Effect of Confinement on Heat Transfer Between Gas-Droplets Round Impinging Jet and Flat Plate

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Abstract
The work presents the results of numerical investigation of the flow structure and heat transfer of unconfined and confined impact mist jets with low mass fraction of droplets ($M_{L1}\leq 1$ %). Mathematical model is based on the solution to RANS equations for the two-phase flow in Euler approximation. For the dispersed phase was used Reynolds stresses model, turbulent heat flux and temperature fluctuations equations by Zaichik et al. (1997). Addition of droplets causes significant increase of heat transfer intensity in the vicinity of the jet stagnation point compared with the one-phase air impact jet.

Introduction

Turbulent round impinging jets are widely used in many industrial applications. This has been due to high heat and mass transfer rates of the impinging jet. To design and optimize jet impingement cooling, it is essential to determine and understand the effects of such important parameters (such as nozzle-to-plate distance, Reynolds number and confinement effect). At cooling of turbine and electronic components, especially interesting is jet impingement occurring in a partially confined space.

The use of a gas-droplets mist impinging jet is one of the efficient methods of surface cooling augmentation. The method providing significant increase of heat and mass transfer rate between the target wall and impact mist jet Accurate prediction of flow and combined heat transfer in the mist jet impingement poses a significant problem.

The aim of the present work is numerical prediction of the effect of droplets evaporation on the flow and heat transfer in turbulent two-phase impinging confined and unconfined jets.

Mathematical model

The numerical model based on the Eulerian/Eulerian approach. For the gas phase we used the set of steady-state, axisymmetric RANS equations in connection with an appropriate turbulent $k-\tilde{\varepsilon}$ model by [1]. Despite the deficiency in the method based on RANS equations with LEVM $k-\tilde{\varepsilon}$ turbulence models it turns out to be the major for the most of engineering implementations and will be used in this work for impact gas-droplets jet modeling. The adoption of the Taylor microscale in the damping functions and the inclusion of pressure diffusion terms in both the k and epsilon equations were key features of this model. It was employed a correction of [2] for the appropriate $k-\tilde{\varepsilon}$ model. To improve the behavior of the Hwang and Lin model, a realizability constraint is applied on the turbulent time scale in equation for $\tilde{\varepsilon}$. Additionally we performed computations with using of non-linear eddy viscosity model for the gas phase.

The set of equations includes continuity, momentum, energy, mass concentration of vapor equation in binary gas-vapor mixture and turbulent quantities. Each equation has some extra sink or source terms which modeled the effect of particles on the transport in the gas phase. The turbulence model was modified to the case of evaporating droplets. For the dispersed phase was used Reynolds stresses model, turbulent heat flux and temperature fluctuations equations by [3]. Both the deposition of droplets onto the wall and the heat transfer due to the contact of droplets with the wall were taken into account. The droplets were assumed to undergo instantaneous evaporation on the wall, with no liquid film formed on it.

The discretization of the transport equations in the computational domain was performed by using finite-volume techniques. The QUICK scheme was used for convective fluxes and central differences were utilized for diffusion fluxes. The SIMPLEC solution algorithm was adopted for pressure-velocity coupling. All computations were performed on the grid that comprised 250×200 control volumes (CV) with a high resolution in the wall and axis region. The mesh configuration was tested to be sufficient to provide grid independent results. Additionally, a series of test computations for a gas-droplet flow occupying a total of 350×300 CVs was performed. The computational domain is $20R$. Here, R is the jet radius.

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For the comparative analysis in case of single-phase air jet experimental data set on flow dynamics [1] and heat transfer rate of impact jet [2] have been used.

Results and Discussion

The size of the dispersed phase was d_1=(1–100)×10^{-6} m. The inlet water droplets mass concentration was M_{L1}=0–1 %. In the initial cross-section droplets were monodisperse, downstream from the nozzle exit their size changed in both directions due to evaporation. The diameter of a nozzle is 2R=20 mm. Gas phase velocity on the nozzle exit was U_1=5–20 m/s, the Reynolds number Re=$U_1 2R/\nu$≈(1.3–5.2) ×10^{-6}. The surface temperature was constant T_W=373 K. Gaseous flow and droplets temperatures are 293 K. The computational domain is 20R. The nozzle-to-plate distance H=0.5–10.

In the free jet area widening of the gas-droplets jet is a little more than the single-phase and the profile of the axial velocity is qualitatively similar to the one in the free jet. Lead of the two-phase jet over one-phase is mainly explained by additional generation of the impulse from the particles and insignificantly from their evaporation. As the wall is approached its effect is already pronounced and the value of axial velocity of gas and droplets significantly decreases. The velocity of particles is higher than the gas velocity owing to inertia action. Droplets addition substantially increases heat transfer rate (several times) compared to the one-phase air impact jet due to the droplets evaporation. The influence of confinement on the local heat transfer behavior in the mist flow has been studied. It has been shown that confinement decreases the average heat transfer rate, but the change of the local heat transfer coefficient in the stagnation point is insignificant. The effect of confinement on the heat transfer is considerable only in very small nozzle-to-plate distances (H/(2R)<0.5) both in single-phase and mist impinging jets.

A comparison between our predictions and measurements for mist impinging jet by Kanamori et al. [6] was provided. Use of gas-droplets mist impact flow results in significant growth of heat transfer intensity (more than 2 times compare with one-phase impact jet). Note that for the experiments [6] and our study main increase of heat transfer rate falls to the stagnation region that proves our numerical results. Agreement between our computation results and numerical and measurements data of [6] was rather good.

Acknowledgement

This work was partially supported by the President's Fund for Young PhD Scientists (Grant No. MK-504.2010.8) and by the Russian Foundation for Basic Research (Projects No. 09-08-00929).

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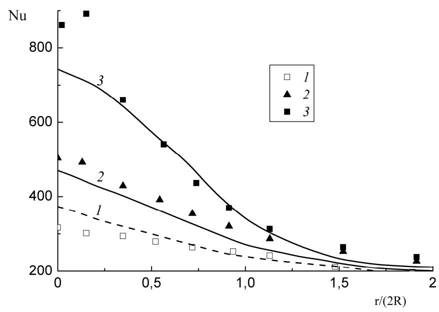

Figure 1. Heat transfer in the mist impinging jet. Symbols are the measurements results [6], curves are our predictions.
1 – M_{L1}=0 (single-phase flow), *2* – 0.05 %, *3* – 0.1, *4* – 0.15.