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	作成者: Kameoka, Toshiyuki, Kawai, Tsutomu
	メールアドレス:
	所属:
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Behaviors of a Water Drop on Horizontal Condenser Tubes

Toshiyuki KAMEOKA* and Tsutomu KAWAI**

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This paper shows an investigation on the behaviors of condensate drops, during dropwise condensation of steam, falling down on horizontal condenser tubes arranged in a vertical row. Since the condensate drops fall down to the bottom of the condenser by repeating the motion on outer surfaces of the tubes and the free falling alternatively, they behave in such manner different from the case of a vertical flat surface as the motion on the cylindrical surface, e.g. the separation from the surface, the free falling and the deformation of the drop shape by striking against the surface. In this paper, these behaviors have been made clear by the experiments using a water drop of known weight in the air.

1. Introduction

Generally speaking, a conventional steam condenser has many horizontal tubes. When dropwise condenstation is applied to the condenser, there may be various factors related to heat transfer during dropwise condenstaion. In order to make clear the state of dropwise condensation, a transparent condenser is made and the state in the condenser is observed. On the basis of this experimental fact, it is supposed that the falling behavior of condensate drops in the vertical direction of a cooling surface is very important. In the case of horizontal condenser tubes arranged in a vertical row, consensate drops fall down to the bottom of the condenser by repeating the motion on outer surfaces of the tubes and the free falling alternatively. For this reason, there are various behaviors of the falling drops which are not observed in the case of the vertical condenser surface. The behaviors are as follows; the motion on the cylindrical surface, the separation from the surface, the free falling, and the deformation of the drop shape by striking against the surface. In this paper, these behaviors have been made clear experimentally in the air using a water drop with known weight.

2. Behaviors of the Condensate Drops on the Horizontal Condenser Tubes

In order to make clear behaviors of condensate drops on horizontal condenser tubes during dropwise condensation of steam, a transparent condenser was made and the behaviors of the drops were observed. The condenser consists of a glass tube of 300 mm

* Department of Mechanical Engineering, College of Engineering.
** Department of Mechanical Engineering, Wakayama Technical College.

in diameter and four condenser tubes (brass tube of 25.4 mm in diameter) coated with oleic acid as promoter.

Photo. 1 shows the state of condensate drops on horizontal tubes during drpowise condensation. There are large condensate drops on the upper parts of every condenser tube, especially the top tube in the vertical row. The reason is that falling condensate drops have the sweeping action peculiar to the case of a horizontal tube, that is, in Fig. 1, the

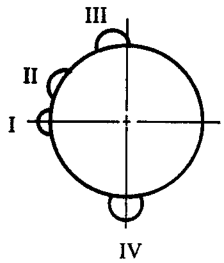


Fig. 1. Diagrammatic condensate drops on a cylindrical surface.

condensate drops on the entire surface of a horizontal tube have about the same diameter in the initial stage of steam supply. As the resting drop on the side portion of a cylindrical surface has the smallest critical weight, the drop I moves first and reaches at the lower part of the tube sweeping other adhered drops on its path. After a while, the drpo II which adheres at the upper part of the drop I moves and reaches at the lower part of the tube in the same way. The process continues and at last the drop which adheres near by the top of the tube moves. Since this drop moves from the top end to the lower one of the horizontal tube, the condensation in the next cycle begins simultaneously all over the area of the swept path. As the process occurs at random on several parts of every tube surface, the adhered drops distribute as shown in Photo. 1. The drop of a small weight that reaches at the lower part of the tube hangs down at the point and increases thermal resistance. However, if the drop weight is large, the drop separates from the tube surface and freely falls and raeches at lower tubes. The tube is swept by the falling drops except the top one in the vertical row, and the falling drops reach at several points on the lower tubes.

When a falling drop strikes against a tube surafce, as shown in Photo. 2–(a), the drop is depressed, spreads and coalesces with adhered drops. In the next moment, the depressed drop shrinks and becomes dropwise state and falls down along the tube surface.

In the case of many horizontal tubes arranged in the vertical row, many falling drops pass through on the surface of the lower tube and increase thermal resistance owing to a diminution in active condensate area. Photo. 2–(b) shows the state and the coalescing drops become flooding state. When the flood strikes aganist the tube surface, it spreads broadly and decreases the acitve condensate area.

The decrease of the active consensate area owing to falling drops relates to several factors, e.g. the interfacial condition, the number, size and velocity of falling drops. Fig. 2 shows the relation among the velocity u, the moving distance x and the time t of a falling

