Design and Analysis of Thermo-Fuel Production Plant

[1]Abhijeet Patil, [2]Vishal Palkar, [3]Sandeep Chirde, [4]Hemant Shukla, [5]Prof. Vivekanand Navadagi
[1, 2, 3, 4]UG Scholars, Department of Mechanical Engineering, DPCOE, Pune.
[5]Assistant Professor, Department of Mechanical Engineering, DPCOE, Pune.

***Abstract:-* In present study, plastic wastes (polyethylene) were used for the Pyrolysis to get fuel oil that has the same physical properties as the fuel used in aviation industry. The experiment was carried out in two ways, first, thermal Pyrolysis (without the aid of a catalyst) and second, catalytic Pyrolysis (with the aid of a catalyst). The catalyst used for the experiment is Zeolite and silica-alumina in proportion of 1:1. Pyrolysis runs without oxygen and in high temperature of about 500^0C, which is why a reactor was constructed for the reaction and a furnace designed to provide the required temperature. This study shows that the Pyrolysis of polyethylene requires a temperature of about 550ºC and catalyst to waste ratio of 1:10 for it to yield the highest quantity of hydrocarbon. This study also involves the complete Design and Analysis of the Furnace. Various types of analysis like CFD Analysis, Thermal Analysis and Structural analysis were carried out for the Furnace and delivery Pipe of the thermo-fuel experimental setup. This Study focuses completely on the Design, Analysis and Production of Waste Plastic Fuel.**

Keywords:-* Catalytic cracking, silica-alumina, Waste Plastic Disposal, Waste Plastic oil, Engine Emission , Polyethylene, CFD Analysis.

I. INTRODUCTION

Waste plastic has become a very serious environmental problem due to increase use of plastic. Waste plastic being non degradable possess disposal problems and also it cannot be easily recycled and it results in it quality degradation during recycling. Plastic waste goes through total photo degradation and turns into plastic dust which enters in food chain and causes complex health issues to Habitats. Waste plastic is mostly dispose in landfills and sea which results in land pollution and water pollution.

Plastic Production and its use had increase at an alarming or rapid rate in the span of 55 years global production. It was 1.3 M Tones in 1951 and it reached around 245 M Tones in 2006. The maximum demand of polyethene in market is 4.4% annually. Currently the disposal method employ are land filling, Mechanical recycling, biological recycling, thermal and chemical recycling. Asia accounts for 36.5% of the global consumption and has been world's largest plastic consumer from several years. In recent years significant growth in the consumption of plastic globally has been due to introduction of plastic in areas such as automotive field, transport, medical, electronics, infrastructure and furniture.

Due to scarcity of conventional fuel, the price of automobile fuel was going up day by day which will lead to shortage of conventional fuel in future life. There are certain alternative fuel sources for automobile applications. There is one more problem suffering to environment by excessive plastic waste. All plastic need to dispose after their use. By considering the above problems, we are going to make alternative fuel for automobile from the plastic waste.

Thermo fuel is a process of converting waste selected plastic into useful fuel. The process which we are using for conversion of waste plastic is Pyrolysis. Pyrolysis is process of chemical decomposition of any organic material at relative temperature in absence of oxygen. Many researchers have been done on this with and without the use of catalyst. Also they did the analysis of output fuel at different temperature. They did analysis for various quantities of catalysts to find out the maximum fuel output. They compared properties of output fuel with Petrol and Diesel on various parameters. They checked suitability of fuel to the operating engine like Kirloskar, Also They did analysis for decreasing temperature by using different combination of the catalyst.

