Int. J. Heat Mass Transfer. Vol. 10, pp. 1891–1894. Pergamon Press Ltd. 1967. Printed in Great Britain

SHORTER COMMUNICATIONS

FILM CONDENSATION OF SATURATED POTASSIUM VAPOR

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(*Received* 1 *November* 1966)

NOMENCLATURE

A, condensing surface;
g, gravitational acceleration;
Γ, correction factor;
h_{fg}, latent heat of vaporization;
k, thermal conductivity;
L, length;
μ, dynamic viscosity;
p, pressure;
q, condensation heat flux;
R, gas constant;
ρ, density;
σ, condensation coefficient;
T, temperature.

Subscripts
L, liquid;
s, condensate surface at liquid–vapor interface;
v, vapor.

INTRODUCTION

SATURATED potassium vapor was condensed on two different vertical surfaces—nickel 200 and stainless steel 316 as shown in Fig. 1. The test surface was a 4 × 4 in square and 0·75-in thick with two sets of three $\frac{1}{16}$-in dia. chromel–alumel thermocouples—$\frac{1}{16}$-in. in from either surface and on the center plane. One set was $1\frac{1}{2}$-in down from the top and the other $\frac{3}{4}$-in up from the bottom, staggered near the vertical centerline of the plate. Heat was removed at the cold side of the plate by transfer to boiling water. The heat flux was obtained by the temperature gradients determined by both sets of couples and by the steam condensate collected. The average of these three determinations was used. The wall temperature was obtained by extrapolation to the surface and the vapor temperature was measured by two thermocouples in the vapor space—$\frac{1}{2}$-in and 4-in away from the cold surface.

The tests reported here covered a range of absolute pressure of 0·01 atm to 0·6 atm. To verify that the potassium system was leak-tight the potassium was boiled and the system purged for 21 h. It was then evacuated to 10^{-3} in Hg and allowed to stand for 4 days. No detectable leakage was observed.

ANALYSIS

The analysis of the data follows the procedure presented by Sukhatme and Rohsenow [1]. Here the temperature difference between the solid wall and the liquid at the

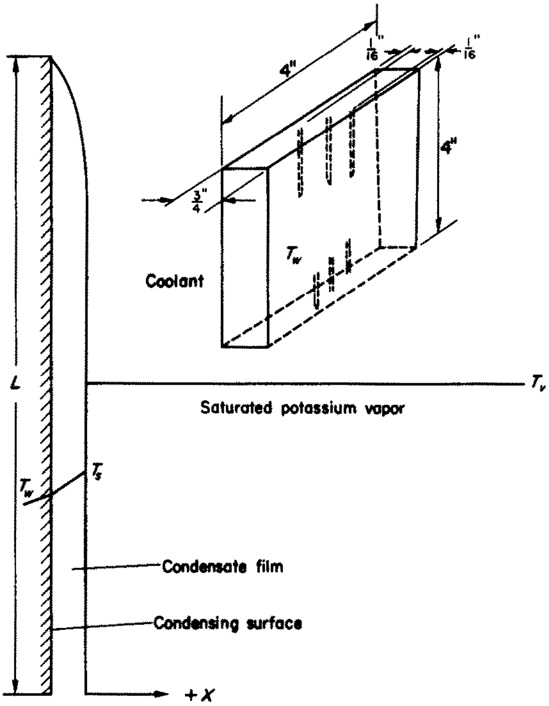

FIG. 1 Film condensation of potassium vapor.

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Table 1. Experimental data and results for saturated potassium vapor condensing on a vertical surface

