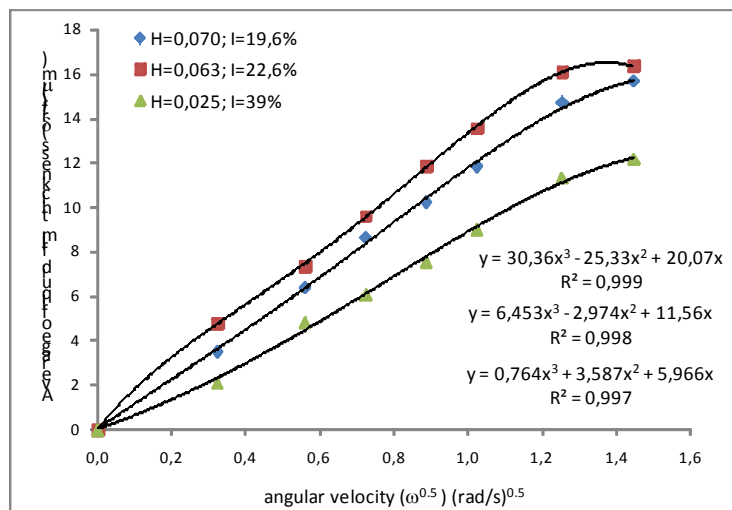
(b)

(c)

Figure-4. Liquid film on topographyc surface disc, in (a) type 1; (b) type 2; (c) type 3.

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From Figure-5, we reviewed form the disk depth towards the water surface, the flat disk material on the depth H=0.07 m (39%), the liquid film thickness value was higher than others. This thing is different with the topographic disk where on that depth, the liquid film thickness value was the lowest. So the flow of the liquid film on the vertically rotating disc, which the topographic disc surface, the thickness value took the opposite with the flat surfaced disc. on the topographic disc surface, there were frictions. On the type 1, the highest thickness was on 19.6% depth, on type 2, on the 22.6% depth, and on the type 3, the highest thickness was on 19.6%. Meanwhile on

the 39% depth, on the three topographic disc types, the thickness value of the liquid film flow was at the lowest.

