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DESIGN AND ANALYSIS OF CERAMIC HEAT EXCHANGER

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ABSTRACT

Demand of world energy consumption is steadily growing due to development of industries and increase of population. However, fossil fuels most available at this time will be exhausted in near future. Moreover, the fossil fuels cause environmental pollution and global warming. Therefore, fuel cell systems become interested in energy market for alternative energy sources. Ceramic heat exchanger is one which can with stand high temperatures ranging from 600-1000oC .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.

KEYWORDS: Ceramic Heat Exchangers, Heat Transfer Rates, Effectiveness, Overall Heat Transfer Coefficient

INTRODUCTION

A heat exchanger is a device that is used to transfer thermal energy (enthalpy) between two or more fluids, between a solid surface and a fluid, or between solid particulates and a fluid, at different temperatures and in thermal contact. Heat exchangers are important engineering devices in many process industries since the efficiency and economy of the process largely depend on the performance of the heat exchangers.

The fluids may be separated by a solid wall to prevent mixing or they may be in direct contact. They are widely used in space heating, refrigeration, air conditioning, power stations, chemical plants, petrochemical plants, petroleum refineries, natural-gas processing, and sewage treatment. The classic example of a heat exchanger is found in an internal combustion engine in which a circulating fluid known as coolant flows through radiator coils and air flows past the coils, which cools the coolant and heats the incoming air

.Due to the many variables involved, selecting optimal heat exchangers is challenging. Hand calculations are possible, but many iterations are typically needed. As such, heat exchangers are most often selected via computer programs, either by system designers, who are typically engineers, or by equipment vendors.

To select an appropriate heat exchanger, the system designers (or equipment vendors) would firstly consider the design limitations for each heat exchanger type. Though cost is often the primary criterion, several other selection criteria are important, High/low pressure limits, Thermal performance, Temperature ranges, Product mix (liquid/liquid, particulates or high-solids liquid), Pressure drops across the exchanger, Fluid flow capacity, Cleanability, maintenance and repair, Materials required for construction, Ability and ease of future expansion

Material selection, such as copper, aluminum, carbon steel, stainless steel, nickel alloys, ceramic, polymer, and titanium. Small-diameter coil technologies are becoming more popular in modern air conditioning and refrigeration systems because they have better rates of heat transfer than conventional sized condenser and evaporator coils with round copper tubes and aluminium or copper fin that have been the standard in the HVAC industry.

Heat exchangers can be classified in a number of ways, depending on their construction or on how fluid move relative to each other through the device. There are various heat exchangers in which some heat exchangers are,

Double pipe heat exchanger

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Shell and tube heat exchanger
Compact heat exchanger
Cross flow heat exchanger

Ceramics

The word "ceramic" came from Greek word it means pottery.
A ceramic is an inorganic,nonmetal or metalloid atoms primarily held in ionic and covalent bonds

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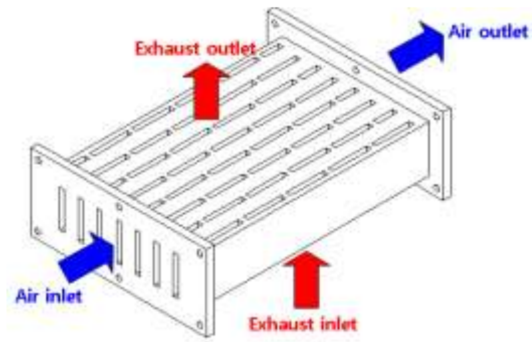

Schematic diagram of ceramic heat exchanger

Low temperature - Although ceramic heat exchangers lend themselves to medium and high temperature applications, they can be used in the 500°F to 1400°F range. If the flue gas is corrosive and/or abrasive, the machine is a practical piece of equipment to preheat combustion air for dryers and other similar processes
Medium temperature - Most ceramic exchangers are designed for the 1400°F to 2200°F range, and Heat Transfer International has several full size exchangers operating successfully in these ranges.
High temperature - Special ceramics can be incorporated into the Heat Transfer International heat exchanger to take temperatures up to 2400°F

MATERIALS AND METHODS

Silicon Carbide, SiC Ceramic Properties

Silicon Carbide is the only chemical compound of carbon and silicon. It was originally produced by a high temperature electro-chemical reaction of sand and carbon. Silicon carbide is an excellent abrasive and has been produced and made into grinding wheels and other abrasive products for over one hundred years. Today the material has been developed into a high quality technical grade ceramic with very good mechanical properties. It is used in abrasives, refractories, ceramic s, and numerous high-performance applications. The material can also be made an electrical conductor and has applications in resistance heating, flame igniters and electronic components. Structural and wear applications are constantly developing.

