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Analysis of Artificially Roughened Solar Air Heater Duct Using Computational Fluid Dynamics

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***Abstract:** In the current work, using computational fluid dynamics, the performance of a solar air heater duct with thin circular wire acting as artificial roughness in an arc-shaped geometry has been examined (CFD). With regard to a variety of roughness parameters and working parameters, the impact of arc-shaped geometry on heat transfer coefficient, friction factor, and performance enhancement was examined. The results of the analysis using various turbulent models are contrasted. The renormalization-group (RNG) k-ε model is used to forecast heat transfer and friction factor in the duct because its results and predictions have been found to be in good agreement. To discuss the overall impact of the roughness and working parameters, the overall enhancement ratio has been calculated. For the range of parameters examined, a maximum value of the overall enhancement ratio of 1.52 was discovered.*

***Keywords:** Solar air heater, CFD analysis, Duct roughness, k-ε model, Friction factor*

I. INTRODUCTION

Solar air heater is basic equipment in which solar energy is stored as heat energy and used for space heating, drying of agriculture products and also in several applications. In addition to generate heat for drying crops, Marine products, concrete, and textile dyeing and water desalination also have been done. The simple design contributes to favourable economics and reliability this result in lower production and operating caused due to smaller number of parts and longer maintenance intervals the system operates smoothly and noiselessly they are environmentally sustainable. However the value of the heat transfer coefficient between the frame and the observer plate reduce the thermal efficiency of the solar air heaters.

All the sides top and bottom are insulated by using acrylic sheets but due to gap in the insulation the thermal performance of the solar air heater is reduced the convective heat transfer. Coefficient in the solar air heater can be increased by changing the material such as aluminium playing sheet, Steel roof metal sheet, Stainless Steel, black coated plastic sheet to increase the thermal efficiency of the solar air heater by using Steel roof metal sheet which increased the convective heat transfer. Coefficient between the observing surface and the flowing air in solar air heater tank acrylic sheets wire used as an insulator to improve the heat transfer rate from the solar air heater heat transfer surface it is important to break the laminar sub layer were created on the absorber plate the shrubs distributed the laminar sub layer in the turbulent boundary region and make the turbulence in the air flowing just near to the wall of the solar air heater. Steel roof metal sheet in solar heaters are the universal service for interception solar heat at low temperature and has been utilized widely for applications of air heating.

Recently a significant number of research works has been published relating to the designing solar air heater using different materials and their working parameters and its efficiency it could be noted that all reviews the main aim was to a government the thermal efficiency of solar air heater by using different materials. However for large scale utilize of solar air heater like in drying application it is desired to have a cheap solar air heater as well as the thermal performance with the steel roof metal sheet solar heater has been study in many papers and compare the performances and investment cost of materials and insulating covers all the solar air heater working under the same conditions then we found that the use of the Steel roof metal sheet in the Solar air heater was recommended in cost. Of you to decrease investment cost also the acrylic sheets they concluded that the solar air heater efficiency was increased and its length is increased till reached to 80 CM there was no table and Management in solar air heater efficiency if it length is longer than 80 CM also many research try to changing the different materials with low cost in some other resources the used plastic as the observer plate by using the Steel roof metal sheet.

The thermal efficiency is increased and become higher than solar heaters in which is used plastic as the observer plate in order to study about the shape of the experiment there are three different methods in first method used glass as the insulator but the main demerits in using glass is the gas is more brittle and it is easily breakable in another method the use vacuum chamber as a insulator the main demerits. In this method is vacuum decreases the temperature and also decreases the thermal efficiency in our experiment we use acrylic sheet as a insulator acrylic sheet is a kind of fibre material which is flexible to some extinct and also prevent heat loss the study of four different materials was made and several objectives are formatted to address the general objective of the present investigation evaluation of the influence of design the operating parameters of a thermal efficiency increased by Steel roof metal sheet solar air heater the main targets of this experiment is to analysing the different observing plate in solar air heater study and discuss the operation after system and evaluate its thermal efficiency.

