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On the wetting mechanism of liquid flow on hot surfaces

X. F. PENG and G. P. PETERSON†
Department of Mechanical Engineering, Texas A&M University, College Station, TX 77843-3123, U.S.A.

and

B. X. WANG
Institute of Thermal Science and Engineering, Tsinghua University, Beijing, China

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Abstract—To clarify some of the governing phenomena and fundamental concepts involved in the wetting process, the physical models and wetting mechanisms for four different types of flow are theoretically, experimentally or qualitatively analyzed and a film flow regime map proposed. The investigation indicates that the wetting behavior and wetting mechanisms for different types of liquid flow are distinct and separate, and that the analytical treatments should be conducted individually for different circumstances. This discussion presents several new concepts, and not only clarifies the fundamental phenomena, but also provides further insight into the mechanisms which govern the wetting of hot surfaces.

INTRODUCTION

THE WETTING of hot surfaces is of interest in a large number of applications, including the cooling of overheated fuel elements during loss-of-coolant accidents (LOCA) in water-cooled nuclear reactors, the design of evaporative coolers and other heat transfer augmentation devices, and more recently, in applications involving the thermal control of high density electronic components [1] and two-phase heat rejection systems for spacecraft thermal control [2]. As a result of these and other applications, numerous analytical and experimental investigations have been conducted [3–20]. While these investigations have provided substantial experimental data and considerable insight into several aspects of the wetting behavior of flowing films, some of the resulting conclusions have been contradictory. In particular, as noted by Olek [21], several of the recent models [10–14] have postulated the existence of separate distinct regions having significantly different heat transfer coefficients.

Historically, it has been assumed that the wetting velocity of thin liquid films was strongly dependent on the initial temperature of the surface over which the liquid was flowing. Since this assumption appeared to be supported by the experimental data obtained in several independent investigations [3–8], the initial surface temperature was frequently included in the analytical correlations developed to predict the wetting velocity of these flowing liquid films [3, 10, 12, 13]. However, a recent analysis by Peng *et al.* [20] indicated that the wetting velocity was in fact independent of the initial surface temperature. By re-evaluating the previously obtained experimental data it was shown that in the initial investigations, some of the fundamental phenomena were not clearly understood and, as a result, several inappropriate assumptions were made in the data reduction process [20].

Realizing this, Peng and Peterson [16–20] proposed several models for investigating the wetting behavior of specific cases, including the wetting of flat surfaces, both heated and unheated, and the wetting of porous cover layers. In these models, the vaporization of the liquid at the wetting front was assumed to be an important aspect of wetting. Consequently, in the theoretical analysis, the wetting velocity was first related to the liquid flow velocity and then exact analytical solutions were obtained to determine the wetting velocity for thin liquid films as a function of the liquid flow velocity, the applied heat flux, and the thermophysical properties of the liquid and the surface over which the liquid was flowing. These theoretical analyses were then compared with several different sets of experimental data [16–20]. The results of this comparison verified the analytical models and indicated that the models were reasonably accurate, provided they were used in only those regions or situations for which they were developed.

The present work attempts to clarify and describe some of the governing phenomena and fundamental concepts involved in the wetting process occurring when flowing liquid films come into contact with

† Author to whom all correspondence should be addressed.

NOMENCLATURE

A	non-dimensional number, equation (15)
B	heat capacity ratio, equation (16)
Bi	Biot number
C	specific heat of plate
C_p	specific heat at constant pressure
h	heat transfer coefficient
h_l	liquid latent heat
h_w	heat transfer coefficient during wetting onset
Ja	Jakob number
k	conductivity of plate
L	wetted distance
P	Peclet number
Pr	Prandtl number
q	heat flux
Q	total heat
Re	Reynolds number
T	temperature
T_f	initial liquid temperature
T_H	initial wall temperature
T_0	plate edge temperature
T_s	liquid saturation temperature
T_w	surface temperature at the wetting front
t	time
U	average velocity of liquid flow
U_w	rewetting velocity.

Greek symbols

α	thermal diffusivity
δ	thickness of plate
δ_l	thickness of liquid film
ρ	density
ϕ	variable of temperature difference.

Subscripts

i	initial
l	liquid
max	maximum value
on	onset
w	wetting.

hot surfaces. The wetting mechanisms and analytical models developed for different types of liquid flow are presented and discussed individually in an attempt to develop a more general model which is not dependent upon the specific flow situation.

