A STUDY ON POOL BOILING HEAT TRANSFER

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Abstract – *This paper describes the heat transfer during boiling of liquids. Boiling heat transfer is an area of increasing interest in many engineering heat transfer and cooling applications. The two basic types of boiling are pool boiling and flow boiling. A discussion on boiling regimes and the boiling curve are to be carried out. The different regimes of boiling i.e., natural convection boiling, nucleate boiling, transitions boiling and flow boiling are to be presented in an easily understandable manner. The enhancement of heat transfer in pool boiling are to be discussed.*

Key Words: **BOILING, POOL BOILING, FLOW BOILING, SUB-COOLED BOILING, SATURATED BOILING, HEAT FLUX.**

1.INTRODUCTION

The basic difference between evaporation and boiling is that evaporation occurs at the liquid-vapour interphase when the vapor pressure is less than the saturation temperature of the liquid at a given temperature whereas boiling occurs at the solid-liquid interphase when the liquid is brought into contact with the surface when the surface temperature (T_W) is greater than saturation temperature (T_{sat}) at that pressure. $\Delta T_{Excess} = T_W - T_{sat.}$ The ΔT_{Excess} is defined as the temperature excess of the surface above the saturation temperature of the fluid. When the excess temperature is raised, the heat flux varies and four regimes where observed namely free convection boiling, nucleate boiling, transition boiling and film boiling. Pool boiling curve is a plot between heat flux q'' and excess temperature. The curve travels from the above four regimes and in shown in fig.3

2.BOILING CLASSIFICATION

The major classification of boiling hear transfer are

1. Pool boiling
2. Flow boiling

Boiling in the absence of bulk fluid flow is called as pool boiling. In pool boiling the fluid body is stationary and the motion of the fluid is due to natural convection or free convection and the bubble motion is due to buoyancy.

Boiling occurs when bulk fluid motion is called as flow boiling or forced convection boiling. The fluid is forced to move in the heated pipe, hence flow boiling is always accompanied by other convection effects.

Pool and flow boiling further classified as

1. Sub-cooled boiling
2. Saturated boiling

In sub-cooled boiling the temperature of main body of the liquid is below the saturation temperature at that pressure whereas the heating surface temperature is above the saturation temperature of the liquid. In saturated boiling the temperature of the main body of the liquid is equal to or above the saturation temperature of the fluid.

2.1 SUBCOOLED BOILING

Subcooled boiling occurs when the bulk fluid temperature over the heated surface is less than the saturated temperature of the fluid and the surface temperature is maintained at the excess temperature which is the difference between the heated surface temperature and the saturation temperature of the fluid. During subcooled boiling the bubbles formed near the heated surface. The liquid particles nearer to the hot surface vaporized as its temperatures reaches above the saturation temperature the bubble moves up and there occurs heat transfer between the bubble and the liquid surrounds it. This bubble disappears soon due to the heat transfer between bubble and the liquid. Now the bubble just acts as energy movers from the hot surface and transferring it to the surrounding liquid as they condense and collapse. This boiling is also called as local boiling.

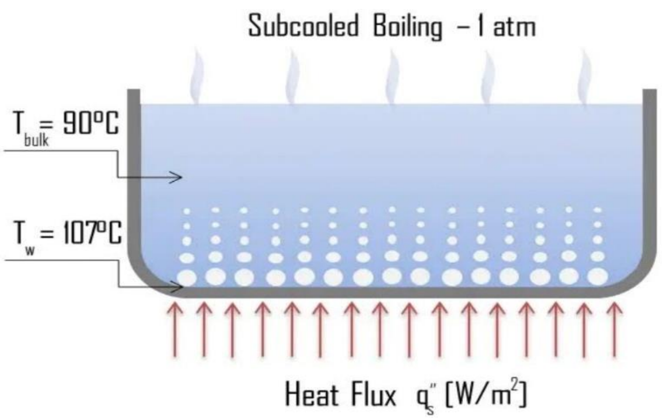

Fig.1 **subcooled boiling**

2.2 SATURATED BOILING

Saturated boiling is also called as bulk boiling. The temperature of the liquid over the heating surface exceeds the saturation temperature of the liquid. Bulk boiling occurs when the system temperature increases or the pressure drops to the boiling point the bubbles are visible, raising to the top and will not collapse when entering the coolant or liquid channel. The bubbles tend to join together and form bigger bubbles and then propelled through the liquid by buoyancy forces and escaping from the free surface

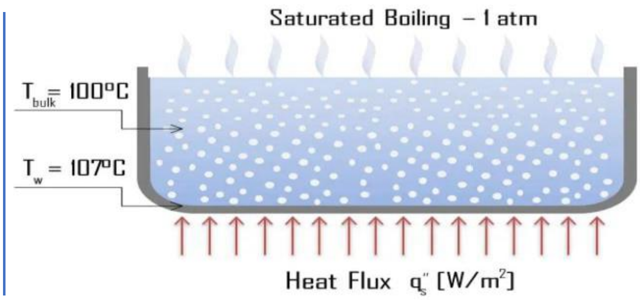

Fig.2 Saturated boiling

3. POOL BOILING CURVE AND BOILING REGIMES

Pool boiling curve is a plot between heat flux (q'') and excess temperature (ΔT_{Excess}). In 1934, work on boiling was done by S.Nukiyama. He noticed that boiling takes various forms, depending on the value of excess temperature. He observed four different boiling regimes namely natural convection boiling, nucleate boiling, transition boiling and film boiling. These four regimes are mentioned on the boiling curve shown in fig.2. The general shape of boiling curve remains the same for different liquids. The shape of the curve depends on fluid-heating surface material combination and the fluid pressure and independent of the geometry of the heating surface. The four boiling regimes are described in detail below.