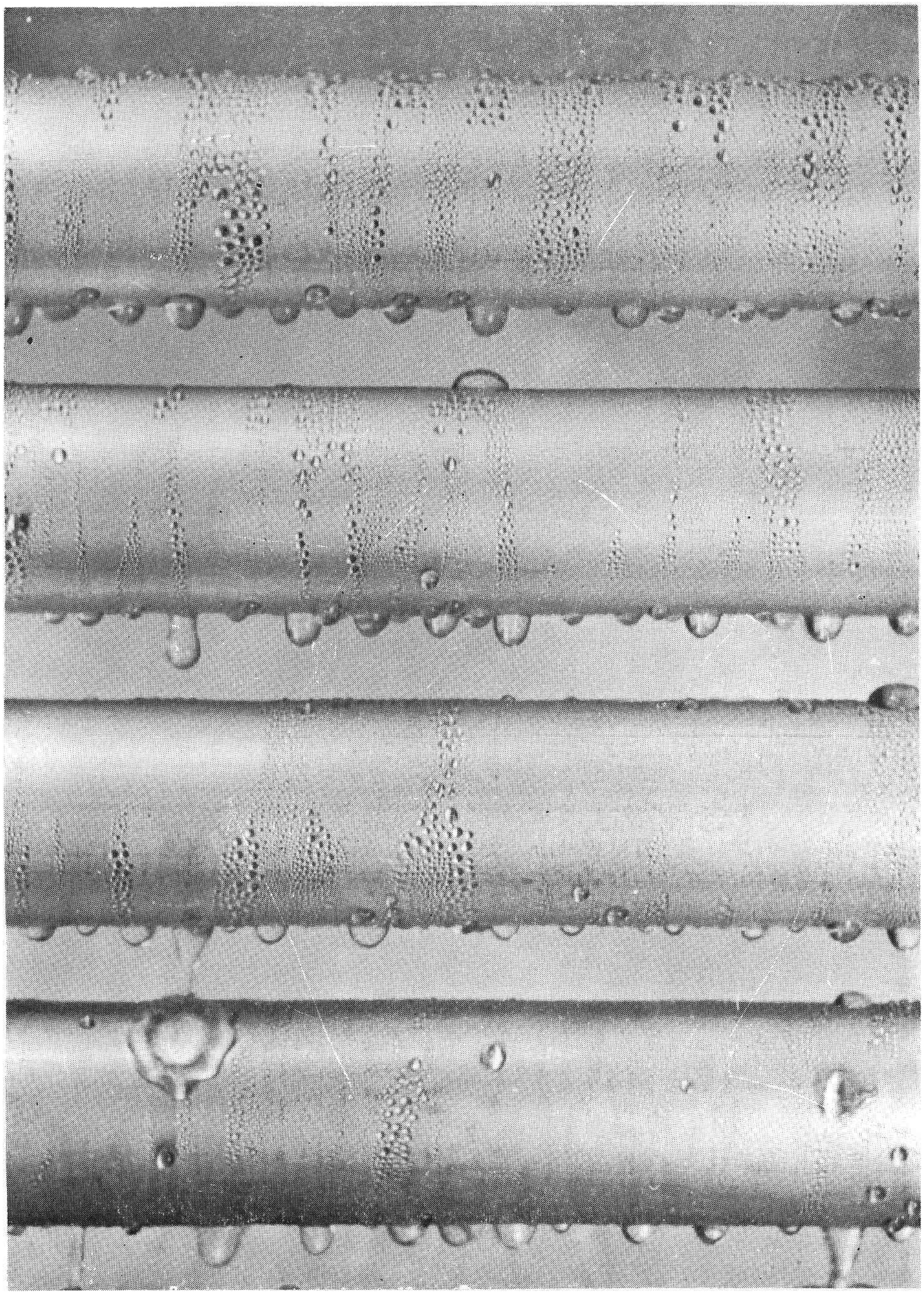
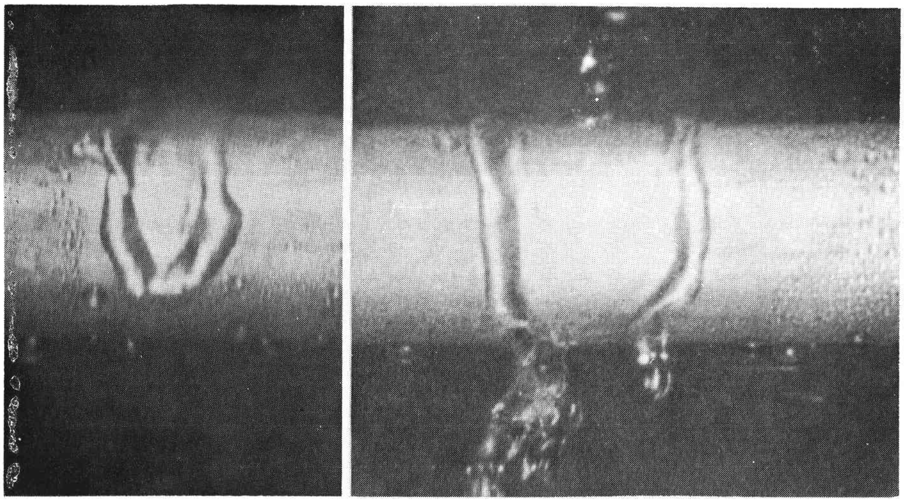


Photo. 1. Condensate drops on horizontal tubes.

drop, where, u is the vertical component of the velocity, x the distance in the vertical direction from the top of the first tube, ①～④ the number of each tube. The velocity of the falling drop u changes hard because the drop repeats the motion on outer surfaces of the tubes and the free falling alternatively.



(a) drop (b) flood

Photo. 2. Deformation of a condensate drop and a flood striking against a condenser tube.

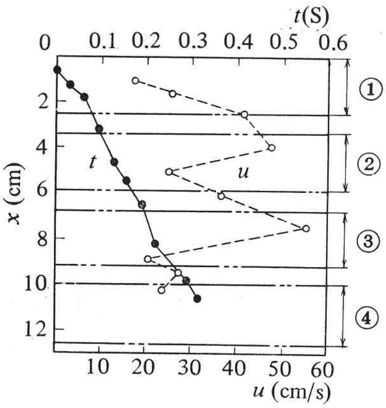


Fig. 2. Relation among the velocity and the moving distance and the time of a falling drop.

3. Behaviors of a Water Drop

Since the falling condensate drops on the condenser tubes change all the time the shape, weight and velocity, it is difficult to analyze theoretically the relation among these factors. Therefore, the relation has been made clear experimentally. Behaviors of a water drop with known weight on a cylindrical surface were taken in pictures by a 16 mm cine camera (film speed 64 frames/sec) in the air using an apparatus shown in Fig. 3, and the motion pictures were analyzed. As shown in Fig. 3, a zircon lamp was used as a point source of light which was made parallel rays by a lens. A water drop was fallen down on an outer cylindrical surface that center axis agreed with a ray axis. The cylindrical surfaces coated with paraffin wax were 12.7 and 22.4 mm in radius. For drop materials, soft water obtained through an ion exchanger and several kinds of surface-tension water added with a surface active agent, Sanmol *P* (manufactured by Nikka Cemistry Seiyaku, Japan) to alter contact angle, were used.

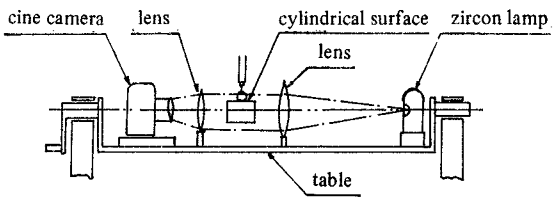


Fig. 3. Outline of the experimental apparatus.

To obtain experimental water drops having desired weight, an injection needle was used and the weights of drops were determined from the number of dripping ones from the needle. When the water drop was placed on an experimental surface, the drops dripped from the needle were first received on a special spoon coated with paraffin wax, holding the spoon tip as close as possible to the surface, and the water drop was moved slowly to the surface from the tip of the spoon.

