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THE PROFILE OF LIQUID FILM'S FLOW ON THE SURFACE ROUGHNESS IN VERTICALLY ROTATING DISC CONTACTOR

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ABSTRACT

The Profile of liquid film on the surface of contact media with the different surface roughness provided the different kinds of flow profiles. The existence of the surface roughness in the nano scale, might cause the reduction of physicochemical resistant factor which potentially prevented the liquid film to adhere and dragged out to the surface of contact media. However, varying the kind of material used as the disk material was related to the characteristics solidity of surface roughness. This parameter dealing with determining the roughness of liquid film had not been investigated by the previous researchers. This work studies measured the thickness of liquid film at the various surface roughness by regulating its rotation speed and the depth of its contact media. Furthermore, *in this study,* the shape of contact media used was disc contactor. The experiment was conducted by varying the disc surface using different materials, they were novotex and acrylic. Meanwhile, the method employed to measure the thickness of film was sponge media and the surface roughness employed the Atomic Force Microscopy (AFM) roughness analysis. Finally, the research result showed that the surface roughness had an effect to the flow profile and the thickness of liquid film. Besides, it also had another dominant effect to its rotational speed, depth of immersion and geometrical dimension.

INTRODUCTION

Doing the material variations that was related to the kind of material used as the disk material, was related to the characteristics solidity of surface roughness. This parameter dealing with determining the roughness of liquid film had not been investigated by the previous researchers. In theoritical studies, the main approach is to use the lubrication approximation. On the area of surface roughness, the transition flow changed into turbulent flow, which could be happened in low Reynolds numbers that learns the influence of surfaces texture in the flow speed profile (Schlichting *et al*, 1968; Cervo *et al*., 2013). It was accepted that surface roughness (Zhu *et al*., 2002; Bonnaccurso *et al*.,2003; Truesdell *et al*., 2006; Cervo *et al*., 2013) surface wettability (Pit *et al*., 2000; Bonnaccurso *et al*., 2002; Choi *et al*., 2003; Qian *et al*., 2005; Maali *et al*., 2008) influence the interaction between liquid and solid at the interface.

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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 (Chen *et al*., 2007; Bhatelia *et al*., 2009; Hendrasarie, 2014). 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 (Bintanja *et al*., 1975; Kim *et al*., 1982; Boumansour *et al*., 1998; Chavan *et al*., 2007) 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, 1978. 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:

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

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

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, 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 1. So the formula was:

$$\delta = \frac{M}{\rho\pi(R^2 - H^2)} \qquad (2)$$

Where M = 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.

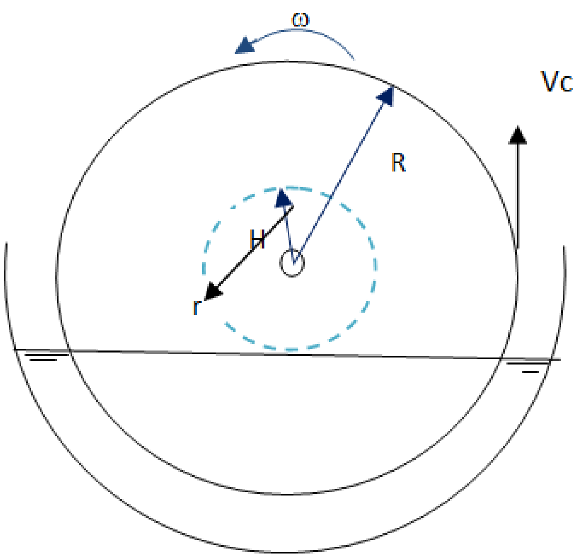


Figure 1. The Rotating Vertically Disc (Zeevalkink *et al.*, 1978)

In addition to disc rotational speed (ω), Zeevalkink *et al.*, 1978, formulated the disc peripheral vertical velocity. The disc peripheral vertical velocity was the function of rotational speed and the radius of disc. With the equation:

$$v_c = \omega (R^2 - H^2)^{1/2} \qquad (3)$$

Where v_c is vertical component of the peripheral velocity at the point of emergence of disc from the liquid surface in the trough (m/min), ω is rotational speed (rpm), R is radius of disc (m), H is distance between water surface and centre of the shaft (m)

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. The purpose of this study was measuring liquid film thickness profile in the vertically rotating disc, with doing the variations in the disc material that was divided into two categories, that were hydrophilic and hydrophobic. This study was experimentally done, with looking at other factor that influenced the liquid film thickness profile that were rotational speed and the disc radius or depth.

