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Heat Transfer Characteristics of Trapezoidal Duct using Delta Wing Vortex Generators

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Abstract

This study experimentally examined the impact of delta wing Vortex Generators (VGs) on heat transfer within a trapezoidal duct using airflow. VGs were installed at varying angles of attack (β). Results revealed a significant enhancement in heat transfer coefficients compared to a smooth duct. The Nusselt Number (NU) consistently increased with Reynolds number (Re) for all configurations. However, a key finding was that VGs significantly increased Nu, even at identical mass flow rates, demonstrating the crucial role of vortex-induced turbulence in augmenting heat transfer. The ratio of Nu with VGs to that without (Nu/Nuo) increased with increasing Re. Notably, the highest Nu/Nuo values were observed at β = 300. Comparing experimental data to theoretical predictions showed a considerably higher Nu/NuD ratio at β = 300. Furthermore, the Stanton Number (St) and Thermal Performance Enhancement Factor (TEF) exhibited substantial improvements with VGs, with the

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highest values recorded at β = 300. These findings strongly suggest that strategically placed VGs can effectively enhance heat transfer within trapezoidal ducts, providing valuable insights for optimizing thermal performance in various engineering applications.

Major Findings: *This study demonstrated that incorporating delta wing Vortex Generators (VGs) significantly enhanced heat transfer within a trapezoidal duct compared to a smooth duct. The Nusselt number (Nu) increased with Reynolds Number (Re), and the presence of VGs further augmented Nu, even at constant mass flow rates, highlighting the crucial role of vortex-induced turbulence. The highest heat transfer enhancement was observed at a VG angle of attack (β) of 300 degrees.*

Keywords: Heat Transfer, Nusselt Number, Reynolds Number, Stanton Number, Trapezoidal Duct, Vortex Generators

1.0 Introduction

Vortex Generators (VGs) have been widely used in various engineering applications to enhance fluid flow and heat transfer characteristics. Among the different types of VGs, delta-wing VGs have gained significant attention due to their simple geometry and effective performance. These VGs create vortices that interact with the boundary layer, leading to increased mixing, reduced boundary layer thickness, and improved heat transfer.

Trapezoidal ducts are commonly employed in various industrial applications, including ventilation systems, heat exchangers, and gas turbine cooling systems. However, the flow within trapezoidal ducts can be complex due to the non-uniform velocity and pressure distributions. To enhance the flow and heat transfer characteristics of trapezoidal ducts, the integration of delta-wing VGs has been proposed.

While numerous studies have investigated the performance of VGs in various geometries, including rectangular and circular ducts, limited research has been conducted on the application of delta-wing VGs in trapezoidal ducts. A comprehensive experimental investigation is necessary to assess the impact of VGs on the flow and heat transfer performance of trapezoidal ducts.

This research aims to experimentally investigate the performance of trapezoidal ducts equipped with delta-wing VGs. By systematically varying the VG parameters such as angle of attack, height, and spacing, the optimal configuration for enhanced flow and heat transfer will be determined. The findings of this study will contribute to the optimization of trapezoidal duct designs and provide valuable insights for various engineering applications.

2.0 Review of Literature

Several experimental studies have been conducted to analyze the effects of delta wing VGs on heat transfer and flow characteristics in trapezoidal ducts. In one study, VGs at angles of 30°, 45°, and 60° were tested and found to produce substantial increases in the Nusselt number and friction factor over a smooth duct. Heat transfer rates were increased by 14% to 67% depending on the angle and Reynolds number[1]. Several comparative studies have been done for the various VG configurations in performance evaluation. For example, trapezoidal winglet-type VGs and rectangular winglet-type VGs in a solar air heater were compared on basis of thermal performance. The result showed better performance of TWVGs; among these, the modified perforated trapezoidal winglet VGs showed reduced pressure loss but retained high heat transfer coefficients[2]. Numerical simulations have been used to optimize the design and layout of VGs. A study using 3D numerical simulations reported that Curved Trapezoidal Winglet Pairs (CTWP) offered better thermos-hydraulic performance than traditional Trapezoidal Winglet Pairs (TWP) because of their streamlined configuration, which resulted in lower pressure drops[3,4]. Another study highlighted the need for optimizing the attack angle and spacing of VGs to achieve maximum heat transfer enhancement[5].

