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DIRECT-CONTACT HEAT TRANSFER CHARACTERISTICS: EVAPORATION OF A DROP DROPPED ONTO A HOT LIQUID SURFACE

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Abstract—The evaporation time and the evaporation mode of liquid drops (*n*-pentane, dichloromethane, acetone and methyl alcohol) dropped onto the surface of a silicone oil at high temperature were measured, and the heat transfer characteristics between the two liquids were disclosed qualitatively over a wide range of temperature difference.

The evaporation time curves generally showed the existence of a maximum and a minimum of apparent heat transfer rate at respective superheats of the hot liquid, similarly to what is observed for liquid–solid contact. The observed evaporation modes were grouped into twelve types.

NOMENCLATURE

h,	distance from the lower end of the nozzle to the surface of hot liquid [mm];
h',	depth from the surface of hot liquid to the position to measure the bulk temperature [mm];
L,	latent heat of evaporation [kJ kg^{-1}];
$\bar{m}_d$,	average mass of the drop [kg];
t,	time [s];
t_s,	remaining time in spherical form (time required from the dropping to the collapse of spherical form of the liquid [s];
t_t,	total evaporation time (time required for complete evaporation of the dropping liquid) [s];
T_f,	flashing temperature [K];
T_{sat},	saturation temperature of dropping liquid [K];
ΔT_L,	temperature of hot liquid minus T_{sat} at Leidenfrost point [K];
ΔT_{sat},	temperature of hot liquid minus T_{sat} [K];
ΔT_{sub},	T_{sat} minus temperature of dropping liquid [K].

Greek symbols

ν,	kinematic viscosity [cSt] $= 10^6$[m^2 s^{-1}];
ρ,	density [kg m^{-3}];
σ,	surface tension [N m^{-1}].

1. INTRODUCTION

PHENOMENA observed at the contact of two liquids being different in temperature from each other have become an important subject of study in connection with liquid–liquid direct contact heat transfer, vapor explosion and the like. Although many researchers have investigated these phenomena, the heat transfer characteristics over wide temperature ranges seem to have not yet been clarified. Such characteristics are supposed to be useful in discerning the most effective temperature difference for direct contact heat transfer and in estimating the explosive potential of a given liquid–liquid combination. The purpose of this work is to disclose the fundamental and macroscopic characteristics of the above mentioned phenomena by means of a special experimental system.

The reason that the heat transfer characteristics at liquid–liquid contact has not been sufficiently elucidated, in spite of the fact that heat transfer characteristics at solid–liquid contact is fairly well known, may be that when an experiment, such as the boiling heat transfer experiment, is applied to liquid–liquid system, the agitation of the interface becomes so violent that not only detailed observation of the situation is impossible but it is also difficult to vary the temperature difference widely and to obtain quantitative data. There have been some experimental studies [1–3] of heat transfer between two liquid layers, but the agitation seems to interrupt the conduct of experiments over wide range of temperature difference. As a method to study a given phenomenon with little influence from the interfacial agitation, a method in which one liquid in drop form is contacted with the other liquid is considered. Actually, in some studies [4–7] on the direct contact heat transfer or the superheat limit of liquids, a liquid in drop form is fed into other higher-boiling point liquids. Also in some vapor explosion studies [8, 9], a liquid mass is introduced into another liquid. However, in these processes, the experiments are limited only to studies on the state before the occurrence of complete evaporation or solidification. Further, because the temperature of the liquid drop or mass may sometimes vary greatly during the experiment, it is very difficult to grasp the behavior at every temperature difference of the two liquids. Thus, it seems difficult to study the characteristics at liquid–liquid contact over wide ranges of temperature or temperature difference by means of ordinarily conducted experimental systems.

In the present study the following experimental system was adopted: a liquid drop was dropped onto the free surface of a second liquid kept at a temperature higher than the saturation temperature of the former liquid. And, the evaporation mode, its change and the evaporation time were measured. Similar phenomena on a solid surface are known as the Leidenfrost phenomenon and related phenomena, and have been studied by many researchers. On the other hand, studies of the phenomena on a liquid surface have been relatively limited. Hendricks and Baumeister [10] have determined the heat transfer of a water sphere floating on a liquid nitrogen in Leidenfrost film boiling. However, many questions concerning the phenomena on a liquid surface, including the characteristics of the evaporation time curve, are yet unanswered.

In the present experiments four species of silicone oil were used as the higher temperature liquid (hot liquid), while as the dropping liquid *n*-pentane and dichloromethane which are miscible in the hot liquid, and acetone and methyl alcohol which are practically immiscible in the hot liquid were used.