Test No.	T_v (degF)	T_w (degF)	$\frac{q_{c\,exp}}{(\text{Btu/h ft})}$	T_s (degF)	p_v (atm)	p_s (atm)	$\frac{(p_v - p_s)}{p_s}$	$\frac{(T_v - T_s)}{T_s}$	σ	σ_{emp}	$q_{c\,emp}$ $\frac{\text{Btu}}{\text{h ft}^2}$	$h_{c\,exp}$ $\frac{\text{Btu}}{\text{h ft}^2\,°\text{F}}$	$h_{c\,emp}$ $\frac{\text{Btu}}{\text{h ft}^2\,°\text{F}}$
1	1052·50	1049·83	34403	1050·16	0·1070	0·1051	0·0185	0·0015	0·258	0·191	24579	12885	9205
2	1055·00	1050·20	53·970	1050·81	0·1092	0·1056	0·0334	0·0028	0·227	0·191	44421	11243	9254
3	1132·75	1129·91	36023	1130·27	0·1947	0·1913	0·0177	0·0016	0·169	0·142	29703	12684	10458
4	1146·80	1140·91	66544	1141·74	0·2148	0·2074	0·0359	0·0032	0·145	0·136	62261	11297	10570
5	1201·50	1197·31	41074	1197·75	0·3104	0·3029	0·0247	0·0023	0·094	0·113	49··861	9802	11900
6	1182·00	1179·35	42445	1179·81	0·2730	0·2690	0·0147	0·0013	0·174	0·120	28309	16017	10682
7	1233·50	1227·39	45571	1227·90	0·3807	0·3675	0·0358	0·0033	0·061	0·102	77976	7458	12762
8	1300·00	1295·85	49943	1296·44	0·5683	0·5566	0·0209	0·0020	0·077	0·083	53759	12034	12954
9	1305·00	1295·00	98824	1296·48	0·5849	0·5567	0·0506	0·0049	0·064	0·083	130459	9882	13045
10	805·50	799·00	44078	799·44	0·0106	0·0099	0·0706	0·0048	0·640	0·625	42753	6781	6577
11	811·00	800·00	80968	800·99	0·0112	0·0100	0·1186	0·0079	0·670	0·619	72093	7360	6553
12	850·73	843·50	45864	843·97	0·0172	0·0160	0·0736	0·0052	0·455	0·490	50550	6343	6991
13	914·00	902·00	80926	903·02	0·0324	0·0291	0·1110	0·0081	0·327	0·363	92031	6744	7669
14	906·50	901·30	43176	901·74	0·0301	0·0288	0·0470	0·0035	0·399	0·366	38786	8303	7458
15	1017·30	1012·00	41355	1012·42	0·0807	0·0775	0·0411	0·0033	0·193	0·223	48460	7802	9143
16*	1218·25	1216·00	29405	1216·28	0·3457	0·3414	0·0126	0·0012	0·116	0·106	26702	13069	11867

* Condensation on the lower surface of a horizontal disc.

liquid–vapor interface is calculated by the Nusselt equation:

$$\frac{q/A}{T_s - T_w} = 0.943\left[\frac{g\,\rho(\rho_L - \rho_v)\,k^3\,h_{fg}}{(T_s - T_w)\,L\,\mu}\right]^{\frac{1}{4}}. \qquad (1)$$

On the vapor side of the interface the heat transfer between the saturated vapor and the liquid at the liquid–vapor interface is given by the Hertz–Knudsen equation:

$$q/A = \frac{\sigma}{\sqrt{(2\pi R)}}\left[\Gamma\,\frac{p_v}{T_v^{\frac{1}{2}}} - \frac{p_s}{T_s^{\frac{1}{2}}}\right]h_{fg} \qquad (2)$$

where

$$\Gamma \simeq 1 - \frac{q/A}{p_v\left(\dfrac{2}{\pi R T_v}\right)^{\frac{1}{2}} h_{fg}}.$$

This equation may be simplified to the following form:

$$q/A = \frac{2\sigma}{(2 - \sigma)}\left(\frac{1}{2\pi R}\right)^{\frac{1}{2}}\left(\frac{p_v}{T_v^{\frac{1}{2}}} - \frac{p_s}{T_s^{\frac{1}{2}}}\right). \qquad (3)$$

Actually, as shown by Bornhorst [2], there is a temperature profile in the vapor near the liquid–vapor interface. For the conditions of the present tests this effect is negligible.

The test data of heat flux and temperatures were used to determine σ in equation (3). Only those data for which $(p_v - p_s)/p_s$ is less than 0·25 are reported because equations (2) and (3) are applicable only at the smaller magnitudes of this quantity. The results are shown in Fig. 2 along with results of various other experimenters. There is remarkable agreement for the results of σ vs. p_s for a wide variety of liquid metals tested as discussed in [3]. Recent results obtained by Mills [9] for steam condensing at approximately 0·01 atm also straddle the line drawn through the liquid metal data. An empirical expression for σ is

$$\left.\begin{aligned} \sigma &= \frac{0.062}{p_s},\ 0.00384 < p_s < 1.0\ \text{atm} \\ \sigma &= 1.0,\ p_s < 0.00384\ \text{atm} \end{aligned}\right\} \qquad (4)$$

CONCLUSION

For the present film condensation of liquid metals may be predicted for design purposes by using equations (1), (3) and (4) provided $(p_v - p_s)/p_s < 0.25$.

REFERENCES

1. S. P. Sukhatme and W. M. Rohsenow, Film condensation of a liquid metal vapor, *J. Heat Transfer* **88**, 19–28 (1966).
2. W. J. Bornhorst, Irreversible thermodynamics at a phase change, Ph.D. Thesis, Mechanical Engineering Department, MIT (June 1966).
3. W. M. Rohsenow, Experimental results for film condensation of liquid metals, Discussion of paper numbers 74, 75, 76, in *Proceedings of the Third International Heat Transfer Conference* Vol. 4, Chicago (August 1966).
4. V. I. Subbotin, M. N. Ivonovsky, V. P. Sorokin and V. A. Chulkov, Heat transfer during the condensation of potassium vapor, (in Russian), *Teplofiz. Vysok. Temp.* **2** (4), 616–622 (1964).
5. R. E. Barry and R. E. Balzhiser, Condensation of sodium at high heat fluxes, in *Proceedings of Third International Heat Transfer Conference* Vol. 2, pp. 318–328. Chicago (1966).