According to the observations of the behaviors of the condensate drops, when the drop material and interfacial condition are same, the motion of a water drop on a cylindrical surface is influenced by the following factors, that is, the drop weight G, the falling height h, the radius of the cylindrical surface r, and the inclination angle α between the tangential line at the cylindrical surface that the drop strikes against and the horizontal line. Thus, the relation among these factors has been made clear experimentally.

Fig. 4 shows the typical examples for the behavior of the water drop on the cylindrical surface of 12.7 mm in radius. The drops in these figures are sketched from those in motion pictures and various behaviors of drops are summarized in these figures, e.g. the rolling down on the cylindrical surface, the hanging down from the surface, the separation from the surface, and the free falling. The numbers written near by each drop in figures show the frame order in the film. Fig. 4-(1)$\sim$(4) show various motions in several values of the inclination angle α and the height h for the drop with the same

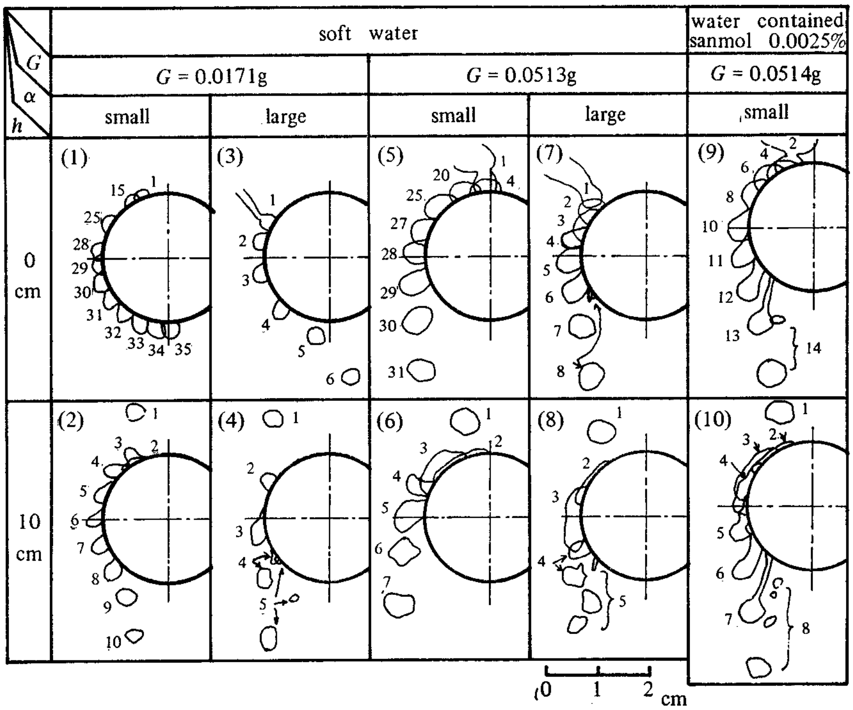
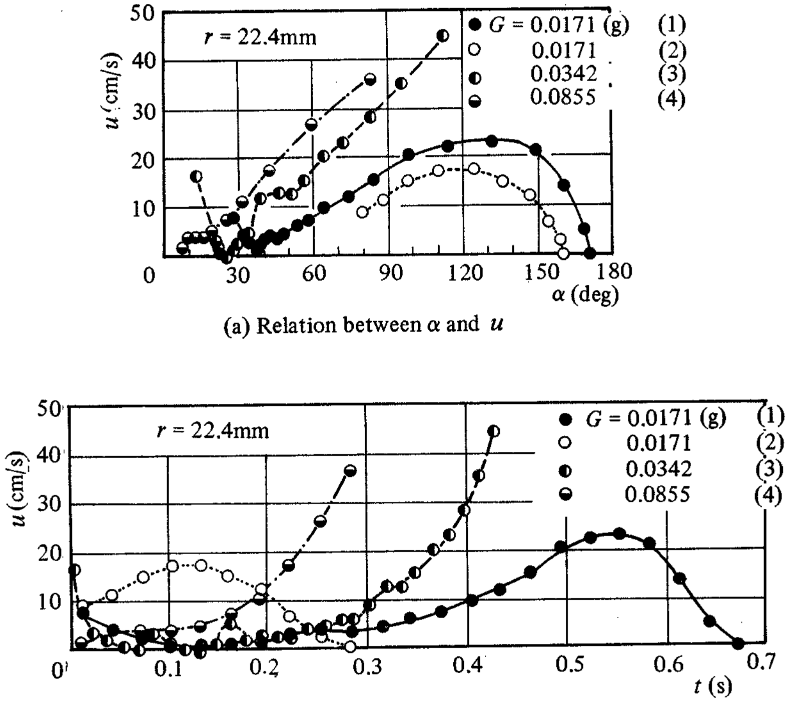


Fig. 4. Behavior of a water drop on a cylindrical surface.

weight. The expression "$h=0$ cm" written in figures means to put the drop as quiet as possible on the surface, and the tip of the spoon is shown with the drop in figures. The expression "$h=10$ cm" means to let fall the drop down from the point at the height of 10 cm to the surface. In the latter case, the drop is in the state of vibratile deformation, and the velocity of the drop on the cylindrical surface is large and the separation from the surface is quick as compared with that for $h=0$ cm. In the case of the heavy weight as shown in Fig. 4-(8), the drop elongates in the direction of its motion on the surface, and separating from the surface, the drop breaks into several droplets. For the low surface-tension water, as shown in Fig. 4-(9) and (10), the drops elongate greatly and wet the surface. Therefore, the separation from the surface delays.

