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ENHANCED INTERFACIAL HEAT TRANSFER BY DIFFERENTIAL VAPOR RECOIL INSTABILITIES

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Abstract—During steady evaporation at subatmospheric pressures, spontaneous interfacial convection may be initiated by the differential vapor recoil mechanism. The onset of such convection is marked by a sudden, order-of-magnitude increase in the rate of interfacial transport. This paper presents the first quantitative measurements of the enhancement. Specifically, interfacial heat-transfer coefficients are measured as a function of evaporative flux and operating pressure for triethanolamine evaporating in the range of 0.2–67 Pa pressure. These data are then compared with similar measurements for a TEA surface immobilized by a soluble surface-active agent, which eliminates interfacial turbulence. In the presence of spontaneous interfacial convection, heat-transfer coefficients increase dramatically with increasing evaporative flux and with decreasing vapor phase pressure (for pressures above 7 Pa). These trends are consistent with the phenomenological model of vapor recoil instabilities and with inferences from linear stability analysis. Such trends are not observed for the surfactant-covered interface. Of particular interest is the sudden decrease in h with decreasing pressure below 7 Pa for the 'clean' interface. At these pressures, the gas phase no longer behaves like a continuum and, consequently, the vapor molecules are increasingly less effective at shearing the vapor–liquid interface and driving liquid flows.

NOMENCLATURE

C_p,	heat capacity of liquid;
E,	evaporation coefficient, commonly equal to unity;
g,	gravitational acceleration;
Gr,	Grashof number $= g\beta L^3(T_B - T_S)/\nu^2$;
h,	average interfacial heat-transfer coefficient;
k,	thermal conductivity of liquid;
L,	characteristic dimension of the horizontal surface;
M,	molecular weight of fluid;
Nu,	Nusselt number $= hL/k$;
P^0,	vapor pressure of liquid at the surface temperature T_S;
P_v,	overbearing pressure in the vapor phase;
Pr,	Prandtl number $= \nu/\alpha$;
R_G,	gas constant;
T_B,	bulk liquid temperature;
T_S,	temperature of the vapor:liquid interface;
T_{sat},	equilibrium or saturation temperature at the prevailing pressure;
T_V,	vapor phase temperature $\approx T_{\text{sat}}$.

Greek symbols

α,	thermal diffusivity of liquid $= k/\rho C_p$;
β,	volumetric coefficient of expansion;
η,	average evaporative flux;
λ,	latent heat of vaporization $= 119\ \text{cal}\,\text{g}^{-1}$;
μ,	shear viscosity of liquid;
ν,	kinematic viscosity of liquid $= \mu/\rho$;
ρ,	density of liquid.

INTRODUCTION

IT IS well known that when liquids evaporate, natural convection currents are often established due to surface cooling which promotes heat transfer to the surface and increases the rate of evaporation. For liquids vaporizing into air, the forces engendering fluid motion are differential buoyancy and surface tension [1,2]. If air is excluded and the liquid is allowed to evaporate at its normal boiling point (1 atm pressure) the surface temperature is virtually independent of position, being at the equilibrium boiling point [3]. Consequently, surface tension gradients are negligibly small and interfacial convection is by density stratification alone. Under such circumstances, interfacial convection currents (as opposed to bulk liquid mixing) increase heat transfer, but only to a limited extent, lowering liquid superheat by ~35% at most at a fixed evaporation rate [4].

On the other hand, if a liquid in contact with its own vapor is evaporated at pressures below 100 Pa, interfacial heat-transfer and evaporation rates can be increased dramatically by the onset of interfacial convection by differential vapor recoil [5,6]. This mechanism for producing interfacial convection proceeds in the following way. Because mass must be conserved at the interface, the change in fluid density on evaporation results in a discontinuity in both the fluid velocity normal to the interface and the rate of transport of linear momentum across it [7]. The result is a downward force on the interface (vapor recoil) which increases with increasing evaporation rate and decreasing pressure. Any disturbance in the form of a local increase in surface temperature will increase the local evaporative flux, causing an increase in the recoil force. Since the liquid surface is deformable, a depres-