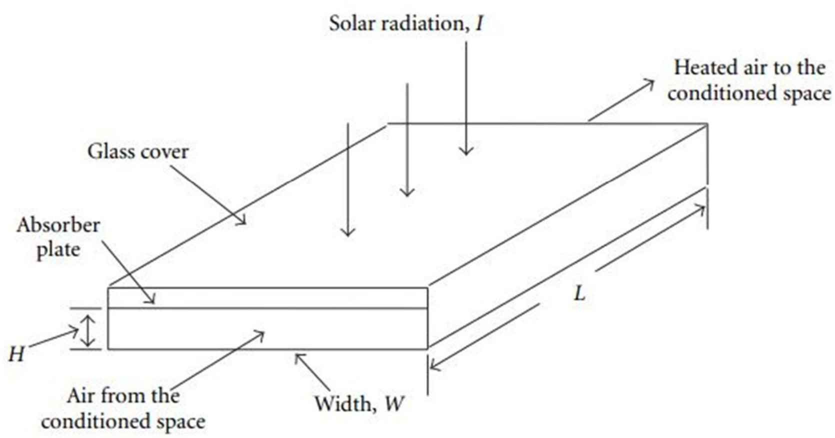

Fig. 1: Schematic view of solar air heater

II. SOLAR AIR HEATER CLASSIFICATION

A conventional solar air heater is essentially a flat plate collector with absorber plate, a transparent cover system at the top and insulation at the bottom and on the sides. The whole assembly is encased in a sheet metal container. The working fluid is air, though the passage for its flow varies according to the type of air heater. Material for construction of air heaters is similar to those of liquid flat plate collectors. The transmission of solar radiation through the cover system and its subsequent absorption in the absorber plate can be given by expressions identical to that of liquid flat plate collectors. Selective coating on the absorber plate can be used to improve the collection efficiency but cost effectiveness criterion should be kept in mind.

A. *Direct Solar Heaters*

In these heaters, the material to be dried is placed in a transparent enclosure of glass or transparent plastic. The sun heats the material to be dried, and heat also builds up within the enclosure due to the 'greenhouse effect.' The drier chamber is usually painted black to absorb the maximum amount of heat.

B. *Indirect Solar Heaters*

In these heaters, the sun does not act directly on the material to be dried thus making them useful in the preparation of those crops whose vitamin content can be destroyed by sunlight. The products are dried by hot air heated elsewhere by the sun.

C. *Mixed Mode Heaters*

In these heaters, the combined action of the solar radiation incident on the material to be dried and the air preheated in solar collector provides the heat required for the drying operation.

D. *Hybrid Solar Heaters*

In these heaters, although the sun is used to dry products, other technologies are also used to cause air movement in the heaters. For example fans powered by solar PV can be used in these types of heaters.

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III. DESIGN OF SOLAR AIR HEATER DUCT CONSIDERED FOR CFD ANALYSIS

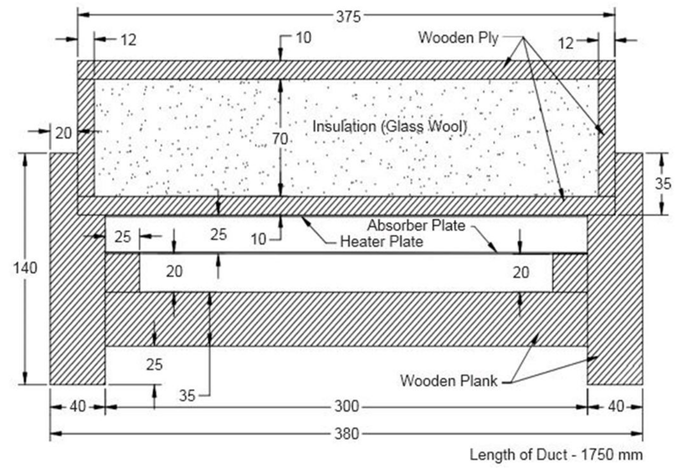

Fig. 02: Sectional view of solar air rectangular duct

For the purpose of this inquiry, the system and operating characteristics have been taken into account. The duct was the system component that was given the most weight. According to Fig. 03, the duct under consideration had inner cross-sectional measurements of 300 mm 25 mm. In keeping with the aspect ratio that many researchers have used for similar investigations, 12 has been used in this study. A 900 mm long entering portion, a 1000 mm long test section, and a 750 mm long exit section make up the flow system. To minimise the effects on the test section, the flow's entry and exit lengths have been maintained. A heater plate was thought to provide a steady heat flux of 1000 W/m2 when it was put over the absorber plate.