II. LITERATURE REVIEW

Pawar Harshal, et. Al, "Waste Plastic Pyrolysis Oil Alternative Fuel For CI Engine". Based on the reviewed paper for the performance and emissions of waste plastic Pyrolysis oil , it is concluded that the waste plastic Pyrolysis oil represents a good alternative fuel for diesel and therefore must be taken into consideration in the future for transport purpose. Further it is concluded that, (i) Engine was able to run with 100% waste plastic oil. (ii) Engine fuelled with waste plastic oil exhibits higher thermal efficiency up to 75% of the rated power. (iii) Brake thermal efficiency of the engine fuelled with waste plastic oil with retarded injection timing is found to be higher. (iv)At full load the brake thermal efficiency decreases with increase in EGR flow rate. (v) At the full load the bsfc is higher WPPO blends show the specific fuel consumption higher than the diesel. (vi)The exhaust gas temperature for plastic oil is higher than diesel. (vii) Unburned hydrocarbon emission is higher by about 15% than that of diesel; with the retarded injection timing it can be reduced. (viii) The NOx emission in waste plastic oil varies from 14.63 to 8.56 g/ kWh without EGR compared to 10.97–8.2

g/kWh with 20% EGR. The NOx emission reduces with increase in EGR percentage, due to the presence of higher heat capacity gases that reduces the peak combustion temperature. (ix) CO emission increased by 5% in waste plastic oil compared to diesel operation. (x) The CO2 concentration decreases with increase in EGR percentages, due to instability in combustion.

Engr. C. O. Osueke et.al: "Conversion of Waste Plastics (Polyethylene) To Fuel By Means Of Pyrolysis." He conclude that, The pyrolysis of waste LDPE (sachet water bag) to yield fuel oil increases with temperature, high yield is obtained from temperature above 300ºC. Reactor for the pyrolysis must be properly lagged before usage to prevent heat loss during the reaction. Every product from the pyrolysis is useful. The physical properties of the fuel oil produced compared favorably with that of aviation fuel JP-4, which shows that the fuel oil can be in place of JP-4 which is more expensive than kerosene.

The pyrolysis of these waste sachets showed that instead of constituting a menace to the society, it could serve as an energy source, 86.5% conversion was achieved during the pyrolysis. The type of lagging used was found to affect the yield. However, pyrolysis of these waste sachets does not only manage the environment but it is also a means of energy source for the aviation industry.

2.1 OBJECTIVES

1) Design of the Model

2) Production of thermofuel.

3) Alternative of Petrol & Diesel.

4) To find the various properties of plastic fuel.

5) Analysis of Model & plastic fuel.

III. METHODOLOGY:

3.1 Introduction of Methodology

In the methodology, we are discussing about the Method and process of conversion of plastic fuel from waste plastic components. It includes the sources of the waste plastic, information about polymerization and random depolymerization. Also the Design and CFD analysis of Process model with its catia design.

3.2 PLASTICS AND TYPES

Plastic is a material consisting of a wide range of synthetic or semi-synthetic organics that can be molded into solid objects of diverse shapes. Plastics are typically organic polymers of high molecular mass. Most plastics contain organic polymers. The vast majority of these polymers are based on chains of carbon atoms alone or with oxygen, sulphur, or nitrogen as well. The backbone is that part of the chain on the main "path" linking a large number of repeat units together. The structure of polypropylene can serve as an example here attached to every other carbon atom is a pendant methyl group (CH_3):

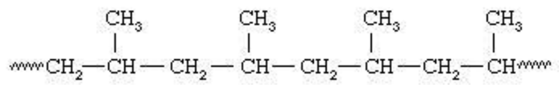

FIG NO. 1: POLYPROPYLENE CHAIN

Due to their relatively low cost, ease of manufacture, versatility, and imperviousness to water, plastics are used in an enormous and expanding range of products, from paper clips to spaceships. They have already displaced many traditional materials, such as wood, stone, horn and bone, leather, paper, metal, glass and ceramic, , in most of their former uses. In developed countries, about a third of plastic is used in packaging and another third in buildings such as piping used in plumbing or vinyl siding. Other uses include automobiles, furniture, and toys. In the developing world, plastics have many uses in the medical field.

