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CO_2 Capture by Using Modified ZSM-5 Zeolite in Diesel Powered Vehicle

V Venkatesh[1], Dr.M Jaikumar[2], Dr. Mylaudy S. Rajadurai[3]
[1]*M.Tech scholar, Automobile Engineering, Hindustan University, Chennai, Tamil Nadu, India*
[2]*Assistant professor, Automobile Engineering, Hindustan University, Chennai, Tamil Nadu, India*
[3]*Head of R&D, Sharda Motors Industries Ltd, Chennai, Tamil Nadu, India*

Abstract: *Emissions from the automobiles causes major damage to the environment. Carbon dioxide is one among the green house gas responsible for enhanced greenhouse effect.Fossil fuel combustion produces maximum amount of CO_2. Reduction of CO_2 from internal combustion engines is mandated to control CO_2 emission. To overcome all these sorts, most of the automobile vehicles are employed with catalytic converter. As parts of our extended effort to control exhaust CO_2 from automobiles, we have undergone a study of CO_2 adsorption using modified ZSM-5 zeolite as a catalyst in the reactor.The exhaust stream from tail pipe allowed passing through the system, which is operated with the help of valves to regulate the flow. A flow meter is installed before reactor will help in measuring the flow velocity. CO_2 adsorption on ZSM-5 zeolite at idle condition is high, whereas it is somewhat lower at rated speeds. Various tests are conducted at different speeds and the results are showing a conformal reduction in CO_2 and other exhaust gases.*

Keywords: *Zeolites, ZSM-5 Zeolite, Diesel Powered vehicle, Adsorption, Carbon dioxide*

I. Introduction

Carbondioxide emissions are the common type of gas emitted from the burning of fossil fuels. The increase in the CO_2 emissions is one of the major environmental problems. It is formed during the complete combustion of fuel. More than permissible levels of CO_2 produced by road vehicles are considered a prime contributor to the climate change mechanism known as "green house effect"[1].Global concentrations of CO_2 in the atmosphere have increased from pre-industrialization levels of approximately 280 parts per million by volume in around 1860 to approximately 316 in 1958 and rapidly to approximately 369 today. Global CO_2 concentration is predicted to rise to above by 750 by 2100.If no action is taken to address the current situation, CO_2 emissions are having an impact on global climate change[3]. Climate change can be reduced by decreasing the emission of heat-trapping gases particularly CO_2 to the atmosphere. The production of CO_2 from various sectors and consumption of CO_2 through natural process are not proportional leading to an unbalanced residual growth of CO_2 in the atmosphere. It has been clearly identified that additional artificial effective technologies are needed to control CO_2 in the atmosphere. In the current study, adsorption of CO_2 is achieved in diesel powered vehicle using modified ZSM-5 Zeolite which derived from Alumino-silicate family of zeolite[4]. The reduction of CO_2 by adsorption on ZSM-5 zeolite loaded reactor emission valves and raw vehicle emission of CO_2 percentage are tested and compared.

II. Testing Engine Overview

Engine Specifications

Engine	2.0L L4 turbo diesel SOHC 16-valve
Displacement	1968
Bore	82.5 mm
Stroke	92.8 mm
Max Power	140 @4000 rpm
Fuel Type	Diesel
Compression Ratio	10.5:1
Emission Norms	BS IV

System Operation

Figure 2. Setup of the reactor chamber system

The exhaust gas from tail pipe is passing throughreduction chamber system. The valves are used to regulate the flow as it needed to collect the sample before and after reactor chamber**.** Flow meter is attached to measure mass flow rate to reactor.

III. Adsorbent Selection Process

The key characteristic parameters used for the selection of adsorbent are listed below:

- Disintegration temperature of the adsorbent
- Desorption temperature
- Limiting reaction
- Back pressure
- Number of active spots remaining post process
- Commercial availability & feasibility

Based on the above parameters we evaluated ZSM-5 Zeolite , ZSM-11 and ZSM-5 Zeolite, Additionally we zeroed down to ZSM-5 Zeolite because of its higher affinity towards absorbing/adsorbing carbon materials. Its higher disintegration, desorption temperature, and availability shows the practical usage.

Fig 3. ZSM-5 Zeolite pellets

Properties of ZSM-5 Zeolite

- Empirical formulae $Na_nAl_nSi_{96-n}O_{192}.16\ H_2O$ (19<n<96)
- ZSM-5 of any pore size can absorb or adsorb CO_2 and to some extent other carbon-based emissions.
- The crystallographic unit cell of ZSM-5 has 96 T sites (Si or Al), 192 O sites, and a number of compensating cation depending on the Si/Al ratio, which ranges from 12 to infinity.
- No deterioration up to temperature of 1100^0C
- The ZSM-5 zeolite limiting factor is calculated as 1.75
- Desorption starts at a temperature significantly above the light off temperature of the commercially available catalytic converters
- Inexpensive and available in varied sizes, powder form, beads, extrusions
- For any adsorbent/absorbent, limiting factor for the adsorption/absorption cycle must be in the range of 1.5-2.0 ZSM-5 is in adequate limit of 1.75.