2. EXPERIMENTAL APPARATUS AND PROCEDURE

Figure 1 shows the experimental apparatus schematically. The hot liquid 1 was placed in a glass vessel 2 of 90 mm I.D. to a height of about 18 mm and was kept at a prescribed temperature with the aid of a heater 3 and a temperature regulator 4. With the aid of a microsyringe 6, a liquid drop 5 was dropped onto the surface of the hot liquid through a nozzle 7 of fine stainless steel tube. Experiments were carried out within the range of drop diameters wherein the liquid drop could be considered as a sphere (up to about 2 mm diameter). The sphericity of a drop was confirmed by comparing the diameter calculated from the measured weight with the diameter observed from above. The weight of the drops of the same liquid dropped through the same nozzle conformed to the normal distribution and the ratio of standard deviation against mean value was about 10%. The temperature of the drop at the time of dropping was kept the same by a small heat exchanger 8 at the top part of the nozzle and was measured with a thermocouple 9 at the outlet of the nozzle. The dropping height *h*, the distance from the lower end of the nozzle to the surface of the hot liquid, could be varied by a fine adjustment 10.

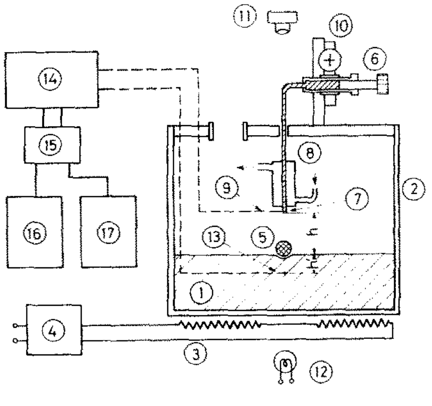

FIG. 1. Schematic diagram of experimental apparatus.

Observation of the evaporation mode of the liquid drop and measurement of the variation in liquid drop diameter in Leidenfrost film boiling were carried out with the apparatus shown in Fig. 1, visually or by use of a motor-driven 35 mm camera 11, with light provided by a lamp 12 at the bottom. Further, for observation from the horizontal direction, a vessel with parallel glass planes on both sides was used. In measuring evaporation time, a single drop was dropped and the time was measured with a stopwatch under visual observation.

To measure the bulk temperature of the hot liquid, the hot junction 13 of a thermocouple was set at the depth $h' = 5$ mm. Through a cold junction 14 and a change-over switch 15, the output of the thermocouple was measured with a self-balancing recorder 16 or a digital voltmeter 17.

Silicone oils of dimethylpolysiloxane series were used as the hot liquid. Table 1(a) shows some properties of the silicone oils used for the study. These oils are relatively stable up to high temperature and their kinematic viscosities can be varied widely without causing a great change in the other physical properties. In the table, S300, for example, is an oil whose kinematic viscosity at room temperature is about 300 centi-Stokes (cSt). Physical properties other than the kinematic viscosity of the hot liquid, which may relate to the phenomenon to be studied, are surface tension and density. However, the macroscopic and general behavior of the phenomenon to be studied could be sufficiently determined by use of the hot liquids shown in Table 1(a) in combination with dropping liquids described later, and only the above-mentioned liquids were used in the present study.

Table 1(b) shows the species and some fundamental properties of the liquids used as dropping liquid. In choosing liquid species, consideration was given not only to solubility with the hot liquid, density relative to the hot liquid and latent heat of evaporation but also to the ability of the species to attain to Leidenfrost film boiling in the temperature range in which the hot liquid is stable.

Further, for the purpose of comparing the results of the present study with those of the Leidenfrost phenomenon of a solid–liquid system, an experimental apparatus with a high temperature solid surface of brass was specially prepared, and a series of experiments was carried out.

Table 1. Properties of liquids used in the experiment

(a) Properties of hot liquids

	ν^* (cSt)† (298 K)	ρ (kg m^{-3}) (298 K)	σ (N m^{-1}) (298 K)	T_f (K)
S300	300 ± 15	0.970×10^3	1.98×10^{-2}	588
S100	100 ± 5	0.965×10^3	—	573
S50	50 ± 2.5	0.960×10^3	—	543
S20	20 ± 1	0.950×10^3	1.84×10^{-2}	513

* Temperature coefficient of viscosity = 0.57–0.60 (= 1 − (viscosity at 372.1 K)/(viscosity at 311.0 K)).

† 1 cSt = 10^{-6} m s^{-1}.

