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LAMINAR FILM CONDENSATION OF A VAPOR CONTAINING A SOLUBLE, NONCONDENSING GAS

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Abstract—An integral theory is indicated for the effect of a soluble, noncondensable gas on the laminar film condensation of stagnant vapor on a vertical surface, and by approximations on the results a compact definition is given for saturated air–steam mistures. Also, approximations on the theory itself yield a simple result for any vapor–gas combination in which the gas fraction is low, the gas is heavier than the vapor, and the Lewis number is near unity. The effect of gas-solubility in the condensate is found to be fully negligible for air–steam mixtures and quite small even for carbon dioxide–steam.

Additional experimental results are given for steam and various gases which generally support the theory.

NOMENCLATURE

c,	ratio of condensate thickness to $x^{1/4}$;
D,	binary mass-diffusion coefficient;
F,	nondimensional function defined by equation (11);
f,	ratio of vapor boundary-layer thickness to $x^{1/4}$;
G,	nondimensional function defined by equation (11);
g,	gravitational acceleration;
H,	Henry's law constant;
h_{fg},	latent heat of vaporization for condensable species;
I,	contraction for an integral (cf. equations (12)–(15));
j,	diffusive mass-flux (positive in y-direction);
k,	thermal conductivity;
M,	molecular weight;
$\dot{m}$,	mass flux (positive in negative y-direction);
P,	pressure;
q,	heat flux;
R,	universal gas-constant;
T,	temperature (absolute scale);
u,	velocity component in x-direction;
v,	velocity component in y-direction;
W,	weight fraction of noncondensable gas;
x,	coordinate parallel to condensing surface;
y,	coordinate perpendicular to condensing surface.

Greek symbols

α,	thermal diffusivity;
Δ,	distance in y-direction to edge of vapor boundary-layer;
δ,	distance in y-direction to edge of condensate film;
η,	nondimensional distance as defined by equation (11);
θ,	nondimensional quantity defined by equation (5);
λ,	free parameter in nondimensional velocity profile;
ν,	kinematic viscosity;
ρ,	mass density.

Subscripts

g,	noncondensable gas;
i,	denotes ith species;
L,	denotes a value in liquid condensate;

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N, Nusselt value;
T, total quantity (e.g. total pressure);
v, condensing vapor;
w, values at the condensing surface;
δ, values at the liquid–vapor interface;
∞, values in the bulk region.

INTRODUCTION

ANALYTICAL and experimental results are presented for the condensation of stagnant steam with the presence of a noncondensable gas on a vertical, isothermal surface for the ripple-free laminar flow that exists at condensate Reynolds numbers of less than about 25. The experimental results are additions to the previous contributions of Slegers [1], and essentially the same experimental system was used.

An integral method of analysis is presented to provide results for gases other than air, to demonstrate the small effect of gas solubility in the liquid, and to provide a simplified computational form of accuracy adequate for many purposes.

Further experimental results are given to demonstrate the edge effects in the basic experimental system and to show the effect of noncondensable gases other than air.

ANALYSIS

The analysis is an integral method, similar to that of Rose [2] and differing essentially only in the form of the velocity profiles adopted. Such an integral method is a time-saving alternative to the exact solution of Minkowycz and Sparrow [3], and an interim device pending the availability of a suitable forward-marching numerical solution of the problem. A numerical computation of this type was made by the authors, but it was found to be so marginally stable that the small length-increments required rendered the program uneconomical and allowed only a few results to be obtained; this was felt to be a consequence of retaining the Nusselt liquid-layer and having the finite-difference mesh cover only the vapor region rather than extending to the wall.

