Experimentation on Pool Boiling With Sodium Dodecyl Sulfate

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Abstract : We have so many applications related to Pool Boiling. The Pool Boiling is mostly useful in arid areas to produce drinking water from impure water like sea water by distillation process. It is very difficult to distill the only water which having high surface tension. The surface tension is important factor to affect heat transfer enhancement in pool boiling. By reducing the surface tension we can increase the heat transfer rate in pool boiling. Over the past few decades, researchers have investigated different passive enhancement techniques to increase the heat transfer coefficient and the critical heat flux. They have used different working fluids, e.g., water, aqueous surfactant solutions, refrigerants, alcohols, binary mixtures. From so many years we are using surfactants in domestically. It is proven previously by experiments that the addition of little amount of surfactant reduces the surface tension and increase the rate of heat transfer. There are different groups of surfactants. From those I have experimenting with anionic surfactant Sodium Dodecyl Sulfate (SDS), which is most human friendly to test the heat transfer enhancement. The effects, of both SDS concentration, and the excess temperature ΔT on heat transfer performance, are studied. The experimental results show that a small amount of surface active additive enhances the heat transfer coefficient h considerably higher, and that there is an optimum additive concentration for higher heat fluxes. Beyond this optimum point, further increase in additive concentration makes h lower.
Keywords: Pool Boiling, Distillation, Sodium Dodecyl Sulfate.

I. INTRODUCTION

Boiling is a liquid-to-vapor phase change process just like evaporation, but there are significant differences between the two. Evaporation occurs at the liquid-vapor interface when the vapor pressure is less than the saturation pressure of the liquid at a given temperature. Boiling, on the other hand, occurs at the solid-liquid interface when a liquid is brought in contact with a surface maintained at a temperature T_s sufficiently above the saturation temperature T_{sat} of the liquid. The boiling process is characterized by the rapid formation of vapor bubbles at the solid-liquid interface that detach from the surface when they reach a certain size and attempt to rise the free surface of the liquid. Bubbles owe their existence to the surface-tension σ at the liquid-vapor interface due to the attraction force on molecules at the interface toward the liquid phase.

Boiling is classified as pool boiling and flow boiling, depending on the presence of bulk fluid motion. Boiling is called pool boiling in the absence of bulk fluid flow and flow boiling in the presence of it. In pool boiling, the fluid is stationary, and any motion of the fluid is due to natural convection currents and motion of the bubbles under the influence of buoyancy. In flow boiling, the fluid is forced to move in a heated pipe or over a surface by external means such as a pump.

Pool and flow boiling are further classified as sub-cooled boiling or saturated boiling, depending on the bulk liquid temperature. Boiling is said to be sub-cooled when the temperature of the main body of the liquid is below the saturation temperature T_{sat} and saturated when the temperature of the liquid is equal to T_{sat}.

One important field of application of boiling and evaporation is in desalination of seawater, which is becoming essential in some arid regions. Small amount of certain surfactant additives are known to drastically change the boiling phenomena of water. It is most desirable that employing surfactant additives in liquids can develop and mature into an enhancement technique for boiling heat transfer. Generally, it is believed that small amount of surfactant can increase boiling heat transfer. The extent of enhancement has been found to be dependent on additive concentrations, its type and chemistry, wall heat flux, and the heater geometry.

II. LITERATURE REVIEW

The mechanism of pool boiling heat transfer has been studied for a long time since it is closely related with the designs of more efficient heat exchanger and heat removal systems. To determine the required heat transfer surface area as well as to evaluate the system performance during postulated accidents, overall heat transfer coefficients applicable to the system are needed. Since pool boiling heat transfer coefficient is factor in determining overall heat transfer coefficients through the heat exchanging tubes of the passive heat exchangers, many researchers have studied about it. With its ability to transfer large amounts of heat with relatively small temperature differences, nucleate boiling has attracted considerable research attention. This mode of heat

transfer is encountered in many different applications ranging from energy conversion systems, to refrigeration and air- conditioning, to chemical thermal processing that employs both Newtonian and non-Newtonian liquids[1].

