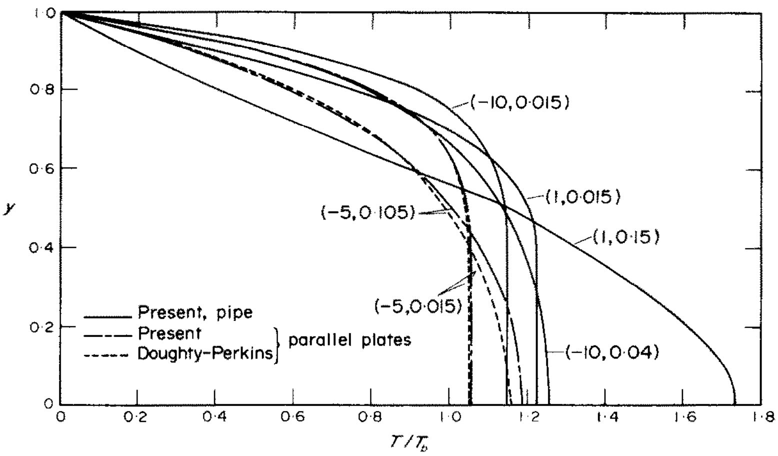

FIG. 2. Temperature distribution (Re_w, x^+) with uniform inlet velocity, $Pr = 0{\cdot}72$.

The numerical calculation of confluent hypergeometric functions is simple and can be tabulated once and for all and the series solutions for the velocity and temperature converge quite rapidly. The method is particularly convenient for different initial velocities and temperatures and for fluids of different Prandtl numbers. For Prandtl number other than 0·72, the temperature profile is the same for the same wall Peclet number provided that $x^+(0{\cdot}72)$ is replaced by $x^+(Pr)$ defined by

$$x^+(Pr) = \frac{0{\cdot}72}{Pe_w}\{[1+Re_w x^+(0{\cdot}72)]^{Pr/0{\cdot}72}-1\}.$$

It can be concluded that the linearized method which has been employed with remarkable success for flow in ducts of impermeable walls is also useful for conduits of porous walls, heated or unheated, provided that the transverse convective terms in the momentum and energy equations are taken into account. Evidently, the method can be applied to problems in other physical contexts such as those cited in [1]. It should also be remarked that more accuracy can be obtained if we make another correction on $U(x)$ as was done in [7], either through the momentum or energy equation. However, the improvement is gained at the expense of the simplicity of the method.

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HEAT TRANSFER AT THE CONDENSATION OF STEAM ON TURBULENT WATERJET

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NOMENCLATURE

α, heat-transfer coefficient;
v, velocity of water jet;
A, the total cross-section of water jet at the mean water velocity;
F, the total surface of water jet;
S, the total cross-section of water jet at the outpouring;
t_s, saturation temperature;
t_{win}, temperature of the entering water;
t_{wout}, temperature of the outgoing water;
ρ, density of water;
c, heat capacity of water;
r, heat of evaporation;
K, $= r/c{\cdot}(t_s - t_{win})$;
We, Weber number.

INTRODUCTION

THE HEAT transfer at the condensation of steam on free-falling turbulent waterjet is seldom investigated. The knowledge of the heat-transfer conditions can be interesting in many relations, e.g. in the designing of mixing type heat-exchangers, or in the investigation after blow down state of nuclear reactors (the investigation of the heat-transfer coefficient between the injected water and the developing steam). The problem to be solved here is always to determine upon what the value of the coefficient of heat transfer depends. We do not yet have any such dimensionless relation for the determination of the coefficient of heat transfer, which is independent from the water-distributor systems (e.g. flat or radial jets).

In the literature [1] there are separate data in dimensionless form for the temperature rise characteristic for the heating of water jets, under 1 atm pressure for flat and cylindrical jets. For the heat-transfer characteristic, mean $\overline{St}$ numbers and their determining parameters are given in [2] for cylindrical jets and for pressures around 1.5 atm. Reference [3] gives the parameters, effecting the heat transfer, for four different water-distributor systems (among them for flat and cylindrical jets) for pressures between 0.2–1 atm, but it does not give them in dimensionless form.

