Heat Transfer Augmentation By Usig Flag Vortex Generator

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Abstract- *The use of flexible plates or "flags" as vortex Creators inside a duct was successfully demonstrated as an one more heat transfer enhancement method. There is a need to conduct further investigations on this technique to fully establish its thermal characteristics. A review of existing literature revealed that the abundance of investigations concerning the dynamics of flags was not complemented by the existing reports on the thermal characteristics of flag vortex generators. The Maximum of studies are Analytical in nature, the need to conduct experimental Study. The same can be said for the thermal performance of flag vortex generators. There are no intensive and extensive investigations on the thermal characteristics of flags vortex generator.*

CFD simulation of rigid flag significantly improved the thermal efficiency than smooth plate. The effects of channel height, and Reynolds number on the thermal efficiency will observe, and an optimal parameter set will be used. Experimental heat transfer over a flat plate and with Flag as vortex generated will be conducted.

Keywords- Flag, Heat Transfer, Vortex Generator.

I. INTRODUCTION

The various techniques are used to enhance the rate of heat transfer over surface of plate. It may be passive or active technique. The significant pressure drags produced by the rib or pin fin protrusion into the flow. Heat transfer inside flow inside the duct can be enhanced by using passive surface modifications such as rib tabulators, protrusions, pin fins, Extended Surfaces and dimples.

This heat transfer improvement methods have practical application for internal cooling of turbine aerofoils, combustion chambers liners and electronics cooling devices, biomedical devices and heat exchangers. The heat transfer can be increased by the following different Augmentation Techniques. They are broadly classified into three different categories:

(i) Passive Techniques
(ii) Active Techniques
(iii) Compound Techniques.

1.1 Vortex heat transfer enhancement technique:

Each Flags acts as a "Vortex Generator" which provides an intensive and stable heat and mass transfer between the surface and gaseous heating/cooling media. Taking advantages of VHTE, as a) higher heat transfer coefficient b) negligible pressure drop penalty c) potential from fouling rate reduction d) simplicity in design and fabrication e) compactness and/or lower cost.

This method is moreuseful in heat transfer enhancement in convective passages for industrial boilers, process heaters and furnaces and heat exchangers variety for other industries like automotive (radiators, oil coolers etc.), heat treating (recuperates etc.), power electronics (convective coolers etc.), aerospace, military, food processors etc.

1.2 Problem Statement

Experimental Investigation of Heat Transfer Enhancement with Inline and Staggered Flag as Vortex Generator and need to compare with Flat Plate.

1.3 Objectives

(i) Investigation of Heat transfer enhancement in Flag as Vortex Generator.
(ii) Pressure drop estimation in Flag Vortex Generator.
(iii) To enhance the heat transfer augmentation with minimum pressure,drop.
(iv) Thermal Performance enhancement analysis in Flag Vortex Generator.
(v) To get experimental results and CFD results for align arrangement of inline and staggered flags comparing with smooth flat plate.

(vi) Experimentation of smooth flat plate, inline flags and staggered flags are carried out for air velocity ranges from 0.5m/s to 2.5m/s.

(vii) Will propose best geometry and best arrangement which gives maximum Thermal Performance.

1.4 FLOW PARAMETERS

Reynold’s Number:

The Reynolds number associated with the flow can be calculated by using following mathematical equation.

$$Re = \frac{\rho V\,Dh}{\mu}$$ ……. …….. (1)

Where, ρ is the density of the fluid in Kg/m3
V is the velocity of the fluid in _m/s
Dh is hydraulic diameter in mm
μ is the viscosity of the fluid in Ns/ m

The hydraulic diameter Dh is calculated by using mathematical relation,

Dh=2(W*H)/(W+H) ……. ……..(2)

Where, W= width of duct and H = height of Duct.

Pressure drop penalty is calculated by taking the ratio of Pressure drop of modified flag i.e. inline flags and staggeredflags to Pressure drop of smooth flat plate.

$$E_{\Delta p} = \frac{\Delta P_{modified}}{\Delta P_{smooth}}$$ …… ………….. (3)

1.5 Geometric Parameters

Test Channel:
The material for test channel is Aluminum.

Table 1. Test section and channel Dimensions.