WETTING VELOCITY

The wetting behavior of flowing liquid films is governed by a large number of factors. These include the wettability of the liquid–solid combination, how much of the flowing liquid is vaporized, and the physical geometry of the solid surface. The wettability of different combinations of liquid–solid combinations have been discussed in considerable detail in other previous investigations and is beyond the scope of the present work. For this reason, in each of the cases presented here, the liquid will be assumed to fully wet the solid surface once initial contact has been made. The amount of vaporization that occurs is, to a large extent, governed by the initial plate temperature. For this reason, it is necessary to examine two distinct types of wetting; one in which no vaporization occurs and the other in which a portion of the liquid is vaporized.

When a liquid film wets a solid surface, no liquid will be vaporized if the initial surface temperature is at or near the ambient temperature. This type of wetting is illustrated in Fig. 1(a), where a fixed amount of liquid comes into contact with a solid surface at ambient temperature, causing a liquid droplet to be formed. This droplet then wets the surface and the liquid–solid interface begins to expand. This interface expansion, or liquid spreading, continues until the appropriate wetting angle is achieved, at which time the liquid droplet film remains at rest and the liquid–solid interface remains stationary. If, however, liquid is continuously fed to the droplet as shown in Fig. 1(b), the liquid–solid interface continues to expand uniformly in all directions. At ambient conditions the initial plate temperature is equal to or less than the saturation temperature, thus no vaporization occurs and hence, the velocity of the wetting front, U_w, is equal to the bulk velocity of the liquid, U.

For vaporization to occur, the surface temperature,

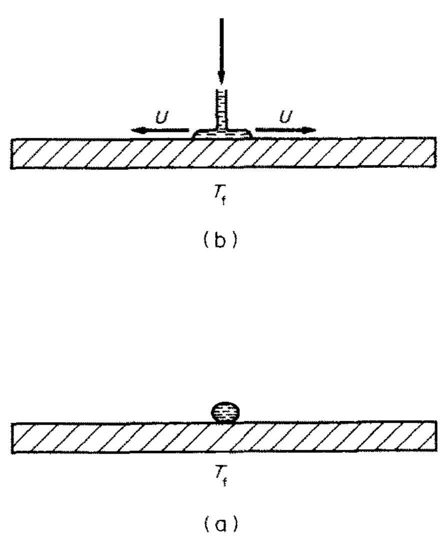

FIG. 1. Wetting of surfaces at or below the wetting temperature.

T_H, must be higher than the wetting or Leidenfrost temperature, T_w. When this happens, the liquid droplet is suspended and does not contact or wet the surface. This is known as the Leidenfrost phenomenon and is illustrated in Fig. 2(a). Once a sufficient amount of liquid has been vaporized, the hot surface cools to a temperature below or equal to the wetting temperature, T_w, and the liquid drop makes contact with and begins to wet the surface in a manner similar to that illustrated in Fig. 1(a). Again, if liquid is continuously fed to the droplet, the liquid–solid interface begins to expand and the droplet spreads. However, because in the dry region the surface temperature is higher than the wetting temperature, i.e. $T_H > T_w$, vaporization and/or sputtering may occur at the liquid front as shown in Fig. 2(b). If the liquid vaporized and/or sputtered is more than that fed, the liquid front will remain in a stationary position and will not advance to wet the dry region.

Although for this situation there is some bulk liquid velocity, the wetting front velocity would be equal to zero. If, however, the liquid fed to the droplet is greater than that vaporized and/or sputtered, the liquid front will advance and wet the surface. In this case, because a portion of the liquid is vaporized or sputtered away, the wetting velocity will be less than the bulk liquid velocity, i.e. $U_w < U$. In still other cases where the surface temperature is very high (i.e. above the critical heat flux) or the liquid does not effectively cool the hot surface, the liquid may spread but not wet the surface and film boiling may occur. For this situation, illustrated in Fig. 2(c), the liquid flow velocity is greater than zero and the liquid spreads, however, the liquid does not wet the surface and hence, the wetting velocity is considered to be equal to zero or indeterminate.

Similarly, the wetting of hot flat surfaces by flowing liquid films can be idealized as shown in Fig. 3. When the liquid flows on a cold or unheated surface, Fig. 3(a), the flow velocity and wetting velocity are equal. When the film front reaches the edge of a surface heated to a temperature above the wetting temperature as shown in Fig. 3(b), the liquid does not immediately wet the surface, but first cools the surface near the wetting front through vaporization or sputtering of a portion of the liquid. Once the surface has been cooled to a temperature equal to the wetting temperature, the liquid film wets the surfaces and the front advances along the flow direction. Again however, if the surface temperature is high enough, the liquid may flow over the surface without wetting it as shown in Fig. 3(c). For this situation, even though liquid flows or spreads and cools the surface, the wetting front velocity would still be assumed to be zero or indeterminate since the liquid does not actually wet the surface.

