Hindawi
International Journal of Photoenergy
Volume 2022, Article ID 3000227, 9 pages
https://doi.org/10.1155/2022/3000227

Research Article

Experimental Investigation on the Effects of Exhaust Emission Reduction in a Single Cylinder CI Engine Fuelled with Diesel and Diesel Plastic Pyrolysis Oil with Zeolite Nanomaterials

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Received 10 February 2022; Revised 12 March 2022; Accepted 18 March 2022; Published 4 April 2022

Academic Editor: V. Mohanavel

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The steady-state activity of zeolite 4A and 5A has been investigated experimentally for nitrous oxide and other emission gases in highly oxidizing conditions, typical for lean-burn engine exhaust. Zeolite has been characterized by XRD and FTIR. The CAD model is designed which shows the layout and basic mounting points of the catalytic converter on the Kirloskar TVI engine. Zeolite 4A and 5A substrate has been made using simple molding techniques, further heating it in an electric heater at 650°C for 6 hours. Several fuels such as plastic pyrolysis oil and diesel oil have been used to investigate the effect of NO on zeolite 4A and 5A substrate. The NO conversion has been found to be decreased by 40% using plastic pyrolysis oil. The zeolite powder has been added with 8% of bentonite clay and 5% of carboxymethyl cellulose powder, and 34% distilled water was stirred constantly to form like molding sand. The applied torque was monitored during stirring, signifying even mixing. The mixture has been kept in the prearranged mold design, and uniform pressure has been applied to guarantee no air holes in the shape. The hole pattern has been made using SOLIDWORKS and has been printed to get reliable openings (10 mm) with the assistance of wooden bars; the prearranged mold has been dried for 92 h in the immediate daylight; thereafter, dry pipes have been taken out from the mold. The subsequent form has been kept in the furnace at first at 150°C. Carboxymethyl cellulose is utilized as a fastener which assists with shaping the mold since it has great binding properties. Significant NO_x reduction of 45~50% using zeolite 5A and 27~30% using zeolite 4A mold structure with diesel fuel was observed. Reduction of 35~40% using zeolite 5A and 13~16% using zeolite 4A mold structure with PPO + diesel fuel was observed.

1. Introduction

The main problem today is the emission of harmful gases from automobiles which affects the environment in several ways. Nitrous oxide is the main threat to the environment such as global warming, ozone depletion, and acid rain [1]. The exhaust emissions include nitrogen oxides (NO_x), hydrocarbons (HC), carbon monoxide (CO), carbon dioxide (CO_2), and particulates [2]. Therefore, many countries have emission regulations such as EURO emission standards and Bharat stage emission standards for Indian cars. Currently, there are several techniques which are implemented to reduce the emissions from an exhaust gas including SCR using urea [3]. The conventional catalytic methods used to reduce NO_x automobile exhaust gases are categorized into (i) decomposition reactions, (ii) nonselective catalytic converter, and (iii) selective catalytic converter [4]. The selective catalytic reduction is used to reduce certain emission gases such as NO_x, HC, CO, and CO_2. Emission control of NO_x is less prominent in lean-burn engines such as diesel engines as it operates in highly oxidizing conditions [5]. The conversion of NO_x into less harmful gases such as N_2 is possible with three-way catalytic converters in spark ignition engines because gasoline engines work in rich-burn conditions [6]. The desire to improve fuel consumption and lower emissions of CO_2 is supposed to surge the demand of diesel

Figure 1: Photographic view of zeolite in powder form.

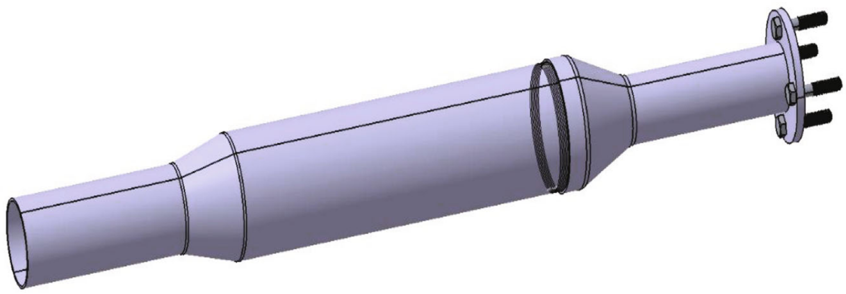

Figure 2: CAD model of catalytic converter casing.

