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An experimental study of saturated pool boiling from downward facing and inclined surfaces

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Abstract—Pool boiling curves for inclinations of 0° (downward facing), 5°, 10°, 15°, 30°, 45°, and 90° are obtained by quenching a 12.8-mm thick copper disk having a diameter of 50.8 mm in a pool of saturated water. Results show that nucleate boiling heat flux decreases as the angle of inclination is increased. However, the decrease in nucleate boiling heat flux with inclination is more pronounced at lower wall superheats. Conversely, the transition boiling heat flux and both q_{CHF} and q_{min}, as well as the corresponding wall superheat, increase with surface inclination. The quenching time of a downward facing surface having an initial wall superheat of 160 K is about six times that for a 5° inclination and 23 times that for a 90° inclination. For all inclinations, quenching always begins at the lowermost position and propagates upward. The average quenching velocity of about 2.6 cm s^{-1}, is almost constant for $\theta \geq 45°$, but increases rapidly with the decrease in surface inclination reaching approximately 6.3 cm s^{-1} at 0°.

INTRODUCTION

Pool boiling from the underside of flat, downward facing and inclined surfaces is of interest in many engineering fields. An example in the chemical industry is the handling of hazardous fluids, such as propane, butadiene, ammonia, ethylene, and vinyl chloride, during a fire involving railroad tankers or storage tanks [1]. Another example is in the safety of Pressurized Water Reactors (PWRs), following a hypothetical complete loss-of-coolant accident, coupled with a failure of the emergency core cooling system. The process involves a large quantity of molten core mixture (corium) which relocates to the bottom head of the pressure vessel. In such an accident, a safety concern is that the molten core corium could melt through the vessel head, and is discharged under high pressure steam on top, into the reactor cavity, below the vessel. One strategy currently being investigated to prevent thermal failure of the vessel bottom head is to flood the reactor cavity with water, which would serve as a heat sink. In this case, heat is conducted through the vessel's stainless-steel wall and dissipated into the water. At low heat flux, heat is removed by natural convection, and as the heat flux increases, pool boiling occurs at the outer surface of the vessel wall. However, the boiling heat transfer coefficient will depend on the angle of inclination and the curvature of the wall. Therefore, it is important to determine the transient boiling heat transfer coefficient and critical heat flux values for water as a function of angular position on the outer surface of the reactor vessel bottom head wall.

Several pool boiling data for R-11, liquid nitrogen, liquid helium, and water have been reported in the nucleate and film boiling regimes for inclined and downward facing surfaces [1–10]; however, only few critical heat flux, q_{CHF}, and minimum film boiling heat flux, q_{min}, values and no transient boiling heat transfer data are available. It is worth noting that all the pool boiling data reported [1–10] are for steady-state heating; hence, they might not be applicable to transient boiling conditions.

For saturated water at atmospheric pressure, Marcus and Dropkin [8] have investigated the effect of inclination from 0° (downward facing) to 90° (vertical) on the nucleate boiling heat transfer coefficient. More recently, the effect of surface orientation on nucleate boiling heat transfer has been extensively studied by Nishikawa *et al.* [9]. Their data for pool boiling of water from a flat copper plate orientated from 0° (upward facing) to 175° (inclined facing downward) showed that the nucleate boiling heat transfer coefficient at lower wall superheat increased with increasing inclination angle, which is in agreement with the results of Marcus and Dropkin [8]. Nishikawa *et al.* [9] reported that there was no marked effect of surface orientation on the nucleate boiling heat transfer coefficient at high heat flux; no data for the downward facing position were reported.

The only q_{CHF} and q_{min} data available for water are those reported by Ishigai *et al.* [10], who investigated pool boiling from the underside of a downward facing flat surface in a saturated water pool at atmospheric pressure. They reported one data point each for q_{CHF} and q_{min} for disk diameters of 25 and 50 mm, respectively.

Because these experiments [8–10] have used the gradual, steady-state heating method to determine the boiling heat transfer coefficient in the nucleate boiling and film boiling regimes for saturated water, no transition boiling data were obtained. In addition to the

NOMENCLATURE

C	specific heat [J kg^{-1}]
d	diameter of the copper disk [m]
E_s	energy stored in disk [J K^{-1}]
H	thickness of the copper disk [m]
q	average wall heat flux [W m^{-2}]
q_{CHF}	critical heat flux [W m^{-2}]
q_{min}	heat flux at minimum film boiling [W m^{-2}]
T	temperature [K]
T_W	wall temperature [K]
T_{sat}	saturation temperature of liquid [K]
t	time [s].
Greek symbol	
ρ	density of disk material [kg m^{-3}].

lack of transition boiling data, the results of these experiments, as indicated earlier, might not be applicable to the transient boiling condition, which is of interest to many engineering applications and is the focus of this research.

In the gradual heating method the electric power to the heater is increased incrementally. After each increase, the input power to the heater is kept constant while its temperature continues to rise with time, eventually reaching steady-state. Depending on the size and material of the heater it can take a long time (up to tens of minutes) for the heater to reach steady-state. When steady-state is achieved, the surface heat flux is calculated from the measured temperature gradient in the heater near the surface, assuming a linear temperature profile and negligible edge losses from the sides of the heater. While the former assumption is only true at steady-state, the latter could be realized when the sides of the heater are adequately insulated. Therefore, the gradual heating method is unsuitable for transient boiling experiments because the temperature profile in the heater near the surface will be nonlinear and the thermal inertia of the heater will be difficult to accurately account for, resulting in error when determining the actual surface heat flux. Furthermore, because in the gradual heating method the input power is varied independently of the surface temperature, the transition boiling regime cannot be detected.