In summary, it is apparent that the wetting behavior of flowing liquid films can vary significantly for

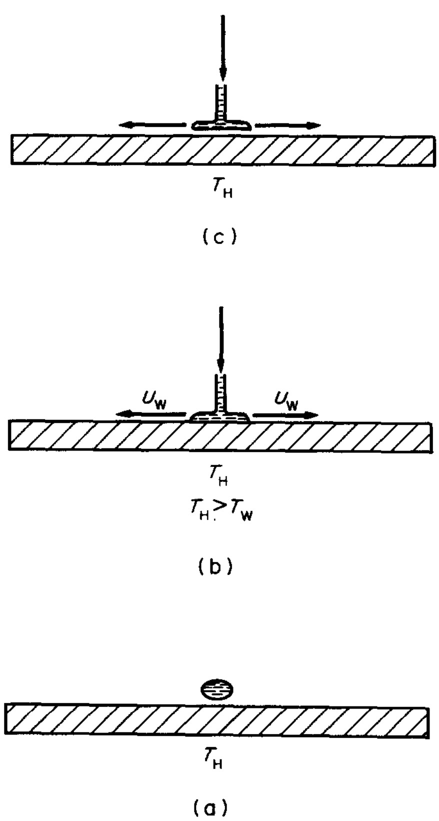

FIG. 2. Wetting of surfaces at elevated surface temperatures.

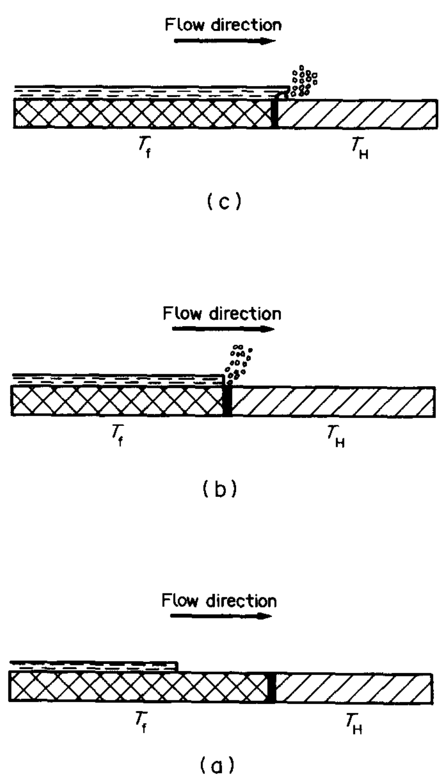

FIG. 3. Flow wetting of heated or hot surfaces.

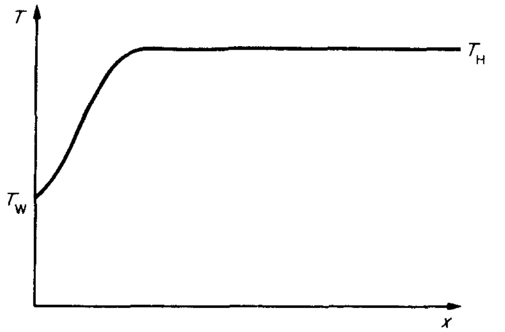

FIG. 4. Temperature distribution at the wetting front.

different situations and as noted by Peng *et al.* [20], it is essential that the wetting velocity be known and understood when evaluating the wetting of hot or heated surfaces.

WETTING ONSET FOR FLOWING LIQUID FILMS

As discussed previously when the surface temperature, T_H, is higher than the wetting temperature, T_w, the liquid may not immediately make contact with and wet the surface. This is also true for the case of flowing liquid films, Fig. 3(c), however, if sufficient liquid is continuously supplied to the heated region, the surface will eventually cool through vaporization and/or sputtering until the wetting temperature, T_w, has been reached. At this point, a wetting front will be established and the liquid front will advance continuously along the plate. The surface temperature distribution along the flow direction that results is shown in Fig. 4.

