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EFFECT OF HIGH MOLECULAR WEIGHT SURFACE ACTIVE AGENT ON HEAT TRANSFER IN POOL BOILING

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ABSTRACT

Boiling is very complex phenomena also it is very effective mode of heat transfer. The boiling phenomenon is affected by different method i.e. active and passive method. Addition of surface active agent is active way to enhance the heat transfer rate. Heat transfer rate enhancement by addition of surface active method is depend on two parameter one is its ionic nature and other is its molecular weight. In this study we are going to understand the effect of high molecular weight surfactant on heat transfer for that purpose we are using Polyethylene glycol having molecular weight 2909.49 g/mol. The experimental result shows that addition of PEG in water increases its surface tension and considerably its surface temperature.

INTRODUCTION

The addition of small amount of certain surfactants in aqueous solution has been known to enhance the rate of nucleate boiling heat transfer significantly, this is occurred due to, the addition of surfactants to water causes no significant change in any other thermophysical properties except that the surface tension is reduced considerably. But some time reverse effect is obtained. This is happened due to the high molecular weight of the surfactant. Addition of high molecular weight surface active substance in DM water will increase its surface tension. Surface tension is an important property which affecting on nucleate boiling. As the surface tension will get increase the rate of heat transfer is will going to change drastically due to change in bubble behavior. Boiling is a very effective and efficient mode of heat transfer, which is encountered in several engineering applications. Important area of application of boiling and evaporation are in desalination of seawater, in distillation process, in chemical industries & in refrigeration system which is becoming necessary in some arid regions. Boiling with surfactant additives is generally an extremely difficult process, and it is influenced by a larger set of variables than the phase-change process of pure water. Besides the wall excess temperature (or wall heat flux), bulk concentration of additives and heating surface geometry, the boiling behavior is also dependent upon the nature of the additive, interfacial properties, its chemistry and foaming etc. There has been wide research and development in enhanced boiling heat transfer. Among the different improvement techniques studied, the use of surface active substance in water has been found to change boiling phenomenon significantly. It is important to understand the effects of surfactants on boiling heat transfer and bubble dynamics. Surface active agents are essentially low-molecular weight chemical compounds, with molecules that consist of a water-soluble (hydrophilic) and a water insoluble (hydrophobic) part. But for this study we are considering this high molecular weight which effects on its thermophysical property. Depending upon the character of the hydrophilic head group, surface active substance are primarily classified as anionic, non-ionic, and cationic. Depending on the ionic character of the surfactant, the molecular weights and surface tension depression in aqueous solutions are generally greater in the order of non-ionic > anionic > cationic. Small concentrations of surfactant in water lower the solutions surface tension significant, and the level of reduction depends on the amount and type of surfactant present in solution. In general, with increasing additive concentration the surface tension σ decreases considerably for low molecular weight surfactant. With increasing concentration, an asymptotic limit of σ is obtained at the critical micelle concentration (cmc) of surfactant, which is characterized by the formation of colloid-sized clusters or aggregates of monomers called micelles. The cmc is a direct measure of the effectiveness of a surfactant to decrease the solvent’s surface tension, and it depends upon the surfactant’s chemistry and ionic structure [1]. The surface tension of aqueous surfactant solutions has also been found to be temperature dependent. Elevated temperatures cause a reduction in surface tension.The study of the saturated pool boiling of a surfactant solution shows a significant enhancement of heat transfer. It showed that the surface tension of the surfactant solution had significant influence on the heat transfer coefficient at boiling of aqueous solution. Pool boiling experiments were carried out for a wide range of surfactant concentrations and heat fluxes. The results verify again that a small amount of surface-active additive makes the nucleate boiling heat transfer coefficient differ than water. It was also found, that for some additives, the heat transfer increases at low concentration of surfactant, reaches a maximum and decreases with further increase in the concentration. Experimental data reported on the effect of surfactants on nucleate boiling heat transfer in water with Polyethylene glycol additives. The enhancement of heat transfer was related to the depression of the static surface tension. Boiling heat transfer coefficients were measured for an electrically heated platinum wire immersed in saturated water, and in water mixed with three different concentrations of sodium dodecyl sulfate (an anionic surfactant). Their results showed that addition of an anionic surfactant to water caused an increase in the convection component and a corresponding reduction in the latent heat component of the heat flux in the fully developed boiling region[2]. The comprehensive reviews on the heat transfer in nucleate pool boiling of aqueous surfactants and polymeric solutions have been published. Experimental studied on nucleate pool boiling with Habon G surfactant additive. They obtained the boiling curves for various surfactant concentrations. Some of those boiling curves exhibit non-monotonous (S-shaped) behavior with respect to wall superheat. They also found an optimum additive concentration to increase the heat fluxes, which was associated with the critical micelle concentration (c.m.c.). It was shown that surfactant additives at low concentrations could enhance the nucleate boiling heat transfer extensively.

