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Pool boiling enhancement with environmentally friendly surfactant additives

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Abstract Boiling heat transfer is used in variety of industrial processes and applications, such as refrigeration, vapor cycle power generation, heat exchangers, petroleum refining, and chemical manufacturing. Enhancements in boiling heat transfer processes are critical for making these applications more energy efficient. The aim of this paper is to demonstrate the water pool boiling phenomena under the influence of environmentally friendly surfactant additives. The test setup used in this study has multiple benefits. First, the test setup enhances teaching in variety of classes through in-class demonstrations and student experiments. An experiment is described to allow the students to visualize and qualify different modes of boiling heat transfer. In addition, the test setup provides a platform for research in boiling enhancement. Using surfactant additives in boiling causes increased number of nucleation sites and decreased level of wall superheat. For determining surfactant effects, different concentrations of sodium lauryl sulfate (SLS), ECOSURF^{TM} EH-14, and ECOSURF^{TM} SA-9 are added to pure water and enhancement through surfactants is quantified. When times until boiling (liquid temperature reaches the boiling point) are measured, 17, 10.3, and 19.6 % lower times found (for SLS, EH-14, and SA-9, respectively) compared to pure water. Wall temperature reduction is measured for 50 ppm SLS 9.48 %, for 300 ppm EH-14 11.3 %, and for 200 ppm SA-9 10.43 %. It can be concluded from this study that a reduction in surface tension leads to a higher nucleation site density and more small bubbles on the boiling surface.

Keywords Heat transfer enhancement · Pool boiling · Surfactants · Experimental · Environmentally friendly

Abbreviations

A	Area (m^2)
c_p	Specific heat at constant pressure (J kg^{-1} K^{-1})
D	Diameter (m)
g	Gravitational acceleration (m s^{-2})
h	Convection heat transfer coefficient (W m^{-2} K^{-1})
h_{fg}	Latent heat of vaporization (J kg^{-1})
m	Mass (kg)
$\dot{m}$	Mass flow rate (kg s^{-1})
q	Heat transfer rate (W)
q''	Heat flux (W m^{-2})
Pr	Prandtl number
T	Temperature (°C)
t	Time (s)

Greek letters

P	Density (kg m^{-3})
σ	Surface tension (N m^{-1})

Subscripts

b	Boiling
exp	Experimentally
l	Liquid
s	Surface
sat	Saturation
theo	Theoretically
v	Vapor
w	Water

Introduction

Boiling enhancement with surfactant additives

The energy crisis and global warming are forcing greater energy efficiency in diverse applications. There is a general

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need to increase the heat transfer rate in pool boiling applications to reduce the energy required for phase change. Researchers found enhancement techniques in heat transfer for boiling by addition of surfactants. It is claimed that a small amount of surface tension reducing agent (surfactant) additive makes the nucleate pool boiling heat transfer coefficient of water increase [1, 2]. This is a cost effective technique and easy to implement. Surfactant additives enhance the boiling phenomenon thermophysics by reducing surface tension and skin friction [2, 3].

Many researchers examined the behavior of the surfactant additives on pool boiling heat transfer. An addition of small amount of surfactant makes the behavior of the boiling quite different from that of water. Hestroni et al. [4] showed that for Alkyl (8–16) glucoside (Plantacare 818 UP) surfactant added water, bubble action was seen to be extremely chaotic, with extensive coalescence during the rise. Bubble formation in surfactant solutions was much smaller than those of water and the surface covered with them faster. It is known that reduced surface tension results in a decrease of energy required initiating bubble growth which corresponds to an increase in bubble quantity with decreased diameter [4].

Hestroni et al. [5] studied the boiling heat transfer and bubble dynamics in the nonionic surfactant solution at various concentrations of surfactant and different heat fluxes. The addition of small amount of surfactant (environmentally acceptable alkyl glycosides) enhanced the heat transfer by reducing the boiling excess temperature and facilitating vapor bubble formation. Boiling in surfactant solutions, when compared to pure water, was observed to be more vigorous [5]. It was shown by Qiao and Chandra [6] that, by the addition of surfactant to water, the surface temperature required to initiate vapor bubble nucleation was reduced from 118 to 103 °C.

