Int J. Heat Mass Transfer. Vol. 13, pp. 55–68. Pergamon Press 1970. Printed in Great Britain

THE RELATIONSHIP OF QUENCH DATA TO STEADY-STATE POOL BOILING DATA

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(*Received* 17 *March* 1969)

Abstract—Experiments are described which establish that under certain conditions there are large differences between the boiling characteristics of quenched specimens and boiling data obtained from conventional steady-state experiments. The distorted boiling curves obtained when quenching can be attributed to elevation of the $q''_{\min}$ condition in the case of Freon-113 and water, and lowering of the $q''_{\min}$ condition in the case of nitrogen. The results have practical implications for metallurgical quenching processes and for heat-transfer studies which use the transient calorimeter approach.

NOMENCLATURE

A,	surface area of quenched specimen;
C,	constant in equation (4);
c_p,	specific heat at constant pressure;
D,	diameter;
g,	gravitational acceleration;
h,	heat-transfer coefficient;
h_{co},	convective heat-transfer coefficient in film boiling;
h_r,	radiative heat-transfer coefficient in film boiling;
h_{fg},	latent heat of vaporization;
k,	thermal conductivity;
Nu,	Nusselt number $= h_{co}D/k$,
q'',	heat flux;
$q''_{\max}$,	maximum heat flux in nucleate boiling;
$q''_{\min}$,	minimum heat flux for stable film boiling;
Ra^*,	Rayleigh number defined in equation (2);
r_0,	outer radius of cylinder or sphere;
T,	temperature;
T_b,	mixed-mean fluid temperature;
T_{sat},	saturation temperature;
T_w,	heated-surface temperature;
ΔT,	temperature difference $= T_w - T_{sat}$;
$\Delta T_{\max}$,	$T_w - T_{sat}$ at $q''_{\max}$;
$\Delta T_{\min}$,	$T_w - T_{sat}$ at $q''_{\min}$;
t,	time;
V,	volume of quenched specimen.
μ,	dynamic viscosity;
ρ,	density;
σ,	surface tension;
$\bar{\sigma}$,	Stefan–Boltzmann constant.

Subscripts

l,	liquid condition;
f,	evaluated at film temperature $= (T_w + T_{sat})/2$;
v,	vapor condition.

INTRODUCTION

QUENCHING is of interest in both metallurgy and heat transfer. Metallurgists control hardness by regulating the temperature history of a quenched piece. The transient temperature distribution in the piece can be predicted if the surface coefficient of heat transfer is known. It is generally assumed that the heat-transfer coefficients can be derived from the extensive data which have been obtained for pool boiling heat transfer. However, the great majority of pool boiling studies have been performed under steady-state conditions with either direct elect-

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rical heating or by use of a high temperature secondary fluid.

Several boiling studies have utilized the transient calorimeter to generate pool boiling data when short test times were dictated [1] or when it was desired to carefully explore the transition boiling region [2]. Pool boiling tests at reduced gravity are time-limited due to short experimental times obtainable with parabolic aircraft flights and drop towers. Quenching experiments are ideally suited for this application since test times can be designed to be of one to two orders of magnitude shorter than comparable steady-state tests. With fluids having high boiling points, film and transition boiling are difficult to obtain with conventional steady-state apparatus due to burnout or lack of a secondary fluid with high enough temperature. These difficulties can be avoided with quench specimens since the boiling curve is traversed in reverse with a test section having wall temperature as the independent variable. Investigators who have employed transient calorimeters have assumed that their data are comparable to data which would have been obtained with steady-state boiling from a similar surface–fluid combination.

Table 1. Quenching in water at atmospheric pressure

Investigator	T_b (°F)	$q''_{\max}$ (Btu/h ft^2)	$\Delta T_{\max}$	$q''_{\min}$	$\Delta T_{\min}$
Pilling and Lynch [3]	209	–	320		750
Wever [4]	212	--	145		650
	166	- -	240		650
	122	—	470	-	930
	77		615		970
Tagaya and Tamura [5]	68	---	470	- -	755
Bradfield [2]	203	160 000	140	50 000	600
	128	850 000	290	80 000	900
	80	1 400 000	700	400 000	1000

An examination of available quench data for water suggests that the generally presumed equivalence of steady-state and quench data is in error. For the first three investigations indicated in Table 1, the wall superheats corresponding to the peak nucleate boiling and minimum film boiling conditions were estimated from inflection points in reported temperature–time curves. These curves were not presented in sufficient detail to permit an accurate estimate of the corresponding heat fluxes. The transient calorimeter data of Bradfield [2] were presented as boiling curves. It has been well established that the peak nucleate condition is quite variable in steady-state boiling; however, for saturated water at 1 atm with horizontal cylindrical heaters, the range should be $q''_{\max} = 2 \times 10^5 - 6 \times 10^5$ Btu/h ft^2 with $\Delta T_{\max} = 30$–60°F. Compared to the steady-state, then, the quench data appear to have lower peak fluxes, and definitely have higher wall superheats. Since $\Delta T_{\min}$ for saturated water at 1 atm is approximately 100°F, it appears that the minimum film boiling condition is also shifted in quenching.