A number of studies have been performed to relate the nucleate boiling heat transfer coefficient to surface tension of a boiling liquid. Some authors carried out their experiments using various pure liquids of different surface tensions, and others used surface active additives to change surface tension of the boiling liquid. The objective of this study is to determine experimentally the influence of a surfactant additive upon the nucleate boiling heat transfer coefficient of water and to optimize the concentration of surfactant for the highest heat transfer rate with low excess temperature. Recent work carried out for experimental and numerical analysis of single bubble dynamics during nucleate pool boiling reviewed as follows:

Klein [3]investigated the effects of APG surfactant solution flows through a micro-channel heat sink in which heat generated due to electronic components were removed. The results show that there exists an optimal surfactant solution concentration and mass flux for enhancing heat removal. Surfactants mixed solution boiling phenomena were also found to stabilize the maximum and average surface temperatures for a wide range of applied heat fluxes. In addition, the use of surfactant solutions at low mass fluxes has led to CHF enhancement when compared to regular water flows. He concluded that the use of surfactants should be considered as a method for improving two-phase boiling flow heat transfer. Further effort should also be invested on revealing proper surfactant additives and performing experiments of surfactant solutions flowing through a various micro-channel heat-sink configurations.

Kotchaphakdee [4] measured heat transfer in nucleate pool boiling of dilute aqueous polymer solutions and compared with results for pure water. Solutes were Hydroxyethyl cellulose (HEC) of three molecular weights, polyacrylamide (PA) of two molecular weights, and acrylamide; solute concentrations ranged from 62 ppm to 500 ppm. Liquids were boiled at atmospheric pressure on horizontal steam-heated chrome-plated surface. Results showed distinct differences in bubble size and dynamics, between polymeric and non-polymeric liquids. Results produced by variations of concentrations and molecular weight appeared to be correlate able with the solution viscosity. The HEC is a surfactant but PA is not, so surface tension is believed to be only a minor variable.

McGills et al. [5] Examined saturated pool boiling of water at low, sub-atmospheric pressures from a heated (12.7 x12.7 mm) horizontal surface. Rectangular fins, fluidized particulate beds, and surface finishes were used to enhance heat transfer. Water at low pressure significantly decreases the boiling performance as compared at atmospheric pressure. However, surface temperatures are reduced to values acceptable for cooling electronic components. All rectangular fin geometries were found to enhance heat transfer, although certain geometries were more effective. Rougher surface finishes reduced wall superheat temperatures. The addition of non-wetting, TFE particles also decreased wall superheat temperatures for the isolated bubble regime. The addition of small copper particles slightly decreased the wall superheat; however, the critical heat flux was significantly reduced.

Urquiola et al. [6]did the boiling experiments with pure water and surfactant solutions of SDS on horizontal heating surface. The static contact angle, rather than the surface tension value, was found to be the leading factor for the results. It has been found that variations of the path of boiling curves of both pure water and surfactant solutions are directly related with the surface conditions, specifically the contact angle. Higher contact angle leads the boiling and contact angle curve of a specific liquid or solution to show better heat transfer characteristics.Experiments also showed that the time both liquid and heater surface interact with each other is an important factor to consider at the time of experimenting with surfactant solutions. Long interactions lead to the increase of contact angle value and heat transfer characteristics.