Key Silicon Carbide Properties

Low density
High strength
Low thermal expansion
High thermal conductivity
High hardness
High elastic modulus
Excellent thermal shock resistance

Silicon Carbide Typical Uses

Fixed and moving turbine components
Suction box covers
Seals, bearings
Ball valve parts
Hot gas flow liners
Heat exchangers
Semiconductor process equipment

General Silicon Carbide Information

Silicon carbide is composed of tetrahedra of carbon and silicon atoms with strong bonds in the crystal lattice. This produces a very hard and strong material. Silicon carbide is not attacked by any acids or alkalis or molten salts up to 800°C. In air, SiC forms a protective silicon oxide coating at 1200°C and is able to be used up to 1600°C. The high thermal conductivity coupled with low thermal expansion and high strength give this material exceptional thermal shock resistant qualities. Silicon carbide ceramic s with little or no grain boundary impurities maintain their strength to very high temperatures, approaching 1600°C with no strength loss. Chemical purity, resistance to chemical attack at temperature, and strength retention at high temperatures has made this material very popular as wafer tray supports and paddles in semiconductor furnaces. The electrical conduction of the material has lead to its use in resistance heating elements for electric furnaces, and as a key component in thermistors (temperature variable resistors) and in varistors (voltage variable resistors).

Aluminum nitride ,(ALN) ceramic properties

Aluminum nitride (ALN), a covalently bonded ceramic, is synthesized from the abudant elements aluminum and nitrogen. It does not occur naturally.

ALN is stable in inert atmospheres at temperatures over 2000oC.It exhibits high thermal conductivity but is, uniquely , strong dielectric this unusual combination of properties make ALN a critical advance material for many future applications in optics ,lighting, electronics and renewable energy.

Key Aluminum Nitride(ALN)properties

High thermal conductivity (70-180Wm-1K-1).Theoretically thermal conductivity of ALN is 280Wm-1K-1.
Low thermal expansion coefficient ,close to that of Silicon
Good dielectric properties
Resistant to corrosion and erosion
Excellent thermal shock resistance
Chemically stable up to 980oC in H2 and CO2 atmospheres, and in air up to1380oC

Typical uses of Aluminum Nitride

Opto-electronics,
Dielectric layer in optical storage media,
Electronic substrates ,chip carriers where high thermal conductivity is essential,
Military applications

General Aluminum Nitride information

Aluminum nitride has a hexagonal crystal structure and is a covalent bonded material. The use of sintering aids and hot pressing is required to produce a dense technical grade material. The material is stable to very high temperatures in inert atmospheres. In air, surface oxidation begins above 700°C. A layer of aluminum oxide forms which protects the material up to 1370°C. Above this temperature bulk oxidation occurs. Aluminum nitride is stable in hydrogen and carbon dioxide atmospheres up to 980°C. The material dissolves slowly in mineral acids through grain boundary attack, and in strong alkalis through attack on the aluminum nitride grains. The material hydrolyzes slowly in water. Most current applications are in the electronics area where heat removal is important. This material is of interest as a non-toxic alternative to beryllia. Metallization methods are available to allow AlN to be used in place of alumina and BeO for many electronic applicationsnon-toxic alternative to beryllia. Metallization methods are available to allow AlN to be used in place of alumina and BeO for many electronic applications.

METHOD

The design parameters of the ceramic heat exchanger was considered from the paper" A THEORETICAL ANALYSIS AND CFD SIMULATION ON THE CERAMIC MONOLITH HEAT EXCHANGER" by Young Hwan Yoon.

Modeling of ceramic heat exchanger by using NX-CAD software.

Create finite volume mesh for 3D model of ceramic heat exchanger by using ANSYS ICEM CFD software and import into ANSYS FLUENT software.

Perform flow analysis of ceramic heat exchanger using ANSYS Fluent software to determine the flow rate.

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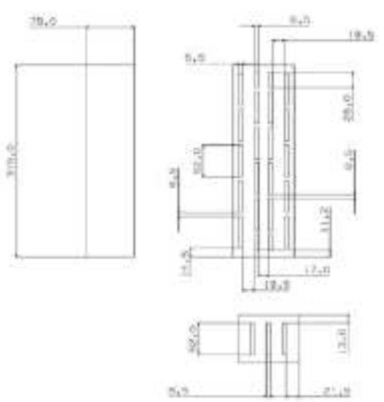
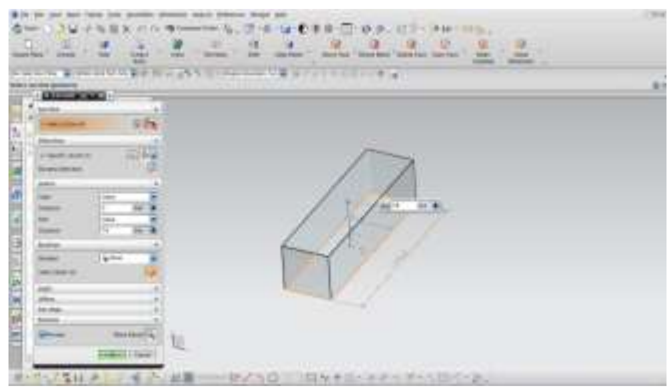
The model of ceramic heat exchanger was taken from the reference papers (a theoretical analysis and CFD simulation on theceramic monolith heat exchanger) .The 3D model of the ceramic heat exchanger is created using NX-CAD software from the 2D drawings. NX-CAD is the world's leading 3D product development solution. This software enables designers and engineers to bring better products to the market faster. It takes care of the entire product definition to serviceability. NX delivers measurable value to manufacturing companies of all sizes and in all industries.



