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Analyzing the Performance and the Emission Characteristics of Palladium Catalyst using different blends of Methanol Fuel and Nano Particles of Aluminium and Titanium Oxides

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Abstract

The high cost and limited availability of precious metals prompted the automotive industry to explore alternative materials for improving catalytic converter performance. This research focuses on the development and optimization of catalytic converters designed to reduce exhaust emissions, ensuring compliance with market needs and regulatory standards. Specifically, it investigates the three-way catalytic converter in a four-stroke engine utilizing commonly available noble metals, particularly palladium as the catalyst. The best way to control vehicle fume outflows is to focus research on temperature requirements on various burdens, which should be between 0 and 100 for noble metal impetus like palladium. Through exploratory work that includes connecting a palladium catalytic converter exhaust system to a motor, it has been discovered that palladium is an impetus in vehicle exhaust systems due to their low intensity conductivity and better execution compared to other materials. Impressive results have been obtained from research on the usage of alternate fuel and nanoparticles helps to reduce environmental deterioration. In this project, diesel and methanol fuel mixes are treated using nanoparticles of Aluminium Oxide (Al_2O_3) and Titanium Oxide (TiO_2). Initially, methanol is used as fuels in terms of blends are B10, B20, B30, and B40, for the experimental work. As per results from optimal blend, adding Nanoparticles of Al_2O_3 and TiO_2 as 10 and 20ppm are consider to getting effective results.

Keywords: Catalytic Converter; palladium catalytic converter; methanol fuel; aluminium oxide nanoparticle; titanium oxide nanoparticle.

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INTRODUCTION

The purpose of a catalytic converter is to chemically change harmful pollutants that the engine has burned while running in an assortment conditions (i.e. starting, driving, power, and idle). Catalytic converters were developed as a result of growing concerns about smog and other harmful vehicle emissions. In a perfect engine, all of the hydrogen in the fuel would be converted to water, all of the carbon would be converted to carbon dioxide, and nitrogen oxides would also convert it to nitrogen dioxide. In practice, the combustion process is not optimal, and automobile engines emit a variety of emissions. Theoretically, when the fuel to air ratio is stoichiometric, the burning of fuel in air will continue until it is finished.

Palladium Catalytic Converter

Up to 90% of hazardous gases from vehicle exhaust, such as hydrocarbons, carbon monoxide, and nitrogen oxides can be converted into less hazardous gases like nitrogen, carbon dioxide, and water vapor by using palladium-based catalytic converters. Palladium catalysts are sometimes referred to as Lindlar's Palladium or Lindlar's Catalyst [1]. Even double bonds can be broken down by the high catalytic activity of conventional palladium catalysts. With such catalysts, alkynes can be hydrogenated to form alkenes. Only alkenes must be produced as the end product using the catalyst.

Generally, palladium catalyst is one type of existing material helps to reduce emissions when operating an engine with this component. Here, methanol fuel was used as a fuel in different blends helps to reduce more amounts of emissions [2]. Engine Output:

- Increase brake thermal efficiency
- Reduce hydrocarbons and carbon dioxide due to more oxidation
- At the time of combustion process, a nitrogen oxide goes up if peak temperatures rise when using methanol fuel that was controlled using palladium catalyst.

Conceptual Design

The Computational Fluid Dynamics (CFD) tool was used to perform analysis after the design portion of computer aided engineering was established [3]. A flowchart in figure 1 can be used to illustrate the process.

Computer Aided Design

CATIA software was utilized in computer-aided design to create the three-way catalytic converter models, which are displayed in the figures 2 and 3 below [4].

Computational Fluid Dynamics

A multiphysics computational fluid dynamics (CFD) tool called Simcenter STAR-CCM+ is used to model how products might behave in real-world operational settings. Simcenter STAR-CCM+ has added automatic design exploration and optimization to every engineer's CFD simulation toolbox. A single integrated platform encompasses CAD, automatic meshing, multiphysics CFD, intricate post-processing, and design exploration [5], [6], [7] & [8].

As a result, engineers may effectively explore the whole design space, resulting in faster and more accurate design decisions.