Surfactant additives may also be used to enhance distillation process productivity by increasing bubble formation and releasing more vapors. The effect of using a surfactant such as sodium lauryl sulfate (SLS) with a small scale solar water distillation process is investigated by Nafey et al. [2]. The percentage of the increase in system productivity is 7 % when the additive concentration of SLS was 300 ppm [2]. Another important field of application of boiling and evaporation is in desalination of seawater, which is becoming vital in some arid regions. Besides heating surface geometry, the wall heat flux (wall excess temperature), and bulk concentration of additives, the boiling behavior is also dependent upon the nature of the additive and its interfacial properties. It was shown by Sephton [7] that addition of small amounts of surfactants to seawater could significantly enhance the boiling desalination process.

The literature survey indicates that addition of a small amount of surfactant can enhance the water pool boiling heat transfer. It can be concluded from these studies that a reduction in surface tension leads to a higher nucleation site density, more small bubbles on the heater surface, and generally a higher heat transfer coefficient [8].

Integration of boiling experiments into heat transfer laboratory

Boiling is the most effective heat transfer method because of its high performance arising from latent heat transport. Understanding the fundamentals of boiling heat transfer enables engineers to reduce size, mass, and volume of boiling heat exchange devices and to improve the thermal performance of components in the process and power plant industries. Researchers and engineers must fully understand the boiling phenomenon and its limitations to avoid cooling system dry out and the critical heat flux (CHF) condition. These conditions cause a dramatic rise in wall temperature, decreased heat transfer, and possible material failure. Hence, the mechanisms and behavior of bubble nucleation and growth attract the interest of researchers.

Heat transfer is one of the core courses of an undergraduate mechanical engineering curriculum that enables students to study various thermodynamic processes and their effects in equipment design, insulation properties, and material selection. Some researchers described various laboratory experiments for demonstrating boiling heat transfer. Abu-Mulaweh and Libii [9] presented boiling experiments that can be integrated in the undergraduate heat transfer laboratory. The experimental setup to carry out their experiments included a metallic plate and a hot plate. The metallic plate included a spherical cavity to pour water in. They measured the change in the excess temperature with total evaporation time and observed different boiling regimes on that heated metallic plate [9]. Mehrotra et al. [10] described an undergraduate laboratory experiment for hands-on experiential learning of boiling heat transfer. The experimental measurements are used for estimating the boiling heat transfer coefficient at varying heat flux and in the presence or absence of stirring.

The apparatus designed and fabricated in this study serves as an inexpensive tool for demonstrating boiling heat transfer. The experiments make it possible for students to observe pool boiling heat transfer, perform a real experimental process, and increase their scientific perception. These experiments will help them build an in-depth understanding of the course material. In this study, the experiments are described to allow the students to visualize and qualify different modes of boiling heat transfer as well as understanding the effect of surfactant additives into boiling. Experimental measurements are used for estimating the boiling heat transfer coefficient at varying heat flux. In addition, power input versus excess temperature data are obtained for pure water and surfactant added water conditions to show the effect of surfactant additives.

Pool boiling

Boiling is liquid to vapor phase change process and includes fluid motion. Because of the fluid motion, boiling and condensing are classified as convective mechanisms. However, there are major differences between boiling and single phase convective heat transfer because of differences between the various fluid properties in the two phases such as thermal conductivity, specific heat, and density. Consumption or release of latent heat, h_{fg} also affects the heat transfer rates significantly during phase change. Boiling occurs at the solid–liquid interface when the surface temperature exceeds the saturation temperature T_{sat} [9].

The boiling process is characterized by the fast formation of vapor bubbles at the solid–liquid interface. When the vapor bubbles reach a certain size they start to detach from the surface and rise to the free surface of the liquid. Bubbles formed during boiling are a result of the surface tension, σ at the liquid–vapor interface due to the attraction force on molecules at the interface.

Boiling is classified as pool boiling and flow boiling. In the case of pool boiling, the fluid is stationary, and its motion near the surface results from natural convection. Boiling is called subcooled when the temperature of the liquid is below the saturation temperature T_{sat} and it is called saturated when the temperature of the liquid is equal to the saturation temperature, T_{sat} [9].

Pool boiling is of interest in high heat flux applications because of its heat removal potential through the latent heat of vaporization and low coolant fluid losses. During pool boiling, the latent heat involved with the phase change from liquid to vapor is significant in the heat removal process. The substantial increase in the heat transfer coefficient allows for pool boiling being used for cooling applications in high powered electronics. It is a technique that does not require any moving parts and is very effective from both the thermal and cost perspectives [9].