The analytic model with pertinent parameters is shown in Fig. 1. The Nusselt solution was retained for the liquid film, and the determination of the liquid-vapor interface temperature, T_δ, thus specifies the solution. For the analysis of the vapor region the properties are considered to be constant except for the density as it occurs in the body-force term. The conservation equations in this region for momentum, energy, and mass then take the usual forms:

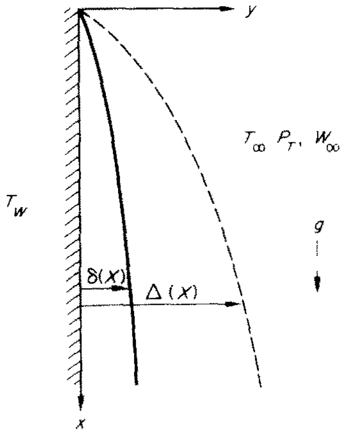

FIG. 1. Analytic model for vapor condensation in the presence of a noncondensable gas.

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = \nu\frac{\partial^2 u}{\partial y^2} + \frac{\rho - \rho_\infty}{\rho} g \tag{1}$$

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \alpha\frac{\partial^2 T}{\partial y^2} \tag{2}$$

$$u\frac{\partial W}{\partial x} + v\frac{\partial W}{\partial y} = D\frac{\partial^2 W}{\partial y^2} \tag{3}$$

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0. \tag{4}$$

The wall and vapor temperatures are taken to be constant and the interface temperature between the condensate layer and the vapor boundary-layer is also constant by the implied similarity of the integral method of solution.

Further, the Lewis number is taken to be unity ($D = \alpha$) so that

$$\frac{T - T_\infty}{T_\delta - T_\infty} = \frac{W - W_\infty}{W_\delta - W_\infty} = \theta. \tag{5}$$

This assumed equivalence of temperature and concentration profiles implies supersaturation of the vapor in the boundary layer (as does the exact analysis of [3] even without such equivalence). It is not known to what extent condensation (fogging) is so avoided in the actual case.

The boundary conditions associated with the continuity and momentum equations in the vapor are zero velocity at infinity and the condensate velocity at the interface. Equality of shear must also exist at the interface, but this condition cannot be fulfilled if the Nusselt condensate film is used; the neglect of this condition has been shown to be unimportant for pure-vapor condensation so long as Prandtl numbers are not very small, and such an approach has been retained here. Across the interface there is equality of the mass flows in the normal direction; the total mass flow into the condensate must be

$$\dot{m} = \frac{g}{\nu_L}\rho_L\delta^2\frac{\mathrm{d}\delta}{\mathrm{d}x} \tag{6}$$

while for each species in the vapor there is

$$\dot{m}_i = \rho_{i\delta}\left(u_\delta\frac{\mathrm{d}\delta}{\mathrm{d}x} - v_\delta\right) - j_{i\delta}. \tag{7}$$

Summating equation (7) over both species and equating the result to equation (6) gives the bulk vapor-velocity at the interface as

$$v_\delta = \frac{g}{\nu_L}\delta^2\,\frac{\mathrm{d}\delta}{\mathrm{d}x}\left(\frac{1}{2} - \frac{\rho_L}{\rho_\delta}\right). \tag{8}$$

With respect to the species equation, the flux of noncondensable gas into the liquid as a result of gas solubility is the increased content of that gas dissolved in the liquid. Because all of the condensate originates from the vapor, the concentration of dissolved gas is uniform in the liquid. Equations (6) and (7) thus yield the restriction

$$W_L\frac{\rho_L}{\nu_L}g\delta^2\frac{\mathrm{d}\delta}{\mathrm{d}x} = \rho_{g\delta}\left(u_\delta\frac{\mathrm{d}\delta}{\mathrm{d}x} - v_\delta\right) - j_{g\delta}. \tag{9}$$

In respect to the energy equation there must be satisfied an energy balance across the interface:

$$\frac{k_L}{\delta}(T_\delta - T_w) = \dot{m}_v h_{fg} + k\frac{\partial T}{\partial y}\bigg|_\delta. \tag{10}$$

In the integral method there are assumed the profiles

$$\left.\begin{aligned} \frac{u}{u_\delta} &= 1 - F(\eta) - \lambda G(\eta) \\ \theta &= 1 - F(\eta) \\ F(\eta) &= 2\eta - 2\eta^3 + \eta^4 \\ G(\eta) &= \frac{\eta}{6}(1 - \eta^3) \\ \eta &= \frac{y - \delta}{\Delta - \delta}. \end{aligned}\right\} \tag{11}$$