The geometric shape and arrangement of VGs have a considerable effect on the effectiveness of these devices. Different curved delta winglet VGs, concave and convex, have been proved to enhance heat transfer in various ways, with a concave type generally showing a better performance than the convex[6]. Delta winglet pairs arranged in a coiled jacket showed that particular configurations, like the common-flow-up, can significantly increase

heat transfer because of stronger vortices developed[7]. In conclusion, the delta wing VGs in trapezoidal ducts have been proven to significantly enhance heat transfer. Experimental and numerical studies have shown that optimizing the geometric parameters and arrangement of these VGs can lead to substantial improvements in thermal performance. These findings underscore the significant potential of delta wing VGs in enhancing the efficiency of heat exchangers and other thermal systems.

Recent research has demonstrated significant advancements in heat transfer enhancement through vortex generators, impingement jets, and twisted tape inserts. Numerical investigations by Yang *et al.*[8] and Min *et al.*[9] highlighted the effectiveness of common-flow-up configurations and longitudinal vortex generators in improving heat transfer efficiency by inducing secondary flows. Experimental studies by Wu *et al.*[10] and Akcayoglu[11] further validated these findings, demonstrating enhanced thermal performance in rectangular and delta-wing vortex generator configurations.

The impact of vortex generators on friction factors and turbulence intensities has been explored by Zangana[12] and Garg *et al*[13], who found that the inclusion of triangular ribs and winglet vortex generators significantly improved thermal performance. Similarly, Atole *et al.*[14] confirmed the effectiveness of rectangular wing vortex generators in triangular ducts, emphasizing their role in augmenting convective heat transfer.

Studies on natural and forced convection, such as those by Moukalled and Darwish[15] and Liu *et al.*[16], have provided insights into heat transfer behavior in complex geometries like trapezoidal cavities and ducts with impingement jets. Their findings indicated that controlled swirl flow and partitioned cavities could optimize heat transfer rates. Twisted tape inserts have also emerged as a promising technique for heat transfer enhancement. Liu *et al.*[16] investigated the effect of varying pitch in cut corrugated twisted tapes and reported increased turbulence and improved convective heat transfer performance. Collectively, these studies highlight the effectiveness of passive heat transfer enhancement techniques in optimizing thermal performance across various applications, reinforcing the importance of experimental and numerical investigations in advancing thermal management technologies.

Recent studies have demonstrated significant advancements in heat transfer enhancement, electronic cooling, and aerodynamic efficiency. Kurhade *et al.*[17] investigated the effect of wavy corrugated twisted tape inserts in double-pipe heat exchangers, revealing improved heat transfer rates due to enhanced turbulence. Similarly, Kurhade *et al.*[18] explored the impact of circular holes in twisted tape inserts, demonstrating notable improvements in forced convection heat transfer. Another study by Kurhade *et al.*[19] analyzed corrugated twisted tape inserts, further confirming their effectiveness in heat transfer augmentation.

In the field of electronic cooling, Kurhade *et al.*[20] performed a thermal performance analysis of electronic components on various substrate materials, highlighting the significance of substrate selection in regulating component temperatures. Furthermore, Kurhade *et al.*[21] provided a comprehensive review of cooling solutions for electronic devices operating in harsh conditions, identifying state-of-the-art methodologies for efficient thermal management. Additional research by Kurhade *et al.*[22] proposed an ANN-GA-based predictive placement strategy for IC chips to enhance thermal cooling efficiency, emphasizing the role of machine learning in thermal management. Wind turbine performance and aerodynamic efficiency have also been extensively studied. Kurhade *et al.*[23] conducted a wind rose analysis for temperature variation using sensor implantation techniques, offering insights into temperature distribution within wind turbines. Moreover, Kurhade *et al.*[24] optimized aerofoil design using CFD simulations and wind tunnel experiments, leading to improved aerodynamic performance and efficiency. Advanced numerical and experimental techniques have been employed in structural and mechanical analysis. Yadav *et al.*[25] investigated the effect of overlapping angles in arc-welded curved plates, demonstrating the relationship between weld geometry and mechanical strength. In another study, Yadav *et al.*[26] compared experimental and numerical investigations on mono-composite and metal leaf springs, revealing key mechanical behaviors under dynamic loading conditions.