2D Modeling of Ceramic Heat Exchanger



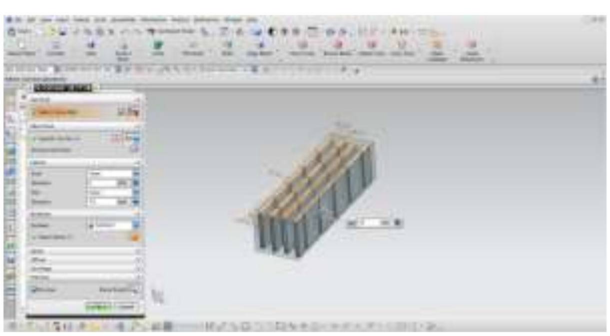
Generation of rectangle cube

Step1: open NX-CAD> goto new>save as name as rectangle.11>click on ok

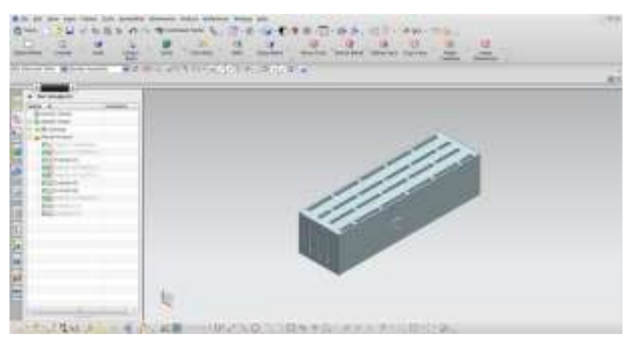
Step2: goto Insert>sketch in task envirnoment>select the XY plane

Step3:goto rectangle command>give the dimensions315X78mm>finish the sketch

Step4:go to extrude option>select the plane and extrude to 105mm



Extrusion of exhaust side rectangle slots



Final rectangle ceramic heat exchanger

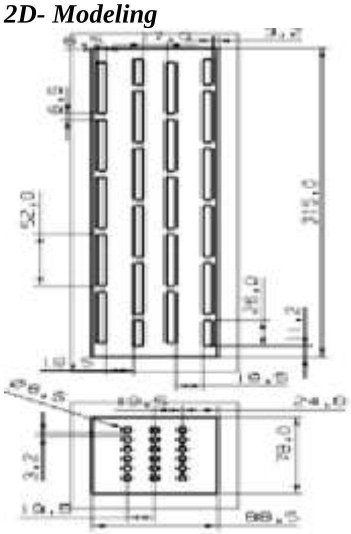
Step 5: go to rectangle > draw rectangle 52X6.5 >finish the sketch

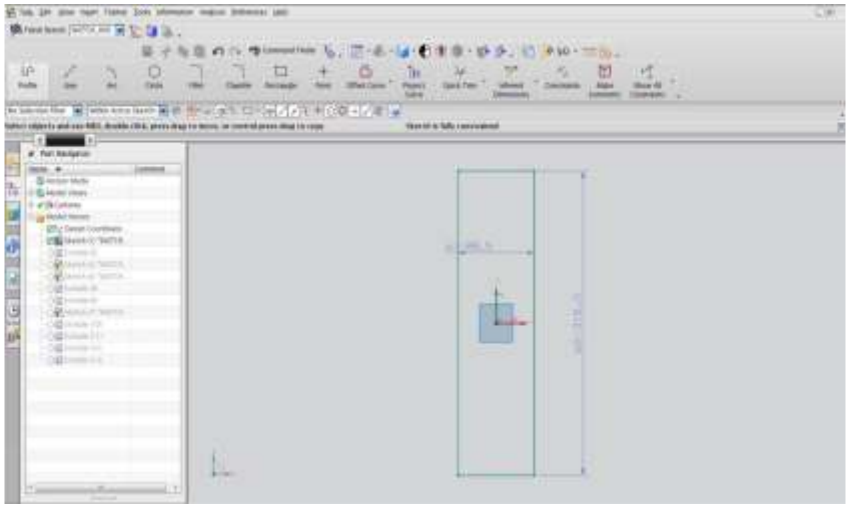
Step 6: go to Boolean operation > select the sketch > subtract