MATERIALS AND METHODS

For the experiment use has been made of a laboratory scale rotating disc apparatus (see Table 1). Type of material as the disc material varied from materials novotex O, novotex I, acrylic (in Fig. 2) and a water reservoir formed semi-cylinder made of acrylic material. 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. And physical property of water is used : $\sigma = 2.69 .10^{-3}$ N/m, $\rho = 996{,}81\ kg/m^3$, $\mu = 0{,}8746.10^{-3}$ kg/m.s. There were several methods for measuring liquid film thickness patched to the disc surface which rounded vertically. But, in this study, the liquid film thickness was below 100μm, because the temperature used was 26°C, suitable with temperature condition in Indonesia. In that temperature, the liquid film that was patched to the disc when the disc came out of water, the thickness was below 100 μm so it was hard to be detected. In this work the amount of water entrained by the discs was measured by holding sponges against one of the discs (along the line CD in Fig.1, 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, used formula no. 3 and the formula of the disc submerged area used the disc total area. In every surfaces of the material variation, atomically photo was done in order to know the surface roughness with using atomic force microscope (AFM) (Nanoscope Iia, Digital instrumen, Vecco, Metrology Group). AFM picture was gained in the condition where the laboratory at the scan rate 1 Hz and at the size 1,0x1,0μm². This type of method worked well to know the measurement of the particle height.

Table 1. Reactor design and operating parameters for laboratory scale

Specifications	Dimensions
Number of discs	1
Mutual distance of discs (m)	0.02
Diameter of discs (m)	0.23
Thickness of discs (m)	0.01
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
Distance between outer disc and trough (m)	0.020

At the Figure 2 below, the reactor used for measuring liquid film thickness, used one disc.

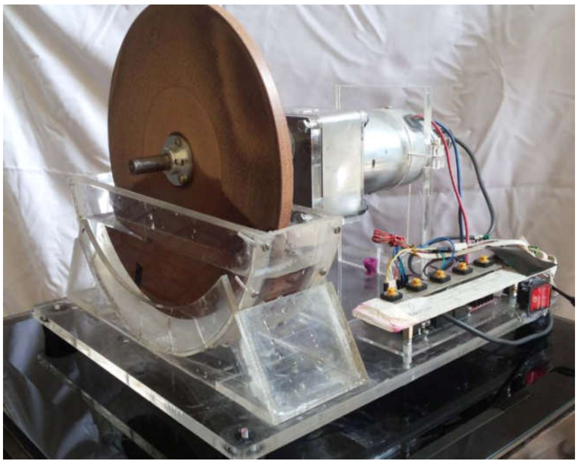
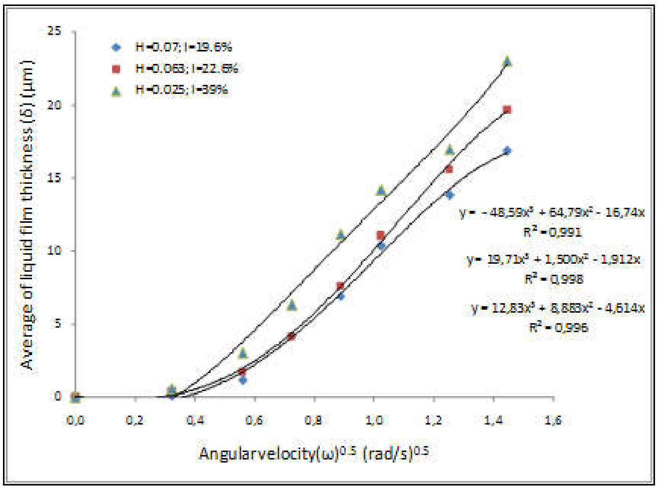