Analysis revealed that the external surface temperature of noble metal, which was depicted in figure 4, ranges from 108 to 384 degrees Celsius. Analysis held on figure 5 internal surface temperature ranges from 212 to 335 degree Celsius. The CFD analysis indicates that both the internal and external representations in figures 4 and 5 emit fewer hazardous emissions; these numbers are almost identical to those of the noble metal [9] & [10].

Table 1. Thermal Analysis

Material	Temperature		Thermal Conductivity
	Min.	*Max.*	
Palladium (Noble Metal)	212°C	335°C	53.7 W/m-K

Here, vorticity followed by a predetermined temperature was well tolerated by the noble metal. Palladium, a noble metal catalytic converter based on results came from CFD analysis as shown in table 1 attach it to the engine's exhaust pipe to conduct the experiment.

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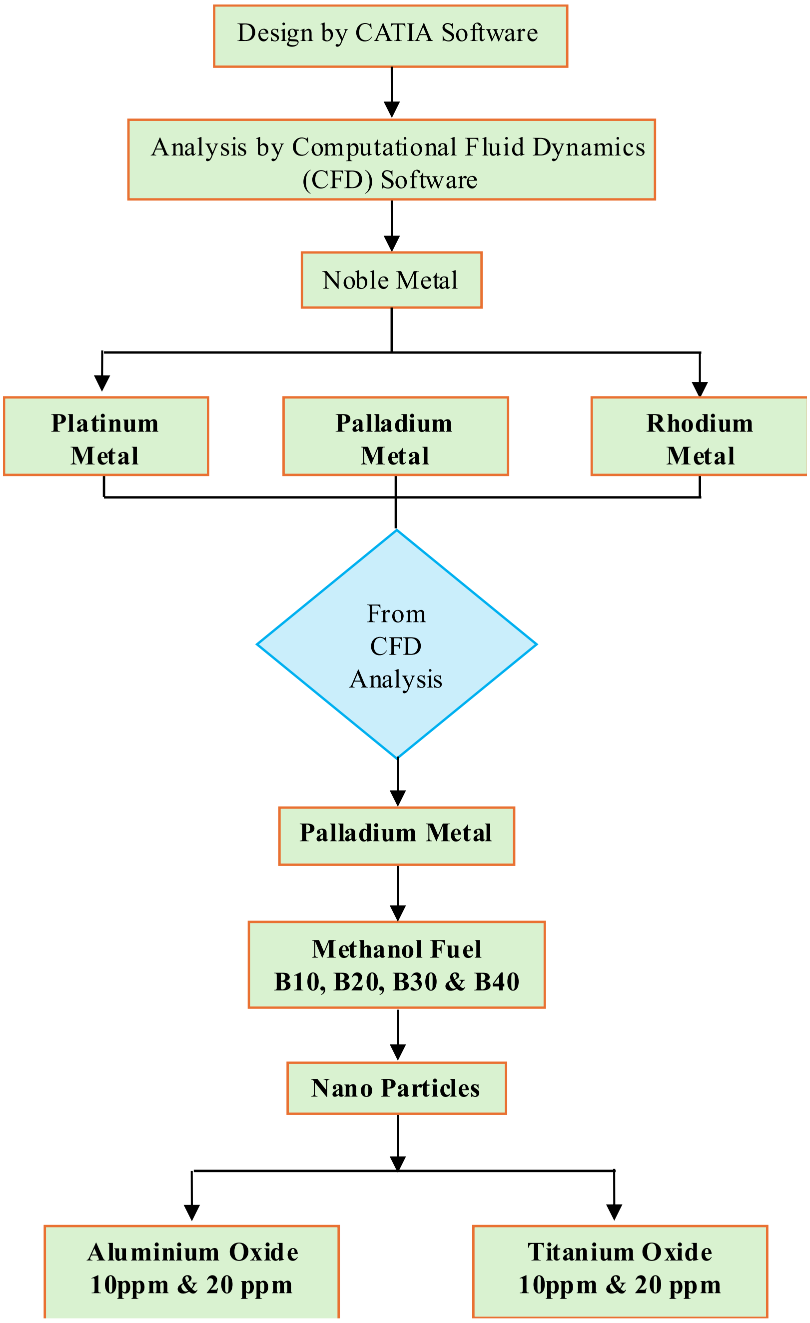