(b) Properties of dropping liquids

	T_{sat} (K)	ρ (kg m^{-3}) (293 K)	L (kJ kg^{-1})	σ (N m^{-1})
n-Pentane	309.3	0.626×10^3	3.58×10^2	1.60×10^{-2} (293 K)
Dichloromethane	313.0	1.32×10^3	3.30×10^2	2.65×10^{-2} (303 K)
Acetone	329.7	0.796×10^3	5.21×10^2	2.00×10^{-2} (323 K)
Methylalcohol	338.2	0.792×10^3	11.01×10^2	2.00×10^{-2} (323 K)

3. EVAPORATION MODES AND EVAPORATION TIME CURVE

3.1. *Typical evaporation process and evaporation time curve*

The evaporation mode, the change of the mode and the evaporation time depend strongly on the combination of the two liquids, the degree of superheat, the lapse of time and other factors. Therefore, typical results will first be described to facilitate a general understanding of the experimental results.

As an example, sketches of the evaporation modes with the lapse of time for the case when a drop of methyl alcohol was dropped onto the S300 surface from h = 5 mm are shown in Fig. 2. The figure shows the change in evaporation mode with time t at each degree of superheat, observed from above. In the lower right part of some columns, the mode observed from the side is also shown. Further, numerals are given in some columns to show the average diameter of typical shapes in mm. In Fig. 2 and some of the other figures, the value ΔT_{sat} is regarded as the principal variable as in the Leidenfrost phenomenon on a solid surface. Here, however, the bulk temperature of the hot liquid is adopted instead of the surface temperature used in the case of a solid.

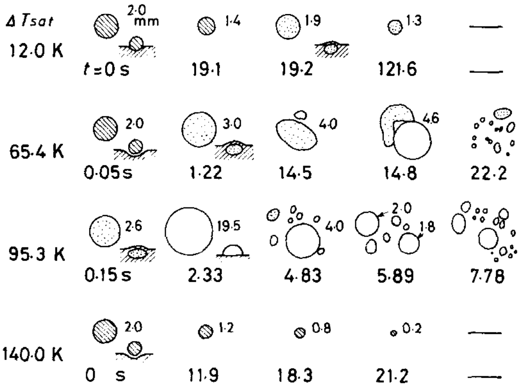

FIG. 2. Sketches of the evaporation mode with the lapse of time after dropping (methyl alcohol–S300).

In the case of ΔT_{sat} = 12.0 K, the liquid drop floats on the hot liquid as a sphere 2.0 mm in diameter (denoted by oblique lines) just after the dropping, and then gradually becomes smaller. But, at t = 19.2 s, the drop sinks and stays just beneath the surface of the hot liquid, taking a somewhat flat state (denoted by dotting). This state shall be called 'floating state beneath the surface' in this paper. Thereafter, maintaining a similar state, it becomes smaller over a very long time and finally disappears. At ΔT_{sat} = 65.4 K, the liquid drop floats on the surface only for a short time after the dropping and soon sinks beneath the surface of the hot liquid. The drop decreases its volume rather slowly, varies in shape and is accompanied by sporadic bubbling (denoted by empty circle). At ΔT_{sat} = 95.3 K, the drop takes a floating state beneath the surface just after the dropping in a short time, and evaporates completely with a large bubble and a lot of small bubbles in succession. At ΔT_{sat} = 140 K, the drop, maintains a floating state on the hot liquid, gradually becomes smaller due to evaporation, and disappears.

As mentioned above, the evaporation mode is affected strongly not only by the degree of superheat, but also in some cases by time elapsed, even at the same degree of superheat.

Figure 3 shows a typical example of a measured evaporation time curve. The curves in the figure were obtained by averaging the time data measured at the occurrence of mode change as a function of the degree of superheat for the methyl alcohol–S300 system. A and A′ (area shaded with widely spaced oblique lines) are regions in which the drop, remaining spherical, is held on the surface of the hot liquid, B (dotted area) is the region in which the drop is held in a floating state beneath the surface, C (area shaded with finely spaced oblique lines) is the region wherein the drop is accompanied by bubbling, and the uppermost bold solid line is the total evaporation time curve. As can be seen from this example as well as the data shown below, the total evaporation time curve for a liquid–liquid system is generally in the form of an S laid sideways, similarly to that for a solid–liquid system, and the evaporation curve reaches the maximum at a specific degree of superheat. Also, at a lower superheat degree, the curve passes the minimum, namely the hourly mean heat transfer rate reaches the maximum value.