At this point, it is necessary to introduce several relatively new concepts or ideas. The first of these is the concept of wetting onset [20]. The onset process or simply onset, consists of that series of events by which the liquid at the leading edge of the wetting front cools the hot surface to the wetting temperature and initiates the advance of the wetting front. The time corresponding to this process will be referred to as the onset time. To better understand this process and the concept of onset time, consider a system similar to that shown in Fig. 5, where a liquid film flows to the edge of a hot plate. As mentioned previously, when the liquid arrives at the edge of the heated or hot region, it is vaporized or sputtered since the plate temperature is higher than the wetting temperature, as shown in Fig. 3(b). Once the plate has been cooled to the wetting temperature, a wetting front, similar to that shown in Fig. 3(c), will be formed. The resulting

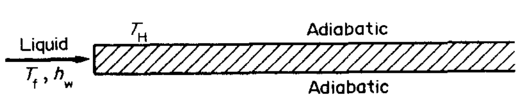

FIG. 5. Boundary conditions for the analytical model.

temperature profile in the plate can then be plotted as a function of position, as shown in Fig. 4. In this example, it is assumed that no heat is lost from the two sides of the plate and that the temperature varies only along the flow direction. As a consequence, the onset process can be approximated by the cooling of a semi-infinite plate with liquid flowing to the plate edge, as illustrated in Fig. 5. The result is a one-dimensional transient conduction problem in a semi-infinite medium with convective boundary conditions. The governing equation for this case can be written as

$$\frac{\partial T}{\partial t} = \alpha \frac{\partial^2 T}{\partial x^2} \tag{1}$$

with boundary conditions

$$t \leqslant 0, \quad T = T_H$$

$$x = \infty, \quad -k\frac{\partial T}{\partial x} = h_w(T - T_\delta)$$

$$x \to 0, \quad T = T_H. \tag{2}$$

The analytical solution for the temperature variation with respect to time at the plate edge has previously been shown to be [20]

$$\frac{4}{3}\left(\frac{h_w}{k}\right)^2 \alpha t = \frac{1}{2}\left[\frac{1}{\left(1 - \frac{\phi_{on}}{\phi_i}\right)^2} - 1\right] + \ln\left(1 - \frac{\phi_{on}}{\phi_i}\right) \tag{3}$$

where $\phi_{on} = T_{on} - T_H$, $\phi_i = T_f - T_H$, and T_{on} is the temperature of the plate edge at any time t provided $t \leqslant t_{on}$. The onset time required for the plate edge temperature to reach the wetting temperature is equal to the difference between the wetting temperature and the initial plate temperature, i.e. $\phi_{on} = \phi_w = T_w - T_H$, and can be found from equation (3) as

$$t_{on} = \frac{3}{4}\left(\frac{k}{h_w}\right)^2 \frac{1}{\alpha}\left\{\frac{1}{2}\left[\frac{1}{\left(1 - \frac{\phi_w}{\phi_i}\right)^2} - 1\right] + \ln\left(1 - \frac{\phi_w}{\phi_i}\right)\right\}. \tag{4}$$

The relationship given in equation (4), provides the criteria by which the onset time can be determined if a wetting front is formed and continuously wets the plate or if the liquid film only cools the plate edge without advancing. Clearly, when $t < t_{on}$ for flowing liquid films, the wetting velocity is equal to zero. This observation not only provides insight into the nature of the wetting process, but must be applied in order to correctly analyze and reduce the experimental data.

As noted previously, Peng *et al.* [20] derived a theoretical relationship for the wetting velocity of a liquid film flowing over an unheated insulated flat plate at some initial temperature T_H. This relationship was found to be independent of the initial surface temperature of the plate. Initially this appeared to contradict the experimental results obtained in several previous investigations [3–7]. To resolve this apparent contradiction, the manner in which the wetting velocity was defined was re-evaluated.

In all of the previous experimental investigations, the wetting front velocity was determined by dividing the distance the wetting front travelled by some time interval, Δt. This time interval was typically measured from the instant the liquid first came into contact with the hot surface [3–7], i.e.

$$U_w = \frac{L}{\Delta t}. \tag{5}$$

As noted above, however, when liquid first comes into contact with the edge of the hot surface, it does not immediately wet the surface. In fact, the time in which the liquid actually travels and wets the surface, Δt_w, should be expressed as the difference between the actual measured time, Δt, and the time required for the liquid to cool the edge region and begin to advance, or

$$\Delta t_w = \Delta t - \Delta t_{on}. \tag{6}$$

Substituting this actual wetting time into equation (5) results in an expression which more accurately reflects the true wetting velocity, i.e.

$$\frac{1}{U} = \frac{\Delta t_w}{L}. \tag{7}$$

Using equation (7) to determine the wetting velocity will result in a value which is somewhat slower than those previously measured. For example, Duffey and Porthouse [6] conducted an experimental investigation of the rewetting velocity as a function of the initial surface temperature for a flow rate of 0.1 g s^{-1}. The results of their investigation are illustrated in Fig. 6, where the circles represent the wetting velocity as determined by equation (5) and originally reported in ref. [6]. These data were later re-evaluated by Peng *et al.* [20] using equation (7) to account for the onset time, and are shown as the triangles. As predicted, the re-evaluated experimental data fall in a narrow band around a horizontal line. This appears to indicate

