Experimental Study Of Aqeous Solutions Of Additives In Pool Boiling Heat Transfer And The Behaviour Of Critical Heat Flux

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Abstract- *Critical heat flux (CHF) is one of the key issues in a heat transfer system. It is directly related to efficiency and safety of the system. At the CHF point, sudden increase of heat transfer surface temperature or deterioration of heat transfer rate are shown, and CHF sets a limit in designing and operating the boiling heat transfer equipment in various power industries such as nuclear, fusion and fossil power plants. Therefore, CHF enhancement can increase the safety margin and allow more efficient operation of power plant due to higher operating heat flux.*

The experimental set up for the present investigation includes electric heating element submerged in water and mounted in the glass pool .A thermocouple and a digital indictor measured the solution temperature. The actual heat transfer rate is obtained by multiplying the voltmeter and ammeter reading.

Additives employed were: ammonium chloride, potassium permanganate, potassium dichromate. Pool boiling experiments were carried out a relatively wide range of surfactant concentrations:500ppm-3000ppm.The boiling results show that, with the addition of small amounts of additives, the rate of heat flux varies and is found to be altered due to increase or decrease in the surface tension and this leads to the variation of the heat transfer.

The enhancement in nucleate pool boiling depends upon concentration of additives or surfactants, ionic nature, molecular weight etc. The heat flux is found to vary at different concentration of the additives in water. The optimum enhancement is at the lower temperature of the solutions taken.

The photographic and visual observations indicate the boiling behaviour as the temperature changes: small, regularly- shaped bubbles clustering on the heater surface reducing coalescence.

Keywords- Heat Flux CHF , Nucleate Pool

I. INTRODUCTION

1.1 BOILING HEAT TRANSFER:

Boiling:

When evaporation occurs at solid – liquid interface it is termed as boiling. The process occurs when temperature of the surface T_s exceeds the saturation temperature T_{sat} corresponding to the liquid pressure

$$q_s'' = h(T_s - T_{sat}) = h\,\Delta T_e$$

Boiling heat transfer is defined as a mode of heat transfer, which occurs with a change in phase from liquid to vapour. There are two basic types of boiling:

1. Pool boiling: *Boiling* of a liquid whose flow results from natural convection, where heated surface is submerged below a free surface of liquid.
2. Flow boiling: where the liquid flows on a heated surface.

1.2 POOL BOILING:

The existence of several regimes of boiling was first clearly discussed by Nukiyama, 1934 .He performed the experiment illustrated in Figure (1.1).A platinum wire immersed in water was heated electrically .the current in the wire and the voltage across the ends of the wire enabled the power, and hence the heat flux, to be calculate. Alsofrom the resistance of the wire the temperature of the wire could be found [2,3].

This diagram in Figure (1.2) was first presented by Nukiyama (1934) and is often referred to as Nukiyama's curve. It is more common nowadays to plot the wall heat flux (qw) versus the temperature difference (ΔT sat.) between the wall temperature (Tw) and the saturation temperature (Tsat.), or to plot the pool boiling heat transfer coefficient (h) versus the heat flux. The existence of several regimes of boiling was first clearly discussed by Nukiyama. The curve of heat flux (q"w) against the temperature difference (ΔT sat.) is the boiling curve. The regions of the curve are well known; Figure (1.3) shows a representation of each region:

1. The natural convection region (AB) where temperature gradients are set up in the pool and heat is removed by natural convection to the free surface and hence by evaporation to vapour space.
2. The path (BC) implies a strong increase in heat transfer performance, and the temperature difference is suddenly decreased.
3. At the onset of nucleate boiling (ONB or point C) the wall superheat becomes sufficient to cause vapour nucleation at the heating surface.
4. In the nucleate boiling region (CD) vapour nucleation occurs at the heating surface, starting with a few individual sites at low heat fluxes. The vapour bubble structure then changes as the heat flux is increased, as a result of bubble coalescence.
5. The critical heat flux (CHF or point D) marks the upper limit of nucleate boiling where the interaction of liquid and vapour streams causes a restriction of the liquid supply to the heating surface.
6. The transition-boiling region (DF) is characterized by the existence of an unstable vapour blanket over the heating surface that releases large patches of vapour at more or less regular intervals.
7. In the film boiling region (FE) a stable film covers the entire heating surface and vapour is released from the film periodically in the minimum film boiling heat flux (MFB or point F), where a further decrease takes the system back to G.

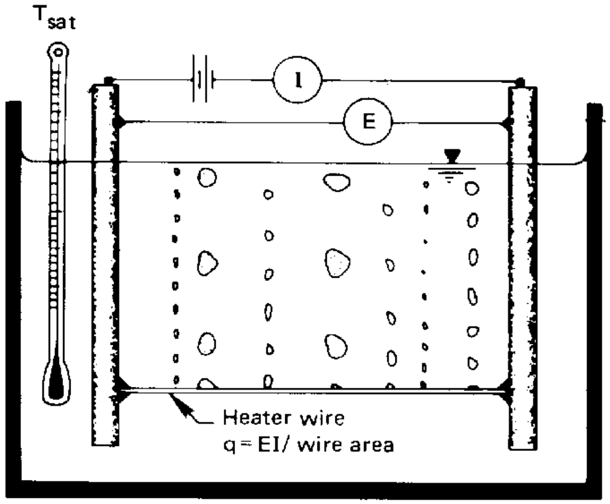


Figure (1.1): Pool Boiling experiment [3].

