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Research Paper

On influence of selected parameters on the spatial distribution of the heat transfer coefficient for an array of air jets

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HIGHLIGHTS

- Inverse analysis used to determine heat transfer coefficient for jet impingement.
- Spatial distribution of was determined for array of air jets.
- Influence of flow and geometrical parameters on results was tested.

ARTICLE INFO

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Heat transfer coefficient
Submerged air jet
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ABSTRACT

The paper deals with the reconstruction of the spatial distribution of the heat transfer coefficient (HTC). Jet impingement heat exchange is pursued by a hot air that flows through set of nozzles. High velocity gas is directed toward targeted surface and produces very high values of HTC. Due to limited operation range of a single jet an array of jets is analyzed. Retrieval of the heat transfer coefficient is pursued in two steps. The procedure starts with assuming of the functional form of temperature and heat flux at fluid–solid interface. Then the functional is parameterized. In second step the definition of the convective boundary condition is used to force the temporal invariability of HTC. The approximation coefficients are determined from a least square fit of the measured and computed temperatures. The study assesses the impact of the geometrical and flow parameters on the heat transfer coefficient produced by an array of jets.

1. Introduction

Nowadays there is a need for an efficient and easy to introduce cooling/heating methods. One of possibilities is provided by an jet impingement. Such heat exchange involves a high velocity jet flow from the nozzle to a targeted surface [1]. Rapid change of the direction of the jet after hitting the object leads to very high values of the heat transfer coefficient (HTC). The value of HTC decreases with the distance from the impingement point. Therefore covering any significant area requires the use of multiple jets. The jet impingement is also easy to implement and by manipulating number and arrangement of the nozzles an arbitrary profile of HTC can be obtained [2]. There are many factors that influences the impingement heat exchange. Those parameters can be typically divided on geometrical or flow ones. A study on the nozzle geometry itself was performed by Whelan [3] while Nada [4] studied different nozzle to sample configuration. Such heat exchange is widely used in practice. Among typical applications one can see drying of textile or paper, cooling of electronic packages, cooling of slabs in steel industry, car or aircraft engines cooling [5]. Theoretically the most straightforward way to analyze jet impingement is to use a computational fluid dynamics (CFD) software. Such approach allows for determining the fluid flow in the jet and around the targeted object as well as the temperature field inside it. This approach has been used to successfully analyze single phase jets by Souris et al. [6], Sharif [7] or Taghinia [8]. Yet, even for such analyses there is an uncertainty involved with the selection of proper turbulence model. The performance of different turbulence models was investigated in [9] by Sunden or [10] by Yang just to name few papers. Also Souris compared k–ε and the Reynolds Stress model for several jet configurations [6]. Some authors claim that simple turbulence models are not sufficient to accurately simulate impinging jets and more advanced techniques such as LES [11] should be applied. One have to keep in mind that more complex flows such as two phase (e.g. water jet in air), mist jet in air, boiling liquid at the impinged surface, combusting jet, impinging flames [12] etc. raise more difficulties in CFD simulation and require huge computing time and power.

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Nomenclature

Latin

a	decision variable (temperature, heat flux, heat transfer coefficient)
c	specific heat, J/(kg K)
d	diameter, mm
h	heat transfer coefficient, W/(m^2 K)
I	number of sampling points (sensor locations)
k	heat conductivity. W/(m K)
K	number of spatial trial functions
l	nozzle to sample distance, mm
N	spatial trial function
q	heat flux, W/m^2
$\mathbf{r}$	vector coordinate, m
r	radius, m
S	number of time steps
t	time, s
T	temperature, K
U	number of temporal trial functions
z	sensor number
Z	number of measurements

Greek

δ	temperature difference, K
Φ	minimized objective function, K^2
ν	kinematic viscosity, Pa s
ρ	density, kg/m^3
Θ	auxiliary temperature field, K

Subscripts

c	from check run
E	boundary where the boundary conditions are known
f	free stream
i	sensor location
k	index of spatial trial function
m	measured
p	index of product of spatial and temporal trial functions
q	heat flux
R	boundary where heat transfer coefficient is to be retrieved
s	time instant
T	temperature
u	index of temporal trial function
z	measurement number

