Thermohydraulic performance of Curved Trapezoidal Winglet Vortex Generator using Sudden Expansion Channel

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Abstract – The goal of this study is to improve heat transfer in sudden expansion channels (SECs) at various angles of attack. The SEC's expansion ratio (ER) is given the value of 2:1. In every example, the angle of attack (β) of VG is adjusted by 15 degrees, ranging from 30 to 90 degrees. This study's findings are contrasted with those of a basic rectangular channel (SRC) using a vector gauge (VG). It is assumed that the flow in the range of Reynolds (Re) numbers under investigation is laminar, stable, and incompressible. The analysis reveals that VGs are more successful in boosting heat transfer against pressure decrease at all angles of attack in SEC than in SRC. In contrast to the friction factor, which remains unchanged at SEC aspect ratios except at higher angles of attack, the rate of heat transfer increases as SEC aspect ratios rise. On the other hand, the friction factor decreases when the VG angle of attack increases. The findings show that the combined influence of longitudinal vortex flow and flow separation is responsible for the increased heat transfer rate.

Key Words: Heat transfer, vortex generator, ramped expansion channel, ramp angle.

1.INTRODUCTION

Transferring thermal energy from one location to another is known as heat transfer. This is important in modern engineering because devices like gas turbine blades, heat exchangers, microelectronic circuit boards, axial and centrifugal compressor blades, combustors, and heat exchangers are used to change the flow of energy wherever it is needed. Every piece of machinery has a unique heat transfer procedure, so we must comprehend how each one operates. Vortex generators have been the subject of successful recent inventions, studies, and testing to improve the effect of heat transfer; these devices are currently in use, even in real-time. Vortex generators aid in delaying the fluid's divided laminar and turbulent flows. To reduce the impact of the pressure penalty caused by the vortex generator, experiments with sudden expansion channel flow have been conducted. When compared to constant area duct flow, the pressure penalty is lessened due to the vortex generators' minimization of the boundary layer.

1.1 Sudden expansion channel

Separated flows are unpredictable, which makes them difficult to comprehend. Different geometries, such as ribs, fences, bluff bodies with splitter plates, abruptly expanding pipelines, and cavities, have been used by researchers to better understand these instabilities and, to some extent, reduce the unpredictability. Because of its one fixed separation point, the sudden expansion ramped duct proved to be the most popular of all. The flow wake can be divided into three primary regions: the shear layer region, the separation bubble or recirculation zone, and the reattachment zone. These divisions are based on significant flow properties that have been examined by earlier researchers in rapid expansion geometries. The general characteristics of a sudden expansion flow result in the development of a thin boundary layer and an adverse pressure gradient, which cause an angular momentum in the flow. The turbulent structures inside the boundary layer merge as the flow continues downstream, increasing the size of the boundary layer. The layer region is the area where the border layer grows and evolves. Low-velocity recirculation is produced in the space between the shear layer and the nearby wall as a result of this flow. In the recirculation zone, a primary vortex is formed in the centre of the ramped shape, while a secondary vortex is formed next to the corner. The reattachment point is the point at which the shear layer eventually bends downward and impinges at a defined location due to the fluid's advantageous pressure gradient. The horizontal distance between the step and the reattachment point is known as the reattachment length. Together, these three areas make up the key components of a rapid expansion flow, which can be changed or manipulated to provide desired results including improved mixing qualities and decreased vibration, noise, and drag.

1.2 Vortex Generator

Vortex generators are basic structures resembling the fin's structure. The fundamental purpose of these aerodynamic gadgets is to keep the overflow over the surface to which they are attached. It is a tool that aids in lowering an aircraft's stall speed in aerodynamic terms. The lowest constant flying speed at which an aircraft can be controlled is known as the stall speed. In order to attain a safety margin between the airspeed and stall speed, vortex generators are tools that aid in lowering the stall speed. By increasing flow turbulence and decreasing the formation of boundary layers, the vortex generators improve heat transfer efficiency. The creation of boundary layers in a channel is lessened by the medium's highly turbulent flow. Based on their features and modes of operation, vortex generators can be categorized. They are active and passive. When generators draw power from external sources such as mechanical components, acoustic or electric fields, or surface vibration, they are called active vortex generators. With their special aerodynamic surface shape, passive vortex generators can produce rolling or longitudinal vertices without the need for outside power sources. Rectangle winglets (RW), rectangle winglet pairs (RWP), delta winglets (DW), and delta winglet pair (DWP) are the often-utilized forms. When the geometry is oriented perpendicular to the direction of flow, it is called a wing; when the vortex generators have different angles of attack, it is called a winglet. The impact of vortex generators in the trapezoidal form is being investigated by recent studies. for a static mixer with a high-efficiency vortex (HEV).

