UDC 536.423.4

AN EXPERIMENTAL STUDY ON DROPWISE CONDENSATION ——THE EFFECT OF THE MAXIMUM DROP SIZE

滴状凝縮過程の実験的研究——最大液滴径の影響

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1. Introduction

The present study is a part of a series of works whose object is to make clear the effect of the departing drop size upon the process of heat transfer by dropwise condensation.

The heat transfer coefficient in dropwise condensation is governed by the rate of drop growth (due to direct condensation and coalescence) and by the distribution of drop size. In the previous report[1] the authors studied the effect of the departing drop size, which is the most significant parameter in the drop size distribution, upon the heat transfer coefficient. The steam shear force and the centrifugal force were both used to change the departing drop size, and the result that the heat transfer coefficient was proportional to the departure diameter to −0.31 power was obtained.

However, the above mentioned methods of removing the droplets have a slight imperfection in that the departing drop diameter measured over the entire condensing surface does not necessarily coincide with the maximum drop diameter at the center of the surface where the heat transfer coefficient is measured.

In the present study, a wiper (just like the one for the automobile) is used to wipe off periodically all the drops on the surface, thus controlling the maximum size at the will of experimenter. The maximum drop size, the rate of drop growth due to coalescence and the heat transfer coefficient are measured at various periods of wiping.

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2. Apparatus

The condenser block used in the experiment is shown in Fig. 1. Similar to

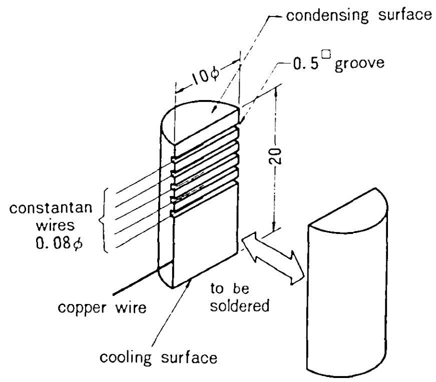

Fig. 1 Split-type copper condensing block

the previous measurements by the authors[1][2] a split-type cylindrical condensing block made of pure copper (purity higher than 99.99%) is prepared for the precise measurement of the heat flux and the temperature of the condensing surface. The diameter of the block is reduced to 10 mm in order to make the time needed for the wiper to sweep through the surface as short as possible. In connection to this, constantan wire of 0.08 mm dia. is used for thermocouple with the purpose of reducing the possible conduction of heat through the wire.