engines [7]. Therefore, it is important to develop a system that can reduce NO emission from lean-burn engines. Though the traditional three-way catalytic converter does not control NO_x emission in oxygen-rich conditions [8], hydrocarbons are generally used to selectively reduce NO_x emissions as it acts as a reducing agent [9]. However, in a lean-burn engine, the hydrocarbon is not present in required quantities to complete decomposition of NO_x. Therefore, there is a need to develop a system that can reduce NO_x emissions from lean-burn engines [10]. Composite honeycomb consisting of microporous zeolite 5A is developed with many potential applications. The cordierite structure of zeolite 5A can be used in diesel engines in order to reduce NO_x emissions in lean-burn conditions [11]. Zeolites are a group of minerals that consists of calcium, sodium, and potassium. One of its properties is that they can be readily dehydrated and rehydrated. They can be used as molecular sieves and powders [12]. They are microporous minerals generally used as catalysts and commercial adsorbents. Zeolite has the property of absorbing impurities [13].

Figure 1 shows the photographic view of zeolite in powder form. The structure of zeolite is porous and thus can trap cations and others of the wide variety [14]. These cations can readily be exchanged with others in a contact solution which is loosely held [15]. These are used as catalysts in several acid catalytic reactions because these ions exchanged zeolite possessing acidity in a wide range. When ash layers and volcanic rocks will react with alkaline groundwater, it results in the formation of natural zeolite [16, 17]. Zeolites which occur naturally are not pure and are polluted by various metals, minerals, and other zeolite. These natural zeolites are not used in some commercial applications where purity and uniformity are important [18]. Compositions of the zeolites consist of Si, O, Al, and other metals like Zn, Sn, and Ti. The word molecular sieve means a particular property of the material and refers to the tendency of selectively sorting molecules based mainly on size [19]. This is because it has a very regular molecular pore structure. For specific separation of gases and removal of NO_2, CO_2, SO_2, and H_2O from exhaust gas streams, zeolites are widely used [20]. The necessity of this research work is to develop an exhaust after-treatment system which is cost-effective and also optimal to achieve current emission norms of the required. The next level of development in this research is to implement urea injection and analyze and compare the performance and emission parameter results.

2. Experimental Work

2.1. CAD Modeling. CAD model has been designed using SOLIDWORKS 2017 considering all the mounting points. The material chosen for catalytic converter is steel. The dimension of the CAD model has been taken using different mounting points of the catalytic converter casing and length between mounting points, and it is shown in Figure 2.

Figure 3: Zeolite mixture.

Figure 4: Zeolite paste.

2.2. Catalyst Preparation Using Carboxymethyl Cellulose. Zeolite powder has been blended in with 8% of bentonite clay, 5% of carboxymethyl cellulose, and 34% of water by mixing as in Figure 3 continually to form like paste. Bentonite clay helps in converting zeolite powder into paste form, and carboxymethyl cellulose is a good binder. These chemicals do not affect the properties of zeolite after preparing mold. During blending, force applied was checked until it arrived at a uniform value, to have a homogeneous combination as in Figure 4. Zeolite paste has been put in the prepared mold cavity, and uniform pressure has been applied consistently to ensure that there are no air holes in the mold. The hole pattern has been made utilizing SOLIDWORKS and has been printed to get uniform opening diameter (12 mm) with the assistance of pipe as in Figure 5.

The outer casing of the catalytic converter has been made using hollow steel tubes which have been welded in order to prepare the outer case. The inlet and outlet section of the catalytic converter (diameter: 70 mm, length: 170 mm, thickness: 4 mm) has been used for the fabrication and reducer (diameter 1: 70 mm, diameter 2: 106 mm, length: 57 mm, thickness: 4 mm), and the main section (diameter: 106 mm, length: 348 mm, thickness: 4 mm) has been used to make the catalytic converter casing. A billet (thickness: 8 mm, diameter: 100 mm) has been used for fitting by drilling four uniform holes of 8 mm. For catalytic converter casing, TIG welding has been used to ensure proper welding between different parts of the catalytic converter and no gaps has been ensured. To enhance the serviceability of the casing, external threading has been done on one side of the main section and internal threading has been done on the reducer, threading up to 20 mm has been done to ensure proper fitting. The catalysts used nowadays in automotive industries are very expensive; the cost of zeolite powder is cost-effective and zeolite has the property of reducing harmful emission gases; that is the motive in selecting zeolite 4A and zeolite 5A for development. Mold was dried in direct sunlight for 96 hours, and then, mold was kept in an oven for 3 hours from 150°C to 600°C by increasing 75°C for every 30 minutes.

Figure 5: PVC pipes as mold cavity.

Table 1: Characteristics of plastic pyrolysis oil and high-speed diesel.

