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A Review on Computational Analysis of Turbulent Heat Transfer in Solar Air Heater by using Roughness Geometry

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A B S T R A C T

In mechanical industries or thermal electricity zone the maximum generally the usage of detail is "AIR PRE HEATER", that's a shape of Heat Exchanger and through this gadget we will boom the temperature of the air which has been too utilized in required purpose. By the usage of the sun air heater we will boom the performance of organization. And using synthetic roughness with inside the shape of repeated ribs on a floor is a powerful method to beautify the price of warmth switch. A numerical research on the warmth switch and fluid waft traits of completely advanced turbulent waft in a square duct having repeated transverse W fashioned rib roughness at the absorber plate has been carried out. The business finite-quantity CFD code ANSYS FLUENT is used to simulate turbulent airflow via artificially roughened sun air heater. The waft Reynolds quantity of the duct various with inside the variety of 3800 to 18,000, maximum appropriate for sun air heater. Solar air heater is working at the precept of compelled convective warmth switch among the wall and an operating fluid (air). But the performance of the air heater is evidently of low cost because of the reality that air has inferior thermodynamics houses in phrases of warmth switch however it may be boom through the converting the form of duct internal vicinity in phrases of roughness of synthetic roughness. The technique used to boom the warmth switch coefficient among the operating fluid (air) and absorber floor is to create the turbulence with inside the sun air heater duct. The turbulence is used to interrupt the viscous sub layer on the absorber floor and alternate into the turbulent air waft from the laminar. Yadav and Bhagoria have simulated the above geometries the usage of ANSYS FLUENT code and RNG kε turbulence model. The outcomes had been offered in phrases of Nusselt quantity as opposed to Re, friction thing as opposed to Re, Nusselt quantity ratio as opposed to Re, friction thing ratio as opposed to Re, and thermal enhancement thing as opposed to Re. From the literature overview noted above, it's miles discovered that each experimental and numerical evaluation works are carried out the usage of the Roughness geometries outfitted at the waft facet of absorber plate. Promvonge et al. have followed a brand new idea to boom the warmth switch in sun air heater duct. Promvonge et al. used ribs as synthetic roughness at the absorber plate and further to this delta winglet, as a swirl waft generator in inlet segment to create the extra turbulence from inlet segment. These idea outcomes in boom of warmth switch price.

Keywords: Artificial Roughness, Solar Air Heater, Roughness Geometry, Nusselt Number, Friction Factor, Thermo Hydraulic Performance, Reynolds Number

1. Introduction

A solar air heater is a type of heat energy collector by which we can collect the solar heat by using a solar heat absorber. And this absorbed heat can be utilized to increase the temperature of air which is passing throw a rectangular duct. In this paper it is focused to present different surface roughness geometries used in various researches and the geometry arrangements. Solar air heaters, because of their simple in design, are cheap and most widely used collection devices of solar energy. It is one of the basic equipment through which solar energy is converted into thermal energy. The main applications of solar air heaters are space heating, seasoning of timber, curing of industrial products and these can also be effectively used for curing/drying of concrete/clay building components. A conventional solar air heater generally consists of an absorber plate, a rear plate, insulation below the rear plate, transparent cover on the exposed side, and the air flows between the absorbing plate and rear plate. A solar air heater is simple in design and requires little maintenance. However, the value of the heat transfer coefficient between the absorber plate and air is low and these results in a lower efficiency [1, 2]. CFD is a science that can be helpful for studying fluid flow, heat transfer, chemical reactions etc. by solving mathematical equations with the help of numerical analysis. It is equally helpful in designing a solar air heater system from scratch as well as in troubleshooting/optimization by suggesting design modifications. CFD employs a very simple principle of resolving the entire system in small cells or grids and applying governing equations on these discrete elements to find numerical solutions regarding pressure distribution, temperature gradients, flow parameters and the like in a shorter time at a lower cost because of reduced required experimental work [3-8].