Sr. No.	Parameter	Dimensions
1	Length of test channel (L)	150mm
2	Width at test channel (W)	150mm
3	Thickness of test channel (t)	15mm
4	Length of duct	1m
5	Height of Duct (h)	100mm

1.6 Calculation Steps

1. Heat absorbed by air: Q = mcp ΔT …… (4)
Where, m is mass flow rate of air
cp is heat carrying capacity rate of air
ΔT is change in temperature of air (To- Ti)

2. Heat transfer by convection Q= hA ΔT …….. (5)
Where, A is heat transfer coefficient of air
A is surface area of test plate
ΔT is change in temperature of (Tw-Tf)

3. Nu= hD/Kf …... (6)
Where, Kf is thermal conductivity of air

4 Enhancement ratio = NuVG / Nuflat …(7)

5 Performance Enhancement Factor =
= (NuVG / Nuflat) / (ΔPVG / ΔPflat)1/3 … (8)

II. LITERATURE REVIEW

Ralph Kristoffer et.al. [1]- The use of flexible plates or “flags” as vortex generators inside a channel was successfully demonstrated as an alternative heat transfer enhancement technique. This paper aims to present a brief review of flag vortex generators for thermal enhancement. Although flag dynamics is widely reported, the review reveals that this heat transfer technique is not widely explored, specifically on the heat transfer performance of flags. Extensive and intensive experimental results are lacking to validate numerical and theoretical predictions. This paper further provides a non-exhaustive list of existing gaps, challenges, and potential research areas in using flags as vortex generators for thermal enhancement, which aims to guide future research directions in this thermal fluid- structure problem. There is a need to conduct further investigations on this technique to fully establish its thermal characteristics. A review of existing literature revealed that the abundance of investigations concerning the dynamics of flags was not complemented by the existing reports on the thermal characteristics of flag vortex generators. Specifically, experimental studies on flag dynamics in confinements are not widely reported. The maximum of study are numerical in nature, essential to conduct experimental validations.\The list of existing gaps, challenges and potential research areas are using flags as vortex generators for thermal enhancement aims to guide future research works in the thermal-fluid-structure problem (2017).

Jae Bok Lee et.al. [2]- A two flexible flags clamped vertically inside a heated channel was numerically modeled to investigate the dynamics of the flexible flags and their effects on heat transfer increments. The penalty immersed boundary method was used to analyze the fluid–structure–thermal interaction between the surrounding fluid and the flexible flags. In the flapping mode, vortices shed from flexible flags merged and increased in values . The combined vertical structures swept out the thermal boundary layer and enhanced thermal mixing In the fluid near the heated wall and the channel core flow.

Compared torigid flags, the flexible flagssignificantly improve the thermal efficiency. The flexible flags with the optimal parameter set resulted in an increase up to 185% in the net heat flux and 106% in the thermal efficiency factor, compared to the baseline flow. The correlation between the vorticity and the temperature field was examined in detail using the dynamic mode decomposition (DMD) method (2017).

Jae Bok Lee et.al. [3]- Two flexible flags clamped in a heated channel were numerically modeled to investigate the dynamics of the flexible flags and their effects on heat transfer enhancement.The FAC generated a reverse karman vortex street that encouraged a greater thermal mixing as compared to the vertical structuresgenerated by the flags in a symmetric configuration (FSC). The effects of the gap distance between the FAC (G/L) and the ratio of the channel height to the flag length (H/L) on the thermal enhancement were characterized to identify the parameters that optimized the thermal efficiency. The presence of the FAC with the optimal parameters increased convective heat transfer by 207% and the thermal efficiency factor by 135% compared to the baseline (open channel) flow. The thermal efficiency factor obtained in the present study was compared with that obtained in the previous studies (2018).

Emmanuel Virot et.al. [4]- Unsteady fluid forces are measured at the flutter and during the post-critical flutter of flags placed in a wind tunnel, focusing on the drag force and the moment around the flagpole. The evolution of these forces during flutter mode changes , induced by varying either the mass ratio or the wind velocity, is discussed by using additional high- speed imaging. For sufficiently high wind velocities, we have shown that the loss of periodicity is correlated with a strong increase in unsteady fluid forces, leading ultimately to a tear of the flag (2013).

