Fog Formation in a Cooler Condenser*

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(Received January, 1955)

Abstract

(1) The limiting conditions of the two steps of fog formation in a cooler condenser, namely fog formation in gas film and in bulk stream, were discussed.
(2) The enthalpy profile in gas film in an air cooler dehumidifier was found to be linear even when fog was forming in it.
(3) Theoretical equations were presented for calculation of the apparent heat and mass transfer coefficients in the case of fog formation in gas film in an air cooler dehumidifier.
(4) In an air cooler dehumidifier, the same enthalpy transfer equation with the same value of transfer coefficient is applicable to all of the following cases: no fog formation, fog formation in gas film and fog formation in bulk stream.
(5) The above three cases were observed in a double tube cooler dehumidifier of air. The results of the experiment verified the above discussions.

1. Introduction

In a cooler condenser, fog may be formed depending upon the conditions. Recently several papers[1)2)3)] were published concerning with limit condition of fog formation. However, they do not mention the two steps of fog formation, i. e. the fog formation in the gas film and the bulk stream of gas**

Though it is recognized that fog formation affects the heat and mass transfer coefficient, a theoretical analysis of this effect has not been accomlished.

The author will discuss these two problems, namely the limit conditions of fog formation and the effect of fog formation on the transfer coefficients.

Also it will be shown that the enthalpy driving force equation[4)5)] can be used in the case of fog formation as well as in non fog formation for the air-water vapour system.

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* The first part of this paper except the notes at the end was published by T. Mizushina, M. Nakajima, T. Omoto and H, Fukusen in Chem. Eng., Japan, **16**, 345 (1952).

** Colburn et al[1)] and Johnstone et al[3)] covered the limit of fog formation in the bulk stream and in the gas film respectively.

2. Limits of Fog Formation

When a gas-vapour mixture is cooled gradually, it becomes saturated at a certain temperature. If there are enough nuclei in the mixture the vapour begins to condense arround the nuclei to form fog.

In order to form fog it is necessary to maintain the condition of supersaturation, although the degree of supersaturation is depending upon the kind, size and number of nuclei.

Accordingly the saturation point is the limit of fog formation.

(1) Limit of Fog Formation in Gas Film.

When a gas vapour mixture contacts a wall whose temperature is lower than the dew point of the mixture, heat is transferred and vapour diffuses from the mixture to the wall.

The temperature and humidity distributions for this case are schematically shown in Fig. 1. The abscissa is the distance from the wall. Both temperature and humidity change linearly through the film and keep constant in the bulk. The saturated humidity line in Fig. 1 is the plot of the points of saturated humidity corresponding to the temperature of each point.

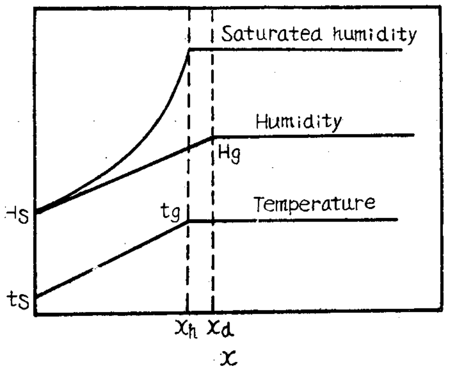

Fig. 1. Schematic temperature and humidity profile— Fog never forms.

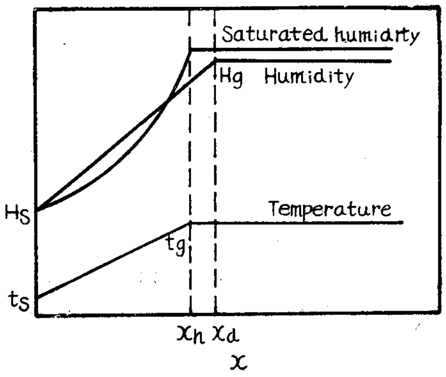

Fig. 2. Schematic temperature and humidity profile— Fog may form in film.

When the humidity is low and the humidity line lies below the saturated humidity line at all points as shown in Fig. 1, there is no point of supersaturation and fog can not form.

This condition may be represented by the following equation.

$$\frac{(dH/dx)_s}{(dH_{sat}/dx)_s} < 1 \qquad (1)$$

In the case of Fig. 2, where the humidity line crosses the saturated humidity line in the gas film, supersaturated points exist and fog may be formed there.

This condition is

$$\frac{(dH/dx)_s}{(dH_{sat}/dx)_s} > 1 \qquad (2)$$

Consequently the limit of fog formation in the gas film is

$$\frac{(dH/dx)_s}{(dH_{sat}/dx)_s} = 1 \qquad (3)$$

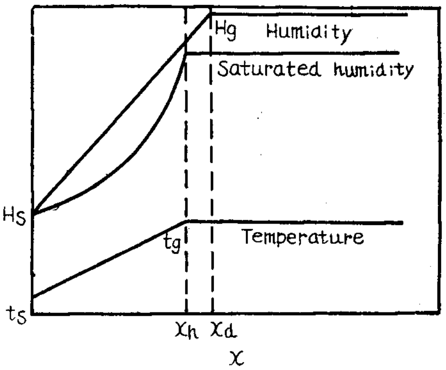

Fig. 3. Schematic temperature and humidity profile— Fog may form in bulk stream.

The following discussion is limited to the case of low humidity.