This apparent discrepancy provided the motivation for this investigation. The object was to investigate the conditions under which transient calorimeter tests can be used to obtain steady-state pool boiling data or, conversely, to ascertain when steady-state pool boiling data may be reliably used to generate temperature histories for quenching operations. The experimental program consisted of a series of steady-state and quench tests for a variety of fluids.

EXPERIMENTAL CONSIDERATIONS

Three fluids were chosen as quenching media. Freon-113 has a relatively low boiling point;

thus film boiling can be established without physical burnout. Distilled water was used because of its popularity in the literature and applications in engineering. Liquid nitrogen is convenient since the quench can be initiated at room temperature, thus avoiding the problem of uniformly heating the test section to high temperatures. Copper was used as a standard surface in constructing the test specimens whenever possible. The high conductivity of copper minimized temperature gradients within the quench specimens, thus permitting relatively simple calculations for the heat flux. Saturated liquid pools were used to avoid pool temperature gradients which would be expected in subcooled tests.

Steady-state pool boiling experiments were performed with Freon-113 and nitrogen, establishing both the nucleate and film boiling regions. The steady-state tests with water were limited to the nucleate boiling region since film boiling could not be sustained with the stainless steel test sections used in this series of experiments.

Steady-state experiments

The test section for steady-state pool boiling of Freon-113 and water is shown in Fig. 1. Due to the high heat fluxes and temperatures characteristic of boiling with these fluids, it was necessary to employ resistance heating of a thin-walled stainless steel tube. The tubing was brazed to copper end plugs, one of which was drilled to accommodate the thermocouple leads. Three chromel–alumel thermocouples were placed along the axis of the tube and held in position by the Santocel insulation. This assembly was clamped in aluminum supports which also served as power leads. The power was supplied by a direct current motor-generator facility.

Due to the more moderate thermal requirements, it was possible to fabricate the nitrogen test section from a commercial cartridge-type heater. As shown in Fig. 2, the heater was placed inside a length of standard hard-drawn copper tubing. The annular space was filled with soft solder, and two thermocouples were inserted in the solder just as it solidified. Insulation and end fittings completed the assembly. Power to the heater was 115 V a.c., regulated by a variac.

The test sections were polished with 500 emery and cleaned with acetone before immersion. The Freon and water tests were performed in a 5 gal Pyrex container with insulated sides having an evaporation shield and a condenser at the top. An immersion heater was used prior to testing to bring the liquid to saturation conditions. Nitrogen tests were made with an open 10 in. dia. Dewar. All tests were run at atmospheric pressure.

The general procedure was to increase the

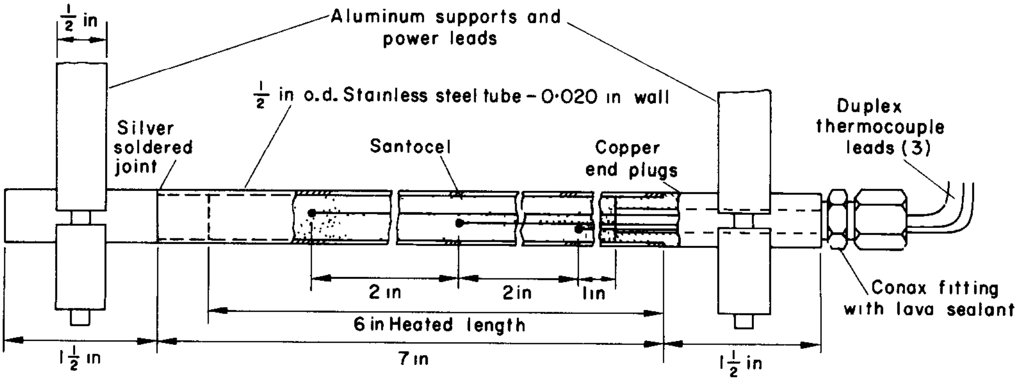

FIG. 1. Test section for steady-state pool boiling of Freon and water.

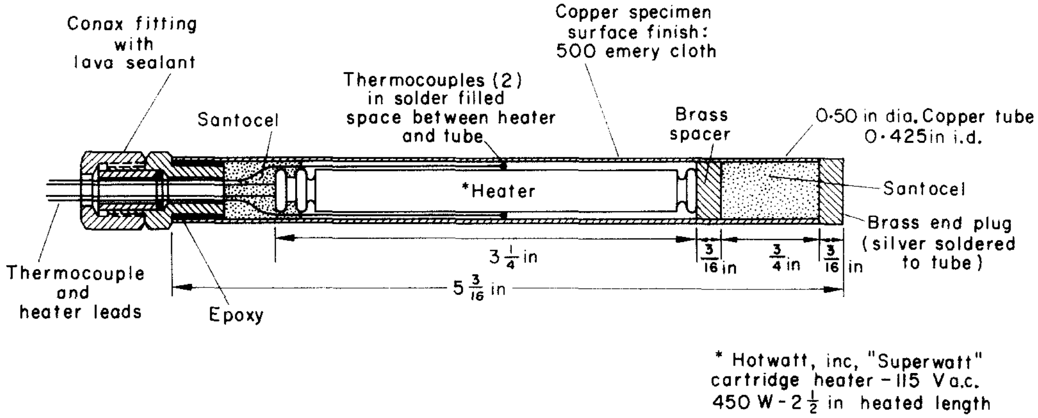

FIG. 2. Test section for steady-state pool boiling of nitrogen.

power level so as to traverse the free convection and nucleate boiling regions until $q''_{\max}$, whereupon the excursion to fully developed film boiling was experienced. The water tests were terminated at this point since the excursion to film boiling resulted in physical burnout, as is commonly observed for large diameter test sections. In the Freon and nitrogen experiments, once film boiling was established, the power was reduced in gradual steps until $q''_{\min}$ where the film was destabilized.