IV. ANALYSIS

A. Solution Domain

It has been thought of how roughness elements might be arranged as arc-shaped ribs fixed to the interior of the absorber plate. As depicted in Fig. 3, the solution domain for CFD analysis has been generated. The duct used for CFD study has dimensions of 300 mm in diameter and 25 mm in height. The absorber plate's thickness has been determined to be 0.5 mm. The sides of the duct were to be made of hardwood planks that were 28 mm thick, while the floor of the duct would be 40 mm thick. For analysis, a uniform heat flux of 1000 W/m2 was taken into account. The top of the duct's underside was thought to have a roughened surface, while the duct's other three sides were thought to have smooth surfaces.

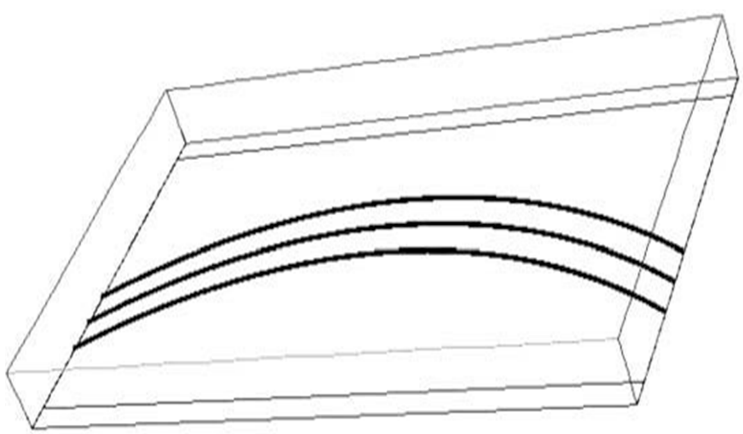

Fig. 03: Solution domain for CFD analysis.

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B. GRID

The geometry chosen makes secondary flows inevitable, therefore employing a 2-D solution domain and gird is not an option. As a result, the 3-D solution domain and grid were chosen. Finer meshing has been applied at these spots in order to closely analyse the flow and heat transfer in the inter-rib zones. Other areas have employed coarser mesh. Mesh creation for the current work was carried out using Ansys 18.1, a commercially available piece of software. Each set of geometries has between 0.95 and 1.982 million cells, depending on the arc angle and roughness height. All simulations were run using twice as many grid points in each spatial direction to guarantee that all results are grid independent and clearly resolved. There were no observable differences between the solutions.

C. CFD Analysis

ANSYS FLUENT Version 18.1 was utilised for the current study. In order to mimic flow and heat transfer as the secondary flow occurs with the chosen shape, a 3-D model rather than a 2-D model has been put up.

The mathematical model used the following assumptions:

1) The flow is three-dimensional, turbulent, well-studied, and fully developed.
2) The duct wall and roughness material's thermal conductivity do not alter with temperature.
3) The material used for the duct wall and roughness is homogeneous and isotropic.

Using Reynolds number, the mean inlet velocity of the flow was determined. Outflow has been referred to as the outlet boundary condition and velocity boundary condition as the input boundary condition. The governing equations were discretized using the SIMPLE algorithm and the second order upwind numerical approach.

V. RESULT AND DISCUSSIONS

In order to determine the validity of the models, the Standard kε model, Renormalization-group (RNG) k-ε model, Realizable k-ε model, and Shear Stress Transport (SST) kU have all been studied for smooth ducts with the same cross-section as roughened ducts. In order to compare the outcomes of the various models, the Dittus-Boelter empirical correlation for the Nusselt number .The link between Nusselt number and Reynolds number for various models, and the computed values for a smooth duct using the Dittus-Boelter empirical relationship. Renormalization-group (RNG) k-ε model results have been shown to be in good agreement with Dittus-Boelter empirical findings. In comparison to empirical correlation data, numerical model results obtained by SST ku have a higher deviation, whereas those obtained by Realizable k-ε and Standard k-ε have a lower deviation. Additionally, for low Reynolds number flows, the results from the Renormalization-group (RNG) k-ε model and the Dittus-Boelter empirical model are nearly identical, but for higher Reynolds number flows, there is some variation in the results. Therefore, to simulate the flow and heat transfer for the current numerical analysis, the Renormalization-group (RNG) k-ε model has been used.