From the equation of diffusion,

$$\frac{dW}{Ad\theta} = D\rho\left(\frac{dH}{dx}\right)_s = k'(H_g - H_s)$$

$$\therefore \left(\frac{dH}{dx}\right)_s = k'\frac{H_g - H_s}{D\rho} \qquad (4)$$

From the equation of heat transfer,

$$\frac{dQ}{Ad\theta} = \lambda\left(\frac{dt}{dx}\right)_s = h(t_g - t_s)$$

$$\therefore \left(\frac{dt}{dx}\right)_s = \frac{h(t_g - t_s)}{\lambda}$$

$$\therefore \left(\frac{dH_{sat}}{dx}\right)_s = \left(\frac{dH_{sat}}{dx}\right)_s\left(\frac{dt}{dx}\right)_s = \left(\frac{dH_{sat}}{dt}\right)_s\frac{h(t_g - t_s)}{\lambda} \qquad (5)$$

Substituting eqs. (4) & (5) into eq. (3)

$$\frac{k'(H_g - H_s)/(D\rho)}{(dH_{sat}/dt)_s\, h(t_g - t_s)/\lambda} = 1$$

In the gaseous systems the following relation can be applied.[6]

$$h/k' = C_p(Sc/Pr)^{\frac{1}{2}}$$

Substituting this relation into the above equation,

$$(t_g - t_s)(dH_{sat}/dt)_s(Pr/Sc)^{\frac{1}{2}} = H_g - H_s \qquad (6)$$

Eq. (6) is the equation of the limit of fog formation in the gas film.

In Fig. 4, the limiting conditions are shown on a temerature-humidity chart of air-water vapour system. These lines repesenting limits are plots of eq. (6)

These limiting conditions can be represented also by enthalpy, $i = 0.24t +$

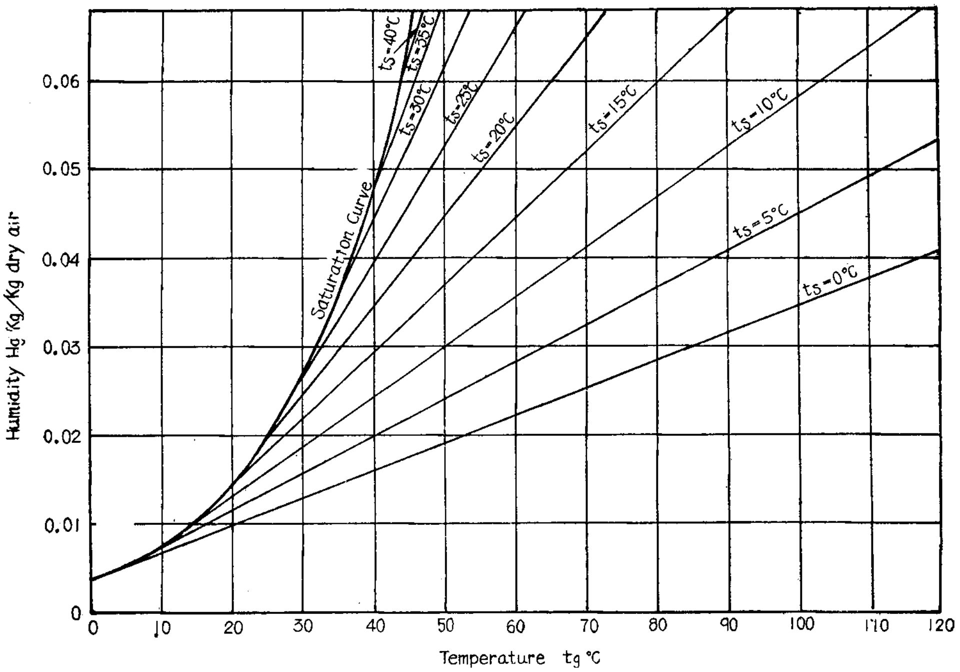

Fig. 4. Limit of fog formation in film for air-water vapour mixture.

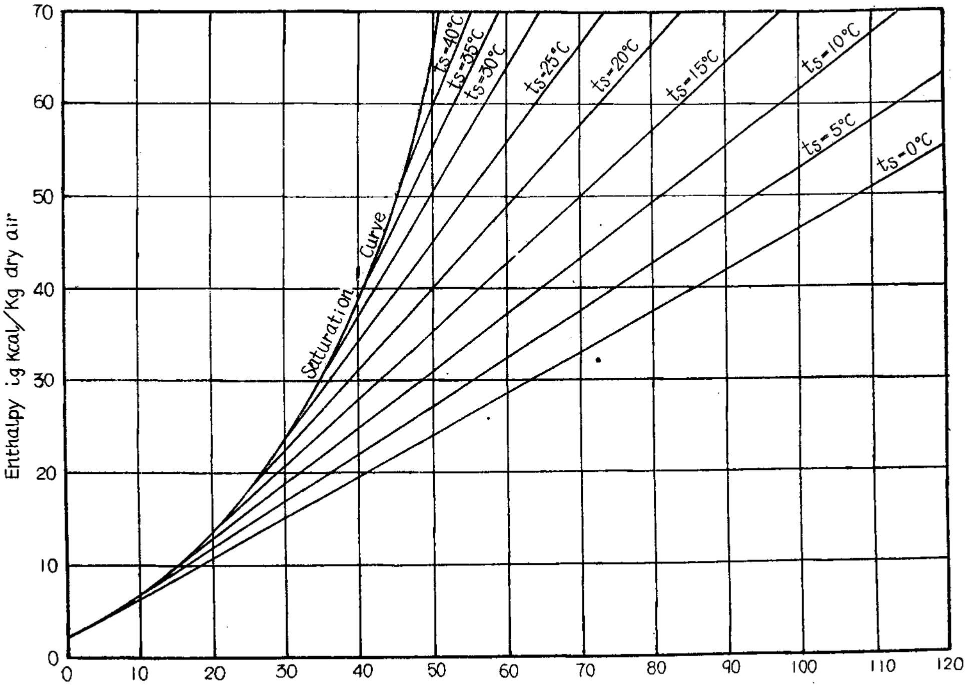

Fig. 5. Limit of fog formation in film for air-water vapour mixture.

