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DROPWISE CONDENSATION—SOME FACTORS INFLUENCING THE VALIDITY OF HEAT-TRANSFER MEASUREMENTS

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Abstract—Reports, of various recent workers in the field of dropwise condensation, suggest that precise and repeatable measurements of the steam-to-surface temperature difference can only be obtained when special precautions are taken to obviate the effects of non-condensing gases.

In the present work, the effects of local venting (i.e. removal of vapour from the vicinity of the condensing surface) were studied. The aim was first to demonstrate that even minute concentrations of non-condensing gases, such as remain in steam after prolonged boiling, can lead to significant errors in measurements of the steam-to-surface temperature difference for dropwise condensation, and second, to investigate the possibility of avoiding such errors by venting without, at the same time, incurring error through disturbance of the condensate.

For a copper condensing surface, promoted with dioctadecyl disulphide ($C_{18}H_{37}SSC_{18}H_{37}$), the time dependence of the steam-side heat-transfer coefficient was also investigated so as to assess the importance of this factor on the repeatability of observations.

Conditions were established for which repeatable results, relating to "gas-free" steam, may be obtained. While operating under such conditions, observations of the steam-to-surface temperature difference were made for a wide range of heat-flux. For these tests, vertical plane copper condensing surfaces, promoted with dioctadecyl disulphide, were used. The steam pressure was about 1·07 bar. The results are compared with those of other recent workers.

NOMENCLATURE

m_v, rate of removal of steam through the vent;
$\dot{Q}''$, heat flux;
$\Delta\theta$, steam-to-surface temperature difference;
α, steam-side heat-transfer coefficient;
ΔP, gauge pressure, i.e. excess of the steam pressure over that of the atmosphere.

Conversion factors

$$\frac{\mathrm{MW}}{\mathrm{m}^2} \simeq 0{\cdot}317 \times 10^6 \frac{\mathrm{Btu}}{\mathrm{ft}^2\,\mathrm{h}} \simeq 0{\cdot}86 \times 10^6 \frac{\mathrm{kcal}}{\mathrm{m}^2\,\mathrm{h}};$$

$$\frac{\mathrm{MW}}{\mathrm{m}^2\,\mathrm{degC}} \simeq 0{\cdot}176 \times 10^6 \frac{\mathrm{Btu}}{\mathrm{ft}^2\,\mathrm{h}\,\mathrm{degF}}$$

$$\simeq 0{\cdot}86 \times 10^6 \frac{\mathrm{kcal}}{\mathrm{m}^2\,\mathrm{h}\,\mathrm{degC}}.$$

1. INTRODUCTION

SINCE the discovery by Schmidt *et al.* [1] of the "ideal" mode of condensation now termed "dropwise", many experimental studies relating to heat transfer in the presence of dropwise condensation have been made. While there is general agreement that the resistance to heat transfer associated with this mode is considerably less than that associated with the filmwise mode, differences between the results of the different workers are very great. This diversity of results has long hindered basic studies of the mechanism of dropwise condensation and, in

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view of recent renewed interest in this subject, it seems important to discover the reasons for such disagreement.

Various recent workers [2, 3, 4, 5] have shown that vapour-side heat-transfer coefficients for dropwise condensation of steam are extremely high and also are very susceptible to reduction by even minute traces of non-condensing gases. In the presence of such gases, the vapour-side coefficient depends on the gas concentration in the remoter vapour, the heat-flux, geometry of apparatus and steam velocity in the region of the condensing surface. Moreover, a recent report [5] suggests that it is impossible entirely to eliminate the effects of non-condensing gases simply by preliminary boiling while "blowing off" steam, and that unless other means are adopted to remove these gases, or special precautions taken to eliminate their effects, precise and repeatable results cannot be expected. Good agreement has been found between the results obtained in two recent investigations [5, 6] in which special care was taken not only to reduce the amounts of non-condensing gases present to a minimum, but also to limit their accumulation at the condensing surface.

Accumulation of non-condensing gas at the condensing surface arises from the fact that gas is brought to the liquid–vapour interface, which is impermeable* to it, by the convective flow set up by condensation of the vapour. In the absence of imposed velocities, an equilibrium condition is established for which the rate of removal of the gas, by diffusion away from the region of higher gas concentration, and by natural convection caused by the density difference arising from the concentration difference, is equal to the rate at which it is brought to the interface. The increased gas concentration at the interface leads to a decrease in the partial pressure and consequently the temperature of the vapour. In practice this is important since the decrease in temperature difference across the condensate leads to a decrease in heat transfer. In the present work, however, we are more interested in the temperature drop itself and its magnitude in relation to the relatively small temperature difference across the condensate in the case of dropwise condensation. Generally speaking, in dropwise condensation experiments, an additional temperature drop in the vapour of similar magnitude to that across the condensate has little effect on the heat transfer, since the vapour-side resistance is small by comparison with the overall resistance. However, such an increase in vapour-to-surface temperature difference is clearly of major importance when the vapour-side resistance itself is being studied.

It is apparent that the gas concentration at the interface will increase with condensation rate, since this determines the rate at which the gas is brought to the surface. Also, the interfacial gas concentration would be reduced by an imposed velocity which assisted in removing gas–vapour mixture from the vicinity of the interface.

The main objectives of the present work were:

(1) to confirm that the temperature drop in the vapour caused by the presence of a few parts per million (such concentrations as remain after prolonged boiling) of air in steam is significant by comparison with the temperature drop across the condensate in dropwise condensation; and

(2) to examine the possibility of limiting the build-up of gas, by venting, to a level at which the lowering of the vapour temperature is not significant, without at the same time introducing errors through disturbance of the condensate.

For the above purposes, a vent was introduced into the steam chamber and the dependence of the steam-to-surface temperature difference on vent position and venting rate were observed. From these observations the authors conclude that the temperature drop in the steam

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* Apart from that proportion of gas which may dissolve in the condensate.

is of similar magnitude to the temperature drop across the condensate when diffusion and free convection are the only means whereby the gas concentration near the interface achieves its equilibrium level. Thus, under these conditions, the observed steam-side heat-transfer coefficients are about half the values for gas-free steam.

