Experimental Investigation of Heat Transfer Augmentation in Rectangular Channel Using Inclined Baffles: A Review

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Abstract- *This experimental study investigates the local heat transfer characteristics and the associated frictional head loss in a rectangular channel with inclined solid and perforated baffles. A combination of two baffles of same overall size is used in this experiment. The upstream baffle is attached to the top heated surface, while the position, orientation, and the shape of the other baffle is varied to identify the optimum configuration for enhanced heat transfer. A constant surface heat flux is applied from the top surface, but the bottom and the side surfaces are maintained at an adiabatic condition. The inline placement of baffles augments the overall heat transfer significantly by combining both jet impingement and the boundary layer separation. Experimental results show that the local Nusselt number distribution is strongly depended on the position, orientation, and geometry of the second baffle plate. The friction factor ratio goes up with an increase in the Reynolds number, but its value depends on the arrangement of baffles. Like single inclined baffle and rib-mounted channels, the frictional head loss is much higher for two inclined baffles.*

Keywords- Baffle, Heat transfer augmentation, inclined baffle, Rectangular channel.

I. INTRODUCTION

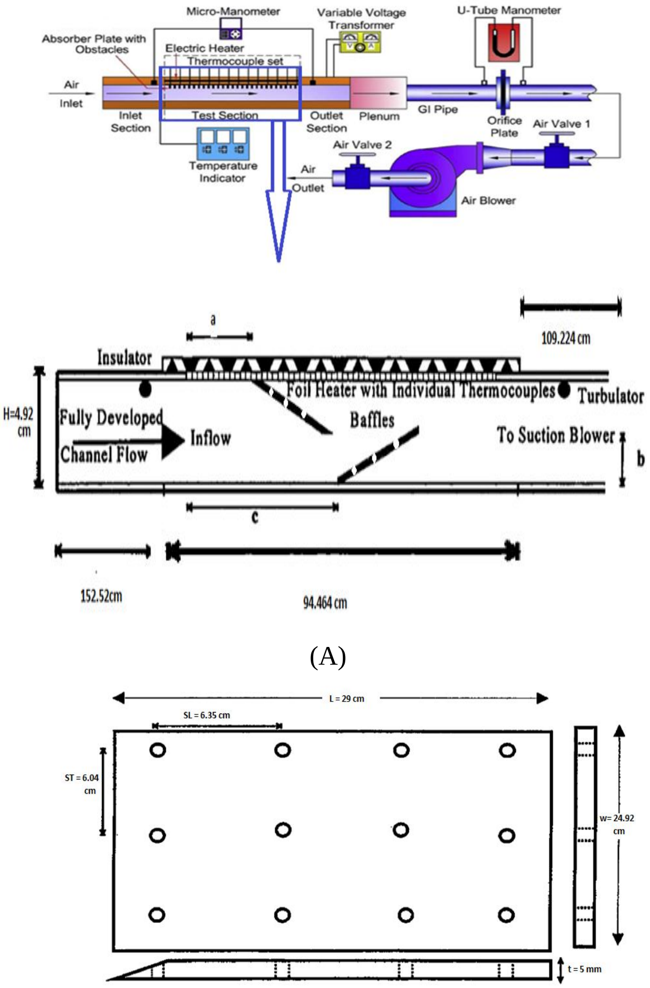
In modern gas turbines, it has become a growing trend to increase the temperature of the combustion product to increase the specific thrust and to reduce the specific fuel consumption. Such a high temperature is far above the allowable temperature of super alloys and thermal barrier coatings (TBC) used in gas turbine blades. In gas turbine, usually air is used in the interior side of the blade to maintain the blade at the proper working temperature. Also in a number of other engineering and industrial applications such as, air-cooled solar collectors, laser curtain seals, labyrinth shaft seals, compact heat exchangers, and microelectronics, air is preferred as a coolant for its lightweight. However, due to the very low thermal conductivity internal cooling with gases is less effective than cooling with liquids. There are several techniques available to enhance the heat transfer coefficient of gases in internal cooling. The most commonly used technique for internal cooling enhancement is the placement of periodic ribs. Ribs are generally mounted on the heat transfer surface, which disturbs the boundary layer growth and enhances the heat transfer between the surface and the fluid.

