GRD Journal for Engineering | Volume 3 | Issue 6 | May 2018
ISSN: 2455-5703

Design & Analysis of Exhaust Heat Recovery System

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Abstract

The exhaust gases from the IC Engine caries away about 30% of heat of combustion. The energy available in the exit stream goes as waste, if not utilized properly. The major technical constraint that prevents implementation of ways to heat recovery system is due to its intermittent and time mismatched demand and availability of energy. In the present work, a storage container is integrated with IC engine setup to extract heat from the exhaust gases using a copper plate being heated by forced convection. The performance parameters pertaining to the heat recovery such as amount of heat covered, temperature achieved at every RPM, velocity of exhaust gases and flow curves will be evaluated, analyzed and reported. The feasibility, advantages and disadvantages of the project have also been discussed.
Keywords- Exhaust, Silencer, Copper Plate, Convection, Conduction

I. INTRODUCTION

Till now, many types of heat recovery systems have been developed but our project pertains to continuous heating of food items to be delivered by delivery boys on a bike. It is a food container coupled with the exhaust of a bike engine being heated by the exhaust gases flowing through the exhaust chamber. It uses a copper plate which acts as a heating surface for the food items. The need of the project is derived from the results of the survey and its applications are wide. Full design along with thermal and fluent analysis has been done and reported. The results are thoroughly discussed and future scope of work has been mentioned.
First of all we noted down the objectives of our task as:-
- To do literature survey on heat transfer and various heat recovery system.
- To select an appropriate heat recovery system according to our need.
- To prepare a mathematical model as well as a CAD model of the system.
- To manufacture and do an experimental analysis.
- To perform data collection and validation.

A. Need

It is often seen that food delivered to home (e.g. pizzas, restaurant food etc.) is not found to be warm enough by the time it gets delivered and nobody likes cold food, do we? Since most of the food is delivered on bikes, we felt that the exhaust heat could be used to maintain the temperature of the food items inside the container being heated by a copper plate during delivery.

Table 1: Tools and Equipment Used

SR. No	Quantity Name	Number	Description or Conversion
1	Mild Steel Plates(walls)	04	6”*12”
2	Mild Steel Plates(base)	01	12”*12”
3	Mild Steel Supports	02	1.5”(height)

4	*Copper Plate*	*01*	*12”*12”*
5	*Inlet Pipe*	*01*	*1”(diameter)*
6	*Outlet Pipe*	*01*	*0.4”(diameter)*
7	*Fiber Plate*	*01*	*12”*12”*
8	*Hinges*	*02*	*-*
9	*Plaster of Paris*	*5kg*	*-*
10	*File*	*01*	*-*
11	*Hammer*	*01*	*-*
12	*Screw Driver*	*01*	*-*
13	*Aluminium Tape*	*01*	*-*
14	*Araldite, M-seal*	*01*	*-*
15	*C-clamps*	*02*	*-*

B. Design Idea

The basic model consists of a box of 12 x 12 sq. inch base with 6 inch walls. There are two pipes inserted into the box diagonally for inlet and outlet of exhaust gases. The walls and base of the box are made of 1.5 mm thick steel plates. The inlet and outlet pipes have 1’’ and 1.5’’ diameters respectively. The reason for choosing steel plates is its low thermal conductivity so that less heat is transferred to the side walls. The whole box is insulated with Plaster of Paris to prevent heat loss from the outside surfaces and eliminate potential danger of injury or burns from the hot plates. The exhaust chamber is separated from the food container using a copper plate which is fixed at a height of 1.5 inch from the base and supported diagonally using two steel struts with square cross section. Copper plate acts as a heating surface for food items. The reason for choosing copper is its high conductivity and easy machinability. The inner surfaces of the walls are covered with Aluminium tape to make the surfaces re-reflecting. The top of the box is covered with a fiber sheet which is hinged to one of the walls.

C. Fabrication

The four walls and base are joined together using gas welding. Pipes are inserted into the previously notched walls and joined permanently by gas welding. The copper plate is supported by two steel struts and fastened to the walls using M-seal. M-seal serves two purposes; it holds the plate fixed with the walls as well as prevents leakage of gases from the exhaust chamber. All the walls are insulated with POP to reduce heat losses and eliminate potential danger.

D. Advantages

- The project aims to keep food warm during the whole course of delivery so that the consumer receives fresh hot food.
- The project utilizes exhaust gases from the engine which were being thrown into the atmosphere directly.
- Application of this project results in reduced air pollution to some extent as some of the polluting particles get deposited inside the box.
- The project is an improvement over the existing design used by delivery boys.