Zheng Li et.al. [5]- Paper presents a 2Dnumerical study of a novel flapping vortex generator mounted on a heatsink fin for airside heat transfer enhancement. The new vortex generator is made with a thin elastic sheet bonded to the inner wall of the heatsink channel with an inclined angle. Our investigations are focused on the effects of the Young’s Modulus of the vortex generator on the oscillations of the elastic sheet, vorticity fields, and heat transfer performance. Results are compared with the heat transfer performances of conventional rigid Flags at two different flow velocities (Reynolds number’s). The developed flapping vortex generator can improve the average Nusselt number by 200% compared with a smooth channel with the same Reynolds number. Modal analysis is performed with transient temperature and vorticity results using dynamic modal decomposition where it is found that a steady modal behavior directly influences the thermal performance of the system. .more discrete patterns near the boundaries of the steady mode in the vorticity field can enhance the internal convective heat transfer rate (2018).

The present study focuses on the heat transfer enhancement using Flag as a vortex generator. The goal of the present research is to compare, experimentally and numerically, the heat transfer characteristics and flow patterns for the smooth plate and using flags. In the present work, for both inline arrangement of flags andstaggered arrangement of flags.

III. PROBLEM STATEMENT

From literature survey we can say that very less work on flag as vortex generator so it is need to investigate detailed thermal performance and need to compare with smooth plate. So the problem statement is:“Experimental Investigation of Heat Transfer Enhancement with Inline and Staggered Flag as Vortex Generator”.

IV. EXPERIMENTAL SETUP

An insulated duct with the specified dimension of 150 mm width and a height of 100 mm, length 1000mm made of glass are used for this experimental study. The smooth flat plate specimen made up of aluminum material with the width 150mm, height 150mm and having a thickness of 10 mm was placed inside the duct.

The location of the specimen inside the duct were ensured such that the flow was hydro-dynamically fully developed condition to ensure prior to the plate. Blower is used to supply cold air into duct or over the flat plate.

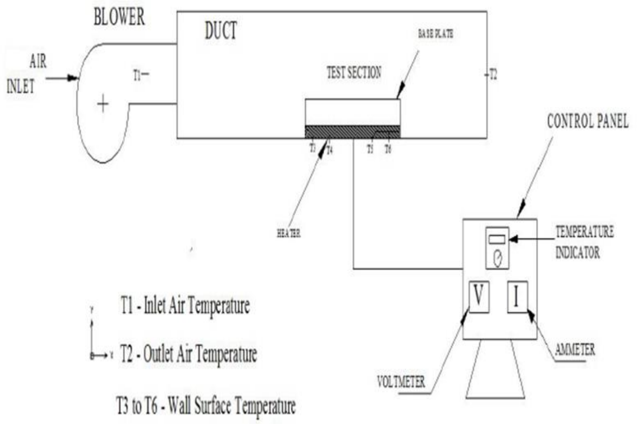

Fig.1: Schematic of Experimental Set up.

Fig.2: Experimental set up

The electric heater with a capacity of 300 W had been placed beneath the aluminum plate impart thermal energy to the air flow along with flat plate. As a result of this, the temperature was increased and as per the requirement of configuration, the heat input was controlled. There is a temperature sensor along with digital temperature indicator to measure inlet and outlet temperature of air. The temperature sensor (TS-01) was providing to measure inlet air flow temperature and temperature sensor (TS-02) was providing to measure outlet air flow temperature. The temperature sensor (TS-03 toTS06) was providing to measure surface temperature of plate. Anemometer is used to measure outlet velocity of air flow.

