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EFFECT OF HEAT FLUX AND PRESSURE ON HEAT TRANSFER COEFFCIENT DURING THE BOILING OF DISTILLED WATER AND BENZENE

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ABSTRACT: *This investigation presents experimental work on the studies of nucleate pool boiling of distilled water and benzene at atmospheric and sub atmospheric pressure. The experimental investigation is carried out on heat transfer studies from a submerged horizontal stainless steel cylinder under the condition of constant heat flux to the pool of distilled water and benzene. The heating surface consisted of a horizontal SS cylinder of 70 mm diameter, 4 mm thickness and the length of 244 mm was taken. The surface temperature of the cylinder was measured at three different positions by means of copper constantan thermocouple. They were placed in three axial holes in the thickness of the heating cylinder. These were at its top-, side- and bottom- positions. The liquid temperatures were also measured at the corresponding positions in the bulk of the liquid. The experimental data were conducted to account for the effect of heat flux and pressure on heat transfer coefficient. The pressure was varied from 35.36 to 100.07 kN/m^2 and the heat flux was varied from 13027.99 to 33740.46 watt/m^2. The heating surface exhibited distinct thermal response to the changes in heat flux.*

For all the data conducted with distilled water and benzene, the heating surface showed a distribution of boiling heat transfer coefficient around its circumference. The coefficient decreases from top- to side- to bottom- positions distinctly. The average value of heat transfer coefficient for the boiling of benzene has functional relationship with heat flux. The data analysis shows that the seven-tenth power law relating heat transfer coefficient is valid for the boiling of distilled water and benzene at atmospheric and sub atmospheric pressures. The effect of pressure for the sub atmospheric pressure range, it is found that the heat transfer coefficient increases with pressure raised to the power 0.32. Actually, the heating surface characteristics and the physico-thermal properties of boiling fluids have marked influence on heat transfer coefficient for sub atmospheric as well as for the data at atmospheric pressure also.

1. INTRODUCTION

Free convection and nucleate pool boiling from horizontal surface are of wide occurrence in process industries, refrigeration industries and in many other industries. Because of their industrial applications, a considerable research has been done by the scientists to investigate the various aspects which may give an insight into the fundamental principles involved. All such studies have been carried out extensively both theoretically as well as experimentally by employing heating surfaces of different materials, shapes and sizes. There are so many parameters which affects the heat transfer coefficient during the pool boiling of liquids. In the present investigation we have conducted the experiments on the boiling of distilled water and the benzene. The effect of the various parameters like heat flux, pressure, surface characteristics etc. has also been studied. The present investigations have been carried out with the following objectives.

I. To obtain the experimental data representing the circumferential temperature distribution of a horizontal cylindrical surface and of the liquid surround it.
II. To conduct the experiments on the boiling fluids like distilled water and benzene at their saturation temperature over a range of low heat flux and atmospheric and sub atmospheric pressures.
III. To account for the parametric effects of operating variable like heat flux, system pressure and heating surface characteristics on boiling heat transfer coefficient and to recommend a generalised correlation.

2. EXPERIMENTAL SET UP

Figure 2.1 shows the schematic diagram of the experimental set up used in the present investigation. A description of the same is given hereunder:

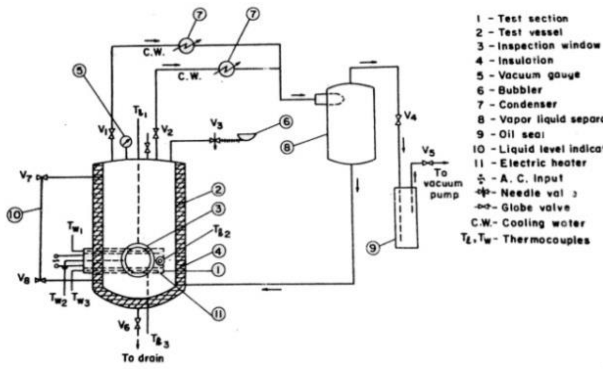

Figure 2.1 Schematic diagram of experimental set-up

The main components of the set up are: a test vessel, a test heating surface, a condenser, a separator, a vacuum pump with a surge tank, and a bubbler. The descriptions of these components are discussed below:

2.1 TEST VESSEL:

The test vessel was built up of “304 AISI” stainless steel. It was cylindrical in shape with a flat top and dished bottom. Its diameter was 240 mm and height 470 mm. The vessel was properly insulated with Rockwool followed by 85% magnesia-asbestos powder and plaster of paris. The liquid level indicator (10) indicates the level of test liquid in the vessel. One end of the test surface (2) was attached to the test vessel, whereas the other was kept floating. The view Ports (3) fitted diametrically opposite to the test vessel helped in visual observation of the bubble dynamics on the heating surface. The vessel contains an opening at its top for removing air from the vessel. A vacuum gauge (5) was used to measure system pressure.

A valve (IV) in the drain pipe was provided to drain out the liquid from the vessel. The thermocouples used for measuring the liquid and the wall temperatures are shownT_{l_1}, T_{l_2}, T_{l_3} and T_{w_1}, T_{w_2}, T_{w_3} respectively. The valve (II) in the vapour line was used to control the supply of vapours the condenser (7) of Figure 2.1.

2.2 TEST SURFACE:

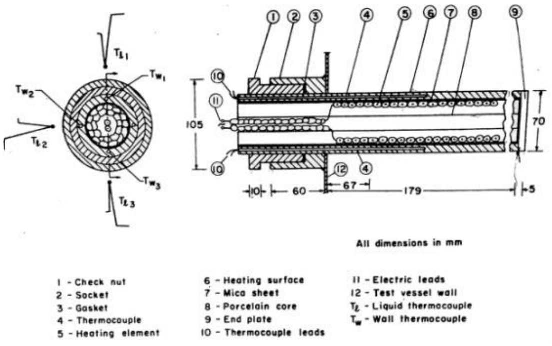

Figure 2.2 Details of Test Surface

Figure 2.2 shows the test surface. It was made of stainless steel having 70 mm diameter, 244 mm length and 5 mm thickness. Out of the total length of 244 mm, the effective length was 179 mm which provided the heat transfer area 3.93×10^{-2} m^2. The test surface was turned, polished and rubbed against 10% grade emery paper to make it smooth and to remove the scaling, if any. An electric heater made of 24 gauge nichrome was used for heating surface. A mica sheet (7) and glass tape provided electrical insulation between heater and testing surface. Three thermocouples T_{w_1}, T_{w_2},T_{w_3} measured the temperature distribution along the circumference of the test surface. A check nut (1) and a gasket (3) were used to prevent any possible leakage from and into the vessel.

2.3 CONDENSER:

It was a shell and tube type condenser having adequate surface area to condense the vapours by means of cooling water flowing in the shell side. The vapours were kept in the tube side. The condenser was pitched to the separator so that the condensate did not stay in it and enter the separator.

2.4 SEPERATOR:

A separator having tangentially entry was used to separate air from the condensate coming from the condenser. The condensate returned to the test vessel through non return valve (III); whereas the air was discharged to the atmosphere by the vacuum pump. The provision of the valve did not permit the test fluid to flow from test vessel to the separator.

2.5 VACUUM PUMP:

A vacuum pump with surge tank maintained the desired vacuum in the system. The vacuum pump was a “HV” series rotary, two stage and oil immersed type manufactured and supplied by Hindustan Pumps and Machinery Corporation, Kolkata. The separator discussed above was provided between the surge tank and the condenser. A needle valve (VI) helped to control the system pressure.

2.6 BUBBLER:

The air bubbler (6) consisted with a beaker filled with distilled water. Air mixed with vapour from the test vessel was carried to the beaker through a flexible pipe dipped in water.

2.7 INSTRUMENTATION:

Copper constantan thermocouple (24 gauges), calibrated over a wide range of temperatures, and measured in the liquid and wall temperatures. The e.m.f. of the thermocouples was measured by the potentiometer with a sensitive galvanometer. The potentiometer had a least count of 0.001 mV. A multipoint selector switch supplied by M/S Toshniwal was used to connect the thermocouples to the potentiometers. A distilled water-ice bath served as cold junction (0°C).