Among the different enhancement techniques investigated, the use of additives for liquids appears to be quite viable and attracted some research. Small amount of certain surfactant additives are known to drastically change the boiling phenomena of water.

The surfactant effect has generated a lot of interest for many years. It is most desirable that employing surfactant additives in liquids can develop and mature into an enhancement technique for boiling heat transfer. Generally, it is believed that small amount of surfactant can increase boiling heat transfer. The extent of enhancement has been found to be dependent on additive concentrations, its type and chemistry, wall heat flux, and the heater geometry. Surfactant is a generic term for a surface-active agent, which literally means active at surface. It is fundamentally characterized by its tendency to adsorb at surfaces and interfaces when added in low concentrations to aqueous system.

The study of the saturated pool boiling of a surfactant solution shows a significant enhancement of heat transfer. Generally, it is believed that small amount of surfactant can increase boiling heat transfer. The extent of enhancement has been found to be dependent on additive concentrations, its type and chemistry, wall heat flux, heater geometry as reviewed recently by Wasker and Manglik (2000). Wu and Yang (1995) reported experimental data on the effect of surfactants on nucleate boiling in water with nine different additives[6][7].

The enhancement of heat transfer was related to depression of the static surface tension. Small concentrations of surfactant additives reduces the surface tension reduces considerably and its level of reduction depends on the amount and type of surfactant presented in the solution. The activation of nucleation sites, bubble growth and bubble dynamics influence the boiling heat transfer coefficient by Wen DS (2000) [5]. Frost and Kippenhan (1997) investigated boiling of water with various concentrations of surfactant ''Ultra wet 60L''. They observed that the increase of heat transfer being related to the reduction in the surface tension [3].The effect of surfactants and polymeric additives on the physical properties of aqueous surfactant and polymeric solutions as reviewed recently by Cheng L (2007)[8].

The measurement results of surface tensions and viscosities by aqueous surfactant and polymeric solutions show the variation of physical properties and interfacial properties affected by concentrations of surfactant and polymeric solutions. Hetsroni G (2000) studied experimentally the saturated nucleate pool boiling of aqueous Habon G solutions on the surface of electrically heated constantan plate. They have concluded that the heat transfer coefficient can be enhanced by the addition of Habon G, depending upon its concentration[4].

The heat transfer increases with increasing the solution concentration and reaches a maximum value at a certain solution concentration, and then decreases with further increasing the solution concentration. The effect of both the surface tension and the kinematic viscosity of aqueous Habon G solutions can explain the features of boiling heat transfer of the solutions.

By Conducting an Experiment on Pool Boiling heat transfer with Sodium Dodecyl Sulfate(SDS), we may get grater Heat Flux results. In Pool Boiling, a little amount of SDS can drastically increase the Heat Flux nearly hundred times. By using SDS in power plants we may get best rate of steam generation. And in sea water desalination and polluted water desalination we may get best heat transfer rates and can produce large quantity of drinking water in minimum time.

III.   EXPERIMENTATION

3.1 Experimental Setup:
The experimental setup consists of a
- Power Supply Equipment,
- Pool Heater,
- Beaker,
- Thermocouples.