$H(595+0.45t)$ vs. temperature as shown in Fig. 5.

In adition the following equation can be derived similarly[3] to eq. (6).

$$(t_g-t_s)(dp_{sat}/dt)_s(Pr/Sc)^{\frac{1}{2}}=p_g-p_s \qquad (7)$$

Eq. (7) is plotted in Fig. 6.

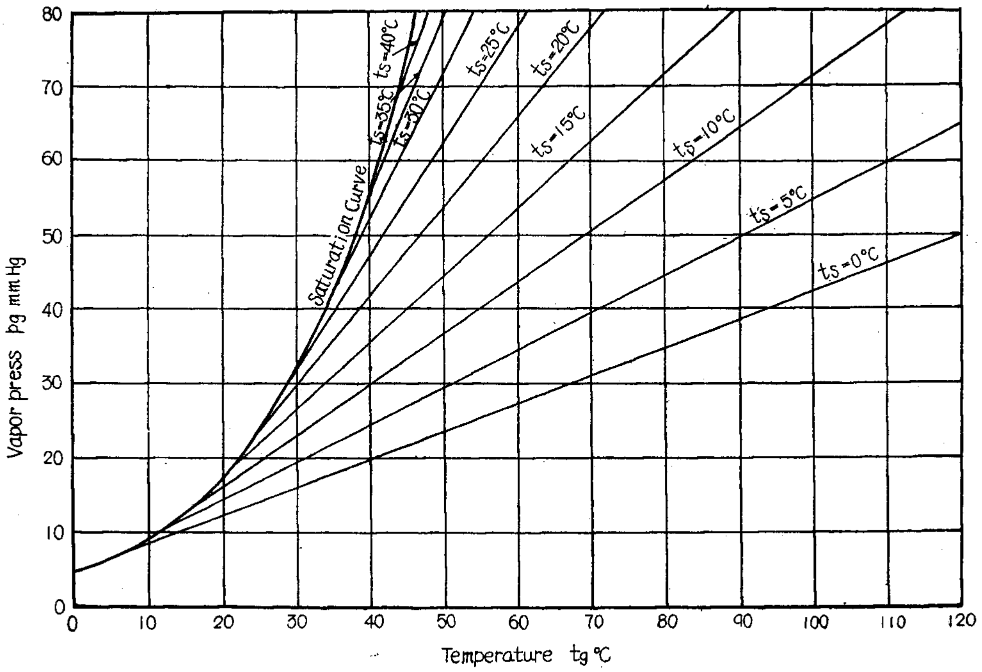

Fig. 6. Limit of fog formation in film for air-water vapour mixture.

When the air is cooled by a wall of a certain temerature, and if the condition of the air is located above the line of the limit corresponding to the wall temperature in Fig. 4, 5 or 6, there is a possibility of fog formation.

It should be noticed that Figs. 4 and 5 apply only to atmospheric pressure, while Fig. 6 can be applied to the other pressures also.

(2) Limit of Fog Formation in Bulk Stream.

In the case of high humidity as shown in Fig. 3, there exists supersaturation over all sections of gas stream. So fog may form in the bulk stream provided there are enough nuclei.

When the air-water vapour mixture at the condition A in Fig. 7 is cooled by a coolig surface

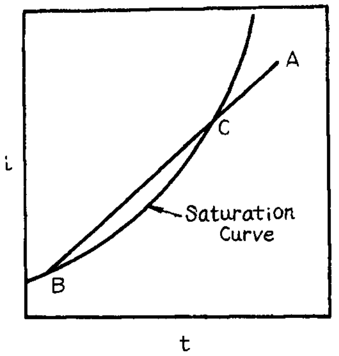

Fig. 7. Limit of fog formation in bulk stream.

of a constant temperature B, the condition of the air changes along the line AB.[5)7)] This line crosses the saturation curve at C. Accordingly the mixture may have fog formation between C and B.

3. Effect of Fog Formation in Gas Film upon Heat and Mass Transfer Coefficients

The follwing discussion in Sections 3, 4 and 5 are limited to only the case of air-water vapour mixture.

Assumtions:

(a) There are enough nuclei for the water vapour in the mixture to condense to form fog at the saturation point.

(b) The size of a particle of fog is so large that the diffusion velocity of the particle in the gas film is negligibly small.

(c) Fog formation does not affect the thickness, heat conductivity and vapour diffusivity of the gas film.

(d) Since the discussion is limited to the air-water vapour system, the thickness of the gas films for heat and mass transfer is about same.

(1) Linearity of Enthalpy Gradient in Case of Fog Formation in Gas Film.

Assuming as above, we can consider the temperature and humidity profiles in the gas film where fog is forming to be as shown in Fig. 8. Since fog is not formed between FG, both temperature and humidity gradients are linear. Water vapour which diffuses through F is condensed partly to form fog between F and S. Hence the nearer the cooling surface, the smaller is the diffusion rate. Accordingly the humidity gradient becomes flatter gradually, while on the other hand the temperature gradient becomes sharper because of the latent heat evolved by the condensed fog. It should be noted that between S and F, the humidity, H, is the saturation humidity corresponding to temperature t at the same value of x.