The single phase, 50 c/s AC supply was stablished by an automatic stabiliser supplied by M/S Paradise Industries, New Delhi. Power input to the electric heater was measured with the help of calibrated ammeter and voltmeter. The power supply to the heater was regulated by an auto-transformer. A calibrated precision grade vacuum gauge was used to measure the system pressure and was mounted on the top of the vessel.

3. EXPERIMENTAL METHODOLGY

The experimental set up was assembled as shown in Figure 2.1. The set up was tested at a pressure for 24 hours. Similarly the set up tested at a vacuum of about 5 kN/m^2. No drop in pressure/vacuum ensured that there was no leakage from/into the system. All the thermocouples were calibrated with a standard thermometer. The maximum deviation was found to be ±0.1 percent.

Before conducting the experiments, the test vessel was rinsed with the liquid to be charged. The experimental work was started with distilled water. The drain valve (IV) was closed and distilled water was fulfilled in the test vessel up to a height above the test surface. This was done by submerging the heating surface in the pool of the liquid for a period of 72 hours followed by boiling for about 24 hours. During the process of stabilization the wall thermocouples readings for a given heat flux and pressure were noted at different intervals of time. No change in their readings ensured that the surface was stablished.

Removal of air from the test vessel is essential; otherwise the data may be erroneous. This was done by closing the valve (II) and opening the air bubbler valve (I). The heater was now switched on and the liquid was boiled for some time. The vapour going to bubbler caused bubbling indicating that the air was going to the bubbler. After sometime the bubbling stopped ensuring that there was no air left in the system. The air bubbler valve was now closed and the condenser valve opened. The data were taken from atmospheric pressure to lower pressures and from low heat flux to higher heat flux by employing predetermined conditions of the experimental work. The readings of the ammeter, voltmeter and the liquid and wall thermocouples were recorded after ensuring a steady state. The heat flux was then changed progressively with the help of autotransformer. After recording the data at one pressure, the system pressure was changed and similar observations were taken.

Similar procedure was followed to obtain experimental data for the boiling of the benzene.

Before charging a new liquid in the data corresponding to atmosphere with the distilled water were repeated. No change in these data ensured that there was no change in the heating surface characteristics. Thus, the data points were reproducible within the tolerance limit of the experiment error.

The values of operating parameters used in this investigation are given in Table 3.1.

S. No.	Boiling Fluid	Heat Flux, W/m^2	Pressure, kN/m^2
1	Distilled Water	13028, 16488, 20356, 24631, 290007 and 33740	100.07, 82.06, 62.71, 48.70 and 35.36
2	Benzene	4834, 7176, 9796, 13028, 16488, 20356, 24631 and 29007	98.07, 81.39, 61.78, 50.03 and 36.29

Table 3.1: Parameters for Saturated Nucleate Pool Boiling

4. RESULTS AND DISCUSSION

4.1 LIMITATIONS OF EXPERIMENTAL DATA:

The practical limitations of the present experimental data are given below:

I. Due to fabrication difficulties, it was not possible to install the thermocouples in the wall thickness of the cylinder at many positions except at the top, the side and the bottom positions of the heating tube, which has been considered adequate for getting average wall temperature as required by Simpson's rule for averaging. These positions are shown in Figure 2.2 of Section 2. As a matter of fact the measurement of wall temperature at more positions would have given better picture of its variation around the heating tube. The average wall temperature then calculated would have been more accurate.

II. As a matter of fact these thermocouples measure the temperature at the centre of the wall thickness. Therefore the outer surface temperature of the heating tube was calculated by subtracting the temperature drop in the wall thickness from the thermocouple readings, as shown in Sample Calculations of Appendix-B.

III. The heat transfer coefficient was calculated as the quotient of heat flux to the temperature difference between outer surface temperature and corresponding liquid temperature. This, as a matter of fact, is based in the assumption that the heat flown radially through the wall thickness and not axially. This seems to be a valid assumption as the length of the heating tube is much larger than its wall thickness.