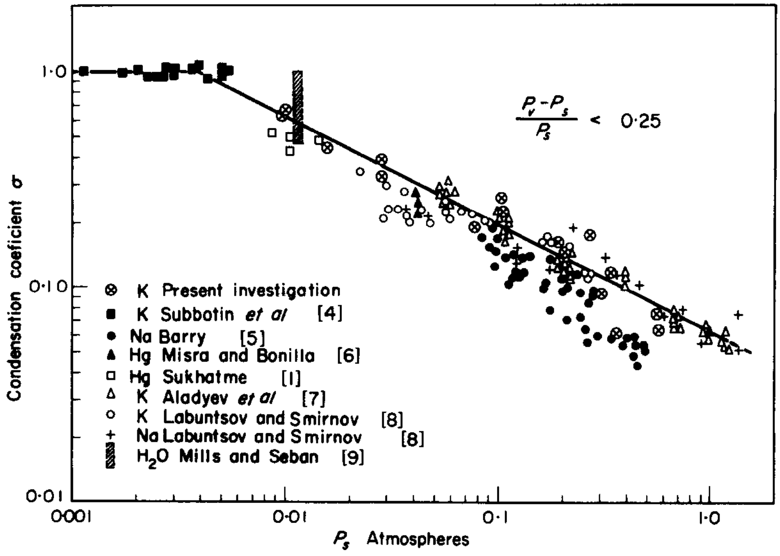

FIG. 2. Condensation coefficient vs. saturation pressure.

6. B. Misra and C. F. Bonilla, Heat transfer in the condensation of metal vapors: mercury and sodium up to atmospheric pressure, *Chem. Engng Prog. Sym. Ser.* 18 **52** (7), 7–21 (1956).
7. I. T. Aladyev *et al.*, Thermal resistance of phase transition with condensation of potassium vapor, in *Proceedings of Third International Heat Transfer Conference* Vol. 2, pp. 313–317. Chicago (1966).
8. D. A. Labuntsov and S. I. Smirnov, Heat transfer in condensation of liquid metal vapors, in *Proceedings of Third International Heat Transfer Conference* Vol. 2, pp. 329–336. Chicago (1966).
9. A. F. Mills and R. A. Seban, The condensation coefficient of water, *Int. J. Heat Mass Transfer* **10**, 1815–1827 (1967).

Int. J Heat Mass Transfer. Vol. 10, pp. 1894–1899. Pergamon Press Ltd. 1967. Printed in Great Britain

THERMAL SCALE MODELING WITHOUT SIMILITUDE

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(*Received* 1 *May* 1967 *and in revised form* 4 *July* 1967)

NOMENCLATURE

A,	area;
B_{ij},	absorption factor, fraction of radiation leaving the node i and being absorbed by the node j;
c,	specific heat [W s/kgdegK];
C,	thermal conductance [W/degK];
f,	"skin" scale factor s/s^*;
F,	"inner" scale factor L/L^*;
g,	temperature ratio T/T^*;
h,	thermal contact coefficient [W/degK m^2];
L,	length;
P,	power dissipated in a node [W];
q,	absorbed heat flux [W/m^2];
Q,	absorbed heat [W];
r,	ratio of absorbed heat fluxes q/q^*;
R_{ij},	radiation factor between the node i and the node j $\sigma A_i \varepsilon_i B_{ij}$;
s,	skin thickness;
t,	time;
T,	temperature [degK];
V,	volume;
x, y,	directions tangential to the skin;
z,	direction normal to the skin.

Greek symbols

α,	absorptivity for sun- or lamp-radiation;
ε,	emissivity;
λ,	conductivity [W/degK m];
ρ,	density [kg/m^3];
σ,	constant of Stefan–Bolzmann;
φ,	incident heat flux [W/m^2].

Subscripts

a,	area (conduction across an interface);
i,	of node i;
j,	of node j;
ij,	from node i to node j;
js,	from node j to space;
m,	material (conduction within a material);
n,	normal (to the skin);
t,	tangential (to the skin).

Superscripts

$*$,	small model;
$'$,	skin.

INTRODUCTION

With the development of more powerful launching vehicles the satellites or spacecraft become larger and larger. Up to now it has been necessary to let the test facilities grow in the same proportion. The laws of thermal similitude were established in the hope that it would be possible to verify or determine the thermal model[†] of a spacecraft after having carried out a test only on a small scale model[‡] of this spacecraft, because that would permit the use of smaller test chambers.

But treating thermal scale modeling of spacecraft from

[†] The term "thermal model" means the thermal mathematical model, i.e. the table containing the factors in the heat balance equation [equation (1.1)].

[‡] The term "scale model" means a smaller physical version of a spacecraft.