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Numerical solution of transpiration cooling method in hypersonic laminar flow using the Kinetic theory model

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Abstract

Transpiration cooling method is proved to be an effective cooling method to diminish the heat flux on the special area of the surfaces of the high-speed vehicles. The cooling process is investigated using nitrogen gas as the coolant and air as the main flow. This study presents a novel approach, as transpiration cooling in hypersonic laminar flow has not been previously simulated through kinetic theory.

Keywords: *Transpiration cooling method, Hypersonic laminar flow, Porous media*

1. Introduction

In the transpiration cooling method, the coolant blows onto the boundary layer (usually the transition or laminar boundary layer), making a thin film cooling effect on the surface to reduce heat flux of the plate. The technique of cooling based on fluid injection is also called "effusion cooling" when multiple blowing holes are arranged closely together or called "transpiration cooling" when coolant is supplied from a porous material [1].

In the effusion cooling technique, a hole on the surface is used to inject the coolant onto the boundary layer of the main stream. Porous media is a piece which has porosity to pass the flow through itself slowly. In this research, the experimental setup of Ifti et al. [1,2] is simulated in two-dimensional to validate results of simulation. The kinetic theory is used to compute properties of the mixture of the coolant and main flow. Nitrogen gas and Air are used as coolant and main flow, respectively. All properties of these fluids are calculated by Ideal gas law. This subject has not been simulated through kinetic model theory yet.

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2. Numerical methods

In the present work, a flat plate with the porous media is considered to simulated to validate simulation results, according to experimental work of Ifti et al. [1,2]. Fig. 1 illustrates the geometry of simulations which is used as reference frame.

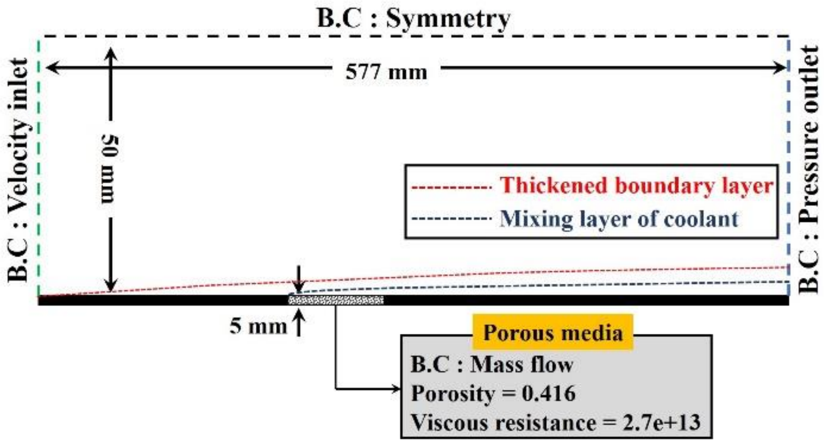

Fig 1. Schematic of the 2D simulation

In the present work, Air is considered as the main flow which is passed on the flat plate and the Nitrogen is used as coolant. Aerodynamic and thermodynamic properties are used in this work are presented in Table 1.

Table 1. Test condition [1]

Parameters	value
Re_u	$12.9 \times 10^6\ m^{-1}$
T_{inf}	$43.57\ K$
P_{inf}	$535\ Pa$
T_c	$293\ K$
Blowing ratio (F)	0.0818%

In the simulation of the transpiration cooling method, continuity, momentum, energy equations, and the equation of state are used for two non-reacting special pieces. The efficiency of coolant is an important parameter which is computed in downstream of injector by Eq. 1 [1,2]:

$$\eta = 1 - \frac{\dot{q}_c}{\dot{q}_{unc}} \tag{1}$$

The mass flux permeated in the boundary layer is defined as Eq. 2 [1,2]:

$$F = \frac{\rho_c u_c}{\rho_{inf} u_{inf}} \tag{2}$$

3. Results and discussion

To validate the accuracy of the simulation, the present work results are compared with experimental and numerical data of Ifti et al. [1,2] which has been measured from x = 0.23 m up to 0.275 m and then the thermal efficiency is computed at the same length. As shown in Fig. 2, the simulation results has good agreement with experimental data for the thermal effectiveness at F= 0.0818%.