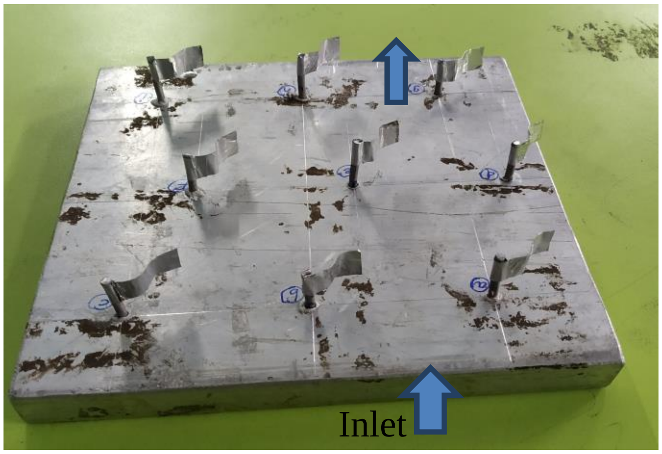

Fig.3: Staggered Flag Arrangement with Test Section

V. CFDRESULTS

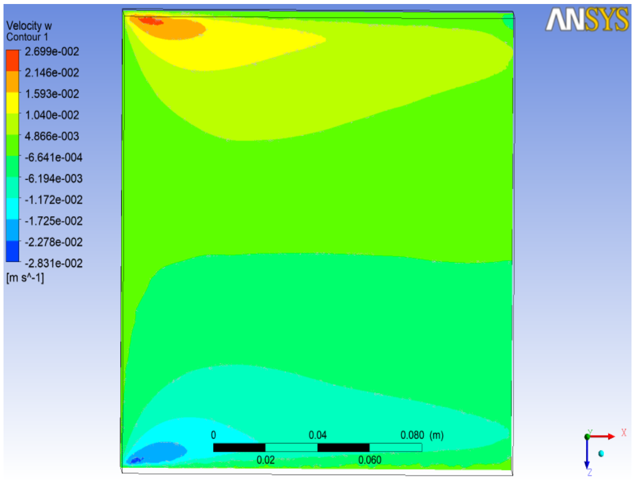

Fig4. Velocity_Fluent_Without Flag

Fig. 4 shows the velocity profile for smooth plate and fig.5, fig.6, fig.7 shows the velocity profiles for the flags with 0 Deg., 45 Deg. And 90 Deg. angle.

Fig.8 shows the velocity profile for flag with staggered arrangement at 45 Deg.