The local values of heat transfer coefficient for the top, the side and the bottom positions were calculated by using the following respective expressions:

$$h_1 = \frac{q}{t_{W_1} - t_{l_1}}$$

$$h_2 = \frac{q}{t_{W_2} - t_{l_2}}$$

$$h_3 = \frac{q}{t_{W_3} - t_{l_3}}$$

It may be noted that in the calculation of heat transfer coefficient, the liquid temperatures as monitored by the liquid thermocouples have been used and not the saturation temperature corresponding to pressure of boiling liquid. However, the differences between the saturation temperature and the reading of liquid thermocouples were small. The value of heat transfer coefficient based on liquid temperature is accepted as these values are smaller than based on saturation temperature. This, as a matter of fact, ensures safer design of the equipment used for boiling of liquids.

IV. The average heat transfer coefficient, $\bar{h}$ was calculated from the values of heat flux, q and the average value of wall superheat, $\overline{\Delta t_w}$ by using the following expression:

$$\bar{h} = \frac{\mathrm{q}}{\overline{\Delta \mathrm{t_w}}}$$

V. The value of average wall superheat was calculated as follows:

$$\overline{\Delta t_w} = \frac{\Delta t_{w_1} + \Delta t_{w_2} + \Delta t_{w_3}}{3}$$

Where,

$$\Delta t_{w_1} = t_{w_1} - t_{l_1}$$

$$\Delta t_{w_2} = t_{w_2} - t_{l_2}$$

$$\Delta t_{w_3} = t_{w_3} - t_{l_3}$$

4.2 NUCLEATE POOL BOILING OF DISTILLED WATER AND BENZENE:

The main objective of this investigation was to conduct experimental data for the boiling of distilled water and benzene under atmospheric and sub atmospheric pressures. Therefore experimental data were conducted for the boiling of distilled water and benzene on a given heating surface. It is clearly seen that these data are functions of heat flux. In the following sections the effect of heat flux on heat transfer coefficient for the boiling of distilled water and benzene from a horizontal heating tube are discussed.

4.3 EFFECT OF HEAT FLUX ON BOILING HEAT TRANSFER COEFFCIENT:

In the Figures 4.1 and 4.2 between heat transfer coefficient and heat flux for the experimental data for present investigation have been drawn for water and benzene respectively with pressure as parameter. These Figures reveal the following characteristics features:

I. The heat transfer coefficient for all the boiling fluids increases linearly with the heat flux with a slope of 0.7. This behaviour is attributed to the fact that the number of nucleation sires increases as the heat flux is raised.

This behaviour is represented mathematically by the following expression:

$$h_1 = C_1 . q^{0.7} \qquad \text{... (4.1)}$$

Where C_1 represented the constant of proportionality.

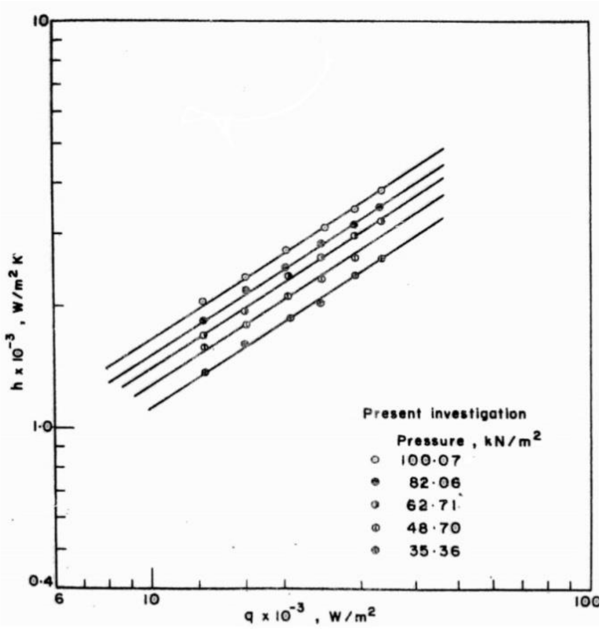

Figure 4.1 Plot of h vs q for pool boiling of distilled water on stainless steel cylinder at atmospheric and sub-atmospheric pressures