Step 7: select x-z plane and sketch the rectangles 52X6.5 > finish sketch

Step 8: go to Boolean operation > select the sketch > subtract

2D- Modeling



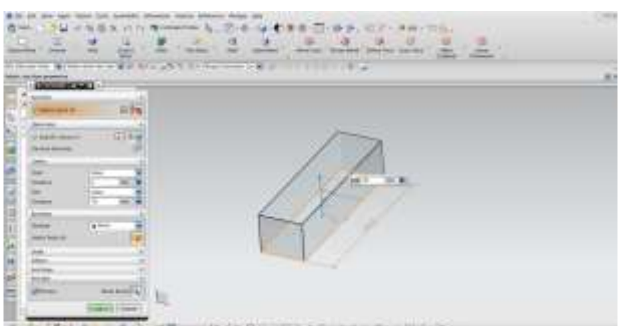


2D-model of ceramic heat exchanger ***Sketch of circular ceramic heat exchanger***

Step1: open NX-CAD> goto new>save as name as rectangle.11>click on ok

Step2: goto Insert>sketch in task envirnoment>select the XY plane

Step3:goto rectangle command>give the dimensions315X78mm>finish the sketch

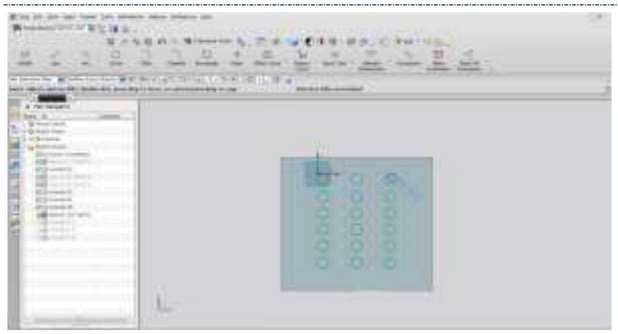


Generation of rectangle cube ***Extrusion of rectangle slots***

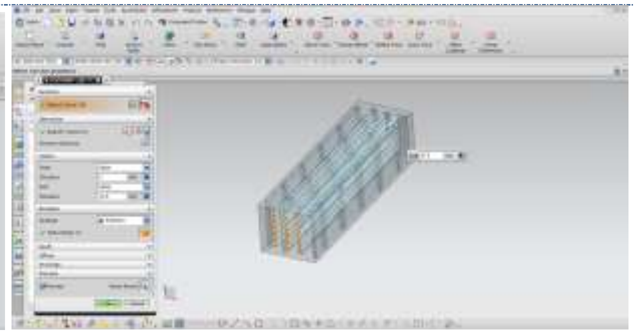
Step4:go to extrude option>select the plane and extrude to 105mm

Step 5: go to rectangle > draw rectangle 52X6.5 >finish the sketch

Step 6: go to Boolean operation > select the sketch > subtract



Sketch of circular tubes



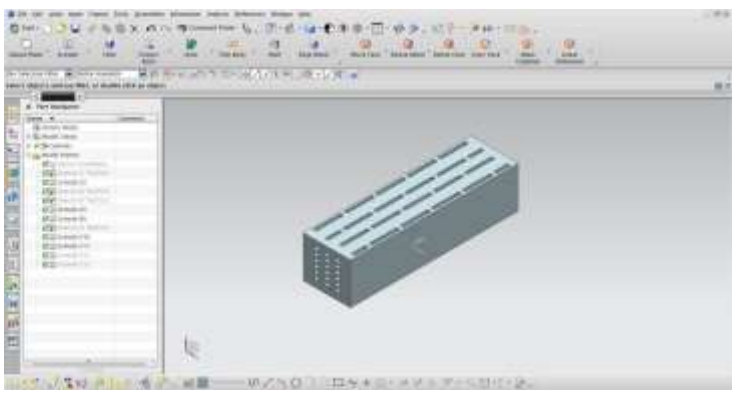
Extrusion of circular tubes

step 7: select x-y plane > draw circle 6.5 > finish sketch

step 8: go to pattern > select the circle > go to curve >select linear object(select axis)>go to count and spacing >count 6 > pitch 16 > ok

step 9: repeat the same for required model

Step 10: go to Boolean operation > select all the circles > subtract



Model of circular ceramic heat exchanger

FLOW ANALYSIS OF CERAMIC HEAT EXCHANGER

CONSTRUCTING THE DOMAIN AND MESHING

CFD allows virtual experimentation and consequently optimization of parameters, such as fluids at different temperatures and wide range of operating boundary conditions. It is very attractive to industry as it saves both time and effort during the design process when compared to alongside traditional experimental methods. However, the degree of confidence in the results is dependent on many factors. In pre-processing stage, the ceramic heat exchanger was designed and meshed using edge and face meshing in order to take care of the sleekness, the figure of the ceramic heat exchanger is shown below. The domain was meshed by using tetrahedral meshing technique. For the flow analysis, the ceramic heat exchanger is generated in NX-CAD and mesh is created in the ICEM CFD software. The domain was meshed using tetrahedral meshing technique.

