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Heat Exchanger for Exhaust Gas Heat Recovery in a Gas-Based Power Plant: CFD Analysis

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ABSTRACT

Energy is one of the most important components of economic growth. But day by day the existing energy resources are depleting at alarming rate. Hence it is necessary to introduce alternate techniques to conserve the energy effectively. With this an attempt has been made to introduce a ceramic heat exchanger with different cross sections.Early Heat Exchangers provide the foundation for numerous applications in process intensification subjected to un satisfactory mass distribution , thermal stresses arising from uneven heating and cooling etc. In order to overcome the difficulties mentioned above, Ceramic materials have been introduced in place of existing materials. Since ceramic materials offer many benefits including high temperature capacity and corrosion resistance. Special and specific design of the heat exchanger surfaces in ceramic heat exchanger surfaces provide equal distribution of inlet flows.

In this project Ceramic heat exchanger of varying tubes were simulated by computational fluid dynamics method(CFD).The multi shaped structure was imported in to fluent 18.2 versions as a physical model. A ceramic monolith heat exchanger is designed to find out the performance and effectivenessof heat transfer. The numerical computation was performed throughout the domain including fluid region in exhaust gas side, ceramic core and fluid region in air side. The entire computation was carried out by using different cross sections viz., Rectangular, Elliptical and Cylindrical duct with air and exhaust in cross flow direction. After comparison of theoretical and numerical computation it is observed that the estimated heat transfer rate in numerical analysis is 15% more than the theoretical analysis

INTRODUCTION

Now a day's energy is more consuming .There is limited supply of energy due to the deficiency of fossil fuels and they are one of major important factors which produce energy. Oil, natural gas and so many resources are there which the factors of energy are. In present days energy is consuming more in transportation. At current rates of production oil reserves will expire soon. However, an even more important factor is that as production rates start to decline, the limited supply of fossil fuels will become increasingly problematic.

A second more important factor is to develop energy efficient vehicles relates to emissions of greenhouse gases. The combustion of fossil fuels generates CO_2 emissions, which absorb re-radiated heat from the earth's surface and thereby contribute to global warming. This greenhouse effect alters natural marine and carbon cycles, reducing the environment's capacity for CO_2storage. The largest share of the globe's CO_2 emissions (45 %) originated from fossil fuels burned for energy generation. Overall CO_2 emissions have increased by 80% since 1970 (and those from the transportation sector have increased by more than 100 %), contributing to an average atmospheric temperature

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increase of around 0.8°C over the same period . While this may sound small in absolute terms, the long term effects of this trend are predicted to be devastating for life on earth.

There is a need to reduce emissions and minimize the consumption of fossil fuel reserves thus there is strong focus on environmental sustainability in vehicle and engine development. Hence it is clear that usage of electric vehicles should minimize the CO_2emissions which are generated from renewable sources.

As a result a lot of research and development work has been devoted to increasing combustion engine efficiency by reducing these losses. This can be done in various ways, including reducing losses due to mechanical friction, optimizing the engine to increase the efficiency of the combustion process, and creating superior gas exchange paths.

1.1 OBJECTIVES OF PRESENT STUDY

- The present work include following objectives
- Designing of Rectangular, circular and elliptical shapes using CREO-PARAMETRIC 3.0
- Simulating the designs with ANSYS FLUENT 15.
- To enhance heat transfer coefficient of Rectangular, circular and elliptical tubes.
- Calculating the heat transfer rate.
- 5. Calculation of heat transfer coefficient for Rectangular, circular and elliptical shape tubes
- Comparing heat transfer coefficient between optimized shapes of tubes.

1. LITERATURE REVIEW

Young Hawn Yoon[1](2009) In their study they found the performance of heat transfer and pressure drop by numerical computation and ξ-NTU method. By comparisons of both performances by the numerical computation and the ξ-NTU method, the effectiveness by ξ-NTU method was closest to the result by the numerical computation within the relative of 2.14%when Stephan's Nusselt number correlation was adopted to the ξ-NTU method among the several correlations.

Chandrakala[2](2015)- In their study the performance of heat transfer and pressure drop is calibrated by numerical computation. The main aim is to reduce the hot side temperature from 1100oc to 600oc and later it passes through the metallic heat exchanger temperature ranges less than 600oc. By increasing the Reynolds number on the cold air side this increase the velocity of the cold fluid Increase the heat transfer rate also increase the velocity by using nuzzling effect on cold air slot. The main purpose using the ceramic is to withstand with high temperature than metal.