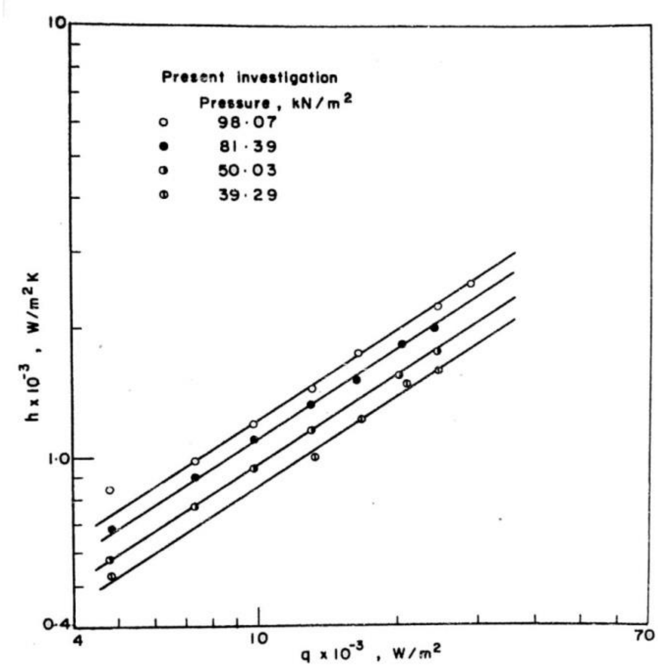

Figure 4.2 Plot of h vs q for pool boiling of benzene on stainless steel cylinder at atmospheric and subatmospheric pressures

II. Increase in the system pressure shifts the curves without changing their characteristics behaviour (i.e. $h_1 = C_1 . q^{0.7}$) to the left indicating that for a given heat flux the heat transfer coefficient increases when pressure is raised. This would happen only when the value of constant C_1 increases with pressure.

As a matter of fact the higher values of pressure decrease the value of surface tension and thereby nucleation sites having smaller radii of curvature also became active. As a consequence of this the number of active sites and thereby induced turbulence increases. Thus for a given heat flux higher values of heat transfer coefficient are attained when pressure is raised.

From the above it is concluded that the constant C_1 in equation (4.1) depends upon the pressure for a given boiling fluid.

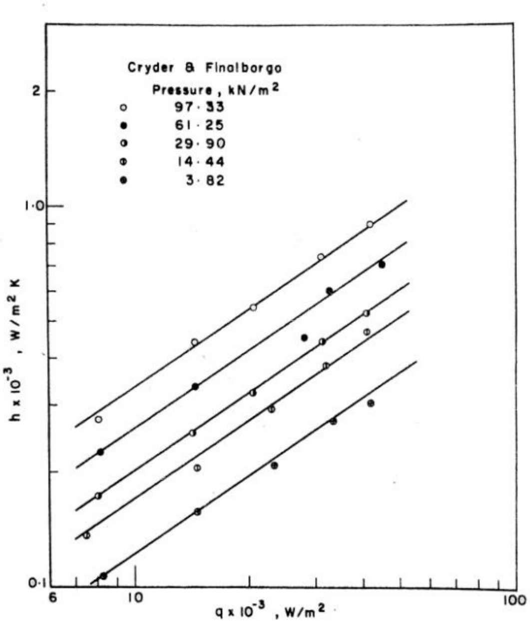

Figure 4.3 Plot of h vs q for pool boiling of distilled water on brass pipe at atmospheric and subatmospheric pressures

The available experimental data of Cryder and Finalborgo at sub atmospheric and atmospheric pressure have been analysed by preparing typical plots of heat transfer coefficient against heat flux as shown in Figure 4.3. It has been found that the plots of Cryder and Finalborgo have essentially the same features as found in present investigation.

From the results, it may be concluded that the value of constant C_1 depends on the following:

1. It changes with the boiling fluid for a given heat surface and pressure.
2. It is also influenced by the variation in heating surface characteristics.
3. It varies with the pressure for a given fluid and heating surface.

4.4 EFFECT OF BOILING FLUIDS ON HEAT TRANSFER COEFFCIENT

To demonstrate the effect of boiling fluids on heat transfer coefficient, the data of earlier investigators and present investigation were re-examined. The data were selected at a given pressure and heating surface but for different fluids. It has been shown in the following Figures.