These tests further indicate that, in certain circumstances, the temperature drop in the steam can, without affecting the temperature drop across the condensate, be made negligible by venting. However, at the highest heat fluxes (greater than about 1·5 MW/m^2), the intensity of venting required to obviate error caused by non-condensing gas was found to introduce significant error through disturbance of the condensate.

In addition to the tests relating to non-condensing gases and venting, the variation of the steam-side heat-transfer coefficient with time was observed for the particular plate–promoter combination used in the present work. For a newly promoted plate, it was found that the coefficient at first increased quite steeply to a maximum value at which it remained for several hours before slowly falling. It is thus to be expected that repeatable results may be obtained only during the time interval for which the coefficient is constant.

Finally, while operating under optimum venting conditions, the dependence of the steam-to-surface temperature difference on the heat-flux was observed. All measurements were made during the time interval for which the heat-transfer coefficient was constant. The range of heat-flux obtained extended down to the lowest heat-flux obtained in [6] and to values higher than those attained in [5].

2. APPARATUS

The apparatus used was a modified form of that described earlier [5]. Steam was generated from distilled water in a glass boiler fitted with two 5 kW heaters. The cruciform glass steam chamber, having limbs of 101 mm (4 in) I.D. was situated directly above the boiler. One horizontal limb of the steam chamber was closed by the test plate and the other by an electrically heated double-glazed window. The test plate was cooled by water which could be either pumped or allowed to flow by gravity feed from the supply tank. Coolant velocities, at the test plate, of up to about 30 m/s could be obtained. The coolant could be pre-heated for operation at low heat-fluxes.

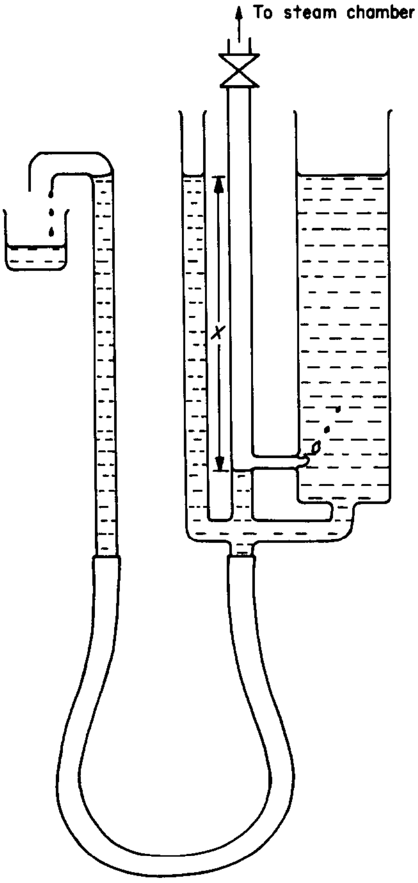

FIG. 1. Pressure stabilizer.

The apparatus was fitted with the simple pressure stabilizing device shown in Fig. 1. This removed the need to regulate precisely the power supply to the boiler heaters according to the condensation and venting rates. The device could be used over a range of gauge pressures up to 0·075 bar (30 inH_2O). The required pressure was obtained by setting the adjustable overflow limb to the desired level. Steam condensed in the right-hand limb and the pressure was thus maintained at the gauge pressure corresponding to the height x (see Fig. 1) of water. Thus, provided excess power was supplied to the boiler, drift of the steam pressure (due to slight out of balance between the boiling and the condensing and venting rates) was prevented.

Two copper test plates were used. The condensing area in each case was 62-mm (2·44 in) high and 70-mm (2·75 in) wide, and the thicknesses were 6·35 mm (0·25 in) and 50·8 mm (2·00 in), for use in the higher and lower heat-flux ranges respectively. The plates were made in halves so that the mating faces were in a vertical plane normal to the steam and coolant faces as before [5]. Butt-welded copper–constantan thermocouples [0·12-mm dia. (40 s.w.g.)] were inserted in grooves, parallel to the condensing surface, in one mating face of each plate. Insulation of the thermocouples from the plates was achieved by filling the grooves [0·25 mm (0·01 in) × 0·25 mm (0·01 in)] with "Araldite" and subsequently machining smaller grooves [0·15 mm (0·006 in) × 0·20 mm (0·008 in)] in the "Araldite". The thermocouples were then cemented into the grooves so that the junctions were at the mid-height of the plates. This was found to be a more permanent and reliable method of insulation than that used earlier [5]. Figure 2 shows a section through a thermocouple groove. The plate of thickness 6·35 mm (0·25 in) had four thermocouple grooves and that of thickness 50·8 mm (2·00 in) had eight thermocouple grooves. The thermocouple positions were determined precisely, by means of a travelling microscope, when the thermocouples had been cemented in the grooves. The junction between the two halves of each plate was sealed by a neoprene gasket of thickness 0·8 mm as before [5].

The method of calibration of the thermocouples, the precautions regarding the thermoelectric measurements and the determination of the thermal conductivities of the plates were the same as those described earlier [5]. Very good linear temperature distributions were obtained in the plates. The heat flux and surface temperature were obtained from the temperature gradient and by extrapolation respectively. For this purpose linear regression of the temperatures against the distances from the steam face was used.

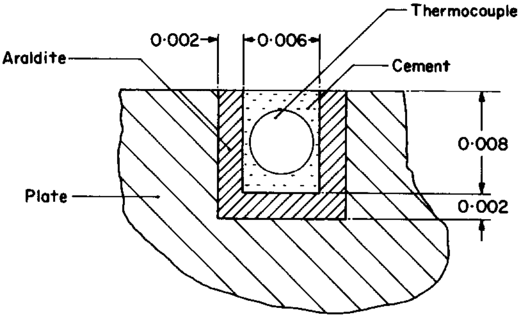

FIG. 2. Detail of thermocouple groove. (Dimensions in inches.)

The condensing surfaces were cleaned and promoted in the manner described previously [5]. Dioctadecyl disulphide* ($C_{18}H_{37}SSC_{18}H_{37}$) was used as promoter. Full details of apparatus and experimental techniques are given in [7].