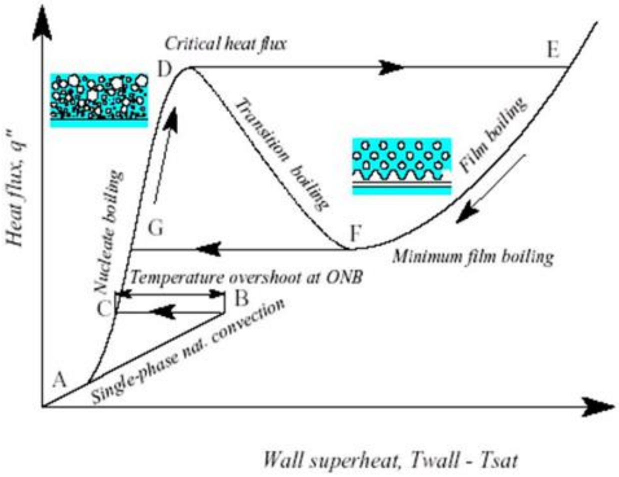


Figure (1.2): Pool Boiling Curve [4]

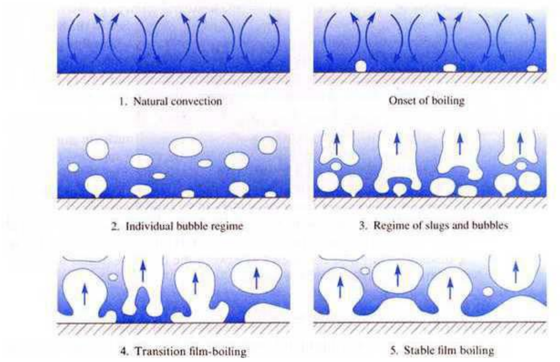


Figure (1.3): The regimes of pool boiling in water at (1 atm) [5].

1.3 POOL BOILING CHF:

The CHF mechanism in pool boiling is the most fundamental and common subject in CHF research. The pool-boiling CHF can be easily described as the change of the heat transfer regime from nucleate boiling to film boiling (or partial film boiling for temperature controlled systems). The problem is that the detailed physical mechanisms leading to the CHF is not sufficiently understood.

The critical heat flux (CHF) condition is characterized by a sharp reduction of the local heat transfer coefficient that results from the replacement of liquid by vapor adjacent to the heat transfer surface (Collier & Thome, 1994). The occurrence of CHF is accompanied by an inordinate increase in the surface temperature for heat-flux-controlled systems, and an inordinate decrease in the heat transfer rate for temperature-controlled systems. The CHF condition is generally more important in the heat-flux-controlled systems such as nuclear reactors since the temperature increase can threaten the physical integrity of the heated surface. The CHF is a very interesting and important phenomenon from both fundamental and practical points of view. From the fundamental point of view, CHF accompanies tremendous changes in heat transfer, pressure drop and flow regime. Heat transfer is maximized at the CHF point and is2drastically degraded after the CHF point. For flow boiling in a confined geometry, the flow regime changes at the point of CHF as shown in Fig. 1.4 If the CHF occurred under bubbly flow condition, the flow regime is changed into inverted annular flow due to the formation of stable vapor film on the heated surface. In the similar way, the slug flow is changed into inverted slug flow and the annular flow into dispersed flow.

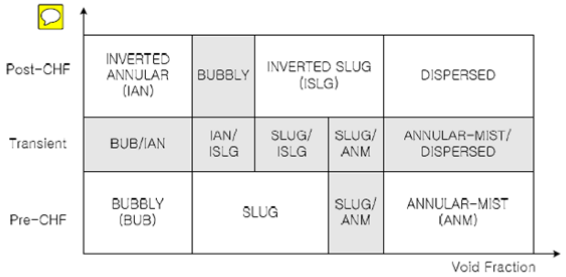


Figure (1.4): Flow regime changes at the CHF

From the practical point of view, there are many application areas involving the CHF, including nuclear power plants, fusion applications, fossil power plants, the electronics cooling, steam generators, etc, as illustrated in Fig. 1.5 In those application areas, the CHF affects significantly on the integrity, safety, and/or economic competitiveness of systems and component.

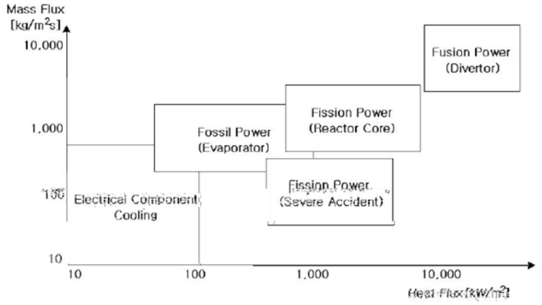


Figure (1.5): The application area of the CHF

The occurrence of CHF can deteriorate the integrity of fuel rods of water-cooled nuclear reactors that contain radioactive fission products. Therefore, the water-cooled reactor cores are designed to preclude (i.e., to assure the very low probability of) the occurrence of CHF during normal operation and anticipated operational transients. For accident conditions of the lower likelihood, it is impossible to preclude the occurrence of CHF; instead, safety analysis is performed with assuming the damage of fuel rods that are assessed to experience the CHF. For the postulated loss-of-coolant accident (LOCA), the safety criteria are given to other parameters such as the peak cladding temperature (PCT). It should be noted that the PCT is significantly affected by the CHF phenomenon

The CHF phenomenon has been extensively investigated over the last four decades mainly with the development of water-cooled nuclear reactors. Recently, the cooling requirement of high-heat-flux components of fusion reactors has also stimulated the research in this area. The ultimate objectives of the CHF research for nuclear applications would be **(a)** to accurately predict the CHF for given conditions, and or **(b)** to enhance the CHF for given operating conditions. An accurate prediction of the CHF requires the understanding of physical mechanisms and parametric trends as well as sufficient experimental data bases. The efforts to enhance CHF have mainly been related to the improvement of nuclear fuel performance.

R&D efforts have been focused on: **(a)** understanding of fundamental characteristics such as physical mechanisms, parametric trends, etc., **(b)** development of reliable prediction models, and **(c)** development and implementation of CHF enhancement techniques. Now many aspects of the phenomenon are well understood and several reliable prediction models (mainly empirical) are available for wide parameter ranges of conventional interests. However, the CHF is still the subject of active research and its application is continuously expanding to new areas.