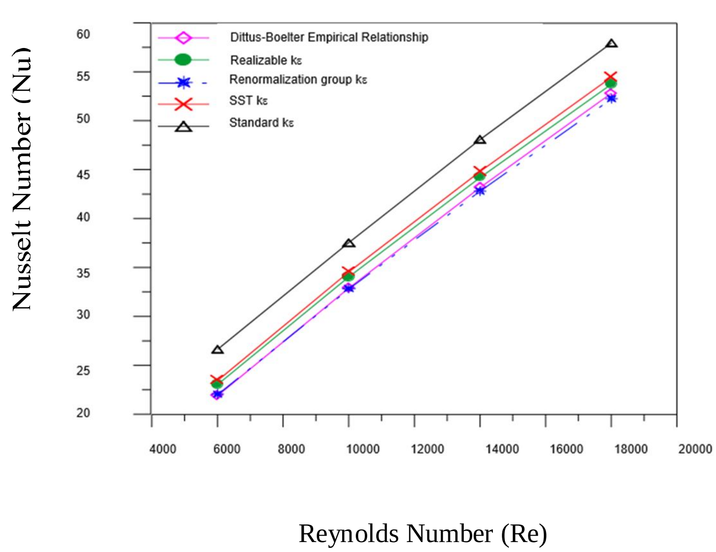

Fig. 04: Re vs Nu for Predictions of CFD models

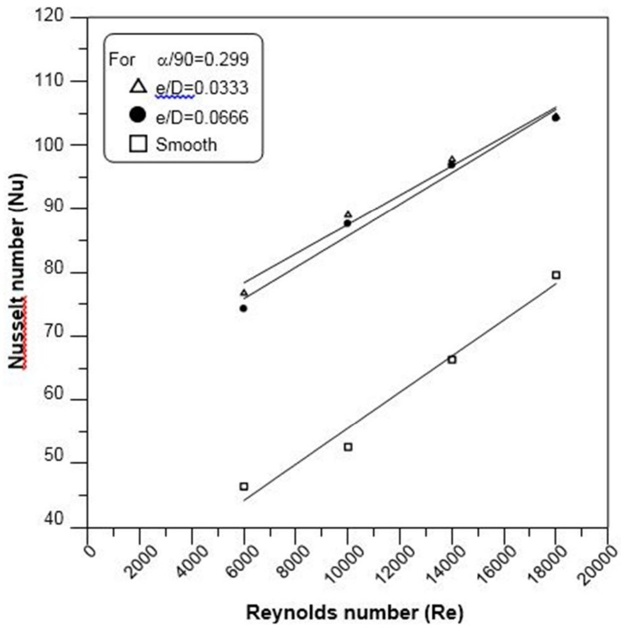

Fig. 05: Re vs Nu in Smooth Duct

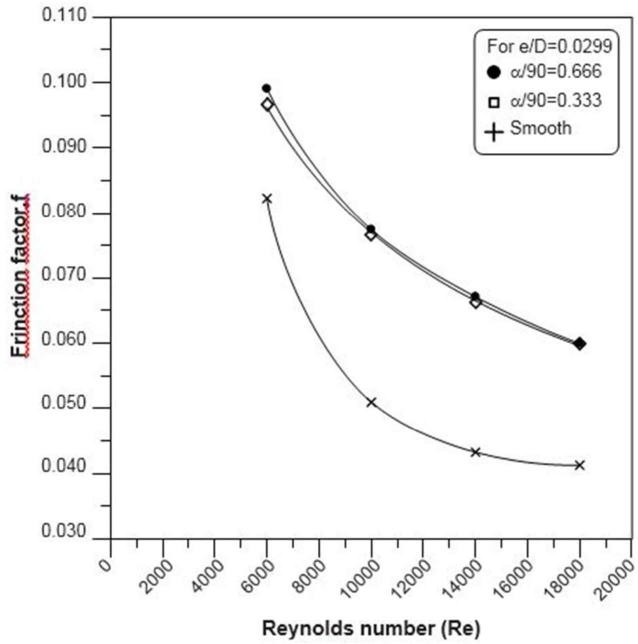

Fig. 06: Re vs Nu in Smooth Duct

The rib given in the form of artificial roughness has an impact on the flow and heat transfer characteristics in the flow direction. The change in Nusselt number values between neighbouring ribs is depicted in Fig.04. Nusselt number values have been discovered to be low close to the rib. The cause might be that only conduction causes heat to be transferred around the rib. Nusselt number values have been seen to reach extremely high values both upstream and downstream of the rib. As the flow gets closer to the rib, the Nusselt number starts to decline, eventually reaching a lower value. The Nusselt number rises when the flow passes the rib downstream, though.