Bergles et al. [7] had reviewed an overview of enhanced heat transfer technology. Phase-change processes, such as pool and flow boiling, are generally very effective modes of heat transfer. However, the demands of modern thermal systems have required the development of methods to enhance boiling systems. While heat fluxes above 10^8W/m^2 have been accommodated in carefully controlled situations, the required fluid and the convective conditions usually dictate maximum heat fluxes several orders of magnitude lower. Two major contemporary areas, enhanced surfaces for pool boiling and enhanced surfaces and inserts for forced convection boiling/vaporization, was discussed, as they facilitate the attainment of high heat fluxes. In addition to these passive techniques, active techniques and compound techniques are mentioned.

Dhir et al. [8]had reviewed a number of purely empirical and mechanism based correlations for nucleate pool boiling. Empirical correlations differ from each other substantially with respect to the functional dependence of heat flux on fluid and surface properties, including gravity. The mechanism-based correlations require knowledge of the number density of active sites, bubble diameter at departure and bubble-release frequency. However, because of the complex nature of the sub processes involved, it has not been possible to develop comprehensive models or correlations for these parameters. This, in turn, has led to the pessimistic view that mechanistic prediction of nucleate boiling is a hopeless task. However, there is an alternative to the past approaches i.e. complete numerical simulation of the boiling process. Value of this approach for bubble dynamics and associated heat transfer is shown through excellent agreement of predictions with data obtained on micro fabricated surfaces on which active nucleation sites can be controlled.

Laurien et al. [9] did the numerical prediction of bubbly flows based on a two or three-dimensional two-fluid formulation. The importance of various extensions or simplifications of this model formulation was demonstrated and discussed in view of a realistic and accurate simulation of sub cooled pool boiling of water with the possibility of the system pressure (and thus saturation temperature) increasing in time. If the bubbles are assumed to rise always with their terminal velocity the momentum equation of the gas phase can be omitted. The energy equation is only necessary, when gas is superheat. The bubble size is an important model parameter for the heat and mass exchange as well as for the momentum exchange between bubbles and liquid. In order to take observed bubble-size spectra into account a numerical approach using population classes would be discussed.

It has been shown that the main phenomena of boiling, recondensation and system pressure calculation can be simulated using an approach with computational fluid dynamics. The simulations showed a strong dependency from certain model parameters – for example the bubble diameter which is extremely important for the recondensation phenomena. To overcome this difficulty, an approach using different bubble classes is proposed.

Laurien et al.[10]had taken general fundamental equations of the two fluid formulations to model bubbly flows and boiling. It was derived from the compressible Navier-Stokes equations of fluid mechanics by using temporal averages of state variables. The equations were simplified for incompressible flows and compared to the spatially averaged equations. It is concluded that among the various formulations of the two fluid equations, the equations based on temporal averaging provide a reasonable basis for the numerical simulation of bubbly flows. In particular the analogy to the Reynolds-Averaged Navier-Stokes Equations can be utilized to extend the existing single phase turbulence models to model the liquid phase turbulence.

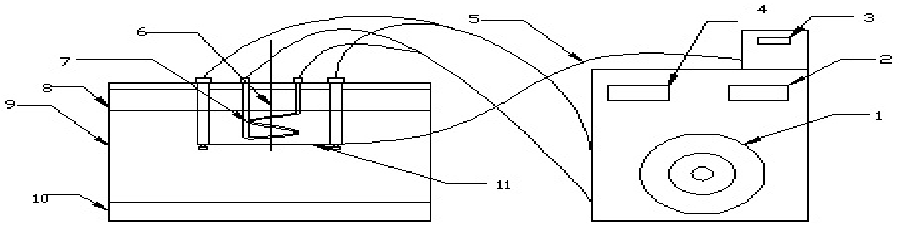

Figure 1Schematic Figure of Experimental Setup

1. Dimmer stat **2**.Ammeter 3.Digital Temperature Indicator **4**.Voltmeter **5**.Thermocouple **6**.Thermometer **7**.Auxiliary Heater **8**.Water level **9**.Glass pool **10**.Wooden platform **11**.Nichrome Water

EXPERIMENTATION

The apparatus for experimental studies on pool boiling is shown in Figure 1. It consists of a clear cylindrical glass container. One auxiliary water heater is provided in container to heat the water up to saturation temperature i.e. 95^0C. One thermometer is used to measure the water temperature. Nichrome wire is used as superheated surface to transfer the heat to water. This Nichrome wire is connected to the mains via Dimmer stat. An ammeter is connected in series while the voltmeter connected across it to read the current and voltage. These controls are placed inside the control panel.

