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HEAT TRANSFER EFFICIENCY OF IMPINGING JETS

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Summary: *The experiments with the impinging air jets are referred to. The attention is paid to the comparison of the heat transfer efficiency for different nozzles and experimental geometries. The comparison by means of free convection is discussed and explicit formulas are introduced.*

Key words: *impinging jets, heat transfer, free convection*

1 INTRODUCTION

As was referred to at IM2000 [1], a series of experiments concerning impact streaming of air has been done at TU Chemnitz. The purpose of these experiments has been to compare the heat transfer efficiency for various nozzles and geometrical arrangements. In the experiments, local temperatures on a homogeneously heated (heat flux intensity q), perpendicularly to the air stream (temperature of air equal to the ambient temperature t_o) positioned plate was measured. In this way, the results of the experimental effort are the sets of the radial temperature distributions T(r) parameterized by the geometrical parameters and the intensity of streaming. The standard way of the treatment of the experiments of this type is the calculation of an effective heat transfer coefficients $\overline{\alpha}$ as a mean of local heat transfer coefficient $\alpha(r) = q/T(r)$. This approach is misleading in many cases because of singular behavior of α near $T = 0$. That is why, the 'cooling function' M was introduced in [1] as

$$M = \int \frac{T_f - T(r)}{T_f} dS, \tag{1}$$

where T_f is the temperature of the plate heated by q and cooled only by free convection (all temperatures designated by capital T are related to t_o). To make the calculation of M manageable, a suitable mathematical description of $T_f = T_f(q)$ relation is necessary.

2 DESCRIPTION OF THE FREE CONVECTION

Free convection (FC) from horizontal surfaces has important applications in industry. This fact explains a pertinent interest in this subject over last more then fifty years - [2], [3], [4], [5] etc. The nature of FC makes a theoretic approach less fruitful, that is why the subject is treated prevalently in an experimental way.

The results of the experimental investigation of FC are usually introduced in the form of the correlation between Nusselt (Nu) and Rayleigh (Ra) number

$$Nu = C \cdot Ra^n, \tag{2}$$

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where the C and n are results of the correlation and Ra is the product of the Grasshof and Prandtl numbers, $Ra = Gr \cdot Pr$,

$$Ra = \frac{g\beta T_f L^3}{a\nu}, \tag{3}$$

where g is gravitational acceleration, β coefficient of thermal expansion, L characteristic linear dimension of heated area, a thermal diffusivity, and ν kinematic viscosity. Nu is defined as

$$Nu = \frac{\alpha L}{k}. \tag{4}$$

In this connection, the α_f is to be understood as a short form for q/T_f, which are the quantities actually measured in experiment.

On the other hand, for the practical purposes, the FC is usually described by means of the relation

$$q = \alpha_f \cdot T_f \tag{5}$$

(Newton's cooling law), where the α_f is understood as a material characteristic for the ambient medium.

The experimental experience expressed in the eq. (2) can be transformed into the form of eq. (5): The substitution of the definitions of Nu, Ra, and T_f from the eq. (5) into the eq. (2) makes from it an algebraic equation for α_f. By means of its solution, the relation between T and q can be written as

$$T_f = \frac{G(L,n)}{F(C,n)} \cdot q^{\frac{1}{n+1}}, \tag{6}$$

where

$$F(C,n) = (Ck)^{\frac{1}{n+1}} \cdot \left(\frac{g\beta}{\nu . a}\right)^{\frac{n}{n+1}}, \tag{7}$$

and

$$G(C,n) = L^{\frac{1-3n}{n+1}}. \tag{8}$$

The right hand side of eq. (6) is factorized into three parts one of which depends only on material constants of the medium (F) and the second one is purely geometrical (G).

A standard set of values C and n is after [2], [3], and [4] based on [5] as follows: $C = .54$ and $n = 1/4$ for the laminar (Gr $< 2.10^7$) and $C = .14$ and $n = 1/3$ for the turbulent (Gr $> 2.10^7$) case respectively. For the turbulent case, which can be regarded as the 'usual' one, the exponent of the geometrical factor is zero. It makes the process independent of the area concerned - an implicit assumption of the eq. (5). The relation between q and T has now the form

$$T_f = \frac{q^{3/4}}{F_a(C,1/3)}. \tag{9}$$

This equation summarizes the experimental experience for the FC in the turbulent case, i.e. the content of the eq. (2), in an explicit form suitable for direct applications.

3 CONCLUSION

The equations (1) together with (9) introduce the 'cooling function' M in such a way, that
1) $M = 0$, if the jet doesn't work,
2) M has no singularities for $T(r) = 0$,
3) if $\alpha_1(r)$ and $\alpha_2(r)$ ar well defined for all r, then $(\overline{\alpha_1} < \overline{\alpha_2}) \Rightarrow (M_1 < M_2)$
4) M corresponds to an intuitive idea of a 'strength of cooling'.
The 'cooling function' M defined in this way can be useful as a criterium for comparison of the efficiency of the heat transfer of various impinging jets, therefore.

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