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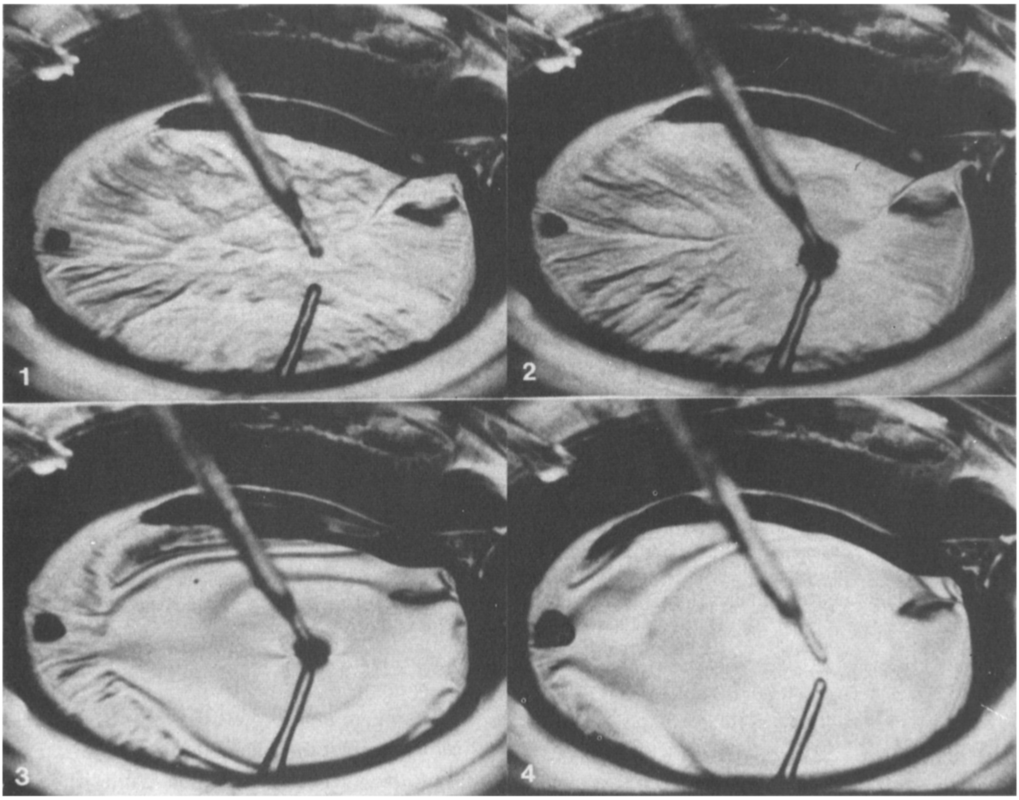

FIG. 1. Photographic sequence of the TEA surface evaporating in the main flask A demonstrates the effect of a surface-active solute on interfacial convection by differential vapor recoil: (1) clean working surface, (2) probe with additive coating is touched to surface, (3) additive spreads over surface and suppresses interfacial convection, and (4) torpid surface remains with an evaporation rate one-tenth that measured in frame (1). Total elapsed time is about 5 s.

sion or crater is created whose walls are sheared by the departing vapor. Hot liquid is dragged up to a point of already higher temperature, amplifying the original disturbance [8].

With the aid of linear stability analysis we have predicted criteria for the onset of spontaneous interfacial convection by differential vapor recoil and have demonstrated that this mechanism dominates interfacial behavior for evaporation into a partial vacuum [8, 9]. The analysis confirms that the potential for vapor-recoil instability increases as the evaporative flux is increased and as the pressure is decreased. Furthermore, experiments and stability analysis reveal the extreme sensitivity of the vapor recoil mechanism to interfacial contamination [6, 10]. For convection to be induced by this mechanism, the surface must be mobile. It is well known that surface-active solutes impart an elasticity to the surface of polar liquids which diminishes or even eliminates interfacial motion under many circumstances [11]. Thus, the addition of even trace amounts of a surface-active material to a liquid evaporating under vacuum can wipe out all interfacial convection produced by differential vapor recoil. The effect is graphically illustrated in Fig. 1, in which 0.34 mg of α-tocopheral acid succinate (a water-soluble vitamin E derivative) is added to an evaporating surface of triethanolamine (TEA) in our experimental apparatus. Frame 1 shows a clean surface of TEA steadily evaporating at about 10 Pa pressure and the accompanying small-scale interfacial turbulence due to differential vapor recoil. In subsequent photographs a probe containing the surfactant is touched to the surface (frame 2), the surfactant spreads over the surface (frame 3), and completely damps out the small-scale interfacial convection currents within seconds (frame 4). Simultaneously, the evaporation rate drops off precipitously while the bulk liquid temperature rises, indicating a substantial reduction in the rate of interfacial heat transfer in the system.