3.2.1 Common plastics and uses

TABLE NO 1: PLASTIC TYPE AND USES

No.	Name of Plastic	Uses
1	Polyester (PES)	Fibbers, textiles
2	Polyethylene terephthalate (PET)	Carbonated Drinks bottles, Peanut butter Jars, Plastic film, microwavable packaging.
3	Polyethylene (PE)	Wide range of inexpensive uses including supermarket bags,PlasticBottles
4	High-density polyethylene (HDPE)	Detergent bottles, milk jugs, and molded plastic cases
5	Polyvinyl chloride (PVC)	Plumbing pipes and guttering, shower curtains, window frames, flooring
6	Polyvinylidene chloride (PVDC)	Food packaging
7	Low-density polyethylene (LDPE)	Outdoor furniture, siding, floor tiles, shower curtains, clamshell packaging
8	Polypropylene (PP)	Bottle caps, drinking straws, yogurt containers, appliances, car fenders (bumpers), plastic pressure pipe systems

9	Polystyrene (PS)	Packaging foam/"peanuts", food containers, plastic tableware, disposable cups, plates, cutlery, CD and cassette boxes
10	High impact polystyrene (HIPS)	Refrigerator liners, food packaging, vending cups
11	Polyamides (PA) (Nylons)	Fibers, toothbrush bristles, tubing, fishing line, low strength machine parts: under-the-hood car engine parts , gun frames
12	Acrylonitrile butadiene styrene (ABS)	Electronic equipment cases (e.g., computer monitors, printers, keyboards), drainage pipe
13	Polyethylene/Acrylonitrile Butadiene Styrene (PE/ABS)	A slippery blend of PE and ABS used in low-duty dry bearings
14	Polycarbonate (PC)	Compact discs, eyeglasses, riot shields, security windows, traffic lights, lenses
15	Polycarbonate/Acrylonitrile Butadiene Styrene (PC/ABS)	Used in car interior Exterior parts, and mobile phone bodies
16	Polyurethanes (PU)	Cushioning foams, thermal insulation foams, surface coatings, printing rollers

3.2.2 PLASTICS USED

TABLE NO 2: USEFUL TYPES OF PLASTIC TO CONVERT INTO FUEL

Selection of plastic resin	Thermo fuel system suitability
Polyethylene	Very good
Polypropylene	Very good
Polystyrene	Very good (gives excellent properties)
ABS resin(ABS)	Good ,requires off-gas counter measure
Polyvinylchloride(PVC)	Not suitable, should be avoided
Polyurethane(PUR)	Not suitable, should be avoided
Fiber reinforced plastic(FRP)	Fair, Pre-treatment required to remove fiber
PET	Not suitable, should be avoided

3.3 CONVERSION METHODS FOR THERMOFUEL

There are two methods of conversion of Plastic into fuel as follows:

i) Pyrolysis (without O_2)
ii) Random Depolymerisation (with O_2)

3.3.1 Pyrolysis Process

Pyrolysis is the process of thermal degradation of plastic without oxygen. Where we heated the plastic in a chamber, Due to abse1nce of oxygen plastic is directly convert into the gas which gases we are cooled by suitable method. For this process we need temperatures about 350^oC to 430^0C which can be reduced by suitable catalyst.

Pyrolysis of plastic method has followed steps:

i) Purging oxygen from furnace.
ii) Heat the plastic evenly by increasing range.
iii) Pyrolising the plastic.
iv) Catalytic conversion of the gases to specific carbon chain lengths.
v) Condensation of gases (vapour) which are come from the furnace by suitable cooling method for better quality.
vi) Removal of sulphur and residual contaminant.

3.3.2 Random Depolymerization

Random Depolymerization is a process for the reduction of complex organic materials in the presence of oxygen (hydrous pyrolysis) into crude oil usually waste product of various sorts often biomass and plastic. It is natural geological process though to be involved in production of fossil fuels. Under pressure and heat, long chain polymer of hydrogen , oxygen and carbon decompose into short chain petroleum hydrocarbon with a maximum length of around 18 carbon.

Process: In this process, feed stock material is first ground to small chunks and mixed with water. Water improves the heating process and contribute hydrogen to reaction then the pressure vessel or reaction chamber is heated around 250^o C , vapour naturally rises to pressure 600psi (4 MPa). This condition held for 15 minutes to fully heat the mixture. The minerals are removed and the hydrocarbon send to second stage reactor where they are heated to 500^o C it lead to break down the longer hydrocarbon carbon chain by Fractional Distillation.