Fuel properties	Diesel	Plastic oil	Diesel + PPO
Density of fuel (kg/m^3)	832	794	813
Calorific value of fuel (kJ/kg)	45550	42500	43850
Kinematic viscosity (at), 40°C (cSt)	3.50	9.00	6.20
Flash point (°C)	52	60	55

Table 2: Engine specifications.

Specification	Parameter
Engine type	Kirloskar
No. of cylinders	Single cylinder
No. of stroke	Four-stroke
Cylinder diameter (mm)	87.5
Stroke (mm)	110
Compression ratio	17.5 : 1
Powered by	Diesel
Horse power (HP)	6.5 kW @ 1500 rpm
Dynamometer	Eddy current dyno

2.3. Welding of the Outer Case. The welding process used while fabricating the casing has been TIG welding (Tungsten Inert Gas). In this method, nonconsumable electrode is used to direct arc onto the metal surface until it gets to the

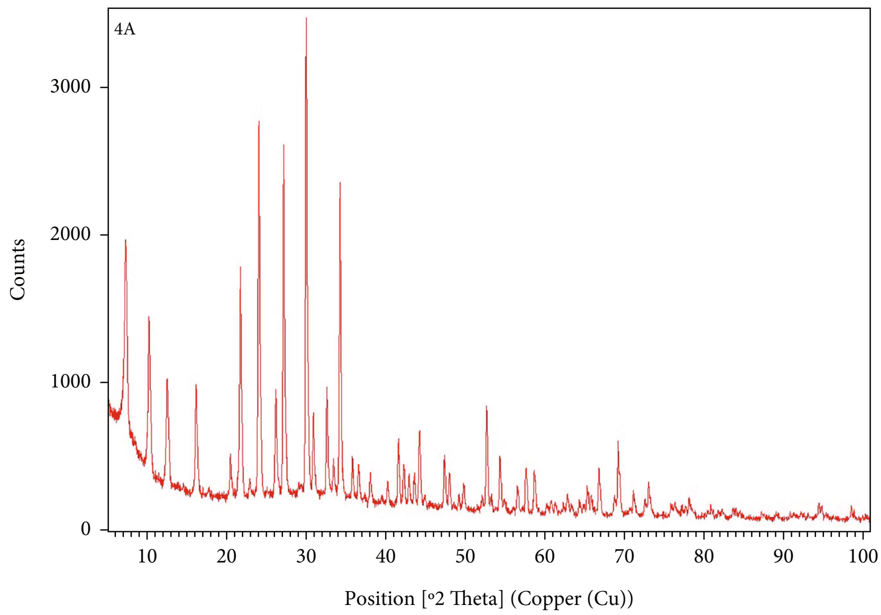

Figure 6: XRD pattern of zeolite 4A catalyst.

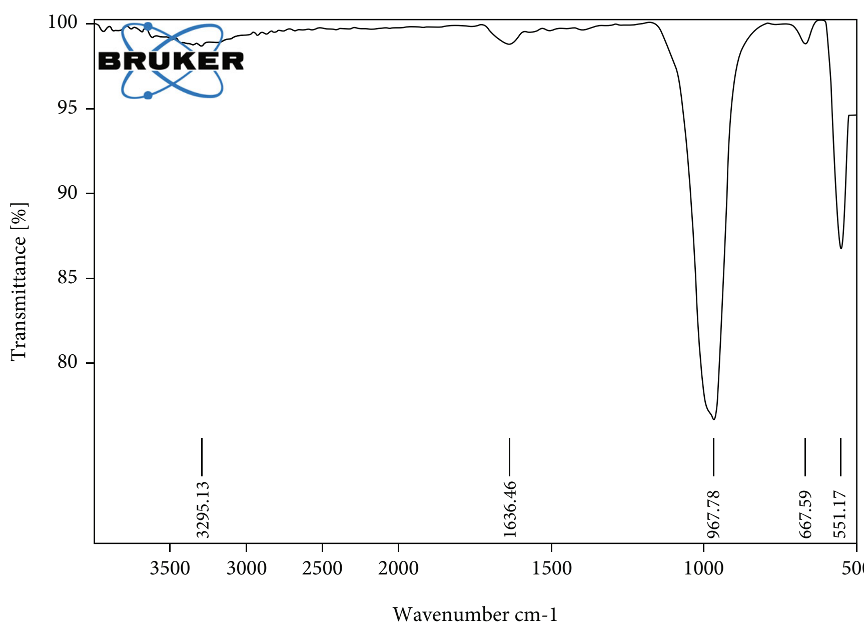

Figure 7: FTIR pattern of zeolite 4A catalyst.

melting point, and then, filler rods are poured in uniform motion to get proper weld with no gaps. This method has been preferred over arc welding because it forms a few blowholes when compared to arc welding, which prevents gas from passing through the metal surface.