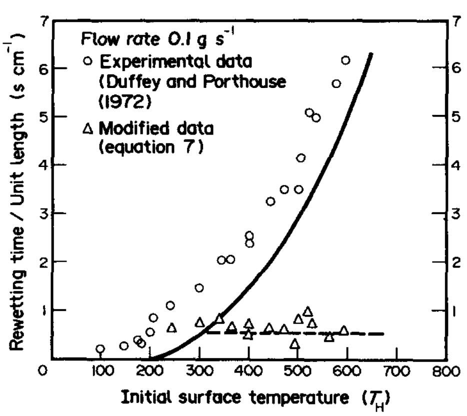

FIG. 6. Comparison of measured and modified data as a function of initial surface temperature.

that the wetting velocity is relatively constant and independent of the initial plate temperature and supports the theoretical analysis of Peng *et al.* [20] discussed previously. It is worth noting that, although the wetting velocity has been shown to be independent of the initial plate temperature, both analytically and experimentally, the initial surface temperature significantly affects the onset process and the onset time. These results provide insight into the mechanisms that govern the wetting of hot surfaces and help to clarify the fundamental phenomena.

Although the concept of onset time also exists for a plate or surface to which heat is continually added, this case is slightly different. If a flat plate with thickness δ is assumed to be heated from below, the governing equation for the case of transient one-dimensional conduction is expressed as

$$\frac{\partial T}{\partial t} = \alpha \frac{\alpha^2 T}{\sigma x^2} - \frac{q}{\delta \rho C} \tag{8}$$

with boundary conditions

$$t \leqslant 0, \quad \frac{\partial T}{\alpha t} = \frac{q}{\rho C \delta}$$

$$x = 0(t \geqslant 0), \quad -k\frac{\partial T}{\partial x} = h_w(T - T_f)$$

$$x \to \infty, \quad \frac{\partial T}{\alpha x} = 0. \tag{9}$$

Using these boundary conditions, the onset time, t_{on}, can be determined for liquid flowing over flat heated surfaces in a manner similar to that presented for the case of an unheated plate.

WETTING MECHANISMS FOR FLOWING LIQUID FILMS

As described above, when a liquid film is flowing over a flat surface and reaches a hot or heated region, the liquid will not immediately wet the hot surface, but will remain stationary for some period of time, the onset time, while the surface cools to the wetting temperature. Once this temperature has been reached, the liquid front will wet the surface and continue to advance. Several investigations [3–9] have experimentally investigated the effects of several aspects of flowing liquids on the wetting of different surfaces and again the conclusions reached have been somewhat contradictory. Peng and Peterson [16–20] conducted a series of investigations to determine the effects of various parameters on the wetting velocity of flowing liquids. These investigations, however, were for specific situations and no general conclusions about the wetting of liquids flowing over flat plates were proposed.

In order to properly evaluate the previous investigations and to draw any general conclusions, it is first necessary to categorize the flow of liquid films into four general categories based upon the wetting behavior, the heat transfer mechanisms and the liquid flow characteristics. These four categories are thin, moderate, thick and flooding film flow. In the following discussion, these four categories are presented and discussed individually.

Thin liquid film flow

Typically, the wetting velocity for a thin liquid film flowing on a flat surface is quite small due to the large viscous forces. This wetting velocity is further reduced for cases where the surface temperature is higher than the wetting or saturation temperature, since the liquid vaporizes to cool the hot dry zone immediately adjacent to the wetting front. This problem has been investigated previously [16, 17] by assuming that the heat conducted from the heated or hot region was absorbed by vaporization of liquid at the wetting front. This resulted in an analytical expression which could be used to predict the wetting velocity of a thin liquid film flowing over a plate to which a constant heat flux had been applied [16, 17]. This expression was given as a function of the physical and thermophysical properties as

$$U_w = \frac{1}{2}\left[U + \left(U^2 - \frac{4q\alpha}{\rho_l \delta_l h_f}\right)^{1/2}\right]. \quad (10)$$