Limitations: The process only breaks long molecular chain into shorter one so small molecule such as CO_2 or methane cannot be converted to oil through this process. It is very long process and higher maintenance and production cost. The process breakdown the almost all materials that are fed into it.TPD even efficiently breakdown many types of hazardous material such as poisons and difficult to destroy biological agents such as prions.

That is why we chose the Pyrolysis process of converting fuel from plastic because of its advantages over Random Polymerization.

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3.4 DESIGN OF MODEL

3.4.1 Experimental Setup

The following diagram shows the setup model of the experiment. The Pyrolysis process includes the heating of plastic components in required condition of temperature and pressure in vacuum. In the setup we need furnace which sustain and control the temperature range from 300^0c to 600^0c. Due to constant heating the plastic in the furnace it can be converted in to vapour form. Hence we need the huge pipes to carry the vapours into the condenser. The hog pipes must carry the very hot gases with less amounts of thermal errors. Then we need condenser for cooling the exit gases which is filled by coolant e.g. water and connecting pipe which carries hot vapours from furnace to condenser. The whole setup is placed on the table approx 2-3 ft from ground. It helps to easy working as well as reducing the thermal errors.

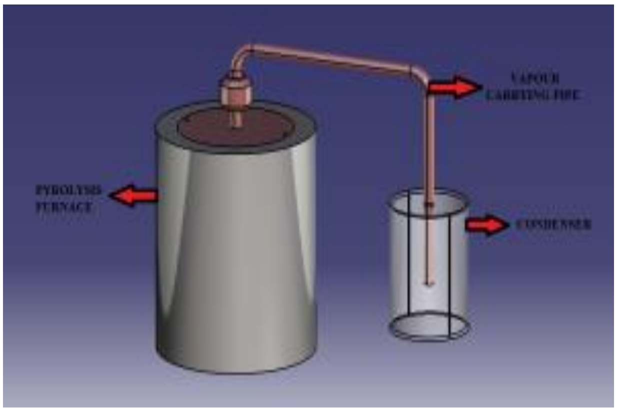

FIG NO 2: EXPERIMENTAL SETUP OF PRODUCTION OF PLASTIC FUEL

The setup of apparatus of Production of plastic fuel manly consisting of following parts:

a) Reactor
b) Furnace
c) Vapour carrying pipe
d) Condenser
e) Heating coils

(a) REACTOR: Reactor is a stainless steel tube of length (l) 145mm, Internal Diameter (I.D.) 37mm, Outer Diameter (O.D.) 41mm sealed at one end and an outlet tube at the other end. The reactor is to be placed inside the furnace for external heating with the raw material inside for internal heating. We use electric heating method for the heating plastic. The reactor is made with the following: stainless steel, mild steel. The reactor is heated by electrical heating to temperature of about 350ºC to 650ºC. We are using fire bricks as a insulating material as it is easily available in the market.

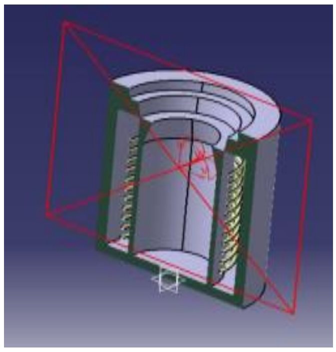

FIG NO 3(A): CATIA MODEL OF REACTOR WITH INTERNAL HEATING COIL.

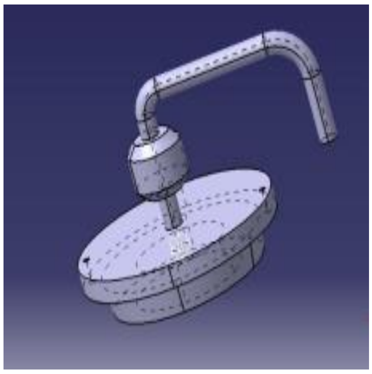

FIG NO 3(B): REACTOR HEAD AND CONNECTING PIPE

***(b)** FURNACE:* Furnace provides the heat to the reactor for pyrolysis to take place; it has a thermocouple to control the temperature. We need 230V AC electric supply to heat the reactor as we are using electric furnace. The electric heating coil creates temperature above 350ºC inside the reactor which starts to melt the plastic component and led to convert into the vapour.