The glass container is kept on a stand. The glass container is filled with 2 Litter water and surfactant mixture. To measure the temperature of bulk water i.e. saturation temperature of water one K-type thermocouples are used and temperature of main heater using digital temperature indicator.

In experimental procedure the water and surfactant mixture is added in to the glass container. PEG surfactant with various concentrations will be taken for the experimental purpose. Auxiliary heater is connected to mains, when switch is ON electricity is supplied to the heater. This heater is used to heat the mixture up to the saturation temperature. When thermometer shows the saturation temperature the auxiliary heater will turn OFF.

Experimental work is concentrated on bubble formation on Nichrome wire for that purpose; electricity is supplied to the main heater surface through Dimmer stat. The required amount of heat flow will be maintained by Dimmer stat through an ammeter and voltmeter. As the temperature of the Nichrome wire will increase above saturation temperature, the mixture surrounded to Nichrome wire will start changing the phase from liquid to vapor as temperature of surface is superheated and bubble will form. The temperature of the Nichrome wire is indicated by the temperature indicator which is connected to the thermocouple which is in contact with Nichrome wire.

To study the kinetics of vapor bubble in pool boiling phenomena for pure water with and without surfactant a camera is fixed near to apparatus in such a way that boiling phenomenon can be recorded by camera to make observations in terms of bubble nucleation, growth and its departure.

Initially, 2 L of demineralised water is taken in the borosil glass pool and is heated to the saturation temperature by a secondary heater. As the temperature reaches about 95^0C, the auxiliary heater is switched off and the Nichrome wire heater is switched on. The electric supply to the Nichrome wire is gradually increased, and the current and voltage are measured at each step by constantly recording the temperature of the water and wire. The phenomenon is recorded on camera for further analysis. As the boiling heat transfer rate is very sensitive to the state of the heating surface, boiling of pure water was carried out until the reproducibility of the boiling curve became very good before beginning of each set of experiments with the addition of various amounts of surfactant. This state of the heating surface must be ensured for the Nichrome wire used for heating purposes, because for some runs, the wire breaks at critical heat flux (CHF) and is replaced by a new piece of wire. Thus, for complete experimentation, a long single Nichrome wire is cut into 0.10-m-long pieces.

Various researchers have investigated a number of surfactant for heat transfer enhancement. Here we have used PEG surfactant is which is having high molecular weight. PEG is come under nonionic surfactant that has a hydrophilic polyethylene oxide chain and an aromatic hydrocarbon lipophilic or hydrophobic group. PEG is soluble at 25 °C in water, ethylene glycol, ethyl ether, ethyl alcohol. It is environment friendly surfactant. For this studies different concentration of PEG, viz., 100, 200, 300, 400, 500, 600, 700 ppm is added in dematerialized water to determine the effect of different concentration.

The procedure from the beginning is repeated by emptying the pool of distilled water and filling it with aqueous surfactant solutions of different concentrations. The Nichrome wire is changed every time and thermocouple reattached.

RESULTS AND DISCUSSION

The surface tension measured at various concentrations is shown in Figure 2**Error! Reference source not found.**. The surface tension is increase by the addition of polyethylene glycol. PEG is an anionic surfactant. It is clear from figure that, as the PEGis adding in DM water its surface tension is get increase. It is observed as temperature of solution is increasing, the surface tension depression is occurred. Continues depression of surface tension is obtained using different concentration of PEG form 100 to 700 ppm.