Conversely, in the quenching method the thermal inertia of the surface is taken into account when determining the surface heat flux. This is done by placing thermocouples in the test section and close to the heat transfer surface to determine the mean temperature of the heated disk. The disk is initially heated up to a high temperature, then quenched in a large pool of the boiling fluid, which is maintained either at saturation or at a subcooled condition. Then the surface heat flux is determined from the rate of change of the energy stored in the disk with time. Because in the quenching method the surface heat flux is dependent on the surface temperature the transition boiling regime is easily measured.

In the present study the quenching method is used to determine the effect of surface inclination on heat transfer in the various pool boiling regimes for saturated water at near atmospheric pressure (~0.086 MPa in Albuquerque, NM). In the experiments the inclination angle is varied from 0° (horizontal facing downward) to 90° (vertical).

EXPERIMENTAL SET-UP

A schematic diagram of the experimental apparatus is shown in Fig. 1. A Pyrex beaker, 25 cm high and 15 cm in diameter, is used to contain the saturated water. The beaker is insulated on the outside with a fiber glass sheet wrapped in aluminum foil. A Corning PC100 electric heater with a flat surface is used to heat the water in the beaker and the test section. Details of the test section are given in Fig. 2.

The test section is made of a copper disk 12.8 mm thick and 50.8 mm in diameter. The copper disk is encased in a water sealed Marinite C mold. Because of its low specific heat and thermal conductivity, Marinite is used to insulate the copper disk on the sides and at the back surface. The mold is housed in a Bakelite skull for additional insulation. Five K-type thermocouples are used to measure the temperatures of the copper disk at several locations. Three thermocouples are placed in the copper disk, 1 mm from the boiling surface, and the other two are placed in the disk, 3 mm from the insulated back surface (see Fig. 2). The orientation of the boiling surface is adjusted to the desired angle with the aid of an aluminum support frame (see Fig. 1). The test section is mounted to and dismounted from the support frame readily with a slide-and-lock mechanism. A high speed data acquisition and control system controlled with an 80486 personal computer is used for temperature monitoring and data acquisition.

EXPERIMENTAL PROCEDURE

The distilled water in the Pyrex beaker is degassed by keeping it boiling for about 15 min prior to performing the experiments. The procedures for the quenching tests are as follows.

(1) Prior to each test, the heat transfer surface of the copper disk is polished using No. 1200 silicon carbide sand paper and then cleaned with acetone.

(2) The test section is mounted onto the support frame and the heat transfer surface is oriented to the desired angle with respect to the water surface before the test section is heated up. In all experiments thermocouple 3 is kept at the uppermost position and

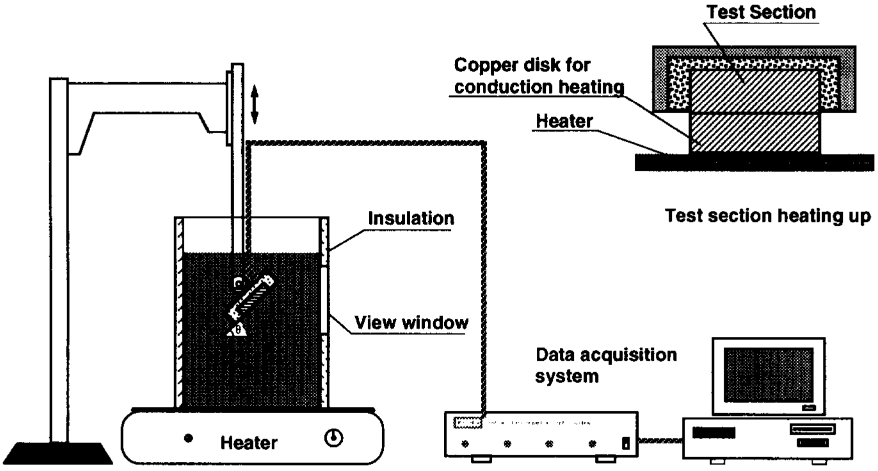


FIG. 1. A schematic diagram of the experimental set-up.

thermocouple 1 is kept at the lowermost position (see Fig. 2). In this arrangement it is possible to determine the average velocity of the quenching front on the heat transfer surface from the thermocouple signals, as will be shown later.

(3) The water level in the pool is adjusted such that the center of the heat transfer surface is initially at the same depth (57 mm) below the water level in the beaker after the test section is fully submerged in the pool. This depth changes slightly during quenching due to water evaporation.

(4) The water pool is brought to full boiling by setting the Pyrex beaker on the surface of the electric heater before submerging the test section into the pool.