Equation (2) is discarded as it is redundant to equation (3) via the Lewis number unity specification and the assumed equivalence of concentration and temperature profiles. The profiles from equation (11) are used to integrate equations (1) and (3) and to evaluate the flux terms of equations (9) and (10); in the resulting equations, the distance x can be eliminated by the specification $\delta = cx^{1/4}$ for the condensate-layer thickness and $(\Delta - \delta) = fx^{1/4}$ for the vapor-layer thickness. This produces the following forms for the conservations of momentum and noncondensable species, and for the interface continuities of gas and energy respectively:

$$\frac{5}{16}\frac{g^2 I_1 c^4 f}{\nu_L^2} + \frac{1}{8}\frac{\rho_L g^2 c^5}{\rho_\delta \nu_L^2} = \frac{1}{2}\frac{g\rho c^2}{\nu_L f}\left(2 + \frac{\lambda}{6}\right) + gI_2 f \tag{12}$$

$$\frac{3}{8}\frac{gI_3c^2f}{\nu_L} + \frac{1}{4}\frac{g\rho_L c^3}{\nu_L\rho_\delta} = 2\frac{D}{f} \qquad (13)$$

$$2\frac{D}{f}\rho_\delta(W_\delta - W_\infty) = \frac{1}{4}\frac{g\rho_L c^3}{\nu}(W_\delta - W_L) \qquad (14)$$

$$\frac{k_L}{c}(T_\delta - T_w) = \frac{1}{4}\frac{h_{fg}\rho_L g c^3}{\nu_L} + 2\frac{k}{f}(T_\infty - T_\delta) \qquad (15)$$

in which

$$I_1 = 1{\cdot}1022(10)^{-4}\lambda^2 - 7{\cdot}2750(10)^{-3}\lambda + 0{\cdot}18254$$

$$I_2 = \int_0^1 \frac{\rho - \rho_\infty}{\rho}\,\mathrm{d}\eta$$

$$I_3 = 0{\cdot}18254 - 3{\cdot}6375(10)^{-3}\lambda.$$

The quantities to be determined from a simultaneous solution of these equations are c, f, T_δ, and λ. The computer solution for these is described in [4]; basically it involved the choice of an interface temperature, T_δ, which fixed W_δ via the saturation relation and the prescribed system pressure. Equation (14) then yielded the quantity c^3f, and this was combined with equation (15) to give c^4. The values of c and f yielded λ from equation (13), and these values were used to test the realization of equation (12). A failure required a new guess of T_δ, and an interpolation scheme guided the successive guesses for a rapid attainment of the correct interface temperature.

With the temperatures specified the heat flux to the wall,

$$q = k_L\frac{T_\delta - T_w}{\delta},$$

was known, and this was compared to the flux q_N specified by the Nusselt solution based on the overall temperature difference so that $T_\delta = T_\infty$. In each case the liquid properties were evaluated at the temperature $T_w + 0{\cdot}3\,(T_\delta - T_w)$.

ANALYTIC RESULTS

Figure 2 shows, by solid curves, results for a saturated steam–air mixture at 115°F giving the flux ratio q/q_ω as a function of the overall temperature difference, $T_\infty - T_w$. Dashed curves are the exact results of Minkowycz, and the approximate method shows reasonable correspondence with them. Two points computed from a numerical solution as discussed previously and using the GENMIX [5] code are also shown. One, for $W_\infty = 0{\cdot}02$, agrees with [3] and supports the numerical solution; the other, for $W_\infty = 10^{-4}$, supports the result of the integral method in this range of gas concentrations for which no exact solutions are available.