3. VENTING TESTS

For the purpose of examing the effect of the distance of the vent from the condensing surface, a movable vent of 4-mm I.D. was used (see Fig. 3). The vent was operated by a screw, with a micrometer head, which drew a steel wire up the stem of the vent tube. The wire was attached to the rear end of the vent which moved towards the condensing surface as the wire was drawn up the stem, and was retracted by a spring when the wire was slackened. The vent was so positioned that its axis passed through the junctions of the thermocouples in the plate and

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[*] Supplied by the National Engineering Laboratory U.K. and used in earlier investigations [5, 6].

its distance from the plate could be known to within 0·25 mm (0·01 in). The vented steam could be passed through an auxilliary condenser so as to observe the venting rate. Further details may be found in [7].

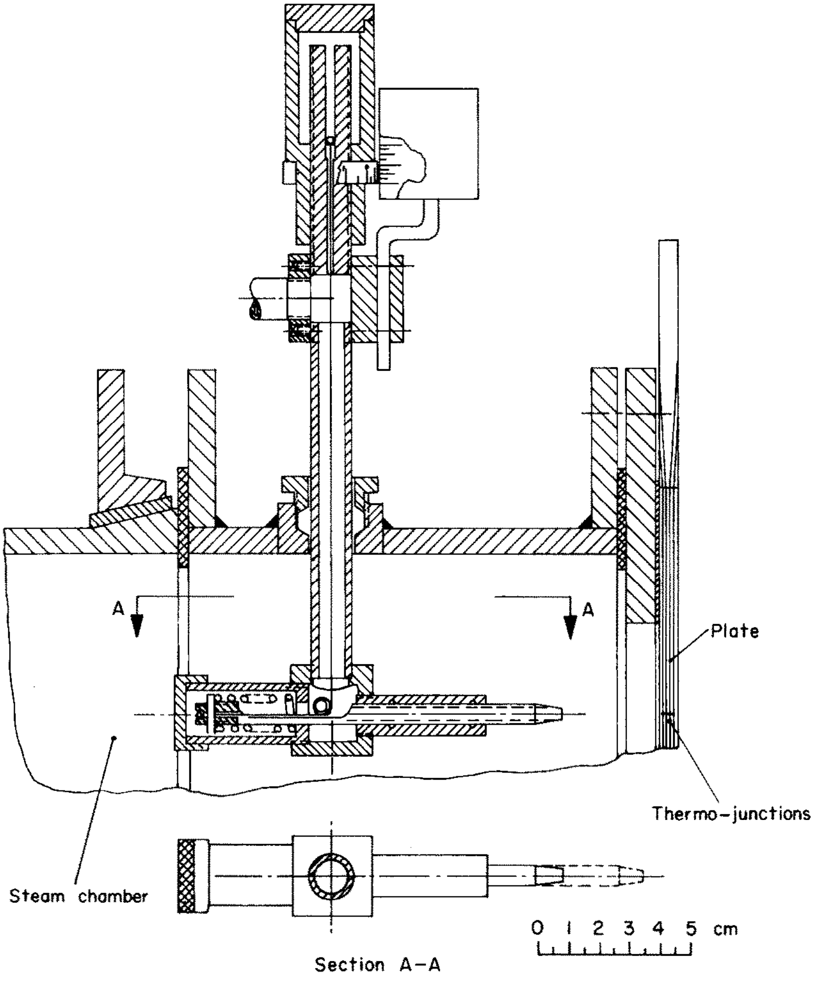


FIG. 3. Movable vent.

Before carrying out any tests the water in the boiler was boiled very vigorously, while blowing off steam to atmosphere through the main steam-chamber vent (13-mm dia.) for about 15 min. Venting was then continued using the close vent for at least 3 h until steady conditions were attained (see Section 4). The proportion of non-condensing gas in the steam, remote from the condensing surface, was measured using a method similar to that used by Furman and Hampson [8] and Welch and Westwater [9] and found to be less than 5 ppm by mass.

Using the plate of thickness 6·35 mm, the variation of the steam-to-surface temperature difference, $\Delta\theta$, with vent position, was observed for several different coolant-flow rates. (In these tests a constant coolant-flow rate gave a virtually constant heat-flux, since the varying steam-side resistance was only a small fraction of the overall resistance.) The valve on the vent was kept fully open and the steam pressure maintained at 27 inH_2O above atmospheric pressure. The rate of removal of steam through the vent under these conditions was found to be about 0·68 g/s.

The results of these tests are shown in Fig. 4. In general the steam-to-surface temperature difference increased with distance of the vent from the surface. However, for moderate and low heat fluxes, a range of vent position exists for which the steam-to-surface temperature difference is independent of vent position. This range diminishes with increasing heat flux until at the higher heat fluxes the graphs have no horizontal portion.

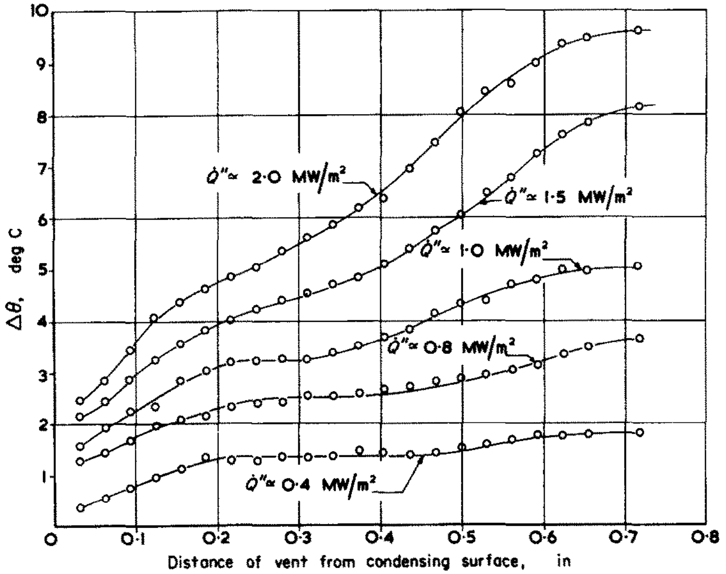


FIG. 4. Effect of vent position on the steam-to-surface temperature difference for a fixed venting rate. (ΔP = 27 inH_2O, m_v = 0·68 g/s.)