The variation in flow characteristics downstream of the rib is blamed for it. Just downstream of the rib, vortices are produced by the existence of ribs along the flow direction, and the fluid also separates from the wall. Separated flow reduces heat transfer, whereas vortices cause fluid to mix and hence increase it. The influence of vortices will be more pronounced than the effect of flow separation downstream of the rib and nearby, leading to a rise in the Nusselt number in this area.

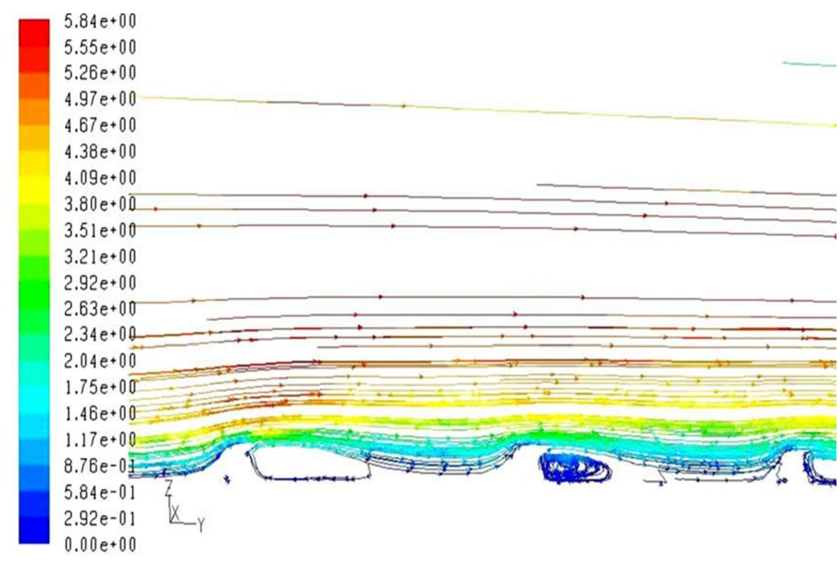

Fig. 07: Path lines at Reynolds number.

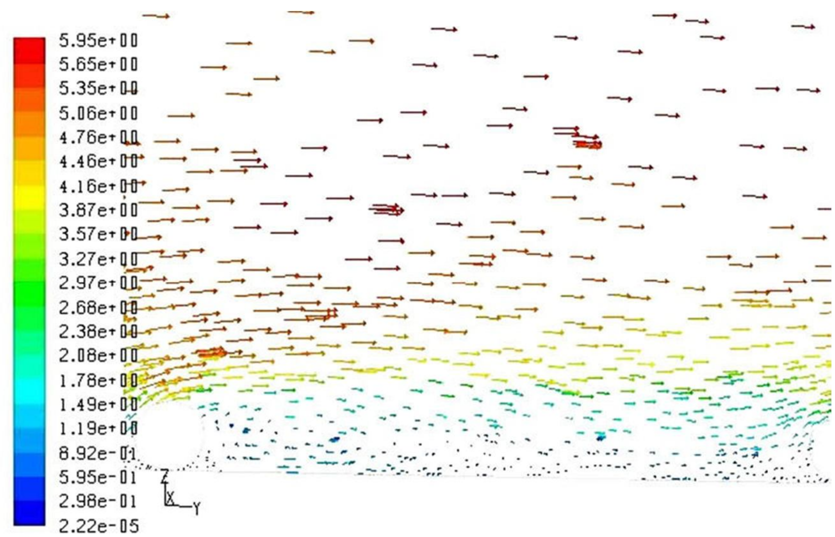

Fig. 08: Velocity vectors for relative arc angle and relative roughness height at Reynolds number