It is hard to distinguish the mode in the A region from that in the A′ region in Fig. 3. However, it is concluded that the drop is in Leidenfrost film boiling in region A, while in region A′ the two liquids are in contact with each other directly or through a thin air layer or, in rare cases, through a thin vapor layer, and the drop is only in a floating state on the hot liquid.

Further, point L in the figure may properly be referred to as the Leidenfrost point and the region between point L and the minimum point can be considered to be a transition region analogous to that on a solid surface.

A good understanding of the evaporation process at each degree of superheat can be made by comparing Fig. 3 with Fig. 2. For example, at ΔT_{sat} corresponding to P–P in Fig. 3, the drop evaporates through the processes: spherical form → floating state beneath the surface → bubbling, while at ΔT_{sat} corresponding to Q–Q, the drop seems to evaporate while remaining in Leidenfrost film boiling. In reality, the drop in the latter case at last suddenly boils with bubbling to complete evaporation, namely it passes through region C, but the residence time in C is so short that no distinct time interval can be shown in the figure. Actually, region C exists up to point L. Further, for the same reason as mentioned above, region B seems not to exist in the transition region at high degrees of superheat, but detailed observation showed that, also in this case, that the drop was in a floating state beneath the surface, though instantaneously, just before the occurrence of boiling with vigorous bubbling.

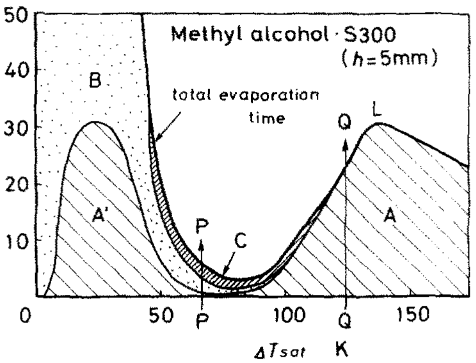

FIG. 3. Typical evaporation time curve (methyl alcohol–S300).

3.2. *Classification of evaporation modes*

Evaporation modes observed in the range of the present experimental conditions were dependent strongly on the combination of two liquids, the degree of superheat, the lapse of time, etc., but typical modes could be generally classified as shown in Fig. 4. The upper half of each column shows the mode observed from above, while each lower half shows the mode observed from the side. Each mode is explained below.

(a) *Leidenfrost film boiling.* This mode corresponds to the Leidenfrost film boiling on a high-temperature solid surface, and a liquid drop, remaining in spherical form, floats on the surface of the hot liquid through a vapor layer, while the surface of the hot liquid is hollowed along the curvature of the liquid drop. This mode usually appears at high degree of superheat, but also appears when the dropping liquid is miscible with the hot liquid, or when the density of the dropping liquid is larger than that of the hot liquid. When the kinematic viscosity of the hot liquid was low or the liquid drop became small, the drop sometimes moved about on the surface of the hot liquid. The experiments showed that the diameter of the drop in this state decreases in proportion to the lapse of time.

(b) *Floating state on the surface.* This mode is observed at low superheat, and it is thought that a spherical drop floats with the two surfaces in contact with each other directly or through a thin gas layer. The rate of volume reduction is very slow, and this state is rarely kept to the end of evaporation and, in the course of time, changes into (c) or (g).

(c) *Floating state beneath the surface.* In this state, a liquid drop, becoming somewhat flat, sinks itself directly beneath the surface of the hot liquid. This state could be observed distinctly only when the drop was immiscible with the hot liquid. The volume reduction rate is very low. This may be caused by the presence of a thin layer of the hot liquid covering the surface of the drop. It was confirmed beforehand that, in the course of the transition from (a) to the boiling state with bubbling, this state or (d) was passed through once in most cases. Thus, this may be one of the important modes.

(d) *Deformed floating state beneath the surface.* It was found that sometimes (c) is deformed with the lapse of time to form such as a thick saucer in which the