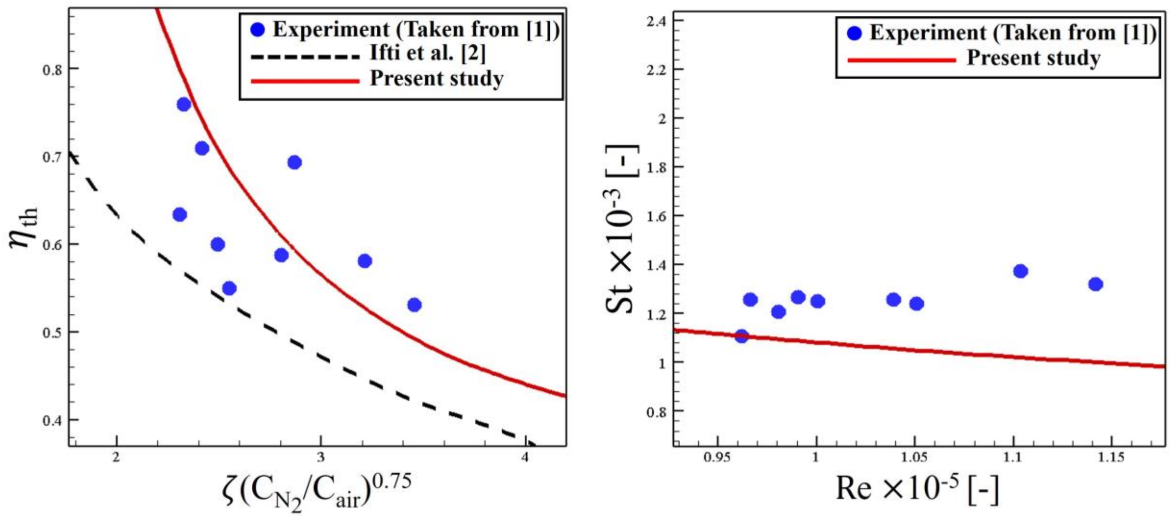

Fig 2. Validation results of thermal efficiency at F = 0.0818% and Stanton number in Eckert reference temperature [3] in uncooled case

Mass fraction of the coolant of mixture on the wall after porous media which is reduced because of increasing mass fraction of air. As shown in Fig. 3, the mass faction of the coolant after the porous is reduced in that it makes a mixture with main flow which is Air. Details will be elaborated in the poster session.

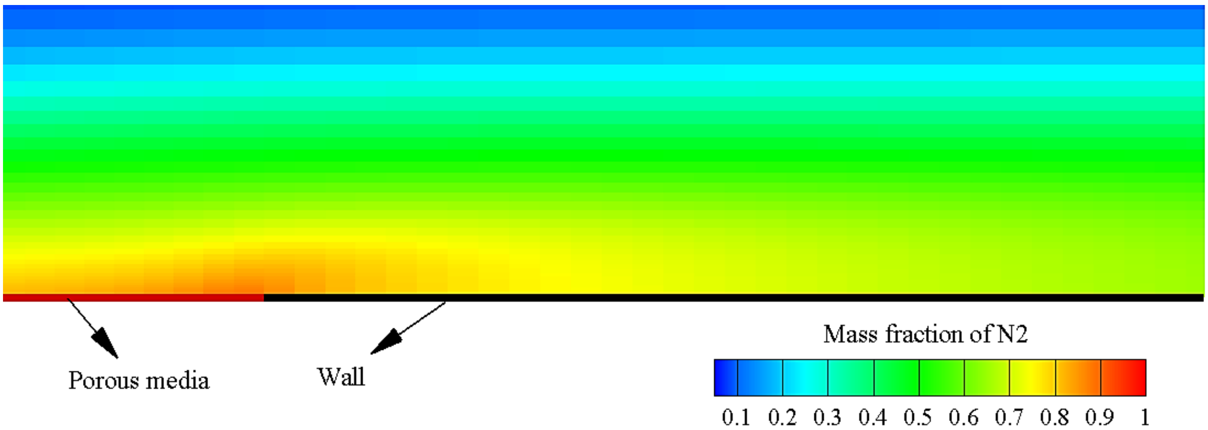

Fig 3. Mass fraction contour of the N_2 coolant

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