In literature, numerous studies on ribbed channel heat transfer are reported, but only the relevant articles are cited here. Sparrow and Tao (1983) obtained enhanced heat transfer in a rectangular channel by inserting rod-type disturbance elements adjacent to the principal wall. In a series of studies, Chandra and coworkers experimentally investigated the heat transfer and associated frictional loss in a rectangular channel with a varying number of ribbed walls (Chandra et al., 1997, 2003). In a separate study, internal cooling heat transfer augmentation is reported for a fully developed turbulent flow in a square channel with V-shaped turbulence promoters (Han et al., 1991). These ribs or surface protuberances are small and do not disturb the core flow. Thus, the turbulence enhancement and boundary layer breakdown are mostly localized near the heat transfer surface, and therefore, the gain in heat transfer coefficient is not significantly offset by the pressure drop penalties.

Another popular heat transfer augmentation technique is impingement cooling that uses high velocity jets to cool the surface of interest. Lin et al. (1997) experimentally showed the heat transfer behavior of a confined single-slot impingement. However, in practical applications often a large region needs to be cooled and multiple jets are required. A multiple jet configuration is normally affected by the cross-flow developed from upstream spent-jets. Goldstein and Seol (1991) have presented the convective heat transfer characteristics from a row of circular air jets formed by the square edged orifices. In a similar experimental work, the effect of excitation on the flow and heat transfer performances is reported (Liu and Sullivan, 1996). Lately, Beitelmal et al. (2000) demonstrated the effect of the impinging jet inclination in cooling a uniformly heated plate. The jet impingement mechanism used in that work is very similar to our current study.

In addition to ribs and impingement, a third common internal cooling enhancement technique is the placement of internal flow swirls, tape twisters, or baffles. The swirl insert and tape twister techniques create a significant amount of bulk flow disturbance, and the pressure drop penalties are much higher compared to the gain in heat transfer coefficient. Baffles also create bulk flow disturbance, but unlike tapes or swirls, baffles are discrete objects. Therefore, the flow disturbance created by baffles may be localized, but more intense. Usually the baffle plate is attached to the thermally active surface to augment heat transfer by providing additional fin-like surface area for heat transfer and better mixing.

II. EXPERIMENTAL APPARATUS



(A)

(B)

Fig.1 Schematic of experimental setup
a) Sectional view of text section
b) A perforated baffle plate with associated nomenclature

Uniform heat flux heaters are fabricated from stainless steel foils. A total of 46 iso-flux heaters of identical size are mounted on the upper surface of the test section, and they are aligned perpendicular to the flow direction. These heaters are connected in series with an online voltage controller in order to supply the same amount of heat to each heater. All other sides of the channel are unheated. Commercial fiberglass insulation is used on the external surfaces to prevent any thermal energy leakage due to convection and radiation. For wall temperature measurement, heaters are connected to copper-constantine thermocouple glued at the center of the foil heater. Moreover, one thermocouple is placed at the inlet (1.55H upstream of the heated test section) and two others are positioned at the outlet (2.3H downstream of the heated test section) to measure the inlet and outlet bulk fluid temperatures, respectively. Each thermocouple is calibrated against a standard thermal bath over the range of the operating temperatures. Two wooden turbulators are attached to the top wall at 1.55H upstream and 2.3H downstream of the heated test section. These turbulators are placed to ensure a turbulent boundary layer and good mixing of the bulk flow for mean temperature measurement.

Two pressure probes are used to measure the frictional head loss, and they are located at 2.45H upstream and 4.4H downstream of the heated test section.