CHARACTERISTICS EFFECTING THE COEFFICIENT OF HEAT TRANSFER

We carried out our investigation according to the method given in [3]. The investigated water-distributor systems are shown in Fig. 1. The experimental vessel had a volume of $0.3m^3$, other experimental parameters were given in [3]. According to the measurements the heat-transfer coefficient depends on the water velocity and the amount of air being present at the condensation, on the other hand it does not depend on the pressure and the steam velocity. The dependence on the water velocity is given in Fig. 2. for different water-distributor systems. The approximated dashed line is given for the initial velocity of water leaving the water-distributor system, while the full line represents approximately the results for the mean velocity of water (increased by the effect of the free falling). It can be seen in both cases that the coefficient of the heat transfer is independent of the water-distributor system, but it depends strongly on the water velocity. The estimated inaccuracy on the determination of the heat-transfer coefficient is $\pm 30\%$, as the heat transfer surface and the temperatures are uncertain. We previously gave the relation between the coefficient of heat transfer and the air content [3]. We have to stress that the features of this relation are independent of the water-distributor systems too.

THE DESCRIPTION OF THE HEAT-TRANSFER RELATIONS IN DIMENSIONLESS FORM

A description of the Stanton number is proposed in [2, 3]. The mean $\overline{St}$ number can be written from the heat balance in the following way:

$$\frac{\alpha}{v.\rho.c} = \overline{St} = \frac{A}{F} \cdot \ln\frac{t_s - t_{win}}{t_s - t_{wout}}. \tag{1}$$

The value of t_{wout} in equation (1) was not known before, so we had to seek the dimensionless quantities in another form. For this we plotted the $\overline{St}$ numbers calculated from the measurements (without air present) in dependence of different dimensionless numbers. On the basis of correlation calculations the $\overline{St}$ number depends mainly on A/F and $K = r/c\,(t_s - t_{win})$ numbers, while it depends weakly on the Pr and We numbers and it does not depend at all on the Re number. According to our results of measurements the following relation can be given independently from the water-distributor system:

$$\overline{St} = 0.0158 \cdot (A/F)^{0.34} \cdot K^{0.22}. \tag{2}$$

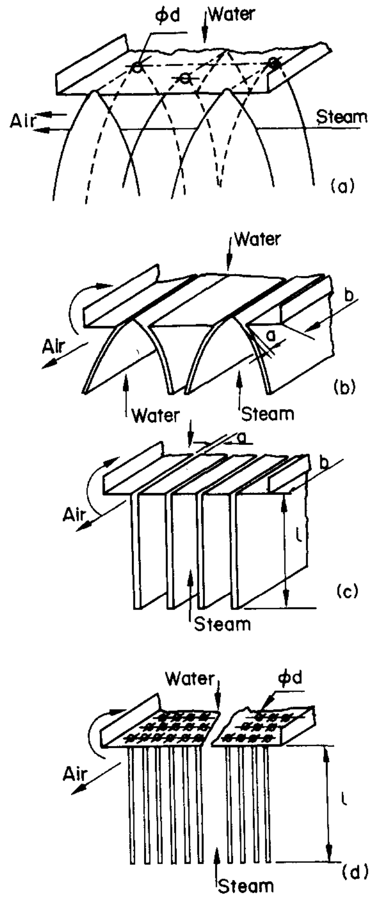

FIG. 1. The investigated water-distributor systems: A, with jet; B, with wedge; C, with lattice; D, with bored tray.

Size (mm)	A	B	C	D
d	13	—	—	6
a	—	4	20	—
b	—	800	750	—
l	500	750	750	750
Numbers of outpourings	16	4	5	360

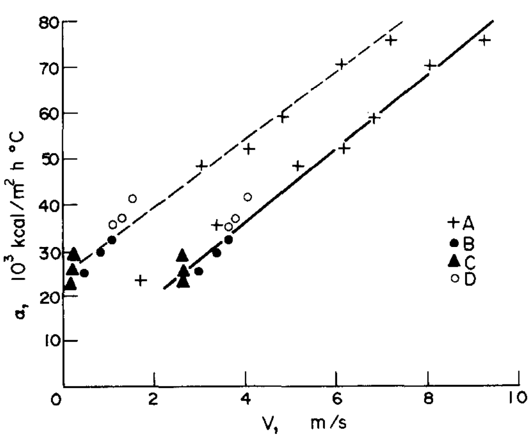

FIG. 2. The measured heat-transfer coefficient in dependence of water velocity at different water-distributor systems.