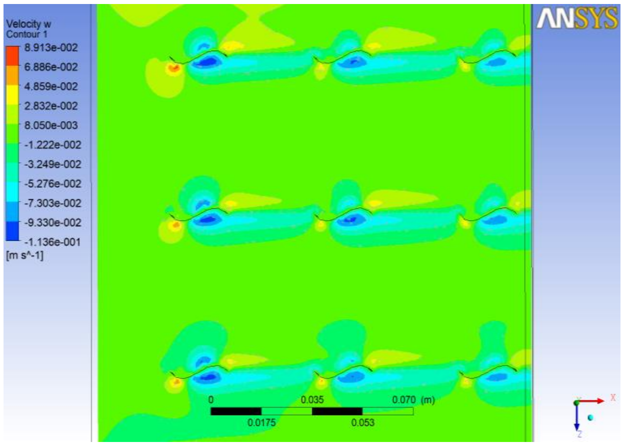

Fig 5. Velocity_Fluent_With Flags at 0°

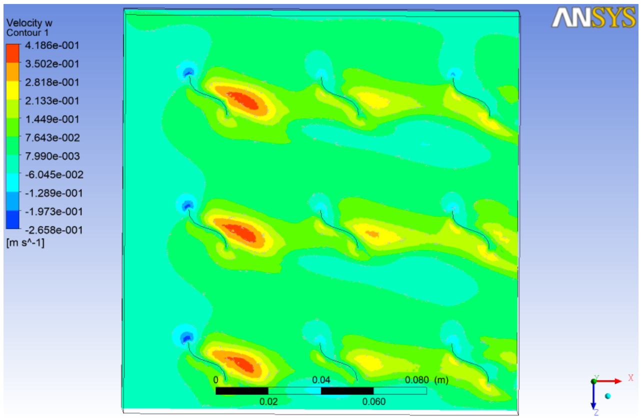

Fig 6. Velocity_Fluent_With Flag at 45°

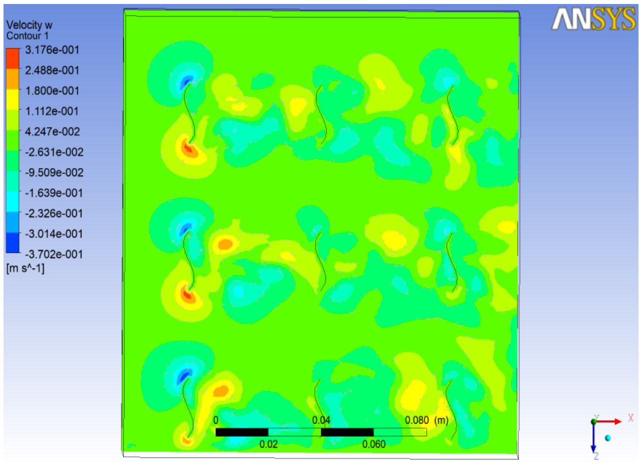

Fig7. Velocity_Fluent_With Flag at 90°

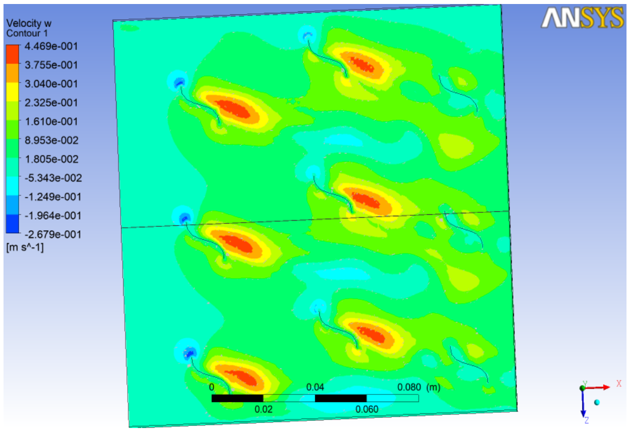

Fig8. Velocity_Fluent_With Staggered Flag at 45°

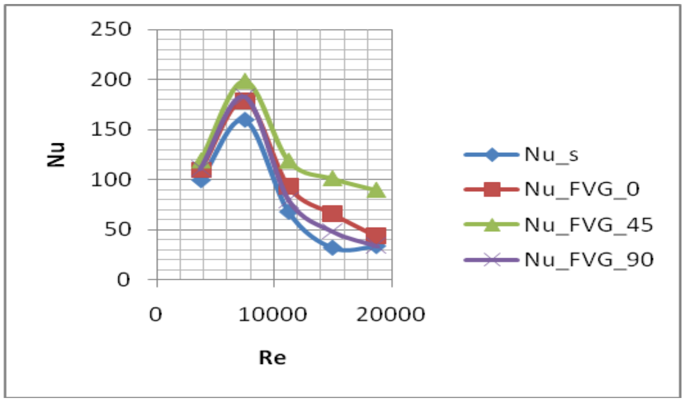

Chart No.1. Re Vs Nu for CFD Results

Pressure drops

Table 2. Pressure Drop for Smooth plate and With Flag at Different angles.

Re	ΔP_smooth	ΔP_FVG_0°	ΔP_FVG_45°	ΔP_FVG_90°
3750	3.24E-02	0.135325	0.0845761	0.122803
7500	1.75E-01	0.135325	0.299071	0.474965
11250	2.94E-01	0.256045	0.666726	0.970787
15000	3.13E-01	0.398072	1.13259	1.62487
18750	4.27E-01	0.555743	1.69534	2.29769

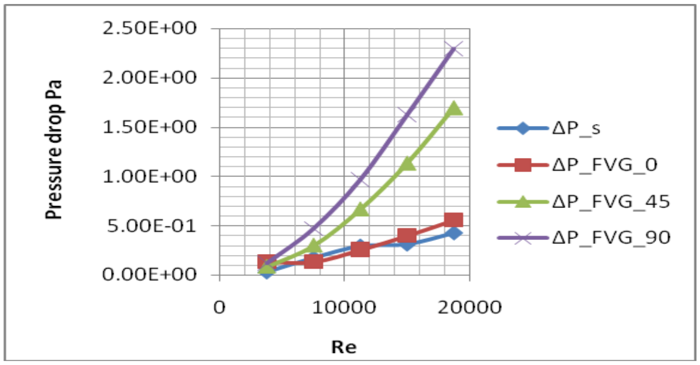

Chart No.2:Reynolds's Number Vs ΔP

Maximum pressure drop occurs at Flag with 90°.

W velocity

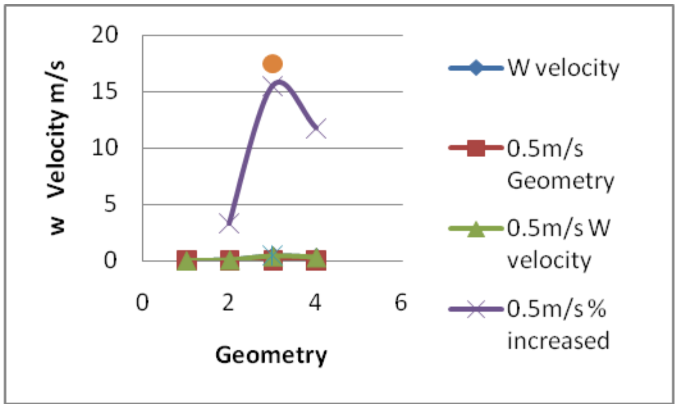

Chart No. 3 : Wvelocity for different Geometry

Maximum Wvelocity occurs at Staggered Flag with 45°.