The maximum heat flux, q_{max}, for which wetting of a surface heated with a uniform heat flux would occur was found to be

$$q_{max} = \frac{\rho_l \delta_l h_f U^2}{4\alpha}. \quad (11)$$

For the case of a hot plate with no heat input, the following relation was also obtained [20]:

$$P_w = \frac{1}{2}\left[\frac{2A+1}{A+1}P - \left(\frac{AP^2 + 4Bi(A+1)}{A(A+1)^2}\right)^{1/2}\right] \quad (12)$$

where the Peclet numbers were defined as

$$P_w = \frac{U_w \delta}{\alpha} \quad \text{and} \quad P = \frac{U\delta}{\alpha} \quad (13)$$

the Biot number was

$$Bi = \frac{h\delta}{k} \quad (14)$$

and the dimensionless grouping A was given as

$$A = \frac{B}{Ja_l}\left(\frac{\delta_l}{\delta}\right) \quad (15)$$

with

$$B = \frac{\rho_l C_{pl}}{\rho C} \quad (16)$$

and

$$Ja_l = \frac{C_{pl}(T_w - T_f)}{h_f}. \quad (17)$$

The maximum heat flux for which wetting will occur as determined by equation (11) is illustrated in Fig. 7, along with the experimental data obtained by Stroes *et al.* [9]. As shown, the wetting heat flux values for Freon TF and denatured alcohol films on copper plates are in reasonably good agreement with the predicted theoretical values for low velocities. However, as the flow velocity increases, the difference between the measured and predicted values increases significantly. In addition to the data of Stroes *et al.*, analytical results obtained from equation (12) are compared with the experimental data obtained by Duffey and Porthouse [6] in Fig. 8. Again, as shown, the predicted and measured values are in good agreement. The results of these two comparisons help to verify the analytical method proposed by Peng and Peterson [16, 17] and Peng *et al.* [20], and indicates that these relationships can be used to predict the wetting behavior of thin liquid films flowing over heated or unheated surfaces with a reasonable degree of confidence, provided that the flow velocity is small. At higher velocities, or for thicker film layers, other methods must be developed or employed.

Moderate liquid film flows

In the analyses described above, all of the liquid was assumed to either be vaporized or to remain on the plate with the advancing front, i.e. in both models the liquid was assumed to be either fully vaporized or to advance with the wetting front at a velocity of U_w. In the actual case, however, when the liquid film becomes thicker and the velocity increases, some of the liquid may leave the plate as droplets due to the explosive forces resulting from boiling. These droplets may be deposited a short distance either ahead or behind the advancing front, as indicated in Figs. 3(b) and (c). To determine how much of the liquid is vaporized and how much is sputtered away, it is necessary to divide the total amount of liquid removed, $\rho_l(U-U_w)$, into two regions: the region immediately adjacent to the hot surface, where the liquid will be vaporized, and the region some distance away from the hot surface where the liquid will be sputtered, as shown in Fig. 3(c).

Peng and Peterson [17] developed a model to account for the effect of sputtering using a boundary layer analysis to modify the expressions for wetting velocity and maximum heat flux. The modified expression was then presented in terms of the Reynolds and Prandtl numbers

$$U_w = \frac{1}{2}\left[U + \left(U^2 - \frac{4q\alpha}{0.58 Re_l^{-1/2} Pr_l^{-1/3} \rho_l \delta_l h_f}\right)\right] \quad (18)$$

where $Re_l = U\delta_l/\alpha_l$. Likewise, a modified expression for the maximum wetting heat flux, q_{max}, was found as

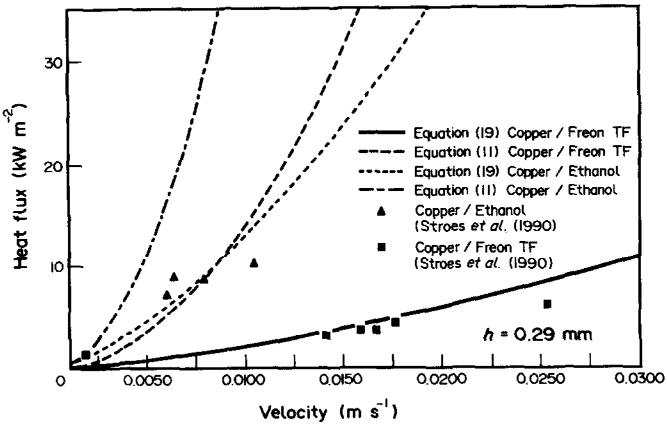

FIG. 7. Comparison of experimental and analytical data illustrating the effect of heat flux on the wetting front velocity.

$$q_{\max} = 0.145 \frac{(\mu_l \rho_l)^{1/2} h_f \delta_l^{1/2}}{\alpha\, Pr_l^{1/3}} U^{3/2}. \tag{19}$$

In addition to comparing the maximum heat flux as predicted by equation (11) with the experimental results of Stroes *et al.* [9], Fig. 7 also compares the experimental results with the modified expression given in equation (19). As illustrated, the modified correlation adequately compensates for the sputtering and compares quite favorably with the experimental data for a wide range of liquid flow velocities. As before, the same type of modification can be introduced for a hot surface with no heat addition. In summary, it is clear that the importance of liquid sputtering increases in significance as the thickness and velocity of the liquid film increase, since these parameters promote the establishment of the upper layer.