The application of machine learning in heat transfer analysis has been explored by Kurhade *et al.*[27], who predicted heat transfer enhancement using fuzzy logic techniques in heat exchangers, highlighting the potential of AI-based models in engineering optimization. Additionally, Waware *et al.*[28] examined heat transfer enhancement in tubular heat exchangers using minijet

impingement, showcasing an innovative method for improving thermal efficiency.

The utilization of nanofluids in heat exchangers has also been a key research focus. Waware *et al.*[29] provided a comprehensive review of recent studies on nanofluid applications, emphasizing their potential in enhancing heat transfer performance. Similarly, Kurhade *et al.*[30] reviewed electronic cooling technologies in extreme environments, identifying challenges, advancements, and future prospects. The research on alternative fuels and emission control technologies has gained significant traction in recent years. Kurhade *et al.*[31] explored the performance and emission characteristics of Calophyllum inophyllum biodiesel blended with dimethyl carbonate, highlighting its potential for reducing harmful emissions in diesel engines. Similarly, Patil *et al.*[32] investigated the use of nanofluids in MQL grinding, demonstrating enhanced cooling efficiency and reduced wear, which can contribute to improved energy efficiency in machining operations.

Studies on welding parameters and material behavior have also provided valuable insights into mechanical performance improvements. Khot and Rao[33] examined the effects of quenching media on laser-welded TRIP steel, revealing its impact on mechanical strength and structural integrity. Additionally, Khot *et al.*[34] analyzed the influence of laser beam power and velocity on welding quality, emphasizing the need for process optimization in manufacturing applications. The role of machine learning in process optimization has been explored by Khot *et al.*[35], who applied predictive modeling techniques to forecast welding strength and deformation, thereby enhancing precision in structural engineering applications. Furthermore, Yadav *et al.*[36] examined the influence of TRIP steel plate thickness on the tensile strength of laser-welded joints, providing crucial insights into material behavior under varying stress conditions. In the domain of thermal management, Kirpekar *et al.*[37] conducted an experimental study on temperature rise inside vehicles with and without I-Cool materials, demonstrating significant improvements in heat dissipation. Their findings contribute to advancements in automotive thermal management systems, potentially enhancing passenger comfort and energy efficiency. Additionally, Suryawanshi *et al.*[38] explored the dynamic performance of five-phase induction motors controlled using fuzzy logic, underscoring the importance of intelligent control strategies in modern electric drive systems. Khot *et.al.*[39-41] and Yadav *et. al.*[42] explored a detailed discussion about laser process parameters and their effect on strength and deformation.

Overall, these studies collectively contribute to advancements in emission control, material processing, thermal management, and intelligent systems, driving progress in sustainable engineering and industrial applications.

3.0 Experimental Setup

The experimental setup, as illustrated in Figure 1, features a comprehensive arrangement for air flow analysis. Central to the system is a blower unit, which is connected to a test section at its delivery end. Positioned downstream of the blower, a flow control valve modulates the air flow through the test section. An orifice meter is installed further along the pipe to quantify the airflow rate. To regulate the air temperature, a heating element surrounds the section of pipe following the orifice. The test section itself is designed as a trapezoidal duct, where two pressure taps are strategically placed to capture pressure readings across the section. Differential pressure measurements are recorded by a U-tube manometer, both across the orifice and within the test section. To enhance flow control, delta wing Vortex Generators (VGs) are mounted on the duct's bottom surface. Surface temperatures are monitored with three thermocouples fixed to the duct's walls: one at the duct's inlet to measure incoming air temperature, another at the outlet to gauge the air temperature post-test, and

