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Application of Machine Learning and CFD for predicting the performance of a aero foil absorber plate solar air heater

Sandip kumar Sadanand Kumbhar[a], Dr.Shriram Shastri[b]
Avinash Patil[c] Dr.Dilip Deshmukh[d]

[a,] M-Tech Mechanical Engineering (Heat & Power) P.G. Student, [b] Professor, [c&d] Assistant Professor, School of Engineering & Technology (SOET), D. Y. Patil University Pune, Ambi, Maharashtra India.

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ABSTRACT
Although the primary source of energy are fossil fuels they have enormous impact on the environment. Renewable energy resources, on the other hand, do not produce greenhouse gases and are considered more sustainable. Solar Air Heaters (SAH) are the devices which are capable of capturing solar radiations and transform them into thermal energy. SAH's are usually placed outside the buildings to trap solar radiations. In order to improve heat transfer characteristics several approaches have been suggested in which artificial roughness has proved to be an efficient method. In this study computational fluid dynamics (CFD) and machine learning (ML) approaches have been utilized for numerical simulation and optimization of performance of a SAH having aerofoil absorber plate. Six parameters, including four flow-related and two geometrical parameters, were used as inputs for the machine learning model. Ribbed surfaces were found to have a Nusselt number that was 2.64 times higher than flat surfaces, indicating far more efficient heat transfer. The friction factor increased by a proportion of 1.333 compared to a level surface. CFD analysis showed that the optimal pitch for the ribbed surface of the aerofoil was 20 mm, and that the optimal rib height was 1.25 mm, yielding an optimal THPP of 2.494. Following examination of the data, it was established that the THPP value for e = 1.3 and p = 19mm yielded 2.689. The total THPP has thus increased by 7.8 percent from its starting point.
Keywords: CFD, THPP, Artificial Roughness, Machine Learning, Solar Air Heater

I. INTRODUCTION

Households, Industries and Businesses are energy intensive areas which require uninterrupted supply of energy to work efficiently. Energy can be harnessed from non-renewable sources such as coal, petroleum and natural gas as well as from renewable sources such as wind, solar, hydro power and biomass energy. Among the renewable energy sources, solar energy is the most widely used energy sources due to abundant supply of solar radiation and being freely available to mankind. The solar radiations from the sun can be exploited for energy generation in two ways: photovoltaic (PV) and concentrated solar power (CSP). In PV technology, solar panels made from semiconductor materials such as silicon are used which generates electricity due to creation of electron hole pairs created when solar radiations are incident over them. On the other hand, in CSP technology concentrating devices such as lenses or mirrors are used to focus the solar radiations over a heating medium usually fluids to generate electricity. [1]. Applications of Solar Air Heaters (SAH's) include space heating and ventilation purposes using solar radiations with air as a heating fluid. Solar air heaters are typically mounted on the exterior of a building, where they can absorb solar radiation and convert it into thermal energy. Performance of a SAH is governed by various factors such as: Thermal Efficiency, Air Flow Rate, Outlet Air Temperature, Heat Gain, Collector Efficiency, Pressure Drop and Payback Period. To improve the heat transfer characteristics in various devices artificial roughness is employed [2]. CFD is a powerful tool that can be used to simulate and analyze the performance of such devices. Heat transfer enhancement is a broad topic that has been studied for several decades [3]. Singh et. al [4] used ANSYS Fluent to analyse a non-uniform cross sectioned square wave transverse rib roughness on an absorber. Bhattacharyya et. al [5] employed an artificial neural network (ANN) model for regression analysis in order to predict heat transfer and thermohydraulic efficiency. The present study aims to numerically simulate and optimize the performance of aerofoil absorber plate of SAH using CFD and ML techniques.

II. METHODOLOGY

2.1 Model Description

Figure 1 depicts the novel SAH structure proposed by this research. The absorber surface of the new apparatus has a coanda bump-shaped aerofoil roughness. The dimensions such as height of roughness (e), width of aerofoil shape (w) and length of SAH are taken as height, and length are 25 mm, 200 mm and 1000 mm respectively. The magnitude of dimensions are similar to experimental and numerical models explored by earlier investigators [6], [7].