Boiling curve

Nukiyama in 1934 used electrically heated nichrome and platinum wires immersed in liquid in his pioneering boiling experiments [11]. Excess temperature is defined as the surface temperature above the liquid's saturation temperature, $\Delta T_e = T_s - T_{sat}$. Pool boiling takes different forms depending on the excess temperature, ΔT_e. These forms are free convection boiling, nucleate boiling, transition boiling, and film boiling illustrated in the boiling curve (Fig. 1) [11].

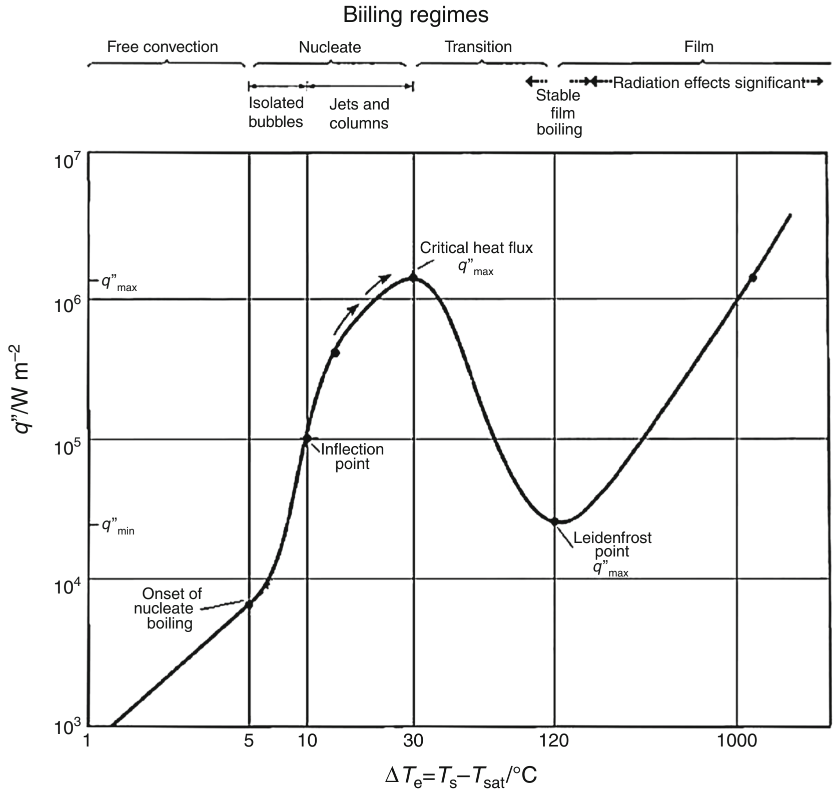

Fig. 1 Typical boiling curve [21]

Subcooled boiling

Boiling is subcooled when the temperature of the liquid is below the saturation temperature, T_{sat}. During subcooled boiling, the thermal energy from the hot plate is transferred to the water as sensible heat. This heat is used to raise the temperature of water from its initial temperature, T_{i} to the saturation temperature T_{sat} [10]. In Eq. (1), q_{in} is the net heat transfer from the hot plate to the water.

$$q_{\mathrm{in}} = m_{\mathrm{w}} c_{\mathrm{p}} \frac{\Delta T}{\Delta t} \tag{1}$$

Saturated boiling

Boiling is saturated when the temperature of the liquid is equal to the saturation temperature, T_{sat}. The heat from the hot plate in this stage is transferred to the boiling water as latent heat. All the heat transferred to the boiling water is used for a phase change from liquid to vapor. Equation (2) first relates the heat from the hot plate, q_{s}, to the convective heat transfer to the water. It then equates the same heat, q_{s}, to the heat escaping during boiling mass transfer.

$$q_{\mathrm{s}} = hA(T_{\mathrm{s}} - T_{\mathrm{sat}}) = hA\Delta T_{\mathrm{e}} = \dot{m}_{\mathrm{b}} h_{\mathrm{fg}} \tag{2}$$

This indicates the heat transfer rate from the heating element to the water is the same as the evaporative heat transfer rate [10].

Experimental setup

The experimental setup is designed to provide controlled, clearly observable, and repeatable boiling conditions. The hardware consists of a beaker, temperature sensors, a hot plate, a liquid dropper, precision scale, and digital camera.