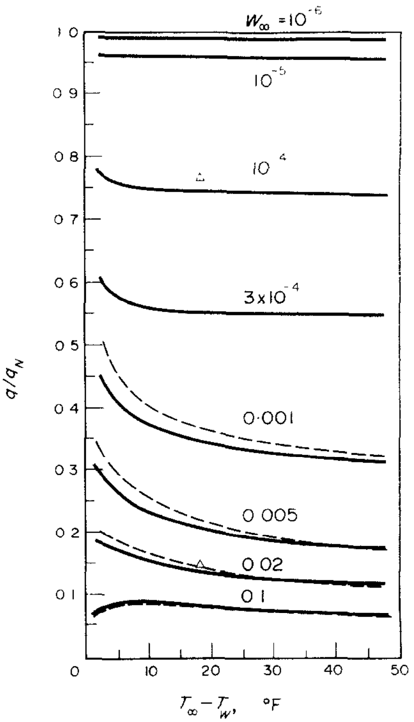

FIG. 2. Effect of noncondensables on heat transfer:
Steam–air at 115°F { ——— integral solution. — — — Minkowycz result. Δ finite-difference.

Every vapor state requires a representation like that of Fig. 2, and, for all saturated states at least, the general nature of the result is similar, to the extent that the value of the ordinate is almost constant for a given gas concentration except at small overall temperature differences. By taking an average value of the ordinate for

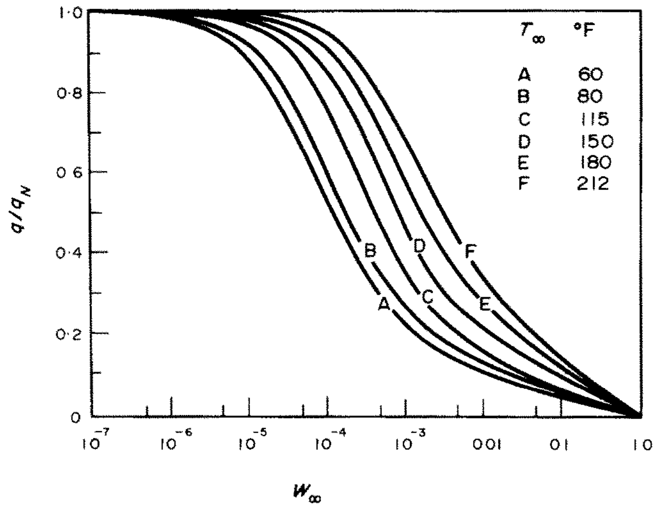

FIG. 3. Overall effect of air on the condensation of saturated steam.

results like those of Fig. 2 the effect of the abscissa is eliminated, and the compiled results are shown on Fig. 3, giving the heat-flux rates as a function of the air concentration for saturated vapor-states at the indicated temperatures. Flux ratios from this figure are within 5 per cent of the correct values except at very small temperature differences. Figure 3 is thus a good summary of the overall effect of air on the laminar film condensation of steam, accurate enough for many purposes.

There is another approximation which produces an acceptable result when the gas concentration is low, and its direct algebraic form makes it applicable to any gas for which the buoyant force is in the direction of film motion. The approximation rests on the observation that, with air and steam, as W_∞ becomes small, then λ, defined in equation (11), becomes nearly zero. If this is assumed, a velocity distribution equivalent to the concentration distribution is implied; a solution is then possible from equations (13), (14) and (15) by obtaining $c^3 f$ from equation (13), c^4 from equation (15) (by neglecting the third term of that equation), and introducing c and f into equation (14). With $W_L = 0$,

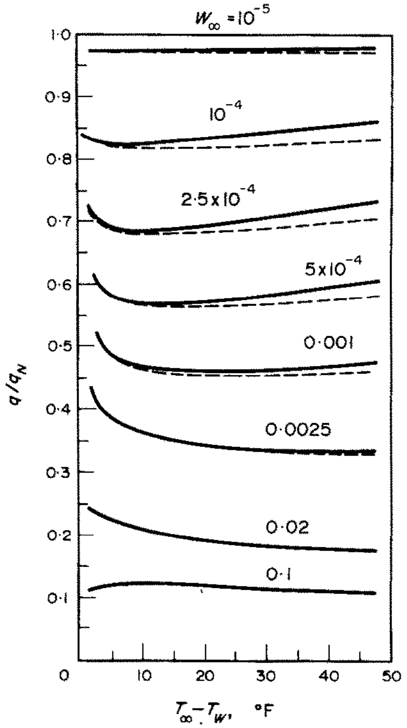

FIG. 4. Effect of gas-solution for carbon dioxide in saturated steam at 115°F: ——— normal gas-solubility; — — — zero gas-solubility.

