Int. J. Heat Mass Transfer. Vol. 16, pp. 669–678. Pergamon Press 1973. Printed in Great Britain

DESTABILIZATION OF VAPOR FILM BOILING AROUND SPHERES

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(*Received* 20 *April* 1972 *and in revised form* 16 *August* 1972)

Abstract—Energy transfer and vapor film destabilization processes have been studied in an experiment where a sphere traveling with a constant velocity of 1·52 m/s was quenched in distilled water. Data were obtained for the instantaneous heat flux and the transient vapor film behavior over a range of sphere temperatures from 260 to 538 C and water subcoolings from 24 to 77 C. The nature of the transient vapor film behavior was studied with high-speed photography during quenching. All experiments were performed at atmospheric pressure.

Two distinctive mechanisms for the destabilization of a stable vapor film were identified. One, a precipitous collapse and the other, progressive instability. The precipitous collapse occurs very rapidly, on the order of 0·25 ms, while the progressive instability requires from 50 to 100 ms for completion. The progressive instability is triggered by small bubble-like irregularities that move on the liquid–vapor interface.

Precipitous instability appears to be dependent on heat flux rather than sphere temperature.

NOMENCLATURE

- A, surface area of sphere, including support nipple;
- C_p, specific heat;
- q'', heat transfer rate;
- T, temperature;
- ΔT, $T_s - T_{int}$;
- V, volume of sphere, including support nipple;
- δ, vapor film thickness;
- θ, time;
- ρ, density.

Subscripts

- b, bulk;
- i, initial;
- int, interface;
- s, sphere;
- sat, saturation;
- t, transition.

INTRODUCTION

THIS paper reports the results of a basic, experimental investigation into the nature of transient film and transition boiling from spheres. High-speed photography was utilized to record the vapor film–liquid interactions as a sphere was quenched, at a constant velocity, in distilled water. From these data, comprehensive descriptions of both stable vapor film destabilization mechanisms and instantaneous heat transfer characteristics have been obtained.

In an earlier study, Stevens and Witte [1] investigated transient film and transition boiling from a 19 mm dia., silver-plated copper sphere for initial temperatures up to 246 C. They reported observing a pulsation boiling phenomenon, associated with transition, in which the liquid–vapor interface oscillated with a rhythmic expansion and contraction normal to the sphere's surface. Bradfield [2, 3] has reported a similar phenomenon for transient pool boiling from a 60·33 mm dia., chrome-plated copper sphere. Bradfield observed that for a very smooth surface, the resulting hydrodynamic disturbance could be detected by loud "bumping" sounds. These hydrodynamic disturbances are presumed to result from flash

evaporation of the liquid as it comes in contact with a large area of the surface of the sphere.

Walford [4] investigated transient heat transfer from a 6·35 mm dia. nickel sphere moving through water. Using high-speed photography, Walford studied the rapidly changing modes of boiling during quenching. In slightly subcooled water, 80 and 95 C, he observed an "Explosive Cavity" phenomenon where a large spherical vapor shell was produced around the sphere. The sphere progressed through this cavity until it contacted the liquid–vapor interface. At this point, a new cavity of equal size was formed. Walford reports that this cycle was repeated with a period of 5–10 ms.

Board *et al.* [5] experimentally investigated transient film boiling from a metal foil, 6 mm dia. and 0·01 mm thick, which was heated under water by a pulsed ruby laser. They reported having observed an "oscillating vapor blanket" boiling mode for foil temperatures below 450 C over a wide range of subcooling. The frequency of oscillation increased linearly from 5 to 15 kHz as the subcooling was varied from 25 to 75 C. For temperatures above 400 C, and moderate subcooling, Board describes a thin vapor blanket with "rapidly moving irregularities" on the interface. As the level of subcooling was decreased further, a "stable thick blanket" was observed.

The present investigation was designed as an extension of the work reported in [1] to higher initial sphere temperatures and decreased levels of subcooling. A primary objective of this work was to determine the manner in which a stable vapor shell becomes unstable at the onset of transition boiling. Recent work [7, 8] suggests that the occurrence of vapor explosions is related to the manner in which a stable vapor film is destabilized at the onset of transition. The term vapor explosion is used to describe those non-chemical explosions that can result when a molten material, usually a metal, is quenched in a liquid. They are referred to as vapor explosions because the energy release is caused by the rapid vaporization of the quenching liquid, resulting in a pressure wave. It is probable that the triggering mechanism for molten metal particle fragmentation (a massive break-up, yielding many small particles) and ultimately the vapor explosion, may be dependent on the behavior of the vapor film at the onset of transition.

