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Experimental study of enhancement of heat transfer and pressure drop in a solar air channel with discretized broken V-pattern baffle

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ABSTRACT

This article presents an experimental study on heat transfer and friction characteristics of solar air channel fitted with discretized broken V-pattern baffle on the heated plate. The effect of geometrical parameters, predominantly the gap width and gap location has been investigated. The roughened baffle air channel has a width to height ratio, W/H of 10. The relative baffle gap distance, D_d/L_v and relative baffle gap width, g_w/H_b has been varied from 0.26 to 0.83 and 0.5–1.5, respectively. Experiments have been carried out for the range of Reynolds number, Re from 3000 to 21,000 with the relative baffle height, H_b/H range of 0.25–0.80, relative baffle pitch, P_b/H range of 0.5–2.5; and angle of attack, α_a range of 30°–70°. The optimal values of geometrical parameters of roughness have been obtained and discussed. For Nu_{rs} the greatest enhancement of the order of 4.47 times of the corresponding data of the without channel has been obtained. The absolute highest data of thermal hydraulic performance parameter has been found to be greater corresponding to D_d/L_v of 0.67, g_w/H_b of 1.0, H_b/H of 0.50, P_b/H of 1.5, and α_a of 60°. The maximum value of the thermal hydraulic performance parameter was found to be 3.14 for the range of parameters investigated.

1. Introduction

The efficiency of compact heat exchangers can be improved by modifying the boundary layer developed on the heated surface. One of the well-known approach of modifying the boundary layer is to break the laminar viscous sub-layer formed on the heat transfer surface by creating rough surface in the form of transverse baffle, angled baffle, V-baffle and perforated baffle etc. Air channel is one of the simplest and extensively used types of heat exchanger in which heat energy is being exchanged between heated wall and air streaming through the system. The major constraint of air channel use is low overall thermal performance due to low heat transfer rate between heated wall and air [1–4]. In order to attain higher thermal performance it is beneficial that the stream at the heat transfer wall should be made turbulent. The baffle roughness has been used extensively for the augmentation of forced convective heat transfer coefficient of air channels. Use of baffle roughness seems to be a useful proposition for improving the local Nu_{rs} [5–8]. For detailed descriptions of some experimental investigations on air channel with transverse baffle, inclined baffle, delta baffle, diamond shaped baffle, V-type baffle etc.

Karwa and Maheshwari [9] experimentally study Nu_{rs} and f_{rs} in a SAC with transverse fully perforated baffles and half perforated baffles attached to one of the broad wall. They reported that for fully perforated baffle the improvement in Nu_{rs} is 79–169% and 133–274% in case of half perforated baffles. Ozgen et al. [10] reported the thermal performance in a SAC with baffles fitted to the heated wall. Bopche and Tandale [11] reported the wholly developed stream in a roughened SAC with U-shaped pattern baffles. Eiamsa-ard et al. [12] investigated the heat transfer improvement in a SAC with winglet delta twisted tape baffles with different β_O and H_b/H. Their studies shows that Nu_{rs} and f_{rs} data with winglet delta twisted tape were superier as compared to without winglet delta twisted tape.

Promvonge et al. [13] mathematically examined the performance of Nu_{rs} and f_{rs} in square channel attached with 45° inclined baffles with a Re ranging from 100 to 1200. They informed that for the 45° baffle with $H_b/H = 0.4$ and $Re = 1200$, Nu_{rs} is superior to that of 90° baffle. Promovong [14] experimentally investigated the turbulent forced convection Nu_{rs} and f_{rs} loss behaviour in a high W/H channel attached with 60° V- shaped baffles. Akpinar et al. [15] experimentally investigate the performance analysis of four types

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Nomenclature

A_p	Surface area of heated plate, m^2
A_o	Area of orifice, m^2
A_f	Area of flow, m^2
C_{do}	Coefficient of discharge
C_p	Specific heat of air, $J/kg\,K$
D_d	Gap or broken distance, m
D_{hd}	Hydraulic diameter of channel, m
f	Friction factor
f_{rs}	Friction factor of roughened baffle
f_{ss}	Friction factor without baffle channel
g_w	Gap or discrete width, m
h_t	Convective heat transfer coefficient, W/m^2K
H	Height of channel, m
H_b	Height of baffle, m
g_w/H_b	Relative gap width
H_b/H	Relative baffle height
K_a	Thermal Conductivity of air, W/mK
L_t	Length of test section, m
L_v	Length of V-type baffle, m
D_d/L_v	Relative baffle gap distance
m_a	Mass stream rate of air, kg/s
Nu	Nusselt number
Nu_{rs}	Nusselt number of baffle channel
Nu_s	Nusselt number of channel without baffle
P_b	Pitch of baffle channel, m
P_b/H	Relative pitch ratio
$(\Delta_p)_d$	Pressure drop across test section, Pa
$(\Delta_p)_o$	Pressure drop across orifice plate, Pa
Q_u	Useful heat gain, W
Re	Reynolds number
T_f	Mean bulk air temperature, K
T_i	Inlet temperature of air, K
T_o	Outlet temperature of air, K
T_p	Plate temperature of air, K
U	Mean air velocity, m/s
V	Velocity of air, m/s
W	Width of channel, m
SAH	Solar air heater
SAC	Solar air channel