no solubility of the gas in the liquid, this gives the form (here W_δ has been expressed in terms of pressure, temperature, and molecular weights).

$$T_\delta - T_w = 0.55 \times \frac{h_{fg} D M_g (P_{v\infty} - P_{v\delta}) \left[P_{v\infty} M_g - P_{v\delta}(M_g - M_v)\right]}{\rho_L k_L R^2 T_\delta^2 W_\infty}. \qquad (16)$$

For a fixed vapor state, i.e. W_∞ and $P_{v\infty}$ known, a selection of T_δ specifies all else on the right side of equation (16) and so fixes the difference $T_\delta - T_w$; consequently the flux ratio, which with constant properties

$$q/q_N = \left(\frac{T_\delta - T_w}{T_\infty - T_w}\right)^{\frac{3}{4}},$$

is determined. Such an evaluation gives about as good a comparison to results like those of Fig. 2 as does Fig. 3, so that equation (16) can be viewed as an alternative way of specifying Fig. 3 for $W_\infty < 0.001$.

Another application of the approximate integral method involves the appraisal of the effect of gas solubility in the liquid. Such solubility tends to increase the heat flux, for gas entering the liquid region does not need to be diffused back into the gas boundary-layer. The essence of the solution of equations (12) through (15) is the same, except that W_L must be evaluated in equation (14); this is done via Henry's law which, when expressed in terms of interface weight fractions, is

$$W_L = \frac{M_g}{M_g - M_v + \dfrac{H}{P_T W_\delta}\left[M_g - W_\delta(M_g - M_v)\right]} \qquad (17)$$

where H is the ratio of the partial pressure of the adjacent gas to the mole fraction of the gas dissolved in the liquid. Typical results from the inclusion of equation (17) with equations (12)–(15) are shown by solid curves on Fig. 4 for carbon dioxide in steam for saturation conditions at 115°F. There dashed curves give the result for zero solubility ($H \to \infty$) to show that even with relatively soluble carbon dioxide the effect of gas solubility on the condensation rate is small. Such effect as exists, with carbon dioxide or any other gas, is larger when the bulk gas concentration is small.

Another view of the effect of gas solubility in the condensate is given by Fig. 5, which refers to a relatively large weight-fraction of 0·01 air in steam, saturated at 212°F. The interface gas concentration is shown as a function of the

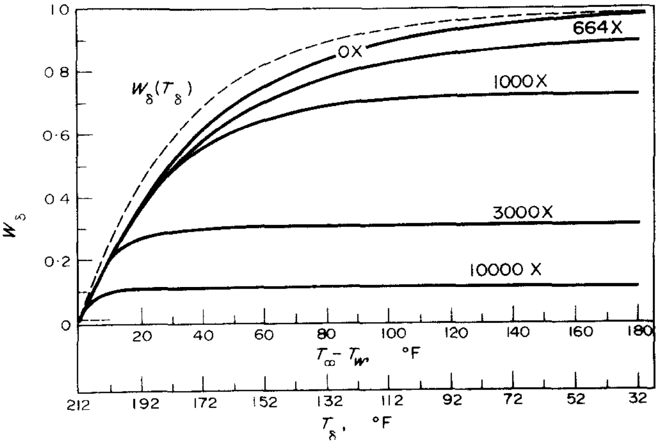

FIG. 5. Interface gas-concentrations for 1 per cent air, with various factors of normal gas-solubility, in saturated steam at 212°F.

overall temperature difference, and the solid curve designated OX gives this result for no solubility and for the actual very small solubility as well. Other solid curves show what the interface weight fraction would be if the actual solubility was multiplied by the factors indicated, and these can be used to judge what occurs with other more soluble gases, having molecular weights and properties somewhat similar to air. In this respect, carbon dioxide is about fifty times, and ammonia about 35 000 times, as soluble in water as is air.