Figure 3 shows a set of boiling curves for water containing PEG of various concentrations. From the figure it is to understand that, the excess temperature value for PEG is increasing but maximum heat transfer rate with low excess temperature is occurred at 600 ppm. If the curves for 600 ppm and 700 ppm are compared, the curve is again shifted toward right in case of 700 ppm. This may be happed due to the critical missile concentration (cmc). The influence of heat flux and additive concentration on the nucleate boiling heat transfer rate of PEG solutions is more evident if the experimental data in Figure 3 are expressed as a plot of heat transfer coefficient versus heat flux, as shown in Figure 4.

The heat transfer coefficient is increased as the heat flux and concentration are increased, except when the heat flux level is higher and the concentration of solutions is higher than 500 ppm. To understand the boiling behavior of aqueous surfactant solutions qualitatively, the boiling history for pure water and PEG solutions was photographed using a high speed camera. In Figure 5, the images of different heat flux with all concentration of PEG are shown. In photograph it is observed that, while comparing boiling of surfactant with pure water, more vigorous boiling is occurred with clusters of smaller-sized and more regularly shaped bubbles. In photograph shows that up to 300ppm concentration vapor blanket thickness is negligible, but as concentration is increases the blanket thickness is also increase. In surfactant solutions, the increase in surface tension is not promoting nucleation site hence bubble size is increase. The coalescence between two neighboring bubbles or sliding bubbles along the heater surface is occurred, as bubbles depart at very low frequencies. The departing bubbles were seen to reach the pool free surface. It is also observed that at high heat fluxes, due to the strong bubbling motion, the liquid free surface in the pool oscillated slightly. Same situation was also observed with the boiling of pure water. Furthermore, with increasing PEG concentration beyond 600 ppm, no significant differences were observed in the boiling evolution in surfactant solutions.

Figure 5shows different photographs of pure water boiling phenomena also. With increasing flux nucleate boiling starts, and as the heat flux increasing continuously the bubble gets detached from the heater surface. It is observed that (Figure 5) the heater wire gets covered with a vapor blanket; which ultimately reduces the heat transfer rate, and after some time, heat flux increases so that the wire becomes red hot and heat transfer occurs due to radiation known as film boiling. This condition forces the boiling process to carry out before or at critical heat flux so that maximum heat transfer rates are possible in the nucleate boiling. This experimentation shows that as molecular weight of surfactant increases its excess temperature is increases.

CONCLUSION

Saturated nucleate boiling is performed on Nichrome wire by using pure water with PEG surfactant which having high molecular weight. Experiment is carried out for relatively wide range of concentration viz., 100 to 700 ppm with different heat flux. The result shows that by adding surfactant of high molecular weight into the water, heat transfer rate is changes drastically as its increasing its surface tension. It was also found that there is critical missile concentration (cmc) for heat flux. The heat transfer coefficient is again lower if concentration is increase than cmc. From the study it is found that heat transfer rate is increase upto 600 ppm with high excess temperature as compared to other surfactant. From this experimentation we come to know that only ionic nature of surfactant not affect the heat transfer rate but also its molecular weight is also have significant effect on it.

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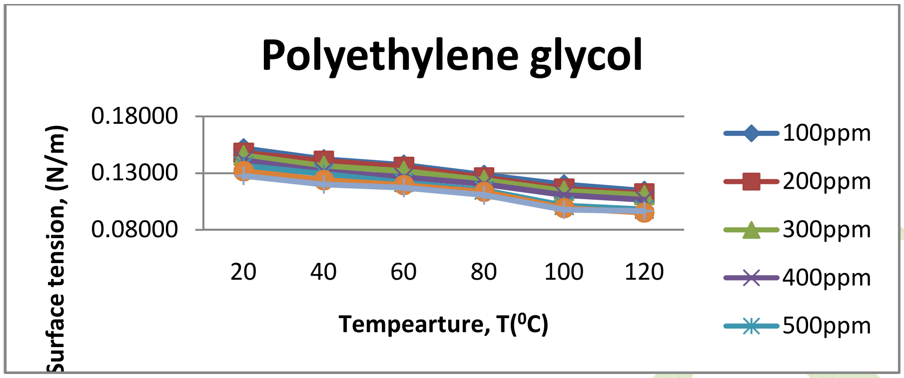