2.4. Threading of Outer Case. Threading at one side of the outer casing is done for the better serviceability, one side of the main section is threaded with external threading, and the larger diameter side of the reducer is threaded internally; threading is done to place the catalyst in the main section with the mesh and the separator supporting the catalyst inside the section. Internal thread on the large diameter side of reducer is done through the lathe machining, the reducer is fixed on the tool post, and after setting the reducer at right angle to the lathe axis, the threading operation is done using a thread gauge; the depth of cut on the reducer is given by the compound slide, and the internal threading is finished on reducer. For the external threading on the main section of the outer case, it has been machined by lathe machining.

2.5. Fabrication of Flange. The flange has been prepared using a billet of thickness 8 mm which has been turned to get the required diameter of 100 mm, four holes have been drilled uniformly of 8 mm diameter, and a center hole was milled of diameter 50 mm. Further, the flange has been

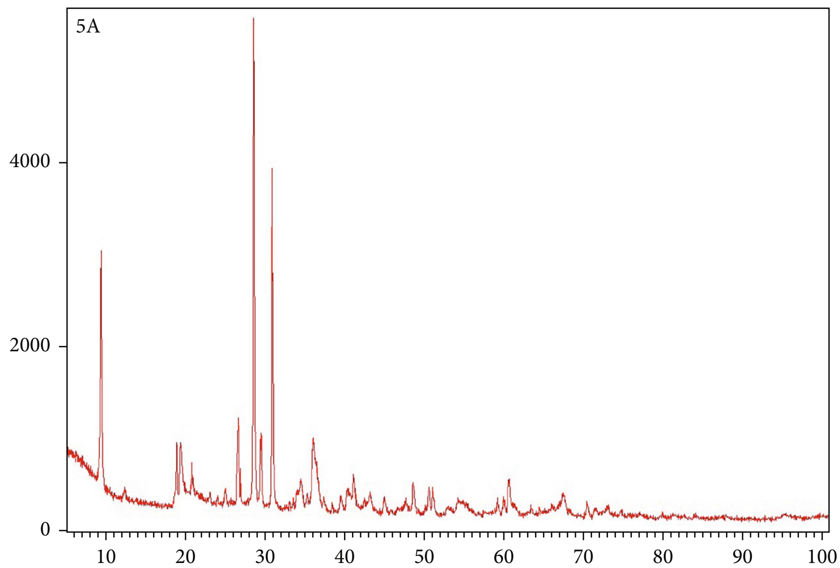

Figure 8: XRD pattern of zeolite 5A catalyst.

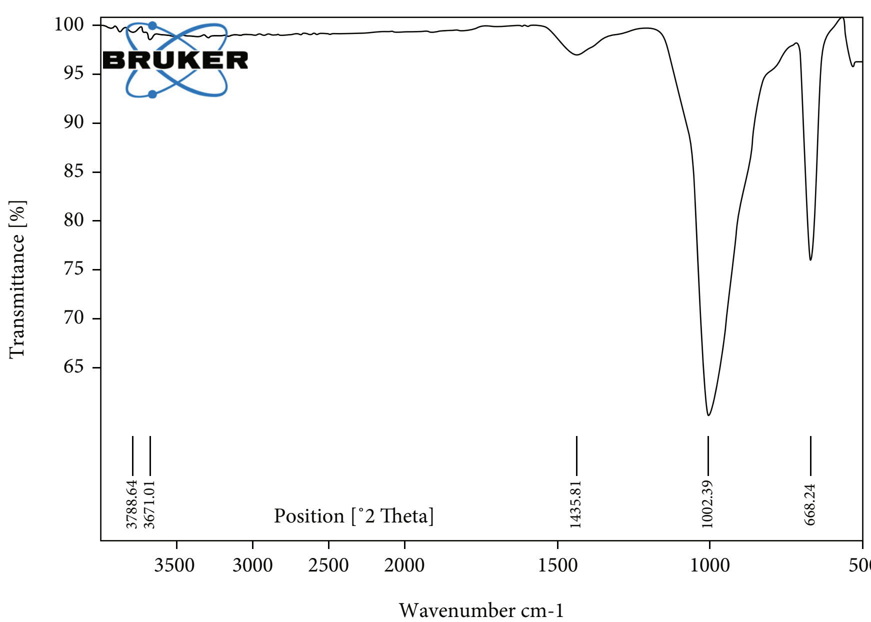

Figure 9: FTIR pattern of zeolite 5A catalyst.

welded to ensure proper fitting on the catalytic converter and mounting points.