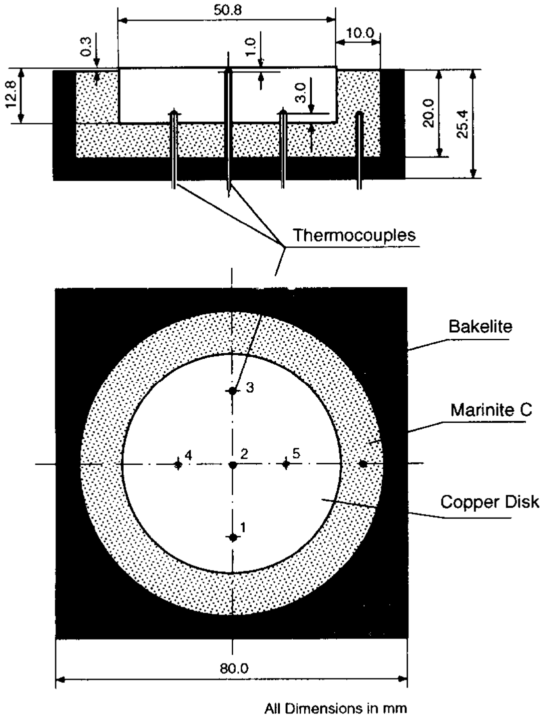


FIG. 2. A schematic of the instrumented test section.

(5) To heat up the test section, a copper disk of the same diameter as the copper disk in the test section is placed on top of the heater surface. When the copper disk is heated up, the test section is placed on top of it and heated by conduction. This method is chosen to avoid burning the Bakelite skull of the test section by direct contact with the heater surface. The maximum temperature of the copper disk in the test section is limited to 533–539 K before quenching to avoid surface oxidation in the air.

(6) The heater is turned off and the data acquisition program is activated. Then the test section is lowered into the saturated water pool as a signal is given by the computer and quenching starts. Subsequently, all thermocouples, including those measuring the pool and the insulation temperatures (see Fig. 2), are scanned simultaneously once every 100 ms.

RESULTS AND DISCUSSION

The energy storage in the copper disk of the test section can be estimated from the measured mean temperature of the disk. In the experiment the mean temperature of the copper disk, T_{1-5}, is calculated as the average of the five thermocouple readings in the disk. At a wall superheat of 160 K the maximum temperature difference among all thermocouples was about 2.2 K; it decreased to a minimum of about 0.16 K at the minimum film boiling heat flux for 0° inclination. The largest temperature difference among all thermocouples occurred at the critical heat flux; it reaches as much as 30 K at 90° inclination but decreases as the surface inclination is decreased.

The energy storage in the copper disk is then determined as

$$E_s = \left(\frac{\pi d^2}{4}\right) H \rho C T_{1-5}. \qquad (1)$$

Since only one side of the copper disk is transferring heat to the water pool, the average surface heat flux at any instant can be calculated from the rate of change of the energy storage in the disk as:

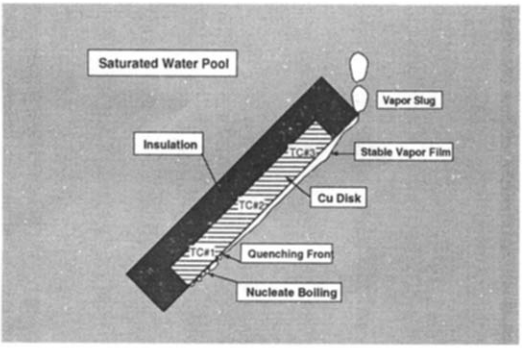
$$q = -\left(\frac{4}{\pi d^2}\right)\frac{\mathrm{d}}{\mathrm{d}t}(E_s) = -H\frac{\mathrm{d}}{\mathrm{d}t}(\rho C T_{1-5}). \quad (2)$$

Experimental uncertainties in temperature measurements and inclination angles are about ±0.15 K and ±0.5°, respectively.

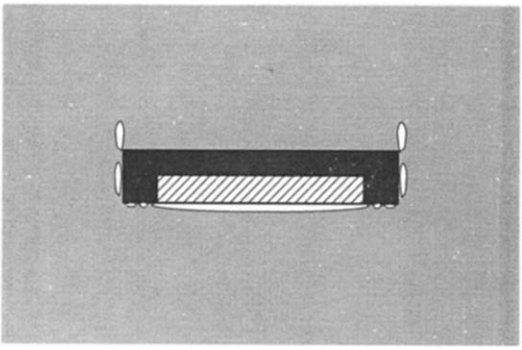
After quenching the test section in the saturated water pool a wavy, but stable, vapor film covers the entire heat transfer surface at high wall superheat. The vapor is seen escaping in large slugs from the edge of the disk (see Fig. 3). However, the release frequency of the vapor slugs from the edge of the disk, the quenching behavior, and the duration of stable film boiling varied with surface inclination.

Effect of inclination on quenching behavior

In all experiments, following vapor film destabilization and collapse, nucleate boiling always began at the lowermost position, as detected by thermocouple (TC) 1, then propagated upward, as indicated by TCs 2 and 3. However, the time it took to quench the whole surface increased as the inclination decreased. These results will be discussed further later in the paper.



(a) Inclined position



(b) Downward Facing Position

FIG. 3. An illustration of boiling behavior on an inclined surface.