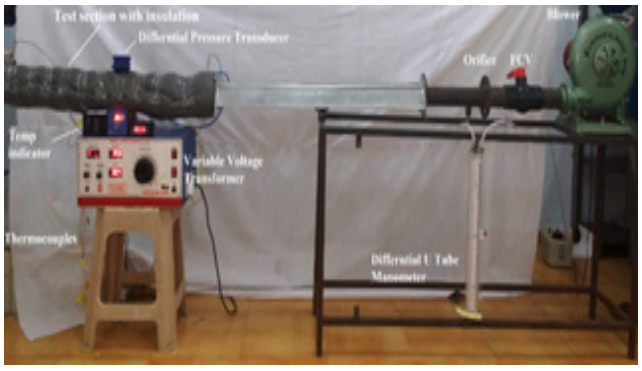


Figure 1. Experimental setup of a duct.

one along the wall to track the thermal conditions within the duct itself. This setup allows for precise monitoring of airflow dynamics and thermal behaviours within the system.

Figure 1 presents the schematic diagram of the experimental apparatus. The duct system was crafted from a 1 mm thick galvanized iron sheet, incorporating a 1000 mm long inlet duct, an 800 mm test duct for assessing convection and fluid friction, and a 200 mm exit duct. The combined length of the inlet and test ducts ensured the establishment of a fully developed turbulent flow. To ensure consistent heating, a Nichrome wire electric heater was spirally wound around the duct's exterior, with power regulated at 150 watts using a variable-voltage transformer. The duct's 1 mm wall thickness promoted effective heat transfer by minimizing thermal resistance. Thermal insulation was provided by a 20 mm glass wool blanket and a 5 mm foam layer. Airflow was generated by a 0.56 Hp centrifugal blower, connected to the duct via a 60 mm diameter pipe, with the flow rate adjusted by a control valve. Airflow measurements were taken using an orifice meter, while differential pressure across the test section was monitored with both a manometer and a digital pressure transmitter. Thermocouples were placed to measure the inlet and outlet air temperatures. The data gathered from the temperature and pressure readings enabled the calculation of forced convection and fluid friction characteristics within the system.

4.0 Results and Discussion

4.1 Heat Transfer Characteristics

4.1.1 Effect of Reynolds Number on Nusselt Number

The Figure 2 shows the effect of the Reynolds number on the experimental value of the Nusselt number. From the observations taken, experimental Nusselt numbers were obtained for the smooth duct as well as for the duct with vortex generators at three different attack angles as stated in section 6.2. These values of the Nusselt number were plotted on the Figure against the Reynolds number. The results for the smooth duct were also plotted on the same Figure to facilitate the comparison.

The Figure 2 demonstrates a clear correlation between the Nusselt number and the Reynolds number across all

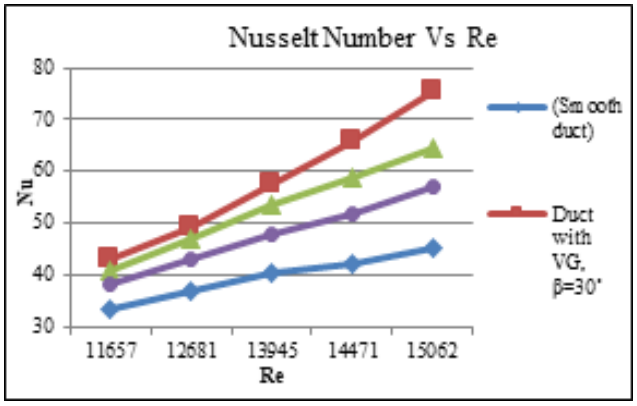


Figure 2. Nusselt number vs Reynolds number.

experimental conditions. In the case of the smooth duct, this trend can be primarily attributed to the increased mass flow rate of air, which enhances the convective heat transfer. A significant observation arises when comparing the Nusselt number of the smooth duct to that of the duct equipped with Vortex Generators (VGs) while maintaining a constant Reynolds number (i.e., identical mass flow rate). In this scenario, the duct with VGs consistently exhibits higher heat transfer rates. This observation strongly suggests that the vortices generated by the delta wing VGs play a crucial role in enhancing heat transfer. The most substantial heat transfer enhancement was observed at a vortex generator angle (β) of 300 degrees, resulting in a Nusselt number of 75. In contrast, the lowest enhancement was observed at β = 600 degrees compared to all other cases, including the smooth duct. Quantitatively, the heat transfer rate was enhanced by 29-67% for β = 300, 23-43% for β = 450, and 14-27% for β = 600, when compared to the smooth duct across the investigated range of Reynolds numbers.