The condensing surface is promoted with silicone resine (KE45, Shin-etsu

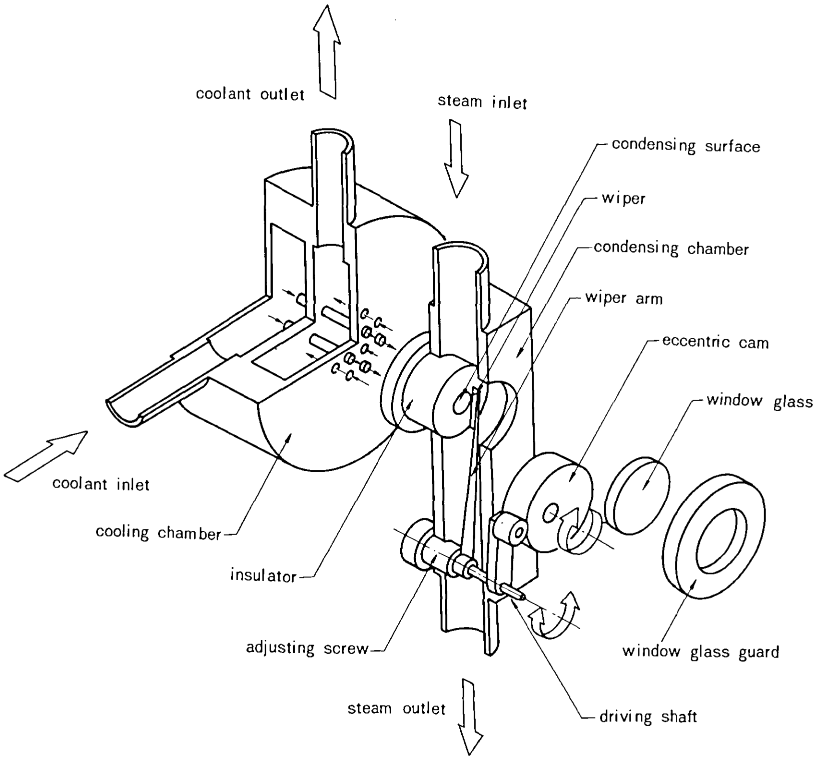

Fig. 2　Exprimental apparatus

Kagaku Co.). Since the surface is repeatedly swept with the wiper, it sometimes happens that the promoter is partly removed. To check if this actually happend, the heat transfer measurements without operating the wiper are carried out before and after every wiping experiment. If the difference between the results of both measurements exceeded 10 %, the experiment is done over again having the promoter newly applied.

Figure 2 shows the condensing chamber and the mechanism of the wiper.

The element of the wiper is made of silicone rubber, 0.2 mm thick, 15 mm long and 3 mm high. It is fixed at the top of an arm made of brass.

The wiper is made to swing up and down with an eccentric cam. The profile of the cam is so chosen that the time required for the wiper to swept through the condensing surface with 10 mm dia. can be as short as possible. In the present apparatus the time needed for the wiper to cross the surface is about 1/8 of the period of reciprocation, the minimum period being 0.05 sec. The contact pressure between the wiper and the surface can be adjusted with a screw on the driving shaft.

The build-up of non-condensable gases onto the condensing surface is prevented as before by the steam flow. The velocity of the steam flow is chosen as 10 m/sec from our experience. The direction of the wiper arm is made parallel to the steam flow so as not to obstruct it.

A 16 mm cine-camera (HIMAC 16HD, Hitachi Co.) and a microscope are used to measure the rate of drop growth. The filming rates are from 500 to 1000 pic. sec and the magnifications are 15 and 50 . The developed films are analyzed with a film editor. The smallest droplet clearly identified when the magnification is 50 is 0.01 mm dia.

For the measurement of the maximum drop size either a video-taperecorder (Sony, DXC-type) or the 16 mm cine-camera is used depending on the period of wiping. The maximum drops are measured among the drops which lie inside a circle of 2.5 mm radius located at the center of the surface at the moment just after the wiper has passed. Since the maximum drop diameters are varied a little at each measurement, the average is taken for ten to twenty reciprocations.

3. Results

3—1 Rate of drop growth

The increase of drop diameter with time is plotted in Fig. 3 . The moment just after the wiper is passed is taken as the origin of time. In the case of Fig. 3 , the period of wiping (τ) is 0.24 sec and the maximum drop diameter (D_{max}) is 0.64 mm. The process of drop growth is illustrated by zigzag lines for three different drops. A least squares fit is calculated for these three cases

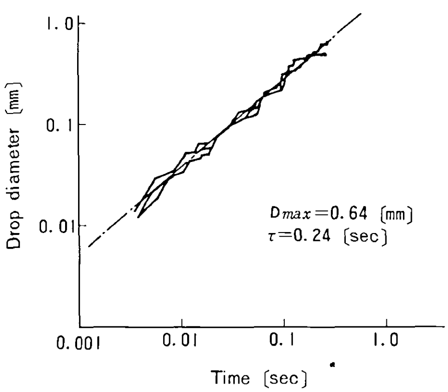

Fig. 3 Process of drop growth

and drawn in Fig. 3 as a dot-dash line. This line is expressed as

$$D=2.1t^{0.87} \qquad (1)$$

where D is the drop diameter [mm] and t is time [sec]. The heat flux is kept constantly 6.4×10^5 kcal/m²h. In our previous measurement[2] the exponents to t in Eq. (1) were found to lie between 0.72 and 0.86 under somewhat different external conditions.