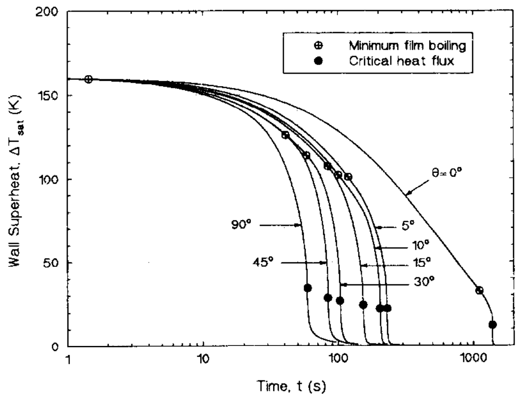


FIG. 4. Effect of surface inclination on wall superheat during quenching.

In Fig. 4, the wall superheat, ΔT_{sat}, is the difference between the mean wall temperature and the water saturation temperature in the pool. The mean wall temperature, T_W, is taken equal to the average readings of the three thermocouples placed close to the boiling surface (see Fig. 2). As shown in Fig. 4, the time needed to quench a downward facing surface having an initial wall superheat of 160 K (about 1300 s) is six times that for a 5° inclination and 23 times that for a 90° inclination. For comparison purposes the *quenching time* is defined herein as *the time it takes the fully submerged boiling surface to reach the critical heat flux (CHF) or for* $|\mathrm{d}T/\mathrm{d}t|$ *to reach its peak value* (see Figs. 5 and 10). As Fig. 4 shows, the quenching time increases moderately, from about 60 s to 105 s, as the inclination decreases from 90° to 30°, then it increases rapidly as the inclination angle is decreased below 30°. However, the quenching time is more than doubled, from about 105 s to 230 s, as the inclination angle is decreased from 30° to 5°. The steepest rise in quenching time (more than 600%, from approximately 230 s to 1390 s) occurs as the surface inclination is decreased from 5° to the downward facing position. This dramatic increase in quenching time with

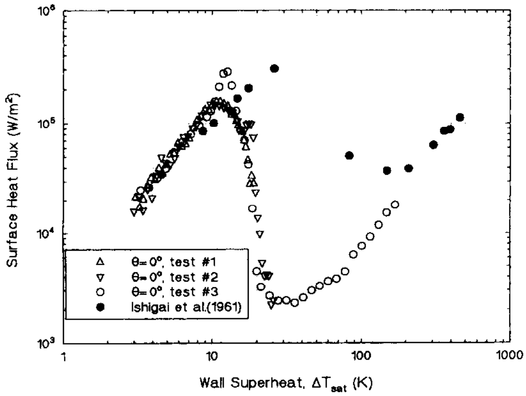


FIG. 5(a). Saturated water pool boiling data for a downward facing surface and comparison with the results of Ishigai *et al.* [10] for a downward facing surface having a diameter of 50 mm.

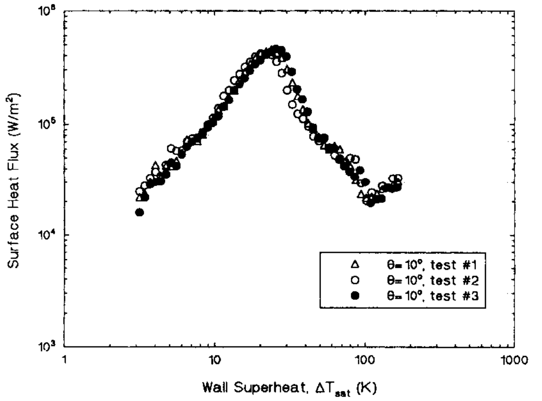


FIG. 5(b). Saturated water pool boiling data for 10° inclination.

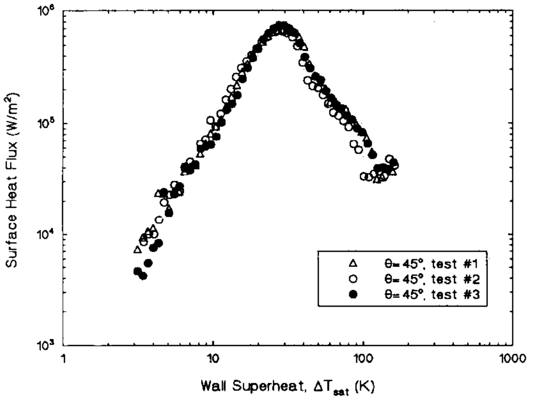


FIG. 5(c). Saturated water pool boiling data for 45° inclination.

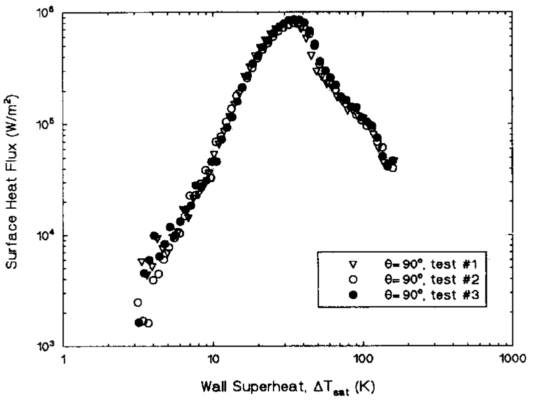


FIG. 5(d). Saturated water pool boiling data for 90° inclination.

decreased inclination is reflective of the behavior of film boiling and affects not only q_{CHF} and $q_{\min}$, but also transition and nucleate boiling heat transfer, as discussed later.