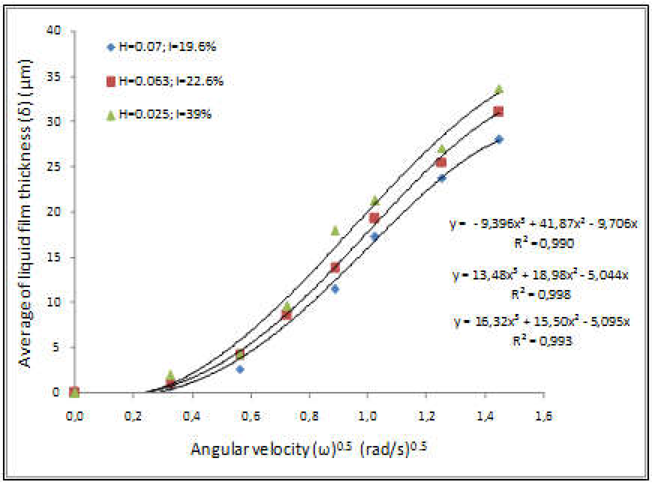
Figure 2. Rotating vertically disc apparatus

RESULTS AND DISCUSSION

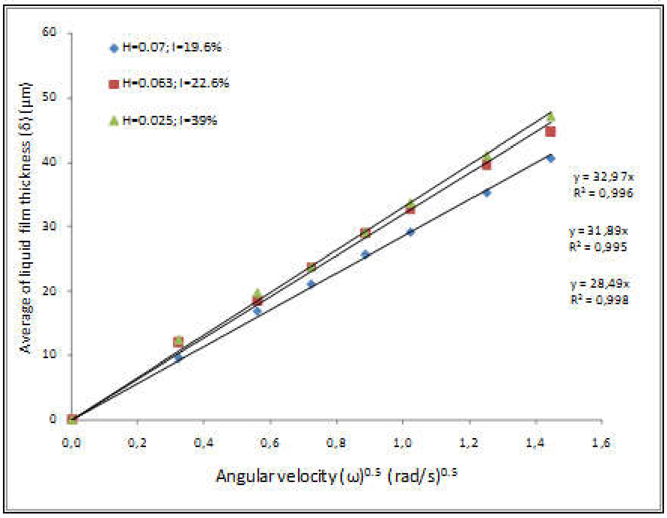
The Influence of the disc material and rotational speed toward liquid film thickness: The relation between disc material and liquid film thickness would be reviewed with looking at the relation of liquid film thickness with disc rotational velocity root. Below the liquid film thickness profile in every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



(a)



(b)



(c)

Figure 3. Liquid films thickness profile in materials (a) Acrylic, (b) Novotex O (c) Novotex I

In Fig. 3, 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, dan 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). This is due to the influence of the material characteristics of the disc used. In research Bintanja *et al.*, 1975 and Zeevalkink *et al.*, 1978) the disk material used is made polystyrene. The liquid films thickness profile on the surface of the material polysterene, in accordance with the material novotex I of this research, which was showed the relationship liquid films thickness profile of the rotational velocity is linear. Differences in the thickness profile of liquid films on the surface of the disc, with varied materials, related to the nature of the material. The material properties based on wet ability surface and contact angle (α), which is divided into two properties, namely surface hydrophilic or hydrophobic surface. Novotex O and acrylic, are included in the group of hydrophobic surface, while novotex I category hydrophilic surface. The influence of disc material towards liquid film thickness and peripheral velocity. The relation of disc material toward liquid film thickness, would be reviewed deeper with looking at the relation liquid film thickness with peripheral velocity. Below at the Fig. 4, was the review result toward liquid film thickness profile in every materials with doing the variation in the disc radius and disc peripheral velocity.