3.3. Liquid film flow profile on the topographic disc and flat disc surface

The topographic disc surface, based on the rotational speed, the liquid film thickness was lower than the flat disc. The increasing of liquid film thickness slowed down on the 20 rpm rotational speed. This phenomenon was different with the liquid film flow on the flat disk which was significantly increased on the 20 rpm rotational speed.
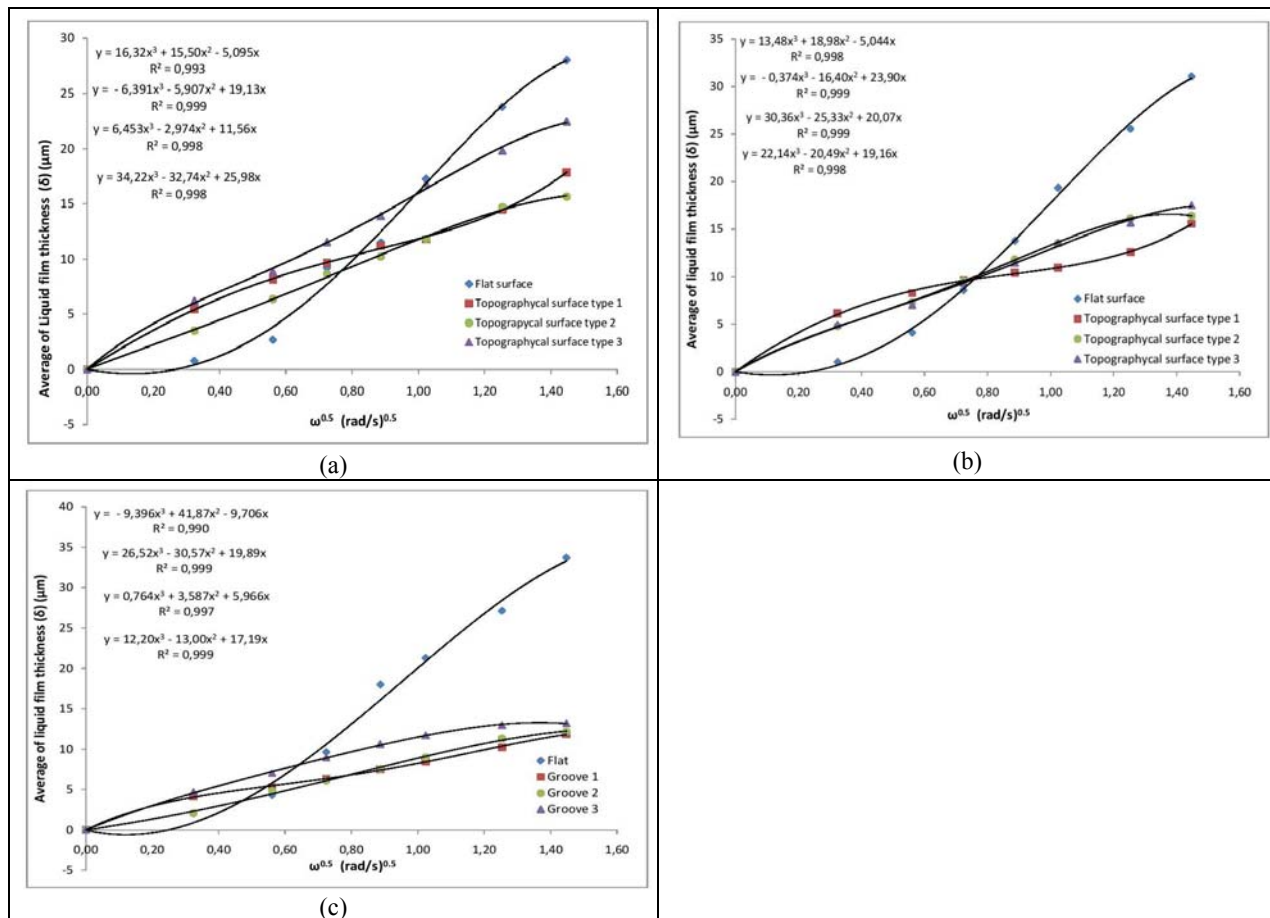

Figure-5. The comparison between liquid film thickness on the flat surface and topographic surface on the disc depth towards water surface, (a) H = 19.6 %; (b) H = 22.6%;(c) H = 39%.

On the topographic disc surface, which were obtained by the phenomenon of the liquid film thickness relationship with the rotational velocity, according to the disk surface is flat. By increasing the speed (in this study limited to 20 rpm) then the value of the film thickness of the liquid film increases. The results of the measurements, obtained the film thickness of the liquid in novotex contoured type 1= 4.144-17.842 μm; contour type 2= 2.099-16.386 μm; contour type 3=4.676-22.482 μm, the thickness of the obtained value is lower than the flat disk surface in the range of 0.107-33.724 μm.

In other hand, the liquid film flow profile on topographic surface on the lower rotational velocity 0.105 rad/sec - 0.785 rad/sec, the value of liquid film thickness on topographic surface disc, was still higher if it was compared with the flat disc, the range of value 2.099-13.903 μm (see Figure-6). While in the flat disc, the thickness of the liquid films increased significantly after the rotational speed of more than 7.5 rpm (0785 rad/sec), up to 20 rpm (2,094 rad / sec). And the rotation speed of above 7.5 rpm is turbulent flow.

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3.4. The visualization of liquid film flow profile on the hydrophobic flat surface.