Figure 1. Flowchart

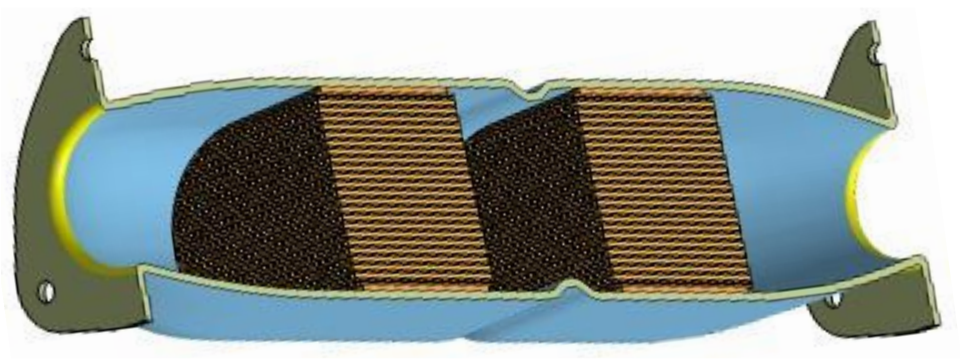

Figure 2. 3D Model of Three Way Catalyitic Converter

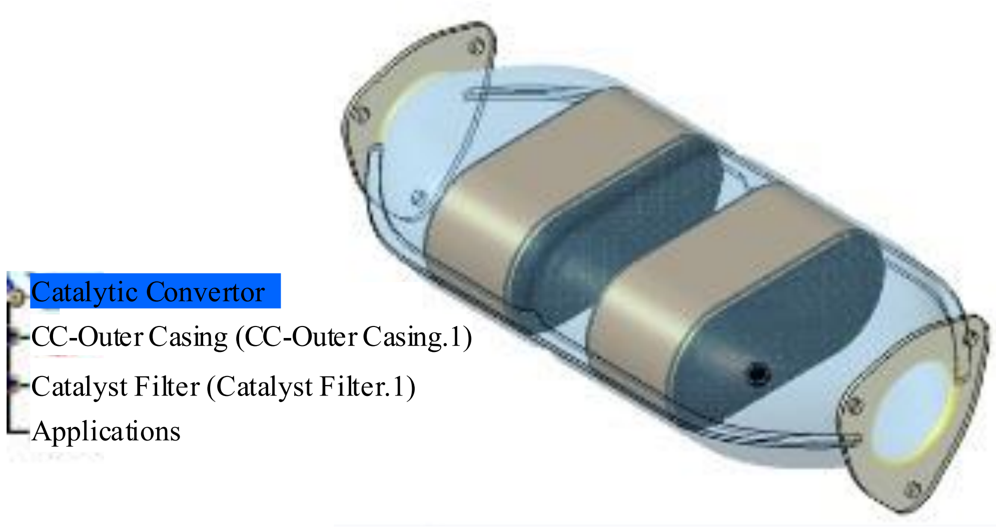

Figure 3. 3D Model overall view of Three Way Catalyitic Converter

Noble Metal:

Figure 4. CFD Analysis on External Surface of Palladium Alloy

Figure 5. CFD Analysis on Internal Surface of Palladium Alloy

METHODOLOGY

A catalytic converter and the experimental data can be used to carry out the following study. In order to test the noble metal, the experiment was originally carried out on a four-stroke, single-cylinder, variable compression ratio diesel engine connected with Palladium three-way catalytic converter [11],

[12] & [13]. The technical specifications are shown in table 2. The compression ratio stayed at 19:1 over the entire experiment. After the calorimeter was mounted, the catalytic converter was installed on the engine's exhaust side, 170 mm from the exhaust flange as shown in figure 6 [14]. Performance and emission tests were conducted when the load was changed from minimum to maximum conditions [15] & [16]. The findings were visually depicted as changes in carbon dioxide, nitrogen oxide, hydrocarbons, brake specific fuel consumption, brake thermal efficiency, and brake power with respective to load [17], [18], [19] & [20].