Figure 2Effect of Temperature and Concentration of Polyethylene Glycol on Surface Tension in Water

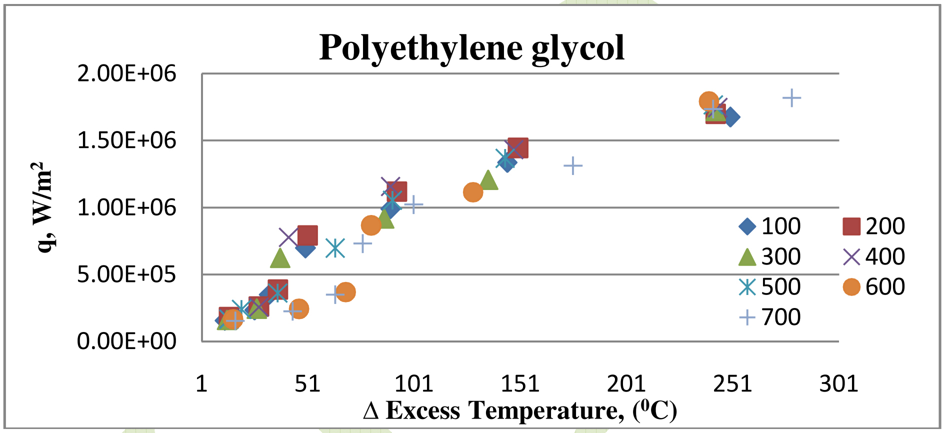
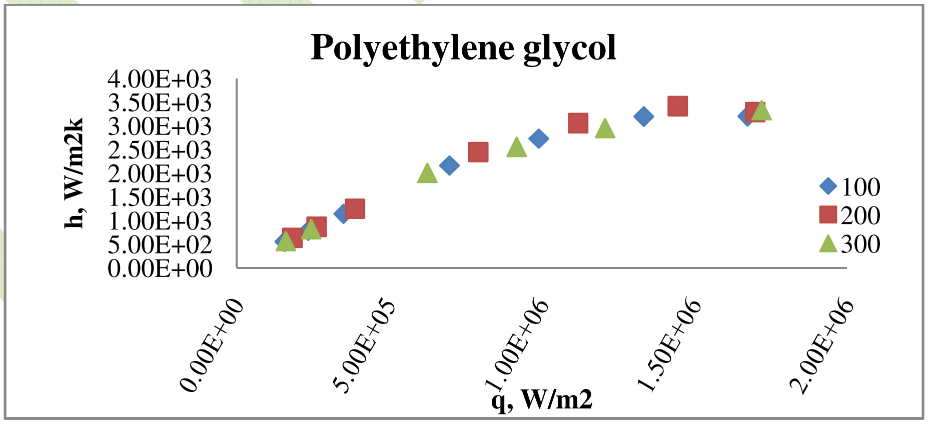
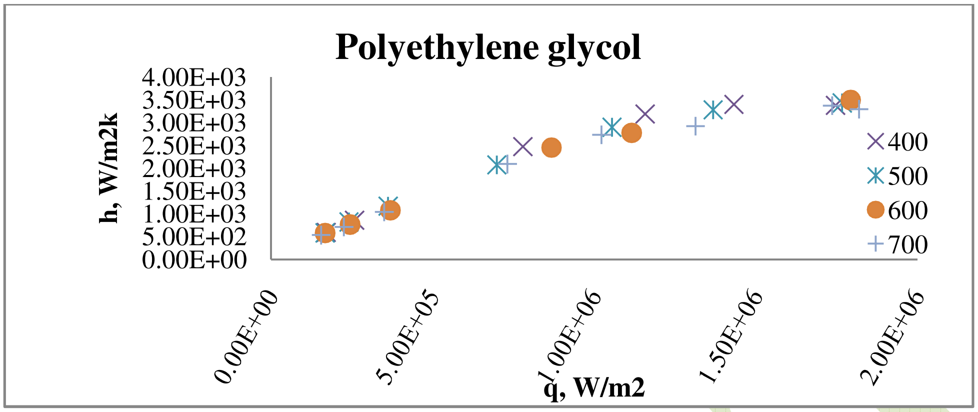