4.1.2 Effect of Reynolds Number on Nusselt Number Ratio

The Figure 3 depicts the trend of the ratio of the experimental Nusselt number for the duct with VGs to that of the smooth duct as a function of Reynolds number. At a Reynolds number of 11657, the experimental Nusselt number of the duct with VGs was found to be 1.296, 1.23, and 1.142 times that of the smooth duct for angles of attack, β = 300, 450, and 600 respectively. Similarly, at a Reynolds number of 15062, the same ratios were 1.668, 1.426, and 1.268 respectively. It can be readily observed

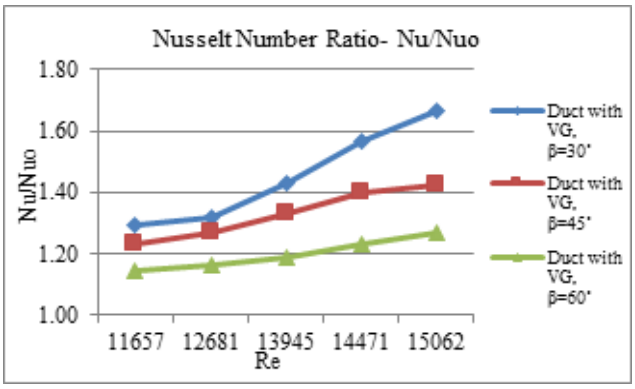


Figure 3. Nusselt number ratio of duct with VG to that of smooth duct Vs Reynolds number.

from the Figure that, for a specific Reynolds number, and hence for a constant mass flow rate, VGs will increase heat transfer by a significantly larger amount in comparison to a smooth duct. This observation supports strong evidence of a positive influence of VGs on heat transfer enhancement.

4.1.3 Variation in Ratio of Experimental and Theoretical Nusselt Number

The Figure 5 shows the change of experimental to theoretical Nusselt number ratios with the changing Reynolds number. The experimental values of the Nusselt numbers were based on the measured experimental results, whereas the theoretical Nusselt number value for both ducts smooth as well as having the vortex generators

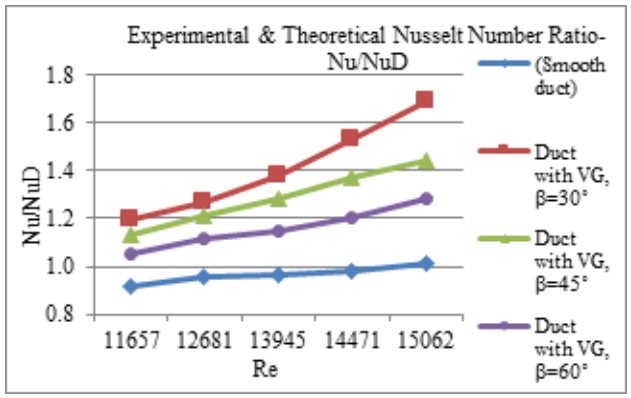


Figure 4. Ratio of experimental to theoretical Nusselt number vs Reynolds number.

VG was evaluated in the Dittus-Boelter equation and finally, ratios of the experimental with theoretical Nusselt number versus the number of the Reynolds number plot were presented. From the Figures 4 presented above, experimental Nusselt number values in a smooth duct were systematically observed to be lesser than the corresponding predicted values for that smooth duct. On the contrary, the installation of VGs on that mass flow rate or equivalent Reynolds number considerably resulted in enhancing Nusselt numbers for heat transfer rates that happen in such ducts compared to that based on predictions with the help of pure theoretical models. At a Reynolds number of 11657, the experimental Nusselt number values were 1.051, 1.132, and 1.193 times higher than the theoretical values for VG angles (β) of 600, 450, and 300 degrees, respectively. Similarly, at a Reynolds number of 15062, the experimental Nusselt number values were 1.284, 1.445, and 1.69 times higher than the theoretical values predicted by the Dittus-Boelter equation.

