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Research paper

Analysis of numerical results for two-pass trapezoidal channel with different cooling configurations of trailing edge: The effect of dimples

Waseem Siddique*, Naveed Ahmed Khan, Inamul Haq

Department of Mechanical Engineering, Pakistan Institute of Engineering and Applied Sciences (PIEAS), Nilore, Islamabad 45650, Pakistan

HIGHLIGHTS

- CFD analysis of the effect of dimples on heat transfer in a two-pass trapezoidal channel was performed.
- ANSYS Fluent was used to carry out the CFD analysis.
- Maximum heat transfer enhancement is attained with the channel with inline arranged dimples having H/d ratio equal to 0.25.
- Staggered arrangement of the same dimples reduces pressure drop but also effects enhancement in heat transfer negatively.
- H/d ratio of dimples is an important parameter and its optimum value should be found out.

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ABSTRACT

Internal cooling of the gas turbine blades is imperative for the enhanced inlet temperature of gas turbine. In this paper, numerical results of two-pass trapezoidal channel provided with dimples for internal cooling of a gas turbine blade are discussed. Three configurations of dimples are compared and enhancement in heat transfer has been reported. Also pressure drop along the channel for all cases has been predicted. It is found that for the channel with inline arranged dimples having H/d ratio equal to 0.25, maximum heat transfer enhancement is attained. Staggered arrangement of the same dimples reduces pressure drop but also effects enhancement in heat transfer negatively. The thermal performance of the dimples size suggests that H/d ratio of dimples is an important parameter and its optimum value should be found out.

1. Introduction

Gas turbine plays a key role in the power plant industry. Industry has always sought to increase the efficiency of gas turbine. Increasing the inlet temperature of a gas turbine has proven to increase its efficiency. However, increase of inlet temperature results in a decrease of operating life of the turbine. Various methods are used to address this issue. One of the methods is to internally cool the turbine blades. Air from the compressor is used for the internal cooling of the blades. In case of advanced gas turbines, the temperature at inlet of the blade is 1800 K. Compressed air at 953 K is used for internal cooling which results in lowering the blade temperature to 1300 K thus preventing the thermal failure [1].

The trailing edge of the blade has key importance in efficacy of the turbine. It should be thin and sharp to reduce losses associated with flow aerodynamics but on the other hand it is exposed to very high thermal loads which requires efficient cooling configuration. Conventional method of cooling the tip region is to provide the slots in the trailing edge where from the coolant leave the blade and mix with the main gas stream. But when steam is to be used as a coolant, it is not allowed to mix with the main gas flow, thus eliminating any chances of using film cooling. Thus internal cooling is the only method for heat transfer. The heat transfer in the internal pathways provided in the blades is enhanced by increasing the surface area and turbulence. This can be achieved by using small turbulators like pins/fins and ribs on the walls of these channels. The turbulators enhance the heat transfer in two ways: they induce secondary flow to intensify the flow turbulence and increase the surface area for convective heat transfer. In recent years, efforts aimed at improving internal cooling have led to the use of a new method: roughening the walls of the blade internal channels with dimples [2].

Dimples are arrays of depressions or indentations on surfaces which generates strong vortices resulting in higher turbulence

* Corresponding author.
E-mail address: waseem@pieas.edu.pk (W. Siddique).

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Nomenclature

C_p	Specific heat, [J/kg K]
d	Diameter of dimple, [cm]
D_h	Hydraulic Diameter of channel [mm]
h	Heat transfer coefficient, [W/(m^2 K)]
H	Depth of the dimple, [cm]
k	Turbulence kinetic energy, [J/kg]
K	Thermal conductivity of the fluid, [W/(m K)]
m	Mass flow rate, [kg/sec]
Nu	Nusselt number, (h D_h/K)
P	Pressure, [N/m^2]
Pr	Prandtl number, ($C_p\mu$/k)
Re	Reynolds number, ($\rho U_{in} D_h/\mu$)
T	Temperature, [K]
U	Velocity, [m/sec]
W	Width, [mm]
Greek symbols	
Δ	Difference
ρ	Density, [kg/m^3]
η	Thermal performance
μ	Viscosity, [kg/s m]

around it and downstream and thus augment the heat transfer. They also result in lesser pressure drop compared to ribs because they do not protrude into the flow to induce any drag [3]. Fig. 1 shows the effect of dimple on flow in a duct. As shown, fluid gets separated when it enters the dimple. Inside the dimple, it divides into a recirculation zone which is a low heat transfer area and a flow reattachment zone which is high heat transfer region. After leaving the dimple, vortices are shed which results in enhancement of heat transfer on the plateau of the dimple. This separation and reattachment results in heat transfer augmentation on one hand but also increases pressure drop compared to a smooth surface.