E. Disadvantages

- Deposition of unburnt carbon particles on the base plate of the box.
- Vibrations in the copper plate due to high velocity of exhaust gases.
- Increase in noise due to turbulence in the flow of exhaust gases.

We used Computer Aided Engineering approach to make our project. We focused on various fundamental aspects of design which are listed below:

F. Recognition of Need

We found that delivery boys could actually use this concept for delivery of food items. This would help them in maintaining the appropriate temperature of food stuff for a sufficient amount of time. We surveyed different delivery outlets of various companies to get a first-hand opinion about the application, usage and feasibility of the concept.

G. Generation of Alternate Designs

1) Design 1

We first thought of a tube and shell type heat exchanger which gets mounted on the exhaust of a bike. Exhaust gases carrying heat flow through the tube while mineral oil flows in the shell after getting heated up. This oil is utilized in heating a container in which food items are kept. After dumping heat into the container, the oil is circulated through the system again. This goes on and after a few minutes, steady state is achieved.

2) Design 2

A food container separated from the exhaust chamber by a copper plate to be heated directly by exhaust gases through forced convection.

H. Reasons for Dropping and Adopting Ideas

1) Design 1

Why did we drop it??

When we run experiments on mineral oil, it didn't flow much due to its high viscosity and stickiness. Temperature had little effect on the viscosity of oil. Low flow rates would have led to less heat transfer through the container and hence the idea was not feasible.

2) Design 2

Reasons for adopting this idea:

- Minimalistic design.
- Easy flow of exhaust gases.
- Leakage of exhaust gases is prevented.
- More heat transfer.

I. Other Fundamental Aspects of Design

1) Modelling

After adopting this idea and checking its feasibility, we made a CAD model of the project on CATIA using the same dimensions. We also developed a mathematical model for calculations of heat transfer. Convection combined with conduction is the basis of calculations of heat transfer through the copper plate.

2) Experimentation and Testing

As far as experimentation is concerned, all experiments are run on Pulsar 200cc engine for the collection of temperature data for analysis on ANSYS. Both fluent and thermal analysis was done; results were collected and discussed upon.

II. AUTHOR GUIDELINE FOR MANUSCRIPT PREPARATION

A. CAD Modelling

Modelling software CATIA is used to make the CAD model of the product. Various views have been shown for giving complete description of the project.