This suggests that the experimental Nusselt values for the smooth duct are lower than the theoretical model forecast. However, the incorporation of VGs greatly improves the experimental results of the Nusselt number, and this increase persists even at a constant mass flow rate and Reynolds number. This rise in Nusselt number indicates that VGs have a significant effect on increasing heat transfer rates above the theoretical estimates. For VG angles (β) of 600°, 450°, and 300°, empirically calculated Nusselt numbers were 11657 Reynolds numbers, which were 1.051, 1.132, and 1.193 times higher than the theoretical values. Similarly, at a Reynolds number of 15062, the experimentally determined Nusselt numbers were 1.284, 1.445, and 1.69 times more than the theoretical Nusselt numbers predicted by the Dittus-Boelter equation.

4.1.4 Variation in Stanton Number with Reynolds Number

Figure 5 illustrates the relationship between the Stanton number and the Reynolds number. As the Reynolds number increases, the Stanton number also increases, which aligns with expectations for a smooth duct. A higher mass flow rate enhances convective heat transfer, leading to more efficient heat removal by the air.

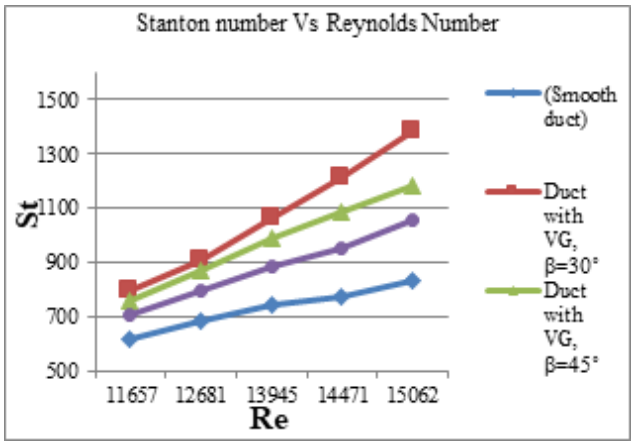


Figure 5. Relationship between the Stanton number and the Reynolds number.

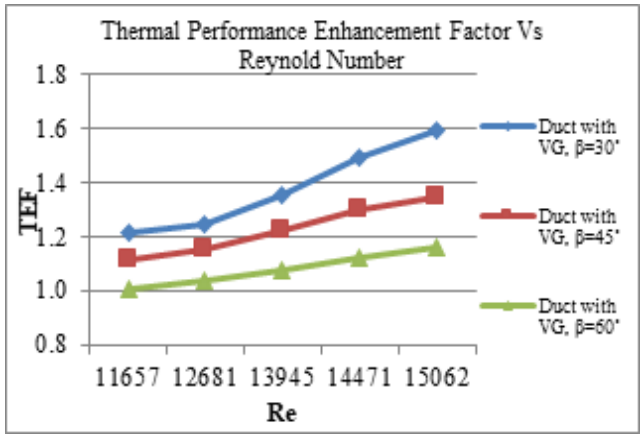


Figure 6. Thermal performance enhancement factor vs Reynolds number.

However, when comparing the Stanton numbers of the Vortex Generator (VG) section duct with the smooth duct under identical mass flow rates, a significant trend emerges. The ducts equipped with delta wing VGs consistently exhibit higher Stanton numbers, indicating a substantial improvement in heat transfer performance. This confirms that the presence of delta wing VGs effectively enhances thermal energy dissipation by promoting better mixing and turbulence within the airflow.