EXPERIMENTAL APPARATUS

The experimental apparatus used in this study employs a quenching technique. A heated 25·4 mm dia. silver sphere was propelled through a pool of subcooled, commercial grade distilled water at a constant velocity of 1·52 m/s.

The sphere, which is shown in cross-section in Fig. 1, was fabricated from 99·9$^+$ per cent pure silver using a sand mold. The silver was cast

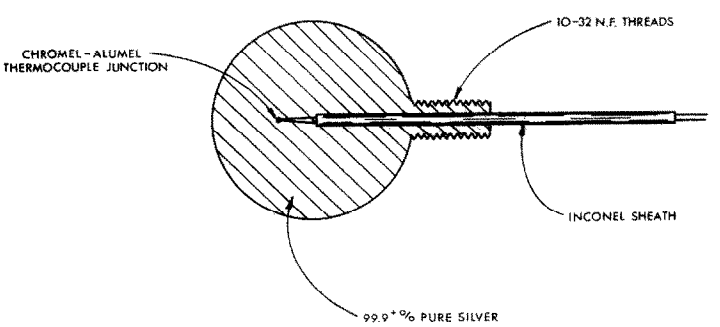

FIG. 1. Cross-section of silver sphere-calorimeter.

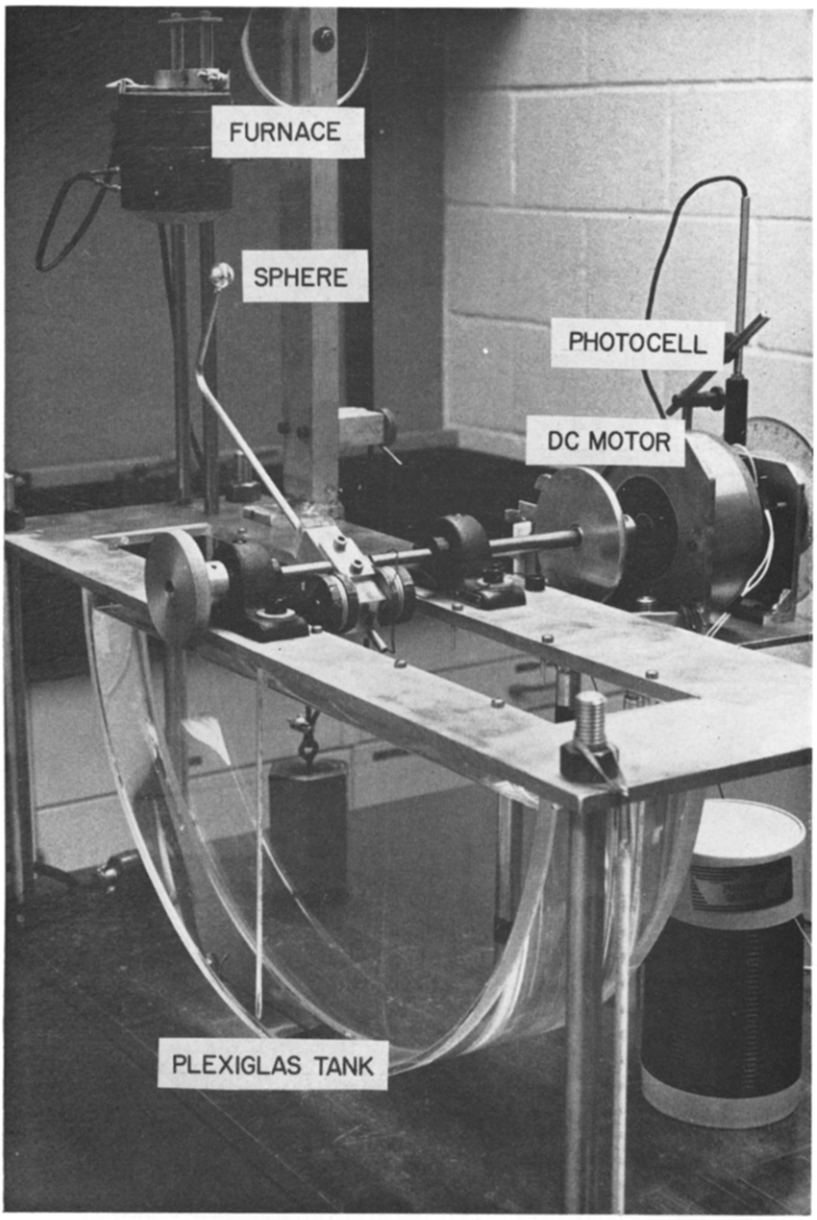

FIG. 2. Transient forced covection boiling apparatus.

around a 30-gage, pre-welded Chromel–Alumel thermocouple junction. The thermocouple wires, from the junction, were encased in an Inconel sheath, packed with an insulating material. The surface of the cast calorimeter was polished to a mirror-like finish prior to use. Subsequently, after each quench test the sphere was repolished to remove residual oxidation and maintain the mirror-like finish.