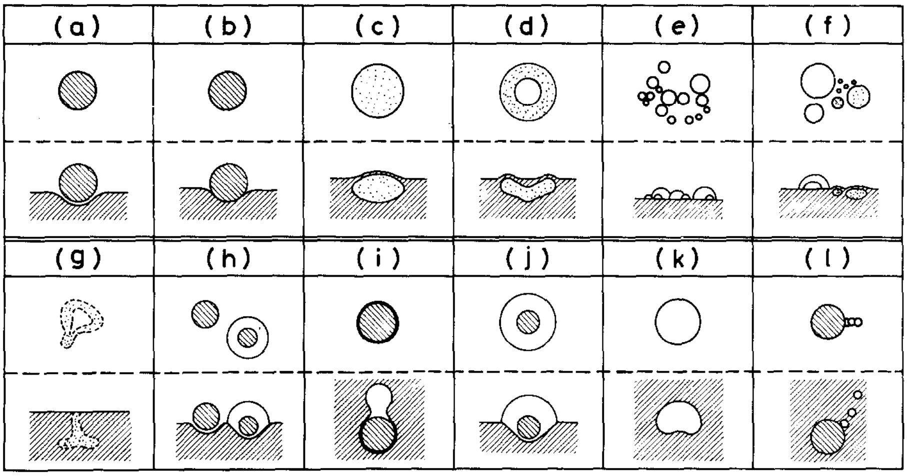

FIG. 4. Sketches of classified evaporation modes.

hot liquid stays or to form a more complicated shape and then split into smaller parts.

(e) *Instantaneous boiling on hot liquid.* Directly after a drop is brought from (a) state to contact with the hot liquid, it boils to complete evaporation instantaneously. Sometimes this boiling is attended with scattering of the hot liquid. As the latent heat of evaporation is decreased, the boiling tends to be more vigorous.

(f) *Slow boiling on hot liquid.* Following the floating state beneath the surface, a drop repeatedly bubbles, splits into many droplets, and then boils slowly to evaporate. This mode can be observed only for immiscible liquids, at a lower degree of superheat than that in (e).

(g) *In solution.* This mode is the process, in which, after a miscible liquid drop contacts directly with the hot liquid, it dissolves in the latter. Owing to the dissolution, it is impossible to establish the total evaporation time. In some cases when the viscosity of the hot liquid was high and the degree of superheat was also somewhat high, instantaneous boiling of the dropping liquid, which had apparently once dissolved in the hot liquid, was observed.

(h) *Splitting state.* In this case, a drop splits into several droplets at the time of dropping, and all droplets evaporate in the same mode or partly in other.

(i) *Film boiling in hot liquid.* In this mode, a liquid drop sinks into the hot liquid and, forming a vapor film around itself, evaporates. This mode was observed more often for dropping liquids with larger density.

(j) *Leidenfrost film boiling with dome.* This state is a kind of Leidenfrost film boiling but the upper part of the drop is covered with a dome-like film of the hot liquid. It appears that the drop, once sunk in the hot liquid, may rise again to the surface after film boiling occurs. The dome breaks up when it has grown to about 4 to 5 times the size of the drop.

(k) *Instantaneous boiling in hot liquid.* In this mode, a drop suddenly boils to evaporate in the course of sinking in the hot liquid. A single bubble is formed, which increases rapidly in volume and then rises quickly. This mode is observed when a sinking drop, having no vapor film, comes in direct contact with the hot liquid. The dropping liquid may be superheated to reach its limit, and thus this mode may correspond to that referred to by Mori *et al.* [11] as "single bubble boiling". When this boiling phenomenon occurred near the surface of the hot liquid, it was sometimes accompanied by the scattering of liquid droplets. Further, when it happened at the bottom of the vessel or in contact with a side wall, an highly explosive boiling was observed.

(l) *Slow boiling in hot liquid.* In this mode, small vapor bubbles continuously evolved from a part of the surface in the hot liquid.

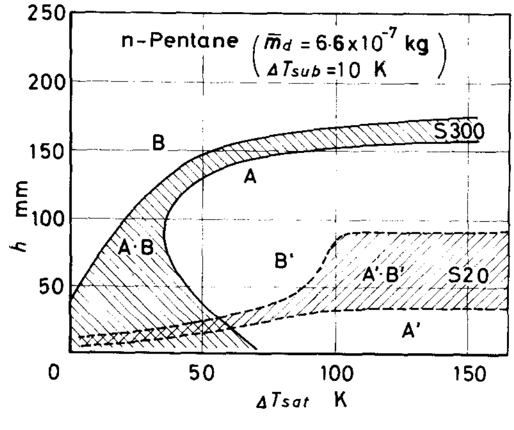

FIG. 5. Relation between remaining tendency in spherical form and dropping height.