4. Drop Velocity on a Cylindrical Surface

The velocity of the center of a drop which moves along a cylindrical surface coated with paraffin wax of 22.4 mm in radius is shown in Fig. 5. The velocity was determined by projecting the movies frame on a screen and measuring the distance in circumferential direction which the drop moves. Fig. 5-(a) shows the relation between the velocity u and the inclination angle α. The angle is 0 deg. at the top on the cylindrical surface. Fig. 5-(b) shows the relation between the velocity u and the moving time t. In these examples, owing to an existence of some falling height, curves (1) and (3) show the unusual



(a) Relation between α and u

(b) Relation between t and u

Fig. 5. Drop velocity on an outer cylindrical surface. (experiment)

states at the initial stages of the motion. One of the reasons is an existence of the initial velocity, and this is the same as the state on the curve (4). These phenomena are influenced by the respectively complicated relation among α, G and h as described later. If G_0 denotes the critical weight of a resting drop on a surface inclined with α, drops with $G > G_0$ on the inclined surface begin to move even if the falling height is zero. The velocity is calculated theoretically for a tailless drop. The equation[1] of the water drop moving on the inclined flat surface is given as follows

$$\frac{G^{2/3}\gamma^{1/3}}{g}\frac{d^2x}{dt^2} - G^{2/3}\gamma^{2/3}\sin\alpha + \left\{\sigma\Delta\Theta\, k_1 k_2 \frac{f(\theta_m)_1}{U_{Rc}} + \frac{\pi^2}{8}\mu k_1^4 f(\theta_m)_1^4\right\}\frac{dx}{dt}$$
$$+ \sigma\Theta_0 k_1 k_2 f(\theta_m)_1 = 0\,, \qquad (1)$$

where G is the weight of the drop, γ the specific weight, g the acceleration of gravity, x the distance, t the time, α the inclination angle, σ the surface tension, k_1 and k_2 constants, $f(\theta_m)_1$ a function of the contanct angle of the drop, U_{Rc} the critical velocity, μ the viscosity, θ_A and θ_R the contact angles of the foremost and hindmost, respectively and subscript c shows the critical point which changes from tailless to tailed drop, subscript o the state which begins just to move, and Θ_0 and $\Delta\Theta$ are as follows

$$\Theta_0 = (\cos\theta_R - \cos\theta_A)_0\,,$$
$$\Delta\Theta_0 \doteqdot (\cos\theta_R - \cos\theta_A)_C - (\cos\theta_R - \cos\theta_A)_0\,.$$

The equation is given for the cylindrical surface of r in radius as follows

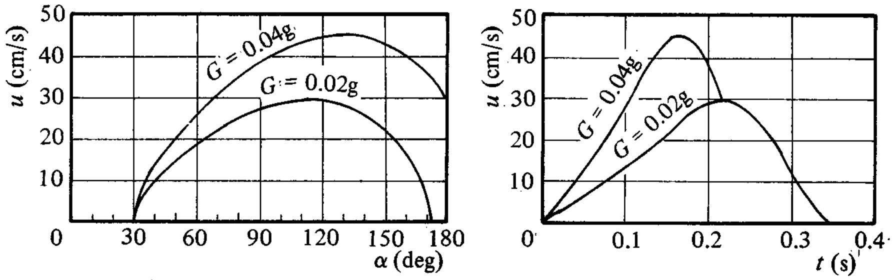
$$\alpha = x/r\,. \qquad (2)$$

Combining equations (1) and (2)

$$\frac{d^2\alpha}{dt^2}+\left\{\sigma\Delta\Theta\, k_1 k_2\frac{f(\theta_m)_1}{U_{Rc}}+\frac{\pi^2}{8}\mu k_1^4 f(\theta_m)_1^4\right\}\frac{g}{G^{2/3}\gamma^{1/3}}\frac{d\alpha}{dt}$$
$$-\frac{g}{r}\sin\alpha+\frac{\sigma\Theta_0 k_1 k_2 f(\theta_m)_1}{G^{2/3}\gamma^{1/3}}\frac{g}{r}=0\,. \qquad (3)$$

The velocity of the water drop on the cylindrical surface is calculated by putting respective values for every factor in the equation (3).

Fig. 6 show results of the calculation in the case of a tailless water drop. The data of the calculation are the same as those of the experiments, that is, $r=22.4$ mm, $\alpha=30°$ and $h=0$ cm. Values of other factors are as follows, $\theta_m=90°$, $\Theta_0=0.305$, $\Delta\Theta=1.095$, $\gamma=1.0$ g/cm^3, $\sigma=0.0739$ g/cm, $\mu=1.3\times10^{-5}$ g s/cm. The results agree with experimental ones in the tendency of the curve.



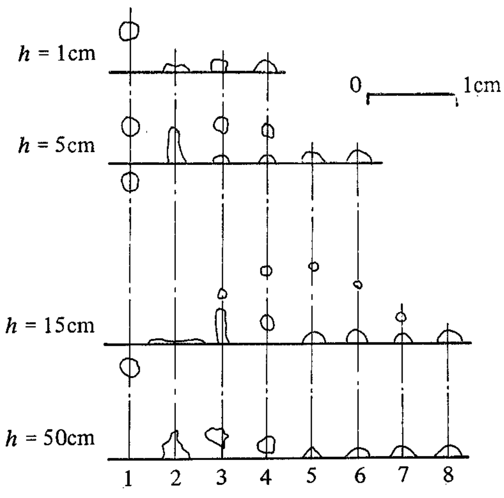
(a) Relation between α and u (b) Relation between t and u

Fig. 6. Drop velocity on an outer cylindrical surface (theory).

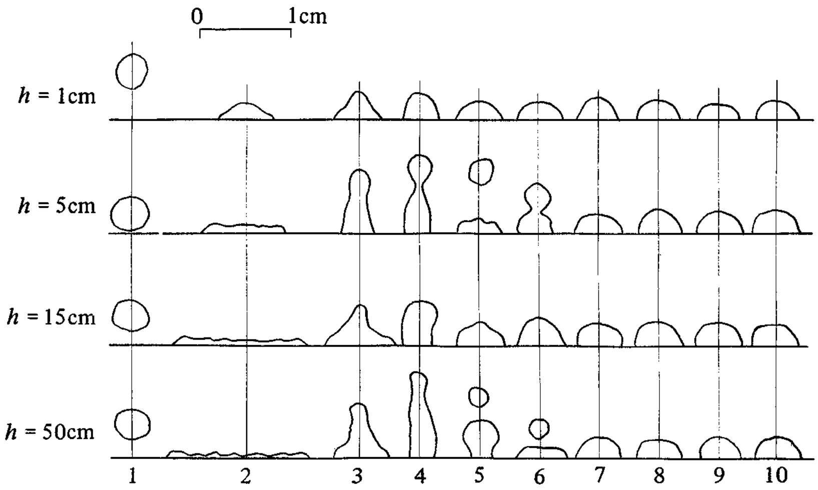
5. Effect of the Falling Height h

According to the experimental results shown in figures 4 and 5, it can be supposed that the falling height is the very important factor as for the velocity of the drop on the cylindrical surface and the separation from the surface. Since it is difficult to calculate the effect theoretically, it is determined from the following experiments. A flat surface is used in the experiments, as it is difficult to fall a water drop on the point of a cylindrical surface that has an exact inclination angle determined previously and to examine only the effect of the angle. The cylindrical surface shown in Fig. 3 is converted by a sheet glass surface coated with paraffin wax. In the experiments, variable parameters are the inclination angle of the surface, the falling height and the drop weight.