Table 2. Technical Specifications of Engine Setup

Name of The Engine	**Kirloskar**
Name of The Engine Setup	Variable Compression Ratio Diesel Engine
Brake Horse Power	5 HP
Speed	1500 rpm
Fuel	Diesel
Number of Cylinders	Single
Orifice Diameter	20 mm
Bore Diameter	80 mm
Stroke Length	110 mm
Compression Ratio	12:1 - 20:1
Starting	Self Start (Or) Cranking
Working Stroke	Four Stroke
Engine Cooling	Water Cooled
VCR Cooling	Water Cooled
Ignition	Compression Ignition
Governor System	Mechanical Governor
Type of Load	Electrical Loading

Figure 6. Four Stroke Single Cylinder Variable Compression Ratio Diesel Engine with Palladium Catalytic Converter

Here, fuel blend preparation in table 3, Nanoparticle proportions as shown in table 4, along with technical properties of fuel in table 5 are shown in below.

Fuel Blend Preparation:
Here, taken concentrations are good enough to avoid agglomeration and ensure uniform dispersion. Typically, below ~ 25 ppm dispersion is easy

Table 3. Different Proportions of Fuels

Proportions of the Blend	Percentage of Diesel	Percentage of Methanol
B10	90%	10%
B20	80%	20%
B30	70%	30%
B40	60%	40%

Table 4. Different proportions of Nanoparticles

Proportions of the Best Blend	Chemical Name of Nanoparticle	Proportions of Diesel + Biofuel + Nanoparticle
B40	Al_2O_3	60% + 40% + 10ppm
B40	Al_2O_3	60% + 40% + 20ppm
B40	TiO_2	60% + 40% + 10ppm
B40	TiO_2	60% + 40% + 20ppm

Table 5. Technical Properties of Diesel and Methanol Fuel

Properties	Diesel	Methanol
Specific Gravity	0.85	0.78
Calorific Value (kJ/kg)	43000	22700
Flash Point (°C)	49	12
Fire Point (°C)	56	36
Kinematic Viscosity (cs)	2.7	0.692

Experimental Procedure

The engine's performance characteristics are the subject of the experiment. The steps are as follows:

1. Attach the panel to the electrical connections that are required.
2. Verify the engine's lubricating oil and tank's fuel levels.
3. Release the dynamometer's load, if any.
4. To allow fuel to enter the engine, open the three-way cock.
5. Crank the engine to start it and bring it to a steady state.
6. Slowly tighten the rope brake drum's yoke rod handle to load the engine.
7. Take note of the following measurements for the specific condition:
   a. Engine speed
   b. Duration of 10cc diesel fuel consumption.
   c. Readings from manometers
8. Repeat the experiment with varying loads and record the readings above.
9. Once finished, release the load and turn off the engine.

RESULTS & DISCUSSION

The graphical representation shows on X-Axis as Load and on Y-Axis as Performance parameters like Brake Power, Brake Specific Fuel Consumption and Brake Thermal Efficiency also Emission parameters such as, Nitrogen Oxide, Hydro Carbons and Carbon Dioxide.

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Here, the short forms are mentioned in graphs, as B10, B20, B30 &B40 that is Blends variation from 10 to 40, Pd-B40-10ppm represents Palladium Catalytic Converter, blending proportional is 40& 10parts per million of Nano particles, Pd-B40-20ppm represents Palladium Catalytic Converter, blending proportional is 40 & 20 parts per million.

As per graphical representations, figure 7 to 12 shows a Palladium Catalytic converter, figure 13 to 18 shows a comparison of Palladium Catalyst with Nanoparticles of Aluminium Oxide (Al_2O_3) [21] and Titanium Oxide (TiO_2). From Palladium Catalyst B40 gives best result compared to B10, B20 & B30. According to Nano Particles, for 20ppm of Aluminium Oxide get better results compares to 10ppm. For Titanium Oxide shows best result in 10ppm compared to 20ppm. Also compares with both nanoparticles Titanium Oxide (TiO_2) reduce more emissions.