Data were reduced to the standard form of pool boiling curves; heat flux vs. difference between the surface temperature and liquid saturation temperature. The average heat flux was obtained from power measurements and heated section dimensions. The thermocouple readings for the Freon and water test section were averaged and corrected by the temperature drop across the tube wall to obtain the average heated surface temperature. The nitrogen test section was oriented so that the thermocouples were located at the top and bottom. The two temperatures differed only slightly; however, since the lower thermocouple provided a more sensitive indication of the collapse of film boiling, it was used in calculating the surface temperature.

Quenching experiments

The basic apparatus used for all of the quenching experiments is shown schematically in Fig. 3. The containers were the same as those utilized in the steady-state experiments. The mechanism for dropping the specimens was mounted on an adjustable metal frame to accommodate both changing liquid levels and different specimens. The immersion depth was maintained greater than 2 in., in accordance with the recommendations given in [6].

The test specimens were of solid copper with 0·5 in. cross-section diameter. A 3 in. long rod was used for the Freon experiments and initial water experiments. A chromel–alumel thermocouple was led through a 0·063 in. hole drilled along a diametral direction at the mid-point of the rod to within 0·032 in. of the opposite surface. The thermocouple bead was wedged against the bottom of the hole. The lead wires were carried out through a stainless steel support tube brazed to the copper rod. Several water quenches were made with a 6 in. long rod having thermocouples placed at the mid-point near the surface, near the mid-point at the centerline, and near the surface 1·5 in. from the end. Toroidal specimens were utilized for the majority of the water tests and for all of the nitrogen tests. The tori were machined from a solid block to 0·5 in. diameter cross-section and 5·5 in. diameter. Three chromel–alumel (water) or copper–constantan (nitrogen) thermocouples were installed near the surface at 120° intervals.

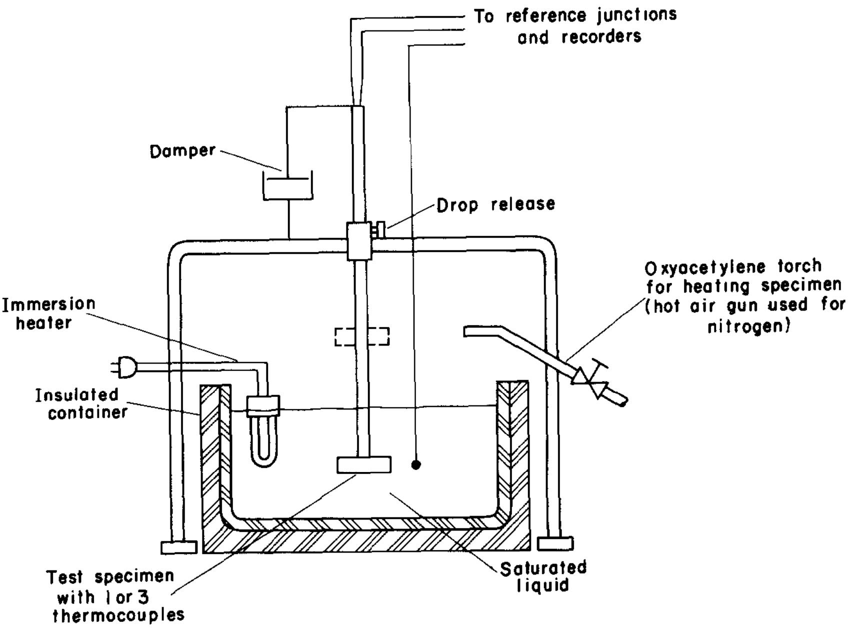

FIG. 3. Apparatus for quenching experiments.

The test surfaces were carefully finished, and given a final polishing with 500 emery and cleaned with acetone. The Freon and water pools were brought to saturation with the immersion heater; the ambient heat transfer was sufficient to keep the nitrogen boiling. The test specimens for Freon and water tests were uniformly heated by an oxyacetylene torch to 1000°F and 1100°F, respectively. The torch heating caused no more oxidation than oven heating in an air atmosphere, and was preferred due to its rapid heating rate. A hot air gun was used to heat the test specimens back up to ambient temperature after each nitrogen test. Ambient temperatures of approximately 80°F insured well established film boiling at the onset of quenching. After heating, the recording system was turned on and the drop release was activated. The thermocouples were used with individual reference junctions and provided with separate X–Y recorders having one scale for thermocouple e.m.f. and one scale for elapsed time.