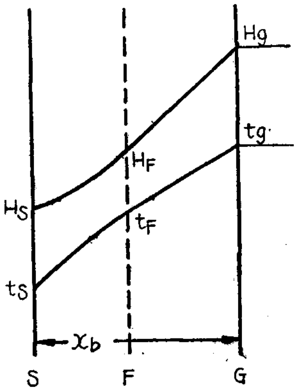

Fig. 8. Temperature and humidity profile in the film where fog is forming.

Consequently the following equation is derived.

$$x_b h\left(\frac{dt}{dx}\right)_b + x_b k' L\left\{\left(\frac{dH}{dx}\right)_b - \left(\frac{dH}{dx}\right)\right\} = x_b h\left(\frac{dt}{dx}\right)$$

where h and k' are heat and mass transfer coefficients respectively in the case of no fog. Namely

$$h = \lambda / x_b, \qquad k' = D\rho / x_b$$

The above equation can be applied whether fog is formed or not. In the case of no fog formation,

$$(dH/dx)=(dH/dx)_b\ , \qquad (dt/dx)=(dt/dx)_b$$

From these two equations we can derive the above equation.

The above equation is rearranged to give

$$h\left(\frac{dt}{dx}\right)_b+k'L\left(\frac{dH}{dx}\right)_b=h\left(\frac{dt}{dx}\right)+k'L\left(\frac{dH}{dx}\right)$$

To the air-water vapour system $h/k'=C_H$ can be applied, and also the values C_H and L are considered as constants in the small range of temperature and humidity.

Hence

$$k'C_H\left(\frac{dt}{dx}\right)_b+k'L\left(\frac{dH}{dx}\right)_b=k'C_H\left(\frac{dt}{dx}\right)+k'L\left(\frac{dH}{dx}\right)$$

Accordingly

$$\left(\frac{di}{dx}\right)_b=\frac{di}{dx}=\frac{i_g-i_s}{x_b} \tag{8}$$

From this equation it is concluded that the enthalpy gradient in the gas film is linear regardless of whether fog is formed in the gas film for the air-water vapour system.

(2) Enthalpy Transfer Rate.

$$-G\frac{di_g}{dA}=x_bh\left(\frac{dt}{dx}\right)_b+x_bk'\left(\frac{dH}{dx}\right)_b 595$$

where 595 kcal/kg = Latent heat of vaporization of water at 0°C,

Substituting $k'=h/C_H$ into the above equation, and also considering the value of C_H as a constant,

$$-G\frac{di_g}{dA}=x_b\frac{h}{C_H}\left\{C_H\left(\frac{dt}{dx}\right)_b+595\left(\frac{dH}{dx}\right)_b\right\}=x_b\frac{h}{C_H}\left(\frac{di}{dx}\right)_b$$

Substituting eq. (8) into this equation

$$-G\frac{di_g}{dA}=\frac{h}{C_H}(i_g-i_s) \tag{9}$$

Eq. (9) can be applied whether or not fog is formed in the gas film

(3) Apparent Heat Transfer Coefficient.

Since the relation of x vs. i is linear, we can replace the profile of t vs. x with that of t vs. i. Fig. 9 is the t-i diagram of air-water vapour system. The temperature of the cooling surface is at S. If the condition of the bulk of air stream is at G, there is no fog formation, and the temperature gradient in the film is linear like GS. When the condition of air is at G' instead, there is a possibility of fog formation in the film as mentioned in Section 2.

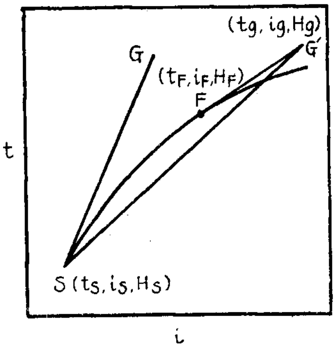

Fig. 9. Temperature profile where fog is forming.

From the assumption of this section, no part should not be supersaturated. Hence the temperature gradient is not linear like $G'S$ but a curve like $G'FS$. $G'F$ is tangent to the saturation curve at F.

In such a case, the heat transfer rate is

$$dQ/(Ad\theta)=h_a(t_g-t_s)$$

where h_a is the apparent heat transfer coefficient.

The heat transfer rate can be represented also as follows.

$$\frac{dQ}{Ad\theta}=hx_b\left(\frac{dt}{dx}\right)_b$$

Accordingly,

$$\frac{h_a}{h}=\frac{(dt/dx)_b}{(t_g-t_s)/x_b}$$

Taking into account the linear relation of i vs. x,

$$\frac{h_a}{h}=\frac{(t_g-t_F)/(i_g-i_F)}{(t_g-t_s)/(i_g-i_s)} \tag{10}$$

where subscript F means the point F in Figs. 8 and 9.

In the case when the cooling surface is at 0°C, the values of h_a/h are calculated by eq. (10) as shown in Fig. 10.

(4) Apparent Mass Transfer Coefficient.