A dashed curve on Fig. 5 gives the saturation relation $W_\delta = W_\delta(T_\delta)$ using the auxiliary abscissa scale for T_δ, so that when W_δ is determined from $T_\infty - T_w$, T_δ can also be determined, and so the flux ratio

$$q/q_N = \left(\frac{T_\delta - T_w}{T_\infty - T_w}\right)^{\frac{3}{4}}.$$

Figure 6 shows these flux ratios, corresponding to Fig. 5.

EXPERIMENTAL RESULTS

The following sections describe additional experimental results [4] obtained from the same experimental system as was used by Slegers. Condensation occurred on a 2-in wide by 5-in. high vertical surface contained in a large bell-jar within which the vapor was maintained by a boiler. The heat flow was inferred from temperatures measured in the copper block of which the condensing surface was one face, and the temperatures of this face were inferred by extrapolation of the temperatures measured within the block. The vapor of high gas concentration falling with the condensate from the lower edge of the condensing surface was mixed again with the steam issuing from the boiler through apertures located a considerable distance below the lower edge of the condensation surface.

There is an inherent deficiency in the use of a condensing surface of finite width because of edge effects whereby the film is slightly thinner at the edge. This, together with the local film imperfections that are induced, increases the apparent overall conductance of the film and distorts the temperature field in the copper block, affecting both the inferred heat-flux and surface temperature. Slegers thus obtained average conductances about 15 per cent above the Nusselt theory for pure-steam condensation, and in the later experiments this excess increased to about 25 per cent. Attempts to modify the layer thickness by placing shims against the edges of the face had no material effect on this magnitude.

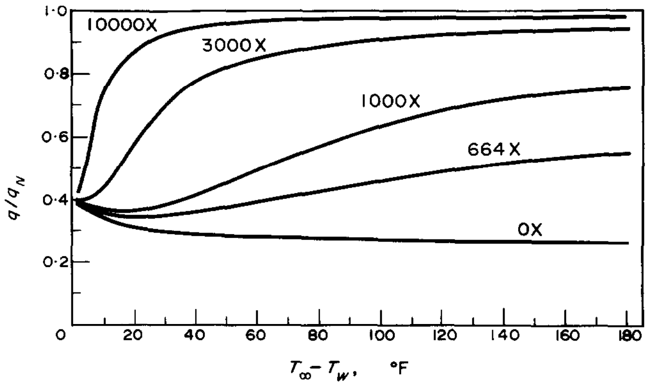

FIG. 6. Influence of gas solubility on heat transfer for 1 per cent air, with various factors of normal gas-solubility, in saturated steam at 212°F.

To resolve the "edge" problem, a vertical copper tube, cooled on the inside to provide condensation on the outside, was installed in the system. Condensate was collected by an annular trough immediately beneath the cylinder, since with this configuration the heat flux could not be metered. Noncondensable gas (air) entered the system during the start-up process, and this gas tended to accumulate and remain in the vicinity above the trough despite vigorous aspiration of the vapor in the bell jar; not until this region was continuously aspirated locally were conductances corresponding to the Nusselt solution obtained. The ultimate attainment of results in excellent agreement with the Nusselt predictions indicated that the higher values obtained using the vertical plate were due indeed to edge effects. However, the need to aspirate the region of the collecting trough prevented the operation of the system with noncondensable gas without extensive further modifications. These were not carried out, and the presented results for noncondensable gases were all obtained on the vertical plate system.

To verify the earlier performance, condensation was measured for air and steam with a 0·005 weight fraction of air in saturated steam at 115°F. Table 1 gives these results as well as those found by Slegers. Since the latter were quoted as measured values reduced by 8 per cent to compensate for the estimated consequence of errors in the flux determination, the present values, so reduced, are also given in Table 1. The present values, even when reduced, are above those of Slegers, and both groups are above the theory but are of the correct magnitude.