Data reduction for quench experiments

The traditional approach to quenching experiments is to employ a single internal thermocouple and assume the system to be thermally lumped. The heat flux can then be computed from the direct measurement of the temperature–time slope from the cooling data

$$q'' = -(V/A)\rho c_p \mathrm{d}T/\mathrm{d}t. \tag{1}$$

In some experiments, however, the internal thermal resistance of the specimen cannot be neglected. Accordingly, recent investigators of quenching phenomena have expended considerable effort to develop accurate instrumentation and data reduction techniques which will account for internal temperature gradients in the specimen. Stolz *et al.* [6, 7] recorded the temperature history at several internal points of a spherical specimen. The inverse heat conduction problem was then solved numerically by extrapolating the measured temperatures to the surface and taking the gradient at the surface. Merte and Clark [1] measured the temperature near the surface of a sphere and utilized a finite-difference calculation to obtain the internal temperature distribution, which, in turn, yielded the instantaneous heat flux. With precise thermocouple positioning and careful differencing procedure, these numerical techniques give quite accurate results. However, it would appear that uncertainty could be introduced by assuming that the system is spherically symmetric. In general a considerable variation in the coefficient of heat transfer would be expected over the surface [6]. The thermocouples are generally placed to infer the temperature and/or heat flux at a particular point on the surface, but this point is not necessarily indicative of the entire surface. This suggests that an accurate assessment of the instantaneous average heat transfer coefficient during quenching can best be made with a specimen having negligible internal resistance.

The lumped parameter approach is usually considered to be accurate to within several per cent if the Biot number, hr_0/k, is less than about 0·2 [8, 9]. Since the maximum Biot number in the present case was approximately 0·24, for water at the peak nucleate heat flux condition, it was thought appropriate to compare a manual solution using equation (1) with a finite difference computer solution. The numerical solution was carried out using essentially the same scheme as employed by Merte and Clark [1]. As shown in Fig. 4, the manual lumped parameter solution compares favorably with the computer solution, thus indicating that the lumped parameter approximation is adequate for the present experiments. The majority of the present quench data were reduced by using equation (1), with the specific heat evaluated at the instantaneous wall temperature. It is estimated that the wall superheat is accurate to within ±5°F and heat flux uncertainty is of the order of ±5 per cent, the primary uncertainty being in the measurement of the slope of the T–t trace

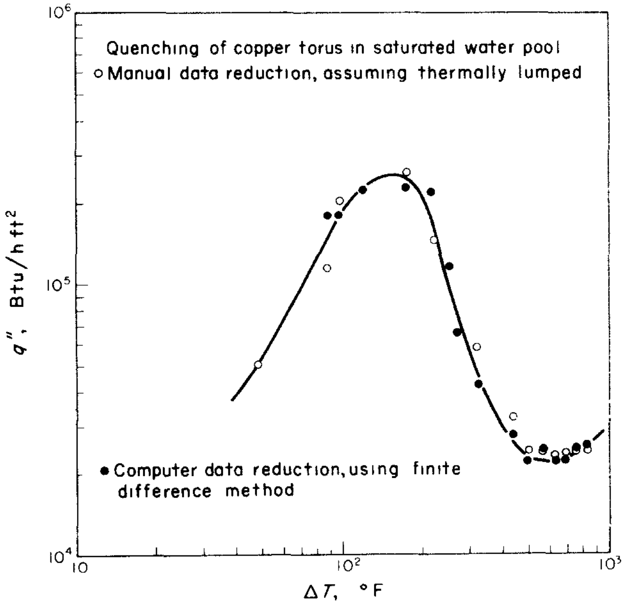

FIG. 4. Comparison of lumped parameter solution with finite difference solution.

Further details relating to the experimental procedure and data reduction can be found in [10].

DISCUSSION OF RESULTS

Freon-113 *results*

Two boiling curves are indicated in Fig. 5 for the electrically heated test section. The experiment started with a clean specimen; however, when film boiling was reached, the test section became fouled with carbon. The deposit, characteristic of the high temperature decomposition of fluorocarbon compounds, built up rapidly as the film boiling region was traversed. After nucleate boiling was established, the power was reduced and a second boiling curve was generated. The scale caused the nucleate region to shift to lower wall superheat, probably due to a favorable change in the nucleation site distribution. The peak nucleate heat flux was relatively unaffected by the scale, and was in good agreement with data reported recently for large diameter tubes [11]. In the film region, the heat-transfer coefficient is slightly higher than that for the clean specimen. Apparently the disturbance created by the scale irregularities overshadowed the additional conduction resistance.

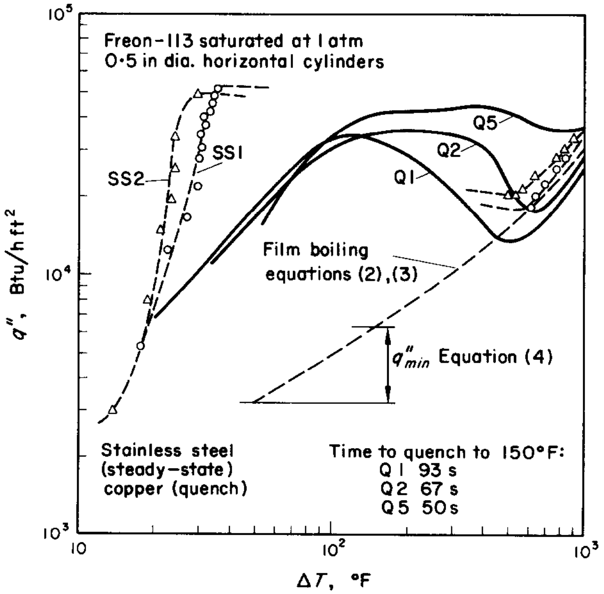

FIG. 5. Comparison of quench and steady-state data for horizontal cylinders in Freon-113.