The sphere was mounted on a support tube via the threaded nipple shown in Fig. 1. This tube was attached orthogonally to the drive shaft of a low internal inertia d.c. motor. The motor shaft was mounted transversely above a semicircular Plexiglas tank, as shown in Fig. 2. The tank is 10·2 cm wide with 30·5 cm radius and was filled with approximately 13·2 l. of commercial grade distilled water. During tests where the water temperature was above room temperature, a 500-W, copper immersion heater (not shown in Fig. 2) was installed on the interior bottom surface of the tank. An electric furnace, mounted on a pair of vertical rails, could be lowered over the sphere to obtain the desired initial temperature. The sphere heating furnace is shown in Fig. 2 in its raised position.

For those experiments involving water temperatures above ambient, the heating of the water partially de-aerated the water. No attempt was made to completely de-aerate the water, however.

The position and velocity of the test sphere were continuously monitored by a tracking system composed of a timing disk and a photoelectric cell. The timing disk was attached to the rear stub shaft of the d.c. motor, thus the movement of the disk reflected the travel of the calorimeter. As the disk rotated, the photocell detected the passage of station markers on the edge of the disk. In this way, both the position and velocity of the test sphere could be accurately determined as the shaft made one revolution. The rear face of the timing disk was used as the loading surface for a felt-faced torque clutch. This clutch was used to pre-load the d.c. motor to such a level that the increased drag of the sphere in the quenching pool did not cause significant variations in the sphere velocity.

The output of the sphere thermocouple and the photocell were displayed simultaneously on a dual-beam oscilloscope. A Polaroid camera was mounted on the oscilloscope to record the two traces. As the sphere passed through the pool of distilled water, high-speed motion pictures were taken through the side of the Plexiglas tank with a Fastax 16-mm camera. The camera framing rate was varied from 4000 to 5000 frames per s.

A single experiment consisted of having the heated sphere make one pass through the Plexiglas tank. The first 180-degrees of travel for the sphere was in the area above the tank, as can be seen in Fig. 2. During this travel, the hot sphere would reach its terminal velocity prior to entering the pool. Tests were conducted in 24, 60 and 77 C distilled water. The velocity of the sphere was held constant at 1·52 m/s. The range of initial sphere temperature was from 260 to 538 C in steps of 55·6 degrees. All tests were conducted at atmospheric pressure. Further details of the experimental apparatus and the test procedure may be found in [6].

RESULTS AND DISCUSSION

In the following, verbal descriptions of the observed phenomena are given in preference to selected frames taken from the high speed movies. Frame by frame sequences yield little information unless viewed in motion. Frame by frame sequences have been constructed, however and are contained in a comprehensive report [6]; the reader is invited to consult reference [6] for these details.

The nature of stable film boiling

Three types or modes of stable film boiling were observed during the course of this investigation. As would be expected, the type of stable vapor shell that was generated around the calorimeter upon entering the pool was dependent upon the initial sphere temperature and the level of subcooling of the quenching

pool. Figure 3 is a plot showing the type of film behavior that was observed for the initial sphere temperature–water temperature combination range covered in this study.

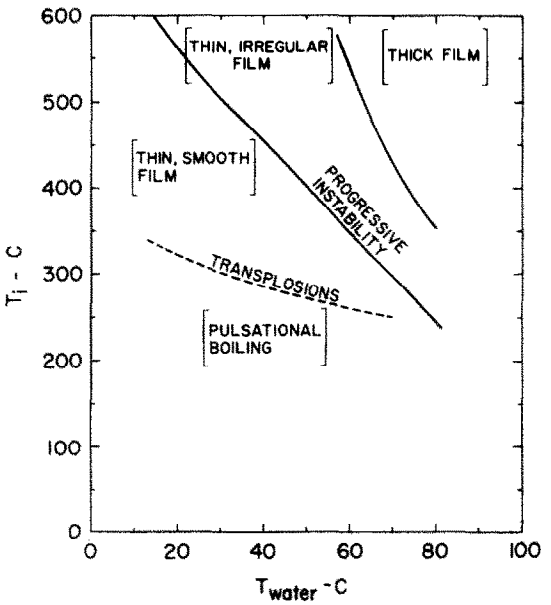

FIG. 3. Boiling characteristics for 25·4-mm dia. silver sphere quenched in water.