2.6. Mesh Preparation with Metal Separators. Wire mesh is used with metal separators to ensure that the mold is kept at 1.5 cm distance between when the exhaust gas is passed through the catalytic converter. Wire mesh has been selected to ensure that the gas flow between the molds is adequate.

2.7. Fuel and Engine Specification. The fuel used for emission analysis is recycled plastic waste oil blended with diesel as shown in Table 1. Diesel with zeolite 4A and 5A catalyst is analyzed for emission of HC, NO_x. Test on diesel and plastic pyrolysis oil blend ratio of 50 : 50 with zeolite 4A and 5A catalyst is carried out on the engine with specification shown in Table 2, and the readings are taken. The major problem with the degradation of plastic is the very wide product range and the necessity of high temperature; to overcome this problem, catalytic degradation is done to reduce the temperature range of the reaction and also to improve the quality of the product.

3. Result and Discussions

3.1. XRD and FTIR Characterization of Zeolite Catalysts. Zeolite 4A X-ray diffraction patterns are shown in Figure 6. Zeolite has the property of observing oxygen from

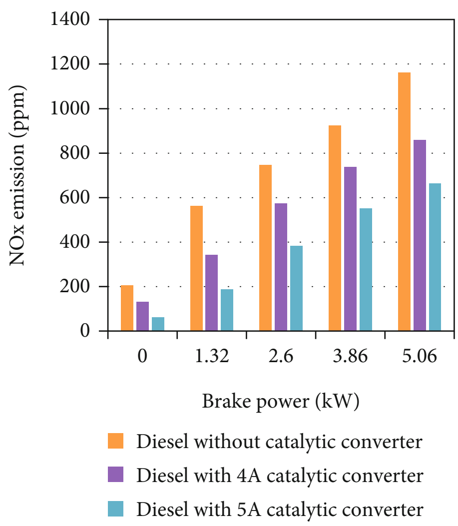

FIGURE 10: NO_x emission with diesel with zeolite 4A and 5A catalyst.

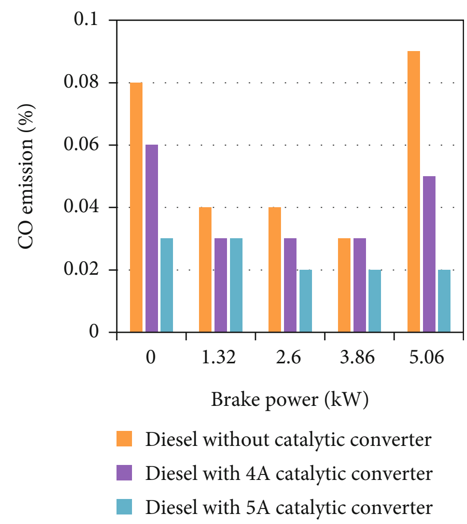

FIGURE 12: CO emission with diesel with zeolite 4A and 5A catalyst.

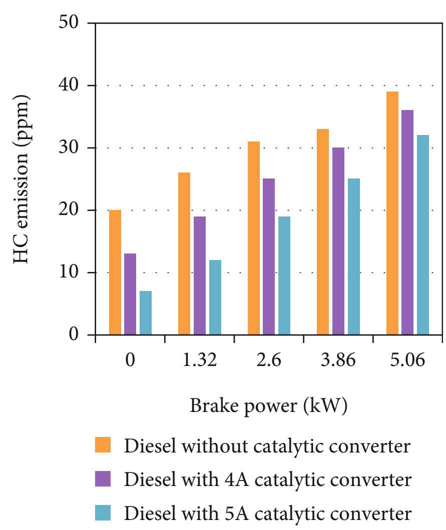

FIGURE 11: HC emission with diesel with zeolite 4A and 5A catalyst.

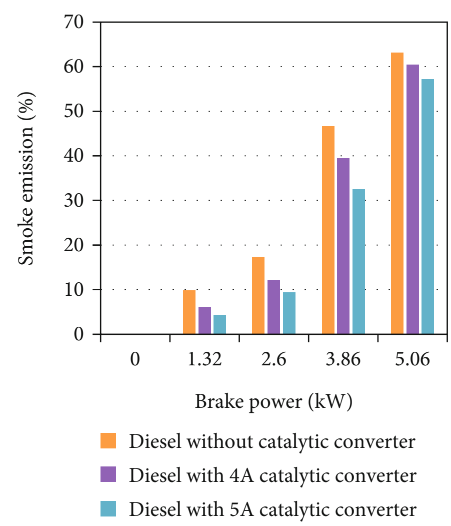

FIGURE 13: Smoke emission with diesel with zeolite 4A and 5A catalyst.

the harmful gases, it observes oxygen from NO_x and splits it into NO_2 and O_2, and it also converts HC, CO, and CO_2. The characteristic diffraction peak of zeolite 4A appears at 24°, 28°, 30°, and 34.3°. It can be clearly seen that the peaks correspond to those of zeolite 4A. The curve shows the scattered intensity vs. 2θ for a crystal solid is almost 0 everywhere except at certain angles where maximum high peak occurs.

