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Experimental investigation on impingement-effusion film-cooling behaviors in curve section

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ABSTRACT

A new series of test pieces with different geometrical configuration and geometry dimensions are designed to experimentally investigate on impingement-effusion cooling behavior in curve effusion wall of combustion chamber. The test results show that the discharge coefficient increased with the increasing blowing ratio. The effusion hole–hole spacing has an effect on the discharge coefficient and the discharge coefficient commonly decreased with the increment of effusion hole–hole spacing. The blowing ratio greatly effects cooling behavior. The bigger blowing ratio is favorable for improving cooling characters. At the curved effusion wall, to begin with, cooling effectiveness increased slowly and kept a steady value in subsequence. But, for the rear end of curved effusion wall, it decreased slowly. With decreasing of effusion hole angle and effusion hole–hole spacing, cooling effectiveness is enhanced. Meanwhile, blowing ratio, effusion angle and effusion hole–hole spacing take an evident effect on the discharge coefficient.

1. Introduction

Gas turbine with higher temperature and pressure has become a general trend for improving the engine performances to some extents. However, a serious problem for aero-engine combustion chamber is that the quantity of cooling air is reduced in contrast to higher gas temperature. Hence, novelty cooling methods using less air consumption are urgent and important. The reverse flow annular combustor of gas turbine has a highest cooling-surface area to combustor volume ratio, so its combustion systems must be provided with the highest cooling air flows for survival (see Fig. 1). In the case of high temperature condition, it is required to improve curved combustor liner reliability of reverse flow combustor and more effective cooling schemes. The impingement/effusion cooling technique is a possible solution to enhance cooling effectiveness in combustor liner cooling of reverse flow combustor, where an array of jet impingement and film cooling are combined (see Fig. 2). With respect to this technology, inner surface of combustor liner is cooled by impingement of cooling air and outer surface facing hot gases is protected by film effusion cooling.

Impingement/effusion cooling has been investigated and developed since 1980s. Hollwarth et al. [1,2] measured average and local heat transfer coefficients on the effusion surface, and reported that arrays with staggered vents consistently yield higher heat transfer rates than do the impinging jets on the solid plates. Nazari and Andrews [3] studied film cooling performance with the effects of number of holes for impingement/effusion cooling. Zhang et al. [4] numerically studied the flow field and heat transfer characteristics for impingement/effusion cooling configurations. The impingement/effusion holes arrangements in the two parallel perforated plates were

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Nomenclature

A	flow cross-sectional area, m^2
C_d	discharge coefficient
M	blowing ratios, $(\rho U)_c/(\rho U)_m$
m	flow ratio, kg/s
P	static pressure, Pa
T	temperature, K
U	average velocity of stream, m^2/s
o	overall
re	reality
s	impingement space
th	theory
w	wall

Superscript

*	total

Subscripts

an	annulus coolant
c	coolant
e	effusion
i	impingement
m	main stream

both chosen as staggered pattern and the angles between effusion holes and the surface were all set as 30°. The distance between the two parallel perforated plates was three times as the diameter of effusion hole, and the adjacent hole-to-hole spacing was set as 3.0, 4.0 and 5.0 times as the diameter of effusion hole, respectively. Cho and Rhee, and Rhee et al. [5–8] investigated the effects of gap distance, Reynolds number and holes arrangement on the heat/mass transfer characteristics near an effusion hole, and they reported that interaction between adjacent impinging jets is very weak for the small gap distance. Levels of Sherwood number increase monotonically with Reynolds number showing that the patterns of heat/mass transfer are similar for all tested Reynolds numbers. Local and average convection heat transfer coefficients were investigated inside the effusion holes in the impingement/effusion cooling schemes by Lin et al. [9,10]; they concluded that the pressure distribution has great influence on the heat transfer enhancement inside the effusion holes entrance.

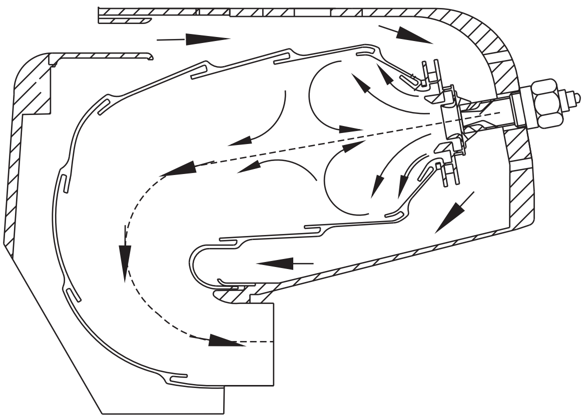

Fig. 1. Schematic of reverse flow combustor.

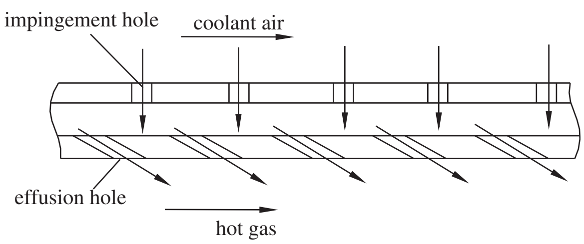

Fig. 2. Schematic structure of impingement/effusion cooling.

Goldstein and Jin [11] studied the film cooling effectiveness and mass/heat transfer coefficient downstream of only one row of holes with the inclination angle of 35° deflection angle of 45°, using the naphthalene sublimation technique and the heat/mass transfer analogy. Ling et al. [12] obtained the film cooling effectiveness and heat transfer coefficient for a full coverage film cooling wall with the inclination angle of 20°, deflection angle of 0°, and hole-spacing of 16d to 10d, using the transient liquid crystal technique. Expensive liquid crystal paint was used on the measured surface and complicated liquid crystal color analysis was done after the experiment. Probably due to the high expense and inconvenience of the experiment, Ling's research only dealt with the first several rows of holes and more downstream rows, with quite a few rows between skipped. Zhang [13] experimentally investigated the overall cooling effectiveness of three effusion cooling test plates. The test plates had different hole-spacing, different deflection angle and the same inclination angle. Based on the IR measured cooling effectiveness data, different effusion cooling configurations were evaluated and the optimum configuration was determined. Gustafsson et al. [14] investigated the temperature distribution on effusion-cooled plates with different temperature ratios and velocity ratios between hot gas and coolant, and different injection hole-spacing, inclination angle and thermal conductivity of the test plates. Harrington et al. [15] performed an experimental investigation on the adiabatic effectiveness of large-scaled full coverage film cooling plates, considering the effect of the mainstream turbulence. Ekkad et al. [16] obtained both film cooling effectiveness and heat transfer coefficient from a single test by means of the transient infrared thermography technique. Cho and Rhee [17,18] also investigated heat/mass transfer and flow characteristics of an impingement/effusion cooling system with various