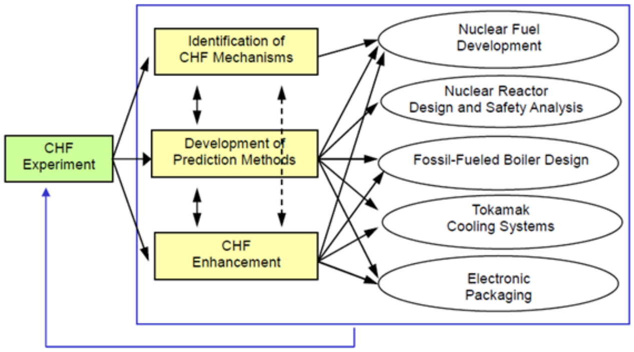


Figure (1.6): CHF Research and Major Applications

There have been excellent reviews on CHF in books and journals (Collier & Thome, 1994; Hewitt, 1982; Bergles, 1977, 1979; Theofanous, 1980; Katto, 1985, 1994; Chang & Baek, 1997).

II. LITERATURE SURVEY

2.1 INTRODUCTION

Saturated nucleate boiling of aqueous solution of additives on a nichrome wire heater has been experimentally investigated. The boiling performance is enhanced by using additives. The variation of heat flux and boiling phenomenon is observed up to 3000 ppm concentration of each additive. For concentrations more than 2600 ppm, significant enhancement is not recorded for potassium dichromate and ammonium chloride and for potassium permanganate enhancement is seen up to 3000ppm. Enhancement observed is due to the change in the thermo physical properties of the aqueous solution. It is observed that as additives are added to water, the surface tension of the mixture considerably changes. The experiment is carried out above on critical heat flux apparatus is to observe the behavior of boiling at higher heat flux and variation of heat flux with change in concentration of the solution at different temperatures.With its ability to transfer large amounts of heat in relatively small temperature differences, nucleate boiling has attracted considerable research attention. Boiling with Additives is generally a very complex process, and it is influenced by a larger set of variables in comparison to the phase-change process of pure water. Besides the wall heat flux or (temperature difference), heating surface geometry, and bulk concentration of additives, the nucleate boiling behaviour is also dependent upon, among others, the role played by surface tension, interfacial stresses, the nucleation process. Furthermore, it appears that the boiling mechanism itself is influenced by the nature of Additive and its chemistry in the solution [24].

2.2 POOL BOILING WITHOUT ADDITIES (pure water):

2.2.1 BUBBLE NUCLEATION:

In nucleate boiling, bubbles are created by the expansion of entrapped gas or vapour at small cavities in the surface. The bubbles grow to a certain size, depending on the surface tension at the liquid – vapour interface and the temperature and pressure. Depending on the temperature difference, the bubbles may collapse on the surface, may expand and detach from the surface to be dissipated in the body of the liquid, or at sufficiently high temperatures may rise to the surface of the liquid before being dissipated.

2.2.2 BUBBLE DYNAMICS:

Bubble dynamics includes the processes of bubble growth and bubble departure.

Bubble growth and collapse has been the focus of research for many decades since the earliest study by Lord Rayleigh (1917) [24]. Generally, two points of view with respect to the growth of a bubble on a heated surface have been put in the literature. According to the first perspective Mikic et al., (1970), the growth of a bubble occurs as a result of evaporation all around the bubble interface. The energy for the evaporation is supplied from the superheated liquid layer that surrounds the bubble since its inception. The second point of view is that most of the evaporation occurs at the bubble base due to the evaporation of micro-layer present between the vapour-liquid interface and the heater surface [25].

The diameter to which a bubble grows before departure is dictated by the balance of forces acting on the bubble. Fritz (1935) [14],correlated the bubble departure diameter by balancing buoyancy, which acts to lift the bubble from the surface, with the surface tension force, which tends to hold the bubble to the wall, and gave the following expression for departure diameter.

$$d_b = 0.0208\,\varphi^{\sqrt{(\sigma \div g(\rho l - \rho v))}} \qquad \text{.........................(2.1)}$$

Here φ is the contact angle measured in degrees. Several expressions obtained empirically or analytically by involving various forces acting on a bubble have also been reported [24].

These correlations, however, show considerable inconsistency in predicting the departure diameters with the wall superheat, possibly due to the merger of bubbles at high heat fluxes [27]**.**After the departure of bubble from the surface, cooler bulk liquid fills the space vacated by the bubble. A new bubble at this location will grow when the superheated liquid layer is re established and the inception criterion is satisfied [24] .

III. EXPERIMENTAL WORK

3.1 INTRODUCTION:

The experiment was carried out to study the variation and behaviour of heat flux by using different kinds of additives in water and observe the boiling phenomenon at certain concentrations of solution taken. The experimental details include the apparatus used for experimentation, aqueous solutions used such as various cationic and anionic solution samples at various concentrations. The aim of this study is to determine the critical heat flux of pure water with and without addition of surfactants and to qualify the effects of surfactant concentration and ionic nature etc. On nucleate boiling performance of water.

This experimental set up is designed to study the pool boiling phenomenon up to critical heat flux point. The pool boiling over heater wire can be visualised in the different regions up to critical heat flux point at which the wire melts. The heat from the wire is slowly increased by gradually increasing applied voltage across the test wire and the change over from natural convection to nucleate boiling can be seen.

The formation of bubbles and their growth in size and number can be visualised, followed by the vigorous bubble formation and their immediate carrying over to surface and ending thus in the breaking of the wire indicating the occurrence of critical heat flux point. This is repeated for various temperatures of the water in the container up to the saturation temperature.

3.2Nichrome wire:

A nichrome wire of length 100 mm and 0.122 mm diameter is taken.

Figure(3.7)Nichrome wire

3.2.1 THERMOMETER:

- A long thermometer of 400^0C is used.
- Glass thermometer filled with mercury is used

Figure(3.8) Glass Thermometer

3.3 EXPERIMENTAL PROCEDURE:

Initially, 2.5 L of distilled water is taken in the glass pool and is heated to the saturation temperature by a supplementary heater. As the temperature reaches about95◦C, the supplementary heater is switched off and the Nichrome wire heater is switched on.