3.3. *Effects of dropping height and subcooling of liquid drop*

Prior to systematic experiments on the evaporation time, an examination was made on the effects on results of the factors enumerated in the heading. Figure 5 shows the results of experiments carried out to see whether a drop of *n*-pentane dropped from a height *h* remains spherical on the hot liquid or not. S300 and S20 were used as hot liquids. In each case, at the lower right of the hatched part (A or A′), the drop remains spherical, while at the upper left part (B or B′), it dissolved directly at the time of dropping, and in the hatched part both modes coexisted. As can be seen from Fig. 5, the drop tends to remain spherical, in general, at smaller *h* and larger ΔT_{sat}, though the tendencies in the two hot liquids were different from each other. Considering the above facts and the purpose of this study, the main experiments were carried out at $h = 5$ mm.

Figure 6 shows an example for the effect of the initial subcooling of the liquid drop on the remaining time in spherical form t_s. It is impossible to establish the evaporation time for a miscible liquid drop, because such a liquid drop is dissolved in direct contact with the hot liquid making the interface unclear, and moreover, because the phenomenon is not evaporation but dissolution. Thus, t_s was considered for miscible liquids. However, in the region where the degree of superheat is higher than that of the maximum point in Fig. 6, t_s is equal to the evaporation time, because the drop evaporates in the state of Leidenfrost film boiling. Further, the maximum point is the limit of existence of Leidenfrost film boiling. Thus, because the maximum point is at any rate the point of apparent maximum evaporation time, it can be considered as the Leidenfrost point for miscible liquid. As can be seen from Fig. 6, when the ΔT_{sub} is reduced, the Leidenfrost superheat becomes lower. This may be caused by the fact that the subcooling is lower, and the formation of the vapor film at the time of initial contact is more satisfactory. In the following experiments, ΔT_{sub} was taken generally within 10 K, but in one series of experiments in which a comparison was necessary, ΔT_{sub} was kept in the same.

3.4. *Curve of remaining time in spherical form for miscible liquid drop*

As explained in the preceding section, in the case of a drop which was miscible with the hot liquid, the remaining time in spherical form was considered instead of the evaporation time. But as shown in Fig. 6, *n*-pentane drops below the Leidenfrost superheat were dissolved immediately after dropping and the existence of a transition region was hardly observed. Also, as the experimental data at $t_s = 0$ in the figure shows, drops even above the superheat were sometimes dissolved immediately.

Figure 7 shows the t_s curve of dichloromethane for each hot liquid. It was found that the hot liquid has little effect on Leidenfrost film boiling at a high superheat, but remarkable effects at a low superheat. In the figure, the evaporation time curve on a brass surface is also shown for comparison. Evaporation modes of representative S300 system are as follows. At $\Delta T_{sat} < -10$ K, the drop is dissolved directly in the hot liquid. At $-10\ \mathrm{K} < \Delta T_{sat} < 100$ K, the mode changed (a) → (g) or sometimes through (a) → (g) and the drop sunk into the liquid and soon boiled explosively at the bottom of the vessel. At $\Delta T_{sat} > 100$ K, the drop evaporated intact in (a).

From the above results it may be concluded that the curves of the remaining time in spherical form, namely the apparent evaporation time curves, for miscible liquid drops resemble the form of an S laid sideways. But, an inflection point can scarcely be observed on the curve for S20 in Fig. 7, and this curve may be an exceptional one which lies on the extension of Leidenfrost film boiling region.

3.5. *Evaporation time curve for immiscible liquid drop*

Figure 8 shows the evaporation time curve and the time curve of mode change for an acetone drop dropped on S300. The evaporation mode could be

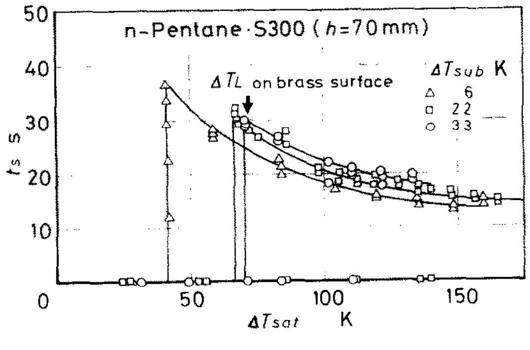

FIG. 6. Remaining time in spherical form versus initial subcooling of drops.

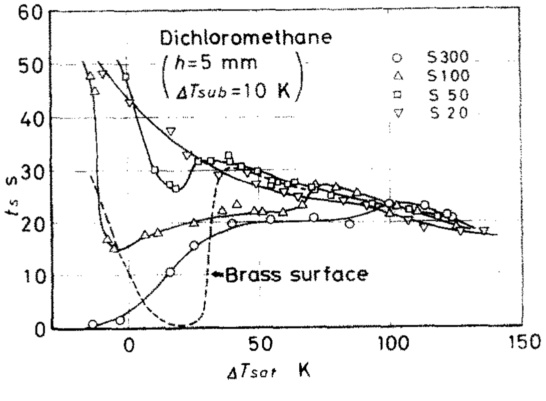

FIG. 7. Remaining time in spherical form versus the degree of superheat for dichloromethane.