In summary, then, the following trends in interfacial heat transport can be expected when differential vapor recoil disrupts the interfacial layer during evaporation under vacuum. First, the interfacial heat-transfer coefficient for the liquid phase will depend explicitly on evaporative flux and vapor phase pressure as well as on the thermal driving force. It will increase as the evaporative flux increases and as the vapor phase pressure decreases. Second, the interfacial heat transfer-coefficient will be extremely sensitive to interfacial contamination. When a surface-active solute is added to the evaporating liquid, the heat-transfer coefficient will be reduced substantially despite the surfactant's minimal effect on bulk flow patterns. This is in contrast to the experimental results of White [4] which show only a limited effect of surfactants on interfacial heat transfer during evaporation at atmospheric pressure. In addition, the heat-transfer coefficient for a surfactant-laden interface will no longer display an explicit dependence on evaporative flux and pressure.

The purpose of the present paper is to present results of our quantitative experimental investigation of interfacial heat transfer during steady evaporation into a partial vacuum. Conditions conducive for interfacial convection driven by differential vapor recoil are studied. The evaporating surface is either clean and mobile or contaminated and torpid. Results are interpreted in light of the expectations described above.

EXPERIMENTAL APPARATUS

Ideally, experiments designed to investigate spontaneous convection by differential vapor recoil should parallel the experiments of Schmidt and Milverton [12] among others for buoyancy driven convection and those of Palmer and Berg [13] for surface tension driven convection. In their experiments, measurements were made of the conditions needed to produce convection in thin, quiescent liquid layers heated from below. However, it is extremely difficult to establish, maintain and measure a uniformally thin (<5 mm) steadily evaporating liquid pool in a vacuum. Consequently, in the present study evaporation rates from deep layers are measured. Although gross bulk convection patterns are present, the interfacial turbulence produced by differential vapor recoil is so intense and of such small scale that its effects on interfacial heat transfer are easily distinguishable from the effects of bulk convection.

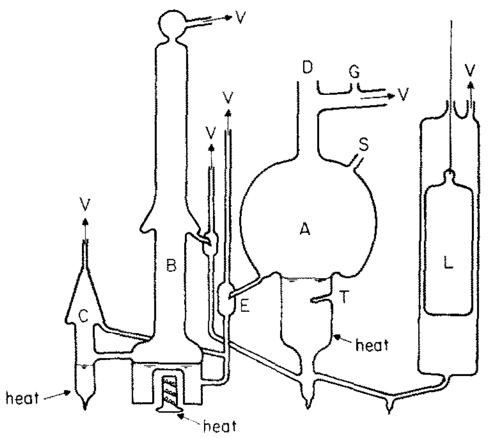

FIG. 2. Schematic diagram of the all-glass apparatus for measuring steady evaporation rates from 'all-working' surfaces of TEA. Impurities are successively concentrated from A to B to C by continuous distillation with surface overflow. Heat is supplied where indicated with windings of nichrome wire; cooling for condensation is supplied by forced air. Vacuum is produced by a mechanical pump and oil diffusion pump in series (not shown) connected at V.

The all-glass apparatus used in the experiments is shown schematically in Fig. 2. Liquid in the main flask A steadily evaporates from the vapor:liquid interface only, with no sub-surface boiling, and condenses entirely on the walls of this flask which are cooled by forced air convection. The condensate then flows through a calibrated dropper E to the boiler B, which provides an additional purification step before the liquid is returned to A. The dropper was calibrated under experimental conditions, and permits a quick, straightforward determination of the evaporation rate to within ±2% by counting drops, as long as the evaporation rate is in the range 0.01–0.15 ml/s. The interfacial area of the evaporating liquid in A is 43.6 cm^2. Operating pressure is measured with both a thermocouple gauge and a Pirani gauge at G. Bulk liquid temperature is measured to within ±0.2°C with a mercury thermometer inserted in the thermocouple well T. The temperatures of the vapor phase and of the condensate return from B are measured with chromel–alumel thermocouples. By raising or lowering the plumb level control L, the liquid level in A is lowered to contain the interface during evaporation rate measurements and raised to overflow the interface and shed interfacial contaminants during the continuous repurification procedure between experiments.