Table 1. q/q_N *for* 0·005 *air in saturated steam at* 115 *F*

$T_{\infty} - T_w$ (°F)	10	20	30	40	50
Theory	0·26	0·21	0·19	0·18	0·17
Present	0·36	0·32	0·29		0·25
Slegers	0·33	0·25	0·20		
Present, less 8 %	0·33	0·29	0·27		0·23

This excess became much greater for measurements made with $W_{\infty} = 0·0003$ in saturated steam at 115°F when for $5 < (T_{\infty} - T_w) < 20$°F there was found $0·95 > q/q_N > 0·90$, contrasted to the theoretical prediction of $0·60 > q/q_N > 0·55$. Slegers found general correspondence with prediction for $W_{\infty} = 0·0001$ at 80°F. It may be that the mixing of the vapor of high air concentration descending from the condensing surface with the efflux from the boiler was less effective at the higher pressure of the 115°F operation, and therefore the actual "ambient" air concentration was lower in the region of the condensing surface. Figure 3 reveals the high sensitivity of the flux ratio to air concentration at low gas concentrations.

GASES OTHER THAN AIR

Meaningful experiments with highly-soluble gases were not possible with the experimental apparatus used; the solution of such gas into the condensate which collected in various regions of the apparatus precluded an accurate knowledge of the bulk gas fraction in these cases. Results using the vertical plate were, however, obtained with argon, carbon dioxide, and krypton, all at $W_{\infty} = 0·005$ in saturated steam at 115°F. These are shown on Fig. 7, together with the prediction of the theory for each of the gases. The figure shows also additional results for carbon dioxide at this concentration at a temperature of 140°F.

The results for carbon dioxide and argon are from 12 to 16 per cent above the theory, while those for krypton are closer, and for these heavier gases, the agreement is better than that indicated for air in Table 1. This effect is probably a combination both of experimental error and of theoretical error associated with the assumption of Lewis number unity.

Results were also obtained with helium for $W_{\infty} = 0·0003$ in saturated steam at 115°F. Faired values from these results are indicated in Table 2. Because the buoyant force for this light gas is upward, opposed to the direction of condensate motion, the basic theory does not apply, but to provide some comparison there is shown in Table 2 the flux ratio evaluated from equation (16) in which the buoyancy force is implicitly neglected. There is a vast difference between measurement and theory in respect to which there must be considered the following points: (a) the discrepancy found for air at low concentrations, perhaps due to non-uniformity of the gas distribution within the enclosure, and (b) the actual flow in the gas layer, which is much different than that for the heavier gases.

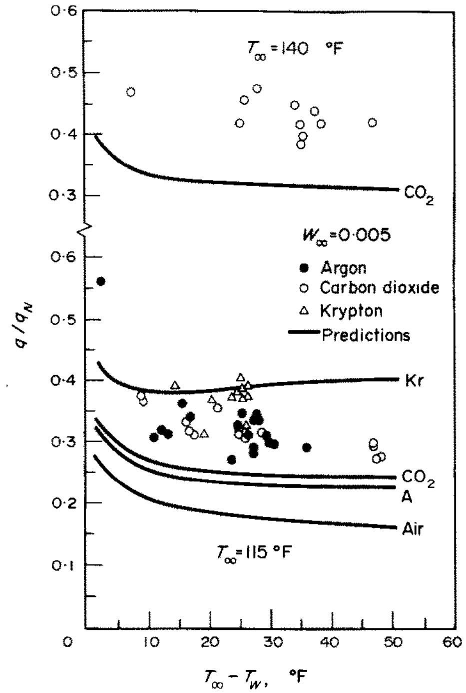

FIG. 7. Experimental heat-transfer results for steam condensation with various noncondensable gases.