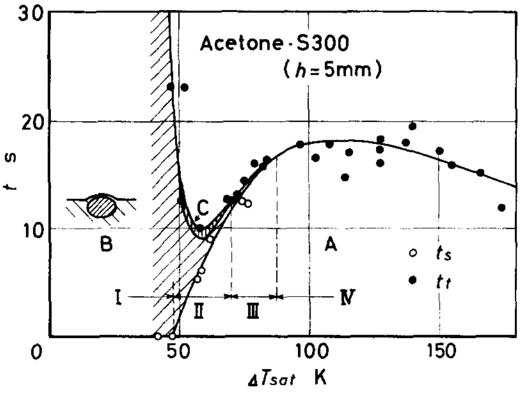

FIG. 8. Evaporation time curve and evaporation mode for acetone–S300.

classified into four regions according to the degree of superheat. In region I, (c) → (d) modes were observed and the larger ΔT_{sat} was, the more amorphous (d) was. In region II, mode changed (a) → (c) or (d) and then the drop disappeared through (e). In region III, the major part of the evaporation time is in (a) mode and before disappearance of the drop, the mode changed from (c) to (e) or (f). In region IV, the drop evaporated, maintaining the mode (a).

Figure 9 shows the results of experiments on the total evaporation time (empty marks and solid lines) and the remaining time in spherical form (black marks and dotted lines) for methyl alcohol drops. Results for S300 have already been described in detail in Section 3.1. For S100, the modes and their changes are almost the same as those for S300, except for a shift toward less superheating to some extent. For S20, as for the dichloromethane–S20 system, the maximum and minimum points which are usually found in other cases are not observed on the t–ΔT_{sat} curve. But, in the range $50\text{ K} < \Delta T_{sat} < 100\text{ K}$, gentle inflection points and considerable scattering of data are observed. Thus, it may be considered that the evaporation time curves, including that for S20, are generally in the form of an S laid sideways in the range of this experimental conditions.

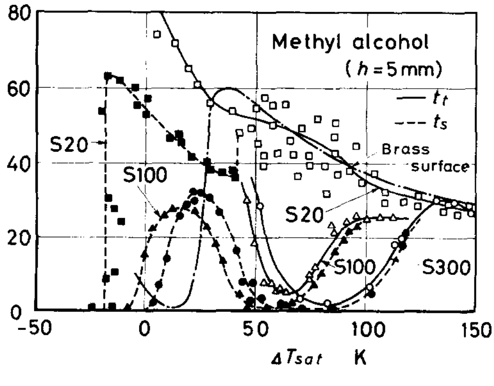

FIG. 9. Evaporation time curves and remaining time curves in spherical form for methyl alcohol.

4. CONSIDERATION ON EVAPORATION TIME CURVE

As can be seen from Fig. 9, etc., even in systems consisting of the same dropping liquid and silicone oil of the same dimethylpolysiloxan series, the effects of the silicone oils on evaporation differ, especially in the low superheat range, depending on the nature of the silicone oils. This phenomenon seems to be complicated and troublesome to investigate and is probably caused not only by physical properties, such as viscosity, surface tension, density and the like, but also by affinity between the two components or between the hot liquid and the dropping liquid vapor or the atmosphere, solubility, diffusion coefficient and so on. However, this phenomenon is not the main subject of the present study and is therefore not discussed here.

From the view point of heat transfer behavior, the fact that the total evaporation time curve is generally in the form of an S laid sideways may be very important. The fact shows that the characteristics of average heat transfer coefficient, which is proportional to the term $1/(t_t \cdot \Delta T_{sat})$ [12], versus the degree of superheat, agrees qualitatively with that during boiling of liquid on a solid heating surface. Also, the evaporation time curve may be a measure in choosing an effective heat transfer condition. For example, to increase the heat transfer capacity, it may be effective to contact both liquids at the degree of superheat which is near the minimum evaporation time point.

Further, as shown in the case of Fig. 9, the minimum evaporation time is about 3 s for S300, about 6 s for S100, while for S20, though not precisely established, about 40 to 60 s. It may be reasonably anticipated that a liquid–liquid combination with less minimum evaporation time contains more potential for explosive behavior at their contact. Therefore, for the purpose of examining the possibility of the occurrence of explosive behavior for a given liquid–liquid combination, an attempt to draw an evaporation time curve, as shown in Fig. 9, may be one of these measures. For example, only from the heat transfer rate, explosive behavior would not be expected in the combination of methyl alcohol and S20, but if S100 and S300 should be used in place of S20, the possibility of explosive boiling would increase.