The experimental test setup allows clear viewing of the boiling in a clear glass beaker (Figs. 2, 3). A data acquisition PC collects and displays temperature sensor readings and includes a large stopwatch display for clear experiment coordination and logging. Type K thermocouples were used with adhesive mounts to ensure measurement on the beaker's interior bottom surface. Response time of thermocouples is 0.002 s (in still H_2O). The transparent beaker enables clear viewing for both the students and the digital camera, a CASIO EX-FH-20. One of the thermocouples is attached to the base for recording base temperature of the beaker and the other is positioned in the water to measure water temperature. Graduated beaker enables observation of the amount of liquid evaporated. Free convection, nucleate, and film boiling observations are shown in Fig. 2.

For surfactant tests, surfactant is added into 400 mL of water and mixed for 1 min with magnetic stirrer unit in the hot plate. A magnetic stirrer agitates the water by using a stir bar inside the hot plate. The speed of hot plate can be adjusted by a speed regulator. After stirring, the mixture is started to heat with the hot plate.

Surfactant effects

SLS ECOSURF$^{\mathrm{TM}}$ EH-14 and ECOSURF$^{\mathrm{TM}}$ SA-9 are used in this paper as a boiling enhancing surfactant and the results are reported. SLS is an organic compound with the formula $CH_3(CH_2)_{11}OSO_3Na$. SLS is an anionic surfactant used in many cleaning and hygiene products. EH-14 and SA-9 are chosen because they are purchased as environmentally friendly alternatives to SLS. ECOSURF$^{\mathrm{TM}}$ EH-14 (90 % active) is a 2-ethyl hexanol EO–PO nonionic surfactant, alcohol alkoxylate. ECOSURF$^{\mathrm{TM}}$ SA-9 is a nonionic seed oil

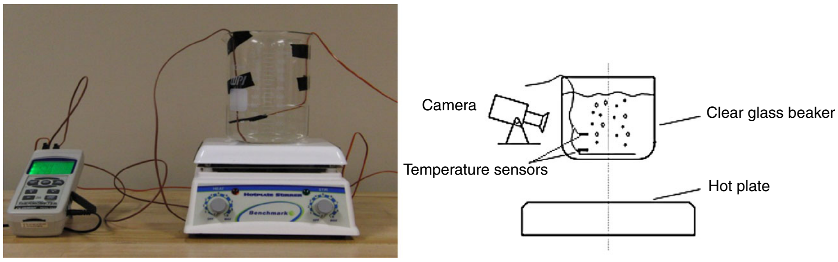

Fig. 2 Experimental test setup

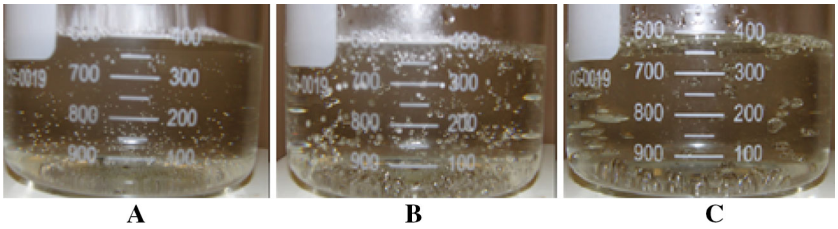

Fig. 3 Observation of boiling **a** free convection, **b** nucleate boiling, and **c** film boiling

surfactant. Both EH-14 and SA-9 are biodegradable. The term biodegradable is commonly associated with environmentally friendly products that are capable of decomposing back into natural elements [12]. Rossol [12] wrote that “biodegradable substances break down into more than one set of chemicals, which are usually called primary and secondary degradation products. Any of these may be toxic.”

For each surfactant experiment, a dose of the SLS, EH-14, or SA-9 was added to pure water in the beaker and the mixture was stirred with the magnetic stirrer for a minute. The mixture was then brought to boiling with the hot plate.

Experiments and results

In this section, an experiment designed for straightforward integration into an undergraduate heat transfer laboratory is presented first, then surfactant tests and results follow.

Project: comparison of boiling heat transfer coefficient, h, using experimental and theoretical methods

Problem statement

The bottom of a Pyrex beaker, 0.102 m in diameter, is measured as maintaining a surface temperature of $T_s = 116$ °C when heated by a hot plate (Fig. 4).