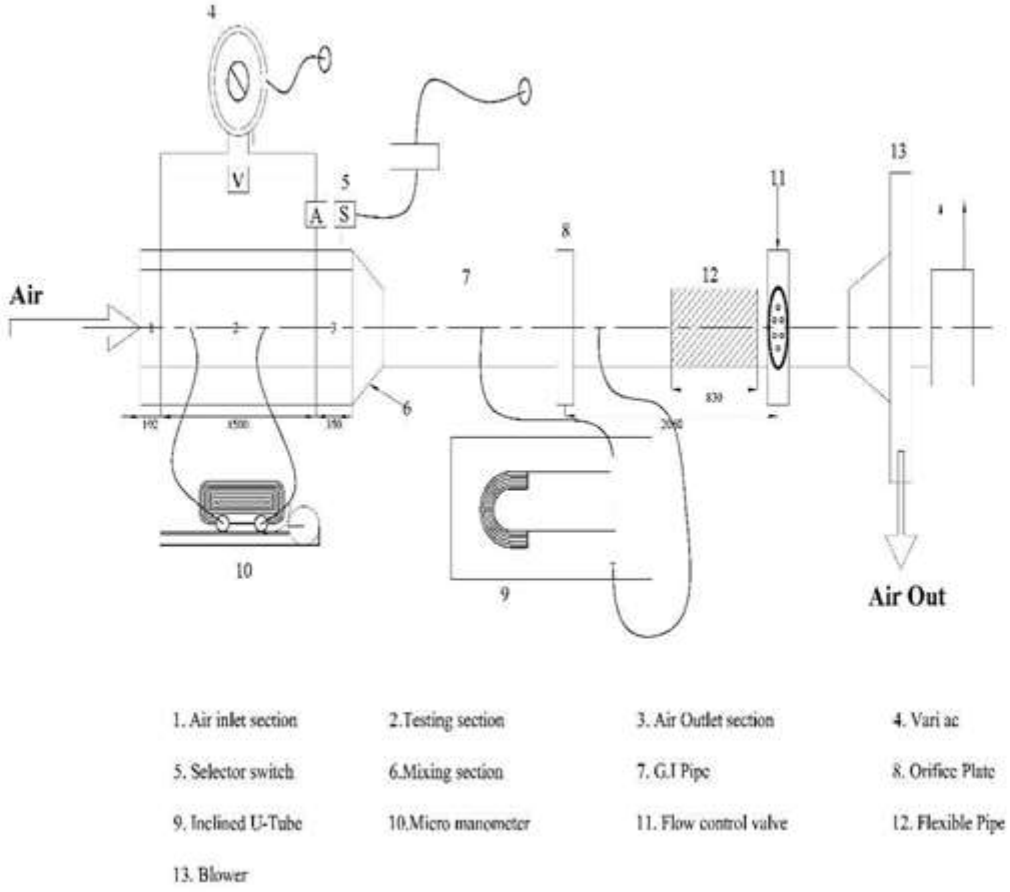


Figure 1 A schematic view of setup of SAH

There are four aerofoil geometrical parameters: the peak point from the leading edge of the coanda protrusion, height, pitch and width of the aerofoil shape. The parameter ranges for the two categories of parameters investigated in this research, pitch and height of the aerofoil, are enumerated in Table 1 below.

Parameters	Values
Height of rough ness(e)	0.5 mm– 1.5mm
Hydraulic diameter of air passage (D_h)=4WH/[2(W+H)]	0.044m
Relative roughness height (e/D_h)	0.0111–0.0334

Stream wise position of the peak point from the leading edge(Pk)	25%
Width of the aerofoil shape (w)	16mm
Roughness pitch(p)	16mm, 20mm, 24mm, 28mm,32mm,36mm
Reynolds number(Re)	3148.71-14529.38
Testing length	1500mm
Solar radiation(I)	$1000W/m^2$

Table1. Range of values of parameters

2.2 Governing Equations:

Continuity Equation: $\nabla\cdot(\rho u)=0$………(1)

Momentum Equations

$\partial(\rho u)/\partial t+\nabla\cdot(\rho uu)=-\nabla p+\nabla\cdot\tau$…………………..(2)

$\partial(\rho v)/\partial t+\nabla\cdot(\rho uv)=-\nabla p+\nabla\cdot\tau$…………………..(3)

