Effect of Surface Roughness on Contact Angle Measurement of Nanofluid on Surface of Stainless Steel 304 by Sessile Drop Method

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Abstract. Contact angles play an important role in the mass and heat transfer. Stainless steel 304 has been used for nuclear power plan structure material until now. An experiment to measure contact angle of demineralized aqua and nanofluid containing nano particle of zirconia on metal surface of stainless steel 304 with sessile drop method was conducted. The measurement to measure the static contact angle and drop of nano fluid containing nano particle zirconia on stainless steel with different surface roughness was carried out. It was observed that stainless steel 304 was good hydrophylic properties with decreasing surface roughness of stainless steel during drop of aqua demineralized and nano fluid respectively. As a result the contact angle of demineralized aqua is decreased from 97.39 to 78.42 and contact angle of nano fluid from 94.3 to 67.50 respectively with decreasing surface roughness of stainless stee 304. Wettability of nanofluid on surface stainless steel 304 is better than aqua demineralized.

1. Introduction

The interaction of a fluid with a solid surface of metal is referred to as wettability. When the fluid coverages spontaneously out as a thin film over the surface of metal, it is said as wetting the surface of metal. When the interactions are weak, the fluid drops on the solid surface of metal and the liquid locally wets the surface. The wetting phenomena plays an important role in the mass and heat transfer such as heat exchanger, steam generation, waste heat recovery and emergency cooling system. An index of wetting properties is defined by the magnitude of contact angle between the liquid and solid surface of metal (1,2). Solid metal provides planar surface that allow the geometric measurement of a contact angle on the metal. If the contact angle is lower than 90° the material is hydrophilic otherwise it is hydrophobic. Contact angle can be calculated by Young equation (3) and this equation is valid for the ideal surface such as chemically homogenous, non-reactive and insoluble. Values of the contact angle were determined by use of a goniometer or from captured image of a droplet. Building on the digital images of the droplets geometrical approach and developed tangent method were applied.

Nanofluids are colloidal mixture of nano particles in a base fluid. The properties of nanofluids are significantly enhances the heat transfer coefficient and conductivity characteristics of the original fluid. These nano particles usually metal or metal oxide, increase the conduction and convection coefficients of base fluid (4,5). Experimental studies on nanofluid single-phase heat transfer have been reported in the literature. Alumina-water and titania-water are studies in turbulent convective heat transfer in tubes (6). Laminar convective heat transfer and viscous pressure loss of alumina–water and zirconia–water nanofluids have were been studied (7). The studies of nanofluids for nuclear power plants application such as primary and secondary cooling system and emergency core cooling systems(ECCSs) were carried out by a number of researcher. This studies were characterized by the improvement of critical heat flux (CHF) of nanofluid after injection in experiment of loss of coolant accidents (LOCAs). The benefits of nanofluid during simulation accident conditions. It is clear that the nanofluid engineered ECCSs should be compatible with conventional systems during normal operations to make nanofluid technologies practical in Nuclear Power Plants.(8)

The purpose of the present study is to study the contact angle of demineralized water contain nanoparticle zirconia on the metal surface stainless steel 304 with different surface roughness in nanofluid solution will be studied. The stainless steel 304 as an engineering material is used as nuclear material structure in the secondary cooling system (9,10). The contact angle is highly influenced by surface finish of the metal and nanofluids. Contact angle fluid and solid of stainless steel 304 in nanofluids media contain nanoparticle ZrO2
is rarely studied. The present work is to investigate the contact angle behavior of nanofluid containing 0.01 gpl nanoparticle ZrO$_2$ on stainless steel 304 surface with different surface roughness using a sessile drop method for evaluation.

2. Experiments

2.1. Material and nanofluid

The specimens used in this experiment were circular discs of stainless steel 304 having 1.6 cm in diameter and 2 mm in thickness. The specimens are stainless steel with the major chemical composition (in wt%) 18.21% Cr, 8.40% Ni, 0.39% Si, 1.56% Mn, 0.45% Mo, 0.025% C balanced Fe. The specimens were roughed by wet grinding with different emery paper 230, 500, 800 and 1000 grit, degreased with detergent after that cleaned with ultrasonic cleaner in alcohol solution. Finally, the specimens dried in air freely.

In the present study ZrO$_2$ was used as nanoparticles while demineralized water was applied as a base fluid. Nanofluid is produced by mixing aqua demineralized water (adm)  and 0.01 gpl ZrO$_2$ nanoparticles. The nanofluids were prepared by incorporating 0.01 gram of ZrO$_2$ nanoparticles with an average particle size of 30-70 nm mixed into 1 L aqua demineralized water by magetit stirrer for 30 minute. Dispersants were not used to stabilise the suspension, and ultrasonic vibrator operating at a frequency of 44 kHz was used to stabilise nanofluid for 20 min in order to the ZrO$_2$ particles were dispersed and stabilized in aqua demineralized water.