CO_2 Adsorption Chamber

The adsorption studies are carried out using the adsorption chamber filled with the ZSM-5 Zeolite material. Adsorption chamber is chosen to minimize ZSM-5 Zeolite abrasion. The size of the chamber is taken about 100mm diameter pipe and length about 300 mm as it is already explained in the design calculation criteria. ZSM-5 zeolite is filled in a wire mesh housing as shown in the figure (a).The ZSM-5 Zeolite filled wire mesh housing is inserted inside the chamber shown in the figure (b). The chamber with two outlet flanges is attached to diesel operated vehicle for performance evaluation[5].

Figure 4. Reduction Chamber

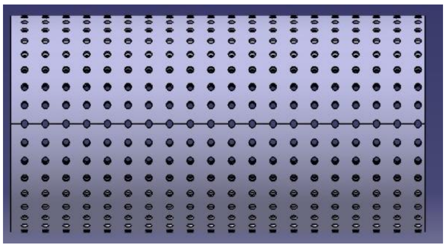


Figure 5. Trap

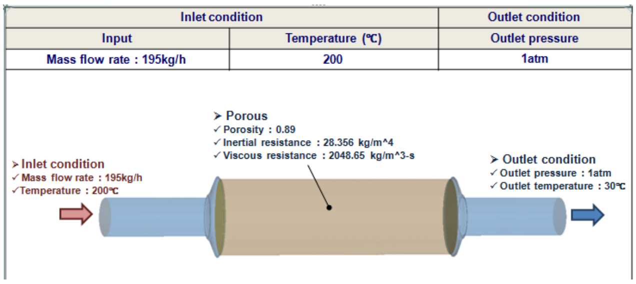
IV. Design Validation

To validate any convertor design, it is necessary to confirm the flow uniformity. We validated our design by analyzing it through CFD.

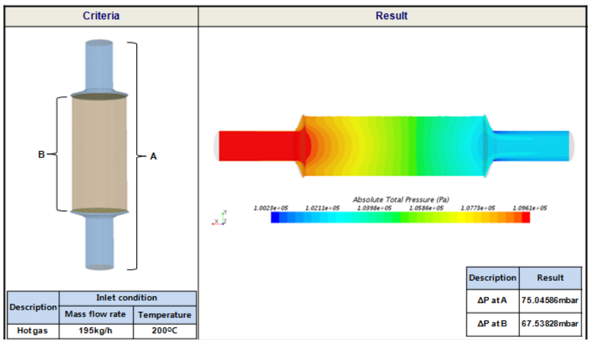
CFD Analysis (Flow uniformity)

For CFD, geometry is meshed with polyhedral mesh and a refined prism layer mesh near the wall. Internal flow field uses the compressible Navier-stokes equation. The high Reynolds number k-Ɛ turbulence model is used with standard wall functions for near-wall treatment. The equations of mass and momentum are solved using a simple algorithm for velocity and pressure in the fluid domain. Constant density is used for the solid region. CFD model has approximately 0.4 million cells with maximum skewers angle of 85 degree.

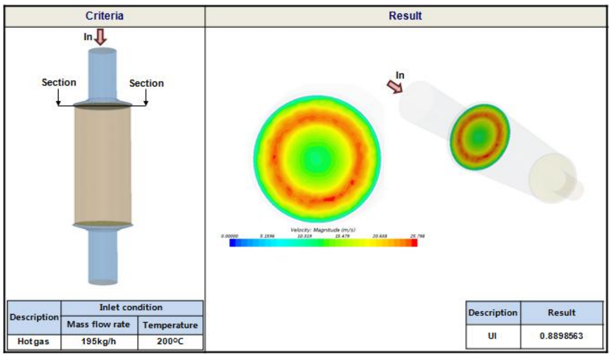
Boundary conditions



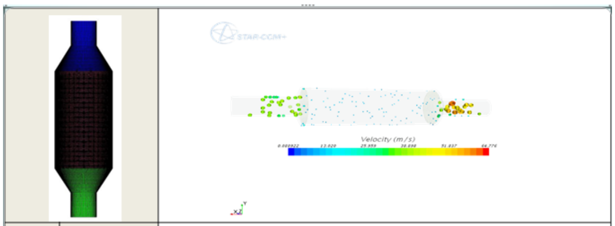
Pressure Drop



Uniformity Index



Summary



Inlet condition	Mass flow rate	195kg/h
	Temperature	200ºC
Outlet pressure		1atm
Pressure drop		75.04586mbar
Uniformity index		0.8898563

Observations

- As per the above results, the uniformity and pressure drop are within the target criteria.
- The difference of pressure drop between cases A and B is 7.51 mbar.
- The uniformity of the zeolite reactor in catalyst front face is 0.89.