Types of Furnace: There are many types of the furnace according to the method of heating as follows:
a) Electric heating furnace
b) Coal burning furnace
c) Oil furnace (Diesel)
d) Solar furnace

Selection of Furnace: On the basis of our requirement we select the electric furnace for heating the reactor. Because It is eco-friendly method of heating and easily available. Heating coil gives maximum efficiency of heating than others. By using thermo couples we can control specific temperature. We need to maintain the temperature between specific degrees for the higher accuracy of output. That is why we selected electric type of furnace.

(c)CONDENSER: A heat transfer device used for condensing steam to water by removal of the latent heat of steam and its subsequent absorption in heat receiving fluid. Steam condenser may be classified as contact or surface condenser. In contact condenser, the condensing takes place in chamber in which steam and cooling water mix. It is provided by sprays, baffles. In surface condenser the condensing takes place separated from cooling water or

other heat receiving fluid. Here we are using surface condensing method for condensing the vapor gases from the reactor.

Condenser cools all the heated vapour coming out of the reactor. It has an inlet and an outlet for cold water to run through its outer area. This is used for cooling of the vapour. The gaseous hydrocarbons at a temperature of about 350ºC are condensed to about 30ºC – 35ºC.

(d) HEATING COIL

The heating coil is made in circular shape to surround the reactor completely. The material used for manufacturing heating coil is Nichrome alloy (80% nickel & 20% chromium). The heating coil provides the high temperature up to 400-600^{0}C required for carrying out the pyrolysis process inside the reactor.

IV. RESULTS AND DISCUSSION BASED ON CFD ANALYSIS

4.1 ANALYSIS OF PYROLYSIS FURNACE PIPE

The following analysis was carried out in the analysis part

(a) CFD (Computational Fluid Dynamics)

The results obtained for,

- Pressure Contour
- Velocity Streamline

(b) STRUCTURAL:-

- Deformation
- Equivalent Von-misses Stress

(c) THERMAL:-

- Total Heat flux
- Temperature

4.2 INTRODUCTION TO CFD

CFD (Computational Fluid Dynamics) is essentially a branch of continuum mechanics which deals with numerical simulation of fluid flow and heat transfer problems.

CFD deals with approximate numerical solution of governing equations based on the fundamental conservation laws of physics, namely mass, momentum and energy conservation.

4.3 CFD ANALYSIS OF PYROLYSIS FURNACE-PIPE

The CFD analysis of the Pyrolysis furnace –pipe was carried out in ANSYS 15.0 Workbench (Fluent). The component (pipe) was modeled in CATIA V5, which has the dimensions. The model was converted to IGS format. The IGS file was imported to Ansys Workbench for further Processing.

The work carried out in ANSYS Workbench 15.0

The IGS file was imported to the Geometry Menu of the Fluent-Static structural-Steady State Thermal Custom Service part of Tool Box.

- Geometry: The IGS file was imported and the Dimensions were chosen to be in mm.
- Meshing: The Meshing part was carried out in the Meshing Window.
  1. Named Selections of inlet and outlet were created by selecting the respective part of the model.
  2. The Model was then fine meshed up to ………………. No of nodes.
- Setup: The Setup window was opened by using Single Precision Solver. The Problem was selected as Pressure Based, Steady Time and Absolute Velocity Formulation Problem. The following steps were carried out further for the analysis,

  1. *Problem Setup toolbar*

- Models dialog box:
  Selecting energy equation (ON).
  Viscous Model dialog box- K-epsilon (2 equations) (ON).
- Material Dialog box
  Selecting Fluid menu – Dialog box.
  The material database was created by selecting Diesel/Gasoline from Fluent Database.
- Boundary Conditions Dialog Box
  1) Inlet Menu
  Assuming 40 m/s Velocity
  Temperature entered was 500^{0}c
  2) Pressure Outlet menu
  Finalizing the default settings for this option
  3) Wall Menu
  Selecting Convection option and entering the value of heat transfer coefficient as 63.9 W/m2 K.
- Solution

Solution initialization menu

1. Selecting standard initialization
2. Compute from :- all zones
3. Computing :- initialize

Run calculation toolbox option:-

1. Check case for errors
2. Selecting number of iterations to be 30
3. Calculate

The result was calculated for 30 iterations.