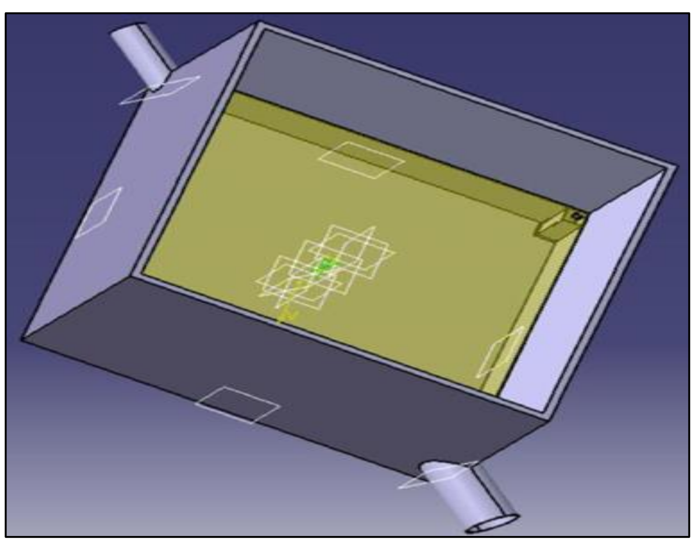

Fig. 1: Isometric View

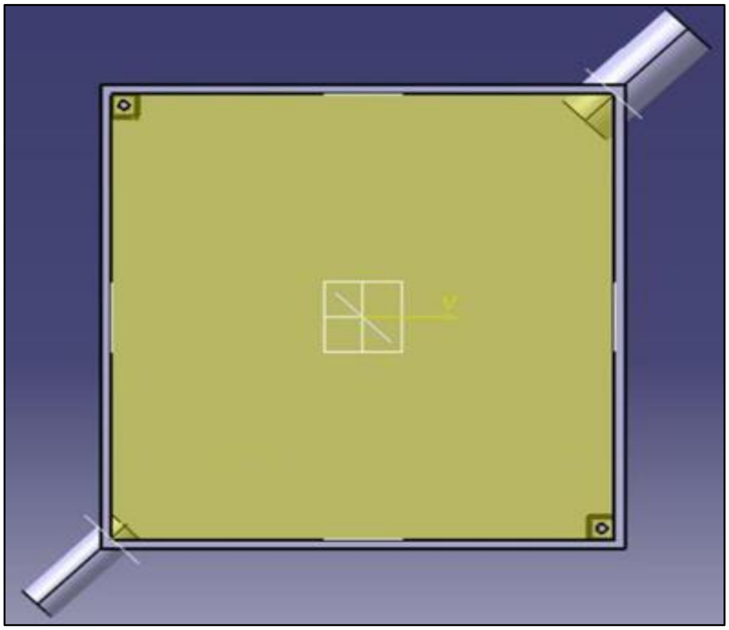

Fig. 2: Top View

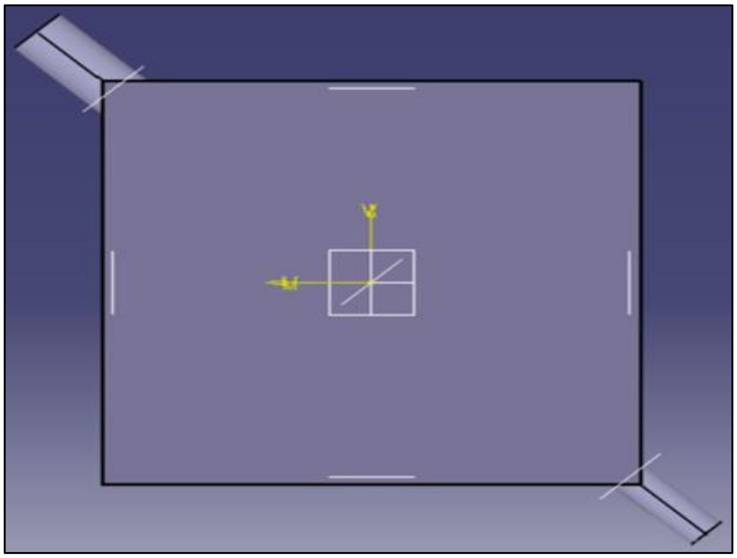

Fig. 3: Bottom View

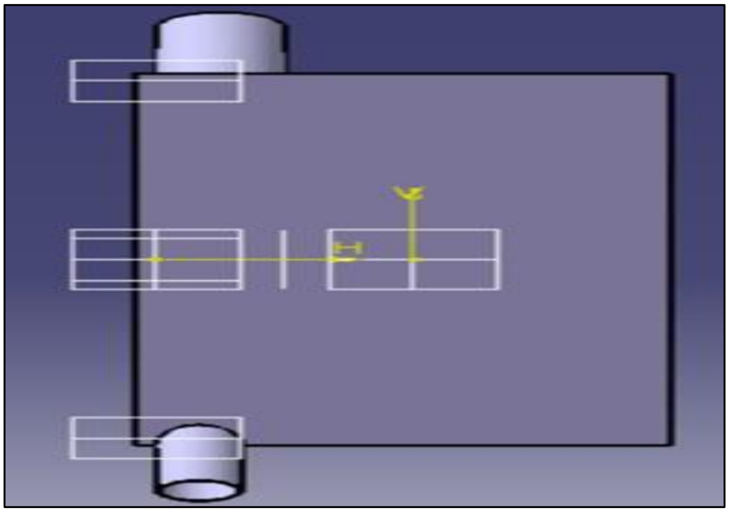

Fig. 4: Left Side View (V)