Figure 4 also shows that the difference in wall superheat between minimum film boiling and CHF decreases as the inclination is decreased. These results reflect the fact that decreasing inclination prolongs film boiling, causing the wall superheat, and hence the energy stored in the disk, at the time of minimum film boiling to be lower. Subsequently, the wall superheat at CHF and the value of CHF is lower (see Figs. 5 and 6).

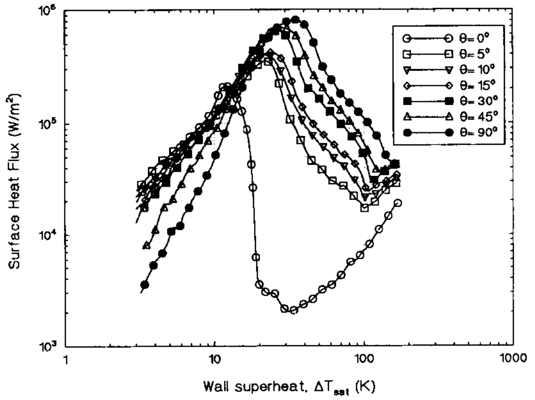


FIG. 6. A comparison of saturated water pool boiling data for all inclination angles.

Effect of inclination on behavior of film boiling

Visual observations at an inclination of 90° show that a wavy, but stable, vapor film covers the whole heat transfer surface at high wall superheat. Vapor is seen to escape from the upper edge of the disk (see Fig. 3). As the wall superheat decreases, approaching the minimum film boiling temperature, the surface of the vapor film becomes less wavy. Below the minimum film boiling temperature, however, the surface of the vapor film becomes unstable. Eventually, the vapor film collapses locally, generating large vapor volumes over the heat transfer surface. Similar observations are made with other inclined surfaces. However, as the inclination angle is decreased, the duration in film boiling increases and the transition boiling becomes less violent.

For a downward facing surface ($\theta = 0°$), the behavior of vapor film is quite different from that at other inclinations. At high wall superheat a thick, wavy but stable vapor film forms on the heat transfer surface with vapor escaping from the edges of the test section. As the wall temperature drops, the vapor film becomes more stable and the frequency at which the vapor escapes from the vapor film decreases. When minimum film boiling is approached, the vapor film becomes so stable that the film surface is like a mirror. At this stage vapor no longer escapes from the vapor film and the surface temperature of the copper disk decreases slowly with time. After a long stand-still period (several minutes), the vapor film begins to swell and shrink periodically while the surface of the vapor film stays relatively flat. Eventually, the vapor film collapses as the wall superheat becomes too low to sustain a stable film boiling (see Fig. 3).

Effect of inclination on boiling heat transfer

The complete boiling curves for the downward facing position (0°) and for inclination angles of 10°, 45°, and 90°, are presented in Figs. 5(a)–(d), respectively. A close examination of these curves reveals the strong effect of the inclination on pool boiling heat transfer in all boiling regimes. For comparison the boiling curves for all seven inclination angles (0°, 5°, 10°, 15°, 30°, 45°, and 90°) are plotted in a single graph in Fig. 6. Figure 5(a) compares the present experimental results with those of Ishigai *et al.* [10], for a downward facing copper disk having a diameter of 50 mm, in the film boiling and nucleate boiling regimes. Note that while there is a reasonable agreement in these boiling regimes, the present results of q_{CHF} and $q_{\min}$ are lower than those of Ishigai *et al.* [10]. This difference could be directly related to the difference in the heating method used in the experiments. In the gradual heating method used by Ishigai *et al.* [10], the steady-state values of both q_{CHF} and $q_{\min}$ are higher than the transient values obtained herein using the quenching method.

The data presented in Fig. 6 show that the transition boiling heat flux and both q_{CHF} and $q_{\min}$, as well as the corresponding wall superheat, increase with surface inclination. Note that for a downward facing surface these heat fluxes are about an order of magnitude lower than those for the nearest inclination of 5°. This is because the former sustains stable vapor film for a significantly longer period than the latter (see Fig. 4), resulting in a lower minimum film boiling temperature, which is indicative of the lower energy storage in the disk. As stated earlier, such low energy storage at the time of destabilization and collapse of film boiling results in a lower transition film boiling and lower q_{CHF}. Conversely, the disk cools off rapidly in the nucleate boiling regime, resulting in the highest nucleate boiling heat flux (see Fig. 6).

As delineated in Fig. 6, while the critical heat flux decreases with decreased inclination, the angle of inclination has an opposite effect on nucleate boiling heat transfer. At the same wall superheat the nucleate boiling heat flux decreases with inclination angle, while the decrease is more pronounced at lower wall superheats. The effect of inclination angle on nucleate boiling heat flux at several wall superheats is shown in Fig. 7. Also plotted in this figure are the results of Nishikawa *et al.* [9] from their boiling experiments for saturated water. Despite the difference in the heating method used, Fig. 7 shows a reasonable agreement between the nucleate boiling data of Nishikawa *et al.* [9] and the present data at low wall superheat. At higher wall superheats (wall superheat of 14 K and 18 K in Fig. 7), Nishikawa *et al.* [9] reported no marked effect of surface orientation. However, the present data show a slight decrease in nucleate boiling heat flux with an increase in surface inclination.