These observations are consistent with the view that a significant proportion of non-condensing gas remains in the steam even after prolonged boiling. Thus, as the vent approaches the surface, the concentration of non-condensing gas at the liquid–vapour interface is progressively reduced, thereby decreasing $\Delta\theta$. When the interfacial gas concentration reaches about 0·5 per cent, the temperature drop in the steam is about 0·1 degC (assuming the gas to be air). This is less than the precision with which the surface temperature was measured [7]. Further reduction in the interfacial gas concentration, as the vent is brought closer to the interface, produces no observable change. When the vent is so close to the surface that the induced vapour velocity disturbs the condensate (about 0·23 in for the venting rate used), a further decrease in the steam-to-surface temperature difference occurs. At the higher heat fluxes, when the rate of arrival of the non-condensing gas at the interface is correspondingly higher, the interfacial gas concentration is still significant (i.e. greater than about 0·5 per cent) when the vent reaches the position at which the condensate is appreciably disturbed.

The results shown in Fig. 4, with the interpretation given above, indicate that the temperature drop in the steam, resulting from the presence of a few parts per million of non-condensing gas, in the absence of forced convection, ranges from about 0·5 degC at a heat flux of 0·4 MW/m^2 to about 4 degC at 2 MW/m^2. In the former case the flat portion of the curve gives $\Delta\theta$ for gas-free steam while the value of $\Delta\theta$ for the most remote vent position gives the value found in the absence of venting. For the higher heat flux $\Delta\theta$ for gas-free steam has been estimated as the value at the 0·25 in vent position. These temperature drops are clearly significant by comparison with the temperature drop across the condensate (the value of $\Delta\theta$ for gas-free steam) i.e. about 1·4 degC at 0·4 MW/m^2 to about 5 degC at 2 MW/m^2.

In order to examine the effect of venting rate, the above tests were repeated for various steam chamber pressures. The coolant flow rate was kept constant (corresponding to $\dot{Q}'' =$ 1 MW/m^2) and the valve on the vent left fully open. It is thought unlikely that the small fractional pressure changes in these tests should have any effect save that brought about by the consequent change in the venting rate. The results of two such tests, carried out on different occasions, are shown in Fig. 5. It may be seen that, for the ranges studied, $\Delta\theta$ is dependent on

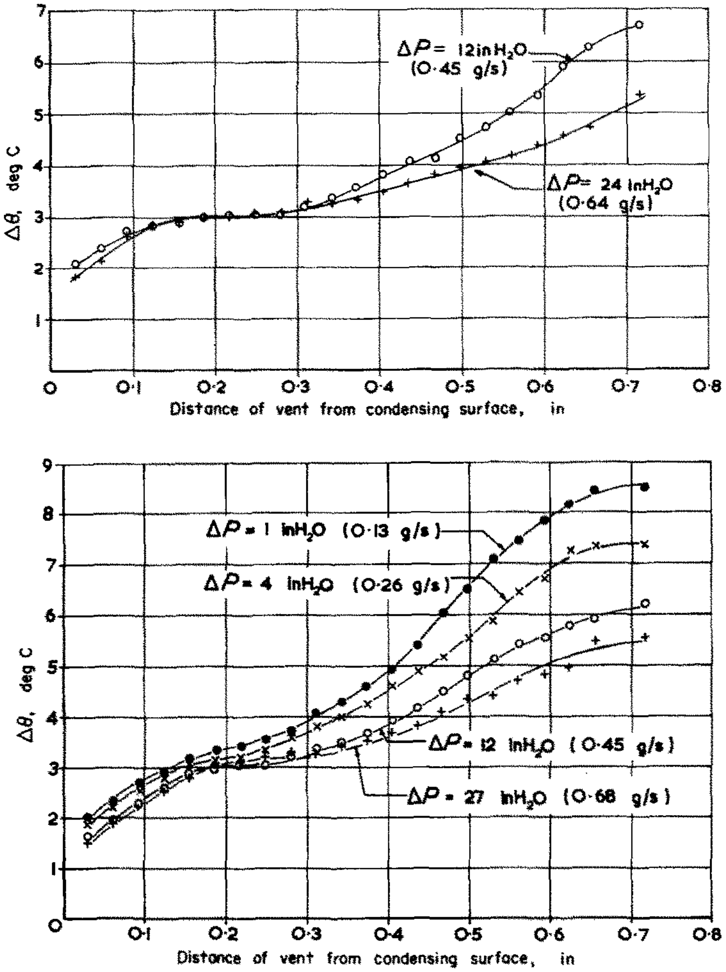


FIG. 5. Effect of vent position on the steam-to-surface temperature difference for various venting rates. (Different venting rates obtained by varying steam pressure with a fixed valve setting. $Q'' = 1$ MW/m^2.)

venting rate at both remoter and closer vent positions. However, when the vent is situated between about 0·2 in and 0·3 in (i.e. between about 5 mm and 8 mm) from the condensing surface, $\Delta\theta$ is independent of venting rate when the latter exceeds about 0·3 g/s.

These results are consistent with those given in Fig. 4 and may be interpreted in the same manner. When the vent is relatively remote from the condensing surface, the build up of gas near the surface is greater (thus $\Delta\theta$ is greater) and is more sensitive to change in the venting rate. When the vent is very close to the surface, increase in venting rate causes increase in the disturbance of the condensate and thereby reduces $\Delta\theta$. As would be expected, some non-dependence on venting rate is found in the range of vent position for which $\Delta\theta$ is independent of position.

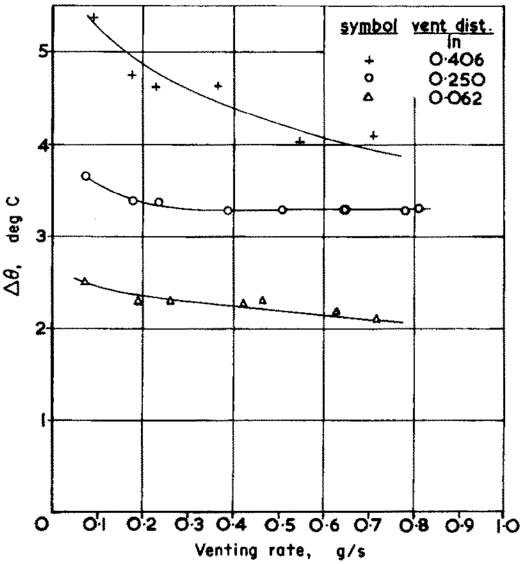


FIG. 6. Effect of venting rate on steam-to-surface temperature difference for three vent positions. (Different venting rates obtained by varying the valve setting. $\Delta P = 24\,\text{inH}_2\text{O}$, $Q'' = 1\ \text{MW/m}^2$).