The inverse analysis provides an attractive alternative of retrieving the information about the impingement heat exchange. The main advantage of this approach is that only the pure heat conduction problem in the impinged solid needs to be solved, which is a way of circumventing the difficulties associated with modeling the turbulence in the fluid. The price to pay is the temperature at the outer surface of the impinged body that needs to be measured experimentally. The temperature sensors used in the inverse analysis need not necessarily be located on the fluid-solid interface. In theory, the inverse analysis can be used to retrieve any type of boundary conditions (BC). Yet the HTC is most frequently retrieved. The choice is motivated by weak dependency of HTC on temperature level. This allows for pursuing experiments at room temperatures and use the results for other temperature levels. Such an approach additionally minimizes the influence of heat radiation. One have to keep in mind that inverse problems are ill-posed. It means that such problems are sensitive to the noise in the input data and thus often require additional efforts to obtain reliable results [13].

Inverse analysis is very often used to determine BC for a jet impingement. Some researchers investigated boundary temperature [14] or heat flux [15]. When HTC is retrieved, the common way is to find the heat flux and either retrieve or measure [16] the temperature and then apply the definition of the Newton's cooling law [17]. The direct determination of the HTC is also possible but is more computational demanding and time consuming. Such approach was applied for HTC retrieval for a thermal sensitive coating by Liu [18]. Similar approach for determination of the HTC for film cooling was presented by Chen in [19]. His data reduction method required huge amount of measurement data that were obtained from transient thermochromic liquid crystals measurement. Mostly the jet impingement is analyzed under steady state conditions [4]. As the inverse analysis require large amount of data, the experiments are preferably carried out in transient state [16] or [20]. Such measurements are also less sensitive to the errors and can be conducted much faster.

The approach presented here offers the possibility to determine the HTC directly form the temperature measurements. It uses an inverse technique to determine the spatial HTC distribution which allows for decoupling the complex fluid flow from the conduction inside the targeted object. The HTC is defined through boundary temperature and heat flux. Thus, the superposition principle can be applied to divide the retrieval procedure for a finite number of simple problems. As for impinging jets the HTC does not change in time [21] such feature is used as an additional stabilization of the results. Previously developed technique was extended to work with multiple jets. Additional algorithm was introduced to determine the location of the impingement point for each nozzle and the radius of the functions associated with nozzles. The aim of the study is to investigate the influence of basic geometric and flow parameters on the spatial distribution of HTC on the surface of a solid impacted by a jet produced in the nozzle system. Analyzed parameters as nozzle diameter, nozzle position, nozzle distance from impacted object and flow as Reynolds number influence the maximum and minimum value of the HTC produced at the impinged surface, the active area of the jet and allows for manipulating of the

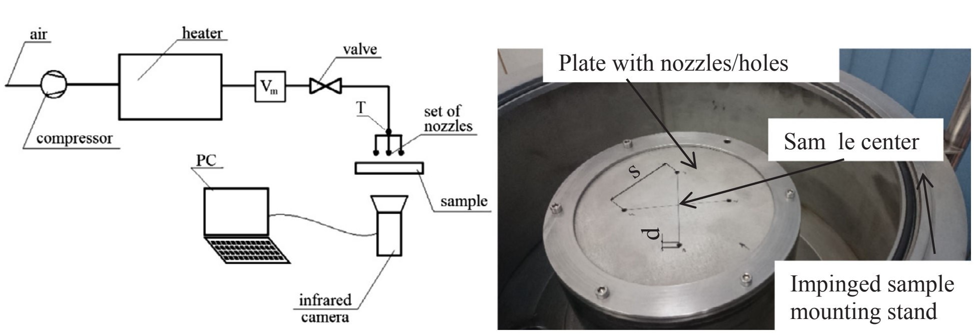

Fig. 1. Sketch of: (a) experimental rig (left) and (b) set of nozzles (right).