(a) This part will provide estimates of the power required to boil water in the beaker, q'', the evaporation rate, $\dot{m}_b$, heat transfer coefficient, h, the CHF, q_{max}'', and minimum heat flux, q_{min}''. The minimum heat flux is the minimum amount required to achieve boiling. The CHF represents the maximum heat flux for boiling water at normal atmospheric pressure.

(b) In this part, using different power inputs of the hot plate, corresponding T_s, $\dot{m}_b$, and h values will be obtained. The experimental results will be compared with the theoretical results.

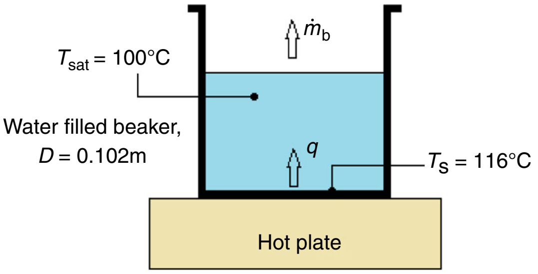

Fig. 4 Schematic of the problem statement

Assumptions

1. Steady state conditions.
2. Water exposed to standard atmospheric pressure of 1 atm.
3. Water is at uniform temperature $T_{sat} = 100$ °C.
4. Negligible losses from heater to surroundings.

Saturated water, liquid (100 °C): $\rho_l = 957.9$ kg m^{-3}, $c_{p,l} = 4.217$ kJ kg^{-1}, $\mu_l = 279 \times 10^{-6}$ N s m^{-2}, $Pr_l = 1.76$, $h_{fg} = 2{,}257$ kJ kg^{-1}, $\sigma = 58.9 \times 10^{-3}$ N m^{-1}. Saturated water, vapor (100 °C): $\rho_v = 0.5956$ kg m^{-3} [13].

Analysis

The excess temperature, $\Delta T_e = T_s - T_{sat} = 16$ °C. Nucleate pool boiling will occur at this excess temperature (Fig. 1). The correlation for estimating the heat transfer rate per unit area of plate surface is given by Eq. (3) Rosenholf correlation [14]:

$$q_s'' = \mu_l h_{fg} \left[\frac{g(\rho_l - \rho_v)}{\sigma} \right]^{1/2} \left(\frac{c_{p,l} \Delta T_e}{C_{s,f} h_{fg} Pr_l^n} \right)^3 \tag{3}$$

Values for $c_{s,f}$ and n corresponding to different surface–liquid combinations are given in [14–16]. The value for n is 1.0. The literature tables represent experimentally determined numbers where the values of $c_{s,f}$ are changed from 0.006 (for water-brass) to 0.0133 (for water-stainless steel) for variety of surface–fluid combinations. In the absence of such information $c_{s,f}$ of 0.013 may be used as approximation [16]. Substituting numerical values, the boiling heat flux, q_s'', is obtained as 5.6×10^5 W m^{-2}.

$$q_s = q_s'' A = q_s'' \frac{\pi D^2}{4} \tag{4}$$

The boiling heat transfer rate is obtained as 4.54×10^3 W by using Eq. (4). All the heat addition to the beaker will result in water evaporation from the beaker under steady state conditions [13]. Hence, the evaporation rate, $\dot{m}_b$ is obtained as 0.0020 kg s^{-1} from Eq. (5).

$$\dot{m}_b = \frac{q_s}{h_{fg}} \tag{5}$$

$$q_{max}'' = C h_{fg} \rho_v \left[\frac{\sigma g(\rho_l - \rho_v)}{\rho_v^2} \right]^{1/4} \tag{6}$$

The CHF represents a key point on the boiling curve. Operating a boiling process close to this point is desired, but there is a risk of dissipating heat in excess of this amount [13]. Equation (6) is Kutateladze’s [17] expression for CHF. For large horizontal plates, a value of $C = 0.149$ is used [17].

Substituting the numerical values, q_{max}'', is obtained as 1.26 MW m^{-2}. CHF represents the maximum heat flux for boiling water at normal atmospheric pressure. Therefore,

Table 1 Comparison of boiling heat transfer coefficient, h, for experimental and theoretical methods