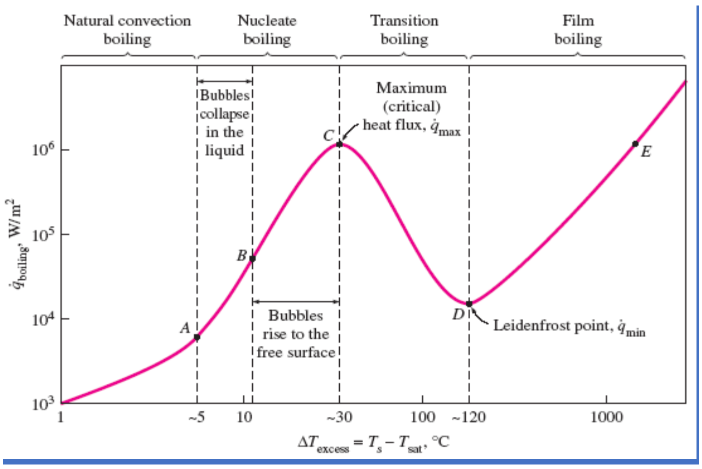

Fig.3 Poll boiling curve for water at 1atm

3.1 NATURAL CONVECTION BOILING

This process is shown in the boiling curve up to point A. Pure substances at a specified pressure starts boiling when it reaches the saturation temperature at that pressure. No bubbles formed on the heating surface until the liquid is heated few degrees above the saturation temperature (about 2^{0}C to 6^{0}C for water), so the liquid is slightly super-heated in this case a metastable condition and evaporates and it raises to the free surface. In this mode of boiling the fluid motion is by natural convection currents and heat transfer from the heating surface to the fluid is by free or natural convection.

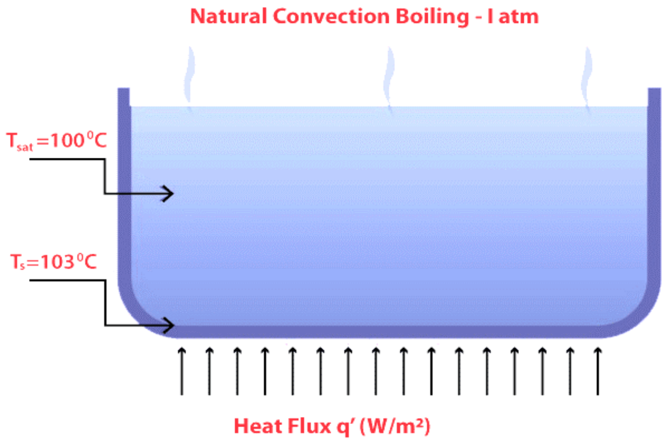

Fig.4 Natural convection boiling

3.2 NUCLEATE BOILING

This process is shown in the boiling curve from point A to point C. The first bubble forms at point A of the boiling curve at several special sites on the heating surface. More number of bubbles form at a faster rate in the nucleation sites as it moves along the boiling curve towards point C. The nucleate boiling regime can be split into two d3602different regime, regime A to B and regime B to C. In the regime A to B, isolated bubbles are formed at several nucleation sites on the heated surface. The bubbles collapses in the liquid between A and B shortly after they separate from the surface. The stirring and agitation caused by the movement of the liquid to the heated surface is responsible for the increased heat transfer coefficient and heat flux in this region. In region B to C the heater surface temperature is increased further, more and more number of bubbles formed in a large number of nucleation sites and there formed large number of continuous column of vapour in the liquid. These bubbles move up to the free surface and gets breakup and release their vapour content. More heat fluxes obtain in this region due to the combined effect of liquid entrainment of the liquid and evaporation. Higher value of ΔT_{Excess} , the evaporation rate reaches higher values and large heater surface area is covered by bubbles which prevents the liquid to reach the heater surface and wet it. The heat flux

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increases with increasing ΔT_{Excess}, and reaches a maximum at point C. The heat flux at this point is called as critical heat flux or maximum heat flux.