There are two different kinds of vortices produced by the vortex generated. We refer to these as longitudinal and

2. Methodology

Research using sound methodology yields discoveries that are sound scientifically. The comprehensive plan it offers makes the process simple, effective, and manageable. It also helps to steer researchers in the right direction. A poorly defined research technique makes it difficult to find reliable and accurate data, draw meaningful conclusions, and contribute to the body of knowledge.

Fig. 1

transverse vortices. While longitudinal vortices form when the produced vortices are in the direction of the medium's flow, transverse vortices act perpendicular to the flow direction. Because they function by first forming a boundary layer at the vortex generator and then causing vortices that cause a turbulent flow that prevents the formation of a boundary layer in the channel, longitudinal vortices have been found to be more effective than transverse vortices. Curved trapezoidal winglets (CTWVGs) are being used in the experiment to create secondary flows in a fully formed flow through a step flow duct that faces backward. In the duct, these DWVGs create longitudinal vortices. The impact of single-curved delta winglets has been studied extensively, and the results show that they improve the heat transmission effect. Our goal is to comprehend the flow properties and heat transmission with the double-curved delta winglet vortex generators (DC-DWVGs).

3. Design Calculation

Setting up an experiment is a crucial step in carrying out a study. The experiment involves designing the vortex generators and the sudden expansion ramping flow duct by consulting references from different journals and modifying their specifications according to the needs. The final output varies depending on the stability, capacity, performance, and durability of the materials utilized in the process.

3.1. Sudden Expansion channel dimensions

Comic Section

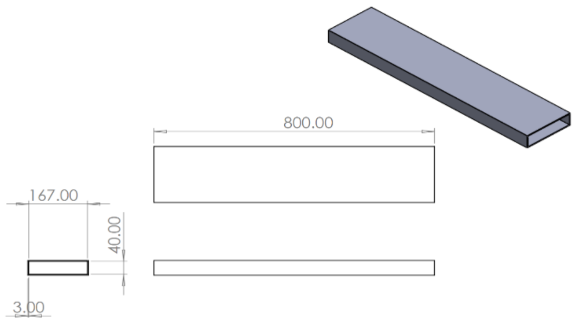

Fig. 2 (All dimensions are in mm)

Testing Section

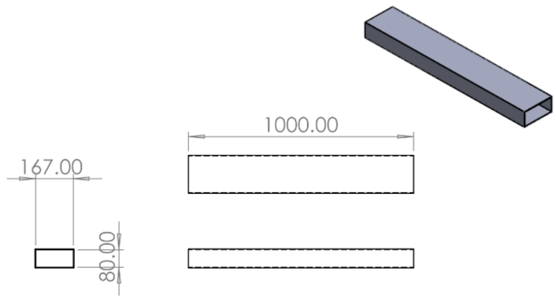

Fig.3 (All dimensions are in mm)

3.2. Trapezoidal Vortex Generator Dimensions

- Height = 27 mm
- Length = 45 mm
- Radius = 23 mm
- Thickness = 1mm
- Material = Curable Alumina

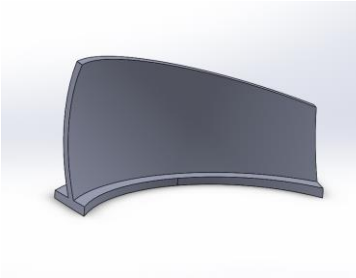

Fig. 4 SolidWorks Model of Curved Trapezoidal Winglet

Fig. 5 Curved Trapezoidal winglet vortex generators

4. Component Specification

S.No.	MATERIALS	DIMENSION
1	Copper Plate	1000 x 167 x 2.5 mm
2	Plexiglass(acrylic) Sheet	1800 × 167 × 3 mm
3	Thermocouple (T-type)	ø = 0.2mm (Accuracy = 0.02°C)
4	Nylon	1 kg
5	Rock Wool	200 Cubic Feet Per Minute
6	Heater (stainless steel)	1000mm × 200mm
7	Variac Controller	0-240 V (single phase)
8	Data Acquisition System	18 channels
9	Thermometer	Accuracy = ±0.02°C

Table. 1. Component Specification

5. Experimental Setup

The rock-wool insulation bed is positioned at the bottom of the test section, with the heater employed in between the copper plates. We utilize an air blower on the other side of the entrance to change the direction of the air flow. Variac controllers are used to regulate both the heater and the blower's voltage input. Plexi sheet is used to construct the test and comic sections, which are joined to form a channel that is enclosed on all sides except the input and outflow. We employ 18 "T-type" thermocouples, which are affixed to the copper plate's bottom in a direction parallel to the stream to measure the temperature of the plate. A data acquisition system (DAQ) is then used to measure the readings from these thermocouples and display the corresponding outputs. The mass flow rate of air at the comic section's input is measured with a vane anemometer. Pressure transducers are used at the channel's entrance and outflow to measure the pressure decrease.