1. *Thin, smooth film.* For initial sphere temperatures of 371 C and higher in 24 C water the sphere would enter the pool surrounded by a glassy smooth, stable vapor film. The vapor film is almost perfectly spherical and because of the large degree of subcooling, vapor is being condensed at the liquid–vapor interface in the wake region at approximately the same rate as it is being formed around the front of the sphere. As a result, there is no large trailing vapor wake behind the sphere, and the sphere travels through the pool enclosed in a thin shell of vapor.

Accurate measurements of the vapor film thickness were not possible with the present experimental apparatus. By visual comparison, it is estimated that the vapor film thickness does not exceed 0·25 mm over the majority of the sphere. This estimate is an average value of the vapor film thickness around the sphere.

At a point approximately 160 degrees measured from the stagnation point to the flow, the vapor film deviates from a perfect sphere. In this region, vapor can be observed to collect in a shape that approximates a toroidal annulus. The vapor film thickness in this region may be several times the average vapor film thickness.

2. *Film with bubble-like irregularities.* The second type of stable film boiling was observed to occur at all three levels of subcooling that were investigated, i.e. 24, 60 and 77 C. The sphere was observed to be enclosed in a stable, well-defined vapor shell, as just described, but small irregularities, which had the appearance of small hemispherical bubbles, could be seen traveling along the liquid–vapor interface. These small bubbles, which appear to have an average diameter of less than 1·6 mm are formed over the front hemisphere and then swept along the liquid–vapor interface to the rear portion of the sphere. The bubbles appear to coalesce into the toroidal pocket described previously. The appearance of these bubble-like irregularities on the liquid–vapor interface is a significant result. As will be discussed later, they play an important role in the vapor film destabilization process.

Initially, it was thought that the bubble-like irregularities might consist primarily of air produced during the boiling process, especially since the water was not completely de-aerated. However, this was shown not to be the case since under many conditions the irregularities condensed, indicating that only small amounts of non-condensibles were present.

At each level of subcooling these interfacial bubbles were observed to behave differently. In 24 C water, they would persist for only a short time and then degenerate. A point is eventually reached where the bubbles are damped completely and a glassy smooth vapor film predominates. When the water temperature was 60 C, the bubbles did not die out, but remained active and played a key role in the film destabilization process. For a water temperature of 77 C the demise of the bubbles resulted in the third mode of stable film boiling.

3. *Very thick, smooth film.* For initial sphere temperatures of 371 C and higher in 77 C water the sphere would enter the pool and establish a stable vapor film with the bubble-like irregularities visible on the interface. The bubbles would, after a short interval, disappear and leave the sphere surrounded with a very thick, extremely smooth, stable vapor film. By comparative measurements this vapor film thickness was estimated to be from 1·0 to 1·5 mm. This is from 4 to 6 times thicker than the vapor films observed at higher levels of subcooling. Each time this thick stable vapor film was observed, there was a correspondingly large decrease in the instantaneous heat transfer rate. The thick vapor blanket was thus quite effective in insulating the calorimeter from its surroundings.

One of the more curious aspects of the thick vapor film was the influence of initial temperature on its establishment. At a $T_i = 371$ C, the vapor shell with bubble-like irregularities persists for roughly two-thirds of the way through the tank (approximately 330 ms). When the initial temperature was increased to 538 C, the bubbles die out when the calorimeter is about three diameters under the surface (approximately 45 ms).

The destabilization mechanism for the thick vapor film was not determined in this study. The combination of a limited quench time, 500 ms at a constant velocity of 1·52 m/s, and low heat transfer rates during thick vapor film boiling made it impossible to observe the onset of transition for this case; i.e. the sphere moved completely through the pool without experiencing transition onset.

THE DESTABILIZATION OF VAPOR FILMS

The end of a condition of stable film boiling comes with the onset of transition boiling. Associated with this onset is the destabilization of the vapor shell surrounding the sphere. A primary objective of this work was to determine the manner of vapor film destabilization at the onset of transition. Two types of vapor film destabilization mechanisms were identified.