3.1.1 Power Supply Equipment:
The power supply equipment consists of a Voltmeter, Ammeter and Temperature Indicator. The Voltmeter is of maximum 240 Volts, and Ammeter is of maximum 4.05 Amperes. The voltmeter and ammeter are used to set the constant power supply.
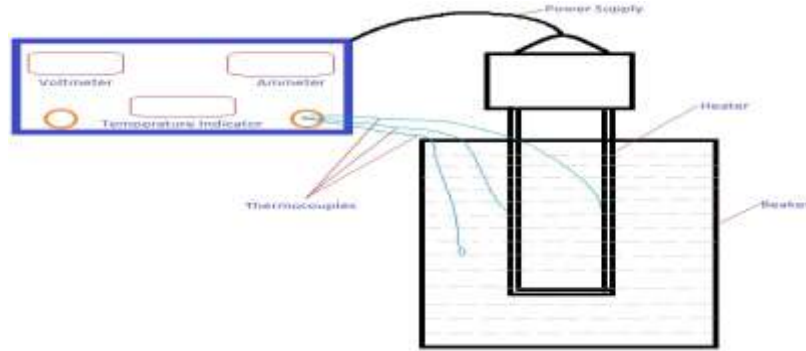
Fig: 1 Experimental Setup line diagram.

The temperature indicator is used to show the temperature measurement by required number of temperatures marked reader. And thermocouples also connected to this power supply which converts the temperature measurement to digital form and shows the reading.

3.1.2 Pool Heater:
The pool Heater of polished stainless steel of length 600mm and 3.75mm radius is used. The heater is connected to the power supply equipment to regulate the amount of power supply.

3.1.3 Thermocouples:
Thermocouple is used to measure the temperature of matter and transfers it to the digital reader. A thermocouple is a temperature-measuring device consisting of two dissimilar conductors that contact each other at one or more spots, where a temperature differential is experienced by the different conductors (or semiconductors). It produces a voltage when the temperature of one of the spots differs from the reference temperature at other parts of the circuit.
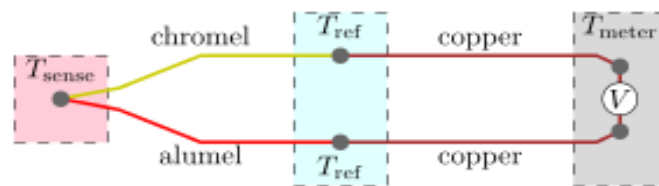

Fig: 2 Thermocouple

3.2 Procedure:
A beaker of one liter volume is taken and filled with pure water. A heater is dipped into the water which is connected to power supply equipment. Two thermocouples are attached to heater surface to measure the temperature of the heater surface. The power supply is switched on to the heater. The supplying heat is set to constant at voltmeter reading(V) is set to 120 volts and ammeter reading(I) is adjusted to 2.05 amperes.

Fig: 3 Practical Experimental Setup

After reaching the saturation temperature bubble formation is started on heater surface. Then the values of temperatures of heater surface is noted and tabulated. After a certain interval time again the temperature readings are noted and tabulated. This process is continued for up to the end of nucleate boiling.

The process is repeated for every 10 ppm SDS concentration up to 100ppm and from that process is repeated for every 100ppm concentration up to 1000ppm and further the concentration is increased by 500ppm up to 3000ppm. Tabulated all those readings and calculated the Heat flux(q_s) and Coefficient of Heat Transfer (h). The Heat flux is calculated by using Rohsenow Nucleate Boiling correlation.

IV. OBSERVATIONS & CALCULATIONS

4.1Observations:

Table: 1 Experimental values of Pure Water

Pure Water				
Time (min)	Ts (°C)	ΔT (°C)	q (KW/m²)	h (KW/m².°C)
23	104	4	9.009	2.25
25	104.5	4.5	12.827	2.85
27	105	5	17.596	3.52
29	105.5	5.5	23.42	4.25

Table : 2 Experimental values of 10ppm Concentration

10ppm				
Time (min)	Ts (°C)	ΔT (°C)	q (KW/m²)	h (KW/m².°C)
22	104	4	12.827	2.85
24	104.5	4.5	17.596	3.51
26	105	5	23.42	4.25
28	105.5	5.5	30.4	5.06