1.1. Artificial roughness on upper layer of duct

Artificial Roughness approach has been utilized by the researchers given that lengthy time frame for the enhancement of warmth switch from the absorber plate of the sun air heater. This kind of heater has flat plate absorber with insulation to save you the warmth loss from the heater and the higher maximum a part of the duct is roughened to create turbulence within side the air that is passing throw.

For the evaluation of the overall performance of the sun air heater with synthetic roughness, a few parameters are used e. g Relative roughness pitch, Relative roughness height, Angle of assault and factor ratio. Various roughness geometries were utilized by the researchers for warmth switch evaluation a number of the geometries are V formed, Square formed, W formed, cord rib, transverse rib grooved, metallic grit rib and chamfered rib however we're the usage of right here X-formed roughness at the higher layer of the duct or solar warmth soaking up plate.

A lot of research were mentioned within side the literature on artificially roughened surfaces for warmth switch enhancement however maximum of the Studies had been completed with contrary or all of the 4 partitions roughened for excessive Reynolds range variety within side the region of fuelling turbine Airfoil cooling system, fuelling cooled nuclear reactors, cooling of digital equipment, transport machineries, combustion chamber liners, missiles, re-access vehicles, deliver hulls and piping networks etc.

1.2. Application of Solar Air Heater

Solar air warmers, due to their easy in design, are reasonably-priced and maximum broadly used series gadgets of sun power. It is one of the primary gadget via which sun power is transformed into thermal power. The foremost packages of sun air warmers are area heating, seasoning of timber, curing of commercial merchandise and those also can be successfully used for curing/drying of concrete/clay constructing components.

2. Performance of Solar Air Heater

The overall performance of this air sun heater cans represents the diploma of usage of enters to the gadget. Thermal overall performance worries with warmness switch technique with inside the collector and hydraulic overall performance worries with strain drop with inside the duct. A traditional sun air heater is taken into consideration for short evaluation of thermal and hydraulic overall performance with inside the following sub-sections. Design and production information of such form of traditional gadget are defined through Garg and Prakash. The thermal overall performance of flat plate sun air heater may be discovered through thinking about the power stability among sun power absorbed through absorber plate and beneficial thermal power output of the gadget followed through a few losses.

2.1. Thermal performance

Thermal performance of a solar air heater can be computed with the help of Hottel–Whillier–Bliss equation reported by Duffie and Beckman [9,10].
The energy balance equation can be written as follows

$$Qa = Ap\,[IR(\tau\alpha)e] = Qu + Q1 \qquad (1)$$

Where, Qa is the energy absorbed by the absorber plate,
Ap is the area of the absorber plate,
I is the intensity of insulation,
R is the conversion factor to convert radiation on horizontal surface to that on the absorber plane,
$(\tau\alpha)e$ is the effective transmittance absorptance product of the glass cover-absorber plate combination,
Qu is the useful energy gain and Ql is energy loss from the collector.

The useful energy gain can be expressed in terms of inlet air temperature Ti and other system and operating parameters as:

$$Q_U = A_C\, F_R\, [I(\tau\alpha)_e - U_L(T_i - T_a)] \qquad (2)$$

Where F_R is given by:

$$F_R = Cp/APU_L[1-\exp(-F'U_LAP/cp)] \qquad (3)$$

Where

F_R is the collector heat removal factor which indicates the thermal resistance meet by the absorbed solar energy in reaching to the flowing air.
$U_L$is the overall loss coefficient and Ti and Ta are the inlet air and ambient temperatures respectively.
F' is termed as collector efficiency factor which provides the relative measurement of thermal resistance between absorber plate and ambient air to that of thermal resistance between the air flowing through collector and the ambient air.
Collector efficiency factor (F') is expressed as:

$$F' = 1 / (1+U_L / he) \qquad (4)$$

Where he is the effective heat transfer coefficient between the absorber plate and flowing air. The thermal efficiency of the collector is the ratio of useful heat gain to the incident solar energy falling on the Collector.
Therefore:

$$\eta th = Qu / IAp = F_R[(\tau\alpha)e - U_L(Ti\text{-}Ta) / I] \qquad (5)$$

According to the above equation, the thermal performance of the sun collector can be stepped forward through growing the price of FR which relies upon on collector performance thing F'. By improving the warmth switch coefficient among absorber plate and air, better values of F' can be achieved. Roughening of absorber floor has been observed to be the handy and powerful approach to beautify the convective warmness switch costs from the absorber floor to air.