The FTIR spectra of the sample show certain characteristics of absorption bands assigned to zeolite 4A. These spectra are in good agreement with zeolite 4A formed by conventional method, and it is seen in Figure 7.

Zeolite 5A X-ray diffraction patterns are shown in Figure 8. The characteristic diffraction peak of zeolite 5A appears at 9°, 28.10°, and 31.3°. It can be clearly seen that the peaks correspond to those of zeolite 5A. The peaks of the scattered intensity vs. 2θ for a crystalline solid are nearly zero all over apart from those at some angles, where the highest peaks occur maximum; these are deflected beams.

The FTIR spectrum of the sample confirms the characteristic absorption of bands assigned to zeolite 5A. This spectrum is also in good contract with that of zeolite 5A equipped by using conventional gel technique and displayed in Figure 9.

3.2. Emission Test on Diesel Engine. The emission test has been conducted on the Kirloskar single cylinder diesel engine. The test has been performed to analyze emission reduction using zeolite 4A and 5A as catalysts. The emission gases to be measured are nitrous oxides (NO_x), hydrocarbon (HC), carbon monoxide (CO), and smoke, and it is shown in Figures 10–13. First using diesel base engine

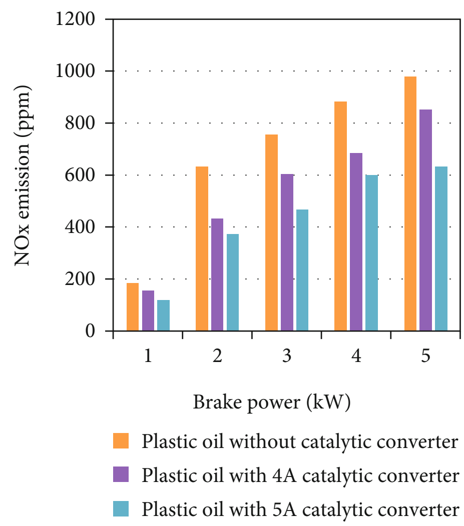

Figure 14: NO_x emission with diesel + PPO with zeolite 4A and 5A catalyst.

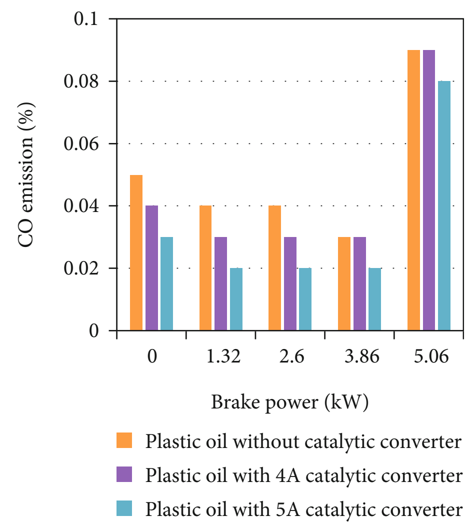

Figure 16: CO conversions with diesel + PPO with zeolite 4A and 5A catalyst.

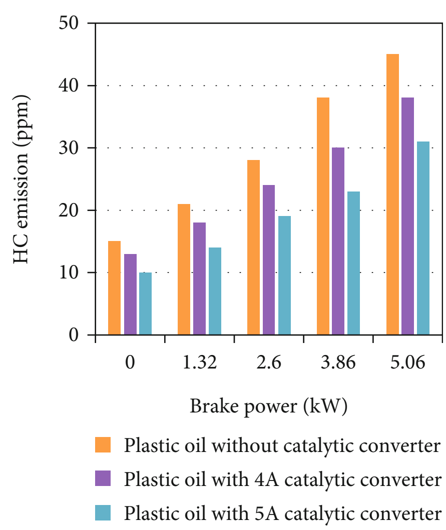

Figure 15: HC conversions with diesel + PPO with zeolite 4A and 5A catalyst.