Figure 6 Stanton number vs Reynolds number

4.1.5 Effect of Reynolds Number on Thermal Performance Enhancement Factor

Based on the above discussion, there is a strong dependence on the heat transfer coefficient on both increasing the Reynolds number and the introduction of vortex generators. However, in all these increases in the coefficient of heat transfer, an equal increase in the friction factor due to increased flow resistance in the vortex generators will take place. It is seen that this friction factor increases the demand more pumping power for the system. In some situations, the percent rise in heat transfer might be lower than the percent rise in the friction factor. Under these conditions, the configuration proposed would be of no practical value and even leads to an energy loss compared to the reference situation, at least if expressed as the ratio of net power inputs. It is, therefore, important to determine the system's thermal performance using some form of the enhancement factor of thermal performance. The enhancement factor provides a numerical evaluation of the relative enhancement in the heat transfer for a corresponding enhancement in the friction factor, providing a clear-cut measure of the system's thermal performance.

Figure 6 depicts the fluctuation of the Thermal Performance Enhancement Factor (TEF) with Reynolds number. The TEF, a metric that measures heat transfer efficiency, was determined for the duct with vortex generators and displayed against the Reynolds number. The Figure shows that the duct with a vortex generating angle (β) of 300 degrees had the highest TEF, ranging from 1.217 to 1.595 across the tested Reynolds number range. The TEF for β = 600 degrees ranged from 1.002 to 1.158, whereas β = 450 degrees varied from 1.11 to 1.345. The findings indicate that the vortex generator arrangement with β = 300 degrees offers the best thermal performance. This design shows the greatest improvement in heat transmission while incurring the least increase in friction factor.

4.2 Effect of Angle of Attack of on Flow and Heat Transfer

The impact of the delta wing Vortex Generator's (VG) angle of attack on flow and heat transfer characteristics was explored and compared to a baseline case that used a trapezoidal duct without VGs. Figure 7 how how friction factor and Nusselt number vary with Reynolds number

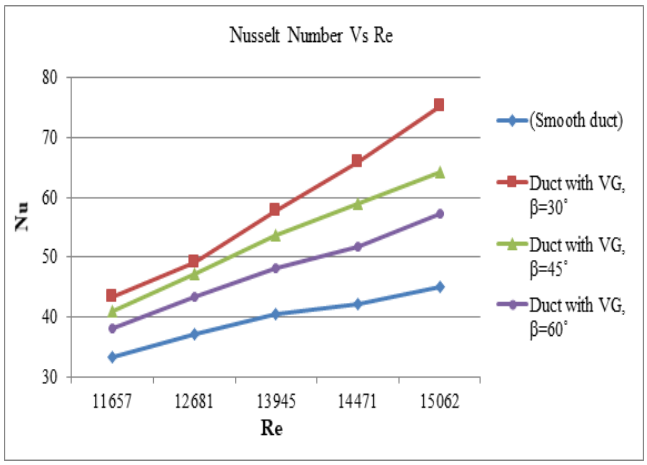


Figure 7. Nusselt number Vs Reynolds number.

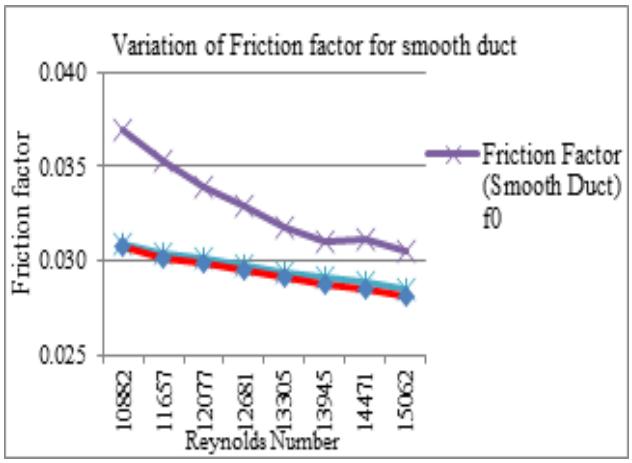


Figure 8. Variation of Experimental and theoretical friction factor for a smooth duct.

at different VG angles of attack. The friction factor and heat transfer coefficients were consistently higher in the duct with delta wings than in the baseline scenario. The friction factor gradually increased with increasing VG angle of attack (β).