2.2. Hydraulic performance

Hydraulic overall performance of a sun air heater worries with strain drop (DP) with inside the duct. Pressure drop debts for electricity intake through blower to proper air by a duct. The strain drop for absolutely evolved turbulent float via duct with Re<50,000 is given as follows equation:

$$f = \frac{2\Delta pD}{\rho L u^2} \qquad (6)$$

Where,

$$f = 0.079Re^{-0.25} \qquad (7)$$

2.3. Thermo-hydraulic performance

It is important that even as comparing the overall performance of a sun air heater with recognize to the enhancement of thermal gain, the strength spent in propelling air need to additionally be taken into account. It is suitable that layout of sun air heater need to be made in this kind of manner that it need to switch most warmth strength to the flowing fluid with minimal intake of blower strength. Therefore so as to research ordinary overall performance of a sun air heater, Thermo-hydraulic performance of a solar air heater is given by the following index

$$\text{Thermo hydraulic performance } = \frac{Nu_r/Nu_s}{(f_r/f_s)^{1/3}} \qquad (8)$$

It is necessary that while evaluating the performance of a solar air heater with respect to the enhancement of thermal gain, the energy spent in propelling air should also be taken into

3. Applications of CFD in Various Aspects of Solar Air Heaters

A lot of experimental and theoretical research had been mentioned to assess overall performance of sun air heater. Kumar *et al.* [11] experimentally investigated warmth switch and friction traits of sun air heater via way of means of the usage of discrete W-formed roughness on one extensive wall of sun air heater. The most enhancement of Nusselt range and friction thing due to supplying synthetic roughness become observed to be 2.sixteen and 2.seventy five instances that of clean duct. Mittal *et al.* [12] supplied a evaluation of powerful performance of sun air heater shaving exclusive styles of geometry of roughness factors at the absorber plate. The powerful performance become computed via way of means of the usage of the correlations for warmth switch and friction thing advanced via way of means of numerous investigate- torso in the investigated variety of working and gadget parameters. Prasad and Saini [13] advanced numerous layout curves for artificially roughened sun air heater that gave the most advantageous thermo-hydraulic overall performance. *Prasad* and Saini [14] investigated the impact of relative roughness pitch (P/e) and relative roughness peak (e/D) on the warmth switch coefficient and friction thing for completely advanced turbulent glide in a sun air heater duct with small diameter protrusion on wires at the absorber plate. It become observed that for a given relative roughness pitch, each the Nusselt range and friction thing elevated with growing relative roughness peak and for a given relative roughness peak each the Nusselt range and friction thing reduced with growing relative roughness pitch, however now no longer in direct proportion. Aharwal *et al.* [14] finished an experimental research of warmth switch and friction thing traits of a square duct roughened with repeated rectangular move-phase split-rib with a hole, on one extensive wall organized at a bent with admire to the glide direction. The most enhancement in Nusselt range and friction thing become located to be 2.fifty nine and 2.87 instances of that of the clean duct respectively. The thermo-hydraulic overall performance parameter become observed to be most for the relative hole width of 1.zero and the relative hole function of zero.25. Muluwork [16] finished an experimental evaluation of a sun air heater having V-formed staggered discrete ribs at the absorber plate and mentioned that most warmth switch enhancement took place at an attitude of assault of 60^{zero}. Prasad and Mullick [17] applied synthetic roughness in a sun air heater duct withinside the shape of small diameter wires to boom the warmth switch coefficient for relative roughness peak and relative roughness pitch of zero.019 and12.7, respectively. Gupta [18] investigated the impact of relative roughness peak, attitude of assault and Reynolds range on warmth switch and friction thing in square duct having round twine ribs at the absorber plate. The most enhancement of Nusselt range and friction thing due to supplying synthetic roughness become observed to be 1.eight and 2.7 instances that of clean duct. Vermaand Prasad [19] investigated the impact of geometrical parameters of round twine ribs on warmth switch and friction thing. It become located that the cost of warmth switch enhancement thing varies from 1.25 to 2.08 in the variety of parameters investigated. The cost of most advantageous thermo-hydraulic overall performance becomes observed to be approximately 71% similar to roughness Reynolds range of 24. Karwa [20] finished a comparative experimental take a look at of augmented warmth switch and friction in are ct angular duct of a sun air heater with square move-phase ribs organized in V-non-stop and V-discrete pattern. The overall performance of V-down ribs becomes located to be higher than that of V-up ribs. Sahuand Bhagoria [21] experimentally investigated the impact of 90^{zero} damaged ribs as roughness factors and observed that thermal performance lies withinside the variety of 51–83.5%. The most enhancements in warmth switch become mentioned on the pitch of 20mm. Guptaetal. Saini and Saini [22] studied the impact of arc formed ribs on the warmth switch coefficient and friction thing of square sun air heater ducts.