VI. EXPERIMENTAL RESULTS

Table 3. Experimental Re Vs Nu for Smooth Plate, Inline and Staggered Flag Geometry

Re	Nu_s	Nu_inline	Nu_stag
3778.378	182.2296	234.0125	271.8897
7556.757	428.41	553.8462	595.9086
11335.14	720.5077	840.1742	1023.879
15113.51	906.9328	1117.221	1372.396
18891.89	1044.214	1265.035	1556.652

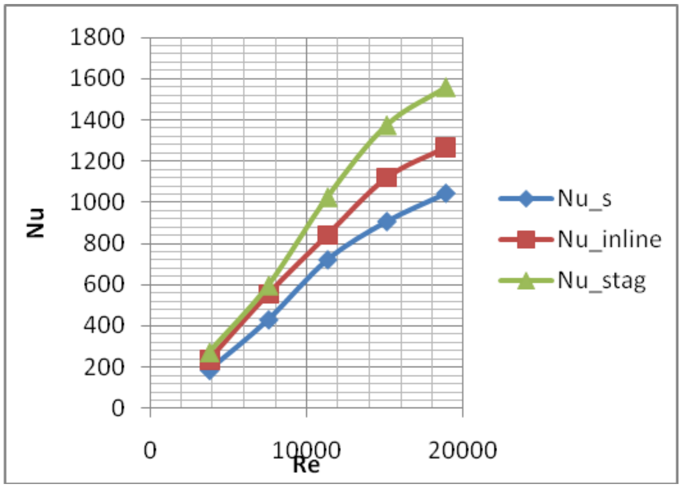

Chart No.4:Reynolds's NumberVs Nusselt Number

From table 3 and chart 4 the heat transfer enhancement of inlineflag vortex generator is gives higher Nu varies from 16% to 28%, While the staggered flag vortex generator gives 39% to 51% more heat transfer than flat plate.Comparing with staggered and inline flags, the staggered flag gives 7% to 23% more heat transfer enhancement than inline flag as vortex generator.

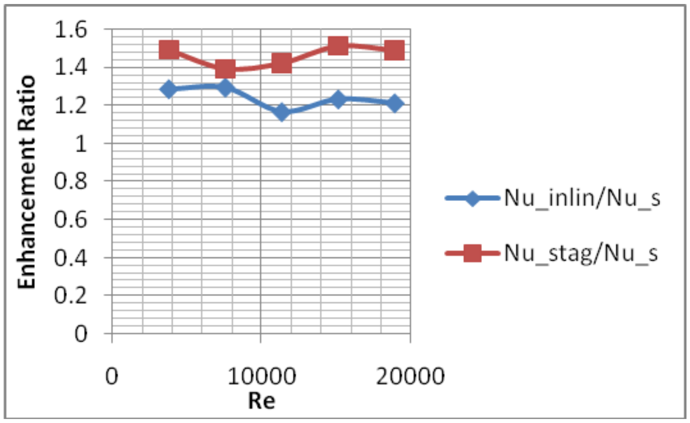

Chart No.5: Reynolds's Number Vs Enhancement Ratio

From chart 5. it shows that the enhancement ratio of staggered is varies from 1.3 to 1.5 while inline is varies from 1.1 to 1.4. The percentage enhancement of staggered is from 7 to 23 % than the inline arrangement.

VII. CONCLUSION

This paper work shows that the Staggered Flag Arrangement with using "Flags" is leads to greater heat transfer enhancement. The main purpose of extended surface to increase the heat transfer rate. The advantages of the Flags are fluid mixing is more and boundary layer separation occurs in Channel which will help increase heat transfer Rate.

The Inline and Staggered Flags Arrangement give more heat transfer enhancement than the smooth Plate but the Staggered Arrangement is more effective than the Inline Flags Arrangement.

The heat transfer enhancement of inline flag vortex generator is gives higher Nu varies from 16% to 28%, While the staggered flag vortex generator gives 39% to 51% more heat transfer than flat plate.

Comparing with staggered and inline flags, the staggered flag gives 7% to 23% more heat transfer enhancement than inline flag as vortex generator.

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