Solution window was closed

Results window:-

1. Inserting streamline starting from inlet and giving no. of points to be 200 and applying. We obtain the Velocity Streamline.

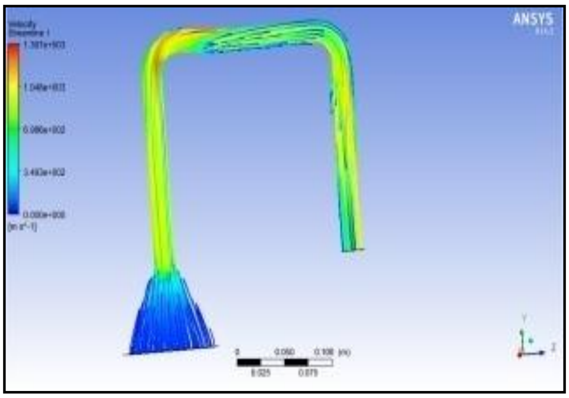

FIG NO 4: VELOCITY STREAMLINE ALONG THE PIPE.

The above result shows the velocity streamline flow along the pipe.

2. Inserting Contour:-

From location: wall solid and applying. We obtain the pressure contour.

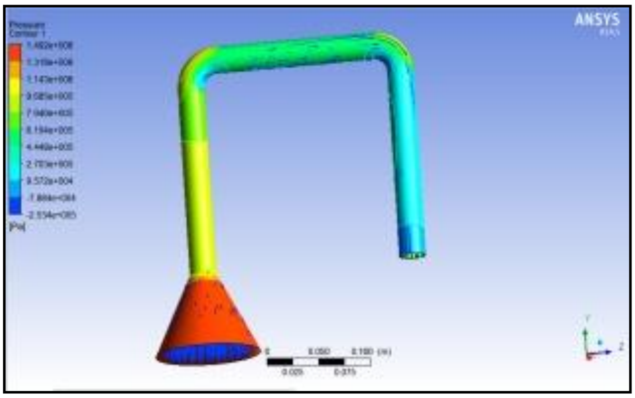

FIG NO 5: PRESSURE CONTOUR ALONG THE PIPE.

The above result shows the pressure distribution along the pipe.

The maximum pressure is near the converging pipe. The value of maximum pressure is 1.4 N/mm^2. The pressure reduces as we move further along the pipe.

4.4 STATIC STRUCTURAL PART

- Engineering Data

Structural steel was selected and the properties of the materials were entered.

Model:

1. Mesh: The model of the same geometry was remeshed in static structural window.
2. Static Structural
3. Import load (solution)
   - Pressure was imported
   - The imported pressure was then linked with all faces of the meshed model.
4. Solution

   In Solution Part, we get select the following
   - Stress (Von Mises)
   - Total deformation.

The problem then solved and the results obtained were

Total Deformation

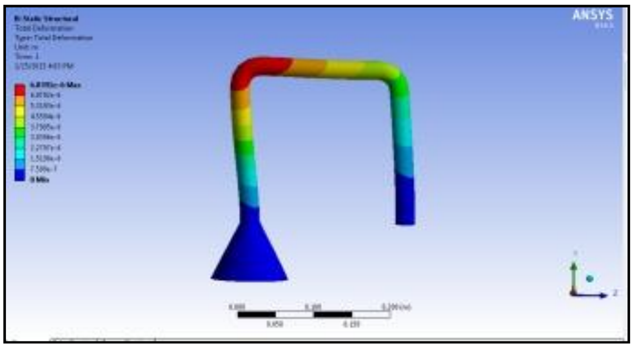

FIG NO 6: TOTAL DEFORMATION IN PIPE.

The Above Result shows that then Maximum Deformation is seen on the bend with red area. The value of maximum Deformation Obtained due to High Temperature Fluid Flow is 0.006mm, which is almost negligible.