Enhancement of warmth switch and friction thing become mentioned to be of order 3.6 and 1.seventy five instances respectively over clean sun air heater duct for relative arc attitude cost of zero.333 and relative roughness peak cost of zero.042. Saini and Verma [23] investigated the impact of roughness and working parameters on warmth switch and friction thing in a roughened duct supplied with dimple-form roughness geometry for the variety of Reynolds range from 2000 to 12,000, relative roughness peak from zero.018 to zero.037 and relative roughness pitch from eight to 12. The most cost of the warmth switch become observed to be similar to relative roughness peak of zero.037 and relative roughness pitch of 10. Karmare and Tikekar [24] finished an experimental research of warmth switch to the airflow withinside the square duct of an issue ratio 10:1. The pinnacle wall floor become made hard with steel ribs of round move phase in staggered way to shape described grid. The roughened wall becomes uniformly heated and the alternative partitions have been insulated. The impact of relative roughness peak of grit, relative roughness pitch of grit and relative duration of grit on the warmth switch coefficient and friction thing have been investigated via way of means of authors. Kumar *et al.* Kumar *et al.* [25] finished an experimental research to decide the warmth switch distributions in sun air heater having its absorber plate roughened with discrete w-formed ribs. It becomes mentioned that thermal overall performance of the roughened duct becomes observed to be 1.2–1.eight instances the clean channel for variety of parameters investigated. Jaurker *et al.* [26] investigated the impact of relative roughness pitch, relative roughness peak and relative groove function on the warmth switch coefficient and friction thing of rib-grooved synthetic roughness. The most warmth switch becomes received for a relative roughness pitch of approximately 6, and it becomes reduced on both facet of the relative roughness pitch. The most advantageous circumstance for warmth switch becomes observed at a groove function to pitch ratio of zero. Four in comparison to the clean duct. As in comparison to clean floor, the presence of rib grooved synthetic roughness will increase the Nusselt range as much as 2.7 instances, at the same time as the friction thing increases as much as 3.6 instances with inside the variety of parameters investigated. Layek *et al.* [27] investigated warmth switch and friction traits of repeated essential transverse chamfered rib-groove roughness. Authors mentioned that Nusselt range and friction thing become elevated via way of means of 3.24 instances and 3.seventy eight instances respectively as examine to clean duct. Maximum enhancement of Nusselt range and friction thing become received similar to relative groove function of zero.