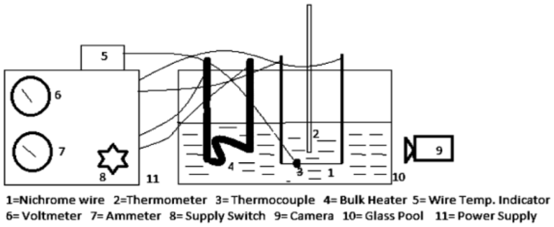


Figure (3.9): Experimental set-up for pool boiling Behaviour

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 additive. 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 0.15-m-long pieces.

Various researchers have investigated a number of surface-active agents for mass and heat transfer enhancement. The additive used here is ammonium chloride, potassium permanganate, potassium dichromate.

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.

3.4 CALCULATIONS:

Determination critical heat flux in nucleate pool boilng:

Critical heat flux (q) :

Critical heat flux **q = Q / A = VI / A** in $\mathrm{Mw/m^2}$

All the heat generated in these experiments was from the heater. The energy generated by the heater can be calculated using the current (I) and the voltage (V).

At steady state, heat from the heater is transferred to the test fluid while some is lost through natural convection from the glass.

Heat input = VI

Q – Heat Input in watts

Q = VI

V – voltage in volts

I – current in amps

A – Heater Surface Area in m^2

A = πDL

D – diameter of nichrome wire in mm

L– length of nichrome wire

3.5 SYSTEMS STUDIED:

Aqueous solutions of Ammonium salt a cationic surfactant and compounds such as potassium dichromate and potassium permanganate having different concentrations (measured as the ppm additive content) were prepared by dissolving weighted samples in pure water.

The boiling curve for pure water was first established. The water data provide the baseline reference for the surfactant solution results.
The concentration of each surfactant that used in this study was;

Anionic and Cationic surfactants:

- NH_4Cl :(500,1000,1500,2200,2600) ppm
- $K_2Cr_2O_7$:(500,1000,1500,2200,2600)ppm
  $KmnO_4$:(500,1000,1500,2200,2600)ppm

Figure(3.10): Solutions samples of $K_2Cr_2O_7$ and $KMnO_4$

Potassium permanganate is an inorganic chemical compound with the formula $KMnO_4$. It is a salt consists of K^+ and MnO−4 ions. Formerly known as permanganate of potash or Condy's crystals, it is a strong oxidizing agent. It dissolves in water to give intensely pink or purple solutions, the evaporation of which leaves prismatic purplish-black glistening crystal

Potassium permanganate (KMnO4) is used primarily to control taste and odours, remove colour, control biological growth in treatment plants, and remove iron and manganese. In a secondary role, potassium permanganate may be useful in controlling the formation of THMs and other DBPs by oxidizing precursors and reducing the demand for other disinfectants (Hazen and Sawyer, 1992).

The mechanism of reduced DBPs may be as simple as moving the point of chlorine application further downstream in the treatment train using potassium permanganate to control taste and odours, colour, algae, etc. instead of chlorine. Although potassium permanganate has many potential uses as an oxidant, it is a poor disinfectant

IV. RESULTS AND DISCUSSIONS

Nucleate pool boiling experiments and the measured heat transfer performance of aqueous solutions of the three different surfactants are described in this chapter.

The results of solutions of different concentrations are presented, and the optimum enhancement in heat transfer is identified. Graphs are drawn to study the variation of heat flux at different concentrations.

The variation of heat flux is explained by two sets of graphs.

a) Critical heat flux (q”) Vs Concentration (ppm)
b) Critical heat flux (q”) Vs Temperature(T°c)

CHF Vs Conc.

AMMONIUM CHLORIDE (NH_4CL):

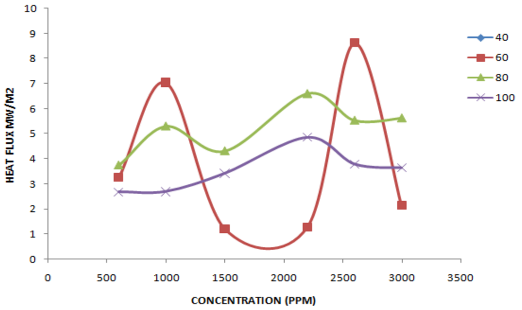


Figure (4.1) Heat flux variation for NH_4CL at different concentrations

The highest critical heat flux is observed at 60^0C and no enhancement is recorded after 2600 ppm . As the temperature is increased to 100^0C lower values of q” were observed. At 80^0C, moderate values were observed and no enhancement in q” value is observed after 2200ppm.

POTASSIUM PERMANGANATE ($KMnO_4$):

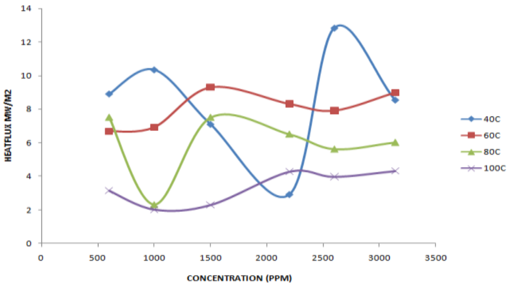


Figure (4.2): Heat flux variation for $KMnO_4$ at different concentrations

The drastic fall in critical heat flux is at 2200pm and with a sudden rise in heat flux curve the highest value is recorded at 2600ppm.

When $KMnO_4$ solution is heated at different concentrations varying temperatures, the enhancement of critical heat flux is up to 2600 ppm and after that no enhancement is recorded.