Table: 3 Experimental values of 50ppm Concentration

50ppm				
Time (min)	Ts (°C)	ΔT (°C)	q (KW/m²)	h (KW/m².°C)
18	107	7	48.28	6.89
20	108	8	72.07	9.09
22	108.5	8.5	86.45	10.17
24	109	9	102.63	11.4

Table: 4 Experimental values of 100ppm Concentration

100ppm				
Time (min)	Ts (°C)	ΔT (°C)	q (KW/m²)	h (KW/m².°C)
13	111.5	11.5	220.07	19.13
15	112	12	250.04	20.83
17	112.5	12.5	282.61	22.6
19	113	13	317.9	24.45

Table: 5 Experimental values of 400ppm Concentration

400ppm				
Time (min)	Ts (°C)	ΔT (°C)	q (KW/m²)	h (KW/m².°C)
10	113	13	317.9	24.45
12	114	14	397.05	28.36
14	114.5	14.5	441.13	30.42
16	115	15	475.09	31.67

Table: 6 Experimental values of 500ppm Concentration

500ppm				
Time (min)	Ts (°C)	ΔT (°C)	q (KW/m²)	h (KW/m².°C)
9	113.5	13.5	356.01	26.37
11	114	14	397.05	28.36
13	115	15	475.09	31.67
15	115.5	15.5	524.2	33.81

Table: 7 Experimental values of 800ppm Concentration

800ppm				
Time (min)	Ts (°C)	ΔT (°C)	q (KW/m²)	h (KW/m².°C)
6	114.5	14.5	441.13	30.42
8	116.5	16.5	598.48	36.27
10	117	17	691.6	40.68
12	118.5	18.5	891.3	48.17

Table: 8 Experimental values of 1000ppm Concentration

1000ppm				
Time (min)	Ts (°C)	ΔT (°C)	q (KW/m²)	h (KW/m².°C)
4	117	17	691.6	40.68
6	118.5	18.5	891.3	48.17
8	120	20	1126.16	56.3
10	121.5	21.5	1399.02	65.06

Table: 9 Experimental values of 1500ppm Concentration

1500ppm				
Time (min)	Ts (°C)	ΔT (°C)	Q (KW/m²)	h (KW/m².°C)
3	118.5	18.5	891.3	48.17
5	119	19	965.54	50.81
7	120	20	1126.16	56.3
9	122.5	22.5	1603.45	71.26

Table: 10 Experimental values of 2000ppm Concentration

2000ppm				
Time (min)	Ts (°C)	ΔT (°C)	Q (KW/m²)	h (KW/m².°C)
2	120.5	20.5	1212.75	59.15
4	121	21	1303.67	62.07
6	122.5	22.5	1603.45	71.26
8	124	24	1946	81.08

Table: 11 Experimental values of 2500ppm Concentration

2500ppm				
Time (min)	Ts (°C)	ΔT (°C)	q (KW/m²)	h (KW/m².°C)
1	122	22	1498.91	68.13
3	123	23	1712.74	74.46
5	124.5	24.5	2069.91	84.48
7	125	25	2199.53	87.98

Table: 12 Experimental values of 3000ppm Concentration

3000ppm				
Time (min)	Ts (°C)	ΔT (°C)	q (KW/m²)	h (KW/m².°C)
3	117	17	691.6	40.68
5	118.5	18.5	891.3	48.17
7	119.5	19.5	1043.79	53.52
9	122.5	22.5	1603.45	71.26

4.2 Calculations:

Here the power supplied to the pool heater power requirement to be determined.
Assume Water is boiled at 1 tam pressure on a stainless steel tube surface. At 100^0C

Heat flux $q_s = \mu_l\, h_{fg}\left(\dfrac{g(\rho_l - \rho_v)}{\sigma}\right)^{0.5}\left(\dfrac{c_{pl}(T_s - T_{sat})}{C_{sf}\, h_{fg}\, \rho\, r_l^n}\right)^3$

$$\ldots\ldots\ldots\ldots (1)$$

h_{fg} = Enthalpy of vaporization = 2257 KJ/Kg,

ρ_v = Density of the vapor = 0.6Kg/m^3,

μ_l = Viscosity of the liquid = 0.282*10^{-3} Kg/m-s,

σ   = Surface tension of the liquid-vapor interface
      = 0.0589 N/m,
Pr_L = Prandtl number of the liquid   =1.75,
ρ_l = Density of liquid= 958.4 Kg/m^3,
C_{pl} = Specific heat of liquid = 4220 J/Kg k,
n   = 1 for water.