Precipitous instability

The first mechanism of film destabilization has been given the name "transplosion", a word coined to describe an apparently explosive destruction of a stable vapor shell. With no visible indication of an impending change in the mode of boiling, the vapor shell surrounding the sphere suddenly appears to "explode". The effect of this miniature explosion is to cause the spherical shell to become unstable. The duration time for a transplosion was observed to be less than 0·25 ms. Immediately following a transplosion, the vapor film goes into pulsation boiling, which will be discussed in more detail later.

In each of the transplosions observed during this investigation, the entire vapor shell appears to have experienced the phenomenon simultaneously. It should be pointed out, however, that the minimum resolution time from the high-speed motion pictures was 0·25 ms. It is conceivable that the transplosion does indeed propagate around the vapor film; but, because of the limited framing rate, it appears to occur instantaneously on the photographic films. The minimum time required for a transplosion cannot be determined from the presently available data.

The transplosion phenomenon was observed to occur in water at 24 and 60 C. In 24 C water it was the only mechanism by which a stable vapor film was destabilized for initial sphere temperatures in the range 371–538 C. For initial temperatures of 315 C and lower, a stable vapor film would not be established upon entering the 24 C pool. When the water temperature was increased to 60 C, transplosions were observed only for one initial temperature, $T_i = 315$ C. Figure 3 shows the conditions under which transplosion occurred.

Progressive instability

The second mechanism of vapor film destabilization can be described as a progressive vapor film instability. This instability is induced in an otherwise stable vapor shell when the small

bubble-like irregularities, described previously, begin to grow and collapse while traveling irregular paths over the surface of the vapor shell. These perturbations trigger oscillations in the vapor shell, resulting in pulsation of the entire vapor film normal to the surface of the sphere. In comparison to the precipitous transplosion, the progressive vapor film instability is a gradual phenomenon, requiring on the order of from 50 to 100 ms to complete.

This second type of vapor film destabilization was observed at water temperatures of 60 and 77 C, see Fig. 3. In the 60 C water, the progressive vapor film instability was noted for initial temperatures in the range 371–538 F. At a bulk water temperature of 77 C, this type of instability took place at initial temperatures of 260 and 315 C. For initial temperatures of 371–538 C in 77 C water, the bubble-like irregularities would disappear from the liquid–vapor interface and the thick stable vapor shell, described previously, would result.

THE TRANSITION BOILING SEQUENCE

Once a stable vapor shell has been destabilized, whether by a transplosion or progressive vapor film instability, the sequence of events during transition boiling was observed to be the same in all cases. This transition sequence is composed of two distinct boiling modes that are described here as pulsation boiling and 3-region boiling.

Pulsation boiling is established immediately following the termination of stable film boiling. Pulsation boiling is just what the name implies; i.e. a phenomenon where a thin vapor shell is pulsing with a rhythmic expansion and contraction motion normal to the surface of the sphere. This oscillatory pulsing of a thin vapor film was observed at all points on the surface of the sphere, but the most intensive pulsations were seen on the front hemisphere.

There are two ways in which pulsation boiling was observed to proceed. In a few instances the pulsations appear to be regular, i.e. the entire vapor film will pulsate as a shell. It was more common, however, for the pulsations to be irregular in nature. The vapor film grows outward over one area, while it collapses elsewhere. Limitations of the experimental equipment made an exact determination of the frequency of pulsation impossible. Based on numerous observations the pulsation frequency is estimated to be in excess of 2 kHz.

The second phase of transition boiling is accomplished through a phenomenon described here as 3-region boiling. The end of pulsation boiling is marked by the appearance of a small pulsating circle of vapor covering only the forward stagnation region, initially. The circle becomes a ring and quickly begins to expand and sweep rearward over the front hemisphere in the form of an oscillating toroid of vapor. As this ring of pulsating vapor works its way around the sphere, it divides the sphere and thus the name 3-region boiling. In the area that has already been swept over by the pulse line, extremely active nucleate boiling is observed. The pulsing vapor ring makes up the second region. In the third region, the area behind the pulse line, the surface is covered with a thin film of vapor which appears to be pulsating mildly in response to the relatively large perturbations of the vapor toroid. A drawing of 3-region boiling is shown in Fig. 4.

As the sphere continues to cool, the pulse line gradually works its way rearward, finally closing

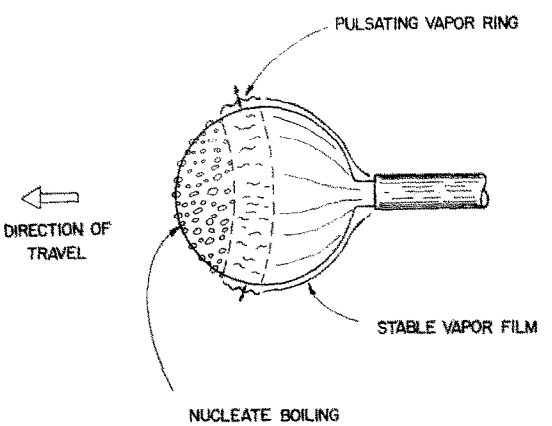

FIG. 4. Sketch of 3-region boiling.

on the rear hemisphere. The entire surface of the sphere would then be covered with nucleate boiling, transition having been completed.