POTASSIUM DICHROMATE ($K_2Cr_2O_7$):

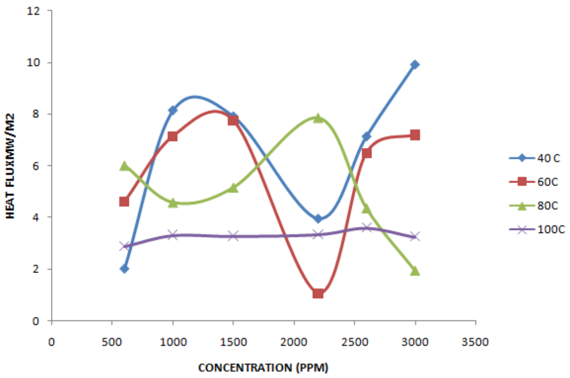


Figure (4.3): Heat flux variation for $K_2Cr_2O_7$ at different concentrations

In potassium dichromate the least heat flux is recorded at 2600ppm concentration and the highest value is obtained at 3000 ppm and after that no enhancement is seen. At 100^0C the heat flux is almost constant and linear with a very slight variation. There is a drastic fall in heat flux at 2600ppm for 60^0C, 40^0C and at the same point of concentration there is a sudden rise in q” value with increase temperature at 80^0C

CHF Vs TEMP

AMMONIUM CHLORIDE (NH_4CL):

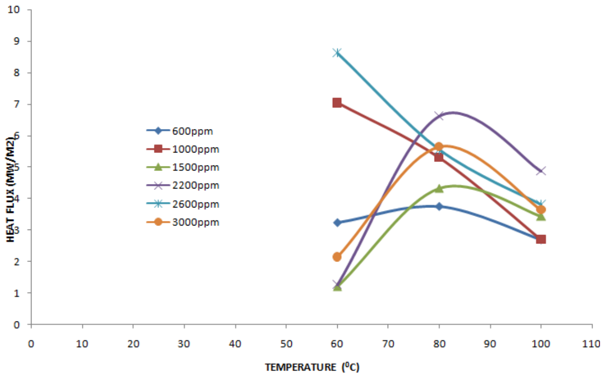


Figure (4.4) Heat flux variation for NH_4CL at different temperatures

There is a linear increase in critical heat flux at 80^0C, in the order 2200ppm > 3000pm >1000ppm >1500ppm >600ppm and the value of q" is highest at 2600ppm at 60^0C.

POTASSIUM PERMANGANATE ($KMnO_4$):

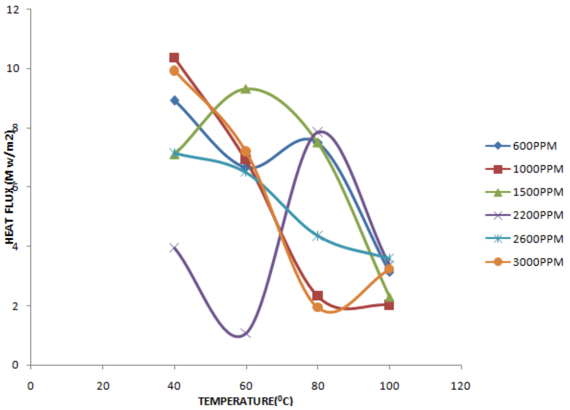


Figure (4.5): Heat flux variation for $KMnO_4$ at different temperatures

The behavior of heat flux is almost same at 1000ppm and 3000ppm , but the values of q" at 1000ppm are slightly higher than those at 3000ppm.At 60^0C the values of q" at 3000ppm,1000ppm, 600ppm,2600ppm almost coincided and there is a linear increase in the order 1500ppm>3000ppm>1000ppm>600ppm>2600ppm

POTASSIUM DICHROMATE ($K_2Cr_2O_7$):

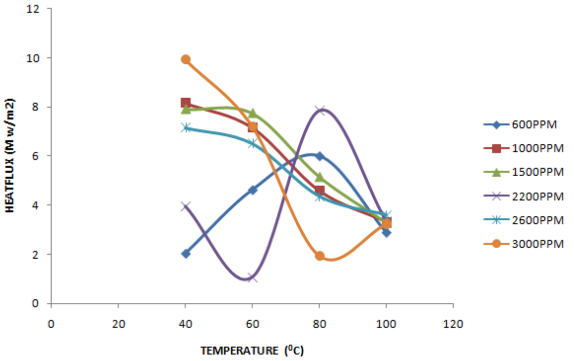


Figure (4.6): Heat flux variation for $K_2Cr_2O_7$ at different Temperatures

The value of heat flux is highest at 40^0C and as the temperature of solution increased to 80^0C the value of q" varies as

2200pm>600ppm>1500ppm>1000ppm>2600ppm>3000ppm

COMPARISION GRAPHS

CHF Vs TEMP:

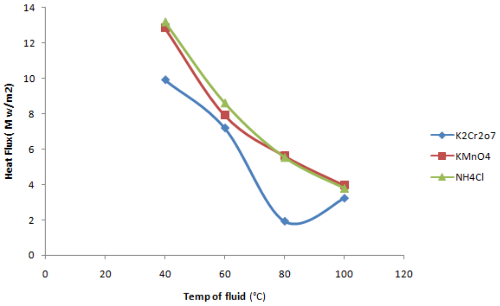


Figure (4.7): Heat flux variation forNH_4Cl, $KMnO_4$, $K_2Cr_2O_7$ at different Temperatures

When heat flux and temperature graphs were compared ammonium chloride has the highest value of heat flux at 60^0C, the point where the three curves almost coincide .

CHF Vs CONCENTRATION

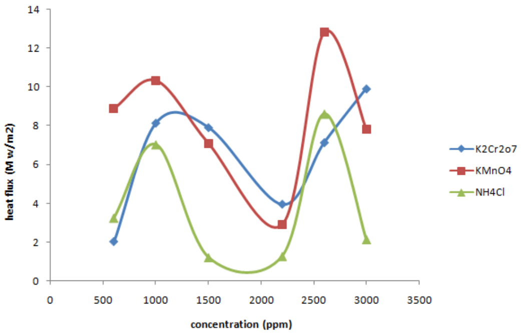


Figure (4.8): Heat flux variation forNH_4Cl, $KMnO_4$, $K_2Cr_2O_7$ at different Concentrations

When the three (q" Vs ppm) curves were observed, potassium permanganate has highest heat flux value among the three at 2600ppm and there is a sudden rise from 2200ppm