III. THEORY

The local heat transfer coefficient, h, is obtained as

$$h = \frac{q - q_l}{A_s(T_w - T_b)}$$

where, As is the surface area of the heater, Tw is the wall temperature, and Tb is the bulk mean temperature. The heat input, q, from the heaters are calculated as

$$q= VI$$

where V and I are the voltage and current applied across the heaters, respectively. The heat lost, ql, is estimated from a separate heat loss experiment done on the test facility without airflow. A heat loss characteristic curve is developed for each thermocouple location and it is found that the maximum local heat loss, ql, is less than 5% of the total local heat supplied, q. The wall temperature is measured directly by the thermocouple attached to foil heater and the bulk temperature is calculated from the energy balance, i.e., bulk temperature increase is equal to the net thermal energy supplied to the air stream divided by the mass flow rate, _m, and specific heat, cp. In this study, the wall to ambient temperature difference is kept below 35°C and the bulk temperature rise from inlet to outlet is less than 3°C. The flow Reynolds number is calculated as

$$Re = \frac{\rho VD}{\mu}$$

Where ρ is the fluid density, μ is the fluid viscosity, V is the channel average velocity and D is the channel hydraulic diameter. Although the channel centerline velocity is measured using a pitot-static tube, a relation is derived to get an average velocity, V, from centerline velocity, U, (V = 0.766U) for turbulent flow by using 1/7th power law. The mass flow rate within the channel is varied by changing the flow area of the suction blower, and the flow Reynolds number in this study is ranged between 12,000 and 41,000. Since all experimental results are presented for air at a single characteristics dimension (D = 8.217 cm), the flow Reynolds number range presented in this study corresponds to the lower and upper pumping capabilities of the suction blower. The local Nusselt number is calculated as

$$Nu = \frac{hD}{k}$$

Where k is the thermal conductivity of the fluid. The average Nusselt number, Nuav, is the arithmetic average of all local Nusselt numbers along the heated part of the channel. The friction factor is evaluated from the pressure drop as

$$f = \frac{\Delta PD}{\frac{1}{2} L_e \rho V^2}$$

where ΔP is the pressure drop across the heated test section and Le is the length of the heated test section. A micro manometer is used to find the pressure drop along the channel with and without baffles. Since two pressure taps are located upstream and downstream of the actual test section, a correction on the pressure drop is performed based on the smooth channel analysis. The extra lengths (probe locations are 2.45H upstream and 4.4H downstream) are assumed to have smooth channel pressure drop properties, and this pressure drop is deducted from the measured pressure drop to get the pressure penalty in the test section. In this study, the pressure drop correction is less than 4% of the total pressure drop.

IV. LITERATURE REVIEW

PRASHANTA DUTTA, AKRAM HOSSAIN [1] investigates the local heat transfer characteristics and the associated frictional head loss in a rectangular channel with inclined solid and perforated baffles. The upstream baffle is attached to the top heated surface, while the position, orientation, and the shape of the other baffle is varied to identify the optimum configuration for enhanced heat transfer. A constant surface heat flux is applied from the top surface, but the bottom and the side surfaces are maintained at an adiabatic condition. The friction factor ratio goes up with an increase in the Reynolds number, but its value depends on the arrangement of baffles. Like single inclined baffle and rib-mounted channels, the frictional head loss is much higher for two inclined baffles.

PRASHANTA DUTTA, SANDIP DUTTA [2] investigation of frictional loss and heat transfer behavior in a rectangular channel with iso-flux heating from the upper surface is presented for different sizes, positions, and orientations of inclined baffles attached to the heated surface. Both solid and perforated baffles are used. Inclined perforated baffle combines three major heat transfer techniques, e.g. boundary layer separation, internal flow swirls, and jet impingement. Results indicate that there exists an optimum perforation density to maximize heat transfer coefficients and this optimum perforation exhibits a strong jet impingement technique from the lower confined channel along with other enhancement techniques of heat transfer.