All experiments were done with triethanolamine (TEA) as the test fluid because it has a suitable volatility at convenient temperatures (~0.1 Pa at 25°C) and because its interfacial mobility can be altered in a controlled fashion with the addition of minute amounts of surface-active solutes. It was found that an 'all-working' TEA surface could be produced consistently by continuous redistillation with surface overflow (at 0.5 Pa) between experiments [10]. Thus, the interpretation of results was not complicated by the unpredictable effects of spurious interfacial contamination. Under no circumstances did torpid regions cover more than 5% of the total interfacial area of the evaporating liquid in the 'clean surface' experiments. Numerous replications of experiments verified that such small extents of torpidity had no measurable effect on the results.

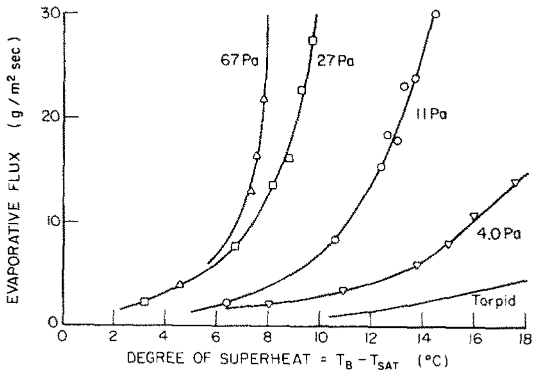

FIG. 3. Typical experimental evaporative flux data.

DATA AND ANALYSIS

In the experiments, overall evaporation rates and thus average evaporative fluxes were measured as a function of the bulk liquid temperature, with pressure held constant. Experiments were done at pressures ranging from 0.2 to 67 Pa both with 'clean' evaporating surfaces and with surfaces immobilized with Igepal-970, which is a soluble surfactant for TEA (see [10] for details). Data for contaminated (torpid) surfaces are presented only for surfaces which exhibited no visual signs of spontaneous interfacial convection. Typical data are shown in Fig. 3. The curve labeled 'torpid' represents only a portion of the data taken at 27 Pa pressure with a contaminated surface. These data actually extend to 27° of superheat, at which point the evaporative flux is only 10 g m^{-2} s^{-1}. Comparison of this curve with that for a clean surface at 27 Pa pressure reveals the dramatic increase in evaporative flux and thus in interfacial heat transfer afforded by spontaneous convection via differential vapor recoil.

Visual observations of the natural convection patterns in the interior of the liquid indicate that there are two main regions of convective heat transfer in the liquid. Heat transfer between the heated container walls and the bulk liquid occurs by a somewhat regular, large-scale turbulent motion driven by differential buoyancy. On the other hand, heat transfer to the vapor : liquid interface appears to occur by a more complicated pattern of random, small-scale interfacial convection which transports heat from the bulk liquid to the surface. These observations suggest that the characteristic driving force for interfacial heat transfer is the difference between bulk liquid temperature T_B and surface temperature T_S. Thus, the average interfacial heat-transfer coefficient h is defined as

$$\text{heat flux} = \lambda\eta = h(T_B - T_S). \qquad (1)$$

Temperature measurements made with a 0.008 cm dia. thermocouple on a telescoping probe reveal that the thermal boundary layer at the vapor : liquid interface is less than 0.1 cm thin and that the bulk liquid temperature is uniform. Compared to the lateral extent of the surface (~7.5 cm), this boundary layer is extremely thin and suggests that wall effects may be neglected. A number of experiments were done with heat supplied asymmetrically to the flask (to one side of the cylindrical wall and also to just the bottom of the flask) to substantially alter the large-scale natural convection patterns in the bulk liquid. Only minor differences in the heat transfer data were observed and trends in the data were unaltered. Finally, inspection of Fig. 1, frame 1 indicates no noticeable, lateral variation in the intensity or scale of interfacial turbulence and suggests that a simple average heat-transfer coefficient as defined by equation (1) will adequately describe the character of interfacial heat transfer in these experiments.