The effects of surface inclination on q_{CHF} and $q_{\min}$ and the corresponding wall superheat are delineated in Figs. 8 and 9. In Fig. 8, the critical heat flux and minimum film boiling heat flux are plotted as functions of inclination angle. As this figure shows, both heat fluxes decrease gradually with the decrease in inclination down to about 30°, below which a faster decrease in both critical heat flux and minimum film boiling heat flux occurs as the inclination is reduced to 5°. Note the precipitous drop in these heat fluxes as the inclination is decreased from 5° to the downward facing position. Figure 8 also shows that for $\theta > 5°$, while both q_{CHF} and $q_{\min}$ increase with inclination, the former increases at about twice the rate of the latter.

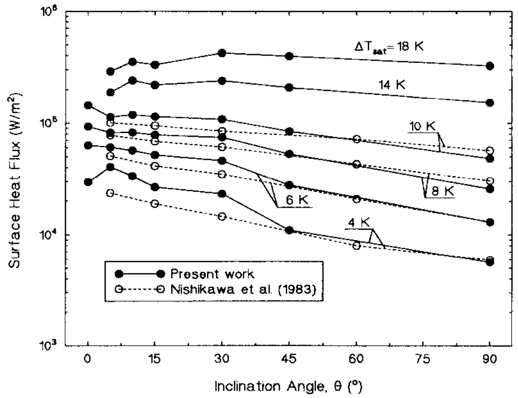


FIG. 7. A comparison of nucleate pool boiling data with that of Nishikawa *et al.* [9] as a function of inclination and wall superheat.

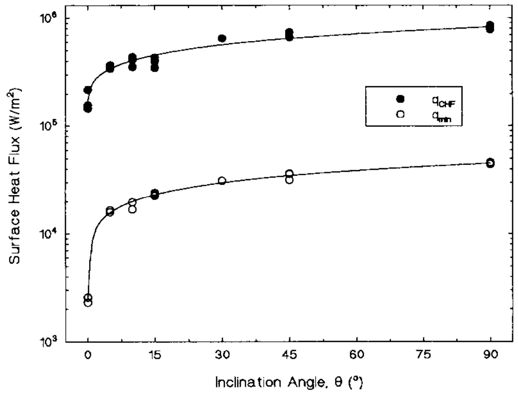


FIG. 8. Effect of inclination angle on both q_{CHF} and $q_{\min}$.

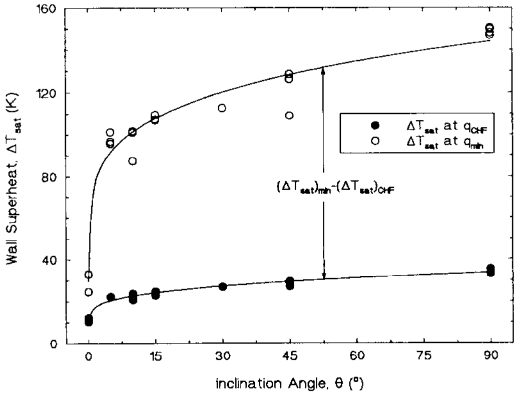


FIG. 9. Effect of inclination angle on wall superheat corresponding to q_{CHF} and $q_{\min}$.

Plotted in Fig. 9 are the wall superheats corresponding to the critical heat flux and minimum film boiling heat flux as functions of the inclination. Similar to the heat flux, the wall superheats at both heat fluxes increase with increasing inclination, but at different rates. Note that the difference between the wall superheats at critical heat flux and at the minimum film boiling also increases with inclination.

Effect of inclination on quenching front

As indicated earlier, in the experiments the copper disk is submerged in the saturated water pool while TC 3 is kept at the uppermost location and TC 1 is kept at the lowermost positions (see Figs. 1 and 2). Therefore, a comparison of the temperature–time history recorded by these thermocouples and that of TC 2, located at the center of the disk, qualitatively shows the effect of inclination angle on the progression of the quenching process of the disk. Figures 10(a)–(c) present the time derivation of temperatures recorded by all three thermocouples for inclinations of 0°, 45°, and 90°, respectively. In all inclined surfaces, quenching begins at the lowermost location and propagates upward. These figures demonstrate that the wall superheat corresponding to the peak values of $|dT/dt|$ are slightly lower at 45° than at 90° inclination, but are significantly lower at 0°. These peak values of $|dT/dt|$ correspond to the critical heat flux, q_{CHF}, at the respective TC locations at the boiling surface (see Figs. 10 and 11). Also, because of the very long period of stable film boiling for the latter, quenching begins at wall superheats that are about an order of magnitude lower than those for the former.

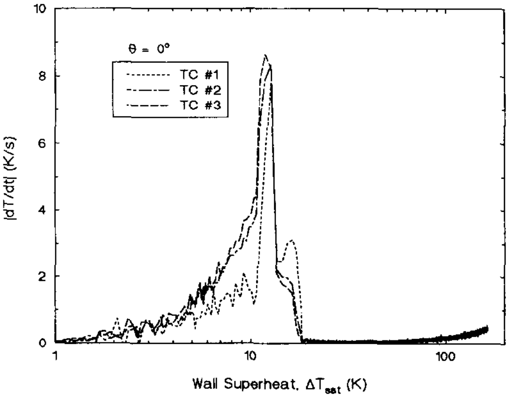


FIG. 10(a). Cooling rate recorded by the surface thermocouples as a function of wall superheat for 0° inclination.