Finally, further confirmation of the above observations was obtained by observing the variation of $\Delta\theta$ with venting rate for three different vent positions. For these tests a constant coolant flow rate was used (corresponding to $\dot{Q}'' = 1\ \text{MW/m}^2$) and the steam pressure was kept constant at a gauge pressure of about 24 inH_2O. Variation of venting rate was obtained by adjusting the valve on the vent. The results are shown in Fig. 6. It is again seen that for the two extreme vent positions $\Delta\theta$ depends on the venting rate, being more strongly dependent for the more distant position. For the intermediate position $\Delta\theta$ does not depend on venting rate provided this exceeds about 0·25 g/s.

In all of the venting tests reported above, erratic fluctuations of the plate temperatures were observed for the more remote vent positions and for the lower venting rates. For the most remote positions and the lowest venting rates the surface temperature varied over a range of more than 1 degC. It is suggested that these temperature fluctuations arise from the disturbance of the gas "blanket" by the falling drops.

It is difficult to conceive an alternative explanation to that given for the results shown in Figs. 4–6. It may thus be concluded that, in the absence of forced convection, gas concentrations in the supply steam of as little as a few parts per million, can have a very significant effect on the steam-to-surface temperature difference.

For the present case, the vent should be situated between about 5 mm and 8 mm from the condensing surface and the venting rate should exceed about 0·4 g/s in order to obtain results which are vitiated neither by the presence of non-condensing gases nor by venting. When operating under these conditions, the results should be the same as those which would be obtained in the complete absence of non-condensing gases and venting, for heat fluxes up to about 1·5 MW/m^2. For higher heat fluxes the results depend on vent position and thus will be less accurate.

It should be noted that the above limits of vent position and venting rate relate to the present plate, steam-chamber and vent geometry and to the non-condensing gas concentration found in the present work. The possibility of attempting to provide a correlation for the guidance of other workers was considered. However, this would have involved a very large number of tests in which vent diameter and gas concentration in addition to vent position, venting rate and condensation rate were varied. Even then the result would only apply to the present steam chamber and plate geometry. It is thought that the results given in Figs. 4–6 should provide a rough guide to future workers using apparatus not too dissimilar from that used in the present work.

4. EFFECT OF TIME

It has been reported earlier [5] that, when using a newly promoted plate, the surface temperature was found to increase with time to a steady value. These observations were made after minimizing the concentration of non-condensing gases by boiling, and while using a close vent in order to obviate the effect of the remaining "gases".

The present authors have examined this time-dependence more closely. For several different coolant flow rates, the variation of the steam-to-surface temperature difference with time was observed. The plate of thickness 6·35 mm was used and the vent was set at a distance of 6·3 mm from the condensing surface.

Before assembling the promoted plate on the steam chamber, the water in the boiler was boiled very vigorously, blowing off most of the steam to atmosphere through the main steam-chamber vent (13-mm dia.) for about 15 min, in order to expel air from the steam chamber. The main vent was closed and the close vent used, the valve being kept fully open and the gauge pressure maintained at about 16 inH_2O. Under these conditions the venting rate was about 0·5 g/s. For runs lasting longer than about 4 h the vented steam was taken to a reflux condenser and the condensate therefrom was returned to the boiler.

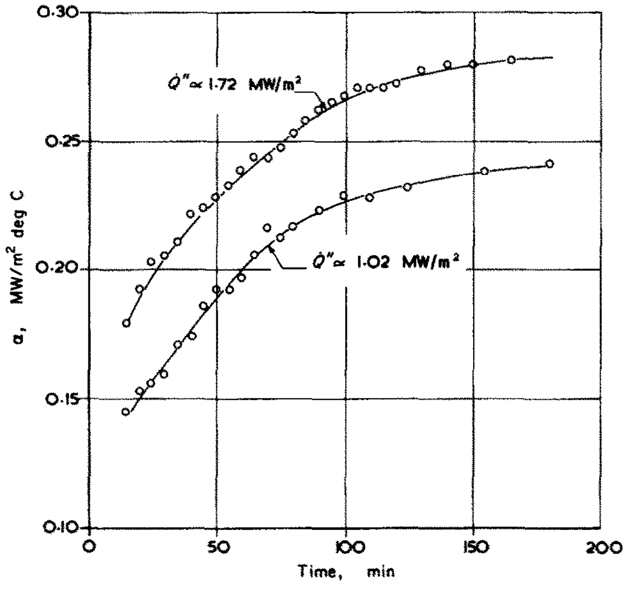


FIG. 7. Initial variation of steam-side heat-transfer coefficient with time. (ΔP = 16 inH_2O.)

Figures 7 and 8 are typical of the results obtained. It seems probable that the initial increase in the steam-side heat-transfer coefficient, during the first 3 h, is due to removal of excess promoter by the condensate. However, no clear correlation between the rate of increase or the subsequent rate of decrease in coefficient with condensing rate was found.

It may be noted that the rate of fall of the heat-transfer coefficient with time is very small. During the 4 h after the maximum coefficient had been reached, the steam-to-surface temperature difference increased only by about 0·1 degC and in the following 20 h by less than 1 degC.

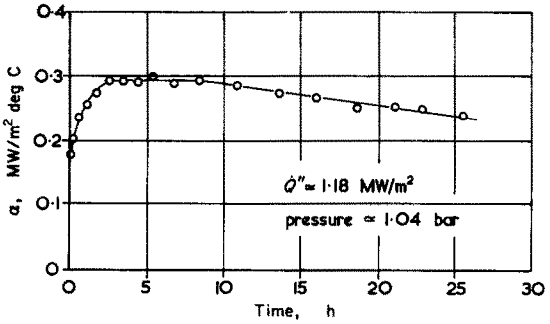


FIG. 8. Variation of steam-side heat-transfer coefficient with time over a longer time interval.

It has been reported [5, 8] that, when a promoted surface is exposed to air for several hours after a condensing run, dropwise condensation usually occurs when the surface is again subjected to steam, provided that the coolant is passed continuously during the interval of shut-down.