Within the Reynolds number range, the Nusselt number for the duct with a VG angle of attack of β = 300 degrees showed a 29-67% enhancement relative to the baseline. In contrast, the corresponding friction factor increase was milder, ranging from 14% to 21%. For β = 450 degrees, the Nusselt number and friction factor increased by 23-43% and 19-36%, respectively. At an angle of attack of β = 600 degrees, delta wing VGs increased heat transfer by 14-27 % and friction factor by 31-49 % compared to smooth ducts. The angle of attack rises, as does the flow restriction or obstruction induced by the VGs. This intensifies the longitudinal vortices and disrupts the flow.

4.3 Validation for Smooth Duct

In essence, the researchers are verifying the accuracy of their experimental setup and methodology by comparing their findings to well-known and widely accepted correlations for heat transfer and friction in smooth ducts.

4.3.1 Variation of Friction Factor for Smooth Duct

Figure 8 below shows variations of experimental and theoretical friction factors for smooth ducts. The experimental friction factor for the smooth duct is calculated from the observations taken. Also using the correlations of Blasius and Petukhov, friction factors were numerically predicted for the observations taken for smooth duct. These values were then plotted against the Reynolds number to facilitate the comparison.

The friction factors obtained in this study were compared to those predicted by the Blasius and Petukhov correlations. The results for the smooth duct exhibited excellent agreement with the correlation data, with a maximum deviation of approximately 15%. This agreement was particularly strong for Reynolds, exceeding 11657 when compared to the Petukhov friction factor correlation.

4.3.2 Variation of Nusselt Number for Smooth Duct

The Figure 9 below shows variations of experimental and theoretical Nusselt numbers for smooth ducts. The experimental Nusselt number for smooth duct is calculated from the observations taken. Also using the correlation of dittos bolter, the Nusselt number was numerically predicted for the observations taken for smooth duct. These values then were plotted against the Reynolds number to facilitate the comparison. A comparison of the Nusselt number obtained from the present work with those from correlation of Dittus bolter was done. In the figure, the present smooth duct results are in excellent agreement within 08% error with the correlation data

5.0 Conclusion

Vortex generators at optimal angles of attack likely resulted in significant improvements in heat transfer coefficients compared to the baseline case without vortex generators. The following points are drawn from the experiments

1. In all cases, the number of Nusselt exhibited a positive correlation with the Reynolds number. This trend for the smooth duct can be attributed to the increased mass flow rate of air, which enhances heat transport capacity. However, when comparing the Nusselt number for the smooth duct to that of the duct with Vortex Generators (VGs) at identical mass flow rates (i.e., the same Reynolds number), a significant increase in heat transfer was observed for the duct with VGs. This observation strongly suggests that the vortices generated by the delta wings exert a substantial influence on the heat transfer process.

2. The ratio of the Nusselt number for the duct with VGs (Nu) to that of the smooth duct (Nuo) demonstrated a consistent increase with increasing the Reynolds number. For the VG angle of attack (β) of 300 degrees, the highest Nu/Nuo values were reported, reaching 1.668 and 1.296 across the investigated Reynolds number range.

3. When comparing the experimental Nusselt numbers to those predicted by theoretical models, the ratio of experimental Nusselt number (Nu) to theoretical Nusselt number (NuD) was found to be significantly higher for β = 300 degrees, reaching values of 1.19 and 1.69 across the studied Reynolds number range.

4. The Stanton number (St) values obtained during the experiments were 1384 and 796 for β = 300 degrees across the investigated Reynolds number range.

5. The Thermal Performance Enhancement Factor (TEF) was found to be 1.217 and 1.595 for β = 300 degrees, indicating a significant improvement in thermal performance.

6.0 Author Contibution

Gokul Navnath Wakchaure, Nilesh Navanath Kokare, Yatin Madhukar Bhamare: Experimental setup preparation, parameter optimization, and test conduction. Sagar Vijay Jagtap, Perumallapalli Gandhi: Literature Review. Avinash Shivajirao ChavanPatil, Sachin Kandharkar: Elaboration of results and discussion session. Sunil D. Kamble, Aditya Jadhav: Justification of comments after reviewing the article. Rahul Shivaji Yadav, Anant Sidhappa Kurhade: Preparation of graphical abstract, Reviewer suggestion, communication with editor, reference section, and preparation of video

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