3—2 Maximum drop size

Figure 4 shows the change in the maximum drop diameter. The period of wiping ranges between 0.06 and 0.4 sec.

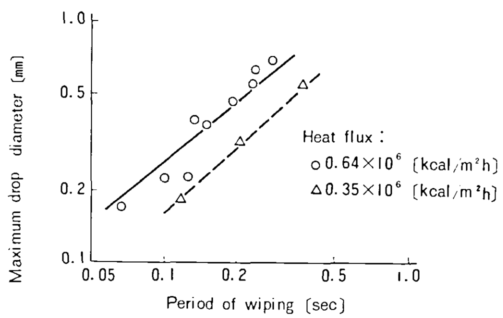

Fig. 4 Maximum drop diameter vs. wiping period

Circles are for the heat flux of 0.64×10^6 kcal/m²h and triangles are for 0.35×10^6 kcal/m²h. The least squares calculation is applied for the circles and the relationship as follows is obtained:

$$D_{max}=1.8\tau^{0.83} \qquad (2)$$

where D_{max} is the maximum drop diameter [mm] and τ is the period of wiping [sec]. The coefficients (2.1 and 1.8) and the exponents to t and τ (0.87 and 0.83) do not coincide between Eqs. (1) and (2). These differences, however, are not thought to be of great significance, considering the scatter and the accuracy of the data. Therefore, the relationship between the maximum drop size and the period of wiping is (within a moderate range of τ) considered to be identical with the rate of drop growth.

3—3 Heat transfer coefficient

The change in the heat transfer coefficient is plotted in Fig. 5 against the maximum drop diameter which changes from 0.17 to 0.70 mm. The white circles represent the data for the heat flux of 0.64×10^6 kcal/m² h and the white triangles are for 0.35×10^6 kcal/m² h. Also the results of measurements using the steam shear force are plotted in the graph with black circles and triangles.

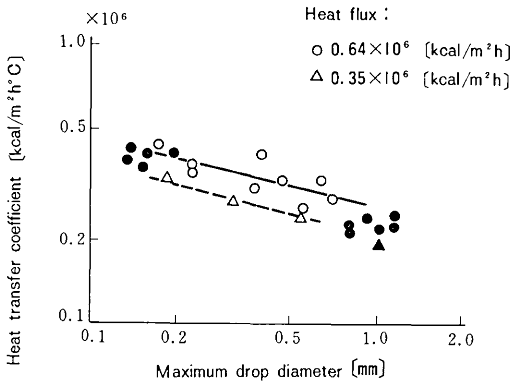

Fig. 5 Heat transfer coffeicient vs. maximum drop diameter

The least squares fit is obtained for the white marks, the slope being −0.24. In the previous report it has been found that the heat transfer coefficient is proportional to the departing drop diameter to −0.31 power. The cause of such difference may be in the difference between the departing drop size and the maximum drop size, the difference in the drop size distribution, or the effect of the finite sweeping time. On the other hand, such difference cannot be considered as significant, judging from the scatter and the error of the data. The detailed discussion remains after the more elaborate measurements, however.

4. Conclusion

The maximum size of the drops on the condensing surface was changed artificially by sweeping off the drops with a wiper. The relationship between the maximum drop size and the heat transfer coefficient was measured and a similar expression was obtained as the one found in the previous experiment in which the relationship between the departing drop size and the heat transfer coefficient was sought for.

In the studies which will follow, the authors plan to measure the drop size distribution and the fluctuation of surface temperature to make clear how the droplets having different sizes contribute to the total heat transfer process.

(Manuscript received Oct. 3, 1975)

References

(1) Tanasawa, I. et al.: *Proc. 11th Heat Transfer Symposium* (in Japanese) (1974), 229.

(2) Tanasawa, I. and J. Ochiai: *Bull. JSME*, 16 (1973), 1184.