In the present work, the steam-to-surface temperature difference was observed over a range of heat flux on successive days, between which the surface was left in contact with air but with coolant passing. The results of these tests are shown in Fig. 9. During the first three days no change in the appearance of the surface was observed. By the ninth day the surface had become discoloured, the drops were somewhat less regular in shape and grew to a larger size before falling.

5. EFFECT OF HEAT FLUX

Both test plates were used to investigate the effect of heat flux on the steam-to-surface temperature difference. The close vent was set at a distance of 6·3 mm (0·25 in) from the condensing surface. The water in the boiler was first boiled vigorously for about 15 min while blowing off most of the steam to atmosphere through the large vent. This was then closed and venting was continued using the close vent with the valve fully open. The steam pressure was maintained at about 24 inH_2O above atmospheric. All measurements were made during the time interval for which the heat-transfer coefficient was constant, i.e. between 3 and 8 h

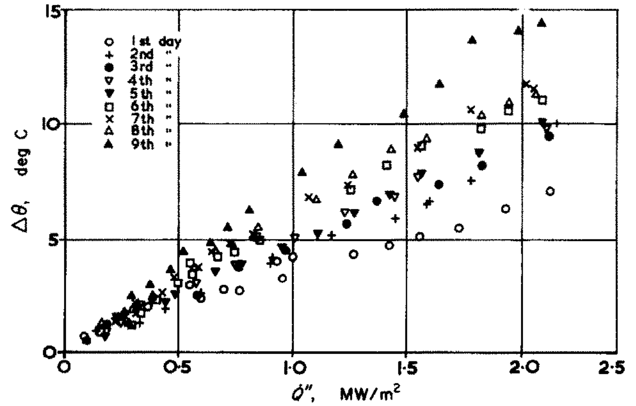
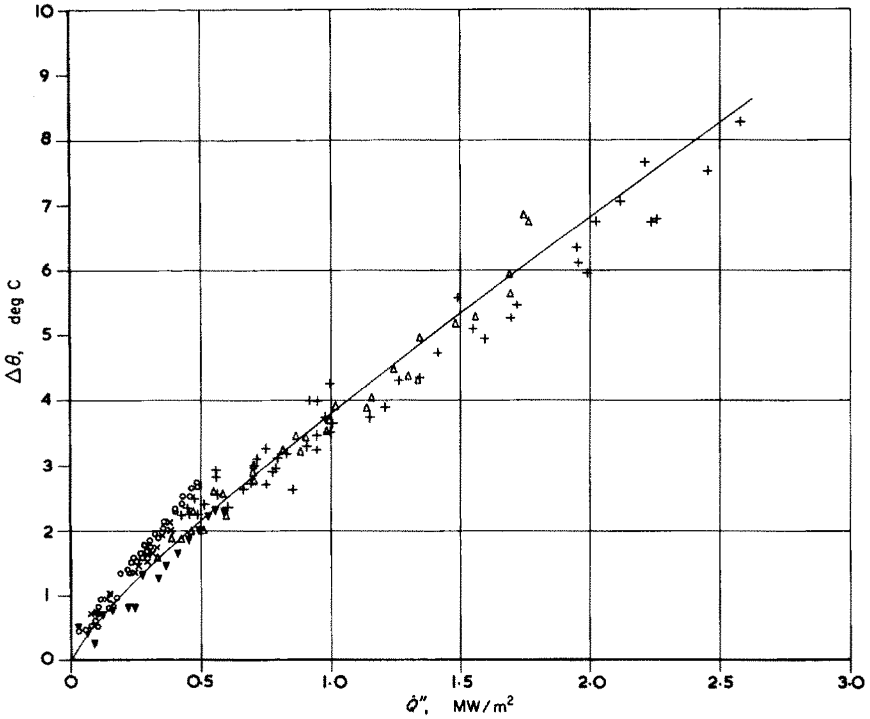


FIG. 9. Time dependence of the performance of a promoted surface with intermittent operation and without repromotion. (Pressure ≃ 1·04 bar.)



Symbol	Ref.	Comments
+	Present	0·25 in Plate
×	Present	0·25 in Plate (coolant heated)
○	Present	2·00 in Plate
△	[5]	
▼	[6]	
/	[10]	Taking $\kappa_{21} = 1{\cdot}04$

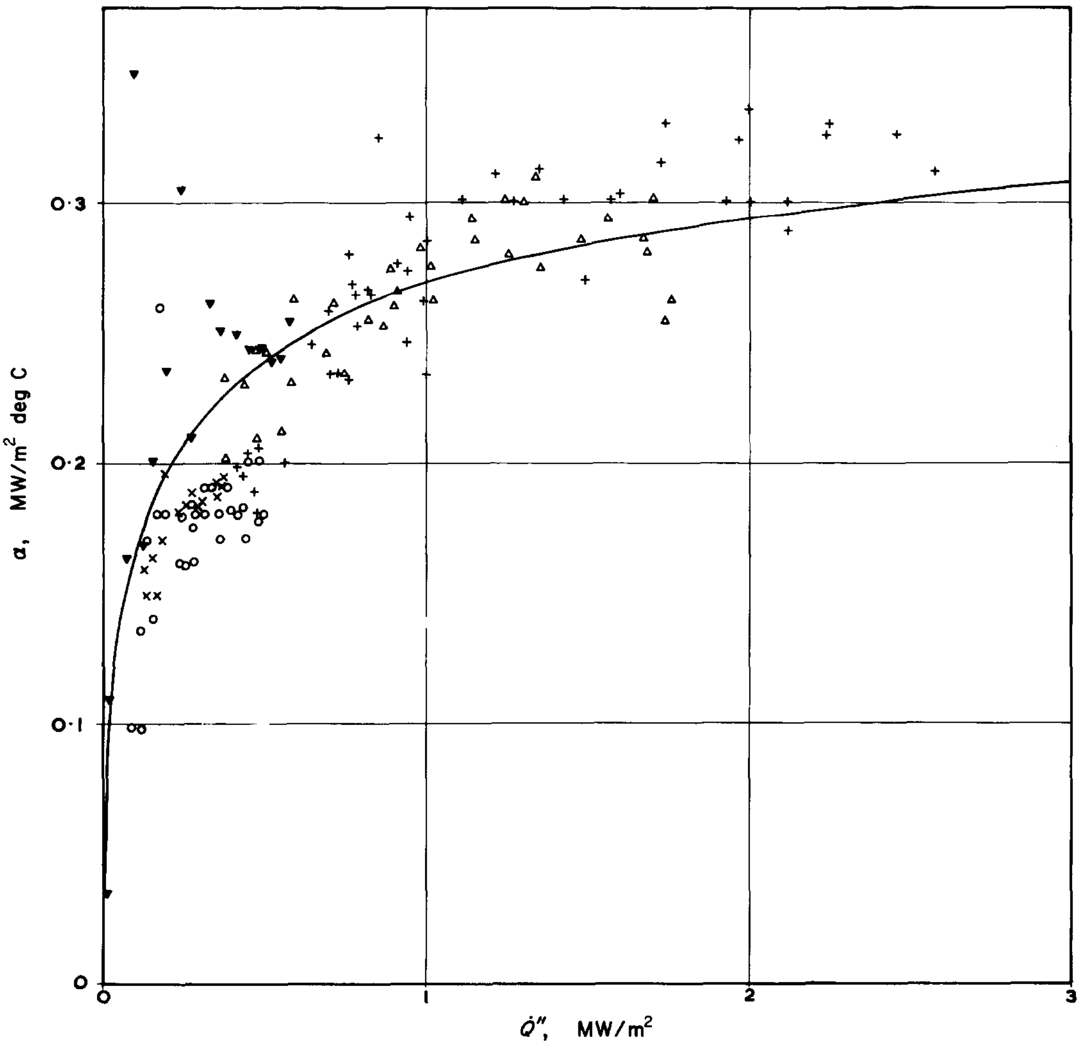
FIG. 10. Variation of steam-to-surface temperature difference with heat flux. (Pressure ≃ 1·07 bar.)