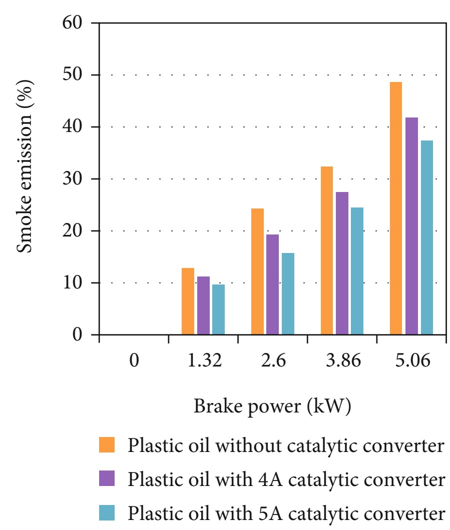

Figure 17: Smoke emission with diesel + PPO with zeolite 4A and 5A catalyst.

performance and emission without and with different catalyst have been tested.

The graph shows NO_x ppm at each load without and with catalytic converter. The graph explains that there is significant reduction in NO_x with each catalytic converter. The graph shows that NO_x reduction is higher with zeolite 5A than zeolite 4A at all loads.

The graph shows HC ppm at each load without and with catalytic converter. The graph explains that there is significant reduction in HC with each catalytic converter. The graph shows that HC reduction is higher with zeolite 5A than zeolite 4A at all loads.

The graph shows CO% at each load without and with catalytic converter. The graph explains that there is significant reduction in CO with each catalytic converter. The graph shows that CO reduction is higher with zeolite 5A than zeolite 4A at all loads.

The graph shows smoke at each load without and with catalytic converter. The graph explains that there is significant reduction in smoke with each catalytic converter. The graph shows that smoke reduction is higher with zeolite 5A than zeolite 4A at all loads.

3.3. Test on Diesel + Plastic Pyrolysis Oil Blend (50 : 50). The graph shows NO_x ppm at each load without and with catalytic converter. The graph explains that there is significant reduction in NO_x with each catalytic converter. The graph shows that NO_x reduction is higher with zeolite 5A than zeolite 4A at all loads, and it is seen in Figure 14.

The graph shows HC ppm at each load without and with catalytic converter. The graph explains that there is significant reduction in HC with each catalytic converter. The graph shows that HC reduction is higher with zeolite 5A than zeolite 4A at all loads and displayed in Figure 15.

The graph shows CO% at each load without and with catalytic converter. The graph explains that there is significant reduction in CO with each catalytic converter. The graph shows that CO reduction is higher with zeolite 5A than zeolite 4A at all loads, and it is displayed in Figure 16.

The graph shows smoke at each load without and with catalytic converter. The graph explains that there is significant reduction in smoke with each catalytic converter. The graph shows that smoke reduction is higher with zeolite 5A than zeolite 4A at all loads, and it is displayed in Figure 17.

4. Conclusion

Zeolite 4A and 5A have been used with conventional casting methods using carboxymethyl cellulose as binder to prepare the catalyst for substrate structure. The substrate has been heated at around 650°C for 4 hours with an increase 75°C for every interval of 30 minutes.

(i) Preparation of mold has been accomplished by using 8% of bentonite clay, 5% of carboxymethyl cellulose, and 34% of distilled water

(ii) The outer casing has been welded using TIG welding, and no gaps has been ensured; it is prepared with several metal parts

(iii) Length and dimension of the casing have been calculated for conventional catalytic converter measurements and space constraints

(iv) Exhaust back pressure created by catalytic converter is 60 mbar. The same back pressure was created in without catalytic converter setup by using electrical motor-controlled flap valve

(v) The gap between the molds has been chosen to be 2 cm in order to ensure proper adsorption on zeolite 4A and 5A

(vi) Reduction of NO_x has been proved using adsorption properties of ZSM 4A and 5A and decomposition reaction

(vii) Significant reduction of 42% in NO_x using zeolite 5A and 27% reduction in nitrous oxide (NO_x) using zeolite 4A mold structure were observed

(viii) Comparing zeolite 4A and 5A, it is observed that zeolite 5A has adequate amount of reduction in nitrous oxide and other harmful emission gases from a diesel engine

(ix) These results indicate that the use of zeolite 4A and 5A mold using bentonite clay and carboxymethyl cellulose as a binder is an effective way of reducing NO_x emissions

(x) Zeolite 4A and 5A molds could be used as catalytic converters after calcination to get an adequate amount of reduction in nitrous oxide and other harmful emissions from a diesel engine, typically lean-burn engines

(xi) Future scope of my study is to implement urea injection system in zeolite catalytic converter and validate the emission reduction

Data Availability

The data used to support the findings of this study are included within the article. Further data or information is available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

The authors appreciate the supports from Arba Minch University, Ethiopia, for providing help during the research and preparation of the manuscript.