Fig. 6. Setup

Fig.7.

6. Experimentation and Observation

In this experimentation, we position the Curved Trapezoidal Vortex Generator with the higher leading edge in both common flow up and common flow down configuration and observe their heat transmission capabilities by varying the velocity of the fluid for different attack angles of the vortex generator.

- **Common Flow Up (CFU) configuration of Curved Trapezoidal Vortex Generator – [All angle comparison]**

Friction Factor, $f = (2*\Delta P*D_h)/(\rho*V^2*L)$

Reynolds Number, $Re = (\rho*V*D_h)/\mu$

The relation shows that the friction factor decreases as the velocity of the fluid increases and the Reynolds number increases as the velocity of the fluid increases.

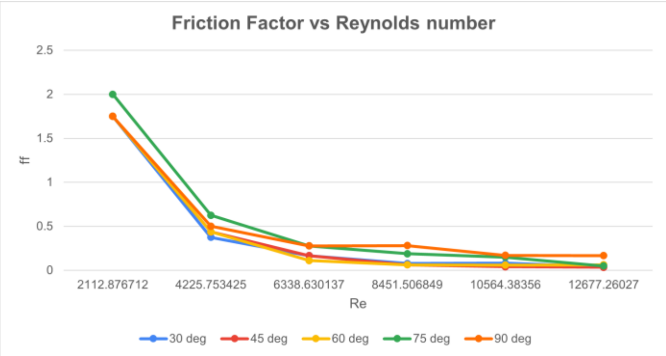

Fig. 8. Friction factor vs Reynolds Number

Nusselt number, $Nu = (h*D_h)/k$

Reynolds Number, $Re = (\rho*V*D_h)/\mu$

The Nusselt number is the function of Reynolds number raised to the certain power along with the Prandtl number.

Laminar External flow, Nu ≈ 0.664 * (Re^0.5) * (Pr^0.33)

Turbulent External flow, Nu ≈ 0.037 * (Re^0.8) * (Pr^0.3)

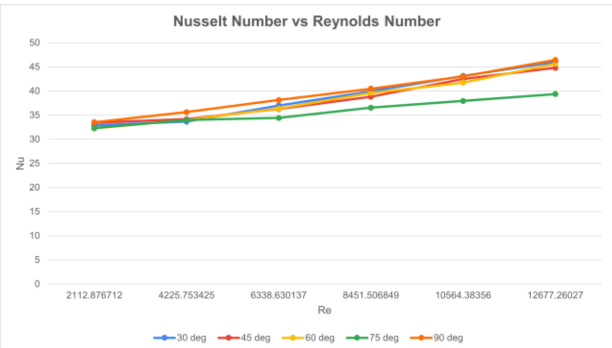

Fig. 9. Nusselt Number vs Reynolds number

Both the above graphs, **(Fig.8.) and (Fig.9.)** implies that the attack angle 90^0 shows the better thermohydraulic performance factor with greater heat transmission rate compared to all other attack angles being positioned in the common flow up configuration.

- **Common Flow Down (CFD) configuration of Curved Delta Vortex Generator – [All angle comparison]**

Analyzing the common flow down performance of the Curved Trapezoidal Vortex Generator in the ramped expansion channel resulted in the following outcomes.

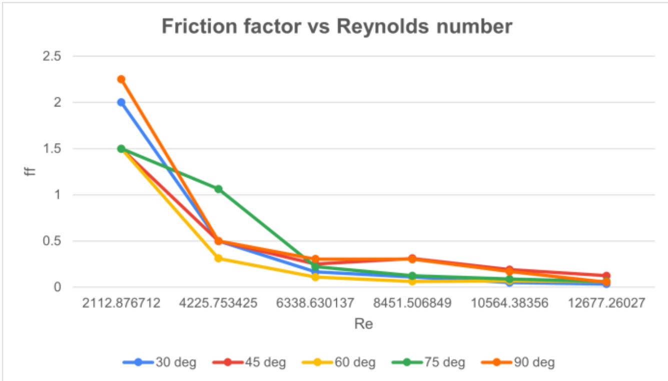

Fig. 10. Friction factor vs Reynolds Number

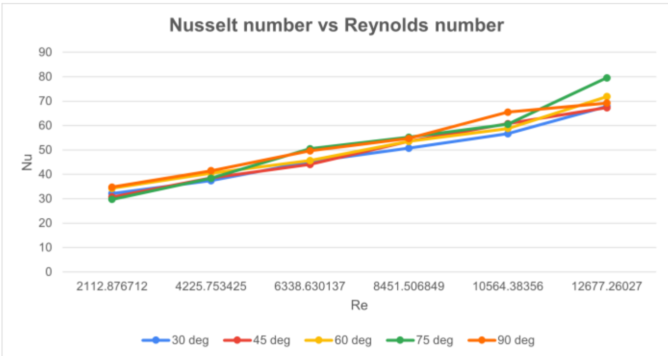

Fig. 11. Nusselt Number vs Reynolds Number

Both the above graphs, **(Fig.10.) and (Fig.11.)** imply that different attack angles show better thermohydraulic performance factors with greater heat transmission rates at different Reynolds numbers being positioned in the common flow-down configuration.