V. Prototype Fabrication

Sample Preparation & Details

Zeolite Chamber Details

Shell Dimension	Dia 100 ×L 300 mm
Shell Volume	2355 cm^3
Cross Sectional Area	78.5 cm^2
Wire Mesh Weight	162 gm
Wire Diameter	0.8 mm
Zeolite used	ZSM-5
Zeolite Pellets Size	3 mm
Zeolite Pellets	1500 gm
Zeolite Pellet Diameter	1.5 mm

Initially a zeolite shell chamber with above specifications is fabricated. To restrict the motion of wire mesh, metal straps are welded in both ends. To maintain optimized back pressure wire mesh is selected with 1.5 mm of diameter and zeolite pellets are loaded layer-by-layer with wire mesh to restrict the movement of pellets during the engine operation.

Zeolite Shell and Loading of Pellets

Figure 6.Zeolite loading

Figure 7. Zeolite shell

The total volume of zeolite in the shell is stuffed in 3 layers, each layer with 1/3 volume to maintain uniform adsorption. Then the cone is fitted with the cones at both ends and then bolting at the inlet end to complete the convertor assembly.

Table shows loading of pellets and the completed zeolite chamber assembly with fixed cone inlet. The inlet end of the reactor is connected to the flow meter assembly with the T section setup and the outlet end of the reactor is exposed to atmosphere and the end is to be connected with the gas analyzer probe to detect the percentage of gas that is emitting.

VI. Testing And Validation

Shows Raw Emission Test Results

Parameters	**Average Values**
Hydrocarbons (ppm)	20.25
CO_2- Carbon dioxide (%)	4.45
NOx- Nitrous oxides (ppm)	64
CO- Carbon monoxide (%)	0.375

Emission Test Results and Comparison

Test conditions

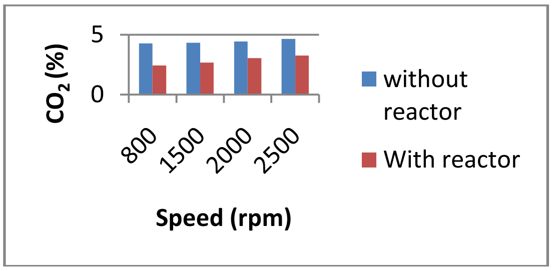
Test is conducted under three conditions are idle, rated, and Maximum RPM ranges with and without CO_2 reduction chamber. The test is conducted by connecting the setup to the vehicle tail pipe and the following data have attained by conducting the test at idle, rated, and maximum rpm of the vehicle while conducting the test.

The test is taken place for every change of speed the reaction time should be 3-5 minutes and the result percentage of CO_2 percentage which is displaying on the monitor screen of AVL gas analyzer.The emission test is done under precise test conditions which the engine is allowed to cool down up to 2 hours for each carbon dioxide measurement.

Figure 8. Shows Results Measured In AVL Gas Analyzer

RPM	HC(ppm)	CO% by vol	CO_2% by vol	O_2% by vol	NOx(ppm)	Lambda
800 (idle)	17	0.02	2.42	17.06	175	5.637
1500	22	0.04	2.68	15.44	70	3.950
2000	25	0.05	3.06	14.80	55	3.549
2500	26	0.05	3.26	15.42	69	3.968

Comparison between with and without reduction chamber



VII. Conclusion

The results of CO_2 reduction from the exhaust of diesel operated vehicle using modified ZSM-5 zeolite are summarized. Adsorption technique is followed to capture the CO_2 emission from the exhaust gas, where the ZSM-5 zeolite locks and holds the carbon molecules. Approximately 43% of carbon dioxide reduction is achieved by the adsorption system particularly at the vehicle is at idle speed and it keep shown some better CO_2 reduction percentage at rated speeds. The valve based reduction chamber technique is successfully executed to route the exhaust gas to CO_2 trap. The capability of ZSM-5 zeolite to adsorb a wide range of Carbon molecules with the stream allowed passing through reactor chamber. The adsorbed system can be effectively used on vehicle to comply with low emission norms.

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