References

[1] S. Mohanavel Vinayagam, M. M. Suresh Kumar, S. M. Ravikumar, and T. Raja, "Feasibility and emission study on employing MgO nanoparticle as oxygenated additive in neat biodiesel," *International Journal of Ambient Energy*, vol. 42, no. 14, pp. 1629–1634, 2021.

[2] S. Komarneni, H. Katsuki, and S. Furuta, "Novel honeycomb structure: a microporous ZSM-5 and macroporous mullite composite," *Communication*, vol. 8, no. 11, pp. 2327–2329, 1998.

[3] Z. Shan, W. E. J. van Kooten, O. L. Oudshoorn et al., "Optimization of the preparation of binderless ZSM-5 coatings on stainless steel monoliths by in situ hydrothermal synthesis," *Microporous and Mesoporous Materials*, vol. 34, no. 1, pp. 81–91, 2000.

[4] "Substrate heating method for coating metal surfaces with high-silica zeolites: ZSM-5 coatings on stainless steel plates," *Microporous and Mesoporous Materials*, vol. 101, no. 3, pp. 374–380, 2007.

[5] B. Ganemi, E. Björnbom, B. Demirel, and J. Paul, "Zeolite Cu-ZSM-5: material characteristics and NO decomposition," *Microporous and Mesoporous Materials*, vol. 38, 2000.

[6] R. Moreno-tost, "Selective catalytic reduction of nitric oxide by ammonia over Cu-exchanged Cuban natural zeolites," *Applied Catalysis*, vol. 50, no. 4, pp. 279–288, 2004.

[7] K. Okada, Y. Kameshima, C. D. Madhusoodana, and R. N. Das, "Preparation of zeolite-coated cordierite honeycombs prepared by an in situ crystallization method," *Science and Technology of Advanced Materials*, vol. 5, no. 4, pp. 479–484, 2004.

[8] B. K. Cho, "Nitric oxide reduction by ethylene over Cu-ZSM-5 Under lean conditions: Study of Reaction Dynamics by

Transient Experiments," *Applied Catalysis*, vol. 155, no. 2, pp. 184–195, 1995.

[9] Faros, *Selective catalytic reduction of nitrogen oxide using an iron impregnated zeolite catalyst*, United states patent, 1995.

[10] O. Krocher, "Investigation of the selective catalytic reduction of NO by NH_3 on Fe-ZSM5 monolith catalysts," *Applied Catalysis*, vol. 66, no. 3-4, pp. 208–216, 2006.

[11] R. M. Heck and R. J. Farrauto, "Automobile exhaust catalysts," *Applied Catalysis*, vol. 221, no. 1-2, pp. 443–457, 2001.

[12] Schneider, *Catalyst for reducing the nitrogen oxide content of flue gases*, United States patent, 1987.

[13] B. Louis, P. Reuse, L. Kiwi-Minsker, and A. Renken, "Synthesis of ZSM-5 coatings on stainless steel grids and their catalytic performance for partial oxidation of benzene by N_2O," *Applied Catalysis*, vol. 210, 2001.

[14] Y. Traa, B. Burger, and J. Weitkamp, "Zeolite-based materials for the selective catalytic reduction of NO with hydrocarbons," *Microporous and mesoporous materials*, vol. 30, 1999.

[15] M. Wallin, "Selective catalytic reduction of NO $_x$ with NH_3 over zeolite H-ZSM-5: influence of transient ammonia supply," *Journal of Catalysis*, vol. 218, no. 2, pp. 354–364, 2003.

[16] D. Florea, *Zeolite catalyst for the purification of automotive exhaust gases*, Surface scienceand catalysis, 1995.

[17] C. D. Madhusoodana, R. N. Das, Y. Kameshima, and K. Okada, "Preparation of ZSM-5 zeolite honeycomb monoliths using microporous silica. Obtained from metakaolinite," *Journal of Porous Materials*, vol. 12, 2005.

[18] M. Cheralathan and G. Balaji, "Experimental investigation to reduce exhaust emissions in a single cylinder CI engine fuelled with methyl ester of neem oil using antioxidant (L-ascorbic acid)," *Journal of biofuels*, vol. 7, no. 3, pp. 305–312, 2016.

[19] M. Cheralathan and G. Balaji, "The effect of antioxidant additives with methyl ester of neem oil on the oxidation Stability," *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, vol. 38, no. 16, pp. 2454–2461, 2016.

[20] G. Balaji and M. Cheralathan, "Influence of alumina oxide nanoparticles on the performance and emissions in a methyl ester of neem oil fuelled direct injection diesel engine," *Thermal science*, vol. 21, no. 1 Part B, pp. 499–510, 2017.