P.Sowjanya[3](2016);In their study they stated that Ceramic heat exchanger has low material cost and also it can withstand high temperatures compared to metallic heat exchanger. Due to this reason it is important to predict the performance of ceramic heat exchanger, before it gets fabricated .In this project CFD analysis is performed on the ceramic heat exchanger having rectangular and circular ducts where aluminum nitride is used to predict and optimize various parameters like heat transfer rate and effectiveness.

2. WORKING OF CFD CODE:

All the CFD codes contain three main elements. They are as follows,

- Pre-processor.
- Solver.
- Post processor.

3.3.1 Pre Processor

It transfers the input of a flow problem to CFD program by means of an operator friendly interface and the subsequent transformation of this input into a suitable format, which can be used by solver. The stage wise preprocessor activities include.

- Determining the geometry of the region of the interest i.e. the computational domain.
- Grid generation or mesh generation (subdivision of the computational domain into small segments, which are called as cells, control volumes)
- Selection of the physical and chemical phenomena that need to be modeled.

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- Definition of fluid properties.
- Specification of appropriate boundary conditions at cells, which coincide with or touch the domain boundary.

The solution to a flow problem (pressure, velocity, temperature etc.) is defined at nodes, corners of each cell. The number of the cells in the grid governs the accuracy of a CFD solution. In general, the larger number of cells the better the solution accuracy, but increases the time required for solution.

3.3.2 Solver

There are three distinct of numerical solution techniques: finite difference, finite element and finite volume method. The outlines of the numerical method that form the basis of the solver perform the following sequence steps:

- Approximation of the unknown flow variables by means of simple function.
- Discretization by substitution of the approximation into the governing equations and subsequent mathematical manipulation.
- Solution of the algebraic equation through an interactive process.

3.3.3 Post Processor

As in preprocessing, a huge amount of development work has recently taken place in the post-processing field. Owing to the increased popularity of engineering workstations, many of which have outstanding graphics capabilities, the leading CFD package are now equipped with versatile data visualization tools. These includes,

3. ANALYSIS OF HEAT EXCHANGER

4.1 Assumptions

1. The governing equations are assumed to be in steady state and taken for compressible fluid.
2. The fluid flowing through the heat sink channel exhibits Newtonian behaviour.
3. The density of the air is taken at constant pressure and at ambient temperature
4. Inlet velocity and temperature of the rectangular and trapezoidal heat sinks isuniform.
5. Uniform air velocity is assumed along the length of the fin
6. The wall resistance and fouling factors are negligible.
7. All the heat rejected from microelectronic processing system assumed to be absorbed in heat sinks.

4.4 NUMERICAL ANALYSIS OF HEAT EXCHANGER

4.4.1. Geometrical Model of rectangular tube heat exchanger;

The geometric model for the rectangular tube Heat Exchanger is as shown in the Fig. 4.2.1

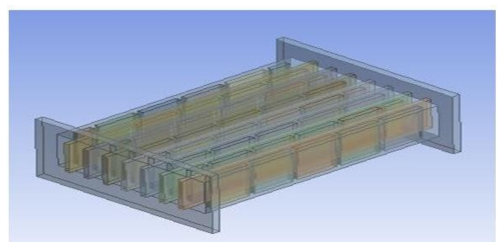

Fig.4.4.1 Fig shows Geometric Model of rectangular tube heat exchanger.

4.4.2. Meshing module of rectangular tube heat exchanger;

The meshing module for the rectangular tube Heat Exchanger is as shown in the Fig. 5.4.2

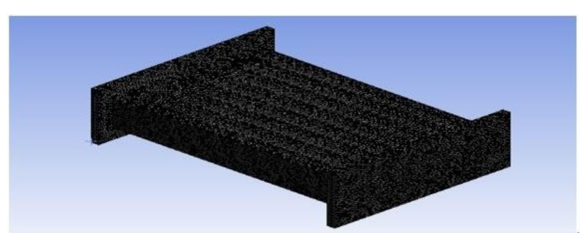

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Fig.4.4.2 shows meshing module of rectangular tube heat exchanger.