5. CONCLUSION

A fundamental study on the heat transfer characteristics at the time of liquid–liquid contact over a relatively wide range of temperature difference was conducted empirically by investigating the evaporation mode and evaporation time of a spherical drop dropped onto a silicone oil surface at high temperatures. The main results obtained under the conditions applied in the present study can be summarized as follows:

(1) The evaporation time curve was generally of the form of an S laid sideways, similar to the curve for a solid surface, that is, the existence of a maximum of evaporation time, i.e. a Leidenfrost point, and a maximum of apparent heat transfer rate were observed. However, the shapes of the evaporation curves were strongly dependent on the combination of liquids.

(2) For a miscible liquid drop with the hot liquid, the remaining time in spherical form was measured. A transition region was not observed for *n*-pentane, but was observed for dichloromethane.

(3) The Leidenfrost superheat was affected not only by the combination of liquids but also by the initial subcooling of the dropping liquid.

(4) Evaporation modes were strongly affected by the combination of liquids, the degree of superheat and the time elapsed after the dropping. The modes were classified into 12 main types and details of each type were explained.

(5) It was observed that just before boiling evaporation accompanied by rapid bubbling, the system always passed through a mode, such as the floating state beneath the surface of the hot liquid, in which the two liquids directly contacted each other.

(6) It was suggested that the evaporation time curve might be used to obtain fundamental data on the capacity for the liquid–liquid direct contact heat transfer, or to estimate the probability of an explosive boiling.

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CARACTERISTIQUES DU TRANSFERT THERMIQUE PAR CONTACT DIRECT: EVAPORATION D'UNE GOUTTE A LA SURFACE D'UN LIQUIDE CHAUD

Résumé—On étudie expérimentalement le temps d'évaporation et le mode d'évaporation des gouttes liquides (*n*-pentane, dichlorométhane, acétone et alcool méthylique) posée sur la surface d'une huile siliconée de température élevée et les caractéristiques du transfert thermique entre les deux liquides sont déterminées qualitativement dans un large domaine de différence de température.

Les courbes de temps d'évaporation montrent généralement l'existence d'un maximum et d'un minimum du flux thermique apparent pour certaines surchauffes du liquide, comme cela est observé dans le contact liquide–solide. Les modes d'évaporation observés sont groupés en douze types.

CHARAKTERISTIK DES WÄRMEÜBERGANGS BEIM DIREKTKONTAKT: VERDAMPFUNG EINES AUF EINE HEIßE FLÜSSIGKEITSOBERFLÄCHE GEFALLENEN TROPFENS

Zusammenfassung—Gemessen wird die Verdampfungszeit und die Art der Verdampfung, wenn ein Flüssigkeitstropfen (*n*-Pentan, Dichlormethan, Azeton und Methylalkohol) auf eine heiße Oberfläche aus Silikonöl auftrifft. Der Wärmeübergang zwischen den beiden Flüssigkeiten wird qualitativ in einem großen Bereich von Temperaturdifferenzen untersucht. Ähnlich wie beim Wärmeübergang fest-flüssig zeigen die Kurvenverläufe der Verdampfungszeit grundsätzlich die Existenz eines Maximums und eines Minimums des bei entsprechenden Überhitzungen vorhandenen Wärmestroms. Die beobachteten Verdampfungsarten werden in zwölf Gruppen eingeteilt.

ХАРАКТЕРИСТИКИ КОНТАКТНОГО ТЕПЛООБМЕНА: ИСПАРЕНИЕ КАПЛИ, НАНЕСЕННОЙ НА НАГРЕТУЮ ПОВЕРХНОСТЬ ЖИДКОСТИ

Аннотация — Определялись время и характер испарения капель *н*-пентана, дихлорметана, ацетона и метилового спирта, нанесенных на нагретую поверхность силиконового масла. Проводилась качественная оценка характеристик теплообмена между двумя жидкостями в широком диапазоне температурных разностей. Кривые времени испарения в большинстве случаев указывают на наличие максимума и минимума интенсивности теплообмена при соответствующих перегревах жидкости аналогично тому, что имеет место при контакте между жидкостью и твердым телом. Наблюдаемые режимы испарения разбиты на 12 групп.