The correlation of Frederking and Clark [12] is frequently used for turbulent film boiling from various geometries in saturated pools

$$Nu = 0{\cdot}15\,(Ra^*)^{\frac{1}{3}} \tag{2}$$

where

$$Ra^* = \frac{D^3 \rho_{vf}(\rho_l - \rho_{vf})\, g(h_{fg} + 0{\cdot}5\, c_{pvf}\Delta T)}{\mu_{vf} k_{vf} \Delta T}$$

which is valid for $Ra^* > 5 \times 10^7$. The total heat-transfer coefficient can be estimated using Bromley's suggestion for the radiation correction [13]

$$h \simeq h_{co} + 0{\cdot}75\, h_r \tag{3}$$

where

$$h_r \simeq \frac{\bar{\sigma}(T_w^4 - T_{\text{sat}}^4)}{\Delta T}.$$

As shown in Fig. 5, the data for the first steady-state run are in good agreement with the prediction of equations (2) and (3). The following relationship for the minimum heat flux in film boiling, developed by Zuber on the basis of hydrodynamic stability theory, is generally considered to be valid for large heaters

$$q''_{\min} = C h_{fg}\rho_v \left[\frac{\sigma g(\rho_l - \rho_v)}{(\rho_l + \rho_v)^2}\right]^{0\cdot 25} \tag{4}$$

where C is variously given as 0·177 [14], 0·13 [15], or 0·09 [16]. It is evident from Fig. 5 that the present data indicate a $q''_{\min}$ well above that predicted by equation (4).

Five successive quench runs were taken without removing the carbon scale which started to form during the first run. As indicated in Fig. 5, the quench times decreased with increased scaling and the boiling curves were shifted considerably. The general effect of the scale was to initiate transition boiling at higher heat flux and wall superheat. During additional experiments, the scale thickened until it fell off, whereupon the next quench reverted back toward a longer quench time. The heat-transfer coefficients are in reasonable agreement with the predictions of equations (2) and (3); however, the film boiling is destabilized much earlier than predicted by equation (4).

Due to the fouling, these tests do not permit a clear comparison of quenching and steady-state boiling. However, some conclusions can be drawn by comparing the initial runs, SS 1 and Q 1. The peak heat flux condition is shifted to lower heat flux and considerably higher wall superheat with quenching. The minimum film boiling condition for quenching occurs at lower heat flux and wall superheat; however, this could be attributed to a greater scale formation in the steady-state case, due to longer exposure at high temperature. In any event, these data suggest that there can be a difference in the boiling curves generated by quench and steady-state tests. Furthermore, the boiling curves are strongly dependent on the surface condition.

Water results

The steady-state tests were limited to a single run in the nucleate boiling range since the excursion to film boiling resulted in heater burnout. The nucleate boiling characteristics indicated in Fig. 6 are in good agreement with

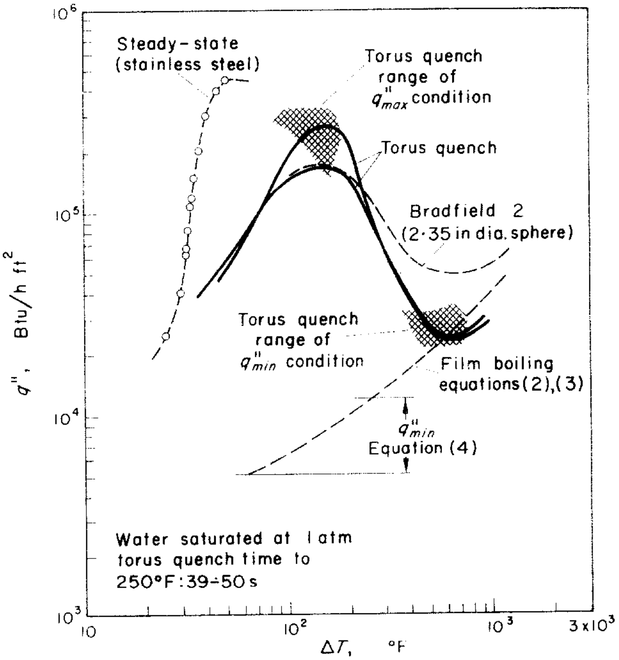

FIG. 6. Comparison of quench and steady-state data for water.

data for large-diameter horizontal stainless steel tubes [11]. The predictions of equations (2)–(4) are included as an indication of the probable behavior in the film boiling region.