At atmospheric pressure, the evaporation rate of a pure liquid at the boiling point is usually determined solely by the rate of heat transfer to the interface from the bulk liquid, the vapor : liquid interface having the equilibrium or saturation temperature at the prevailing system pressure [3]. However, under vacuum conditions the vapor pressure at the boiling point is substantially less and the intrinsic rate at which molecules can leave the vapor : liquid interface becomes an important factor in determining the overall evaporation rate. The relationship between evaporative flux η and surface temperature T_S is given by the Hertz–Knudsen equation [14]:

$$\eta = E\left[\frac{M}{2\pi R_G}\right]^{1/2}\left[\frac{P^0}{\sqrt{T_S}} - \frac{P_v}{\sqrt{T_v}}\right] \qquad (2)$$

where P^0 is the vapor pressure of the liquid at the surface temperature T_S. The evaporation coefficient E is commonly equal to unity [15, 16, 17]. Thus, from the measured value of evaporative flux, the surface temperature may be calculated from equation (2) and the interfacial heat-transfer coefficient computed from equation (1).

Alternatively, the evaporative flux from a torpid surface may be *estimated* from existing correlations of natural convection heat transport in combination with equation (2). For a torpid surface interfacial heat transport is by differential buoyancy only, the vapor : liquid interface being cooled by evaporation. This physical situation for the liquid phase is analogous to that of a fluid above a heated, horizontal plate, the heat-transfer coefficient being given by the dimensionless correlation [18, 19]

$$Nu = \frac{hL}{k} = 0.54(Gr\,Pr)^{1/4}$$

where L is the length of the square heated plate. Although the coefficient 0.54 was determined primarily from experiments with air, extensive natural convection experiments in other situations suggest that any additional Prandtl number dependence (if any) will alter this coefficient only slightly. Therefore, this correlation should yield a reasonable estimate of the liquid phase heat-transfer coefficient (and thus of evaporative flux) for the torpid surface of TEA in our experiments, provided that wall effects are insignificant, large-scale bulk convection plays a secondary role, and thus the characteristic driving force is bulk temperature T_B minus surface temperature T_S.

In our experiments, the interface is circular and L is taken to be the square root of the interfacial area, 6.6 cm. With the physical property data for TEA available from Union Carbide

$$h = [0.0657 + 0.0003(T_B - 120)][T_B - T_S]^{1/4} \qquad (3)$$

where the effect of temperature on viscosity has been included, with T_B and T_S in °C and h in kW m^{-2} K^{-1}. This relationship may now be combined with equations (1) and (2) to predict η and T_S for a torpid surface. The vapor pressure data needed for these calculations was also obtained from Union Carbide and extrapolated by the method of Othmer [20]. In the tempera-

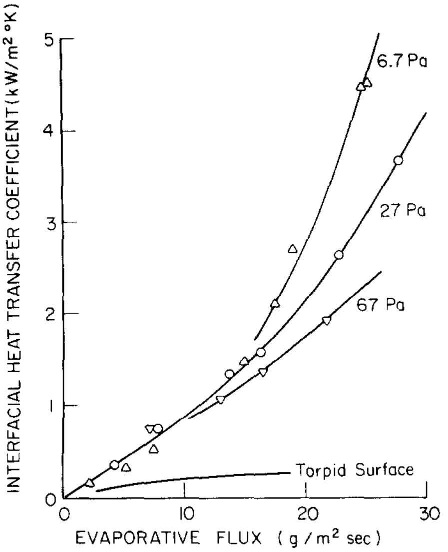

FIG. 4. Average interfacial heat-transfer coefficients as a function of evaporative flux for several constant pressures. The single curve for the torpid surface represents evaporative flux data collected at all pressures studied.

ture range of interest

$$\ln P^0 = 25.620 - 8918.38/T$$

where P^0 is measured in Pa and T in °K. At 27 Pa pressure, the existing natural convection correlations predict evaporative fluxes of 2, 5 and 10 g m^{-2} s^{-1} at superheats of 11, 18 and 26°C, respectively. Referring to Fig. 3, we see that these predictions are extremely close to the evaporative fluxes measured in our experiments. This close correspondence between predictions and the actual experiments with immobilized surfaces further supports the usefulness of a simple average heat-transfer coefficient for correlating our experimental data.