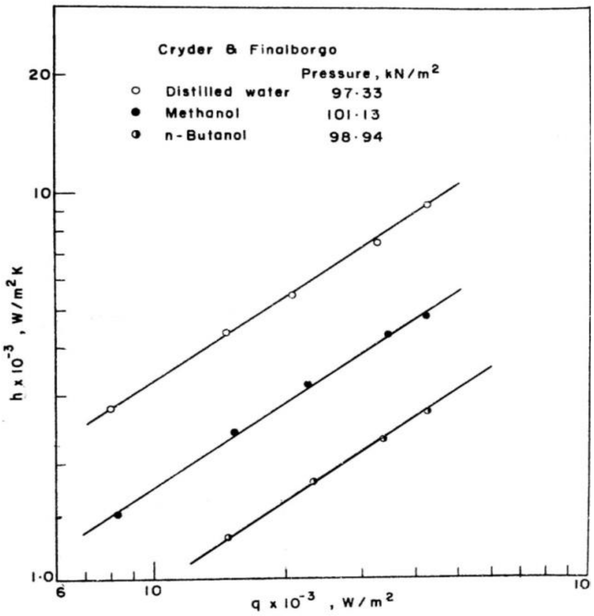

Figure 4.4 Plot of h vs q for different fluids on a brass cylinder at atmospheric pressure

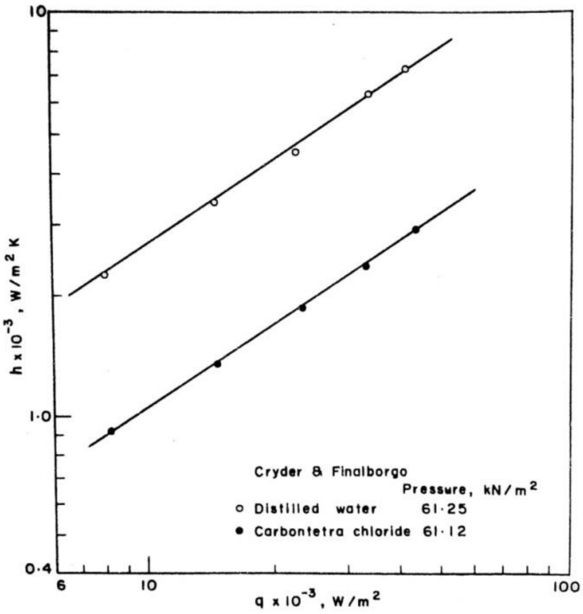

Figure 4.5 Plot of h vs q for different fluids on a horizontal brass cylinder at subatmospheric pressure

From the Figures 4.4 and 4.5, it is seen that for a given heating surface and pressure the data points form a family of parallel straight lines, each line representing a particular fluid. This typical behaviour is due to the differing physico-thermal properties of the boiling fluid.

4.5 EFFECT OF PRESSURE ON BOILING HEAT TRANSFER COEFFCIENT

The effect of pressure on boiling heat transfer coefficient is shown in the Figures below. These Figures represent the plot of heat transfer coefficient Vs pressure.

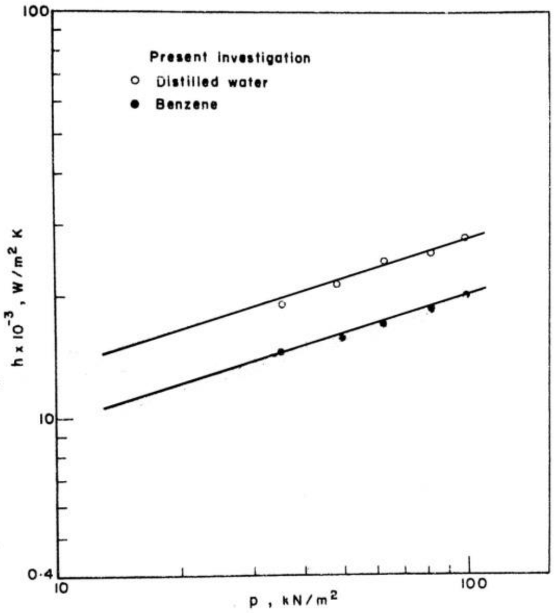

Figure 4.6 Plot of h vs p for distilled water and benzene at a given heat flux (20356 W/m²)