Fig. 7 show behaviors of the drop fallen down on a horizontal surface ($\alpha=0°$). These behaviors are the base in order to analyze the behavior of the drop on the inclined flat surface or the cylindrical surface. In this figure, the shapes of the drops are sketched from those in the movies and arranged with the frame order (the number of the abscissa



(a) $G = 0.0085$ g

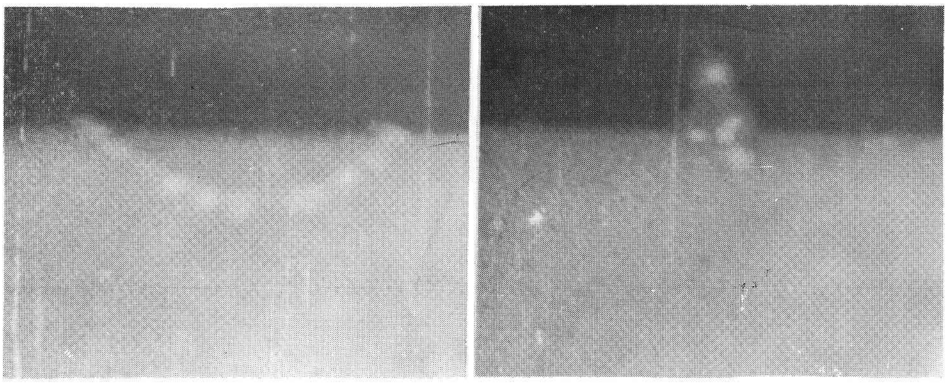


(b) $G = 0.0517$g

Fig. 7. Behavior of a water drop on a horizontal flat surface coated with paraffin wax.

axis). The 1st frames show the states of drops in the air. The 2nd frames show states after the collision of drops with the surface. This figure shows various behaviors of the drop, e.g. the falling drop is depressed and spreads as soon as it strikes against the surface, and in the next moment, the depressed drop stands up and moreover jumps up. Some of drops release small droplets which fall down on the surface and coalesce into a single drop. The coalesced drop is again depressed and spreads, but the 2nd deformation is less than the first one. Such a vibratile deformation of the drop is repeated and finally it becomes a stable and stationary state. For the large falling height, in a moment of the collision, the drop spreads itself to the larger area and becomes hollow state. The fringe of the hollow drop is not uniform and lumps exist in the fringe to the constant distance.

Photo. 3 shows the state mentioned above. A water drop is fallen down on the horizontal tube coated with paraffin wax. Photo. 3-(a) shows that a hollow drop has no smooth fringe in which lumps exist at a constant distance. Photo. 3-(b) shows that the depressed drop shrinks and stands up. The contraction of the drop in such a state is not uniform all over the periphery. For the larger falling height, in the maximum depressed state of the drop, the fringe of the hollow drop is broken and releases small droplets.



(a) (b)

Photo. 3. Deformation of a water drop striking against a cylindrical surface. ($G=0.0517$ g, $h=10$ cm, time interval between frames 0.0312 s)

Behaviors of the drop on the surtace inclined with the angle α are influenced whether the weight of the drop G is larger than G_0 or not. However, in the following experiments, the weight is fixed to the constant value, and thus, by means of change of the angle α, the weight varies indirectly.

1) For the case of $G \leqq G_0$

In this case, a drop on the inclined surface is at rest. If a drop falls from a point of a height h to the surface, the drop moves some distance on the inclined surface before stopping at the position related to the falling height. Fig. 8 shows the typical examples of this experiment. The drops in this figure were sketched from those in the movies under the conditions of $\alpha=10°$, $h=5$ and 50 cm and were divided in the several steps to show clearly its shape. The numbers in the figure show the frame number on the movies. In this figure, the drops of the 2nd frame strike against the inclined surface and move on the distance x_0 from the collision point to the position where drops stop changing the shape and the position. In case h is 5 cm, the drop becomes stationary state at the position of the 14th frame. As shown evidently in Fig. 8, one of the reasons on this state is the same as that for the state as shown in Fig. 5, that is, in the case of the vibratile deformation of the drop, when the drop begins to spread, it stretches in the direction of the inclination of the surface and the center of gravity moves downward. When the drop

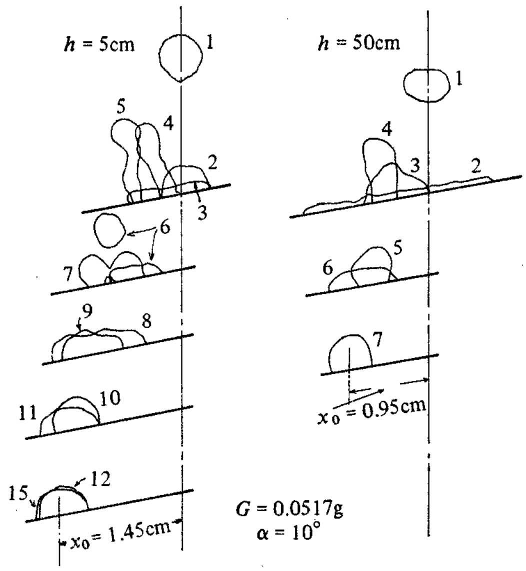


Fig. 8. Behavior of a water drop on an inclined flat surface for $G \leqq G_0$.

shrinks and stands up, owing to the decrease of the contact area, the drop becomes easily in the motion and goes downward. The process is repeated whenever the drop does the vibratile deformation, and the drop moves by the distance x_0.