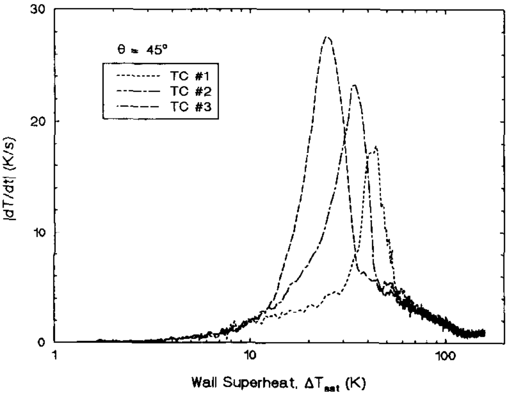


FIG. 10(b). Cooling rate recorded by the surface thermocouples as a function of wall superheat for 45° inclination.

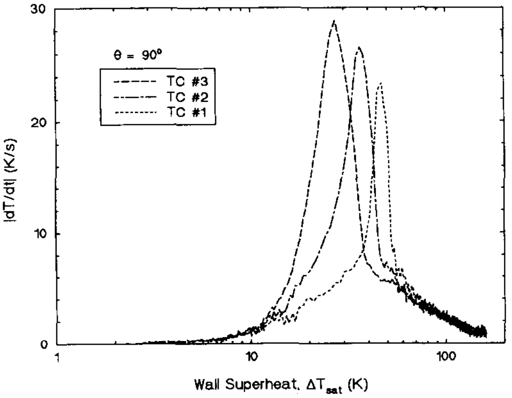


FIG. 10(c). Cooling rate recorded by the surface thermocouples as a function of wall superheat for 90° inclination.

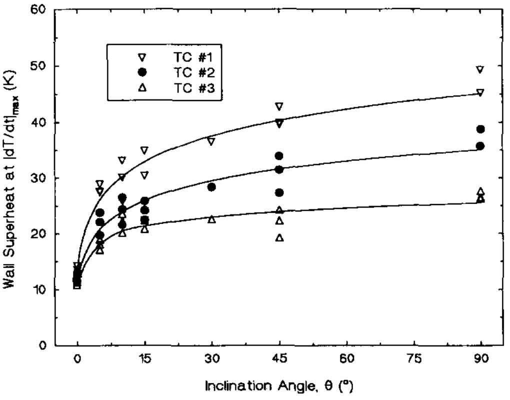


FIG. 11. Wall superheat at time of quenching as measured by surface thermocouples.

Figure 11 plots the measured wall superheat at the time of quenching at the respective thermocouple locations vs the inclination angles of the boiling surface. As this figure shows, quenching always begins at TC 1 (lowermost), where wall superheat is the highest, then it propagates upward to TC 2, then TC 3, at a progressively lower wall superheat. Figure 11 also shows that the difference in the wall superheat at quenching between locations 1 and 2 and between locations 2 and 3 is almost the same, but decreases with reduced inclination and becomes insignificant for the downward facing position. The average quenching velocity, defined as the distance between the thermocouple locations 1 and 3 divided by the difference in quenching time, is plotted in Fig. 12 vs the inclination angle. As this figure shows for $\theta \geqslant 45°$, the average quenching velocity is almost constant at about 2.3

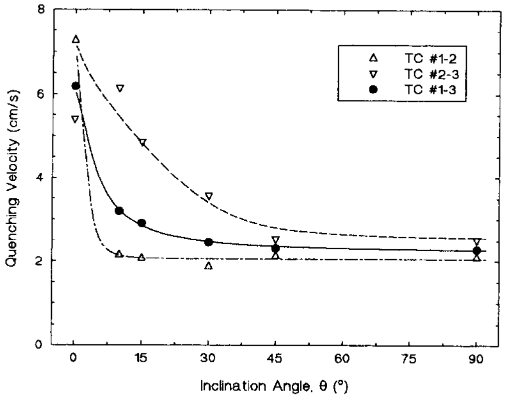


FIG. 12. Average quenching velocity as a function of inclination angle.

cm s^{-1}. At lower inclinations the average quenching velocity increases rapidly with decreasing inclination, reaching about 6.2 cm s^{-1} for the downward facing position (0°).

SUMMARY AND CONCLUSIONS

The effects of surface inclination on heat transfer in the different boiling regimes are studied experimentally by quenching a 12.8 mm copper disk having a diameter of 50.8 mm in a pool of saturated water at near atmospheric pressure. The following conclusions can be drawn from the experimental results.

(1) Critical heat flux and minimum film boiling heat flux, as well as the corresponding wall superheat, increase with increasing angle of inclination.

(2) In the nucleate boiling region, increasing surface inclination results in a decrease in heat transfer rate at lower wall superheats. At higher wall superheats the nucleate boiling heat transfer coefficient decreases slightly with the inclination angle.

