EMISSION ANALYSIS OF A CI ENGINE USING A TITANIUM AND ZINC COATED CATALYTIC CONVERTER

ANALIZA EMISIILOR UNUI MOTOR CI FOLOSIND UN CONVERTIZOR CATALITIC ACOPERIT CU TITAN ȘI ZINC

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Abstract: *The escalating problem of air pollution, exacerbated by the continuous increase in automobile usage for human comfort is closely linked to the emissions from automobile engines. In addressing this environmental challenge, research has pivoted towards alternative strategies to mitigate the harmful impact of these pollutants. This study concentrates on the emission characteristics of a four-stroke mono-cylinder engine, employing a novel approach by using a catalytic converter coated with Titanium (Ti) and Zinc (Zn). Preliminary results indicate a significant reduction in the emissions of hydrocarbons (59%), carbon monoxide (57%), and nitrogen oxides (60%) at full load, in comparison to conventional compression ignition (CI) engines without catalytic converters. These findings underscore the potential of Titanium and Zinc-coated catalytic converters as a viable solution for reducing vehicular emissions, thus contributing to the broader goal of combating air pollution and ensure public health.*

Keywords: Catalytic converter, Titanium, Zinc, CI engine.

Rezumat:. *Problema crescândă a poluării aerului, exacerbată de creșterea continuă a utilizării automobilelor pentru confortul uman, este strâns legată de emisiile de la motoarele de automobile. În abordarea acestei provocări de mediu, cercetarea s-a orientat către strategii alternative de atenuare a impactului nociv al acestor poluanți. Acest studiu se concentrează pe*

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caracteristicile de emisie ale unui motor monocilindru în patru timpi, utilizând o abordare nouă prin utilizarea unui convertor catalitic acoperit cu titan (Ti) și zinc (Zn). Rezultatele preliminare indică o reducere semnificativă a emisiilor de hidrocarburi (59%),monoxid de carbon (57%) și oxizi de azot (60%) la sarcină maximă, în comparație cu motoarele convenționale cu aprindere prin compresie (CI) fără convertoare catalitice. Aceste descoperiri subliniază potențialul convertoarelor catalitice acoperite cu titan și zinc ca soluție viabilă pentru reducerea emisiilor vehiculelor, contribuind astfel la obiectivul mai larg de combatere a poluării aerului și de asigurare a sănătății publice.

Cuvinte cheie: Convertor catalitic, titan, zinc, motor CI.

1. Introduction

The main issue facing the modern world is air pollution. As is the ecosystem, humans and other living things are impacted by air pollution. Vehicle emissions and industrial pollution are major sources of air pollution. Toxic gases are highly present in vehicle emissions. The unburned fuels produce toxic gases like CO, NOx, and HC which are harmful. These gases impact human health by eye irritation, headaches, etc. Diesel engines are more widely used than gasoline engines, due to their low fuel cost and good energy efficiency. Diesel engines are used in many commercial applications like trucks, railways, ships, and commercial vehicles. The industrial and mining industries use diesel as a power source [1,2]. On the other side the CI engine emits higher emissions than the SI engine. There are ways to get around this problem. They are: (i) altering the engine; (ii) changing the fuel's properties; and (iii) the after-treatment process. Engine modification includes coating cylinders and pistons with a catalyst and attempting to boost the fuel burn level. Due to the enormous emissions of petrol and diesel, must use alternate fuels such as bio-blend diesel and CNG. The requirement to regulate engine exhaust emissions is embodied in the after-treatment process. A catalytic converter is one type of emission reduction system which is installed on an automobile's exhaust system [3&9]. The TWC is made up of an exterior housing, heat shield, insulation, substrate with catalyst material, and wash coat. Regarding emission control, the selection of the material and the acquisition of its characterization are the most crucial parameters.