Liquid film flow profile while it was dragged by the vertically rotating disc out of water (drag out), depended from many factors. One of them was the characteristic of the disc surface. From the experiment's result, gained there was a relation between liquid film thicknesses with the disc material types, especially on hydrophobic surface. Narrated at the Figure-6, liquid film profile that was dragged when the disc rotating out of water, in any material variations and rotating speed, at 63mm water depth below the disc axis, or the disc depth at 22.6%.
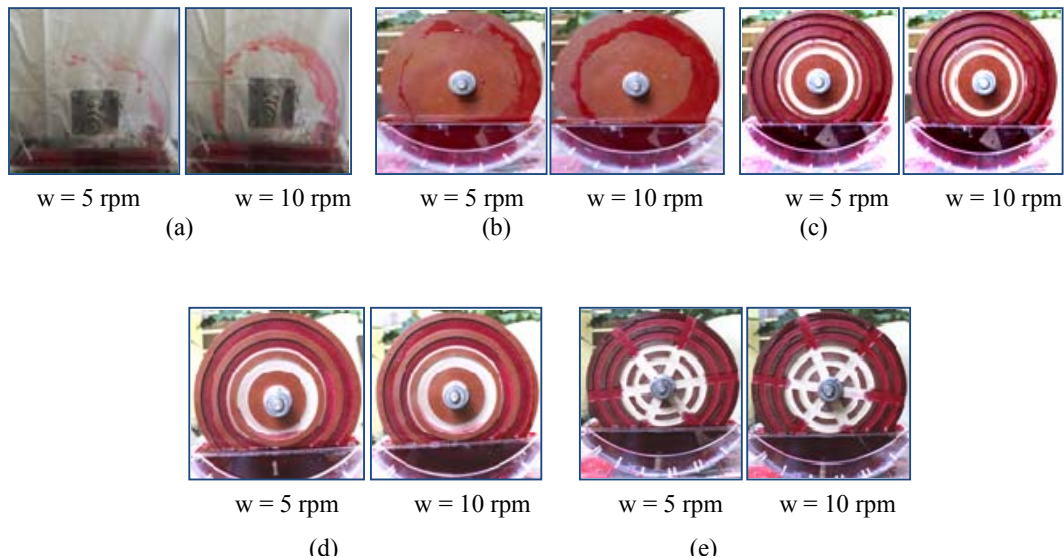

| w = 5 rpm | w = 10 rpm | w = 5 rpm | w = 10 rpm | w = 5 rpm | w = 10 rpm |
| (a) | | (b) | | (c) | |

| w = 5 rpm | w = 10 rpm | w = 5 rpm | w = 10 rpm |
| (d) | | (e) | |

Figure-6. Liquid film flow profile at the disc depth, H= 63 mm, on (a) flat disc, acrylic; (b) flat disc, novotex; (c) topographical disc type 1; (d) topographical disc type 2; (e) topographical disc type 3.

The disc surface characteristic has strong relationship with the surface ability to drag out some water when it was out of water, and when it was dragging in the water surface. Liquid film flow profile from the Figure-7, with acrylic material (Figure-7a), the water easily slipped when the disc was dragged upside. At the 10rpm velocity, the water cannot full fill all of exposed disc. The liquid film flow was only patched a half from the whole exposed area. Meanwhile on the novotex (Figure-7b) much better in dragging the water rather than the acrylic did, but at the lower rotational speed, the liquid film was still hard to patch.

On the topographic disc type 1 and 2 (Figures 7c and 7d) which the surface topography was similar (the difference was only on the topographic width), at the 5 rpm, the liquid film was not patched perfectly when the drag out until at the position where the water was at the top of the disc. Meanwhile at the 10 rpm velocity the liquid film flow was still patched imperfectly, but the flow was thicker when the first drag out process. In other hand on the disc with topography 3, where there was an addition of vertical gap position, evidently the liquid film thickness was higher if it was compared to the both types before.

Vertical position of the gap, causing much of liquid film flow which brought at the first time dragged by the disc, so the liquid film flow thickness value became at most. It was just at the rotational velocity above 7.5 rpm, was still lower than the disc type with flat surface.

4. CONCLUSIONS

Liquid film thickness profile that was dragged up by the disc while it was rotating vertically out of the water, based on the experiment's result, obtained that there was significantly influence of characteristic the surface of disc. The characteristic of the disc surface, in this research was chosen hydrophobic surface. From the experiment's result, known that on the hydrophobic surface, the liquid film could still patch to the disc surface well. When on that hydrophobic surface done some topographic variations on its surface, the liquid film flow was still able to patch on the disc surface. Beside the characteristics of surface factor, there were other dominant factors included property of water, rotational speed and the disc of immersion. Liquid film thickness was increased if the rotational speed was increased too. If it was reviewed from the disc immersion, there was a different on the flat disc and topographical disc. On the flat disc, the thickness value of the liquid film increased with the increasing of the disc depth, in this research, the highest thickness value was on the immersion disc 39%, but on the topographical disc was conversely did.

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