HEAT TRANSFER

Instantaneous heat transfer data were obtained from the experimental temperature–time traces. The instantaneous heat transfer rates were computed by considering the sphere as a lumped parameter system; i.e. that the sphere cooled uniformly. The determination of the heat transfer rate then hinges upon an accurate determination of the slope of the temperature–time curve since

$$q'' \doteq \rho \frac{V}{A} C_p \frac{dT}{d\theta}.$$

Although this model makes the assumption of an isothermal sphere at each instant in time, this is not considered to be a serious source of heat flux error; the sphere was fabricated from pure silver specifically to minimize the existence of temperature gradients.

An error analysis of the heat transfer data is presented in [6]. The heat transfer results are considered to be accurate to within ± 10 per cent overall and to within ± 5 per cent in the film boiling region.

The instantaneous heat transfer results for quenching at a constant velocity of 1·52 m/s at three levels of subcooling are presented in Fig. 5. The effects of subcooling on the heat flux is graphically illustrated by the three curves of Fig. 5. As the level of subcooling was decreased, the level of heat flux likewise decreased. At the same time the curve was shifted to the left, to lower values of superheat. Although both the maximum and minimum heat fluxes are lowered as the level of subcooling is decreased, the minimum is decreased by a larger amount. This results from the fact that vapor formation is enhanced at higher water temperatures. A smaller percentage of the energy leaving the sphere is required to bring the water up to its saturation temperature at the liquid–vapor interface.

THE NATURE OF DESTABILIZATION

As stated previously, the fragmentation of molten metal cooling in a liquid appears to be dependent upon the manner in which the liquid undergoes the transition from film to nucleate

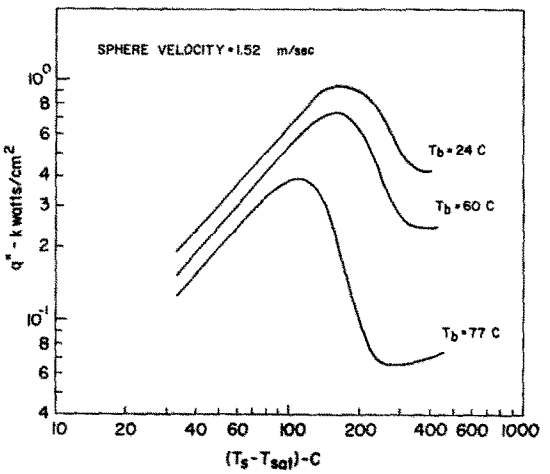

FIG. 5. Instantaneous heat transfer results for quenching at three levels of subcooling.

boiling. Bradley and Witte [8], using high speed photography to study the fragmentation of molten metal jets, have demonstrated that an entire explosive interaction may require only from 200 to 500 μs for completion. If destabilization of the vapor film does indeed induce fragmentation, then it must be the precipitous instability (transplosion) that is responsible. Progressive instability apparently takes too long to develop to account for the fragmentation initiation event.

The transplosion, then, is of considerable importance, and understanding of the physics of the phenomenon is needed. However, the resolution time of the high-speed movies was not sufficient to give a great deal of information on exactly how a transplosion occurs; this, of course, makes a modelling of the phenomenon most difficult.

The experimental data gives some insight into the nature of the instability. It is logical to

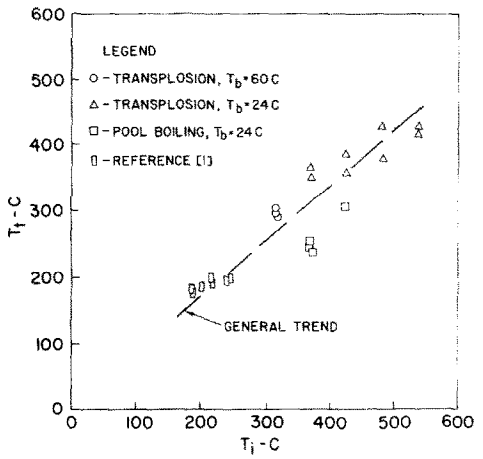

FIG. 6. Transition temperature vs. initial sphere temperature.

assume that the transplosion should not be a function of initial sphere temperature, but that it should occur at a specific sphere temperature dependent upon only the water temperature and sphere velocity. Figure 6 shows that this is not the case; i.e. that the transplosion temperature is dependent upon initial sphere temperature. One must draw the conclusion then that the instability is not a sole function of the sphere temperature.