4.2.1 Nucleate Heat flux:

$q_s = (0.282 \times 10^{-3})(2257 \times 10^3)$

$$\left[\frac{9.81[958.4 - 0.6]}{0.0589} \right]^{0.5} \left[\frac{4220[115 - 100]}{0.013 \times 2257 \times 1000 \times 1.75} \right]^3$$

q_s =636.474×399.30×1.8695
q_s = 47.51×10^4 W/m^2
heat transfer coefficient h = q_s/(T_s-T_{sat})
= 475.1/(115-100)
=31.67 KW/ m^2 $^\circ$C

4.2.2 Stainless Tube heater Design:

Length of stainless tube heater (L)   = 600 mm
Diameter of stainless tube heater (D) = 7.5 mm
Surface area of heater (A) = πDL
                           = π ×7.5×600
                           = 14.137×10^{-3} m^2
Maximum Heat flux is given by ,
$q_{max} = C_{cr} h_{fg} [\sigma g \rho_v^2 (\rho_l - \rho_v)]^{0.25}$. . . . . (2)
Where, C_{cr} = Constant,
Which value depends on the Dimensional Length L* , given by
$$L^* = L\left[\frac{g[\rho_L - \rho_v]}{\sigma} \right]^{0.5}$$ . . . . (3)
Where,
L = Characterstic Dimension of Heater =Radius
  = 3.75 mm

$$L^* = 3.75 \times 10^{-3} \times \left[\frac{9.81[958.4 - 0.6]}{0.0589} \right]^{0.5}$$
L^* =0.478 m ;   0.15<L*<1.2
Therefore, From table , C_{cr} =0.12L$^{*-0.25}$
C_{cr} = 0.1443
q_{max}= 0.1443×2257×1000 $[0.0589 \times 9.81 \times 0.6^2 \times (957.9 - 0.6)]^{0.25}$
    = 325728.55[199.12]$^{0.25}$
q_{max} = 2.23 MW/m^2

4.2.3 Burnout temperature:

Surface Temperature at which burnout phenomenon occurs determined by ,

$$q_{nucleate} = \mu_l h_{fg}\left(\frac{g(\rho_l - \rho_v)}{\sigma}\right)^{0.5} \left(\frac{c_{\rho l}(T_s - T_{sat})}{C_{sf} h_{fg} \rho r_l^n}\right)^3$$ . . . . (4)

$1.22 \times 10^6 = (0.282 \times 10^{-3})(2257 \times 10^3)$

$$\left[\frac{9.81(958.4 - 0.6)}{0.0589} \right]^{0.5} \left[\frac{4220(115 - T_s)}{0.013 \times 2257 \times 1000 \times 1.75} \right]^3$$

T_s = 129.5 $^\circ$C.