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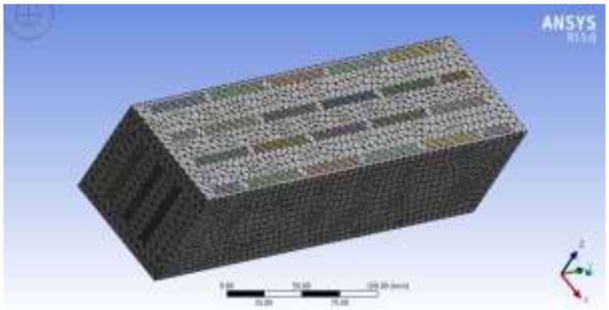
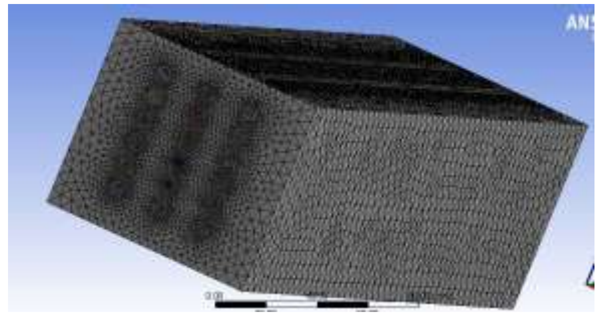


Mesh of rectangle tube heat exchanger



mesh of circular tube heat exchanger

BOUNDARY CONDITIONS:

The CFX software comes with different boundary types which synchronize with the physical conditions. The CFX boundary model has been incorporated which uses "VELOCITY INLET' boundary types for fluid inlet. Flow velocity (5.02m/s) is given as inlet boundary condition for ceramic heat exchanger and temperature of 1123k is given as cool inlet boundary condition, temperature of 833k is given as hot inlet boundary condition. At outlet "OUTLET VENT" is given as the boundary condition. Wall and fluid path are coupled in the boundary condition for heat transfer.

THE SIMULATION APPROACH:

After the meshing has been completed the model is then imported into ANSYS FLUENT pre- processor and suitable boundary types defined. The finite volume approach which is used in ANSYS FLUENT is used to create the solver. The governing equations are then integrated over the whole control volume

All the inputs given for the analysis are shown below:

Title: Models

Model	Settings
Space	3D
Time	Steady
Viscous	Standard k-epsilon turbulence model
Wall Treatment	Standard Wall Functions
Heat Transfer	Enabled

Material: air (fluid)

PROPERTY	UNITS	VALUES
Density	kg/m3	1.225
Cp (Specific Heat)	j/kg-k	1006.23
Thermal Conductivity	w/m-k	0.0242
Viscosity	kg/m-s	1.789e-5
Molecular Weight	kg/kg-mol	28.966
Thermal Expansion Coefficient	1/k	0

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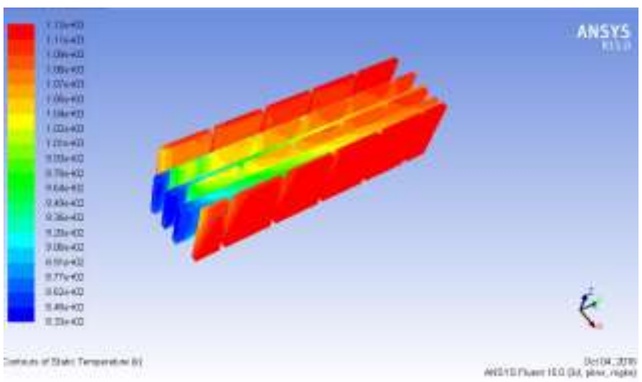
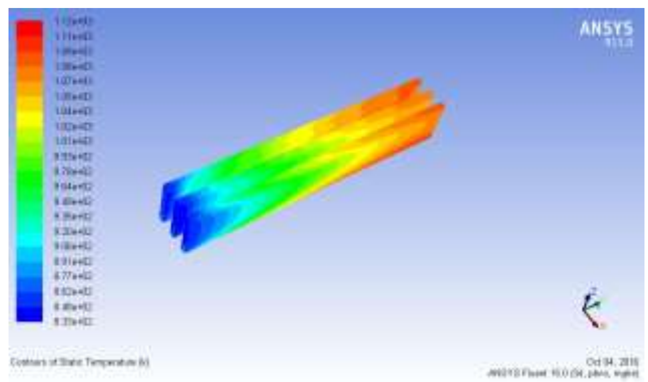
MATERIAL: Aluminum nitride(solid):

PROPERTY	UNITS	VALUES
Density	kg/m3	3260
Cp (Specific Heat)	j/kg-k	740
Thermal Conductivity	w/m-k	170