Discussion about turbulence models

The literature survey reveals that the solar air heaters are thermo-hydraulically more efficient if system operates at Reynolds numbers ranges from 3000 to 19,000. Reynolds number inside the rectangular duct of solar air heater shows that the flow is turbulent.

Authors	Computational methodology	Difference between experimental and simulation results
Arulanandam et al. [28]	• CFD code: TASC flow • Turbulence:- • Mesh: uniform	Close agreement observed
Ammari [29], Chaube et al. [30]	• CFD code: Fluent 6.1 • Turbulence model: SST k– ω • Mesh: rectangular, non-uniform	Good agreement observed , Good agreement observed
Chaube et al. [31]	• CFD code: Fluent 6.1 • Turbulence model: SST k– ω • Mesh: rectangular, non-uniform	Good agreement observed
Wang et al. [32], Varol and Oztop [33]	• CFD Code: CFDRC ACE+ • Turbulence model:- • Mesh: Non-uniform	Good agreement observed, Good agreement observed
Kumar and Saini [34]	• CFD Code: Fluent 6.3.26 • Turbulence model: RNG k– ε • Mesh: non-uniform	Good agreement observed
Karmare and Tikekar [35]	• CFD code: Fluent6.2.16 • Turbulence model: RNG k– ε • Mesh: non-uniform	Good agreement observed
Soi et al. [36]	• CFD code: Fluent • Turbulence model: RNG k– ε • Mesh: non-uniform	Nusselt number 715% Friction factor 720%
Giri [37]	• CFD code: Fluent • Turbulence Model: RNG k– ε • Mesh: Non-uniform	Good agreement observed
Rajput [38]	• CFD code: Fluent • Turbulent model: RNG k– ε • Mesh: uniform	Good agreement observed
Sharma et al. [39]	• CFD code: Fluent • Turbulence model: RNG k– ε • Mesh: non-uniform	Nusselt number 715% Friction factor 715%
Sharma and Thakur [40]	• CFD code: Fluent • Turbulent model: Realizable k–ε • Mesh: uniform	Nusselt number 73% Friction factor 73%
Gandhi and Singh [41]	• CFD code: Fluent • Turbulence model: k–ω • Mesh: Uniform	Good agreement observed except for the friction factor

4. Conclusion

This Paper critiques the research accomplished with the aid of using numerous investigators so one can beautify the warmth switch with the aid of using use of synthetic roughness.

Use of artificially roughened surfaces with distinctive form of roughness geometries of various shapes, sizes and orientation is determined to be the simplest method to beautify the warmth switch fee with little penalty of friction. Roughness with inside the shape of ribs and cord matrix had been especially advised with the aid of using distinctive investigators to gain higher thermal overall performance. Among all, rib roughness became determined the fine performer as some distance as thermal overall performance is involved.

· Correlations evolved for warmth switch and friction aspect for sun air heater ducts having synthetic roughness of various geometries for distinctive investigators also are proven in tabular shape. These correlations may be used to expect the thermal performance, powerful performance after which hydraulic overall performance of synthetic roughened sun air heater ducts.

5. Scope for Future Work

By the usage of this form of warmness exchanger we boom the performance of any device and we'll additionally inspire the renewable electricity reasserts. We understand that there are constrained reasserts of non renewable electricity reasserts. Some of the essential factor destiny scopes of sun air heater are given below: · Broken willing rib roughness achieved excessively properly in comparison to non-stop willing rib roughness and consequently the overall performance of multi V rib roughness will be advanced with the aid of using introducing hole at appropriate location. · V ribs organized in transverse course which had been examined lately confirmed brilliant overall performance and in destiny those V rib arrays might be organized willing to the course of waft and eventually arrays organized in V kind style might be examined with inside the quest of better warmness Transfer costs. · It became determined that wedge form rib roughness achieved higher than different rib shapes as some distance as warmness switch enhancement fee is involved and consequently wedge form ribs mixed with grooves might be the higher mixture so one can get higher enhancement costs in warmness switch.

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