V.   RESULTS & DISCUSSION

5.1 Variation of Heat Fluxes for Different Concentrations:

A Graph is drawn to Heat flux and concentration here we can observe that for the pure water the obtained heat fluxes are very low and it is increased with increase in concentration of the surfactant sodium dodecyl sulfate. Very high heat fluxes are obtained at 1500ppm and 2000ppm.
Fig:4 Graph - Variation of Heat Fluxes for Different concentrations.
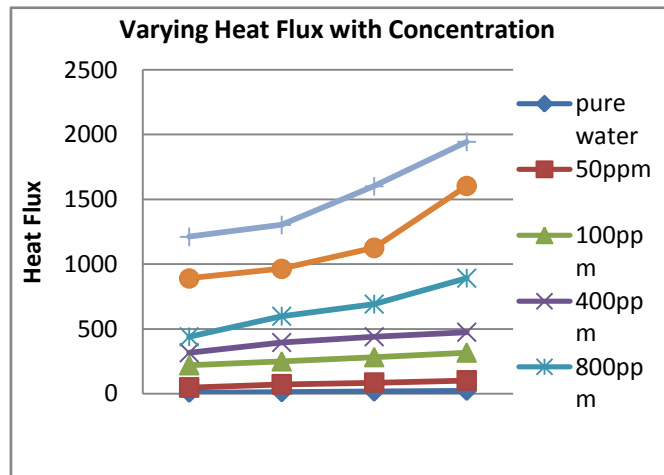
5.2 Concentration Vs Temperature Difference:

A graph is drawn between concentration of SDS and change in temperature. Here we can observe that by increasing the concentration of SDS the temperature difference also increased. For pure water the maximum temperature difference is 5.5^0C and for 2500ppm the temperature difference is 25^0C.

Fig: 5 Graph-Concentration Vs Temperature Difference
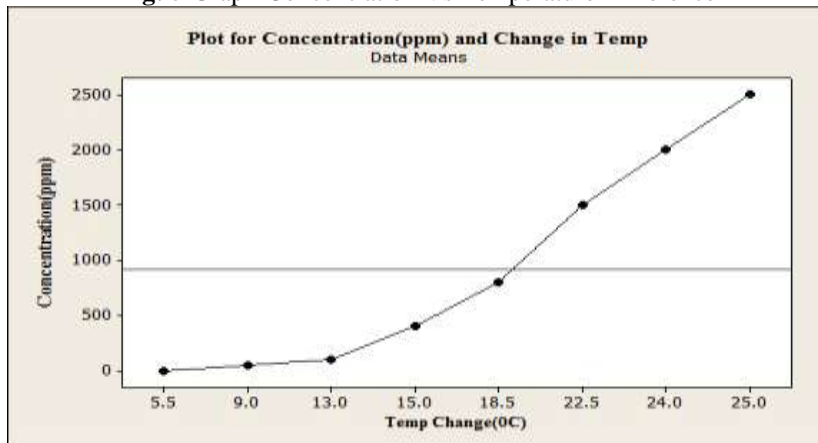
5.3 Heat Flux Vs Concentration:

The Graph is drawn between Heat Flux and concentration of SDS. Here we can observe that the Heat Flux is increased with increase in concentration of SDS. And the minimum heat flux is obtained for pure water and maximum heat flux is obtained for 2500ppm.

Fig: 6 Graph-Heat flux Vs Concentration of SDS.
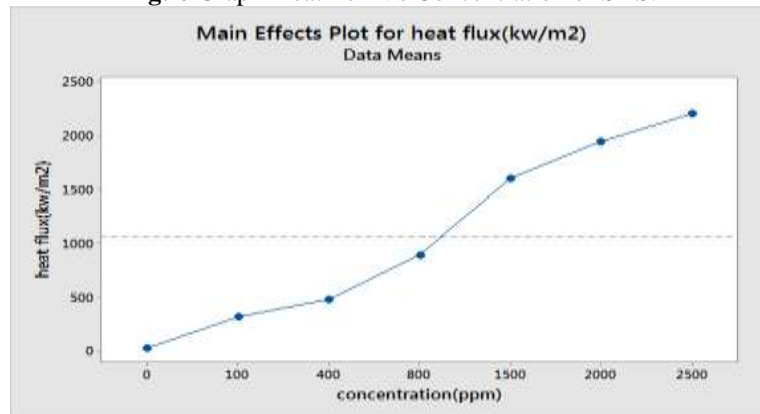
5.4 Concentration and Time of Boiling:

The graph is drawn between concentration of SDS and time of bubble formation. From the graph we can observe that by increase in concentration of SDS the time of bubble formation is decreasing which means the rate of heat transfer increasing with concentration and reducing the time of boiling.