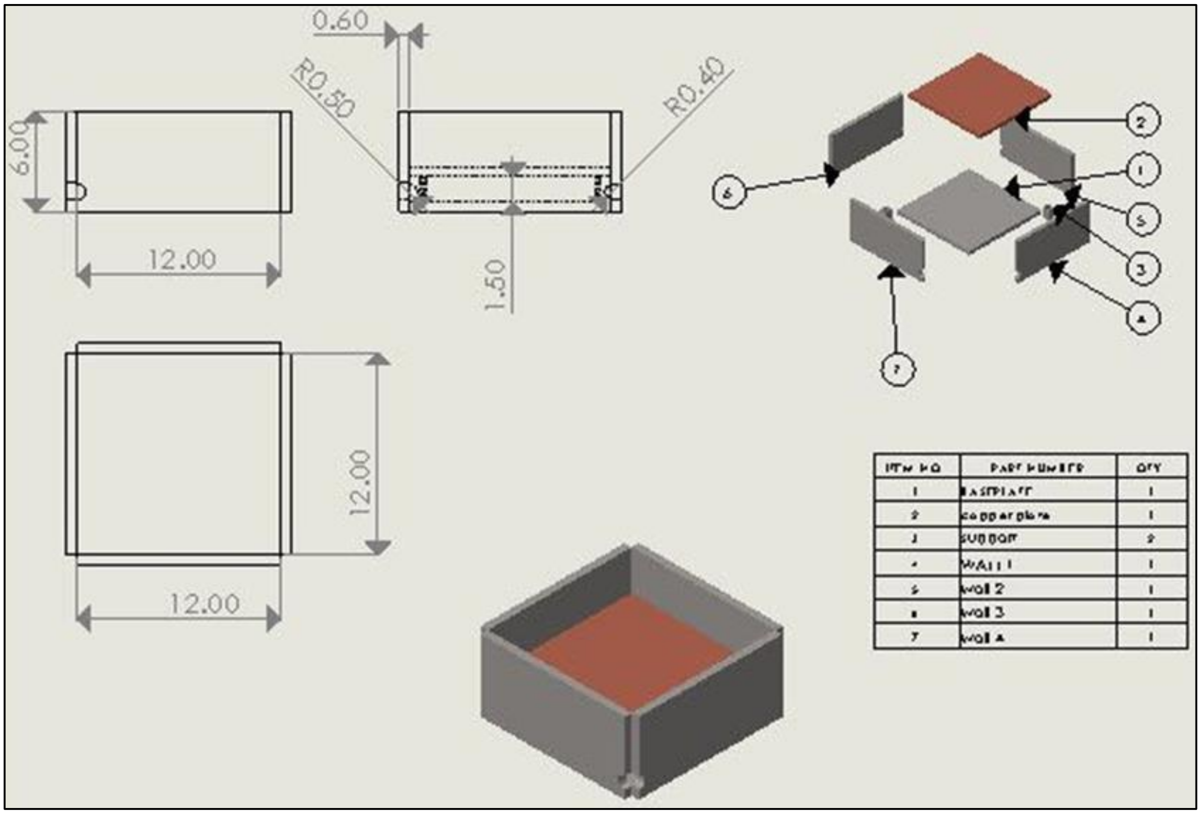

Fig. 5:

III. FLUENT AND THERMAL ANALYSIS

Analysis software ANSYS was used and we have worked with the Fluent 15.0 and transient thermal modules which use the FVM (finite volume method) for analysis purpose and the various profiles namely
Velocity profile
Pressure profile
Turbulence
Were obtained as per the textbook values.

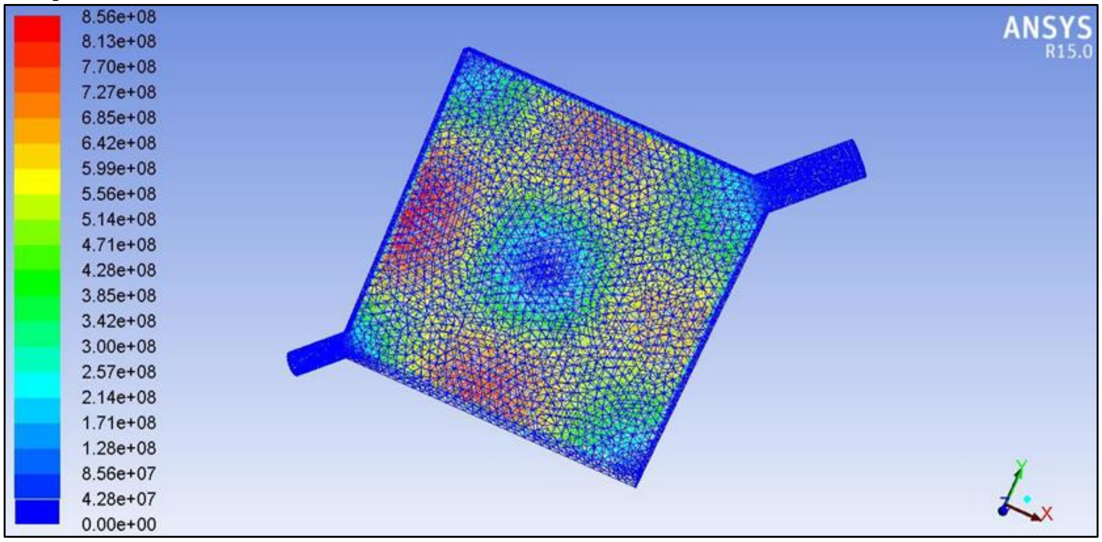

Fig. 6: Velocity Profile at 10,000 RPM

The velocity at maximum RPM was 17.2 m/s. As we can see the velocity contours show a value of 8.56 X 10^8 which extends up to a certain mesh. The exhaust which enters through the inlet pipe has highest velocity at opposite edges and lowest velocity at the center.