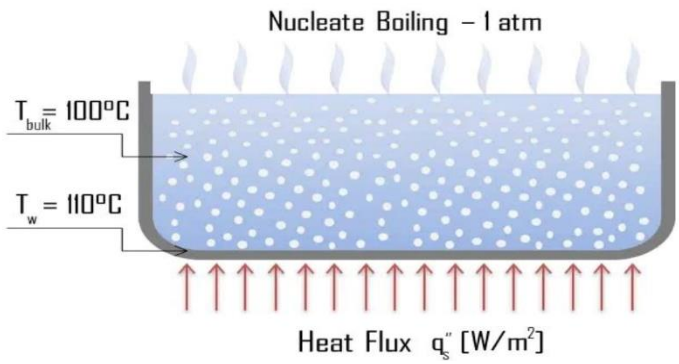

Fig.5 Nucleate boiling

3.3 TRANSITION BOILING

This process is shown in the boiling curve between point C and point D. The ΔT_{Excess} is increased further from point C the heat flux begins to decrease. This is due to large area of heated surface is covered by a vapour film. This vapour film due to its low thermal conductivity of the vapour acts as a thermal insulator. In this regime both nucleate and film boiling partially occurs. At point D the nucleate boiling is completely replaced by film boiling operation and the transition boiling regime is to be avoided in practice.

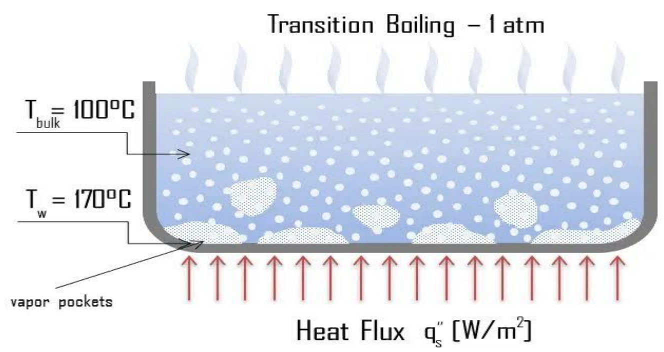

Fig.6 Transition boiling

3.4 FILM BOILING

This process is shown in the boiling curve beyond point D. In this regime the heater surface is fully covered by a stable vapour film. The point D, where the heat flux reaches the minimum is called as Leiden frost point. The heat transfer rate increases with increasing excess temperature due to the heat transfer from the heated surface to the liquid through the vapour film by radiation.

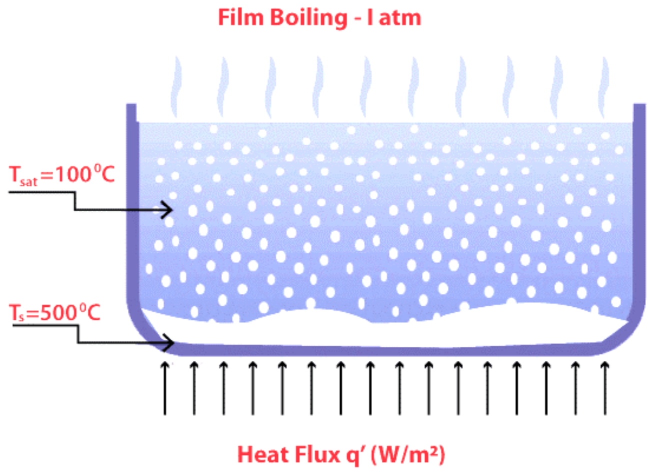

Fig.7 Film boiling

4.HEAT TRANSFER ENHANCEMENT IN POOL BOILING

It was observed that the rate of heat transfer and heat flux in nucleate boiling regime depends on active nucleation site on the hot surface and the rate of bubble formation in each site. Therefore, any modification to increase the number of nucleation sites on the heating surface enhance the heat transfer and heat flux in nucleate boiling regime.

The irregularities on the heating surface including roughness, dirt will create additional nucleation sites and enhance the heat transfer and heat flux during nucleate boiling.

The heat flux in the nucleate boiling regime increases by a factor of 10 by roughening the heating surface.

Special surfaces can be obtained by coating with a thin layer (less than 1 mm) of porous material enhance the heat flux.

Creating cavities on the heating surface mechanically facilitate continuous vapour formation and enhance the heat transfer by a factor of 10 and heat flux by a factor of 3.

Boiling heat transfer can be enhanced by mechanical agitation and surface vibration but, due to its complexity this technique is not in use.

Using gridded metal surface (GMS) having protrusions with coated surface the heat transfer is further enhanced.

Addition of nano particles in the fluid increases the thermal characteristics of the fluid and inturn enhances heat transfer

5. APPLICATION OF POOL BOILING

Pool boiling characteristics has immense heat transfer applications because of the ability to remove large quantities of heat from the heating surface with maintaining lower temperature difference. This gives a reduced size of heat exchanger by enhancing the performance of equipment used in many industries such as process industries, power plant, refrigeration and air-conditioning etc.,

6. CONCLUSION

On studying the pool boiling heat transfer, this article is concluded with

- The pool boiling offers high performance cooling opportunities for thermal problems.
- While observing all four regimes of boiling it was found that the nucleate boiling regime provides the maximum heat flux. Therefore, it is better to operate the boiling equipment in this regime to obtain more heat transfer and heat flux.
- Operating the boiling equipment in transition boiling regime and film boiling regime should be avoided to prevent the heating surface from being burn out.
- Research areas where identified that methods of increasing the number of nucleation sites in heater surface will enhance heat flux

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BIOGRAPHIES

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