The influence of vortices will be more pronounced than the effect of flow separation downstream of the rib and nearby, leading to a rise in the Nusselt number in this area. Both of these effects significantly reduce the value of the Nusselt number further downstream of the rib, where flow is in a separated condition and the influence of vortices is minimal. Flow reattachment occurs further downstream of the rib, sharply raising the Nusselt number's value. In inter-rib regions, Nusselt number similarly rises as Reynolds number does. While downstream of the rib, Nusselt number is higher for higher Reynolds number flow as opposed to low Reynolds number flows. On either side of the rib, the values of Nusselt number are the same for both low and high values of Reynolds number flows.

In Fig. 4, flow paths past the rib along the middle plane are depicted for a Reynolds number of 14,000 as a given value. By using a CFD model, vortices, flow separation, and reattachment were anticipated. The number of vortices, their strength, and their reattachment point vary with respect to the Reynolds number with constant values of relative arc angle (a/90) and relative roughness height (e/D). As seen in Fig. 5, the velocity vectors at 14,000 Reynolds reveal stronger vortices due to the inclusion of the roughness element, which increases the rate of heat transfer.In order to explain additional related phenomena such an increase in Nusselt number for various roughness factors, CFD findings have critically analysed the flow separation and reattachment.

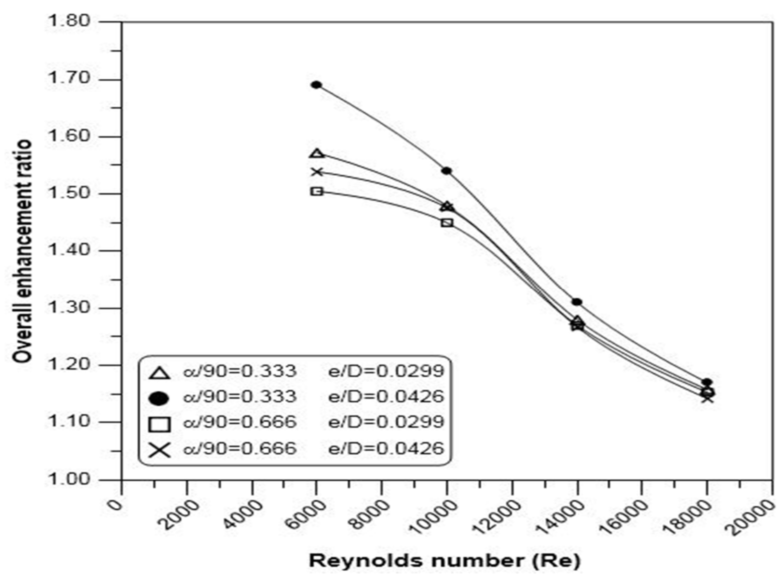

Fig. 09: Different roughness geometries' overall enhancement ratio

It is obvious that a surface roughness that produces a value for this parameter greater than unity can only be beneficial. The performance of the solar air heater is improved with a higher value for this parameter. The overall enhancement ratio for the solar air heater with various rib configurations for Reynolds numbers ranging from 6000 to 18000 is shown in Fig. 12. It has been discovered that the total enhancement ratio is more than one for any combination of roughness, and it peaks around the Reynolds number of 6000.

VI. CONCLUSION

A CFD-based investigation of the fluid flow and heat transfer characteristics of solar air heaters with roughened ducts produced with artificial roughness in arc-shaped geometry has been attempted. During CFD study, a combined effect of swirling motion, fluid detachment, and reattachment that was thought to be responsible for the increase in heat transfer rate was seen. For all combinations of relative roughness height (e/D) and relative arc angle (a/90), it has been discovered that Nusselt number increases with increasing Reynolds number, although friction factor decreases with increasing Reynolds number. For smooth ducts, CFD results have also been verified, and the Dittus-Boelter empirical relationship for smooth ducts was compared with the output of various CFD models. Renormalization-group (RNG) k-3 model findings have been shown to have good agreement across all of the models used. For the range of parameters studied, an overall enhancement ratio with a maximum value of 1.52 has been obtained for the roughness geometry corresponding to a relative arc angle (a/90) of 0.333 and a relative roughness height (e/D) of 0.0426.

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