In the case of fog formation in the gas film and a curved temperature gradient like $G'FS$ in Fig. 9, from eq. (9), the enthalpy transfer rate is as follows.

$$-\frac{Gdi_g}{dA}=\frac{h}{C_H}(i_g-i_s)=\frac{h}{C_H}(C_Ht_g+595H_g-C_Ht_s-595H_s)$$

$$=h(t_g-t_s)+k'\,595(H_g-H_s)$$

And also $G(di_g/dA)$ is represented as follows.

$$\frac{-Gdi_g}{dA}=\frac{dQ}{Ad\theta}+\left(\frac{dW}{Ad\theta}\right)595=h_a(t_g-t_s)+k_a'\,595(H_g-H_s)$$

Accordingly,

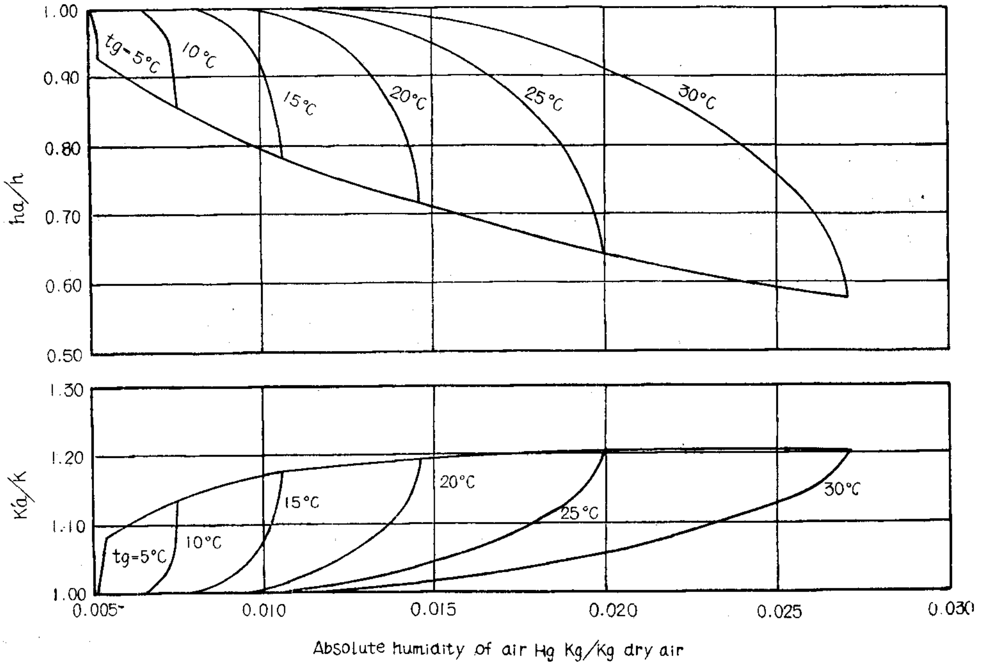

Fig. 10. Apparent heat and mass transfer coefficient when cooling surface temperature is 0°C

$$k_a' = k' + \frac{(h-h_a)(t_g-t_s)}{595(H_g-H_s)} \tag{11}$$

or

$$\frac{k_a'}{k'} = 1 + \frac{h}{k'}\,\frac{(1-h_a/h)(t_g-t_s)}{595(H_g-H_s)} \tag{12}$$

The values of k'_a/k' in the case of the cooling surface of 0°C are calculated by eq. (12) and shown in Fig. 10.

It should be noted that all the water vapour, which is removed from the bulk stream by diffusion in proportion to the apparent mass transfer coefficient, does not reach the cooling surface but that a part of it is changed into fog particles in the gas film and flows along the surfece with the gas stream.

4. Enthalpy Transfer Rate

It has been mentioned that eq. (9) can be applied to the cases of either non fog or fog formation in the gas film.

In this section the case of fog formation in the bulk stream will be considered. Here, the enthalpy of the bulk stream is defined so as to exclude the particles of fog in it.

Accordingly

$$-G\frac{di_g}{dA} = G\cdot C_H\cdot\frac{dt_g}{dA} + G\cdot 595\frac{dH_g}{dA} \tag{13}$$

where H_g is the humidity of the bulk stream, but it deos not include the amount of water in the shape of fog.

On the other hand $-G\cdot di_g/dA$ is equal to the sum of the sensible heat transferred and the latent heat of water vapour diffusing through the gas film.

$$-G\frac{di_g}{dA} = x_b\cdot h\left(\frac{dt}{dx}\right)_b + x_b k'\cdot 595\left(\frac{dH}{dx}\right)_b = x_b\frac{h}{C_H}\left(\frac{di}{dx}\right)_b$$

Since eq. (8) can be applied to this case,

$$-G\frac{di_g}{dA} = \frac{h}{C_H}(i_g - i_s) \tag{14}$$

In the case of fog formation in the bulk stream, the enthalpy transfer rate is represented by the same equation as in the case of no fog. This is similar to the result found for film fog formation.

It should be noted that the amount of water is changed into fog may flow out of the condenser with the bulk stream.

5. Experimental Results.

The apparatus and the procedure of this experiment are about the same as those of the previous paper8), though the present apparatus is equipped with a packed tower humidifier.

The experimental runs divided into three cases:

(a) The condition of the air is outside the limit of fog formation.

(b) The arithmetic mean air condition is in the range of fog formation in the gas film.

(c) The outlet air is saturated and fog may be formed in the bulk stream.

(1) Apparent Heat and Mass Transfor Coefficient in the Case of Fog Formation in the Gas Film.

From eq. (12)

$$\frac{h_a}{k'_a} = \frac{h_a/h}{\dfrac{(1-h_a/h)(t_g-t_s)}{595(H_g-H_s)} + \dfrac{k'}{h}} \tag{15}$$

Substituting the value of h_a/h calculated by eq. (10) and $h/k' = 0.23$ for the case of annuli8) into eq. (15) the values of (h_a/k'_a) are calculated and to be referred as $(h_a/k'_a)_{calc}$.

On the other hand the following equations give the experimental values of h_a/k'_a, to be referred to as $(h_a/k'_a)_{obs}$.

$$\left.\begin{aligned} h_a &= \frac{G(t_{g1}-t_{g2})C_H}{A\{(t_{g1}+t_{g2})/2-t_s\}} \\ k'_a &= \frac{(dW/d\theta)_{obs}}{A\{(H_{g1}+H_{g2})/2-H_s\}} \end{aligned}\right\} \tag{16}$$

The experimental and the calculated values coincide well with each other as shown in Table 1. This may be regarded as a proof of the discussion of the Section 3.