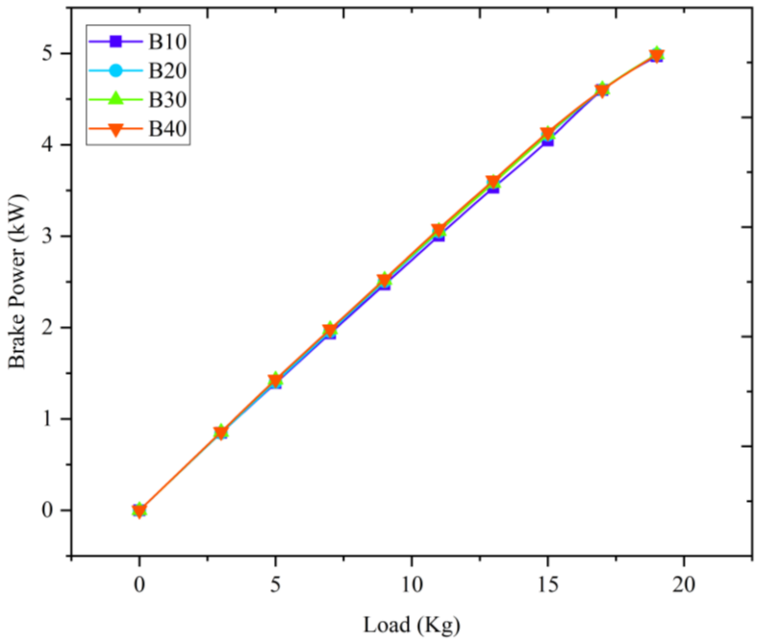

Figure 7. Brake Power Variation with Load for Palladium Catalytic Converter

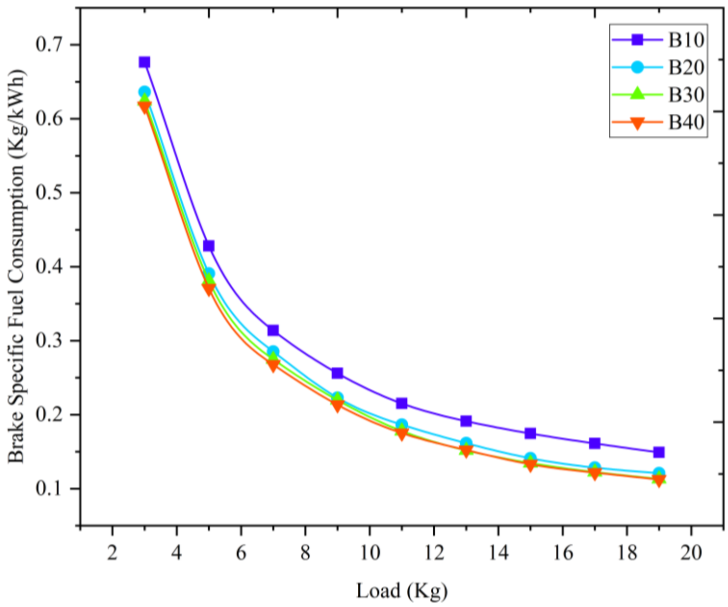

Figure 8. Brake Specific Fuel Consumption Variation with Load for Palladium Catalytic Converter

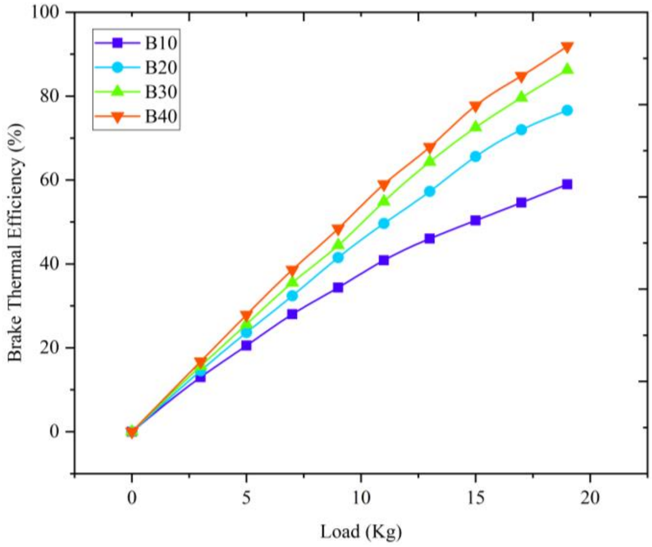

Figure 9. Brake Thermal Efficiency Variation with Load for Palladium Catalytic Converter