Liquid film profile on the disc surface roughness

The determination of the liquid film thickness characteristic needed to calculate the disc material types. After it was tested, had known that there was relation between liquid film thickness with disc material types, especially on its surface's characteristic. The types of material surface that was related to a contact with water, divided into two types, which were hydrophilic surface and hydrophobic surface. The different was if the material surface was hydrophilic, then the water would be easier to be dragged and pasted well when the disc

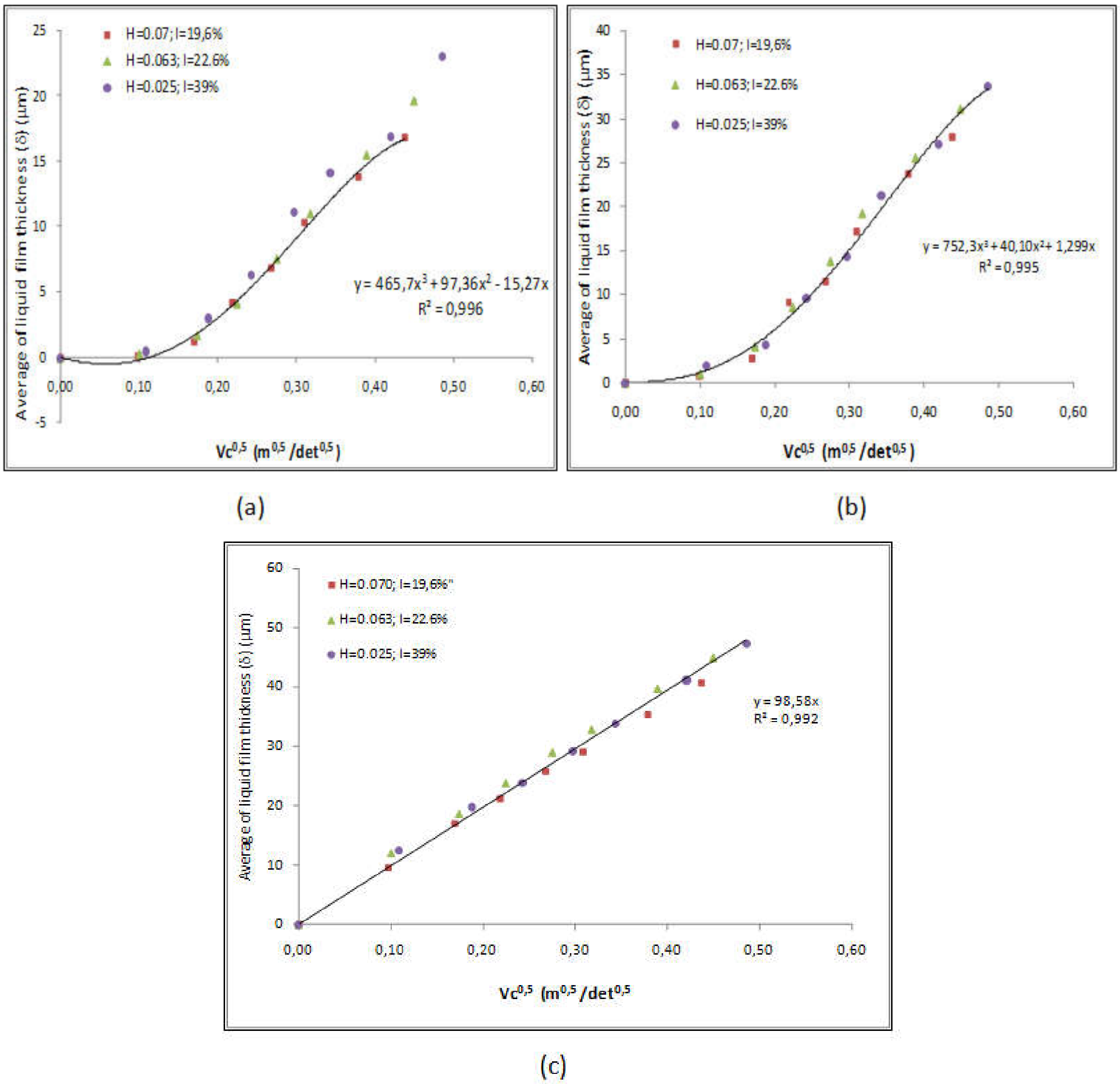


Figure 4. The relation of liquid film thickness with the value of Vc in the disc materials (a) acrylic; (b) novotex O; (c) *novotex I*