Table 1 Observed and calculated values of the ratio between heat and mass transfer coefficient.

Run No.	$(h_a/k_a')_{obs}$	$(h_a/k_a')_{calc}$
F. 1	0.198	0.200
F. 2	0.215	0.223
F. 3	0.221	0.215
F. 4	0.183	0.183
F. 5	0.158	0.171
F. 6	0.189	0.185
F. 7	0.216	0.213
F. 8	0.210	0.210
F. 9	0.205	0.217
F. 10	0.212	0.216
F. 11	0.214	0.222
F. 12	0.228	0.228
F. 13	0.203	0.185
F. 14	0.198	0.189
F. 15	0.206	0.201
F. 16	0.192	0.195
F. 17	0.181	0.178
F. 18	0.191	0.214
F. 19	0.188	0.187
F. 20	0.194	0.187
F. 21	0.199	0.192
F. 22	0.206	0.204
F. 23	0.220	0.211
F. 24	0.233	0.224
F. 25	0.220	0.226
F. 26	0.216	0.226
F. 27	0.220	0.226
F. 28	0.210	0.215
F. 29	0.217	0.220
F. 30	0.190	0.190
F. 31	0.206	0.214
F. 32	0.214	0.204
F. 33	0.214	0.210
F. 34	0.206	0.209
F. 35	0.216	0.212
F. 36	0.214	0.219
F. 37	0.220	0.228

In the present experiment it seems that the air was not supersaturated and that the water vapour began to condense just when the air reached the saturation temperature. A reason for this may be that the air blown through the apparatus had a considerable amount of dust in it.

(2) Enthalpy Transfer Rate.

The values of h in the case of no fog are calculated by the ordinary heat transfer calculation and the values of h_a in the case of fog formation by eq. (16). Fig. 11 shows $h\cdot d_{eq}/\lambda$ and $h_a d_{eq}/\lambda$ plotted against Re. The values of h_a in the case of fog formation are lower than those in the case of no fog, which would be expected from the discussion in the Section 3. Since h and h_a are two different

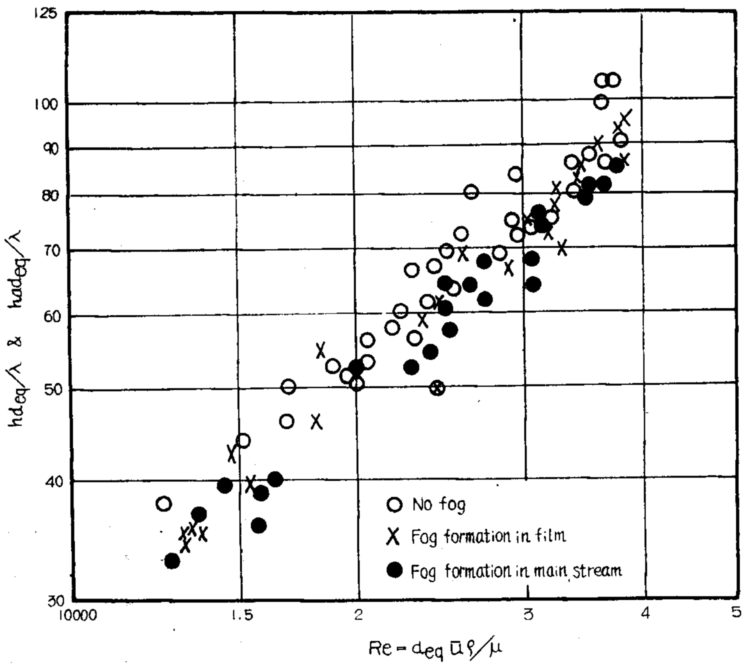

Fig. 11. Correlation of apparent heat transfer coefficients.

kinds of heat transfer coefficient, it would be unreasonable to correlate them simultaneously.

On the other hand, eq. (9) or (14), the equations of enthalpy transfer can be applied whether fog is formed or not.

Hence, the values of h $(=\lambda/x_b)$ can be calculated from the data, regardless of fog formation, using the enthalpy transfer equation.

$$h_e=\frac{C_H G(-di_g/dA)}{i_g-i_s}=\frac{C_H G(i_{g1}-i_{g2})}{A(i_g-i_s)_{av}} \tag{17}$$

The values of h_e for all experimental conditions are calculated by eq. (17), and $h_e d_{eq}/\lambda$ is plotted against Re in Fig. 12. The scattering of the points may be due to the hygrometers used to measure humidity. However, the fact that all the data in Fig. 12 and the values of h in Fig. 11 are correlated by a single line shows that the above discussion is correct.

Consequently, it is suggested that the enthalpy transfer equation is to be used when correlating the data of heat transfer coefficients which include those measured with fog present.