4.4.3temperature,Pressureandvelocity distributions ofrectangular Structure:

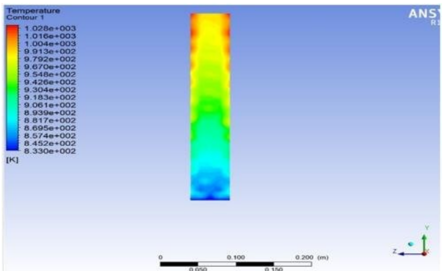

Fig. 4.4.3 Shows Contours Of temperature for rectangular tube heat exchanger at air side

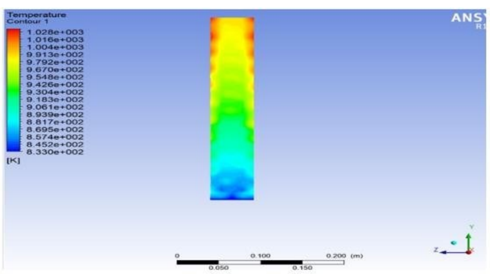

Fig. 4.4.4 Shows Contours Of velocity for rectangular tube heat exchanger at exhaust side

TEMPERATURE, PRESSURE AND VELOCITY DISTRIBUTIONS OF ELLIPTICAL STRUCTURE:

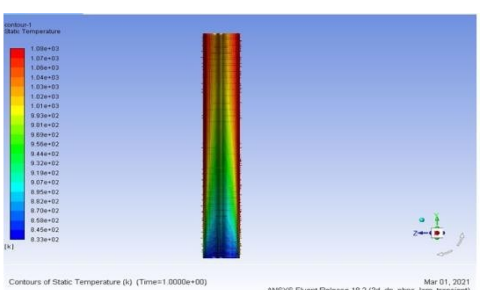

Fig. 4.3.3. Shows Contours Of temperature for elliptical tube heat exchanger at air side

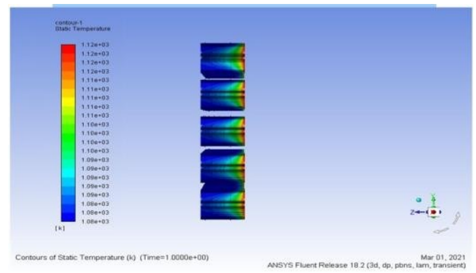

Fig. 4.3.4 Shows Contours Of temperature for elliptical tube heat exchanger at exhaust side

4. Results &Discussion

GRAPHICAL REPRESENTATION:

Fig.5.1. mass flow rate vs. heat transfer rate rectangular tube:

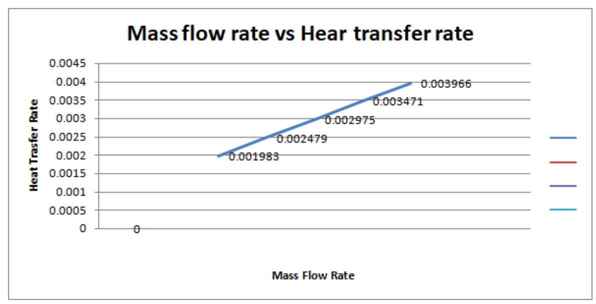

FIG.5.1. mass flow rate VS heat transfer rate

The above Fig.5.1 shows the variation of heat transfer rate with the mass flow rate. As the mass flow rate is increases heat transfer rate is also increases With respect to the mass flow rate. Mass flow ratewillchanges heat transfer rate either rise or fall down and then maximum heat transfer rate will be obtained at 0.003966kg/s.

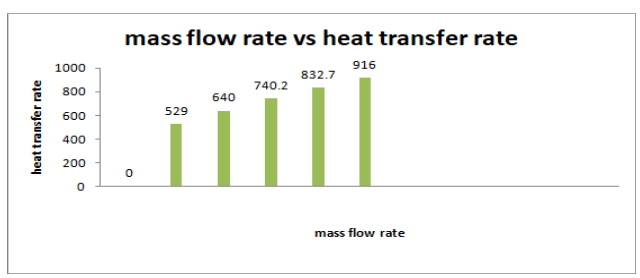

FIG.5.2. mass flow rate VS heat transfer rate

The above Fig.6.2 shows the variation of heat transfer rate with the mass flow rate. As the mass flow rate is increases heat transfer rate is also