The same experiment is repeated with the lower leading edge and the graphs obtained are as follows :

- **Common Flow Up (CFU) configuration of Curved Trapezoidal Vortex Generator – [All angle comparison]**

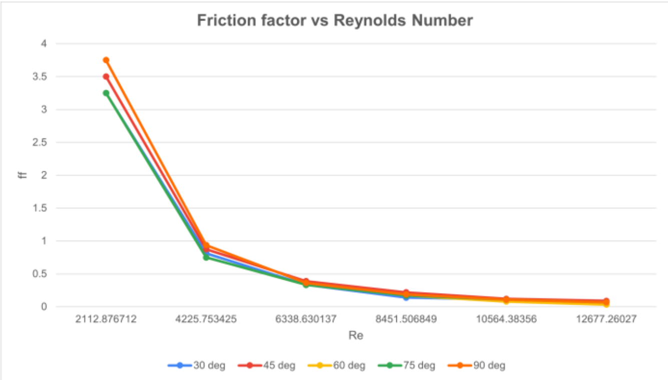

Fig. 12. Friction factor vs Reynolds Number

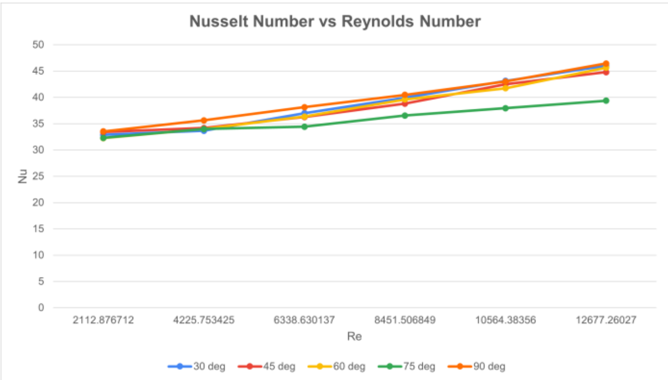

Fig. 13. Nusselt Number vs Reynolds Number

- **Common Flow Down (CFD) configuration of Curved Delta Vortex Generator – [All angle comparison]**

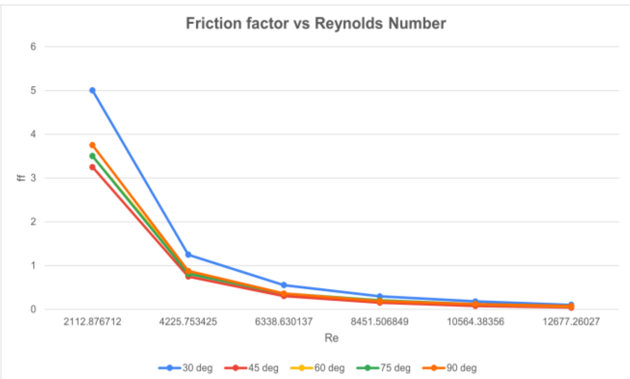

Fig. 14. Friction Factor vs Reynolds Number

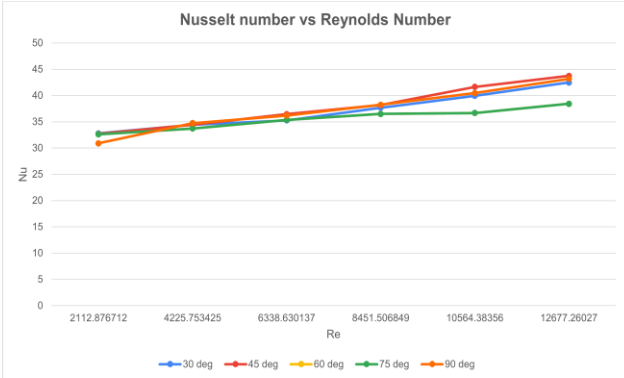

Fig. 15. Nusselt number vs Reynolds number

From the above graphs, **(Fig.12, 13, 14 and 15)** implies that the attack angle 90^0 shows the better thermohydraulic performance factor with greater heat transmission rate compared to all other attack angles being positioned in the common flow up and common flow down configuration.

7. CONCLUSION

Hydrothermal characteristics of the sudden expansion duct are thus analyzed. The heat transfer enhancement can be seen when the vortex generator is placed at 90 degrees in the flow direction, no matter what the configuration. The observed differences are significant and that plays an important role in further improvisations in sudden expansion ducts, ramped expansion, and other channels involved in heat transferring.

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