Preliminary quenching tests were performed with 3 in. and 6 in. long cylindrical specimens. These test sections were chosen so as to be able to compare the quench results with steady-state pool boiling from a tube; however, the end-effects caused considerable uncertainty in interpretation of the data. It was found that transition and nucleate boiling were initiated first at the lower edges of the cylinders, thereby creating large axial temperature gradients. This is illustrated in Fig. 7 for two typical tests, where the differential temperature is taken between the midpoint near the surface and 1·5 in. away near the surface. The axial gradient is dependent on how the nucleation spreads; however, even when the ends were observed to nucleate at approximately the same time, the gradient was considerable. Under these conditions, the radial gradient was small, thus indicating the suitability of the thermally lumped approximation on a local basis. However, local heat balance and temperature could not be considered reliable in the presence of such large axial temperature gradients. These data illustrate the possibility of large metallurgical inhomogeneities in rods subject to rapid quenches.

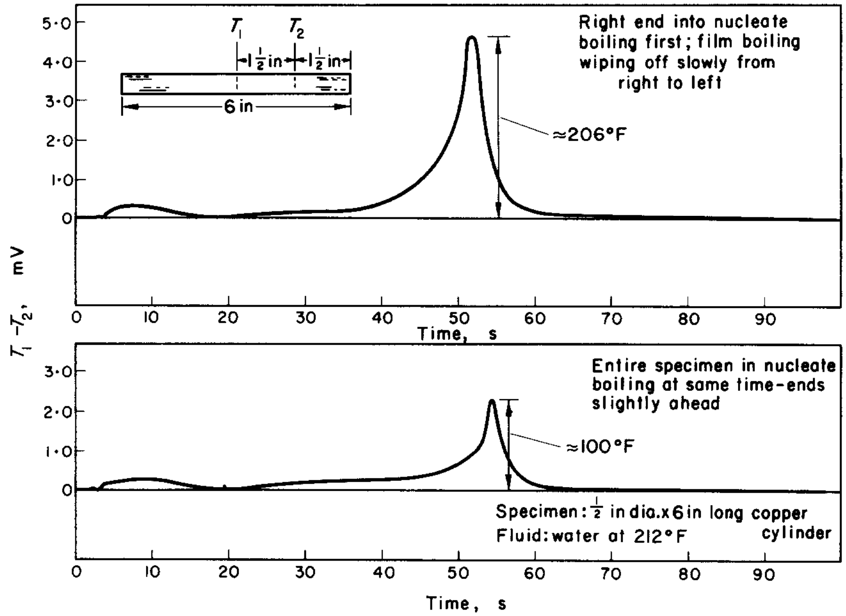

FIG. 7. Axial temperature variation within long cylinder quenched in water.

The toroidal test section was devised in order to eliminate the end effects encountered with cylindrical specimens. All of the boiling curve information presented in Fig. 6 was based on this type of quenching specimen. It was observed that the onset of transition and nucleate boiling would occur at a random location and spread rapidly to the rest of the specimen. Accordingly, the temperature–time traces for the three thermocouples were not identical. It was found, however, that there was no consistent trend in the derived boiling curve plots that could be attributed to the proximity of the thermocouple to the point where transition or nucleate boiling was established. In reducing the data for a particular quench, the T–t data for each location were treated independently; that is, the system was considered thermally lumped on a local basis. By taking a large number of data points it was felt that any effects of the localized initial nucleation would be minimized. Typical derived boiling curves are shown in Fig. 6, and the shaded areas indicate the range of q''_{max} and q''_{min} conditions for 24 experimental observations.

The film boiling portion of the quench is in fair agreement with the prediction of equations (2) and (3); however, the q''_{min} condition is well above the range indicated by equation (4). The q''_{max} condition for the quench occurs at lower heat flux and higher wall superheat than observed for the steady-state test. The boiling curve obtained by Bradfield [2] from a quenching experiment is in qualitative agreement with the trends of the present data. In general, these data corroborate the data of Table 1 which suggest considerable shifts in the boiling curve with quenching.

Nitrogen results

The steady-state data for nitrogen are shown in Fig. 8. The nucleate boiling and film boiling data are in good agreement with saturated pool boiling data for a $\frac{5}{8}$ in. o.d. horizontal copper tube reported by Flynn *et al.* [17]. The film boiling data are somewhat higher than predicted by equations (2) and (3); however, q''_{min} is within the range suggested by equation (4).

Boiling curves derived from typical quench runs are included in Fig. 8. The shaded areas indicate the range of q''_{max} and q''_{min} conditions for 27 tests. The experimental scatter could not be related to quenching sequence or to surface condition, since the surface was always polished in appearance. The boiling curve obtained by Merte and Clark [1], for quenching of 0·5 and 1·0 in. dia. copper spheres, is indicated for comparison. Merte and Clark observed less deviation from run to run, as might be expected since a small sphere should be less subject to variations caused by localized inception of nucleation.