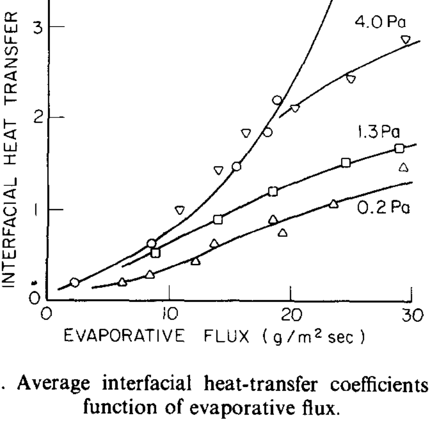

FIG. 5. Average interfacial heat-transfer coefficients as a function of evaporative flux.

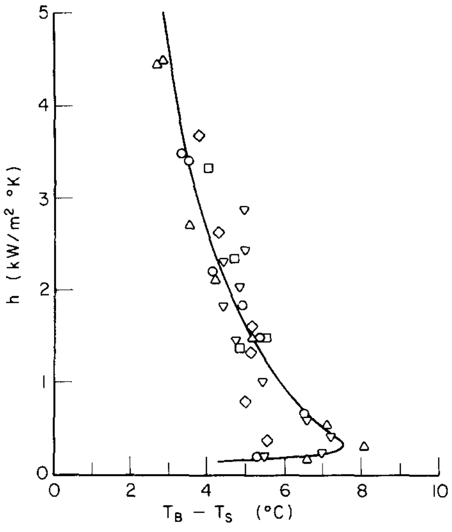

FIG. 6. Experimental values of the temperature difference at the interface as a function of the interfacial heat-transfer coefficient: ▽ 4.0, △ 6.7, ○ 11, ◇ 27, □ 40 Pa pressure.

HEAT TRANSFER RESULTS

Figures 4 and 5 present our experimental results in terms of average heat-transfer coefficients as a function of evaporative flux at various pressures. In all cases notice the sharp increase in h with evaporative flux for surfaces free of surface-active contamination. This strong dependence of h on evaporative flux is real and is not due to a simultaneous increase in the thermal gradient at the interface. In fact, the temperature difference $(T_B - T_S)$ actually decreases with increasing evaporative flux (and h) over most of the range of experimental conditions, as shown in Fig. 6. This trend is entirely consistent with spontaneous convection by differential vapor recoil. Since the intensity of interfacial turbulence should increase as the evaporative flux is increased, we anticipate that the interfacial heat-transfer coefficient will be proportional to both evaporative flux and thermal driving force:

$$h \propto \eta^a (T_B - T_S)^b.$$

With the aid of equation (1) it follows that

$$h \propto [T_B - T_S]^{(a+b)/(1-a)}$$

for any set of experiments at constant pressure. Thus if $a > 1$, h will appear to be inversely proportional to $(T_B - T_S)$. Each data set exhibits a maximum value for $(T_B - T_S)$ at $h \approx 2$ kW m^{-2} K^{-1}. Above this value of h, the intensity of interfacial convection is governed by the differential vapor recoil mechanism, while for $h < 2$ kW m^{-2} K^{-1} natural convection heat transfer is probably due to the buoyancy or surface tension mechanism.

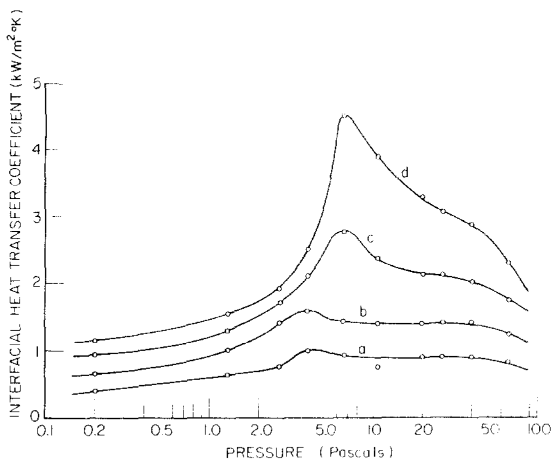

FIG. 7. Pressure dependence of the average interfacial heat-transfer coefficient: (a) 10, (b) 15, (c) 20 and (d) $25 \text{ g m}^{-2} \text{ s}^{-1}$.