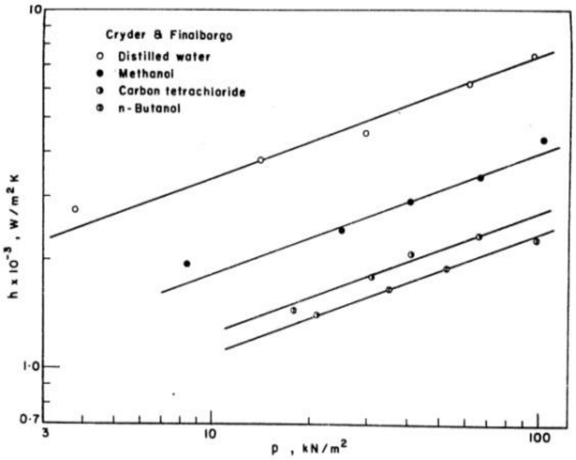

Figure 4.7 Plot of h vs p for different fluids at a given heat flux (33530 W/m²)

Figure 4.6 shows the experimental data of present investigation for distilled water and benzene on SS cylinder for atmospheric and sub atmospheric pressures.

From the figures, it is clearly seen that the slope of all the straight lines is 0.32 indicating that the following relationship holds between h and P in the same trend has been obtained by other investigators also. i.e. $h \alpha p^{0.32}$.

5. CONCLUSION

Based on the results of this investigation and their interpretations, the following conclusions are drawn.

1. The data pertaining to heat transfer from the horizontal SS cylinder to the boiling of water and benzene under atmospheric and sub atmospheric pressures shows that the heat transfer coefficient decreases from-top – to side –to bottom positions of the surface.

2. The boiling heat transfer coefficient for distilled water and benzene changes with heat flux rose to the power 0.7.

3. The boiling heat transfer coefficient for the distilled water and benzene changes with pressure rose to the power 0.32.

4. The boiling heat transfer coefficient changes with the change of boiling liquid, i.e. if the boiling liquid is changed, the thermo-physical properties of the boiling liquid will change. Hence, the change in heat transfer coefficient is observed at a given heat flux and heating surface.

6. REFERENCES

1. Cryder, D. S. and Finalborgo, A. C., 'Heat transmission from metal surfaces to boiling liquids: Effect of temperature of the liquid on film coefficient', Trans. AIChE, Vol. 33, pp. 346-362 (1937).

2. Raben, I. A., Beaubouef, R. T. and Commerford, G. E., 'A study of heat transfer in nucleate pool boiling of water at low pressure', Chem.Eng.Prog.Symp.Ser., Vol. 61, No. 57, pp. 249-257 (1965).

3. Gupta, S. C., 'Heat transfer from horizontal cylindrical surface to liquid pools', Ph.D. Thesis, Department of Chemical Engineering, University of Roorkee, Roorkee (1978).

4. Sharma, P. R., 'Heat transfer studies in pool boiling of liquids', Ph.D. Thesis, Department of Chemical Engineering, University of Roorkee, Roorkee (1977).

5. Nishikawa, K and Urakawa, K., 'An experiment of nucleate boiling under reduced pressure', Memories of the Faculty of Engineering, Kyushu University, Vol. 19, No. 3, pp. 63-71 (1960).

6. Rohsenow, W. M., 'A method of correlating heat transfer data for surface boiling of liquids,, Trans.ASME, Vol. 74, pp. 969-976 (1952).

7. Gaertner, R. F. and Westwater, J. W., 'Population of active sites in nucleate boiling heat transfer' Chem.ENG.Prog.SYmp.Ser., Vol. 56, No. 30, pp. 39-48 (1960).

8. Cichelli, M. T. and Bonilla, C. F., 'Heat transfer to liquids boiling under pressure', Trans. A.I.Ch.E., Vol. 41, pp. 755-787 (1945).