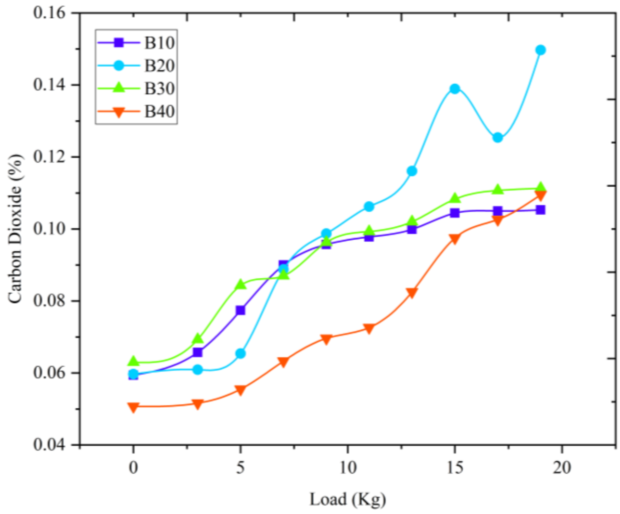

Figure 10. Carbon Dioxide Variation with Load for Palladium Catalytic Converter

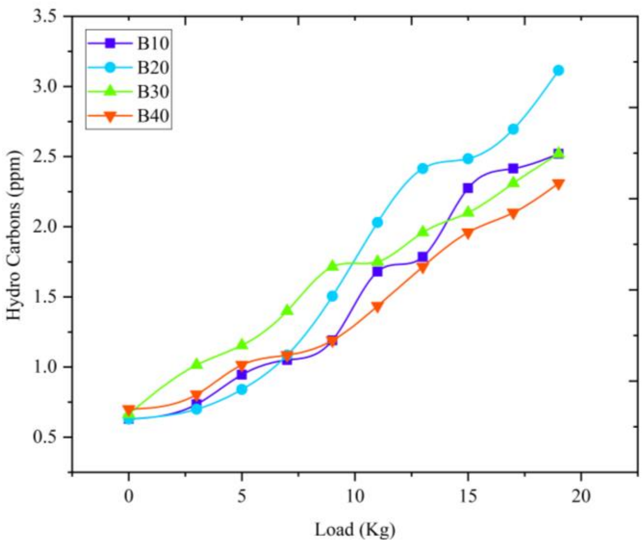

Figure 11. Hydro Carbons Variation with Load for Palladium Catalytic Converter

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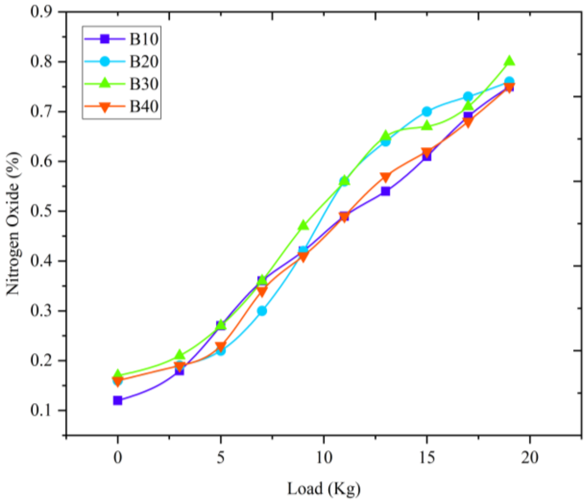