The relation between the moving distance x_0 and the falling height h is shown in Fig. 9. In the figure, the moving distance approaches rapidly the maximum value at a point where the falling height is 5∼10 cm and the moving distance decreases in the region beyond the height of 10 cm. The reason for the existence of the maximum value is explained as follows: in the case of the maximum depression, since the depressed drop has no uniform fringe thickness and moreover its shape on the inclined surface is an ellipse of which major axis agrees with the direction of the inclination of the surface, the depressed drop can not shrink uniformly and the spring decreases and the moving distance decreases also.

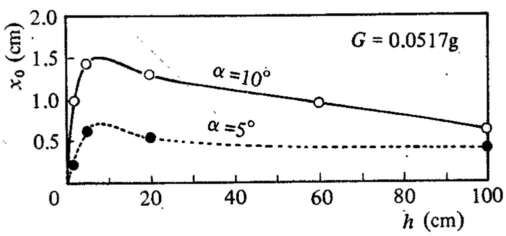


Fig. 9. Relation between h and x_0.

Fig. 10 shows the relation between x_0 and α in case which falling distance is 5 cm, and x_0 is proportional to α in the range of the small angle. The existence of the moving distance on the inclined surface is useful to increase the active condensate area owing to

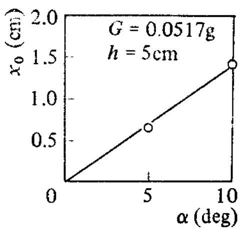


Fig. 10. Relation between α and x_0 on an inclined flat surface.

the separation of condensate drops from horizontal condenser tubes.

2) For the case of $G>G_0$

Water drops with $G=0.0517$ g were fallen down from several falling heights to a surface inclined with different angles, and the velocities of the drops on the surface were measured.

Fig. 11 shows the state of changing the drop shape and moving the drop on the surface inclined with $\alpha=45°$ for $h=0$ and 10 cm. The photographing conditions are the same as those for the states shown in Fig. 4 and 8. In the case of $h=0$ cm, even if the water drop is put on the surface quietly, the drop changes the shape and vibrates at the initial stage of the motion, and the stability of the drop increases with the increase of

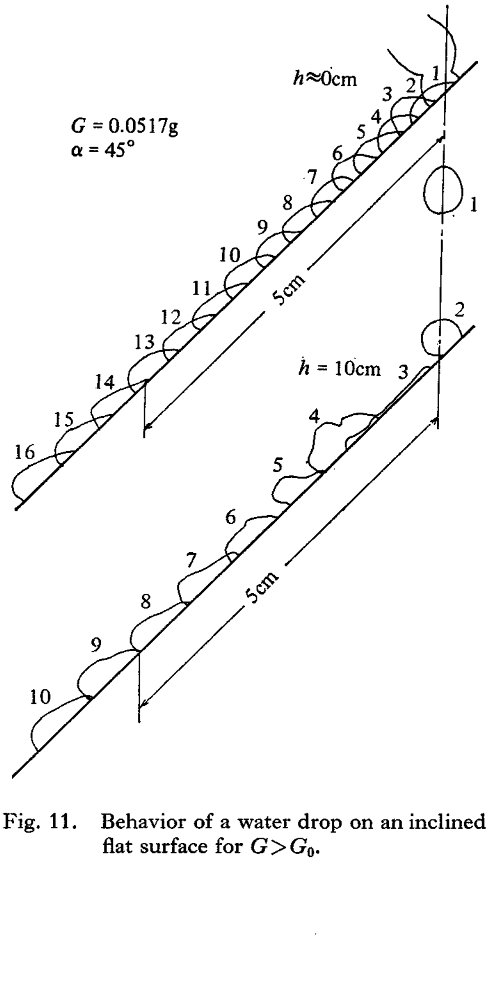


Fig. 11. Behavior of a water drop on an inclined flat surface for $G>G_0$.

the moving distance. In the case of $h=10$ cm, when the falling drop strikes against the inclined surface, the depressed one slips downward remarkably on the surface, and the velocity is larger than that for $h=0$ cm. The drop shape at the downward position on the surface approaches gradually to the stable shape for $h=0$ cm.

Fig. 12 shows the relation between the moving distance and the moving time of drops fallen down from different falling heights to the surface inclined with $\alpha=45°$, and the relation between the velocity of the center of the drop and the moving distance is shown in Fig. 13. From these experimental results, for the height of 0 cm, the velocity increases with the time. On the other hand, in the case of every falling height except 0 cm, the drops have the initial velocities corresponding to the falling height: moreover, the velocities change hard with the time and approach to the constant values.

Since the velocity of the falling drop on the inclined surface changes hard at the initial stage of the motion, mean values of velocities during the moving distance from 0 to 5 cm are calculated for several falling heights, and the ratios of different values of mean velocities to the mean value of velocity for $h=0$ cm are denoted by $U_h/U_{h=0}$ and the ratio is styled by the increasing ratio of the initial velocity. The relation between $U_h/U_{h=0}$ and h is shown in Fig. 14 for the three inclination angles. The curves for every case of α have the maximum points at about $h=10$ cm, and the value at the maximum point is the smallest for the angle of 45°.

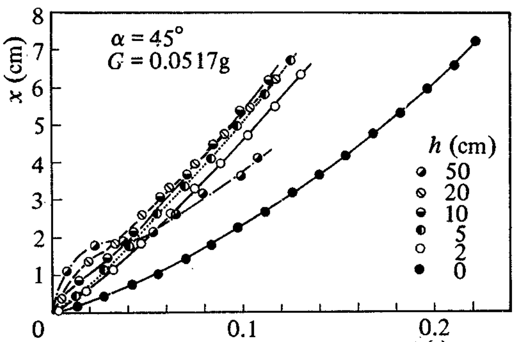


Fig. 12. Relation between x and t.

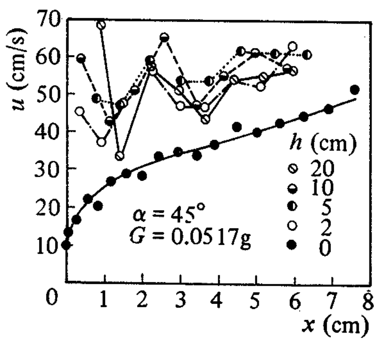


Fig. 13. Relation between x and u.

Fig. 15 shows the relation between the drop weight and the mean value of the velocity during the moving distance from 0 to 5 cm in the case of $\alpha=30°$ for the falling height of 0 and 10 cm, and the increasing ratio at the initial stage are influenced largely as the drop weight is smaller. The reason is that after striking against the surface, the standing up and jumping of a small drop is larger than those of a large drop.