Figure 3Heat Flux vs. Heater Excess Temperature for Various Concentrations of Polyethylene Glycol in Pure Water

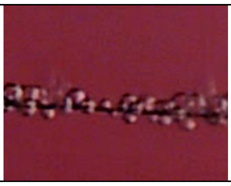
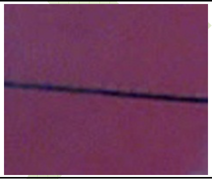
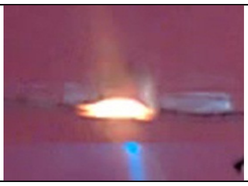
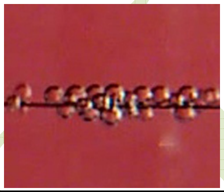
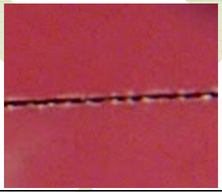
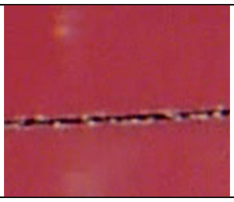
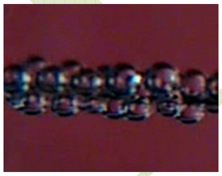
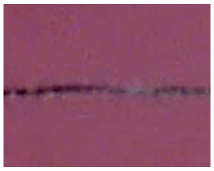
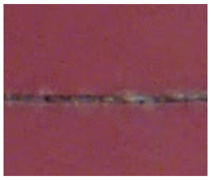


a)



b)

Figure 4(a, b) Heat Transfer Coefficient vs. Heat Flux for Various Concentrations of Polyethylene Glycol in Water

Bubble behavior for PEG with Pure Water at different heat flux			
100 ppm PEG			
			
Heat Flux=1.57E+05 W/m^2	Heat Flux=9.91E+05 W/m^2	Heat Flux=1.34E+06 W/m^2	Heat Flux=1.67E+06 W/m^2
200 ppm PEG			
			
Heat Flux=1.83E+05 W/m^2	Heat Flux=1.12E+06 W/m^2	Heat Flux=1.45E+06 W/m^2	Heat Flux=1.70E+06 W/m^2
300 ppm PEG			
			
Heat Flux=1.62E+05 W/m^2	Heat Flux=9.81E+05 W/m^2	Heat Flux=1.21E+06 W/m^2	Heat Flux=1.72E+06 W/m^2
400 ppm PEG			

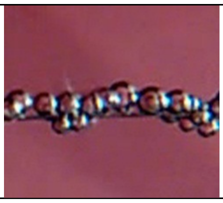
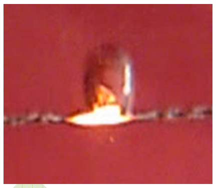
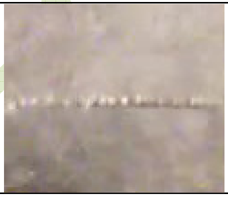
			
Heat Flux=1.70E+05 W/m^2	Heat Flux=1.16E+06 W/m^2	Heat Flux=1.43E+06 W/m^2	Heat Flux=1.75E+06 W/m^2
500 ppm PEG			
			
Heat Flux=1.66E+05 W/m^2	Heat Flux=1.05E+06 W/m^2	Heat Flux=1.37E+06 W/m^2	Heat Flux=1.77E+06 W/m^2
600 ppm PEG			
			
Heat Flux=1.66E+05 W/m^2	Heat Flux=8.67E+05 W/m^2	Heat Flux=1.11E+06 W/m^2	Heat Flux=1.79E+06 W/m^2
700 ppm PEG			
			
Heat Flux=1.54E+05 W/m^2	Heat Flux=1.31E+06 W/m^2	Heat Flux=1.74E+06 W/m^2	Heat Flux=1.82E+06 W/m^2

Figure 5Photo images of bubble of Polyethylene glycol concentration in pure water for different heat fluxes (W/m^2)