after the commencement of boiling (see Section 4).

The results are shown in Figs. 10 and 11 where they are compared with other recent observations for which dioctadecyl disulphide was used as the promoter. Also shown on Figs. 10 and 11 is the line given by equation (30) of Le Fevre and Rose [10].

6. CONCLUDING REMARKS

In the light of the present results relating to non-condensing gases and venting, it is seen that the presence of a few parts per million of a non-condensing gas can lead to very serious errors in measurements of the steam-to-surface temperature difference for dropwise condensation of steam. In the present apparatus, where the condensing surface and the region of lowest gas concentration are separated by a relatively short steam chamber of fairly wide cross section (4-in dia. × 6-in long) the observed steam-to-surface temperature difference is, in the absence



Symbol	Ref.	Comments
+	Present	0·25 in Plate
x	Present	0·25 in Plate (coolant heated)
o	Present	2·00 in Plate
△	[5]	
▼	[6]	
/	[10]	Taking κ_{21} = 1·04

FIG. 11. Variation of steam-side heat-transfer coefficient with heat flux. (Pressure ≃ 1·07 bar.)

of forced convection, almost twice the value relating to gas-free steam. In types of apparatus, such as have been used by some earlier workers, where the steam chamber is supplied from the boiler by a pipe of small diameter, the equilibrium gas concentration in the steam chamber is clearly much larger than that in the supply steam, unless the steam chamber is vented in some way. In such cases we should expect very large errors in the steam-to-surface temperature difference. In cases where the steam chamber has been vented, i.e., excess steam supplied and taken off through a separate pipe, we should expect that the observed temperature differences would vary between the "true" values and the widely erroneous ones obtained in the absence of venting. It is considered that in very few cases would there have been errors in the opposite direction, through disturbance of the condensate, since most earlier workers have sought to avoid significant vapour velocity near the condensing surface.

In view of the above, it seems highly probable that the presence of non-condensing gases, and failure to realize that even minute concentrations of such gases may lead to serious errors, has been the major cause of the wide diversity of published heat-transfer data for dropwise condensation.

The present work indicates that the errors, caused by such gas concentrations as remain in steam after prolonged boiling, may be eliminated by venting. However, care must be taken regarding the position of the vent and the venting rate, so as to ensure that the venting is sufficient to reduce the local gas concentration to an insignificant level without, at the same time, causing errors through disturbance of the condensate. For the present simple steam chamber and vent geometry, it was found impossible to achieve this for the highest condensation rates.

For copper plates, newly promoted with dioctadecyl disulphide and after elimination of the effects of non-condensing gases, the steam-side heat-transfer coefficient increases for about 3 h to a steady value at which it remains for about 5 h before falling slowly. In order to obtain repeatable results, measurements should be made during the interval for which the coefficient is constant. A significant drop in heat-transfer coefficient follows a period of shut-down of about 12 h, even though the coolant is passed continuously and no change is observed in the appearance either of the surface or mode of condensation.

The steam-side heat-transfer coefficient increases with heat-flux and may reach a stationary value towards the upper end of the heat-flux range obtained in the present work (see Fig. 11). The observed dependence of the steam-to-surface temperature difference on heat-flux for this promoter is in quite good agreement with the results of Tanner *et al.* [6] and Le Fevre and Rose [5]. The theory proposed by Le Fevre and Rose [10] is in fair agreement with the above observations.

REFERENCES

1. E. SCHMIDT, W. SCHURIG and W. SELLSCHOP, Versuche über die Kondensation von Wasserdampf in Film- und Tropfenform, *Tech. Mech. Thermo-Dynam., Berl.* **1**, 53 (1930).
2. H. WENZEL, Versuche über Tropfenkondensation, *Allg. Wärmetech.* **8**, 53 (1957).
3. H. HAMPSON, The condensation of steam on a tube with filmwise or dropwise condensation and in the presence of a non-condensable gas, *International Developments in Heat Transfer*, Vol. II, p. 310. Am. Soc. Mech. Engrs, New York (1961).
4. D. W. TANNER, C. J. POTTER, D. POPE and D. WEST, Heat transfer in dropwise condensation—Part I: the effects of heat flux, steam velocity and non-condensable gas concentration, *Int. J. Heat Mass Transfer* **8**, 419 (1965).
5. E. J. LE FEVRE and J. W. ROSE, An experimental study of heat transfer by dropwise condensation, *Int. J. Heat Mass Transfer* **8**, 1117 (1965).
6. D. W. TANNER, C. J. POTTER, D. POPE and D. WEST, Heat transfer in dropwise condensation—Part II: surface chemistry, *Int. J. Heat Mass Transfer* **8**, 427 (1965).
7. E. CITAKOGLU, Heat transfer by dropwise condensation, Ph.D. Thesis, London University (1966).
8. T. FURMAN and H. HAMPSON, Experimental investigation into the effects of cross flow with condensation of steam and steam–gas mixtures on a vertical tube, *Proc. Instn Mech. Engrs* **173**, 147 (1959).
9. J. F. WELCH and J. W. WESTWATER, Microscopic study

of dropwise condensation, *International Developments in Heat Transfer*, Vol. II, p. 302. Am. Soc. Mech. Engrs, New York (1961).