Greek symbols

α_a	Angle of attack,°
β	Ratio of orifice meter to pipe diameter
ρ_a	Density of air, kg/m^3
ν	Kinematic viscosity of air, m^2/s
η_p	Thermo hydraulic performance

of SAH with different obstacles and without obstacle. They reported that efficiency of SAH depends on the surface geometry of collectors, solar radiation of air stream line. Chompookham et al. [16] experimentally studied the effect of winglet vortex type generators on the Nu_{rs} and f_{rs} behaviours for a turbulent stream. Bekele and Mishra [17] carried out the experimental studied of the turbulent air stream and heat transfer characteristics of SAC with delta shaped obstacle attached to the upper wall of a channel. Khanoknaiyakarn [18] carried out an experiment to study Nu_{rs} and f_{rs} by using V-pattern baffles on a broad heated wall of a large W/H channel. The effects of the baffles on Nu_{rs} and f_{rs} were investigated. Sriromreun et al. [19] reported experimental predictions of the Nu_{rs} and f_{rs} for a SAC with Z-shaped baffles. Their experiments were performed by controlling the air stream rate to attain Re values in the range of 4400 to 20,400. Thianpong et al. [20] reported the experimental studies of the collector performance of a SAC with twisted rings type baffles.

Zhou and Ye [21] carried out the experimental studied of the turbulent air stream and heat transfer characteristics of SAC with delta winglet vortex generator baffles attached to the upper surface of a channel. Chamoli and Thakur [22] conducted an indoor experimental investigation to study Nu_{rs} and f_{rs} data of air passing through an air channel that was roughened by V-shaped perforated baffles. Bayrak et al. [23] studied the performance valuation of porous baffles introduced SAC by energy and energy method. They reported that the maximum collector efficiency and air temperature increase are attained by SAC with a thickness of 6 mm and m_a of 0.025 kg/s while the lowermost data are obtained for the SAC with non-baffle collectors with m_a of 0.016 kg/s. Tamna et al. [24] investigated the effect of multiple V-baffle vortex generators to improve Nu_{rs} in a channel fitted with 45° BVG with Re ranging from 4000 to 21000, $H_{\boldsymbol{b}}/H = 0.25$, $P_b/H = 0.5$, 1 and 2 and α_a equal to 45° respectively.

Alam et al. [25] experimentally investigated the effect of H_b/H of 0.4–1.0, P_b/H of 4–12, β_O of 5–25%, α_a of 60° and Re varies from 2000 to 20,000 on V-shaped perforated blocks SAC with W/H of 10. They observed that average improvement in Nu_{rs} for perforated V-shaped blockage is 33% higher over solid blockages, f_{rs} of perforated blockage gets reduced by 32% of the value as compared to solid blockage. Skullong et al. [26] carried out an experimental study on the turbulent flow and heat transfer characteristics in a SAC attached baffles with combined groove baffles. Shin and Kwak [27] studied the effect of the perforation shape for a blockage wall on the Nu_{rs} in a stream passage. It was observed that a blockage surface with wider perforation provided a more uniform Nu_{rs} and greater thermal performance factor. plate. Table 1 summarizes the experimental investigations of some important rib arrangements investigated by the investigators.

Literature review shows that, the transverse baffle shape improve the heat transfer rate by stream separation and creation of vortices on the upward and downward of the baffles and reattachment of stream in inter-baffle spaces. Angling of transverse baffle further enhances the heat transfer on account the movement of vortices along the baffle wall and creation of a secondary stream cell close to the leading end, which outcome in local wall turbulence. V- type baffle of an extended angled baffle benefits in the type of two secondary stream jets as compared to single in case of an angled baffle resulting in still superior heat transfer rate. Making a broken in the baffle is found to improve the heat transfer by disturb the secondary stream and produce advanced level of turbulence in the fluid downward of the baffles. It is hypothesized that discretized broken V-pattern baffle will raise heat transfer rate compared to without broken V-type baffle.

2. Experimental details

2.1. Experimental set-up

To study the outcome of discretized broken V-pattern baffle turbulent promoter on the Nu_{rs} and f_{rs} of air stream an experimental setup was intended and made-up accordance with guidelines suggested in ASHRAE standard [28]. A schematic illustration