(3) The critical heat flux and minimum film boiling heat flux for the downward facing position are significantly lower than those for other inclination angles.

(4) Quenching time depends strongly on the angle of inclination. The quenching time for the downward facing surface is about six times that for 5° inclination and 23 times that for 90° inclination.

(5) For all inclinations, quenching of the boiling surface always begins at the lowermost position and propagates upward. The average quenching velocity of about 2.3 cm s^{-1}, is almost constant for $\theta \geqslant 45°$, but increases rapidly with the decrease in surface inclination, reaching approximately 6.2 cm s^{-1} at zero inclination.

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ETUDE EXPERIMENTALE DE L'EBULLITION EN RESERVOIR POUR DES SURFACES TOURNEES VERS LE BAS OU INCLINEES

Résumé—Des courbes d'ébullition en réservoir pour des inclinaisons de 0° (face vers le bas), 5°, 10°, 15°, 30°, 45° et 90° sont obtenues en trempant un disque de cuivre de 12,8 mm d'épaisseur ayant un diamètre de 50,8 mm dans une eau saturée en réservoir. Les résultats montrent que le flux thermique diminue quand l'angle d'inclinaison augmente. Néanmoins cette diminution est plus prononcée aux surchauffes de la paroi inférieure. Inversement, le flux thermique de transition en même temps q_{CHF} et $q_{\min}$ aussi bien que la surchauffe de la paroi augmentent avec l'inclinaison de la surface. Le temps de trempe d'une surface tournée vers le bas, ayant une surchauffe initiale de 160 K, est environ six fois celui pour une inclinaison de 5° et 23 fois celui pour 90°. Pour toutes les inclinaisons, la trempe commence toujours à la position inférieure et se propage vers le haut. La vitesse moyenne de trempe, de 2,6 cm s^{-1} environ, est à peu près constante pour $\theta \geqslant 45°$ mais elle augmente rapidement quand l'inclinaison de la surface décroît, pour atteindre approximativement 6,3 cm s^{-1} à 0°.

EINE EXPERIMENTELLE UNTERSUCHUNG DES GESÄTTIGTEN BEHÄLTERSIEDENS AN ABWÄRTSGERICHTETEN UND GENEIGTEN OBERFLÄCHEN

Zusammenfassung—Durch Abkühlen einer 12,8 mm dicken Kupferscheibe mit einem Durchmesser von 50,8 mm in einem mit gesättigtem Wasser gefüllten Behälter ergeben sich Siedekurven für folgende Neigungswinkel: 0° (nach unten gerichtet), 5°, 10°, 15°, 30°, 45° und 90°. Die Ergebnisse zeigen, daß die Wärmestromdichte beim Blasensieden mit steigendem Neigungswinkel abnimmt. Die Abnahme der Wärmestromdichte mit zunehmendem Winkel ist bei kleineren Wärmestromdichten ausgeprägter. Dagegen steigt die Wärmestromdichte beim Übergangssieden, wie auch die maximale und die minimale Wärmestromdichte und die zugehörige Wandüberhitzung, mit dem Neigungswinkel an. Die Abkühlzeit einer nach unten gerichteten Oberfläche mit einer anfänglichen Wandüberhitzung von 160 K beträgt ungefähr das 6-fache der um 5° geneigten und das 23-fache der um 90° geneigten Fläche. Bei allen Winkeln beginnt die Abkühlung immer an der untersten Stelle und schreitet nach oben hin fort. Die mittlere Abkühlgeschwindigkeit von ungefährt 2,6 cm s^{-1} ist für Winkel $\theta \geqslant 45°$ nahezu konstant; sie wächst jedoch für kleinere Neigungswinkel stark an und erreicht schließlich 6,3 cm s^{-1} bei 0°.

ЭКСПЕРИМЕНТАЛЬНОЕ ИССЛЕДОВАНИЕ ОБЪЕМНОГО КИПЕНИЯ В НАСЫЩЕННОЙ ЖИДКОСТИ НА ОБРАЩЕННЫХ ВНИЗ НАКЛОННЫХ ПОВЕРХНОСТЯХ

Аннотация—При закалке медного диска толщиной 12,8 мм и диаметром 50,8 мм в большом объеме насыщенной воды получены кривые кипения для углов наклона, составляющих 0° (исследуемая поверхность обращена вниз), 5°, 10°, 15°, 30°, 45° и 90°. Результаты показывают, что тепловой поток при пузырьковом кипении уменьшается с ростом угла наклона, причем эта тенденция более выражена при малых тепловых потоках. Нестационарный же тепловой поток, а также $q_{\text{ктп}}$, $q_{\text{мин}}$ и соответствующий перегрев стенки возрастают с увеличением наклона поверхности. Время закалки обращенной вниз поверхности с начальным перегревом стенки, равным 160 K, почти в шесть раз больше, чем при угле наклона, составляющем 5°, и в 23 раза больше, чем при угле наклона 90°. Для всех углов наклона процесс закалки начинается снизу и распространяется вверх. Средняя скорость закалки, составляющая около 2,6 см · $с^{-1}$, почти постоянна при $\theta \geqslant 45°$, но быстро повышается с уменьшением наклона поверхности, достигая примерно 6,3 см · $с^{-1}$ при 0°.