Figure 12. Nitrogen Oxide Variation with Load for Palladium Catalytic Converter

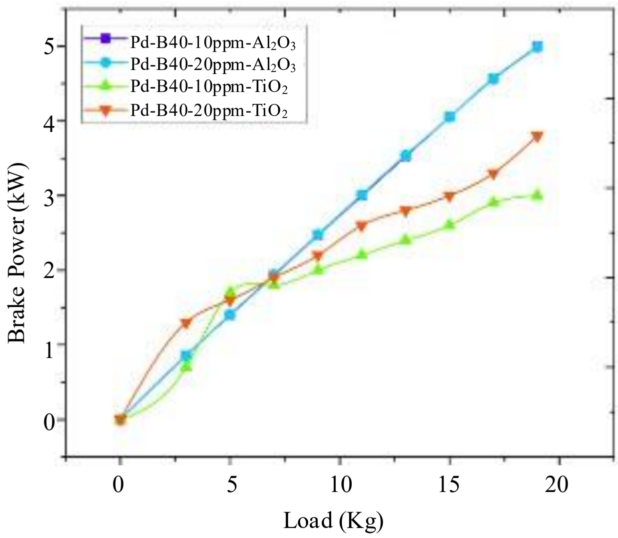

Figure 13. Brake Power Variation with Load for Palladium Catalytic Converter with Al_2O_3& TiO_2 Nanoparticles

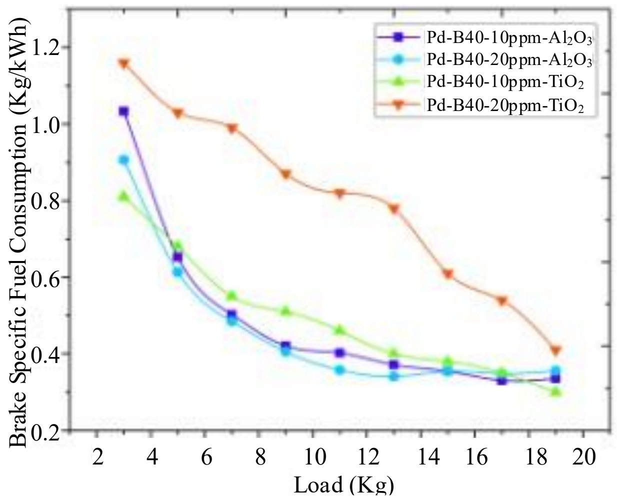

Figure 14. Brake Specific Fuel Consumption Variation with Load for Palladium Catalytic Converter with Al_2O_3& TiO_2 Nanoparticles

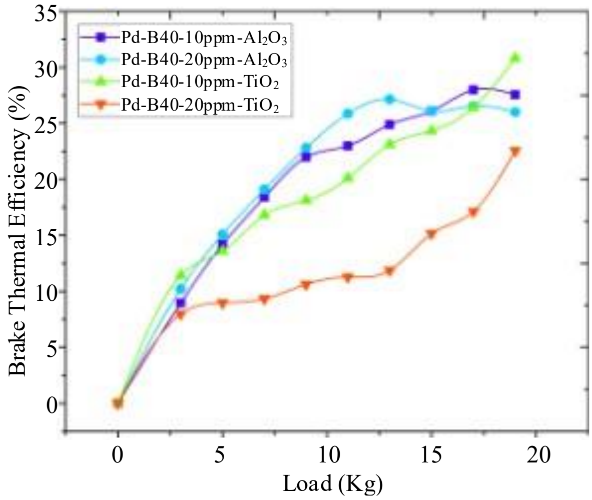

Figure 15. Brake Thermal Efficiency Variation with Load for Palladium Catalytic Converter with Al_2O_3 & TiO_2 Nanoparticles

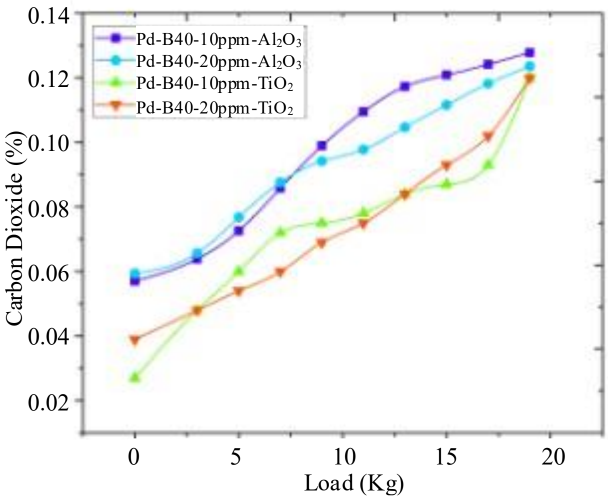

Figure 16. Carbon Dioxide Variation with Load for Palladium Catalytic Converter with Al_2O_3 & TiO_2 Nanoparticles