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increases With respect to the mass flow rate. Mass flow rate will changes heat transfer rate either rise or fall down and then maximum heat transfer rate will be obtained at 0.003966kg/s of an elliptical tube

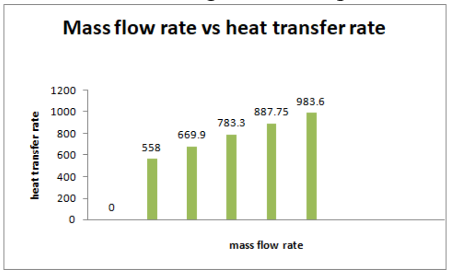

FIG.5.3. mass flow rate VS heat transfer rate

The above Fig.6.3 shows the variation of mass flow rate with heat transfer rate. As the mass flow rate is increases the heat transfer rate is also increases.The above Fig.6.1 shows the variation of heat transfer rate with the mass flow rate. As the mass flow rate is increases heat transfer rate is also increases With respect to the mass flow rate. Mass flow rate will changes heat transfer rate either rise or fall down and then maximum heat transfer rate will be obtained at 0.003966kg/s.

5.6 RESULT TABULAR

Comparison between Reynolds Number & Correlations

Reynolds No		585	736	888	1040	1192
Rectangle	Pressure	0.0198	0.0169	0.00921	0.00650	0.00234
	Velocity	6.231	4.934	2.421	1.0747	0.0543
	Temperature	835.2	834.5	833.12	832.97	831.59
Elliptical	Pressure	0.018064	0.01690078	0.01323807	0.006509	0.00356
	Velocity	0.61700254	0.77143	0.92246	1.0747096	1.098563
	Temperature	833.34	833.15	833.03	832.97	832.56
Cylinder	Pressure	0.227896	0.249018	0.262542	0.293062	0.318870
	Velocity	0.098198	0.196825	1.17370	1.355605	1.5821868
	temperature	832.34	831.01	830.12	829.46	829.16

Comparison between Mass flow rate & Correlations

Mass flow rate	0.001983	0.002479	0.002975	0.00347	0.003966
Reynolds no	585	736	888	1040	1192
Rectangle	525	636.29	736.9	828.86	912.137
Elliptical	529	640	740.2	832.7	916
cylindrical	558	669.9	783.3	887.75	983.6

Effectiveness between rectangle,elliptical and cylindrical shapes from numerical analysis

Comparison between theoretical and numerical effectiveness						
Reynolds no		585	736	888	1040	1192
Effectiveness(Theoretical)	Elliptical	0.41	0.42	0.43	0.45	0.46
	Cylindrical	0.54	0.56	0.57	0.59	0.6
	Rectangle	0.53	0.54	0.55	0.57	0.58
Effectiveness(Numerical)	Elliptical	0.56	0.56	0.57	0.6	0.61
	Cylindrical	0.69	0.71	0.72	0.74	0.75

5. CONCLUSION

In current research the ceramic monolith heat exchanger performance was compared between theoretical and numerical analysis. The theoretical calculations have been executed for the exhaust gas as well as cold air for a measuring domain of 600-1000c. The total heat transfer rate and effectiveness were estimated for theoretical and numerical analysis.The calculations have been executed utilizing NTU method considering numerous Nusselt number correlations taken from the literature.

(1) The performance of the heat transfer by numerical computation was 15% more than theoretical analysis. Among the Nusselt number correlations,the total heat transfer by NTU method with Stephen correlation is more closer to numerical method compared to remaining correlations.

(2) The estimated Effectiveness for rectangular tube heat exchanger,ellipticaltubeheat exchanger and cylindrical tube heat exchanger are 52%, 55% and 62% respectively.

6. FUTURE SCOPE:

In this project the entire work is carried out using ceramic materials of Ni-Cr-Al, NiCrAl + $MgZrO_3$ and $MgZrO_3$. In the same manner it can be carried out by make use of advanced ceramic materials those are high temperature resistant in nature.

Apart from the regular cross sections like Rectangular, Elliptical and Cylindrical, other cross sections can be used by maintaining proper L/D ratio and without varying any mass distribution.

Also instead of simply releasing smoke stack exhaust, it can be used to heat air in the pre heater enabling the pre heater to operate at a lower, energy saving temperature, provided the parameters for a particular application have been established.

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