Moreover, in a design procedure of a cooler condenser it is convenient to use the enthalpy transfer equation because the same value of h calculated by the

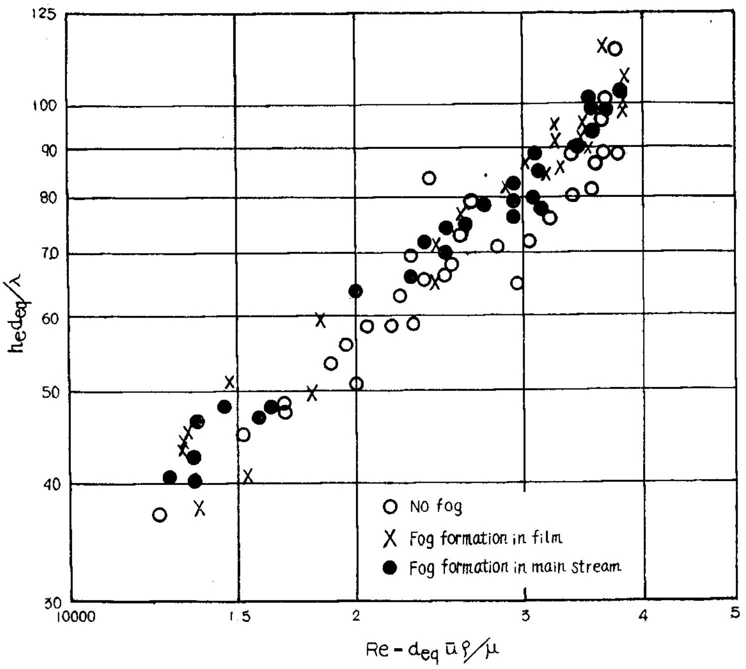

Fig. 12. Correlation of heat transfer coefficients obtained by enthalpy transfer equation.

ordinary heat transfer equation can be used regardless of whether fog is formed or not.

Notation

A:	Cooling surface area	m^2
C_H:	Humid heat	kcal/°C. kg dry air
C_p:	Specific heat at constant pressure	kcal/°C. kg
D:	Diffusivity	m^2/hr
d_{eq}:	Hydraulic diameter of double tube	m
G:	Air flow rate	kg dry air/hr
H:	Humidity	kg/kg dry air
H_{sat}:	Saturation Humidity	kg/kg dry air
h:	Heat transfer coefficient	kcal/m^2. hr. °C.
h_a:	Apparent heat transfer coefficient	kcal/m^2. hr. °C.
h_e:	Heat transfer coefficient obtained by enthalpy transfer equation	kcal/m^2. hr. °C.
i:	Enthalpy of air	kcal/kg. dry air
k':	Mass transfer coefficient	kg/m^2. hr. kg/kg

k_a':	Apparent mass transfer coefficient	kg/m². hr. kg/kg
L:	Latent heat of vaporization of water	kcal/kg
p:	Vapour pressure	mm Hg
p_s:	Saturation vapour pressure	mm Hg
Pr:	Prandtl number	
Re:	Reynolds number	
Sc:	Shmidt number	
t:	Temperature	°C.
x:	Thickness of gas film	m
$dQ/d\theta$:	Heat transfer rate	kcal/hr
$dW/d\theta$:	Water vapour transfer rate	kg/hr
λ:	Heat conductivity of gas	kcal/m. hr °C.
ρ:	Density of gas	kg/m³

Subscript:

av : Average value
b : Boundary of laminar layer and turbulent core
calc : Calculated values
F : Fictitious plane in gas film. Between that film and cooling surface fog is forming.
g : Bulk stream
ob : Observed values
s : Cooling surface
1 & 2 : Inlet and outlet of cooler condenser respectively

Literature cited

1) A. P. Colburn, A. G. Edison; Ind. Eng. Chem., **33**, 457 (1941)
2) H. S. Mickley; Chem. Eng. Progr., **45**, 739 (1949)
3) H. F. Johnstone, Max D. Kelley, D. L. McKinley; Ind. Eng. Chem., **42**, 2298 (1950)
4) W. H. McAdams; "Heat Transmission" 3rd. Ed., p. 356 (McGraw-Hill)
5) T. Mizushina; "Kagaku Kikai Gijutsu" **2**, 61 (1950)
6) T. Mizushina, M. Nakajima; Chem. Eng., Japan, **15**, 30 (1951)
7) T. Mizushina, T. Koto; Ibid., **13**, 75 (1949)
8) T. Mizushine, K. Hara, T. Kyuno; Ibid., **16**, 338 (1952)

NOTE 1 THE TWO STEPS OF FOG FORMATION

For examle

Inlet air condition;

$t_g = 40$ °C $\quad H^{\delta} = 0.033$ kg/kg $\quad i_g = 30$ kcal/kg.

Inlet cooling water temperature;

$(t_w)_{in} = 8$ °C.

Outlet cooling water temperature;

$(t_w)_{out} = 16$ °C.

Gas film coefficient;

$h_g = 20$ kcal/m^2 · hr · °C.

Liquid film coefficient;

$h_w = 320$ kcal/m^2 · hr · °C.

If fog is not formed at all, the condition of air follows the line ABCD of Fig. 13. See H. S. Mickley; Chem. Eng. Progr., **45**, 739 (1949) and T. Mizushina, T. Koto, Chem. Eng. Japan, **13**, 75 (1949)

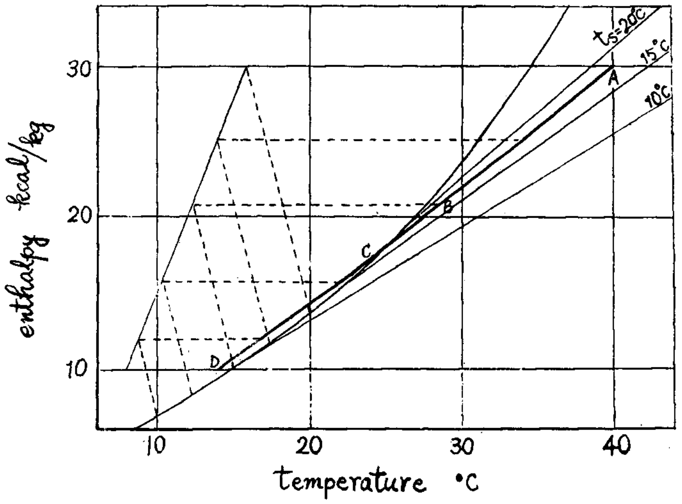

Fig. 13. Change of the condition of air and two steps of fog formation.