From Figure 5, the profile of liquid film thickness based on peripheral disc vertical speed, different on each disc materials. In the acrylic material and novotex O, showed the tendency of liquid film thickness, was non linier. If plotted with the fourth order diffensial (Avanasiev, *et al*., 2008) then the coefficient of determination (R^2) more than 98%. Meanwhile on the novotex I material, the connection between δ_{rf} with peripheral velocity, was linier. Profile that appropriate with formulation approach that used by Zeevalkink[19], but with the slope calculation of the graph at 98.02.

was spinning up, so the assumption of disc spinning speed was equal to liquid film spinning speed (Landau *et al*., 1942; Zeevalkink *et al*., 1978; Krechetnikov *et al*., 2005). The liquid film profile that was dragged while the disc was dragging out of the water, in every material variation and rotational speed, were illustrated in Fig. 6. The water depth was 25 mm under the disc axis. The characteristic of the disc surfaces, were closely related to the ability of the surface itself to dragged up while out of water surface, and down to the water surface (drag in). The profile of the three materials were, in acrylic, the water was easily slipped when dragged up by the disc. At the 20 rpm velocity, the water could not fulfill all of the exposed area, the value of distance of any point on the disc from the center (r) (the water trellis that was dragged by the disc) was half from the exposed area.

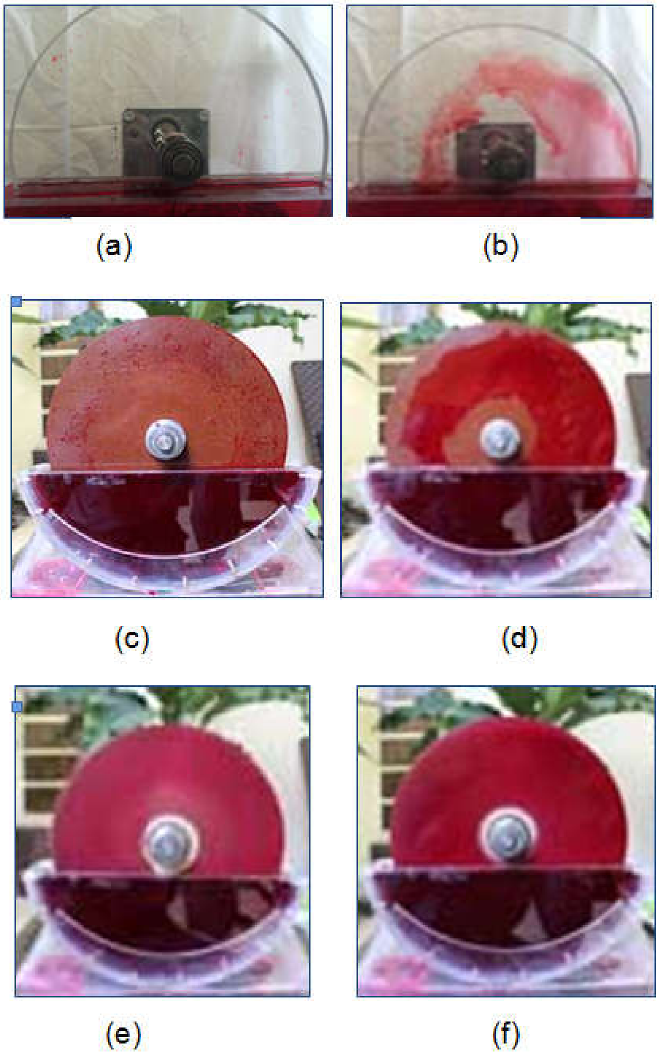


Figure 6. Liquid film profile that was dip coating to the three materials (a) acrylic,ω=1 rpm; (b) acrylic,ω=20 rpm; (c) novotex O;ω=1 rpm; (d) novotex O;;ω=20 rpm (e) novotex I, ω=1 rpm; (f) novotex I, ω=1 rpm; In the disc depth from surface water 25 mm

Meanwhile in the material novotex O, the terms of dragged the water was much better than acrylic, but at the lower rotational speed, the liquid film was still hard to patch into the disc. Material Novotex I, The water was not slipped. So if the rotational speed was increased, the water thickness level was also increased, so the theory that was described in previous study (Zeevalkink *et al*., 1978; Prins *et al*., 1987; Kubsad *et al*., 2004;Palma *et al*., 2009}, could be clearly illustrated. It's just there was water diffusion factor on the novotex I surface area, so when the water was cleaned, it was left on the novotex I, It needed about 2 minute to get it dry.