6. Separation from the Surface

The separation force F normal to a surface acting on a drop with a weight G and a velocity u on an outer cylindrical surface of r in radius consists of centrifugal force and

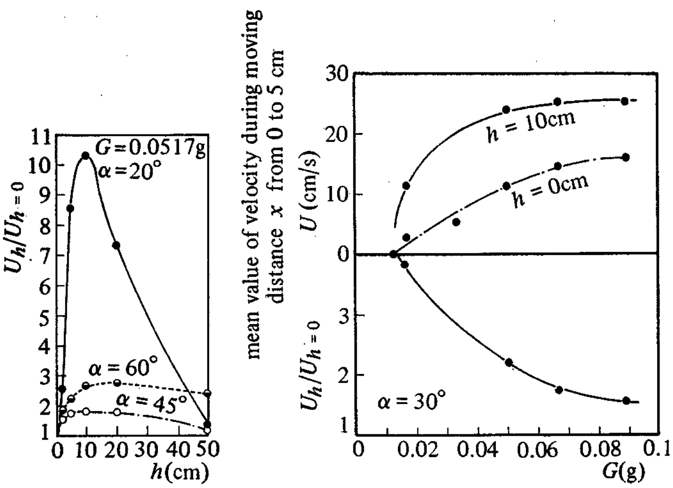


Fig. 14 Fig. 15

Fig. 14. Relation between h and $U_h/U_{h=0}$.
Fig. 15. Relation between G and $U_h/U_{h=0}$.

the normal component of gravity force, thus,

$$F = (Gu^2/gr) + G\cos(\pi - \alpha), \qquad (4)$$

at the point where a drop begins to separate from the surface, this force is as follows

$$F = G_{\theta\,\max}, \qquad (5)$$

where $G_{\theta\,\max}$ is the maximum weight that a drop having the contact angle θ can hang down at rest under the flat plate facing downward, and its value is calculated from the result by Takatama[2]. Fig. 16 shows the force F calculated by the equation (4) for several

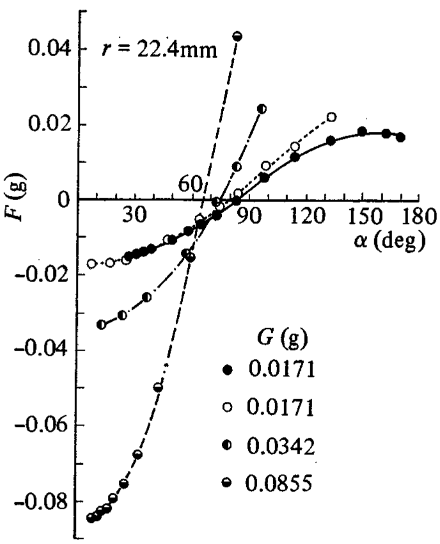


Fig. 16. Force F for a moving drop on a cylindrical surface.

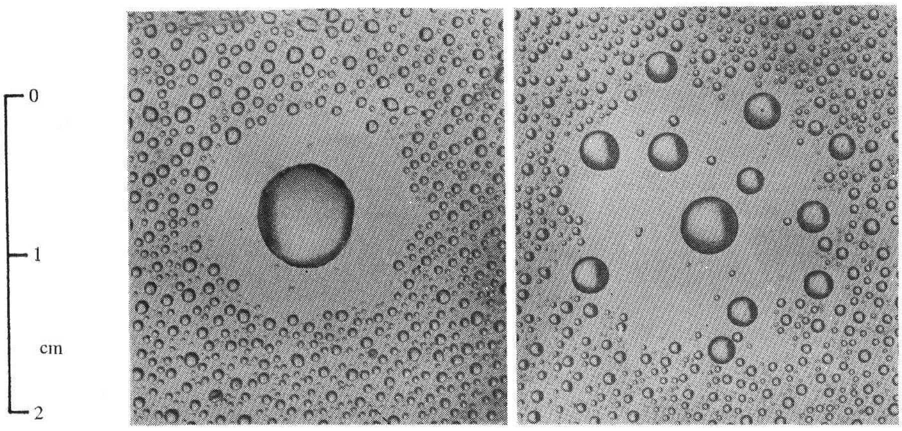
drops moving on the cylindrical surface ($r=22.4$ mm) coated with paraffin wax. Since the contact angle of a water drop on a flat surface coated with paraffin wax is $\theta=105°$, the result[2)] cannot be used. However, judging the state from the shape of the drop, the last plots for separated drops (symbols ○◐◓) show that drops begin to separate from the surface. Therefore, the maximum value $G_{\theta\,max}$ is about 0.02 g from these facts and the force F for the un-separated drop (symbol ●). Moreover, as mentioned previously, since the drop fallen from the point at some height to the surface has the motion of the vibratile deformation of the shape and the drop stands on the surface, its drop can separate under the force F less than $G_{\theta\,max}$. Thus, the following expression is given generally

$$F \leqq G_{\theta\,max}\,.$$

7. The Area swept with a Striking Drop against a Horizontal Tube and the Area covered with a Flood

A drop striked against an inclined surface has a promoting action on the separation of a drop from the surface as mentioned previously and moreover, when the drop is depressed on the surface, its drop coalesces with other adhered ones and sweeps the surface, The swept area was obtained experimentally in the air. Minute water droplets were adhered by a sprayer on a horizontal plate glass coated with paraffin wax. A water drop with known weight was fallen down on the plate glass and the area swept by the fallen drop was measured. Photo. 4 shows its state and for the large falling distance, when the drop strikes against the surface, that breakes into several droplets.