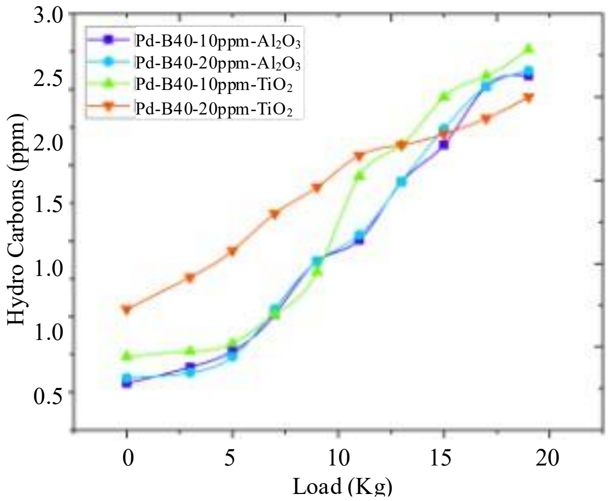

Figure 17. Hydro Carbons Variation with Load for Palladium Catalytic Converter with Al_2O_3 & TiO_2 Nanoparticles

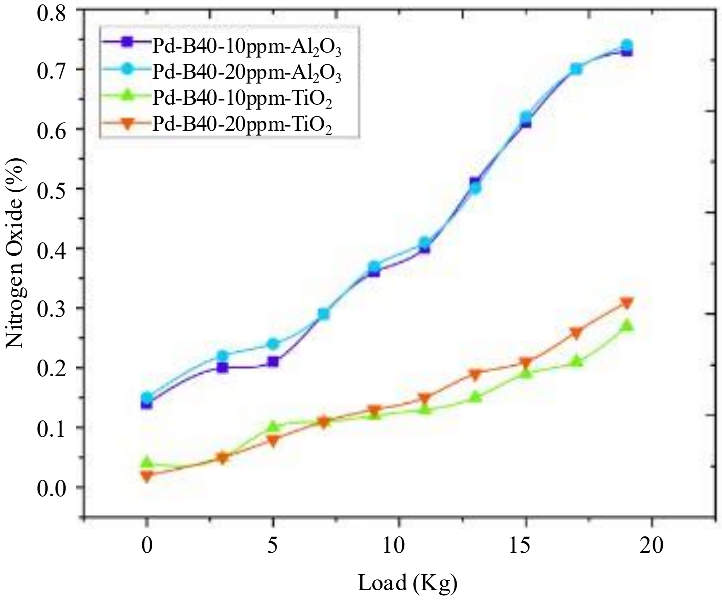

Figure 18. Nitrogen Oxide Variation with Load for Palladium Catalytic Converter with Al_2O_3& TiO_2 Nanoparticles

Any kind of automobiles will use to install this type of catalyst due to reduce emissions [22], [23], [24] & [25]. Catalysts aid in the refinement of crude oil into gasoline and diesel in the petroleum industry. They are employed in the chemical industry to produce synthetic textiles, plastics, and cleaning products. Catalysts are used in the automotive industry to convert toxic exhaust system gases into less toxic emissions [26] & [27].

The following are factors that will continue to scale:

- Regulation of emissions,
- Growth in hybrid vehicles, and
- Recycling and the circular economy.

Scaling obstacles include

- Supply chain concentration,
- Palladium pricing and supply, and
- Environmental issues.

CONCLUSION

The results of this investigation could lead to the following conclusions. Designing and testing the catalytic converter proved successful. Using CFD analysis, the temperature and vorticity of noble metals catalytic converter were investigated. The optimum choice in terms of heat conductivity Palladium catalyst was choose. In addition to improving power and fuel efficiency and lowering emissions while adding methanol fuel and Titanium Oxide nanoparticle helps to reduce carbon dioxide and nitrogen oxide, installing a palladium catalytic converter also according to the findings of the experiments and computations. In the future, it will be regarded as a good catalytic converter for lowering emissions and creating an eco-friendly environment.

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