CHF Vs TEMP

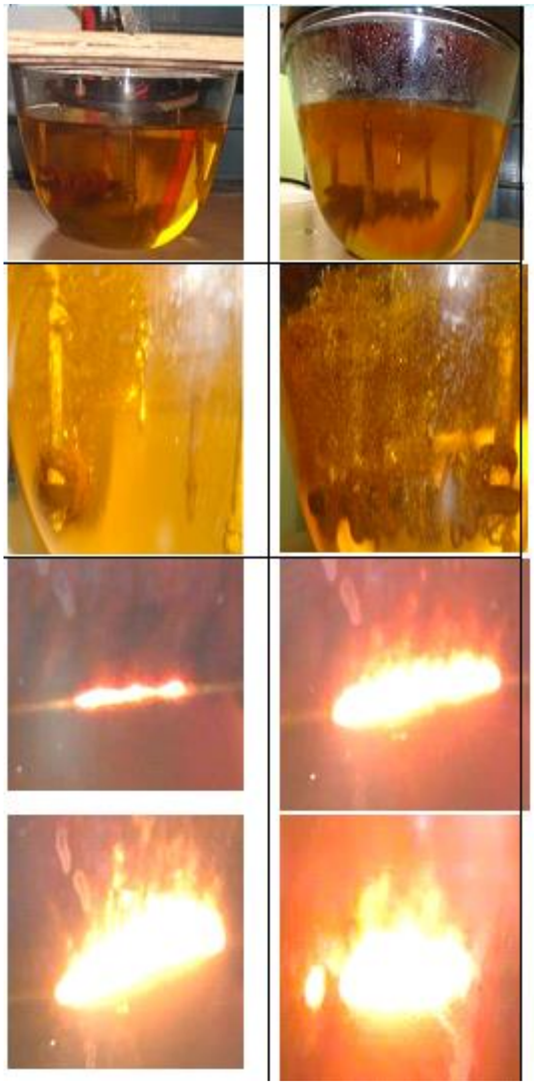
WATER (H_2O):

Boiling in additive solutions, in comparison with that of pure water, is observed to be more vigorous with clusters of smaller-sized and more regularly shaped bubbles. In both additive solution and pure water, the bubbles mostly originate from the underside of the wire heater and then slide along the heater surface before departure. These sliding bubbles tend to knock off the bubbles growing on the top surface of the heater, causing their early departure, and this tendency was observed to increase with increasing bubble departure frequency. With surfactant solutions, the lowering of surface tension promotes nucleation of smaller-sized bubbles and activation of nucleation sites in a clustered fashion, especially at lower heat fluxes. The bubbles depart at much higher frequencies, and the coalescence between two neighboring bubbles or sliding bubbles along the heater surface is minimal. The departing bubbles were seen to reach the pool free surface. At high heat fluxes, due to the vigorous bubbling motion, the liquid free surface in the pool oscillated mildly. This was also observed with the boiling of pure water. Further ,more with increasing concentration beyond a certain amount, no significant differences were observed in the boiling evolution in surfactant solutions having concentrations more than 2,600 ppm.

Boiling behavior and bubble growth of water at different temperatures:

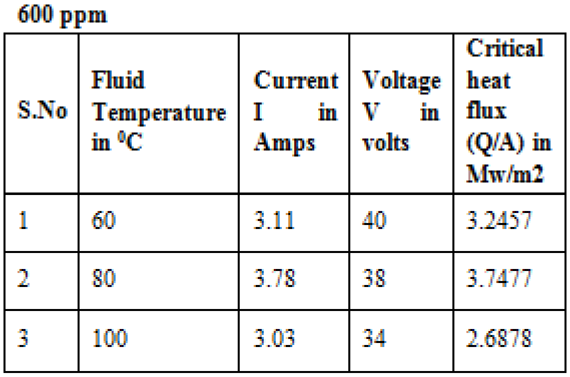
Different photographs of pure water boiling phenomena. With increasing flux nucleate, boiling starts (Figure 4.10), and the bubble gets detached as heat flux continues increasing. At about 0.1 sec of bubble speed, departure was observed for distilled water, and bubble departure continued (Figure 4.10.b). Thereafter, it is observed that (Figures 4.10 f to 4.10 h) the heater wire gets covered with a vapor blanket; heat transfer rate then reduces, and after some time, heat flux increases so that the wire becomes red hot and heat transfer occurs due to radiation.

PHOTOGRAPHS :



READINGS

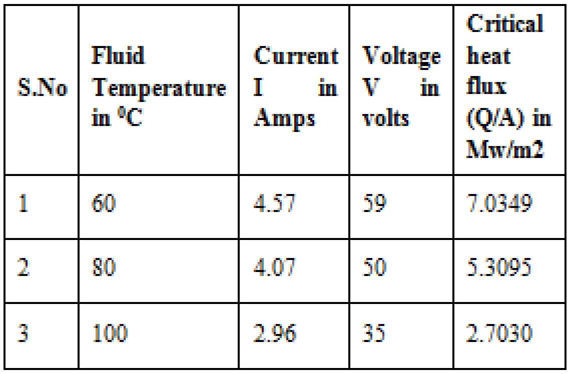
1).AMMONIUM CHLORIDE:



600 ppm

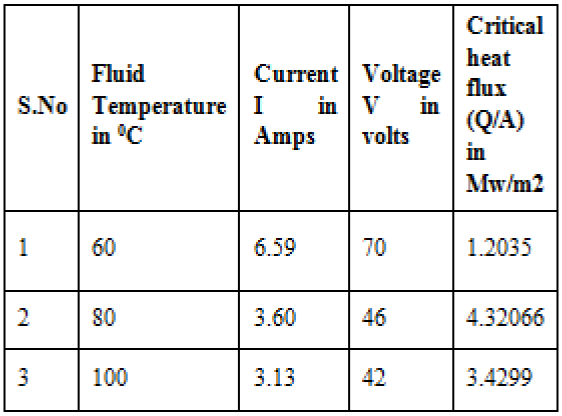
S.No	Fluid Temperature in ⁰C	Current I in Amps	Voltage V in volts	Critical heat flux (Q/A) in Mw/m2
1	60	3.11	40	3.2457
2	80	3.78	38	3.7477
3	100	3.03	34	2.6878