Von Misses stress

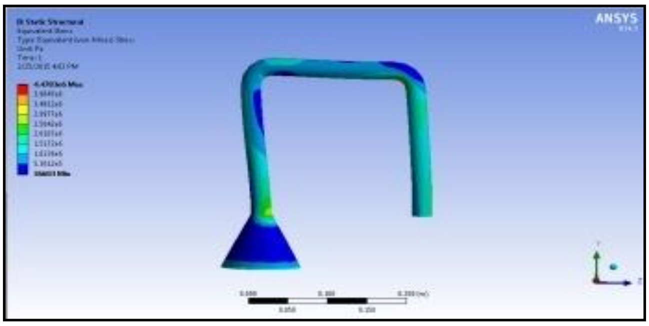

FIG NO 7: VON MISSES STRESS ALONG THE PIPE.

The Result show that the maximum stress is induced at the bend. This value of stress is call von misses stress. The maximum value of stress induced is 4MPa due to high temperature fluid flow.

The design Factor of Safety = 3.

The Yielded Factor of safety = 300/4=70.5 >>>3

Hence, it is safe against failure.

4.5 STEADY STATE THERMAL ANALYSIS:-

- Geometry :-
  The same geometry was linked into the Steady state thermal dialog box.

- Model:-

  1. Mesh :-
     The model of the same geometry was remeshed in steady state thermal window.

  2. Steady State Thermal

- Initial temperature given was 22^0C.
- Temperature at inlet entered was 500^0C.
- For Convection- The film coefficient was given to be 52 W/m^{20}C.
  The ambient temperature was 22^0C.

  3. Solution :-
     In Solution Part, the following were selected
     - Temperature Solution.
     - Heat Flux Solution.

The final results were obtained for

- Temperature

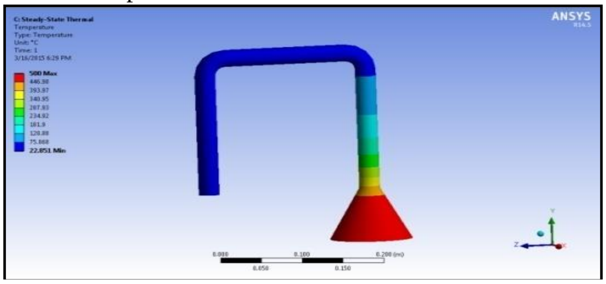

FIG NO 8: TEMPERATURE DISTRIBUTION ALONG THE PIPE.

The above result shows the temperature Distribution along the pipe at outlet of furnace. The maximum temperature is near the furnace because of the incoming high temperature fluid. The temperature goes on decreasing as we move away from the furnace.

- Variation of heat flux along the discharge pipe

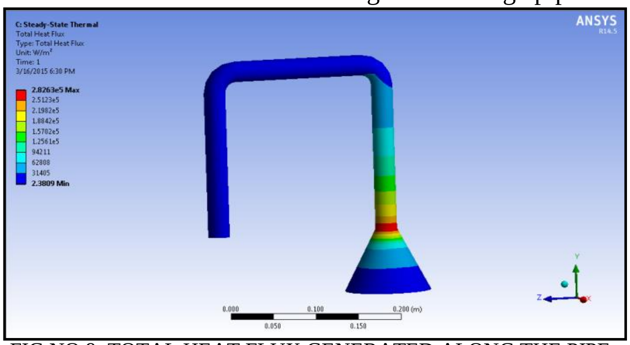

FIG NO 9: TOTAL HEAT FLUX GENERATED ALONG THE PIPE.

In the above manner the overall Analysis i.e. CFD, Static Structural and Steady State Thermal analysis of Pyrolysis Furnace-Pipe was carried out in Ansys 15.0 Workbench.

V. CONCLUSION

After doing the analysis of Thermofuel Production plant in ANSYS 15.0 Workbench, following conclusions were obtained;

1. The Material selected for the furnace was structural steel for its excellent Weldability, Malleability and high conductivity.

2. The model was fined meshed tetrahedral nodes.

3. The Result of Analysis concluded that the design was safe against thermal stresses induced due to high temperature fluid flow. The factor of safety yielded was 72, which is very high as compared to design factor of safety, which is 3.

4. The delivery pipe was design with 45^0 of converging angle with aim to deliver maximum amount of fuel vapour at high velocity to the condenser.

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