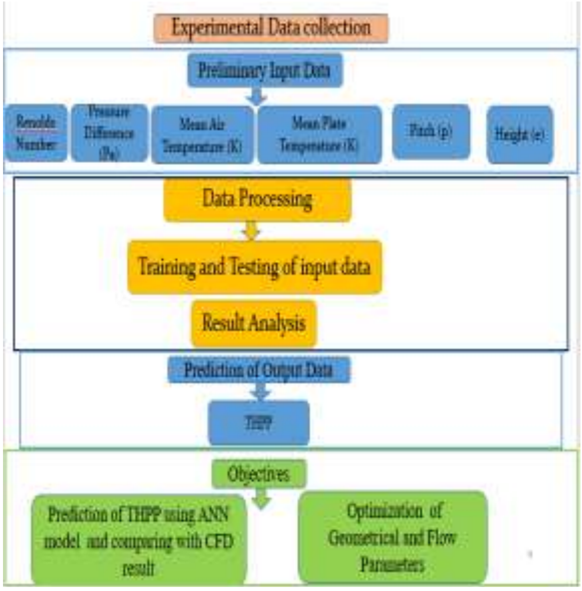
$\partial(\rho w)/\partial t+\nabla\cdot(\rho uw)=-\nabla p+\nabla\cdot\tau$…………………(4)

EnergyEquation

$\partial(\rho E)/\partial t+\nabla\cdot(\rho uH)=\nabla\cdot(k\nabla T)$……………(5)

2.3Methodology

The methodology of building and training ANNs typically involves the following steps:



III. RESULTS AND DISCUSSIONS:

The heat transfer performance of SAH is enhanced due to aerofoil shaped roughness over absorber plate which results in generation of disturbances and vortices on account of improvement in convective heat transfer between absorber plate and air flowing over it. Figure 2 shows the comparison of computational fluid dynamics (CFD) results with predicted values of THPP can be effectively presented in graphical format. Where the predicted values of THPP are plotted on the y-axis and the CFD results are plotted on the x-axis.

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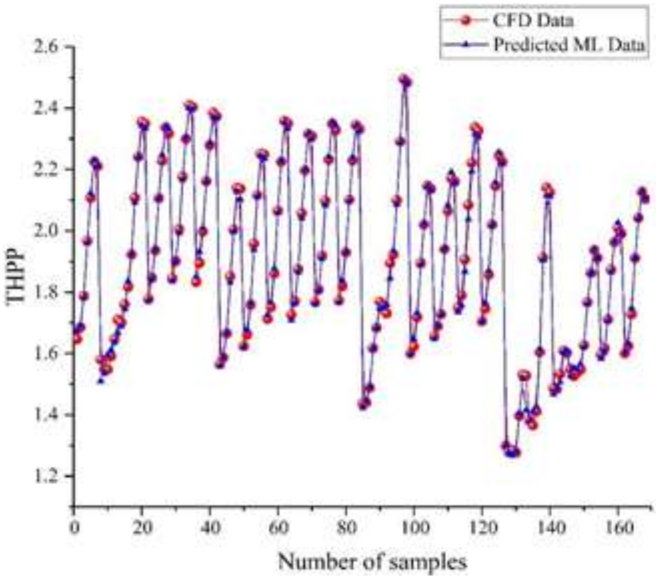

Figure 2. Comparison of computational fluid dynamics (CFD) results with predicted values of THPP

Each point on the plot represents a specific location or time point within the system being studied. To optimize the geometric parameters of the system, a for loop was set up using MATLAB. The for loop iterated over the range of values for each parameter, with the number of iterations depending on the desired resolution and granularity of the parameter values to be explored. This resulted in 1596 data sets being obtained. After analyzing the data sets, it was found that at a geometric parameter e of 1.3 and p of 19mm, the THPP value obtained was 2.689. This represents a 7.8% increase in THPP compared to the initial value. Optimization enabled the identification of geometrical parameters which can positively impact the efficiency of the system.

IV. CONCLUSIONS

This study used numerical simulation and optimisation techniques in combination with machine learning methods to investigate the effects of aerofoil-shaped artificial roughness on the absorber plate of a solar air heater. The modelling using CFD delivered a better understanding of the complex fluid dynamics involved in the heat transfer process and helped to identify the optimal range of parameters that could be used to improve the efficiency of the absorber plate. Six parameters, including four flow-related and two geometrical parameters, were used as inputs for the machine learning model. The Levenberg- Marquardt (LM) algorithm was employed for training the model.

Ribbed surfaces were found to have a Nusselt number that was 2.64 times higher than flat surfaces, indicating far more efficient heat transfer. It was discovered, however, that compared to a level surface, the friction factor increased by a proportion of 1.333.

The computational findings demonstrated that the optimal pitch for the ribbed surface of the aerofoil was 20 mm, and that the optimal rib height was 1.25 mm, yielding an optimal THPP of 2.494.

Following examination of the data, it was established that the THPP value for e = 1.3 and p = 19mm yielded 2.689. The total THPP has thus increased by 7.8 percent from its starting point. Through the optimization procedure, the ideal geometric parameters for enhancing the effectiveness of the aerofoil-shaped roughness were determined.

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