Table 2. q/q_N *for* 0·0003 *helium in saturated steam at* 115°F

$T_\infty - T_w$ (°F)	10	20	30
Experimental	0·73	0·59	0·53
Via equation (16)	0·23	0·19	0·16

SUMMARY

An integral method of determination of the effect of noncondensable gas on condensation on a vertical surface for gases heavier than the vapor has been presented and shown to indicate a relatively small effect of gas solubility in the condensate. An approximate representation defines the effect of air in steam for a wide range of conditions and another approximation is suitable for any gas–vapor combination when the amount of gas is small.

Data for air and other noncondensable gases support the theory in general except for ambiguity at low gas concentrations, and in this range there is essentially more confidence in the theory than in the experiments.

These deductions are limited to ripple-free conditions in the laminar condensate-layer, which for the conditions of the experiments involves condensate Reynolds numbers of less than 25. Results of Spencer [6] for higher Reynolds numbers imply that a reduction in the diffusive resistance of the vapor boundary-layer may exist when ripples occur on the surface of the condensate layer.

ACKNOWLEDGEMENT

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CONDENSATION EN FILM LAMINAIRE D'UNE VAPEUR CONTENANT UN GAZ DISSOUT ET NON CONDENSABLE

Résumé—On indique une théorie intégrale pour l'effet d'un gaz soluble non condensable sur la condensation en film laminaire d'une vapeur stagnante sur une surface verticale et par approximation sur les résultats, on donne une définition compacte pour des mélanges saturés air–vapeur d'eau. De même des approximations sur la théorie elle-même fournissent un résultat simple pour toute combinaison vapeur–gaz dans laquelle la fraction gazeuse est faible, le gaz est plus lourd que la vapeur et le nombre de Lewis proche de l'unité. On trouve que l'effet de la solubilité du gaz dans le condensat est entièrement négligeable pour des mélanges air–vapeur d'eau et très petit même pour des mélanges dioxyde de carbone vapeur d'eau

On présente des résultats expérimentaux additionnels pour la vapeur d'eau et divers gaz qui acceptent généralement la théorie.

LAMINARE FILMKONDENSATION VON DAMPF, DER EIN LÖSLICHES, NICHTKONDIERENDES GAS ENTHÄLT

Zusammenfassung—Es wird eine integrale Theorie angegeben für die Auswirkung eines lösbaren, nicht kondensierenden Gases auf die laminare Filmkondensation von ruhendem Dampf an einer senkrechten Fläche. Durch Näherung der Ergebnisse wird eine zusammenfassende Darstellung gegeben für gesättigte Luft-Wasserdampf-Gemische. Durch Näherungen bei der Theorie selbst ergeben sich einfache Ergebnisse für einige Gas-Dampf-Gemische mit niedrigem Gasanteil, wenn das Gas schwerer ist als der Dampf und die Lewis-Zahl etwa 1 beträgt. Die Löslichkeit des Gases im Kondensat kann für Luft-Wasserdampf-Gemische völlig vernachlässigt werden und ist auch für CO_2- Wasserdampf-Gemische nur von geringem Einfluss.

Zusätzlich sind experimentelle Ergebnisse für Gemische von Wasserdampf mit verschiedenen Gasen gegeben, die im allgemeinen die Theorie stützen.

ЛАМИНАРНАЯ ПЛЕНОЧНАЯ КОНДЕНСАЦИЯ ПАРА, СОДЕРЖАЩЕГО РАСТВОРИМЫЙ НЕКОНДЕНСИРУЮЩИЙСЯ ГАЗ

Аннотация—Приводится интегральная теория для описания влияния растворимого неконденсирующегося газа на ламинарную пленочную конденсацию неподвижного пара на вертикальной поверхности. С помощью ряда аппроксимаций результатов получена компактная формула для насыщенных паровоздушных смесей. В результате же аппроксимации самой теории получена простая формула для любой комбинации пар-газ, в которой доля газа мала, газ тяжелее пара и число Льюисаравно приблизительно единице. Найдено, что влияние растворимости газа в конденсате на пленочную конденсацию пренебрежимо мало для паро-воздушных смесей и очень незначительно для смеси двуокись углерода-пар.

Приведены новые экспериментальные результаты для пара и различных газов, которые в общем подтверждают теорию.