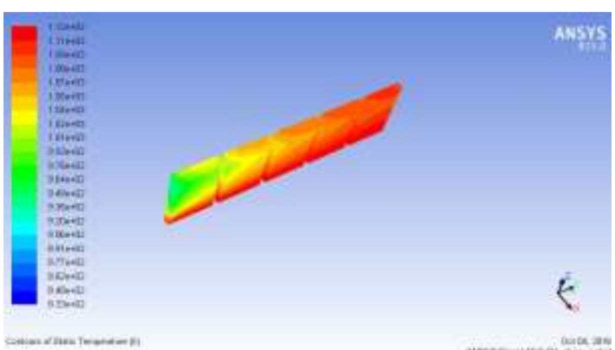
RESULTS AND DISCUSSION
RECTANGULAR CERAMIC HEAT EXCHANGER



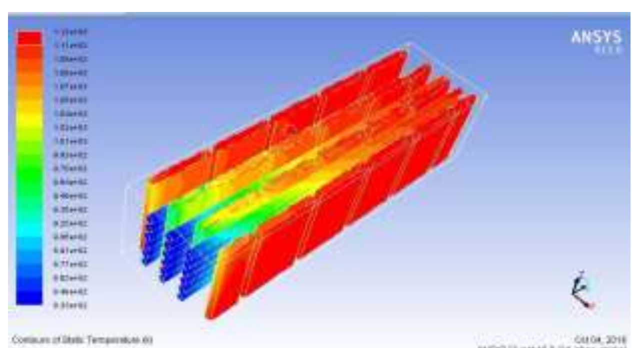
Overall heat exchanger after analysis



air side variation of temperature



Exhaust side slots



over all view of Ceramic heat

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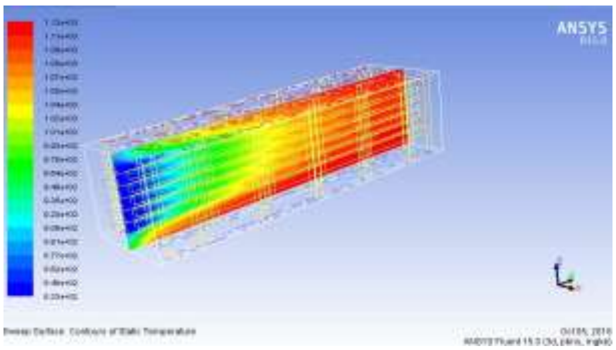
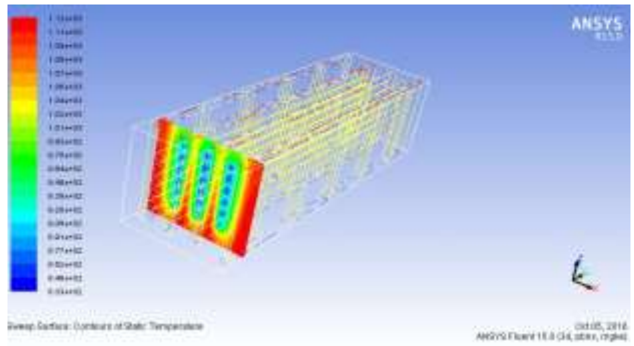
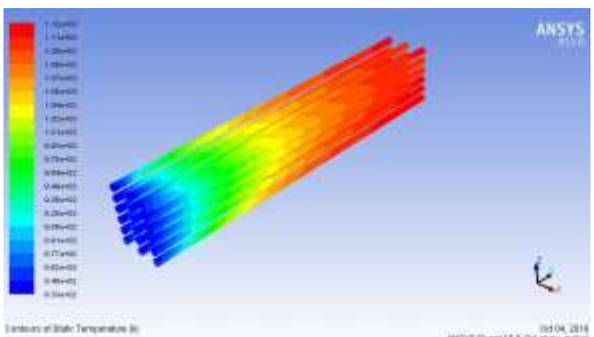
CIRCULAR CERAMIC HEAT EXCHANGER

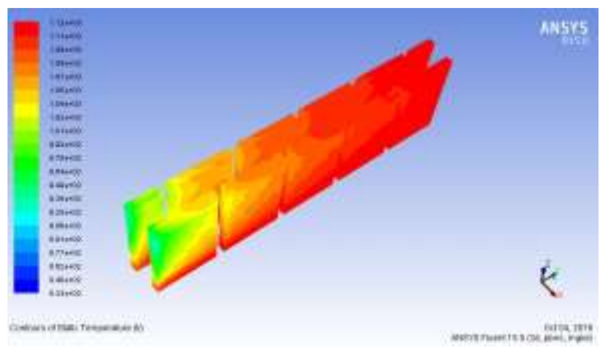




sweep surface ceramic heat exchanger in x-z plane

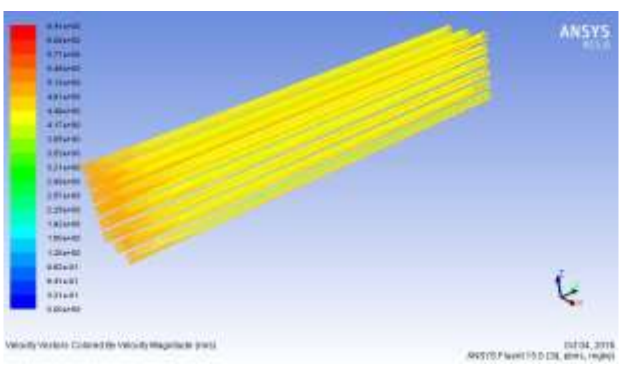
sweep surface of circular ceramic heat exchanger x-z plane