The characterization of the disc surface roughness

The characterization of material surface in this work, just looked from the material surface roughness profile. That factor includes vertically deviation of arithmetic average roughness (Ra) and the deviation standard from Ra value (RMS). Nano structure from the three disk material was observed from the value of several parameters. The photo result with using Atomic Force Microscopy (AFM) roughness analysis, shown at the Fig. 7.

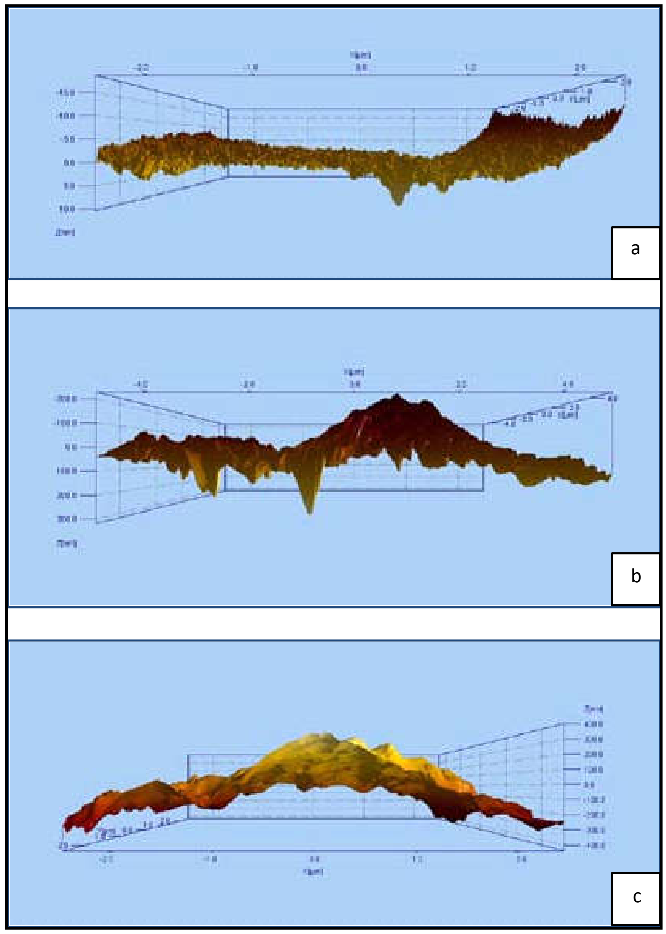


Figure 7. The appearance of the top AFM image 3D Material (a) Acrylic; (b) Novotex O and (c) Novotex I, with a scan range 5,0x5,0 μm^2

The results of measurements of parameters that were analyzed can be seen in Table 2. The Values of surface roughness parameters in all three disc material.

Table 2. Values on the material surface roughness parameters: acrylic, novotex O and novotex I.

No	Parameter	Average Thickness of Liquid Film (δ_{rf})		
		Acrylic	Novotex O	Novotex I
1	Ra (nm)	2,152	50,907	88,352
2	RMS (nm)	1,625	32,497	46,760

The results of surface roughness parameters above provide information on surface characteristics of different depth or height. From the table, could be seen that there were differences of three disc materials surfaces. The lowest roughness value was on the acrylic. Meanwhile the novotex O (the average liquid film roughness was at the 0.767-33.724 μm), had the higher surface roughness parameter value than acrylic (average liquid film roughness was at the 0.107-23.074

μm), but it was lower than novotex I. On the novotex I, having the highest roughness parameter value with the average liquid film thickness was at 9.589-47.139 μm.

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 surface roughness. Beside the surface roughness factor, there were other dominant factors included water viscosities, rotational speed and the disc immersion. The liquid film thickness increased along with the increasing of surface roughness that were classified as hydrophilic surface and hydrophobic surface. From the experiment's result proved that the liquid film thickness increased at the larger surface roughness (hydrophilic surface) rather than hydrophobic surface.

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