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Heat transfer performance of a confined single slot jet of air impinging on a flat surface

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ABSTRACT

In the present work, results of an experimental study are shown. The aim of the study was to determine the thermal performance of a confined impinging slot jet of air. Influence of nozzle width *B*, Reynolds number and nozzle to plate spacing *H*/*B* on the Nusselt number was investigated. Graphs showing lateral variation of the local Nusselt number on the impinging surface for selected experimental runs are presented. The results of the investigations shall help to develop an optimal model of air solar collector, the construction of which uses impinging slot jets. The *Lx* parameter that allows to determine the region with increased intensity of heat transfer was introduced. Mean Nusselt number Nu_{Lx} for this region was determined. For both parameters, correlation functions of Reynolds number, *B* and *H*/*B* were developed using multiple regression method. In the article, graphs that allow assessment of statistical analysis quality are presented.

1. Introduction

Different methods are used to increase intensity of heat transfer. One of the most effective technique is jet impingement on heated surfaces. It is widely used in various industrial processes like cooling electronic and gas turbine components, metal annealing, textile drying, glass tempering and quenching, and many more [1]. Also, the discussed method is often used in food industry [2] for e.g. freezing [3], drying [4], and baking [5].

Above all, jet impingement technique is widely used for point, linear or local cooling of surfaces that generate relatively large heat flux. The area of microjet flow (Fig. 1) can be divided into four main regions [6]. First of them is the free flow region, with a uniform velocity distribution; the second one is the decaying region, where spreading of the jet occurs; the third one is the stagnation region at the site of jet impingement; and the fourth one is the near-wall flow. However, in the work of Chen et al. [7] another four regions at the place of contact between the fluid and the flat surface were defined. For each of them, analytical relations that should be used when describing the border conditions of numerical models were given.

The highest level of heat exchange intensity occurs in the stagnation region, where rapid deceleration of flow is observed. Decrease in velocity in the jet axis and its rapid growth in the direction parallel to the impingement surface occur. High thermal gradient in the boundary layer $(\frac{\partial\theta}{\partial n}|_{atwall})$ normal to the target surface and a very small difference between the jet temperature θ_{jet} and plate temperature θ_{surf} result in a rapid growth of convective heat transfer coefficient h_f (Eq. (1)).

$$h_f = \frac{k_f \frac{\partial\theta}{\partial n}\Big|_{atwall}}{\theta_{surf} - \theta_{jet}}, \tag{1}$$

where k_f is thermal conductivity of fluid.

Increase in h_f value can be even several dozen times larger in comparison to free wall-parallel flow. The nature of this phenomenon depends on many parameters and factors, which are described shortly below.

To a great extent, performance of flow depends on the shape of the nozzle, from which the jet outflows. Among others, Koseoglu and Baskay [8] studied this phenomenon. Using numerical simulations, nine jet exit geometries were examined, beginning from axisymmetric, through elliptic and finally rectangular with different aspect ratios. As proved by experimental studies of Sarkar and Singh [9], slot jets generate more uniform convective heat transfer conditions when compared to circular jets.

Heat transfer distribution is influenced not only by the shape of the nozzle, but also by nozzle dimensions, number and way of nozzle arrangement. Configuration of impinging jets was studied by Sung and Mudawar [10].

Many research works were dedicated to determination of influence of Reynolds number and ratio of nozzle hydraulic diameter to its spacing from the target surface on the local heat transfer distribution.

Experimental studies were performed using different techniques. In most cases, the jets impinged on a plate made from a

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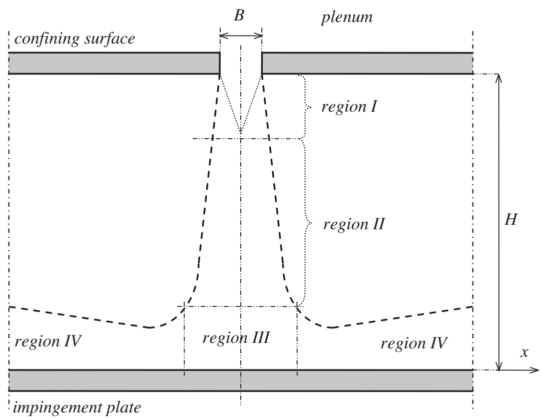