Based on our model of vapor-recoil induced convection, the *liquid phase* heat-transfer coefficient should also increase with decreasing *vapor phase* pressure. This trend is shown clearly in Fig. 4 for pressures above ~7 Pa. However, inspection of Fig. 5 reveals that this trend is reversed for pressures below 7 Pa. This transition from increasing to decreasing h as pressure is decreased is illustrated more clearly in Fig. 7, where h has been cross-plotted against pressure at fixed values of the evaporative flux.

This sudden reversal in the pressure dependence of h suggests that the continuum model for the gas phase no longer applies for our system at pressures below 7 Pa. Interfacial convection via the vapor recoil mechanism is produced by viscous shearing of the liquid by the departing vapor in the vicinity of surface depressions. Any reduction in the efficiency of this viscous shearing process will reduce the effectiveness of differential vapor recoil to disrupt the interface and enhance heat transfer. For pressures below 0.1 MPa (~1 atm) the viscosity of a gas is independent of pressure. However, viscosity is a macroscopic property which is meaningful only if the length scale of the system is very much larger than the mean free path of the fluid molecules. At ~7 Pa pressure the mean free path of TEA molecules in the gas phase is about equal to the length scale for the system* (~1 mm) and the mean free path increases as the gas pressure is reduced. Consequently, as the pressure is reduced below 7 Pa the continuum model becomes inapplicable for describing the gas phase dynamics in our experimental system. The ability of the gas phase to shear the liquid in surface depressions decreases, and thus the interfacial heat transfer coefficient decreases.

Heat transfer data for a TEA surface stabilized with Igepal-970 are also included in Fig. 4. The interfacial heat transfer coefficients for this all-torpid surface are extremely low in comparison to those for a clean surface, despite the fact that all other experimental variables except surface contamination remain the same. Our experimental results also reveal that h for a contaminated surface is independent of pressure, within experimental error. Thus, the curve labeled 'torpid' represents all the data for contaminated surfaces which was collected in the pressure range studied. All the above characteristics reflect the absence of spontaneous convection by differential vapor recoil caused by the increased surface rigidity associated with surfactant contamination.

CONCLUSIONS

The experimental data presented here are the first quantitative measurements of the high rates of interfacial heat transfer produced by spontaneous interfacial convection during steady evaporation at subatmospheric pressures. Interfacial heat-transfer coefficients for clean, convecting interfaces are as much as 20 times greater than those for interfaces immobilized by a surface-active solute. Furthermore, the value of h for a clean surface increases sharply with evaporative flux and shows a distinct pressure dependence. In contrast, the value of h for the immobilized interface is essentially independent of evaporative flux and pressure. All the observed trends in the rate of interfacial heat transfer are consistent with our phenomenological model of natural convection via the differential vapor recoil mechanism.

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* Recall that the thermal boundary layer at the interface was measured to be less than 0.1 cm thin.

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ACCROISSEMENT DU TRANSFERT THERMIQUE A L'INTERFACE PAR DES INSTABILITES DE RECUL DIFFERENTIEL DE VAPEUR

Résumé—Pendant l'évaporation permanente à une pression inférieure à une atmosphère, une convection spontanée à l'interface peut être déclanchée par le mécanisme du recul différentiel de vapeur. L'apparition de cette convection est marquée par un accroissement soudain de l'ordre de grandeur du transport interfacial. On présente les premières mesures de cet accroissement. Les coefficients de transfert thermique interfacial sont mesurés en fonction du flux massique évaporé et de la pression pour l'évaporation de triethanolamine entre 0,2 et 67 Pa. Ces expériences sont comparées avec des mesures similaires pour une surface de TEA immobilisée par un agent surfactant soluble qui élimine la turbulence interfaciale. En présence de la convection spontanée interfaciale, le coefficient de transfert thermique croît considérablement en même temps que le flux évaporé augmente et que la pression de la phase vapeur décroît (pour des pressions supérieures à 7 Pa). Ces tendances sont compatibles avec le modèle des instabilités de recul de vapeur et avec les conclusions de l'analyse linéaire de stabilité. On n'observe rien de tel pour l'interface bloqué par le surfactant. Il faut noter en particulier la diminution soudaine de h quand le pression diminue au dessous de 7 Pa pour la surface "propre". A ces pressions, la phase gazeuse cesse d'être un milieu continu et par suite les molécules de vapeur deviennent beaucoup moins efficaces pour cisailler l'interface liquide–vapeur et provoquer les mouvements du liquide.