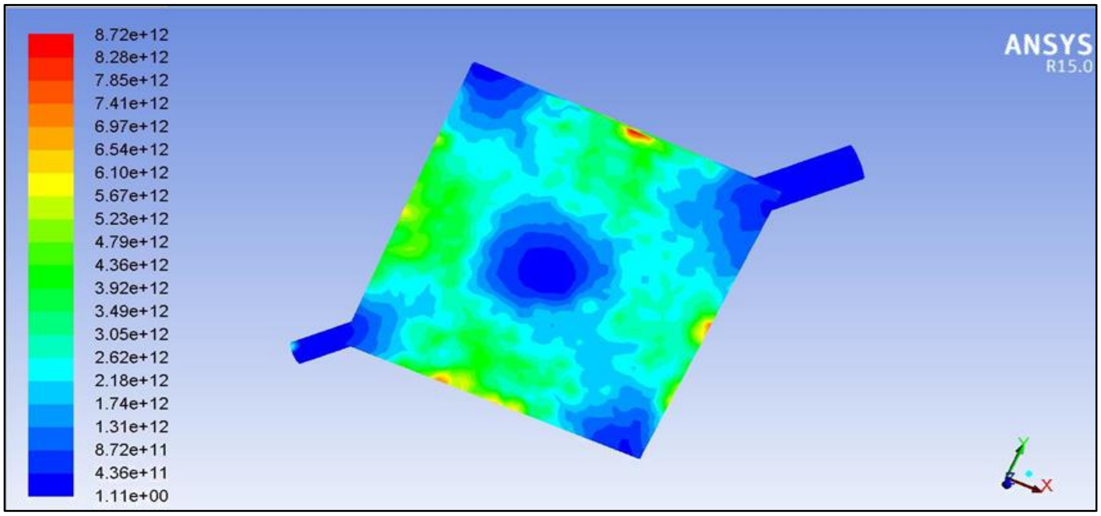

Fig. 7: Turbulence at 10,000 RPM

At maximum RPM, turbulence is maximum at edges adjacent to the inlet and outlet pipes whereas turbulence is minimum at the center.

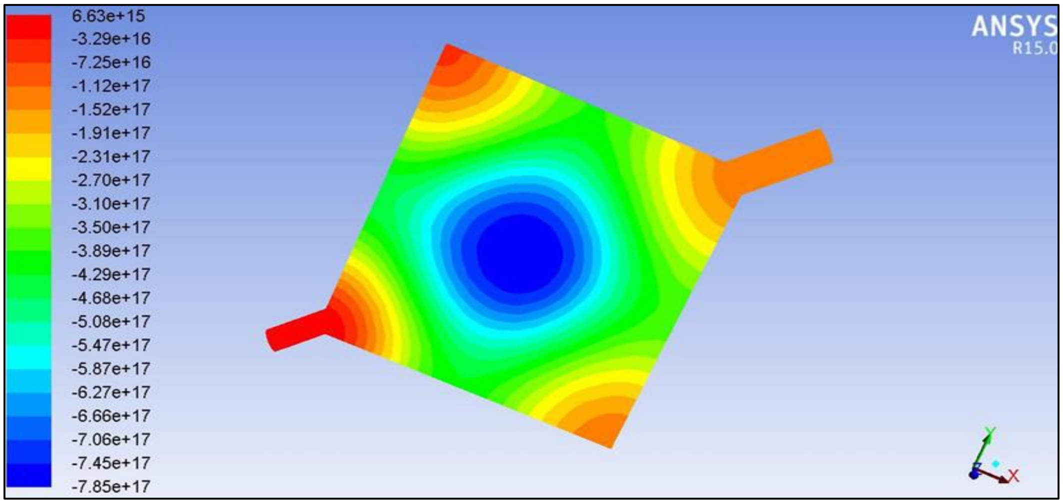

Fig. 8: Pressure Profile at 10,000 RPM

As expected, maximum pressure occurs at the outlet pipe due to minimum velocity at outlet pipe. Minimum pressure was observed at center.