Isaev et al. [5] showed that dimples in a channel enhance heat transfer up to 2 to 2.5 times compare to a smooth channel with a pressure loss penalty of 2–4 times that of a smooth channel. These values show little dependence on Reynolds number and channel aspect ratio. However, the dimple size, dimple depth (depth to diameter ratio = 0.1 to 0.3), distribution and shape (cylindrical, hemispherical, teardrop) effect the heat transfer distribution in the channel [6]. Schukin et al. [7] studied the effect of channel geometry (constrictor and diffuser channels) on the heat transfer downstream of a single hemispherical dimple with sharp edge. The diameter of the dimple was 0.5 mm and depth to diameter ratio (H/d) was 0.5. For the whole range of the of the constrictor/diffuser angle $\theta/2 = 0°–8.5°$, heat transfer increases to 1.2 times compared to a smooth surface at Re = 140,000. Terekov et al. [8] experimentally studied the flow structure, pressure field and heat transfer in a channel with a single dimple on one wall. Two types of dimples were tested: with a sharp edge and with a rounded off edge. The value of H/d was 0.13, 0.26 and 0.5. It was reported that pressure drop increases with the depth of the dimple while heat transfer enhancement was strong in the downstream half of the dimple than in the upstream half. Moon et al. [9] measured heat transfer and pressure drop in a rectangular channel with dimple matrix imprinted on one wall. The effect of channel height on heat transfer and pressure drop of the dimpled wall was studied with dimple H/d was 0.193. The heat transfer enhancement of the order of 2.1 over smooth surface was reported with pressure drop penalty in the range of 1.6–2 times over smooth surfaces. The authors claimed that no detectable effect of the channel height was found on heat transfer and pressure drop for all the channel height to dimple diameter ratio cases studied. In a later study, Moon et al. [10] investigated the heat transfer and friction on a smooth wall where a dimpled wall was also installed in its opposite side. An overall heat transfer enhancement of 1.4–3.08 times was observed on the smooth wall with dimples on the opposite wall. With the increase in the clearance gap, heat transfer enhancement decreased. Mahmood et al. [11] made detailed flow and heat transfer measurements on a dimpled plate and identified specific vortex structure responsible for heat transfer augmentation. Heat transfer enhancement ranging from 1.8 to 2.4 over smooth plate was reported. Mahmood et al. [12] further investigated the effects of the ratio of the inlet stagnation temperature to the local wall temperature on the flow structure in a dimpled channel with four values of channel height to dimple diameter ratio; 0.2, 0.25, 0.5 and 1.00. The authors found the vortex pairs discussed above become stronger as channel height to dimple diameter ratio is decreased. Ligrani et al. [13] performed experiments to examine flow structure on a dimpled wall machined with 13 staggered rows of dimples along the stream wise direction. Each dimple had a diameter of 5.08 cm and depth to diameter ratio H/d of 0.2. The authors identified a primary vortex pair periodically shedding from the central portion of each dimple and observed two additional secondary vortex pairs formed near the span wise edges of each dimple.

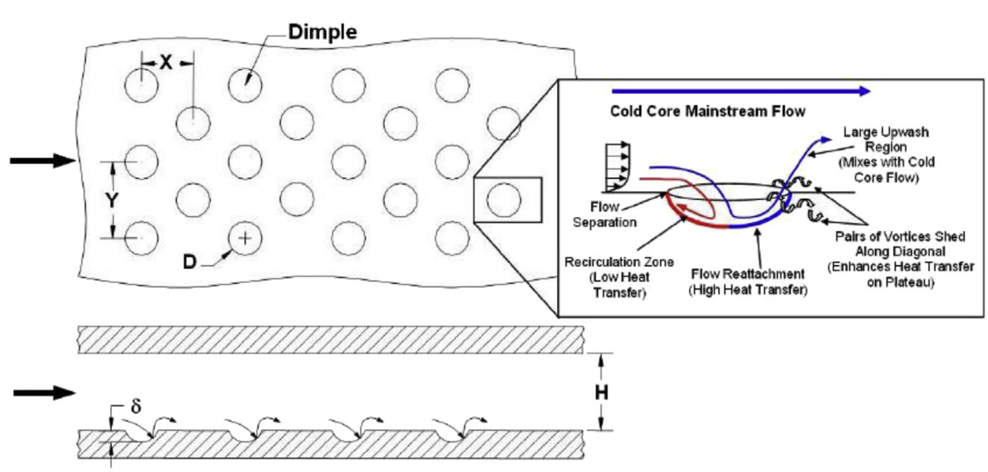

Fig. 1. A conceptual view of dimple induced secondary flow [4].