Heat flux q''/W m^{-2}	T_s/°C	Experimental		Rohsenow		% Error in h
		$\dot{m}_b$/kg s^{-1}	h_{exp}/W m^{-2} °C^{-1}	$\dot{m}_b$/kg s^{-1}	h_{theo}/W m^2 °C^{-1}	
5.6×10^5	116	0.0022	3.78×10^4	0.0020	3.505×10^4	8.0
2.53×10^4	105.7	1.01×10^{-4}	4.85×10^3	9.1×10^{-5}	4.45×10^3	9.1
5.87×10^3	103.5	0.0029	2.28×10^5	2.11×10^{-5}	2.068×10^5	9.7

operation of the heater at $q_s'' = 5.6 \times 10^5$ W m^{-2} is below the critical condition [13]. From Fig. 1, for critical condition, excess temperature is $\Delta T_e = 30$ °C [13].

$$q''_{\min} = C\rho_v h_{fg}\left[\frac{g\sigma(\rho_l - \rho_v)}{(\rho_l + \rho_v)^2}\right]^{1/4} \qquad (7)$$

$q''_{\min}$ (Leidenfrost point) can be obtained as 18.95 kW m^{-2} from Eq. (7). From Fig. 1, for this condition $\Delta T_e = 120$ °C.

Table 1 gives the results of the experiments for different power inputs. From the experiments, error in boiling heat transfer coefficient is obtained and compared with the Rohsenow correlation. Students set the power input of the heater and measure the surface temperature, T_s. From the beaker, students experimentally measure the volume of evaporated water over time and thus mass flow rate, $\dot{m}_b$ at the boiling. After that, h_{exp} is determined from Eq. (2).

On the other hand, $\dot{m}_b$ is calculated theoretically with Rohsenow correlation, Eqs. (3) and (4), and mass flow rate, $\dot{m}_b$ is obtained from Eq. (5). h_{theo} is determined from Eq. (2) using the theoretical value of $\dot{m}_b$. Table 1 shows the comparison of boiling heat transfer coefficient, h, for experimental and theoretical values.

Results of surfactant tests

For determining surfactant effects, different concentrations of SLS, ECOSURF^{TM} EH-14, and ECOSURF^{TM} SA-9 are obtained and enhancement through surfactants is quantified. Mixture concentrations at 50, 100, 200, and 300 ppm are obtained for each surfactant and boiling experiments were conducted. The time for bulk liquid to reach the boiling point, the boiling temperature, and maximum wall temperatures (T_w) are recorded. For SLS 50 ppm, for EH-14, 300 ppm, and for SA-9, 200 ppm found as the most favorable compositions considering lowest time until reaching boiling point and lowest base temperature among other compositions.

Time required for bulk liquid to reach the boiling point for pure water and SLS, EH-14, and SA-9 added water is measured (Table 2). For 50 ppm SLS 17.1 %, for 300 ppm EH-14 10.3 %, and for 200 ppm SA-9 19.6 % shorter time until boiling point is measured compared to boiling of pure water.

Table 2 Time required for reaching the boiling point of pure water, SLS, ECOSURF^{TM} EH-14, and ECOSURF^{TM} SA-9 added water

Composition	Time required for reaching boiling point/s	Boiling Point/°C
Pure water	1356 ± 4	100 ± 1
20 mg SLS + 400 mL water (50 ppm)	1,124 ± 5	101.8 ± 2
120 mg ECOSURF^{TM} EH-14 + 400 mL water (300 ppm)	1,215 ± 5	101.2 ± 1
80 mg ECOSURF^{TM} SA-9 + 400 mL water (200 ppm)	1,090 ± 4	101 ± 1

Table 3 Wall temperature of beaker for pure water, SLS, ECOSURF^{TM} EH-14, and ECOSURF^{TM} SA-9 added water

Heat flux q''/W m^{-2}	Wall temperature T_w/°C			
	Pure water	50 ppm SLS in water	300 ppm EH-14 in water	200 ppm SA-9 in water
5.78×10^4	116	105	102.9	103.9
3.76×10^4	105.7	103.7	102.4	102
2.278×10^4	103.5	101.8	101.7	101.3

The sensors attached to base of beaker and hanged in water are measured the base surface temperature and water temperature. The results are given in Table 3. Measured wall temperature reductions were 9.48 % for 50 ppm SLS, 11.3 % for 300 ppm EH-14, and 10.43 % for 200 ppm SA-9. Excess temperature $(T_w - T_{sat})$ values for varying power inputs for pure water and surfactant added water are given in Fig. 5. Using surfactant additives in the boiling caused increased number of nucleation sites and decreased level of wall temperature.