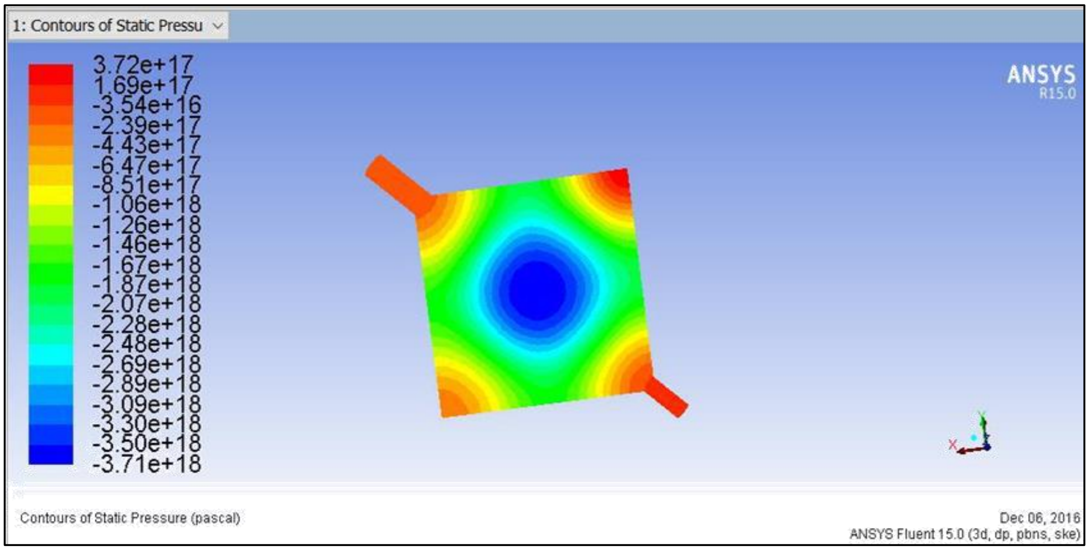

Fig. 9: Pressure Profile at 5,000 RPM

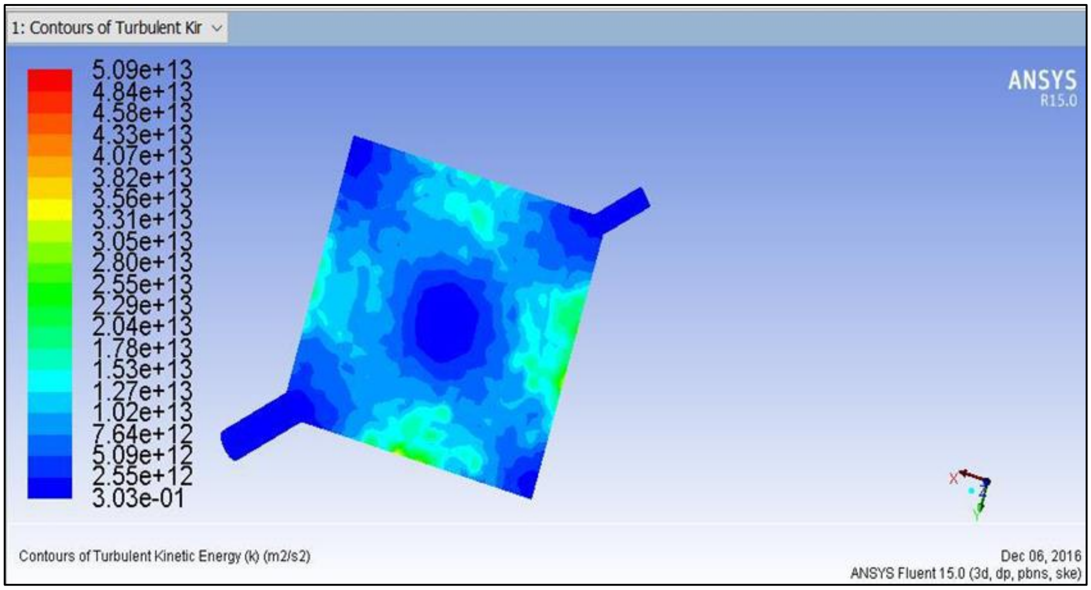

Fig. 10: Turbulence at 5,000 RPM

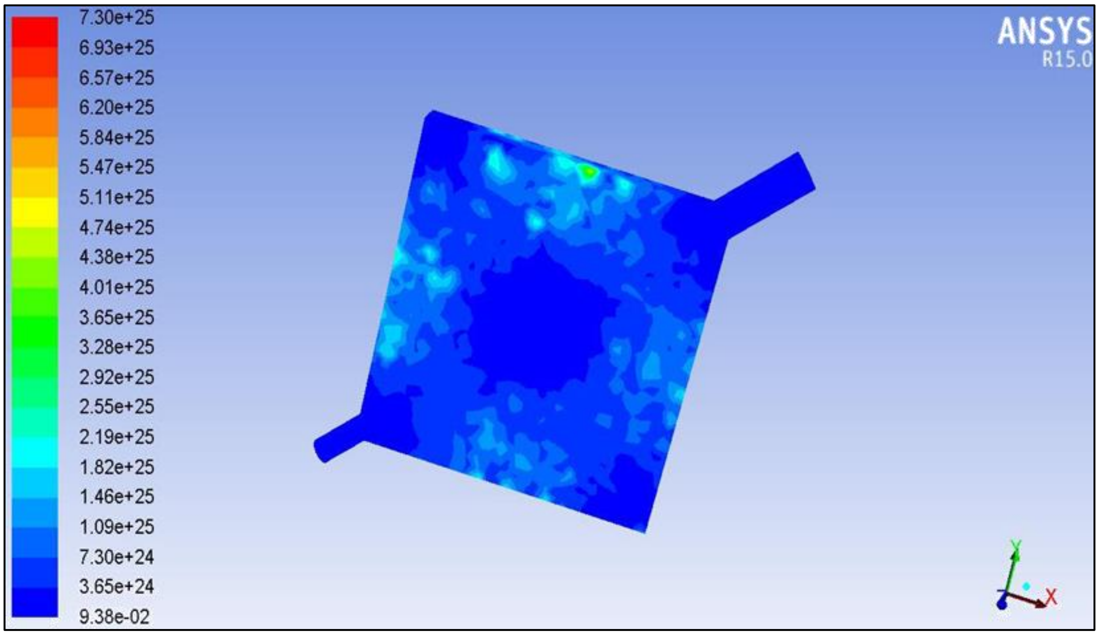

Fig. 11: Turbulence at 3,500 RPM

IV. Future scope

Once the project is successfully accomplished, we will use smarter materials to minimize heat losses. This can be achieved by running the system with different insulating materials. If possible, we will also try to improve the inlet, outlet and container design. We will use plastic foils to cover the food materials so that they don't lose heat as they are being heated.

We will devise a cleaning mechanism for the project as well as try to minimize the vibration levels during highly turbulent flows.

V. Mathematics

A. Available Data

1) Engine Specs of Pulsar 200 NS Motorbike

Displacement = 199.5 cc (4-stroke engine)
Test Speed = 3500, 5000 and 10500 rpm
Bore = 72 mm , Stroke = 49 mm

Length of plate (L) = 12 inches = 30.48 cm = 0.3048 m Width of plate = 12 inches = 30.48 cm = 0.3048 m
Diameter of inlet pipe of the recovery system = 0.03m
Exhaust Gas Velocity at 3500 Rpm
Exhaust strokes take place in 1750 evolutions of the crankshaft.
Exhaust volume flow rate= (Displacement)*(Speed in rpm)/ (No. of exhaust strokes)
= (199.5 cc * 3500)/4 min. = 349125 cc/min.
= 0.005818 cubic meter/sec.
Bore Area =3.14*0.25*(Bore dia^2)
= 4.0694*10-3sq m.
Velocity of piston = Stroke*2*rpm =0.049*2*3500=343m/min = 5.716m/sec.
So the exhaust velocity of the gases at the outlet of the engine = 5.716m/sec.