1000ppm



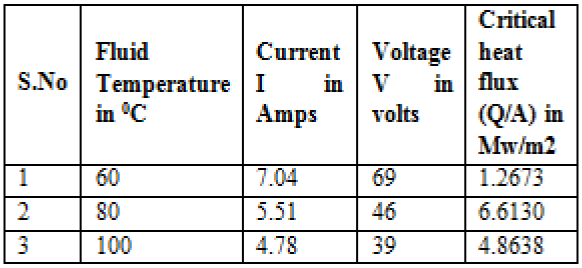
S.No	Fluid Temperature in ^{0}C	Current I in Amps	Voltage V in volts	Critical heat flux (Q/A) in Mw/m2
1	60	4.57	59	7.0349
2	80	4.07	50	5.3095
3	100	2.96	35	2.7030

1500ppm



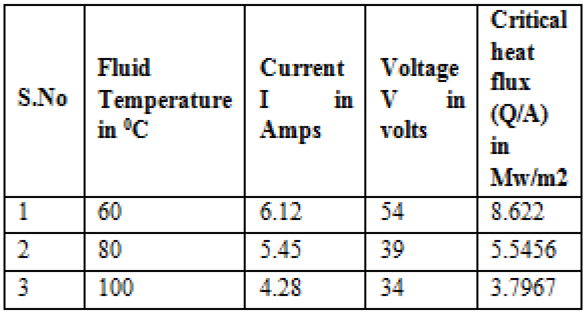
S.No	Fluid Temperature in ^{0}C	Current I in Amps	Voltage V in volts	Critical heat flux (Q/A) in Mw/m2
1	60	6.59	70	1.2035
2	80	3.60	46	4.32066
3	100	3.13	42	3.4299

2200 ppm



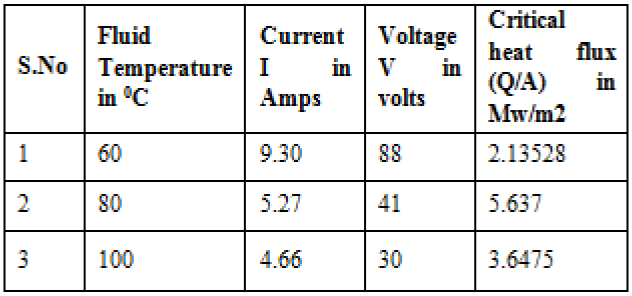
S.No	Fluid Temperature in ^{0}C	Current I in Amps	Voltage V in volts	Critical heat flux (Q/A) in Mw/m2
1	60	7.04	69	1.2673
2	80	5.51	46	6.6130
3	100	4.78	39	4.8638

2600 ppm:



S.No	Fluid Temperature in ^{0}C	Current I in Amps	Voltage V in volts	Critical heat flux (Q/A) in Mw/m2
1	60	6.12	54	8.622
2	80	5.45	39	5.5456
3	100	4.28	34	3.7967

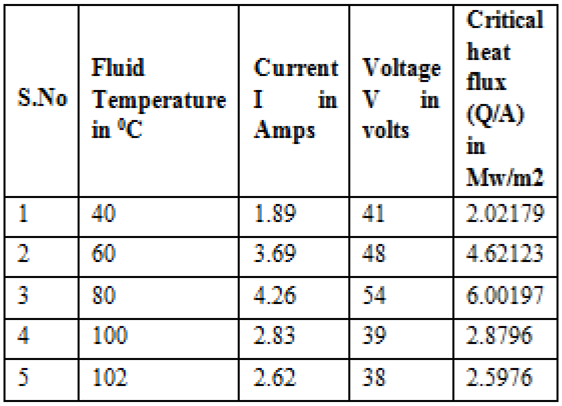
3000 ppm :



S.No	Fluid Temperature in ^{0}C	Current I in Amps	Voltage V in volts	Critical heat flux (Q/A) in Mw/m2
1	60	9.30	88	2.13528
2	80	5.27	41	5.637
3	100	4.66	30	3.6475

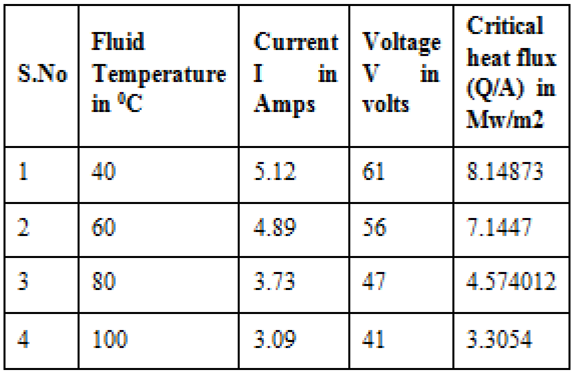
2).POTASSIUM DICHROMATE :

600 ppm



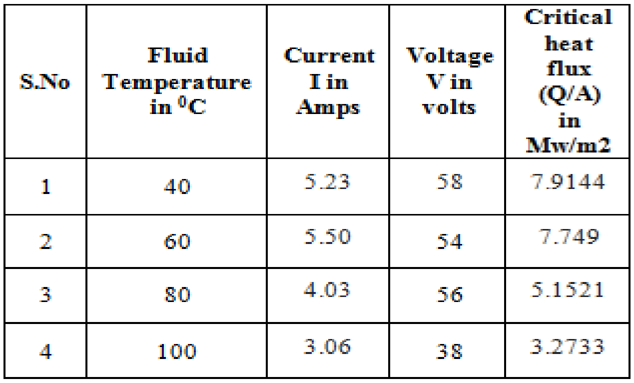
S.No	Fluid Temperature in ^{0}C	Current I in Amps	Voltage V in volts	Critical heat flux (Q/A) in Mw/m2
1	40	1.89	41	2.02179
2	60	3.69	48	4.62123
3	80	4.26	54	6.00197
4	100	2.83	39	2.8796
5	102	2.62	38	2.5976

1000 ppm



S.No	Fluid Temperature in ^{0}C	Current I in Amps	Voltage V in volts	Critical heat flux (Q/A) in Mw/m2
1	40	5.12	61	8.14873
2	60	4.89	56	7.1447
3	80	3.73	47	4.574012
4	100	3.09	41	3.3054

1500 ppm



S.No	Fluid Temperature in ^{0}C	Current I in Amps	Voltage V in volts	Critical heat flux (Q/A) in Mw/m2
1	40	5.23	58	7.9144
2	60	5.50	54	7.749
3	80	4.03	56	5.1521
4	100	3.06	38	3.2733