In studies of design research, Square-shaped cells mechanically perform less than hexagon-shaped cells (lower pressure drop). However, compared to a hexagonal-shaped cell, a square-shaped cell has superior chemical performance (greater specific surface area). When developing the model, it is necessary to take into account the effects of several characteristics, including the substrate used, cone angle, and the diameter and length of the catalytic converter [12].

Numerous researchers are investigating the material and method of catalytic converters. Catalyst role in CO oxidation is more fundamental due to the stronger metal-oxygen connection. Mn_2O_3, CuO, ZnO, TiO_2, Fe_2O_3, NiO, and CO_3O_4 exhibit the highest catalytic activity in CO oxidation out of all the transition metal oxides [11]. The conversion efficiencies of TiO_2/Co-based catalytic converters for NO_x, CO, and HC pollutants are determined to be 93%, 89%, and 82%, respectively, in experiments [12].CI engine tested a zinc - vanadium coated catalytic converter that reduced CO and NO_x by 60% and 70%, respectively [14]. Therefore, zinc and titanium are both inexpensive and efficient oxidation and reduction materials. Therefore, In this current work CI engine is analyzed the emissions formation control using titanium and zinc in a catalytic converter

2. Materials and Methods

The customized ceramic monolith was bought from a vendor and had its dust cleaned by compressed air. This ceramic monolith is characterized by its square-shaped cells. In its composition, Titanium and Zinc were utilized as catalyst materials, with aluminum oxide being employed as a washcoat material. The dip-coating method was used for the application of these materials, necessitating the use of a 1 and 5-liter beaker, a mechanical stirrer, and an aquarium pump as the requisite apparatus.

The wash coating procedure, which spanned an hour, was followed by a drying phase at room temperature for a day and then at 200 ^{0} C in a hot oven for two hours. Then distilled water was used to prepare a zinc acetate solution by dissolving zinc acetate powder in it and adding the NaOH solution. The process of coating adhered to a specific ratio arrangement. This setup was maintained for an hour. Afterward, the membrane, which had been coated with Zinc acetate and NaOH, underwent drying for 12 hours at room temperature and was subsequently dried at 200 ^{0} C in a hot oven for two hours. The appearance of a white hue on the layer signified the presence of zinc acetate. The application of a titanium tetra iso-propoxide coating followed a similar procedure. For this, titanium tetra iso-propoxide liquid was mixed with ethanol to form a titanium solution. The coating process for this solution utilized 0.1 N, equivalent to 45ml of titanium tetra iso-propoxide, to 500 ml of ethanol within the ultraviolet setup.

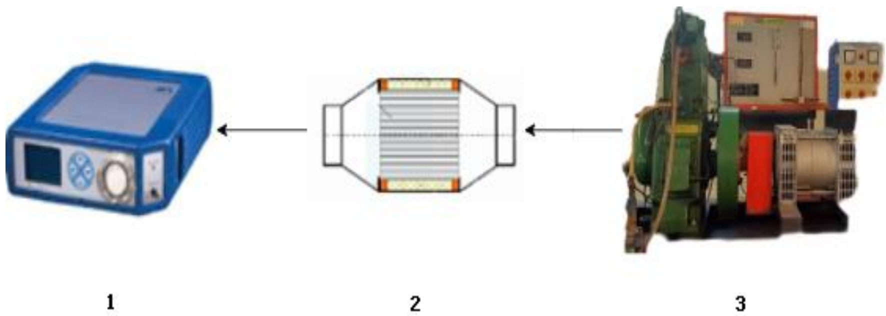
Following the coating, the titanium tetra iso-propoxide-coated membrane was also dried for 12 hours at room temperature and again at 200º C in a hot oven. The emergence of white flakes on the membrane after the drying process indicated the presence of Titanium. The next steps involved testing the coated membrane sample for XRD and FESEM to confirm the presence of the catalyst material. The membrane was then assembled with the catalytic converter's designated outer casing.