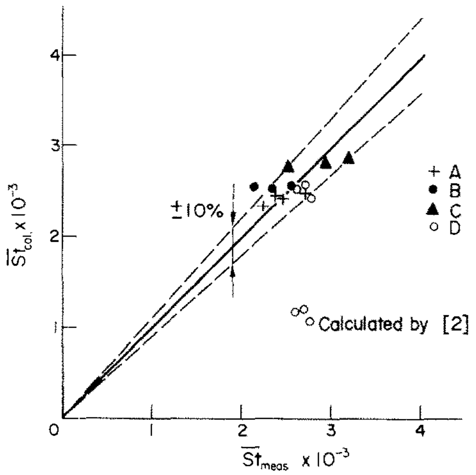

FIG. 3. The relation between the $\overline{St}$ numbers calculated from the dimensionless equation (4) and the $\overline{St}$ numbers, calculated from the measured data.

In our experiments the parameters were changing between $A/F = (4–10) \cdot 10^{-4}$, $K = 10–30$, $We = 0.5–25$, $Pr = 2.5–4.5$, $Re = (4.5–25) \cdot 10^3$. As a characteristic length we chose the thickness of the water jet. The value of A was determined from the initial outpouring cross-section, from the initial and mean velocity by the equation of continuity. The standard deviation between the results of measurements and the values calculated from equation (2) is $\pm 8\%$. The disadvantage of the application of this equation is the fact that we have to know the value of A beforehand. It would be much easier for the designing, if the equation for the $\overline{St}$ number could be given by the initial outpouring cross-section, S. That form is used in [2] as well, in which the $\overline{St}$ number for the cilindrical water jet is given by the relation of the length to the diameter of the jet l/d_0 furthermore using other known dimensionless numbers:

if $We \geqslant 2.7$

$$4\overline{St} = 0.134\,(l/d_0)^{-0.42} \cdot Re_0^{-0.17} \cdot Pr_0^{-0.09} \cdot K^{0.13} \cdot We^{0.35}$$

if $We < 2.7$

$$4\overline{St} = 0{\cdot}133\,(l/d_0)^{-0.41}\, Re_0^{-0.18} \cdot Pr_0^{0.05} \cdot K^{0.11} \times \exp(0.16 \cdot We). \quad (3)$$

The index 0 is related to the parameters at the out-pouring place. The standard deviation between the measured and the calculated (by this equation) values is $\pm 15\%$. In these experiments the parameters were changing between: $l/d_0 = 4–180$; $Re_0 = (1.5–10) \cdot 10^4$ $Pr_0 = 1.8–6.4$; $K = 6–50$; $We = 0.4–5.5$. On the basis of our results of measurements we got the following relation at four different water-distributor arrangements:

$$\overline{St} = 0.00286 \cdot (S/F)^{0.06} \cdot K^{0.084}. \quad (4)$$

In our experiments: $S/F = (5–135) \cdot 10^{-4}$, $Re_0 = (3–180) \cdot 10^3$. $Pr_0 = 3–7$. Figure 3 shows the comparison of the $\overline{St}$ numbers calculated from equation (4) and calculated from the measured results. The standard deviation between the calculated and measured values is $\pm 10\%$. Of course we carried out our investigation with much more experimental data, but for the sake of clarity we show only the mean and the most deviating experimental points. We show in Fig. 3 for comparison with [2], by the equation (3) calculated values for cylindrical water jet. It is a pity that a significant deviation appeared. At present we don't know any other possibility of comparison.

CONCLUSION

In the present paper we investigated the problem of heat transfer at the condensation of steam on turbulent water jet. For the description of heat-transfer relations we gave dimensionless equations, which were independent from the water-distributor systems.

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