B. Analysis of Heat Transfer

The inlet temperature of exhaust at inlet of enclosure = 150C.
Outlet temperature of the gases = 50C
Taking the mean temperature to take the thermal properties; Tm = (150+50)/2 =100C
Inner temp. of copper plate =40C
Properties of exhaust gases at temperature = (40+100)/2 i.e. 70C are:
Kinematic Viscosity (v) =$18.738*10^{-6}$ m^2/sec.
Thermal conductivity (K) = 0.008915 W/mK
Specific Heat (C)= 1060.2 J/kgK
Density(d) = 1.0535 kg/m^3
Prandtl no (Pr)= v*d*c/K
=($18.738*10^{-6}$ *1.0535*1060.2/0.08915)
=2.34
Volumetric Coefficient (b) = 1/(273+70) = $2.915*10^{-3}$ K^{-1}
Since the flow takes place along the diagonal of the plate, length of the flow is taken to be L*sqrt(2) = 0.3048*sqrt(2) = 0.431m
Reynolds No. of the flow (Re) is given by
Re = Vbox*L/v
=5.716*0.431/($18.738*10^{-6}$)
=131475
Since the value of the Reynolds no. of the flow is less than $5*10^5$, flow is laminar.
Now the Grashoff no. of the flow, Gr is given by:
Gr = g*b*(Tm-Ti)*L^3/v^2
=$9.81*2.915*10^{-3}*60*0.431^3/(18.738*10^{-6})^2$
=$3.912*10^8$
To find the type of convection taking place, we calculate the value of Gr/Re^2
=$(3.912*10^8)/(131475)^2$
=0.02
Since this value is less than 1, the type of convection is forced convection.
Now, Value of average Nusselt no. is given by the correlation;
Nuavg= $0.664*Re^{0.5}Pr^{0.33}$; Pr is 2.608 which is greater than 0.6
Therefore Nuavg= $0.664*(131475)^{0.5}*(2.34)^{0.33}$
=318.737
So the value of heat transfer coefficient will be;
h=Nuavg*k/L h= 318.737*0.0089/0.431
=6.67 W/mK
Exhaust Gas Velocity at 10500 Rpm
Exhaust strokes take place in 5250 evolutions of the crankshaft.
Exhaust volume flow rate= (Displacement)*(Speed in rpm)/ (No. of exhaust strokes)
=(199.5 cc * 10500)/4 min. = 523687.5 cc/min.
=0.008728 cubic meter/sec.
Bore Area =3.14*0.25*(Bore dia^2)
=$4.0694*10^{-3}$sq m.
Velocity of piston = Stroke*2*rpm =0.049*2* = 1029 m/min = 17.15 m/sec.
So the exhaust velocity of the gases at the outlet of the engine = 17.15 m/sec.

C. Analysis of Heat Transfer

The inlet temperature of exhaust at inlet of enclosure = 250C.
Outlet temperature of the gases = 80C

Taking the mean temperature to take the thermal properties; Tm = (250+80)/2 = 165C Inner temp. of the copper plate(Ti) = 60C
Properties of exhaust gases at temperature = (165+60)/2 i.e. 112.5 C are:
Kinematic Viscosity (v) =22.9475*10^{-6} m^2/sec. Thermal conductivity (K) = 0.01432 W/mK
Specific Heat (C)= 1071.6 J/kgK
Density (d) = 0.924 kg/m^3 Prandtl no (Pr)= v*d*c/K
=(22.9475*10^{-6} *0.924*1071.6/0.01432)
=1.58
Volumetric Coefficient (b) = 1/(273+112.5) = 2.594*10^{-3} K^{-1}
Since the flow takes place along the diagonal of the plate, length of the flow is taken to be L*sqrt(2) = 0.3048*sqrt(2) = 0.431m
Reynolds No. of the flow (Re) is given by
Re = Vbox*L/v
=17.15*0.431/(22.9475*10^{-6})
=322111.34
Since the value of the Reynolds no. of the flow is less than 5*10^5, flow is laminar.
Now the Grashoff no. of the flow , Gr is given by:-
Gr = g*b*(Tm-Ti)*L^3/v^2
=9.81*2.594*10^{-3}*105*0.431^3/$(22.9475*10^{-6})^2$
=4.06*10^8
To find the type of convection taking place, we calculate the value of Gr/Re^2
=(4.06*10^8)/$(322111.34)^2$
=0.00391
Since this value is less than 1, the type of convection is forced convection.
Now, Value of average Nusselt no. is given by the correlation;
Nuavg= 0.664*$Re^{0.5}Pr^{0.33}$; Pr is 2.608 which is greater than 0.6 Therefore Nuavg= 0.664*$(322111)^{0.5}$*$(1.58)^{0.33}$
=438.255
So the value of heat transfer coefficient will be; h=Nuavg*k/L h= 438.255*0.01432/0.431
=14.56W/mK

VI. Conclusions

This project aimed at providing an alternate way of generating heat with the use of I.C. engines which may be in vehicles, labs or any other applications. Although the major application was observed in the food delivery industry where previously temperature insulating materials were used and the company policy for delivery temperature was never achieved to the perfect mark. As per the survey we conducted the market response for delivery temperatures was 50-55 ◦C which was achieved while taking in consideration the previous backlogs associated with this project such as:

- Stalling of engine.
- No heating or very low heating.
- Contamination of food with exhaust gases

All these problems were solved during the conceptual visualization of the project and temperatures of about 50 ◦C were achieved and recorded. Also, the market responded positively and was very encouraging towards such a project because the crispiness of the food which was a major consideration for many of the food delivery outlets was lost. So this project also solved this particular problem by providing a convective and conductive environment to prevent the food from such a delivery aftermath. Since a constant temperature equal to the delivery temperature is maintained throughout the course of the delivery so the delivery boys need not hurry!

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