Fig: 7 Concentration and Time of Boiling
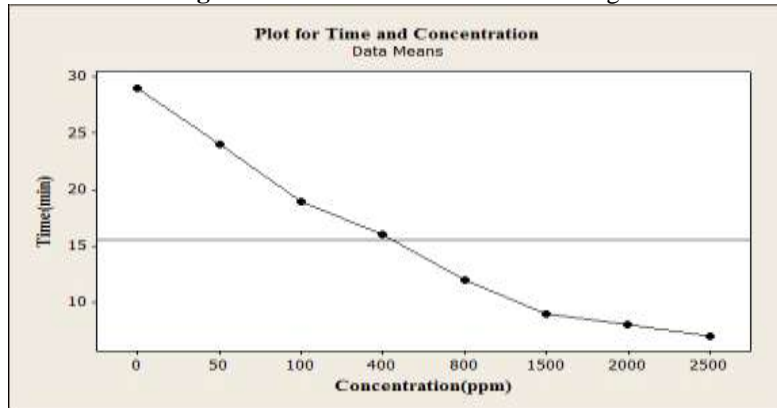
5.5 Time of Boiling and Temperature Difference:

The graph is drawn between time of boiling and Temperature difference, here we can observe that the time of boiling is decreasing when the temperature difference increasing. By this we can said that depending on concentration time of boiling is decreasing and temperature difference is increasing.

Fig:8 Time of Boiling and Temperature Difference
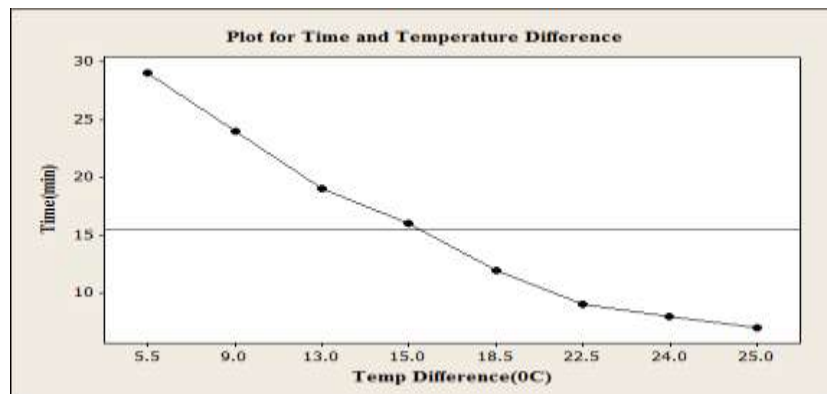
VI. CONCLUSION

Experimentation is conducted on Pool Boiling heat transfer with Sodium Dodecyl Sulfate(SDS).From the results the maximum Heat Flux obtained for pure water is 23.42 KW/m^2 and maximum Heat Flux for 2500ppm is 2199 KW/m^2, which means little amount 2.5 grams of SDS increases the Heat Flux nearly hundred times. Therefore rate of heat transfer increased drastically by using SDS in pool boiling. By using SDS in power plants we may get best rate of steam generation. And in sea water desalination and polluted water desalination we may get best heat transfer rates and can produce large quantity of drinking water in minimum time.

ACKNOWLEDGEMENT

Nomenclature

q_s = Heat flux,

h_{fg} = Enthalpy of vaporization,

ρ_v = Density of the vapor,

μ_L =Viscosity of the liquid,

σ　　 = Surface tension of the liquid-vapor interface,

Pr_L　 = Prandtl number of the liquid,

ρ_l　　 = Density of liquid,

C_{pl}　 = Specific heat of liquid.

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