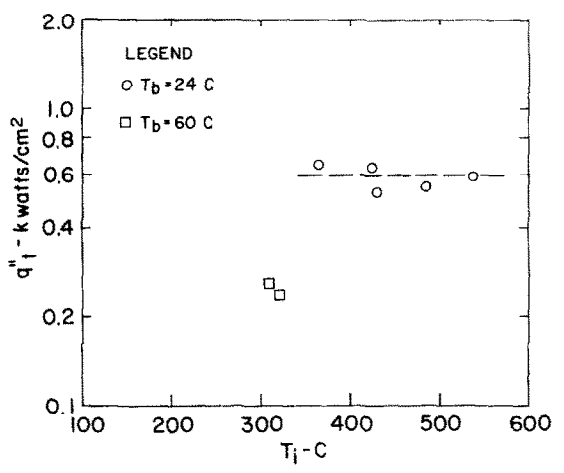

FIG. 7. Heat flux at transplosion vs. initial sphere temperature.

Figure 7 shows that the transplosion is a function of the heat flux just prior to the precipitous instability. Regardless of the initial sphere temperature, q''_i is a constant for a given water temperature. This result indicates that the instability is dependent upon the manner in which energy is transferred across the film to the liquid–vapor interface and then how this energy is partitioned between the formation of vapor and the heating of the subcooled liquid. All of this points to a critical heat flux for precipitous collapse rather than a critical film thickness. If it is assumed that the energy transfer across the vapor film is primarily by conduction and, furthermore, that the temperature profile in the vapor is approximately linear then

$$q'' \propto \frac{T_s - T_{\text{int}}}{\delta}.$$

Thus, for the case of higher initial sphere temperature when T_s is higher at the point of precipitous instability a larger film thickness results. Apparently a condition is reached where the rate of energy being furnished to the liquid–vapor interface is insufficient to maintain the film and it begins to collapse. Then, as the liquid collapses upon the hot surface, it is rapidly superheated, and flashes, causing a re-growth of the vapor film. Pulsation boiling ensues.

Stevens [6] proposes a somewhat different sequence-of-events for the transplosion, but retains the concept that it is triggered by the initial tendency of the film to collapse. Initially, the vapor shell is stable and glassy smooth. It is reasonable to assume that at this point the energy transfer is primarily by conduction across a thin film of vapor. Under this assumption, if the temperature profile in the vapor film is taken to be linear, then q'' is proportional to $\Delta T/\delta$. A thin layer of liquid adjacent to the liquid–vapor interface becomes superheated. Conditions are favorable for this to occur since the interface is smooth and devoid of the surface irregularities that serve as nucleation sites and normally limit the degree of superheat a liquid will sustain.

Simultaneously, the sphere is cooling allowing the vapor shell to grow thinner.

As the vapor shell thins, the heat flux increases quite rapidly, based on a simple one-dimensional conduction model. The transplosion point is reached when the liquid can no longer accept energy without instantaneously flashing into vapor. The flash evaporation front proceeds outward in the form of a spherical shell into the bulk liquid. The vapor film quickly becomes so thick that the conduction path is too long for the sphere to supply the necessary energy at the interface to sustain the growth. Condensation begins and the interface is now moving toward the surface. This vapor shell collapse would then be the first cycle of pulsation boiling.

The essence of Stevens' model is that the liquid–vapor interface is not required to touch the sphere surface. Board *et al.* [5] also express some doubt about the actual contact with the hot surface when the vapor film collapses.

Precipitous instability was never observed when the bubble-like irregularities were present on the liquid–vapor interface. It is probable that the action of these bubbles cause locally strong agitation in the liquid thermal boundary layer. The stirring action of the bubbles is strong enough to keep the liquid adjacent to the interface well mixed. Apparently this causes a condition where the production of vapor is more efficient and the precipitous collapse of the vapor film is prevented.

SUMMARY

A basic experimental investigation into transient boiling around a sphere has shown that there are three types of stable film boiling for the range of conditions studied. Two methods of vapor film destabilization were observed; one a precipitous instability and the second a progressive instability controlled by bubble-like irregularities on the liquid–vapor interface. The precipitous instability appears to be a function of the heat flux rather than the surface temperature of the sphere.