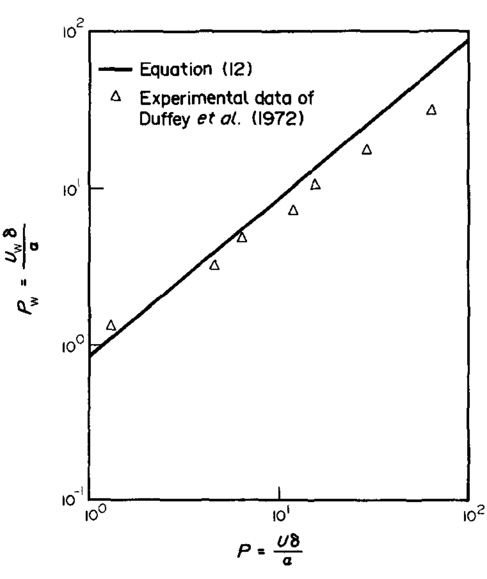

FIG. 8. Relationship between film velocity and wetting velocity Peclet numbers.

Thick liquid film flow

If the liquid film thickness continues to increase, the thickness of the upper layer also increases making the explosive forces occurring in the lower vaporizing layer too small to cause the liquid to sputter and disperse. As a result, the liquid ahead of the wetting front is only partially vaporized and traps a thin vapor film which separates the hot plate and the upper liquid layer. The remaining liquid flows over the vapor film, as illustrated in Fig. 9 and film boiling occurs in the hot dry region of the plate. When this occurs, less liquid is vaporized at the wetting front and the heat transfer from the dry region occurs primarily by conduction. In addition to conduction, convective film boiling also cools the surface resulting in partial wetting, provided that the applied heat flux is below some minimum film boiling heat flux. This phenomenon is referred to as film boiling breakup and has been discussed previously [23–25]. The wetting by film boiling breakup is much different from that which occurs when the wetting front moves smoothly and evenly along the hot surface.

As the vaporization is significantly reduced and relies on conduction, the heat removal in the region near the wetting front is not nearly as efficient. Also, the wetting mechanisms which cause the liquid to flow and wet the hot surface under these conditions are much different, and the wetting process is considerably more complicated than that occurring for the thin or moderate thicknesses. At the present time, little information is known about the wetting of thick liquid film flows and additional investigations into the mechanisms that control the wetting process in this type of flow are necessary.

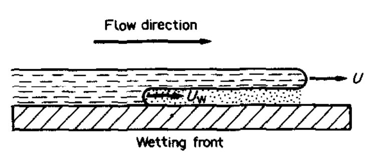

FIG. 9. Schematic of thick and flooding film flow.

Flooding flow

When the liquid film becomes very thick and the flow rate very large, a phenomenon referred to as flooding will occur. If the plate temperature or applied heat flux are high enough, film boiling will occur on the surface as indicated in Fig. 9. For flooding flow, the liquid–vapor interface is highly unstable and waves may frequently come into contact with the heated surface [26]. This is especially true when the liquid velocity is high and some subcooling is present. As a consequence, the wetting front velocity should be considered indeterminate or zero and is of little significance.

If, however, the applied heat flux, if any, is lower than that minimum film boiling heat flux, the liquid will eventually wet the surface. For this case, the wetting behavior is dictated by convective film boiling heat transfer, which is strongly dependent on the liquid velocity and the degree of subcooling. Wang *et al.* [27–31] have systematically investigated the case of flowing film boiling and recently, these investigations have been extended to include the effect of subcooling [31]. However, the ultimate wetting process, which is similar to transition boiling, is still not well understood and the necessary data required to understand the fundamental physical phenomena are not presently available.

From the previous discussion, it is apparent that the film thickness is an extremely important parameter and has significant impact on the wetting behavior of flowing liquids. Although it would be beneficial to be able to quantitatively predict the flow thickness regime, this is not possible at the present time. There are several reasons why this is true, but foremost among these is a lack of sufficient information on the specific flow behaviors, such as how thick the upper layer can be before the termination of sputtering occurs, how the liquid layer intermittently contacts the hot surface in the thick film regime, and what are the flow characteristics of the liquid as it flows over the vapor layer in flooding flow. Another reason, is that all of the parameters which govern the transition from one regime to another are not yet recognized.