Fig. 17 shows experimental results for different drop weights (G_1: G_2: $G_3=1:5:10$). In this figure, d_{max} is the diameter of the swept area and equal approximately to the drop diameter in the maximum depressed state, and d_0 is the diameter of the drop put quietly



(a) $h=5$ cm (b) $h=20$ cm

Photo. 4. Water drop striking against the surface which adheres minute water droplets. ($G=0.0425$ g)

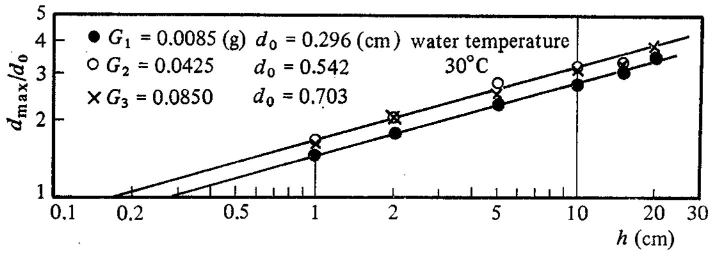


Fig. 17. Relation between h and d_{max}/d_0.

on the horizontal plate glass coated with paraffin wax. The ratio d_{max}/d_0 denotes the magnification coefficient of the depressed drop and is fairly small for the smallest drop. Intersections between experimental curves and the axis of abscissa denote the falling distance which have no extended contanct area and the value for the small drop is larger than that for the large one, because it has a small curveture and large resistance to deformation. The relation for the experimental results is as follows,

$$d_{max}/d_0 = ah^{0.284} \tag{6}$$

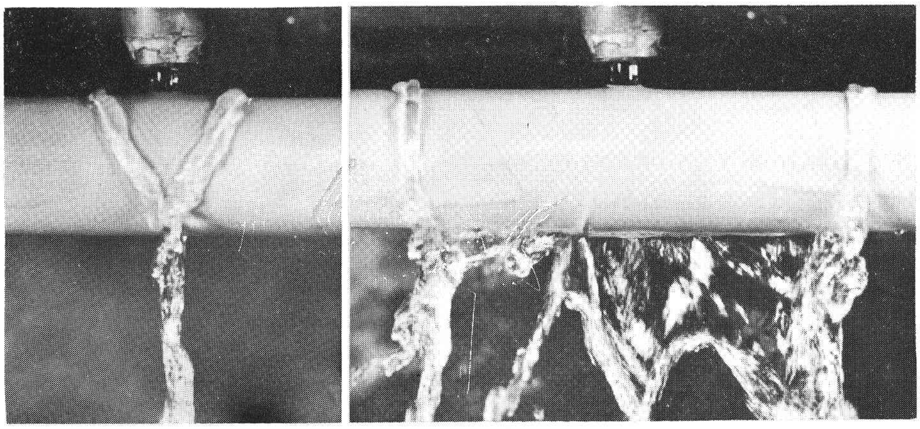
where, the coefficient a is 1.65 for G_1 and 1.45 for G_2 and G_3, and is a function of the several factors, e.g. surface tension of liquid and solid, interfacial tension between liquid and solid and drop weight.

When the falling drop strikes against the surface, the falling distance at the point where the drop breakes are about 15 cm for G_1, about 10 cm for G_2 and G_3, and there is such a tendency as the large drop has the small falling distance. However, in the case of no adhered drop on the surface and the falling height of 50 cm, none of drops breake. If adhered drops exist on the surface, the drop deformation is not uniform, and the existence of the adhrered drops promotes the drop division.

The fact mentioned above is the state for a single falling drop. In the case of many horizontal condenser tubes arranged in the vertical row, many condensate drops pass through the lower tubes. An active condensate area on the cooling surface decreases because the condensate drops become a flooding state and cover the tube surface as shown in Photo. 2-(b). The state covered with the flood was examined by different horizontal tubes coated with paraffin wax and some downward water jets. A nozzle dimension and a distance between the nozzle end and a horizontal tube were determined by experimental results[3]. The length of the nozzle throat is equal to the nozzle inner diameter d_n. The nozzles are 4.8 and 2.5 mm in diameter and horizontal tubes are 25.4 and 12.2 mm in diameter. The center line of the nozzle is settled perpendicular to that of the horizontal tube. The distance between the nozzle end and the top of the horizontal tube is equal approximately to the inner diameter of the nozzle.

Photo. 5 show the flooding state at two water flow rates. When the flow rate is larger than that in Photo. 5-(b), the scattering drops appear in all directions.

Fig. 18 shows experimental results on the relation between Reynolds number for the



(a) water jet velocity 79 cm/s (b) water jet velocity 280 cm/s

Photo. 5. Behavior of a water jet striking against a horizontal tube. (d_n=4.8 mm, d=25.4 mm)

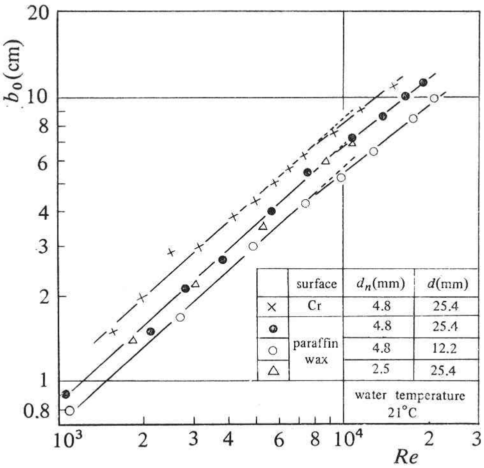


Fig. 18. Relation between *Re* and b_0 on a water jet striking against a horizontal tube.

water jet velocity at the nozzle exist, *Re* and the width covered with the flood on the horizontal tube, b_0. When b_0 is approximately less than or equal to 1.6d, the area covered with the flood is about $\pi b_0^2/4$ and when b_0 is greater than 1.6d, the area is about $\pi d b_0$. It is clear from this figure that no relation has been found between b_0 and d_n, but b_0 relates to *Re*, and b_0 is small for the large contact angle of the water drop and the small diameter of the horizontal tube. In this figure, the slopes of the curves are different at *Re* of about 8000 as the water jet changes from laminar to turbulent flow at the point, and the transition is observed by the change of the transparency of the water jet.

8. Conclusion

Falling condensate drops on the horizontal condenser tubes during dropwise condensation of steam show behaviors different from those on the vertical flat surface as the drops repeat the motion on outer surfaces of the tubes and the free falling alternatively. Behaviors of a water drop with known weight on the outer surface of a horizontal tube have been made clear in the air experimentally. Some behaviors are as follows:

(1) the drop velocity along the cylindrical surface,
(2) the separation from the surface except the bottom point, and the free falling,
(3) the striking motion against the lower tube, and deformation of the drop,
(4) the sweeping and the coalescing action with the depressed drop,
(5) the flooding and the covering state on the horizontal tube surface.

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