Both types of instability trigger pulsational boiling, followed by the so-called 3-region boiling phenomenon, i.e. a situation where nucleate, pulsational and metastable film boiling occur simultaneously on the sphere surface.

ACKNOWLEDGEMENT

The authors gratefully acknowledge support for this work by the U.S. Atomic Energy Commission under contract AT-(40-1)-3936.

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DESTABILISATION D'UN FILM DE VAPEUR DANS L'EBULLITION AUTOUR DE SPHERES

Résumé—Les procédés de transfert d'énergie et de déstabilisation d'un film de vapeur ont été étudiés au cours d'une expérience où une sphère se déplaçant à la vitesse constante de 1,52 m/s est trempée dans de l'eau distillée. On a obtenu des résultats concernant le flux thermique instantané et le comportement transitoire du film de vapeur, dans un domaine de température de la sphère entre 260 et 538°C et des sous-refroidissements d'eau entre 24 et 77°C. Pendant l'operation de trempe on a étudié, par photographie à grande vitesse, le comportement transitoire du film de vapeur. Toutes les expériences ont été menées à la pression atmosphérique.

On a idenfifié deux mécanismes distincts de déstabilisation d'un film de vapeur. L'un est une disparition précipitée, l'autre une instabilité progressive. La disparition précipitée se produit très rapidement en 0,25 ms environ, tandis que l'accomplissement de l'instabilité progressive dure de 50 à 100 ms. L'instabilité progressive est initiée par des petites irrégularités semblables à des bulles qui se déplacent sur l'interface liquide–vapeur. On voit que l'instabilité précipitée dépend plus du flux thermique que de la température de la sphère.

ENTSTABILISIERUNG DES DAMPFFILMES BEIM SIEDEN AN KUGELN

Zusammenfassung—Zur Untersuchung des Energietransportes und der Entstabilisierungsprozesse des Dampffilmes wurde in einem Experiment eine Kugel, die sich mit einer konstanten Geschwindigkeit von 1,52 m/s bewegte, in destilliertem Wasser abgeschreckt. Es wurden Messwerte für die instationäre Wärmestromdichte und das Übergangsverhalten des Dampffilmes in einem Bereich der Kugeltemperaturen von 260 bis 538°C und Wasserunterkühlungen von 24 bis 77°C erhalten. Der Charakter des Übergangsverhaltens des Dampffilmes während des Abkühlens wurde mit Hilfe der High-Speed Fotografie beobachtet.

Zwei deutlich unterscheidbare Mechanismen für die Entstabilisierung des stabilen Dampffilmes wurden festgestellt. Der eine Mechanismus besteht in einem plötzlichen Zusammenbrechen des Dampffilmes, der andere in einer zunehmenden Instabilität. Das plötzliche Zusammenbrechen tritt sehr schnell auf in der Grössenordnung von 0,25 ms, während die fortschreitende Instabilität 50 bis 100 ms zur vollständigen Ausbildung erfordert.

Die fortschreitende Instabilität wird durch kleine blasenähnliche Unregelmässigkeiten, die sich auf der Phasentrennfläche bewegen, ausgelöst. Die plötzlich auftretende Instabilität scheint eher von der Wärmestromdichte als von der Kugeltemperatur abhängig zu sein.

ДЕСТАБИЛИЗАЦИЯ КИПЕНИЯ ПЛЕНКИ ПАРА ВОКРУГ СФЕР

Аннотация—Экспериментально исследовались процессы переноса тепла и процессы дестабилизации пленки пара при охлаждении сферы, движущейся с постоянной скоростью 1,52 м/сек в дистиллированной воде. Были получены данные для локального теплового потока и переходного режима пленки пара в диапазоне температур от 260 до 538°С и нагрева воды от 24 до 77°С. Переходный режим пленки пара изучался во время охлаждения с помощью высокоскоростного фотографирования. Все эксперименты проводились при атмосферном давлении. Установлены два механизма дестабилизации пленки пара: мгновенное разрушение и прогрессирующая нестационарность. Мгновенное разрушение протекает очень стремительно за время поряцка 0,25 миллисекунды, в то время как для наступления прогрессирующей нестабильности требуется от 50 до 100 миллисекунд. Прогрессирующая нестабильность вызывается пузырьковообразными нерегулярностями, перемещающимися на поверхности раздела фаз жидкость-пар. Выявлено, что мгновенная нестабильность зависит от величины теплового потока, а не от температуры сферы.