STEIGERUNG DES WÄRMETRANSPORTS AN DER GRENZFLÄCHE DURCH DIFFERENTIELLE DAMPF-RÜCKPRALL-INSTABILITÄTEN

Zusammenfassung — Während der stationären Verdunstung bei Drücken unterhalb des atmosphärischen Druckes kann durch den differentiellen Dampf-Rückprall-Mechanismus an der Grenzfläche spontane Konvektion hervorgerufen werden. Der Beginn dieser Konvektion is charakterisiert durch eine plötzliche Zunahme der Transportraten an der Grenzfläche um Größenordnungen. Hier wird über die ersten quantitativen Messungen dieser Zunahme berichtet. Es werden insbesondere mit Triäthanolamin, das im Druckbereich von 0,2 bis 67 Pa verdampft, Wärmeübergangskoeffizienten als Funktion der Verdunstungsrate und des Arbeitsdruckes gemessen. Diese Ergebnisse werden dann mit ähnlichen Messungen verglichen, die an einer TEA-Oberfläche gewonnen wurden, welche durgh einen löslichen, oberflächenaktiven Zusatz entspannt worden war, wodurch Turbulenz an der Grenzfläche verhindert wurde. Bei spontaner Konvektion an der Grenzfläche steigen die Wärmeübergangskoeffizienten mit zunehmender Verdunstungsrate und sinkendem Dampfdruck (für Drücke über 7 Pa) drastisch an. Diese Verläufe stimmen mit dem phänomenologischen Modell der Dampf-Rückprall-Instabilitäten und mit den Folgerungen aus den Berechnungen nach der linearen Stabilitätstheorie überein. Bei der entspannten Oberfläche sind solche Verläufe nicht beobachtet worden. Von besonderem Interesse ist die plötzliche Abnahme von α mit zunehmendem Druck bei "sauberer" Grenzschicht unterhalb von 7 Pa. Bei diesen Drücken verhält sich die Gasphase nicht mehr wie ein Kontinuum, und folglich läßt die Schubspannungswirkung der Dampfmoleküle an der Dampf/Flüssigkeits-Grenzfläche merklich nach und damit auch ihr Einfluß auf den Flüssigkeitsstrom.

ИНТЕНСИФИЦИРОВАННЫЙ МЕЖФАЗНЫЙ ТЕПЛОПЕРЕНОС ЗА СЧЕТ ДИФФЕРЕНЦИАЛЬНЫХ НЕУСТОЙЧИВОСТЕЙ ОТДАЧИ ПАРА

Аннотация — В стационарном режиме испарения при давлении ниже атмосферного спонтанная межфазная конвекция может вызываться механизмом дифференциальной отдачи пара. Возникновение конвекции отмечается мгновенным увеличением на порядок величины интенсивности межфазного переноса. В данной работе впервые проведены количественные измерения этого увеличения плотности теплового потока. В частности, измерялась зависимость коэффициентов межфазного теплопереноса от плотности потока испарения и рабочего давления для триэтаноламина, испаряющегося в диапазоне давлений от 0,2 до 67 Ра. Затем проводилось сравнение с данными аналогичных измерений на термоэлектроактивной поверхности с покрытием из ПАВ, исключающим возникновение межфазной турбулентности. При спонтанной межфазной конвекции значения коэффициентов теплопереноса резко возрастали при интенсификации испарения и уменьшении давления в паровой фазе (при давлениях выше 7 Ра). Такое поведение согласуется с феноменологической моделью неустойчивости отдачи пара и с выводами линейного анализа устойчивости. При наличии поверхностно-активного вещества на границе раздела этих тенденций не наблюдается. Особый интерес представляет мгновенное снижение значения α с уменьшением давления ниже 7 Ра для поверхности раздела без покрытия из ПАВ. В этом случае газовая фаза уже не ведет себя как сплошная среда и, следовательно, молекулы пара оказывают значительно меньшее влияние на напряжение сдвига на границе раздела пар-жидкость и течение жидкости.