Clearly the liquid and surface properties, the liquid temperature and velocity, and the heat flux will all affect the transition thickness, however the relative importance is not known. Perhaps the most important is the heat flux level. For example, as the heat flux is increased the vaporization of the liquid cannot occur fast enough to absorb all of the energy and sputtering occurs [32, 33]. As the heat flux continues to increase, the mass transfer becomes a problem and film boiling or non-equilibrium boiling may occur [34]. Similarly, thinner liquid films will require larger heat fluxes in order to cause transition from one regime to another. In the future, it may be possible to develop a flow regime map similar to the one illustrated in Fig. 10. This flow regime map illustrates the relationship between heat flux and film thickness as they affect the various proposed regimes.

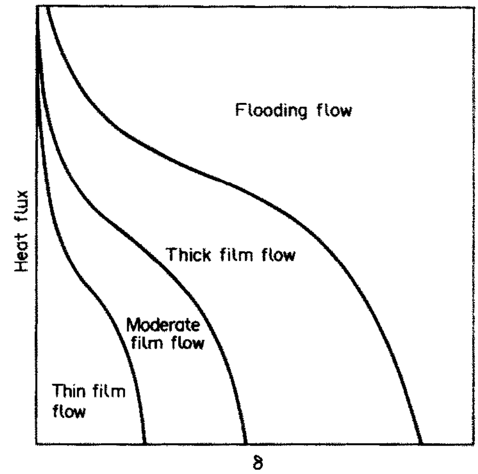

FIG. 10. Proposed film flow regime map.

CONCLUSION

In this investigation, the wetting characteristics of hot and heated surfaces with liquid flow were analyzed and discussed. Several different wetting processes and mechanisms were presented and discussed and the concepts of wetting velocity, wetting onset, and onset time were introduced and analyzed.

The physical models and wetting mechanisms for four different classifications of liquid flow were theoretically, experimentally, or qualitatively analyzed and a film flow regime map was proposed. The investigation indicates that the wetting behavior and wetting mechanisms for different types of liquid flow are distinct and separate, and that the analytical treatments should be conducted individually for different circumstances. This discussion presents several new concepts, and not only clarifies the fundamental phenomena, but also provides further insight into the mechanisms which govern the wetting of hot surfaces.

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SUR LE MECANISME DE MOUILLAGE D'UN LIQUIDE EN ECOULEMENT SUR DES SURFACES CHAUDES

Résumé—Pour clarifier les phénomènes et les concepts fondamentaux dans le mécanisme de mouillage, les modèles physiques et les mécanismes de mouillage pour différents types d'écoulement sont étudiés théoriquement, expérimentalement et qualitativement et on propose une carte des régimes d'écoulement en film. On indique que le comportement du mouillage et les mécanismes pour différents types d'écoulement sont distincts et que les traitements analytiques peuvent être conduits individuellement pour des circonstances différentes. Cette discussion présente plusieurs concepts nouveaux et non seulement les phénomènes fondamentaux sont clarifiés mais aussi elle fournit des enseignements sur les mécanismes qui gouvernent le mouillage des surfaces chaudes.

ÜBER DEN BENETZUNGSMECHANISMUS BEI DER STRÖMUNG VON FLÜSSIGKEITEN ÜBER HEISSE OBERFLÄCHEN

Zusammenfassung—Um einige grundlegende Phänomene und fundamentale Vorstellungen bezüglich des Benetzungsvorgangs zu klären, werden physikalische Modelle und Benetzungsmechanismen für vier verschiedene Typen der Strömung theoretisch, experimentell oder qualitativ analysiert. Es ergibt sich eine Strömungskarte für die Filmströmung. Die Untersuchung zeigt, daß das Benetzungsverhalten und die Benetzungsvorgangs zu klären, werden physikalische Modelle und Benetzungsmechanismen für vier verdie analytische Betrachtung für einzelne Fälle individuell angestellt werden sollten. Die vorgelegte Diskussion zeigt einige neue Konzepte auf. Sie klärt nicht nur die fundamentalen Phänomene sondern gibt auch weitere Einblicke in die Mechanismen, welche die Benetzung heißer Oberflächen maßgeblich bestimmen.

О МЕХАНИЗМЕ СМАЧИВАНИЯ ПРИ ОБТЕКАНИИ ЖИДКОСТЬЮ НАГРЕТЫХ ПОВЕРХНОСТЕЙ

Аннотация—С целью объяснения основных явлений и характеристик процесса смачивания теоретически и экспериментально определяются его физические модели и механизмы при четырех различных типах обтекания и дается карта режимов пленочного течения. Исследование показывает, что поведение и механизамы спачивания при различных типах течения жидкости отличаются друг от друга, так что они должны анализироваться отдельно. Предложено несколько новых концепций, дающих более глубокое понимание механизмов смачивания нагретых поверхностей.