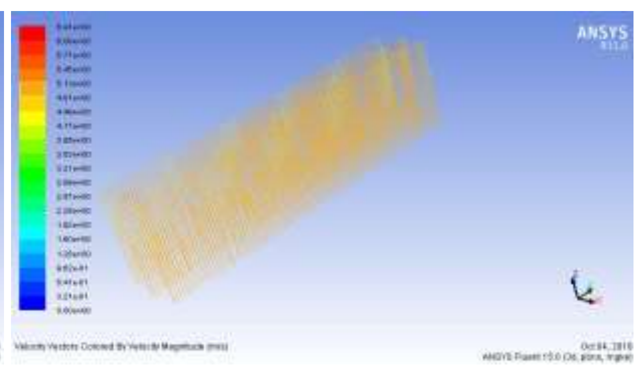




temperature distribution in all circular pipes

counter Temperature in exhaust side ceramic heat exchanger





Velocity distribution in a circular pipes

velocity contours in circular ceramic heat exchanger

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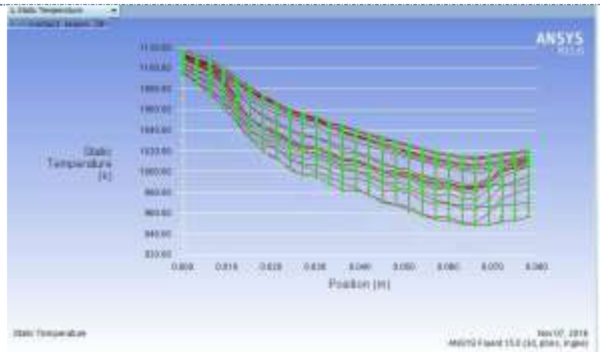
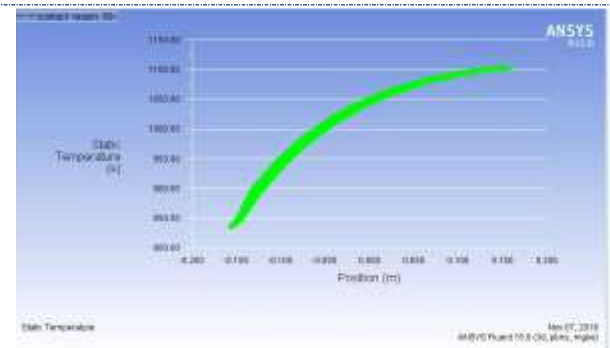
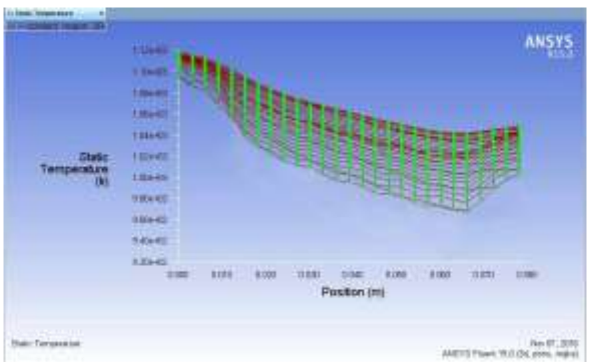
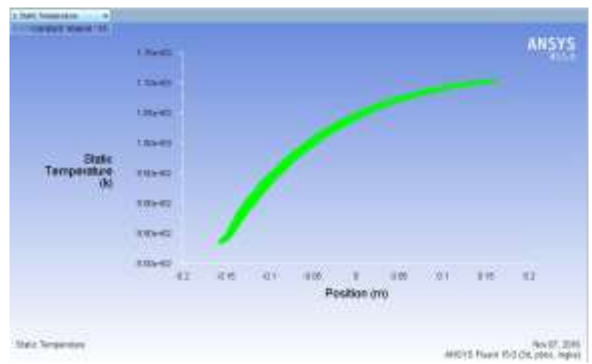




Graph along width for circular ceramic heat exchanger Graph along length for circular ceramic heat exchanger





Graph along width for rectangle ceramic heat exchanger

Graph along length for rectangular ceramic heat exchanger

RESULTS AND DISCUSSIONS

In this project a 3D model of Ceramic heat exchanger is done. The generated 3-D model was imported into ANSYS CFD software using the parasolid format and fluid flow analysis was done on Ceramic heat exchanger. Temperatures at cool air outlet are analyzed by performing fluid flow analysis of Ceramic heat exchanger for inlet velocity and inlet temperature boundary conditions. Optimization of model has been done to improve the heat exchange process. NX-CAD was used for generating 3D model and ANSYS CFD software is used for performing fluid flow analysis.

