Effect of Spreading Time on Contact Angle of Nanofluid on the Surface of Stainless Steel AISI 316 and Zircalloy 4

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Abstract. The solid surface tension plays an important role in the heat and mass transfer system for heat exchanger equipment. In the nuclear power plant industry, the stainless steel AISI 316 and Zircalloy 4 have been used for long time as structure materials. The purpose of the experimental is to study solid state surface tension behavior by measure contact angle Nano fluid contain nano particle alumina on metal surface of stainless steel AISI 316 and Zircalloy 4 by sessile drop method. The experiment is to measure the static contact angle and drop nano fluid contains nano particle alumina on stainless steel 316 and zircalloy 4 with different spreading time from 1 to 30 minute. It was observed that stainless steel 316 and zircalloy 4 lose their hydrophobic properties with increasing elapsed time during drop of nano fluid on the surface of alloy. As a result the contact angle of nano fluid on surface of metal is decrease with increasing elapsed time. While the magnitude diameter of drop nano fluid and wetting surface is increase with increasing elapsed time on the surface of the stainless steel SS 316 and Zircalloy 4.

1. Introduction
Nanofluids are colloidal mixture of nano particles in a base fluid. The properties of nanofluids are improve the heat transfer coefficient and conductivity attributes from the original fluid. These nano particles usually metal or metal oxide, increase the conduction and convection coefficients of base fluid (1). Experimental studies on nanofluid single-phase heat transfer have been reported in the number of literature such as alumina-water and titania-water are studies in turbulent convective heat transfer in tubes. Laminar convective heat transfer and viscous pressure loss of alumina–water and zirconia–water nanofluids have are been studied. From this study nanofluid improved heat transfer compared with based fluid (2,3). 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 (LOCA). The benefits of nanofluid improved CHF during simulation accident conditions (4). 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. 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 for engineering structure 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 (5,6). 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 value can be assessment and calculated by Young equation (7) and this equation is valid for the ideal surface such as chemically homogenous, non-reactive and insoluble. In the experiment the values of the contact angle were determined by use of a goniometer or from captured image of a droplet of liquid. By assembling on the digital images of the droplets of liquid, geometrical approach and developed tangent method were applied to calculate the value of contact angle.

The purpose of the present study is to examine the contact angle of demineralized water contain nanoparticle alumina on the metal surface of stainless steel 316 and zircalloy 4 with different spreading time in nanofluid solution will be studied. The stainless steel 316 and zircalloy 4 as an engineering material is used as nuclear material structure in the secondary cooling system and primary cooling system respectively (8,9). The contact angle is highly influenced by surface finish composition of the metal and nanofluids. Contact angle fluid and solid of stainless steel 316 and zircalloy 4 in nanofluids media contain nanoparticle alumina is rarely studied. The present work is to investigate the contact angle behavior of nanofluid contain 0.01 gpl nanoparticle alumina on stainless steel 316 and zircalloy 4 surface with different spreading time using a sessile drop methods for evaluation.

2. Experimental
2.1 Material and nanofluid
The specimens used in this experiments were circular discs of stainless steel 304 having 1.6 Cm in diameter and 2 mm in thickness. The specimens are stainless steel 316 and zircalloy 4 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 and 98% Zr, 1.4% Sn, 0.24% Fe, 0.15% Cr, respectively. 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 Al2O3 was used as nanoparticles (10) while demineralized water was applied as a base fluid. Nanofluid is produced by mixing aqua demineralized water (adm) and 0.01 gpl Al2O3 nanoparticles. The nanofluids were prepared by incorporating 0.01 gram of Al2O3 nanoparticles with an average particle size of 30-70 nm mixed into 1 L aqua demineralized water by magnetit stirrer for 30 minute. Ultrasonic vibrator operating at a frequency of 44 kHz was used to stabilise nanofluid for 20 min in order to the Al2O3 particles dispersed and stabilized in aqua demineralized water. Figure 1 show micrograph of nanoparticle Al2O3 examination by TEM with magnificiant 150000. The particle size of nanoparticile Al2O3 relatively homogen.

Figure 1. Micrograph nanoparticle Al2O3 examination by TEM with magnificiant 150000
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 (11) 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 316 and zircalloy 4 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 316 and zircalloy 4 after wet grinding was examined by using a SEM microscope to obtained different image.