2200 ppm

S.No	Fluid Temperature in ^{0}C	Current I in Amps	Voltage V in volts	Critical heat flux (Q/A) in Mw/m2
1	40	3.79	40	3.95539
2	60	6.84	60	1.0707
3	80	5.37	56	7.8460
4	100	3.37	38	3.34121

2600 ppm

S.No	Fluid Temperature in ^{0}C	Current I in Amps	Voltage V in volts	Critical heat flux (Q/A) in Mw/m2
1	40	4.80	57	7.1385
2	60	4.22	59	6.496
3	80	4.17	40	4.352
4	100	3.62	38	3.589

3000 ppm

S.No	Fluid Temperature in ^{0}C	Current I in Amps	Voltage V in volts	Critical heat flux (Q/A) in Mw/m2
1	40	9.918	66	9.918
2	60	7.2032	58	7.2032
3	80	1.944	27	1.944
4	100	3.242	38	3.242

3).POTASSIUM PERMANGANATE :

600 ppm

S.No	Fluid Temperature in ^{0}C	Current I in Amps	Voltage V in volts	Critical heat flux (Q/A) in Mw/m2
1	40	5.51	62	8.913
2	60	4.41	58	6.67
3	80	4.64	62	7.505
4	100	2.93	41	3.134

1000ppm

S.No	Fluid Temperature in ^{0}C	Current I in Amps	Voltage V in volts	Critical heat flux (Q/A) in Mw/m2
1	40	5.75	69	10.35
2	60	4.57	58	6.915
3	80	2.35	38	2.32
4	100	2.35	33	2.02

1500 ppm

S.No	Fluid Temperature in ^{0}C	Current I in Amps	Voltage V in volts	Critical heat flux (Q/A) in Mw/m2
1	40	4.86	56	7.1009
2	60	5.25	68	9.314
3	80	4.23	51	7.504
4	100	2.03	29	2.29

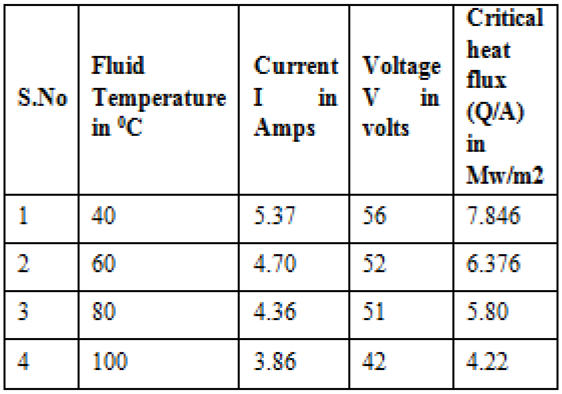
2200 ppm

S.No	Fluid Temperature in ^{0}C	Current I in Amps	Voltage V in volts	Critical heat flux (Q/A) in Mw/m2
1	40	2.66	42	2.914
2	60	5.06	63	8.317
3	80	4.30	58	6.507
4	100	3.40	48	4.2580

2600 ppm

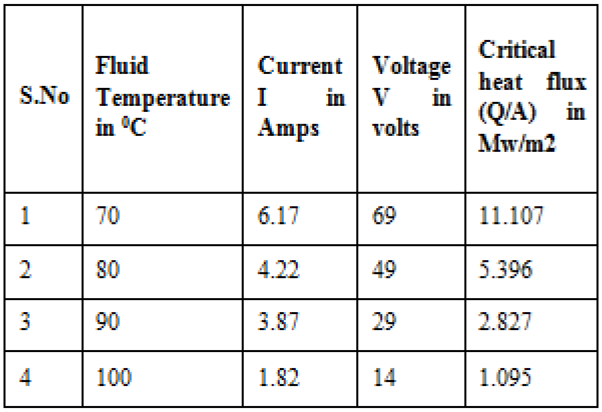
S.No	Fluid Temperature in ^{0}C	Current I in Amps	Voltage V in volts	Critical heat flux (Q/A) in Mw/m2
1	40	7.24	68	12.84
2	60	5.23	58	7.914
3	80	4.23	51	5.62
4	100	3.30	46	3.96

3000 ppm



S.No	Fluid Temperature in ^{0}C	Current I in Amps	Voltage V in volts	Critical heat flux (Q/A) in Mw/m2
1	40	5.37	56	7.846
2	60	4.70	52	6.376
3	80	4.36	51	5.80
4	100	3.86	42	4.22

WATER :



S.No	Fluid Temperature in ^{0}C	Current I in Amps	Voltage V in volts	Critical heat flux (Q/A) in Mw/m2
1	70	6.17	69	11.107
2	80	4.22	49	5.396
3	90	3.87	29	2.827
4	100	1.82	14	1.095

V. CONCLUSIONS

1. The Value of CHF is more at 40°C when graph is plotted between CHF and Concentration the enhancement of CHF is up to 3000 ppm .
2. The enhancement of CHF is recorded up to 2600 ppm for NH4Cl and k2Cr2O7 at 60°C.
3. As the temperature of fluid increases, the size of bubble also increases and it’s much larger at higher temperatures and it ruptures at very high temperatures.
4. It is observed that bubble size decreases as concentration continues to increase. At the same time, bubble density and frequency also increased as concentration increases.
5. It is concluded that the above additives can effectively be used as additives that can enhance heat transfer in nucleate pool boiling.
6. The influence of concentration at different heat fluxes on the boiling curve is shown in graphs.
7. The maximum enhancement in nucleate pool boiling is found to be dependent upon the thermo physical properties, concentration of additive solution, temperature etc.
8. Photographic visualization was carried out to quantify the nucleate pool boiling heat transfer enhancement of aqueous surfactant solutions.
9. This enhancement is characterized by a rapid departure of smaller-sized, regularly shaped bubbles from the heater surface, and an increase in the number of bubbles.
10. At lower temperature the size of bubbles is less and the surface tension is low, therefore the value of critical heat flux is also recorded higher at some points

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