It is clear from Fig. 8 that there is a significant difference between the present steady-state boiling curve and the average boiling curve derived from the quenching experiments. During quenching the film boiling is much more stable; accordingly the onset of transition boiling occurs

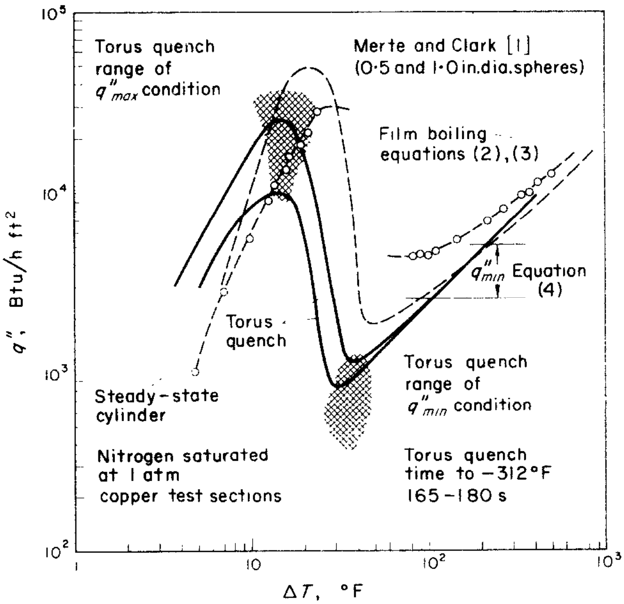

FIG. 8. Comparison of quench and steady-state data for copper test sections in nitrogen.

at reduced heat flux and wall superheat. The data of Merte and Clark suggest a similar shift in the q''_{min} condition.

DISCUSSION

The present tests indicate that there are significant differences between the boiling curves arrived at by steady-state electric heating methods and those derived from quenching experiments. The Freon and water results were quite similar in that the quenching curves were generally displaced to higher superheat. The explanation for this behavior can be given in terms of surface conditions. During a series of quenches with Freon, the surface became covered with a relatively rough, porous layer of carbon. The roughness introduces disturbances in the film which increase the probability of liquid contacting the surface. This effect can be seen in Fig. 9 by comparing Berenson's data for Runs 4 and 17. The liquid spreads rapidly once contact is established since Freon has excellent wetting characteristics. The porous surface also provides nucleation sites for the intermittent nucleate boiling which occurs during transition boiling. Intense nucleate boiling contributes to the high heat fluxes in transition boiling, thus virtually eliminating the characteristic negative-sloping region. As the wall superheat is reduced to about 100°F, nucleation takes over; however, it is probable that the large amount of vapor near the surface cannot be removed in the short time (~1 s) available. The nucleate region of the curve thus has a relatively low slope, similar to that commonly observed with bubble packing near the peak heat flux condition. The general effect of this concentration of vapor is to cause a reduction in q''_{max}.

The difference in the boiling curves for water is also due to surface effects; however, surface chemistry, rather than roughness, is the important consideration. When the quenched piece is preheated, the surface is oxidized and the wettability increases. This effect is evident in the data of Berenson shown in Fig. 9. It is seen that both surface oxidation and addition of a wetting agent (oleic acid) destabilized film boiling at a higher heat flux and wall superheat.

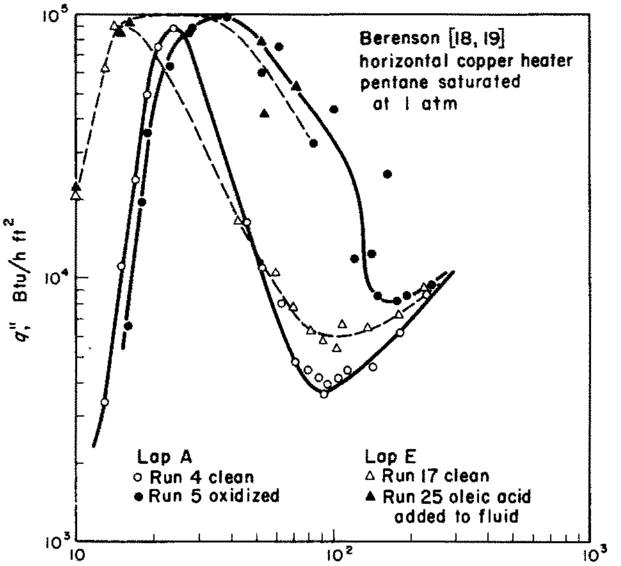

FIG. 9. Effects of wetting agent, oxidation and roughness on steady-state pool boiling.

This early destabilization produces an ill-defined peak heat flux condition, as is observed in the present Freon and water data. In a more recent study, Kovalev [20] showed that q''_{min} was elevated over a factor of two by continued exposure of the nichrome heater to saturated water at high pressure. In general, then, the value of q''_{min} predicted by theory [equation (4)] is to be regarded as a lower limit which can frequently be exceeded for engineering surfaces. Furthermore, the transition portion of the boiling curve is considerably different from that obtained by the usual procedure of linearly connecting up the steady-state q''_{max} point with the q''_{min} point. This alteration of the transition boiling characteristics is particularly significant in quenching since the quench times are greatly affected.