2.2. Sessile drop measurement

Contact angle measurement was carried out to evaluate the wettability characteristics of the stainless steel. The contact angle can be defined as the angle between the liquid phases formed on the surface of a stainless steel and the line tangent to the droplet radius from the point of contact with the surface of stainless steel. The Contact angle perform have been conducted by sessile drop method (12) equipment system from Kruss GmbH goniometer with a resolution of 0.1° in the measuring range of 1-180°. This equipment has been provided by software drop shape analysis (DSA 4) for controlling the experiment and analyzing the drop shape to calculate the contact angle. Droplets of known volume of 2 μL were dropped on a substrate of SS 304 using an automatic dispenser and injected slowly onto the solid surface by a syringe. The experiments were conducted under similar air conditioned laboratory environments. The measured values of the contact angle, the images of the droplets were taken directly after 20 second deposition in order to eliminate the impact of droplet evaporation. The contact angle tests were conducted at an ambient temperature of 27°C.

2.3. Sample characterization

Surface morphology of the stainless steel 304 after wet grinding was analyzed by using a SEM microscope to obtained different image.

3. Results and Discussion

3.1. Surface morphology of stainless steel 304

Figure 1 shows surface morphology of the stainless steel 304 that was analyzed using a SEM microscope after abraded by emery paper. Surfaces morphology with different roughness were produced by grinding stainless steel 304 with different grit a)320, b)500, c)800 and d)1000 emery paper. Fig. 1a shows that the surface morphology after wet grinding with emery paper 320 grit more rough compare with fig. 1b,c and d because the scratch of sample 1.a more deep and width. From Fig.1, it can be concluded that wet grinding of stainless steel 304 changed the surface roughness.
3.2. Effect of surface roughness

Contact angle for the aqua demineralized and nanofluids under investigation are summarized in table 1 and figure 2. In table 1 below, it can be seen that the contact angle of aqua demineralized on surface stainless steel 304 is decreases gradually from 97.39 to 94.3 if surface roughness metal surface decrease from 320 to 1000. From the table clear that contact angle depend on chemical properties and surface roughness. The same phenomena took place on nanofluid where contact angle of nanofluid on surface stainless steel 304 is drop gradually from 78.42 to 67.50 if surface roughness metal surface decrease. This result indicates that wettability of stainleess steel with different surface roughness was strongly depend on surface finish of stainless steel and relation with heat transfer phenomena. In table show seen that the aqua demineralized and nanofluid show hydrophylic properties if the surface roughness increases.

| No. | Roughness | SS 304 Aqua DM | SS 304 Nanofluid |
|-----|-----------|----------------|-----------------|
| 1   | 320       | 97.39          | 94.3            |
| 2   | 500       | 87.11          | 86.21           |
| 3   | 800       | 87.28          | 82.57           |
| 4   | 1000      | 78.42          | 67.5            |

Table 1
Contact angle with different surface roughness by sessile drop measurement
3.3. Effect of ZrO2 on nanofluid

In Figure 2, it can be seen that the contact angle of droplet aqua DM on SS 304 is higher than with nanofluid at different surface roughness. The difference is not significant for abraded paper 320 and 500 but at 800 and 1000 is significant. These observations indicate that the wettability of demineralized water on the surface of stainless steel 304 is less good than the nanofluids.

![Figure 2. Contact angle of a drop aqua demineralized (aqua DM and nanofluid) on Stainless Steel 304 with different roughness of abrasive paper.](image)

The contact angle measurement between the nanofluid and the demineralized water and the tested materials of stainless steel 304 has been measured using the sessile drop method and represented in Fig. 3. This figure showed that wettability properties of nanofluid are more higher than with demineralized water.

![Figure 3. A droplet a) nanofluid and b) aqua demineralized on Stainless Steel 304](image)

4. Conclusion

Wet grinding of stainless steel 304 with different grit emery paper changed the surface roughness. The contact angle measurement of nanofluid contains 0.01 gpl ZrO2 nanoparticles on stainless steel 304 at different surface roughness were conducted by sessile drop. There is a direct relationship between the roughness of surface and wettability. The results show that according to sessile drop examination nanofluid and demineralized water show hydrophilic properties on the surface stainless steel 304 if the surface roughness decreases. The nanofluid has the lower wettability properties compare with demineralized water. The contact
angle value depend on surface roughness. The contact angle of demineralized water is decrease from 97.39 to 78.42 and contact angle of nano fluid from 94.3 to 67.50, respectively with decreasing surface roughness of stainless steel 304. The wettability of the nanofluid on surface of the stainless steel 304 is better than demineralized water.

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5. References

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