3. Results and Discussions
3.1 Optical image of stainless steel 316 and zircalloy 4
Figure 2(a) and (b) shows surface morphology of the stainless steel 316 and zircalloy 4 that was examined by using a SEM microscope after wet abraded by emery paper. Surfaces morphology of the sample relative the same roughness were produced by wet grinding stainless steel 304 zircalloy 4.

![Surface morphology of stainless steel 316 and zircalloy 4](image)

Figure 2. Surface morphology of a) stainless steel 316 b) zircalloy 4 after wet abraded with emery paper

3.2 Effect of Al2O3 in nanofluid on the wettability of Stainless Steel 316 and Zircalloy 4
In Figure 3(a) and (b) showed the contact angle of droplet aqua demineralized and nanofluid on Stainless Steel 316 and Zircalloy 4 as a function of spreading time multiple measurement. From Figure 3(a) and (b) it can be seen that the contact angle value of demineralized water higher compare with nanofluid at different spreading time on the surface of two of materials stainless steel SS 316 and zircalloy 4. From figure 3(a), it is shown that early-stage spreading the contact angle of low-viscosity drops of demineralized water different significantly with nanofluid on a partially wetting substrate of stainless steel 316. For long spreading time, the wetted area is found to grow and the contact angle decrease for all considered wettability’s of demineralized water and nanofluid but different of contact angle significantly between demineralized water and nanofluids. From figure 3(b), it is shown that early-stage spreading the liquid drop of low-viscosity demineralized water different significantly with nanofluid on a partially wetting substrate of zircalloy 4. For long spreading time, the wetted area is
developing and the contact angle decrease for all considered wettabili
ty’s of demineralized water and nanofluid. The contact angle of demineralized water and nanofluid on the surface of zircalloy is not significantly different for long spreading time. It can be concluded that wettabili
ties of nanofluid show good performance compare with demineralized water on the surface of stainless steel SS 316 and zircalloy 4.

Figure 4 depicted the different of the contact angle of nanofluid on the surface of Stainless Steel 316 and Zircalloy 4. From figure 4, it is shown that early-stage spreading the liquid drop of nanofluid different significantly on a partially wetting substrate of stainless steel 316 compared with zircalloy 4. For long spreading time, the wetted area is developing and the contact angle decrease for all considered wettabili
ty’s of nanofluid. Is not significantly different for stainless steel 316 compared with zircalloy 4. It can be concluded that wettabili
ties of nanofluid show good performance on stainless steel SS 316 compare with zircalloy 4.

![Figure 3](image)

**Figure 3.** Multiple measurements at ambient temperature of the spreading of aqua demineralisez and nanofluid on a) Stainless steels 316 b) Zircalloy.

The droplet image of nanofluid on Stainless Steel 316 and Zircalloy 4 has been measured by using the sessile drop method is represented in Fig. 5. This figure showed that the diameter of droplet nanofluid for Stainless Steel 316 and Zircalloy 4 decrease with increasing spreading time. The wettabili
ty properties of nanofluid on the surface of Stainless Steel 316 and Zircalloy 4 are not different significantly due to the function of two materials Stainless Steel 316 and Zircalloy 4 serve as heat exchanger equipment (9). The diameter of droplet decrease with increasing spreading time due to gravitational force at the surface of nanofluid droplet.
Figure 4. Measurements of the spreading of nanofluid on Stainless Steel 316 and Zircalloy 4.

Figure 5. A droplet of nanofluid on Stainless Steel 316 and Zircalloy 4 for 5, 15, 25 second.

4. Conclusion
The wettability behavior of Nano fluids contains 0.01 gpl nanoparticle alumina on the surface of stainless steel SS 316 and zircalloy 4 samples was studied using sessile drop methods. The results obtained can be summarized as follows:
(i) The wettability of nanofluid with 0.01 gpl nanoparticle alumina on the surface of stainless steel SS 316 and zircalloy 4 much better compare with demineralized water
(ii) The values of contact angle decrease gradually with increasing spreading time
(iii) The wettability of the nanofluid and demineralized water on surface of the stainless steel 316 is better compared with zircalloy 4
(iv) The diameter of droplet decrease with increasing spreading time

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