The nitrogen quench does not behave the same as the Freon and water quenches. The onset of transition boiling is clearly delayed and the quench times are longer than those which would be predicted by employing the steady-state boiling data. This cannot be explained in terms of surface effects since the nitrogen has extremely good wetting characteristics. It is improbable that the minor oxidation developed by exposing the quenching specimen to ambient temperature could decrease the wettability. If anything, some frost was developed after the first quench, and it has been demonstrated that frost, even in minute amounts, destabilizes film boiling of cryogens [21]. One possibility is that the nitrogen experiment represents a situation where the characteristic time of the system is comparable to the characteristic time of the process. This would not appear to be the case, though, since the bubble period is much smaller than the time constant of the calorimeter [1, 12]. However, a recent investigation has shown that a considerable time may be required for the collapse of film boiling. Giventer and Smith [22] applied a step decrease in power to an 0·01 in. dia. constantan wire which was initially in film boiling with liquid nitrogen. It was observed that delays of up to 2·5 s were encountered before the nucleate boiling was established. Although the extrapolation of these results to the present conditions is quite tenuous, an effect of this type could explain the late onset of transition boiling.

CONCLUSIONS

This investigation has established that under certain conditions there are large differences between the boiling characteristics of quenched specimens and boiling data obtained from conventional steady-state experiments.

At the start of the quench, the heat-transfer coefficient behaves as predicted by conventional expressions for stable film boiling. Scale deposits may alter the heat-transfer coefficient, however; in the present Freon-113 tests, carbon deposits elevated the coefficient.

The lower limit of stable film boiling is strongly dependent on the surface condition of the quenched piece. With Freon, the carbon deposits caused film destabilization at approximately 10 times the q''_{min} predicted for clean surfaces. Copper oxide was responsible for the q''_{min} for water being about 4 times the predicted value, due to an increase in surface wettability. This early destabilization of film boiling produces a large distortion in the transition and nucleate regions of the boiling curve, with q''_{max} lower and ΔT_{max} higher than that observed for comparable steady-state experiments. During the nitrogen quenches, film boiling terminated at heat fluxes well below those predicted; however, the transition and nucleate regions were similar to those expected from steady-state tests. A possible explanation for the extended film boiling range with nitrogen is that there is a relatively long delay time required for film collapse.

These results suggest that quenching times under engineering conditions will be considerable shorter than would be anticipated by using conventional boiling correlations to calculate the temperature history. Specimens to be quenched usually have surface contamination which will act to destabilize film boiling, thereby reducing the characteristic "slow cooling" portion of the quench. In general, with the complicated shapes usually quenched in industrial operations, the destabilization of film boiling will be highly localized. This could result in highly irregular metallurgical characteristics in the specimen.

These results further imply that the transient calorimeter technique is not generally suitable for obtaining reliable boiling curve information. Unless surface conditions can be strictly controlled, the transition and nucleate boiling regions are greatly distorted. Even with a cryogen, the differences between quench and steady-state boiling curves are sufficient to suggest that the quenching experiment may not provide accurate transition and nucleate boiling data.

ACKNOWLEDGEMENTS

W. G. Thompson's attendance at M.I.T. was supported by Bell Telephone Laboratories, Inc. W. K. Balcezak provided the program for the finite-difference calculations.

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RELATION ENTRE LES DONNEES DETREMPE ET LES DONNEES D'EBULLITION EN RESERVOIR EN REGIME PERMANENT

Résumé—On décrit des expériences qui établissent que, sous certaines conditions, il y a de grandes différences entre les caractéristiques d'ébullition de spécimens trempés et les données d'ébullition obtenues à partir d'expériences classiques en régime permanent. Les courbes d'ébullition distordues obtenues lorsque la trempe peut être attribuée à l'élévation de la condition $q''_{\min}$ dans le cas du Fréon-113 et de l'eau et de l'abaissement de la condition $q''_{\min}$ dans le cas de l'azote. Les résultats ont des implications pratiques pour les processus de trempe métallurgique et pour des études de transport de chaleur qui emploient la méthode transitoire du calorimètre.

DIE BEZIEHUNGEN ZWISCHEN ABSCHRECKWERTEN UND STATIONÄREN SIEDWERTEN

Zusammenfassung—Es werden Experimente beschrieben, mit denen festgestellt wird, dass unter bestimmten Bedingungen grosse Unterschiede zwischen den Siedecharakteristiken von abgeschreckten Proben und Siedewerten aus herkömmlichen stationären Versuchen bestehen. Die verzerrten Siedekurven, die man beim Abschrecken erhält, lassen sich zurückführen auf die Anhebung der $q''_{\min}$ Bedingung im Fall von Freon-113 und Wasser, und die Absenkung der $q''_{\min}$ Bedingung im Fall von Stickstoff. Die Ergebnisse haben praktische Bedeutung für metallurgische Abkühlungsprozesse und für Wärmeübergangsuntersuchungen, die die Ausgleichs-Kalorimeter-Methode benützen.

СРАВНЕНИЕ ДАННЫХ ПО ЗАКАЛКЕ С ДАННЫМИ ПО СТАЦИОНАРНОМУ СОСТОЯНИЮ ПРИ КИПЕНИИ В БОЛЬШОМ ОБЪЕМЕ

Аннотация—Описанные эксперименты показывают, что в определенных условиях существуют значительные отличия между характеристиками закаленных образцов при кипении и данными по кипению в обычном стационарном состоянии. Полученные искаженные кривые кипения при закалке можно объяснить увеличением $q''_{\min}$ ДЛя случая фреона-113 и воды и уменьшением $q''_{\min}$ для случая азота. Результаты можно использовать в металлургических процессах закалки и при исследовании теплообмена методом нестационарной калориметрии.