Discussion

The lowered surface tension with surfactants reduces the critical nucleation radius, thus proceeding more active

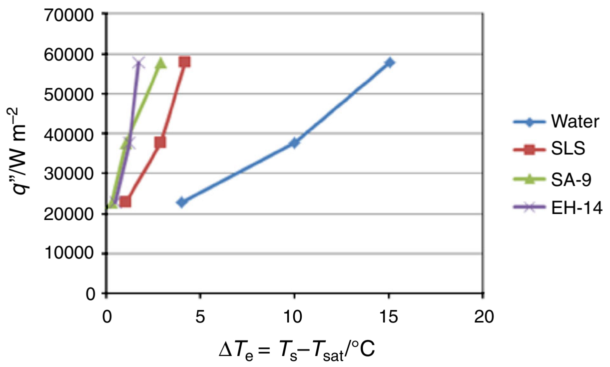

Fig. 5 $T_w - T_{sat}$ values for varying power inputs for pure water and surfactant added water

nucleation sites. It can also allow the departures of smaller sized bubbles [18]. When times until boiling (liquid temperature reaches the boiling point) are measured, 17, 10.3, and 19.6 % lower times found (for SLS, EH-14, and SA-9, respectively) compared to pure water. For SLS and SA-9, close values are observed. The reason SA-9 is reached boiling point faster might be because of its lower viscosity. (Viscosity of pure EH-14 is 85.39 cSt, whereas pure SA-9 is 30.225 cSt.) Hestroni et al. [19] found that for high concentrations, the increase in kinematic viscosity decreased the heat transfer coefficient.

Temperature drop on the wall measured for SLS, EH-14, and SA-9 (9.48, 11.3, and 10.43 %) are very close to each other. Equilibrium surface tensions of pure EH-14 and SA-9 are also close (0.0318 and 0.029 N m^{-1}, respectively). Further experimentation with different binary combinations is recommended along with accurate measurements of dynamic surface tension, contact angle, and kinematic viscosity changes in this region. It is challenging to analyze the influence of one parameter while maintaining others constant in experiments since change of one parameter could change other related properties. Besides the effects of dynamic surface tension, concentration of surfactant (50 ppm for SLS, 300 ppm EH-14, and 200 ppm for SA-9), its chemistry (anionic nature for SLS and nonionic for EH-14 and SA-9), molecular mass, surface wetting, Marangoni convection, surfactant adsorption and desorption, and foaming must be considered to have significant influence on boiling [4]. According to Hestroni et al. [20], the boiling curve of the surfactant solution depends on its concentration and every surfactant solution at given concentration behaves itself as new liquid having the common boiling curve at various level of subcooling.

In this study, considering time until reaching the boiling point, boiling temperature, and maximum wall temperatures (T_w), the most effective compositions were obtained at 50 ppm for SLS, 300 ppm for EH-14, and 200 ppm for SA-9. These concentrations were the most favorable compositions to achieve boiling in the lowest time and lowest base temperature among other concentrations. After that consideration, test results were presented for wall temperature changes for varying heat flux conditions.

Conclusions

With the integration of boiling experiments into coursework, mechanical engineering students will enhance their learning of basic boiling concepts. A project for integration into a heat transfer laboratory is presented and explained. This example project enabled students to compare boiling heat transfer coefficient, h, for experimental and theoretical values with varying heat flux from the hot plate. Instructors can also use the hands-on learning module for subsequent use in the classes to encourage the student's spirit of discovery. Classroom feedback from students will be used to improve the learning modules in successive years. The experimental apparatus is suitable for studying the different types of boiling heat transfer, and the effect of surfactants and power input on heat transfer. Direct assessment of the value of the experiments, such as comparison of lecture exam questions on boiling for those with the lab experience those without would be of interest for a future paper.

From the experimental results of surfactants study, following conclusions are drawn. The bubbles formed in water with surfactant solutions are much smaller than pure water and they covered the surface of beaker base faster. The presence of surfactant reduces the boiling excess temperature ΔT. Boiling curves shifted to the left side and activation of nucleation sites is increased. Results prove that there is an important possibility to enhance the boiling application processes by SLS, EH-14, and SA-9 additives. The most effective compositions were obtained at 50 ppm for SLS, 300 ppm for EH-14, and 200 ppm for SA-9. Experimentation can be extended for searching different surfactants in order to find their most efficient quantity in pure water for boiling heat transfer. For distillation applications, sample of distillate water should be analyzed and be showed that there is no appearing of organic or toxic particles in the distillate water.

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