M.S. LEE , D.H. LEE [3]studied The effect of a number of inclined perforated baffles on the flow patterns and heat transfer in the rectangular channel with different types of baffles is numerically and experimentally checked out. The results show that the flow patterns around the holes are entirely different with different numbers of holes and it significantly affects the local heat transfer, and two baffles provide greater heat transfer performances than a single baffle

PONGJET PROMVONGE[4]conducted The research work to assess turbulent forced convection heat transfer and friction loss behaviors for airflow through a channel fitted with a multiple 60° V-baffle turbulator. Measurements have been carried out for the channel of aspect ratio and height with three different baffle blockage ratios, and three baffle pitch spacing ratios, while the transverse pitch of the V-baffle is set to 2H and kept constant. The air flow rate is in terms of Reynolds numbers based on the inlet hydraulic diameter of the test channel ranging from 5000 to 25,000. The experimental results show that the V-baffle provides the drastic increase in Nusselt number, friction factor and thermal enhancement factor values over the smooth wall channel due to better flow mixing from the formation of secondary flows induced by vortex flows generated by the V-baffle. In addition, substantial increases in Nusselt number and friction factor values are found for the rise in blockage ratio and/or for the decrease in pitch ratio values. Assessing thermal performance of the V-baffled channel, the use of the V-baffle with PR=1 and e/H=0.10 leads to maximum thermal enhancement factor of about 1.87 at lower Reynolds number.

B.K.P. ARY , M.S. LEE , S.W. AHN , D.H. LEE D [5] investigates The effect of a number of inclined perforated baffles on the flow patterns and heat transfer in the rectangular channel with different types of baffles is numerically and experimentally checked out. Reynolds numbers are varied between 23,000 and 57,000. The SST k−ω turbulence model is used in the method to predict turbulent flow. The baffles have the width of 19.8 cm, the square diamond type hole having one side length of 2.55 cm, and the inclination angle of 5°. The results show that the flow patterns around the holes are entirely different with different numbers of holes and it significantly affects the local heat transfer, and two baffles provide greater heat transfer performances than a single baffle.

K. YONGSIRI , P.EIAMSA-ARD , K.WONGCHAREE , S.EIAMSA-ARD [6] presents the results of numerical study of turbulent flow and heat transfer in a channel with inclined detached-ribs . The computations based on the finite volume method, and the SIMPLE algorithm has been implemented. The study encompasses the Reynolds number (based on the hydraulic diameter of a channel) range from 4000 to 24,000. The heat transfer, pressure loss and thermal performance of the inclined detached-ribs with different attack angles(θ) of 0 , 15, 30 , 45, 60, 75, 105, 120, 135, 150and 165 are examined and compared with those of the typical transverse attached rib with θ of 90o. The computational results reveal that, at high reynolds number, the inclined ribs with θ¼60o and 120o yield comparable heat transfer rates and thermal performance factors which are higher than those given by the ones with other angles. On the other hand, at low Reynolds number, the effect of rib attack angle is insignificant.

V. CONCLUSION

This paper presents experimental results for heat transfer in a rectangular channel with two inclined baffles.

A constant heat flux is applied from the top surface of the channel, while other surfaces are maintained at adiabatic condition. The flow Reynolds number is varied between 12,000 and 41,000, and the baffle locations and orientations are varied to obtain a wide range of results. The heat transfer and friction factor results are presented in non-dimensional ratios to minimize the Reynolds number dependency. Main conclusions emerging from this study are as follows:

- The local Nusselt number ratio with two inclined baffles significantly depends on the arrangement (orientation, perforation, and position of the baffles) used. Two inclined baffles augment the local heat transfer coefficient for a longer region of interest.
- The overall heat transfer coefficient is much higher with two inclined baffles than that with a single baffle placed in the same channel. The average Nusselt number can be as high as 5.0 times the average Nusselt number of a smooth channel.
- Localized high heat flux zones can be effectively cooled with properly designed perforated baffles in those regions.
- The local Nusselt number ratio is not a strong function of flow Reynolds number. However, in a particular arrangement the friction factor ratio increases with increase in the flow Reynolds number
- For two inclined baffle cases, the frictional head loss is much higher than that of a single baffle arrangement. Moreover, in two baffle cases the friction factor ratio is larger if the second baffle is attached to the bottom plate instead of the top heated surface.

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