Fig. 1. Characteristic regions in impinging jet flow field.

material with high electric resistance. Depending in the electric current flowing across the test plate, appropriate amount of heat flux is generated. Temperature field created by the jet impingement can be studied in various ways. For examples, in works [11–14], thermocouples were used to determine the temperature distribution. Sensors can be mount in the target surface as a large array of thermocouples or a single high-precision temperature sensing device. Most rarely, the local heat transfer was studied based on sublimation of naphthalene film [15]. In this case, mass to heat analogy was used. The most precise and advanced method used to determine thermal performance of impinged jets is the Liquid Crystal Thermography. Examples of its use can be found in works [8,16]. However, most often, the temperature field created on the other side of the impingement plate is scanned using a long-wave IR camera. Infrared thermal imaging technique was used among others in the following experimental works [17–20].

This method was chosen by the author for his experimental work that consists of three stages. The first one included numerical simulations using algorithms of computational fluid dynamics. Results of calculations and the most important findings were presented in [21,22]. These results were used to prepare an experiment being the second stage of the project. A report of the most important results of this study is presented in this article. The third and the last stage of the work is to construct a prototype air solar panel [23] using impinging jet technique, and experimental determination of thermal performance for this device.

An extensive literature review has shown that in recent years only Belusko et al. [24] used, with success, axisymmetric jet to improve heat transfer between air and corrugated absorber of roof integrated collector. As the results have shown, thermal efficiency of the tested device increased by 21% in comparison to a standard air heater with parallel direction of fluid flow. But the author decided to use slot jets in his solution. Moreover, the impingement surface will be flat because a vast majority of vast majority of

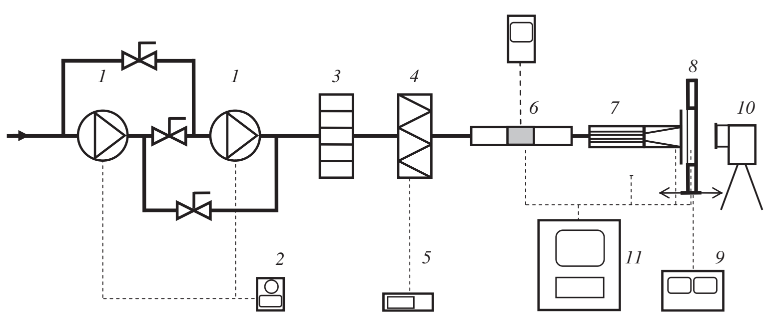

Fig. 2. Schematic illustration of experimental set-up.

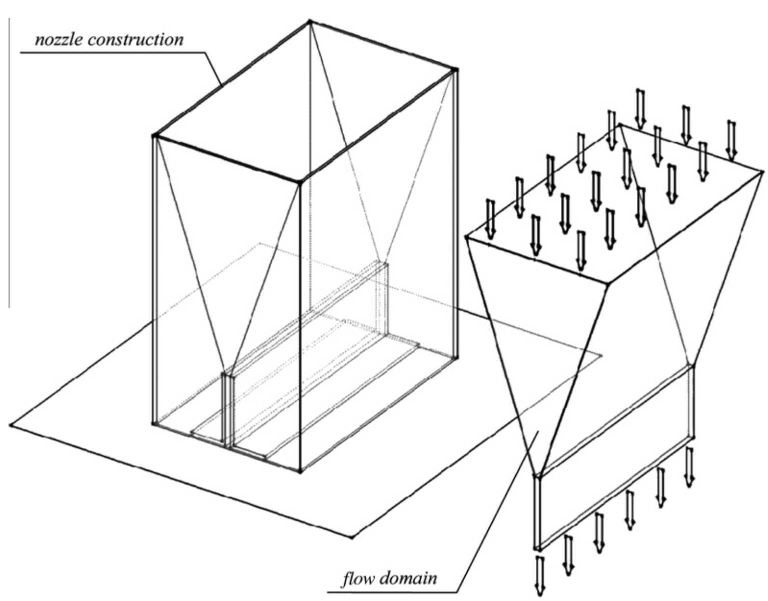

Fig. 3. Configuration of nozzle.