10. E. J. Fevre and J. W. Rose, A theory of heat transfer by dropwise condensation, in *Proceedings of the Third International Heat Transfer Conference*, Vol. 2, p. 362. Am. Inst. Chem. Engrs, New York (1966).

Résumé—Des publications récentes de différents chercheurs dans le domaine de la condensation par gouttelettes suggèrent que des mesures précises et reproductibles de la différence de température entre la vapeur d'eau et la surface peuvent être obtenues seulement lorsqu'on prend des précautions spéciales pour éviter les effets des gaz non-condensables.

Dans ce travail, on étudie les effets de la ventilation locale (c'est à dire l'enlèvement de la vapeur au voisinage de la surface de condensation). Le but était premièrement de démontrer que même de faibles concentrations de gaz non condensables, comme celles qui restent dans la valeur d'eau après un ébullition prolongée, peuvent conduire à des erreurs sensibles dans les mesures de la différence de température entre la vapeur d'eau et la surface pour la condensation par gouttelettes et, deuxièmement, d'étudier la possibilité d'éviter de telles erreurs en ventilant sans introduire, en même temps, une erreur due à la perturbation du condensat.

Pour une surface de condensation en cuivre, recouverte de bisulfure de dioctadécyle ($C_{18}H_{37}SSC_{18}H_{37}$), la dépendance du temps du coefficient de transport de chaleur du côté de la vapeur a été également étudiée afin d'évaluer l'importance de ce facteur sur la reproductibilité des observations.

On a établi les conditions pour lesquelles des résultats reproductibles, se rapportant à la vapeur d'eau "sans gaz", peuvent être obtenus.Tandis qu'on opère sous de telles conditions, on a observé une différence de température entre la vapeur d'eau et la surface pour une gamme étendue de flux de chaleur. Dans ces essais, des surfaces verticales de condensation en cuivre étaient employées recouvertes de bisulfure de dioctadécycle. La pression de la vapeur d'eau était environ de 1,07 bar. Les résultats sont comparés à ceux d'autres chercheurs récents.

Zusammenfassung—Aus verschiedenen neueren Arbeiten auf dem Gebiet der Tropfenkondensation lässt sich schliessen, dass präzise und reproduzierbare Messungen der Temperaturdifferenz zwischen Dampf und Kondensationsfläche nur gemacht werden können, wenn spezielle Vorsichtsmassnahmen ergriffen werden, um Einflüsse von Inertgasen auszuschalten.

In der vorliegenden Arbeit wurden die Einflüsse von lokalem Absaugen (d. h. dem Entfernen von Dampf aus der Umgebung der Kondensationsfläche) untersucht. Die Ziele der Untersuchung waren erstens, nachzuweisen, dass sogar kleinste Konzentrationen von Inertgasen, wie solche, die nach langem Sieden noch im Wasser verbleiben, zu entscheidenden Irrtümern bei der Messung des dampfseitigen Wärmeübergangskoeffizienten bei Tropfenkondensation führen können; und zweitens, die Möglichkeit zu untersuchen, solche Irrtümer durch Absaugen zu vermeiden, ohne gleichzeitig Fehler durch Stören der Kondensation zu verursachen.

Ausserdem wurde für eine Kondensationsfläche aus Kupfer, die mit "dioctadecyl disulphide" ($C_{18}H_{37}SSC_{18}H_{37}$) hydrophobiert war, die Zeitabhängigkeit des dampfseitigen.

Wärmeübergangskoeffizienten untersucht, um den Einfluss der Zeit auf die Reproduzierbarkeit der Beobachtungen festzustellen.

Es wurden Bedingungen hergestellt, für die reproduzierbare Ergebnisse erhalten wurden, die einem "gasfreien" Dampf entsprechen. Unter solchen Bedingungen wurde die Temperaturdifferenz zwischen Dampf und Kondensationsfläche für einen weiten Bereich der Wärmestromdichte gemessen. Für diese Untersuchungen wurden vertikale ebene Kupferflächen, die mit "dioctadecyl disulphide" hydrophobiert waren, benutzt. Der Dampfdruck betrug ca. 1,07 bar. Die Ergebnisse wurden mit jenen neuer anderer Arbeiten verglichen.

Аннотация—В недавно опубликованных докладах различных исследователей в области капельной конденсации предполагается, что точные и воспроизводимые измерения разности температур пар-поверхность можно получить только в случае, если предприняты особые меры для исключения влияния неконденсирующихся газов.

В данной работе изучаются влияния локального выброса (т.е. удаление пара из области, прилегающей к конденсирующей поверхности). Цель данной работы состоит в том, чтобы показать, что даже незначительные концентрации неконденсирующихся газов, которые остаются в паре после длительного кипения, могут привести к значительным погрешностям измерений разности температур пар-поверхность при капельной конденсации, а также в изучении способов избежать таких погрешностей при выбросе не добавляя погрешности за счет разрыва конденсата.

Для медной конденсирующей поверхности, покрытой $C_{18}H_{37}$ $SSC_{18}H_{37}$, также исследовалась временная зависимость коэффициента теплообмена для выявления влияния данного фактора на повторяемость наблюдений.

Установлены условия, при которых можно получить повторяемые результаты, относящиеся к пару «свободному от газа». В таких условиях проводились наблюдения за разностью температур пар-поверхность для широкого диапазона тепловых потоков. В этих экспериментах использовались вертикальные медные конденсирующие поверхности, покрытые $C_{18}H_{37}SSC_{18}H_{37}$. Давление пара было приблизительно 1,07 бар. Полученные результаты сравниваются с результатами недавно опубликованных работ.