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S.no	Model	Inlet temperature of cool air (Kelvin)	Inlet temperature of hot air (Kelvin)	Outlet temperature of cool air (Kelvin)	Outlet temperature of hot air (Kelvin)	Effectiveness
1	Original rectangle	833	1123	973	995	0.48
2	Modified rectangle	833	1123	981	978	0.53
3	Circular	833	1123	996	964	0.56

Calculation of C for cold fluid :

C= Mass flow rate * specific heat

C=mc

=0.001983*1111.7

C= 2.20450W/K

Calculation of C for hot fluid:

C= Mass flow rate * specific heat

C=mc

=0.001983*1138.7

C=2.2580W/K

From this Cmin= 2.20450 and Cmax= 2.2580

C= Cmin/Cmax

= 2.20450/2.2580

C=0.9763

Calculation of U for modified rectangle:

By taking C= 0.97630 and

From the base paper "THREE DIMENSIONAL NUMERICAL ANALYSIS OF CERAMIC HEAT EXCHANGER"

Effectiveness (ξ)

Rectangular

ξ=(T air out – T air in) / (T gas in – T air in)

(981 - 833) / (1123 – 833)

ξ =0.51

effectiveness (ξ)= 0.51

From the graph

NTU = 1.2

NTU = UA/Cmin

Surface area of a rectangle (A) :

A = 2(L*W+L*H+W*H)

2(315\1000*6.5/1000+315/1000*52/1000+6.5/1000*52/1000)

A = 0.03675m2

Therefore

NTU = UA/Cmin

1.2 = U*0.03675/2.20450

U= 71.9836W/m2K

Calculation of U for Circular :

By taking C= 0.97630 and

From the base paper "THREE DIMENSIONAL NUMERICAL ANALYSIS OF CERAMIC HEAT EXCHANGER" Effectiveness (ξ)

Circular :

ξ = (T air out – T air in) / (T gas in – T air in)

= (996-833) / (1123-833)

ξ =0.56

From the graph:

NTU = 1.5

NTU = UA/Cmin

Surface area of circular

$A = 2\pi r^2 + 2\pi rh$

=2*π*(3.25/1000)2+2* π ∗ 3.25/1000*315/1000

A=6.49*10-3m2

1.5 = U*6.49*10-3 / 2.2045, U=508.83W/m2K

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CONCLUSION

The Simulation work is successful and the work is validated in the thesis.In this study simulation is carried out for hot exhaust ,ceramic core, and cold air in the ceramic heat exchanger then to improve the heat transfer rate of ceramic heat exchanger.A circular tubes where placed in place of rectangle duct a comparison is also made for rectangular duct and circular tube heat exchanger to show which gives better performance.

The various conclusions drawn from the thesis work are:

- Temperature variations has been analyzed by performing fluid flow analysis of rectangle slot ceramic heat exchanger is 978K for inlet temperature boundary conditions .And for circular slot ceramic heat exchanger is 964K.
- Effectiveness for rectangle slot ceramic heat exchanger is 51%, and for circular slot ceramic heat exchanger is 56%.
- From the calculations the overall heat transfer rate of circular heat exchanger is 7times better than the rectangular heat exchanger.
- Hence optimization has been done to improve the efficiency. From the above results we observed that the modified ceramic heat exchanger is more efficient that original model.

ACKNOWLEDGEMENTS

The satisfaction that companies the successful completion of any task would be incomplete without the mantion of people who made it possible and whose constant guidance and encouragement crown all the effort with success.
I feel elated to extend my sincere gratitude to Mr.P N SARMA, Head of the Department, Mechanical Engineering, for his encouragement all the way during analysis of the project. His annotations, insinuations and criticisms are the key behind the successful completion of the report and for providing me all the required facilities.
I would like to express gratitude and indebtedness to Mr.M GANESH KUMAR, Assistant Professor, Department of Mechanical Engineering, for his valuable advice and guidance without which this project would not have seen the light of the day, Also, I thankful to Mr.CH VENKATA ANVESH, Assistant Professor, Department of Mechanical Engineering for his assistance and cooperation in Providing all the requirements for successful completion of project.

REFERENCES

[1] [1] Young Hwan Yoon1, Jin Gi Paeng2 and Ki Chul Kim3. Theoreticalanalysis and cfd simulation on the ceramic monolith heat exchanger. Flucome 2009.
[2] [2] Sundaresan Subramanian, Valery Ponyavin,Clayton Ray DeLOsier,YitungChen,AnthonyE.Hechanova. Design considerations for compact ceramic offset strip-Fin high temperature heat exchanger. Engineering conferences international,Hoboken,NJ,USA,September 2005
[3] [3] A. Sommers a, Q. Wang b , X. Han b , C. T'Joen c , Y. Park d , A. Jacobie. Ceramics and ceramic matrix composites for heat exchangers in advanced thermal systems. Applied thermal engineering 2010 (1-15)
[4] [4](Chandrakala N S, Hanoca P, Naveenakumar R) presents Three Dimensional Numerical Analysis of Ceramic Heat Exchanger
[5] [5] (PrabalTalukdarPrabalTalukdar) Associate Professor Department of Mechanical Engineering Department of Mechanical Engineering IIT Delhi