Point A (whose corresponding wall temperature is 20 °C) is located below the limiting line of gas film fog formation for a wall temperature of 20 °C. Therefore, at this point there is no possibility of fog formation.

Since point *B*, whose corresponding wall temperature is 15 °C. is located above the limit line for 15 °C. fog may be formed in the gas film at this point. However, since the air stream is not saturated with water vapour, fog will not form in the bulk stream.

Between *D* and *C*, the air stream is supersaturated. So fog may be formed in the bulk stream.

NOTE 2 EXPANSION OF THE DISCUSSION IN THIS PAPER TO THE CASE OF THE GENERAL GAS-VAPOUR MIXTURE

The discussions in and after Section 3 in this paper were limited to the case of air-water vapour system.

If we can assume that other gas-vapour systems have the same film thickness for heat transfer as for mass transfer, equations (8) to (14) are to be replaced with the following equations. cf. T. Mizushina, T. Koto, Chem. Eng., Japan, **13**, 75 (1949)

Eq. (8) ⟶ $$\left(\frac{di'}{dx}\right)_b = \frac{di'}{dx} = \frac{i_g' - i_s'}{x_b} \tag{8'}$$

Eq. (9) ⟶ $$-G\frac{di_g}{dA} = \frac{h}{\alpha C_H}(i_g' - i_s') \tag{9'}$$

Eq. (10) ⟶ $$\frac{h_a}{h} = \frac{(t_g - t_F)/(i_g' - i_F')}{(t_g - t_s)/(i_g' - i_s')} \tag{10'}$$

Eq. (11) ⟶ $$k_a' = k' + \frac{(h - h_a)(t_g - t_s)}{L(H_g - H_s)} \tag{11'}$$

Eq. (12) ⟶ $$\frac{k_a'}{k'} = 1 + \frac{h}{k'}\,\frac{(1 - h_a/h)(t_g - t_s)}{L(H_g - H_s)} \tag{12'}$$

Eq. (13) ⟶ $$-G\frac{di_g}{dA} = G \cdot C_H \frac{dt_g}{dA} + G \cdot L \cdot \frac{dH_g}{dA} \tag{13'}$$

Eq. (14) ⟶ $$-G\frac{di_g}{dA} = \frac{h}{\alpha \cdot C_H}(i_g' - i_s') \tag{14'}$$

where i' = modified enthalpy $= \alpha \cdot C_H \cdot t + L \cdot H$
$\alpha = \text{constant} = h/(k' \cdot C_H)$

From these equations, it is concluded that

(2′) The modified enthalpy profile in gas film in a gas cooler condenser is linear even when fog is formed in it.

(3′) Apparent heat transfer coefficients can be calculated by eq. (10′) and a t–i' diagram, and mass transfer coefficients by eq. (11′) or (12′).

(4′) In a gas cooler condenser, the same enthalpy transfer equation viz. eq· (9′) or (14′) with the same value of transfer coefficient, is applicable to all of the following cases: no fog formation, fog formation in gas film and fog formation in bulk stream.

NOTE 3 REEVAPORATION OF FOG FORMED IN THE GAS FILM

When the fog formed in the gas film is reevaporated by being mixed with the bulk stream which is not yet saturated, the temperature of the air is lowered and the humidity is raised.

In that case the apparent heat transfer coefficient is calculated by the following equation.

$$\frac{h_a}{h}=\frac{(dt/di)_s}{(t_g-t_s)/(i_g-i_s)} \tag{10a}$$

Since the enthalpy of the gas mixture does not vary by the reevaporation of fog, the apparent mass transfer coefficient is obtained by the similar equation as eq. (12).

For general gas-vapour system,

$$\frac{h_a}{h}=\frac{(dt/di')_s}{(t_g-t_s)/(i_g'-i_s')} \tag{10a'}$$

The value of k'_a is calculated by the equation similar to eq. (11′) or (12′).

In the case mentioned above h_a is larger than h, and k'_a is smaller than k', which is contrary to the situation when the fog formed in the film is separated from the stream as discussed in the foregoing paper.

Therefore, when the fog in the film is separated from the gas stream, the condition of the gas is going to be saturated more slowly than the case of no fog, whereas in the case where the fog is reevaporated, the gas is going to be saturated more rapidly than the case of no fog.

NOTE 4 THE ESTIMATION OF THE AMOUNT OF FOG IN A COOLER CONDENSER

In the case of the low humidity, the graphical method to estimate the amount of fog in a cooler condenser was presented in a previous paper, T. Mizushina and T. Koto ; Chem. Eng., Japan, **13**, 75 (1949).

In the case of the high humidity, the design calculation of a cooler condenser was presented by A. P. Colburn and O. A. Hougen ; Ind Eng. Chem., **26**, 1178 (1934). Using the calculated results the amount of the vapour diffused to the cooling surface can be calculated by $dW/(\theta\cdot dA)=K\cdot M_v(p_v-p_c)$ for each point in the step-to-step calculation.

Plotting these values against the corresponding values of surface area, and integrating graphically, the total amount of vapour which has diffused to the cooling surface is obtained.

On the other hand, the total amount of vapour condensed in the cooler is known from the material balance calculation.

The difference between these two amounts of vapour condensed may be considered to be the amount of fog.