3. Experimental Setup

A conventional CI engine with an energy capacity of 3.5 kW was used to study the emission characteristics of diesel with a Ti-Zn-coated catalytic converter. The results were compared with the conventional engine without a catalytic converter. AVL 444L five-gas apparatus was used for the emission test. An experimental setup of this current study is shown in figure 1 and test engine specification shown in table 1.

Table 1. **Specification of test engine**

Description	Specifications
Engine make	Kirloskar
Bore& Stroke	87.5 mm& 110 mm
Max. Power	3.5 kW @1500 RPM
CR	17.5:1
Nozzle opening pressure	250 bar @ 23 deg before TDC



1. Five gas analyzer 2. Ti-Zn coated catalytic converter 3. 4S diesel engine test rig.

Figure 1. Experimental setup of CI engine Ti-Zn coated catalytic converter

4. Result and Discussion

4.1. XRD Results

The nanoparticles were synthesized through a method involving the utilization of zinc acetate microparticles, sodium hydroxide (NaOH) pellets, titanium tetra isopropoxide, ethanol, and distilled water, aiming at the preparation of titanium-doped zinc oxide (ZnO) nanoparticles. The chosen method for synthesizing these nanoparticles was meticulously designed to ensure the successful incorporation of titanium (Ti) ions into the ZnO lattice. Following the synthesis process, the nanoparticles were subjected to X-ray Diffraction (XRD) analysis, a crucial step carried out in the XRD Laboratory, to confirm the successful doping of titanium into the zinc oxide matrix. The XRD results shown in figure 2 revealed the presence of both ZnO and Ti peaks, confirming the successful doping of titanium into the zinc oxide nanoparticles.

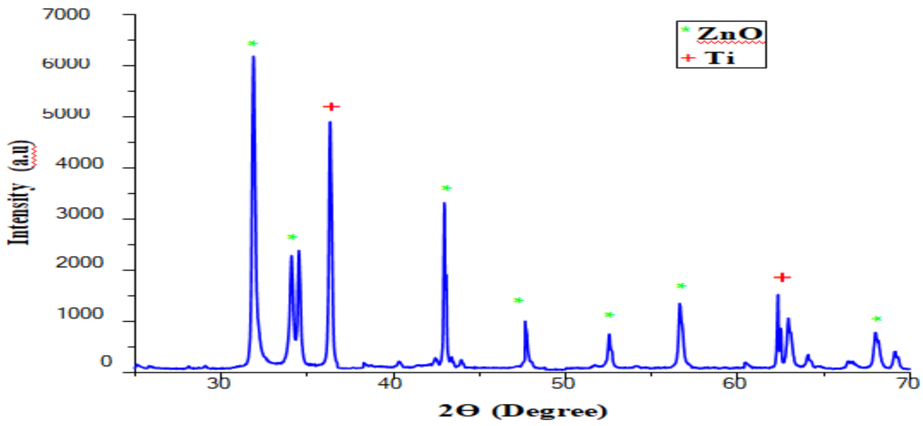


Figure 2. XRD test Results of Ti-doped Zinc nanoparticle

4.2. SEM Results

A sample was submitted for Field Emission Scanning Electron Microscopy (FESEM) analysis to elucidate the microstructural features and the coating level of the catalyst material under study. This precise method allows for the high-resolution examination of surface characteristics, enabling detailed observations at the nanometer scale. SEM analysis of nanaparticles is shown in figure 3. The analysis provided insights into the coated particles, revealing that their average size measures about 98.1 µm. The extent of these details was extracted from the processed images using Image J software, a robust tool known for its capability in analyzing and processing scientific images. Through this software, comprehensive data regarding the material's surface properties were obtained, facilitating the identification of the nano-scale dimensions of the coated material. It was determined that the material exhibited a nano-sphere shape, highlighting the uniformity and spherical nature of the nanoparticles.

This finding has significant implications for understanding the catalyst's functionality and performance, as the shape and size of nanoparticles can greatly influence their catalytic activity. Nano-sphere particles, with their extensive surface area about volume, are often preferred in catalyst design for their potential for higher reactivity.

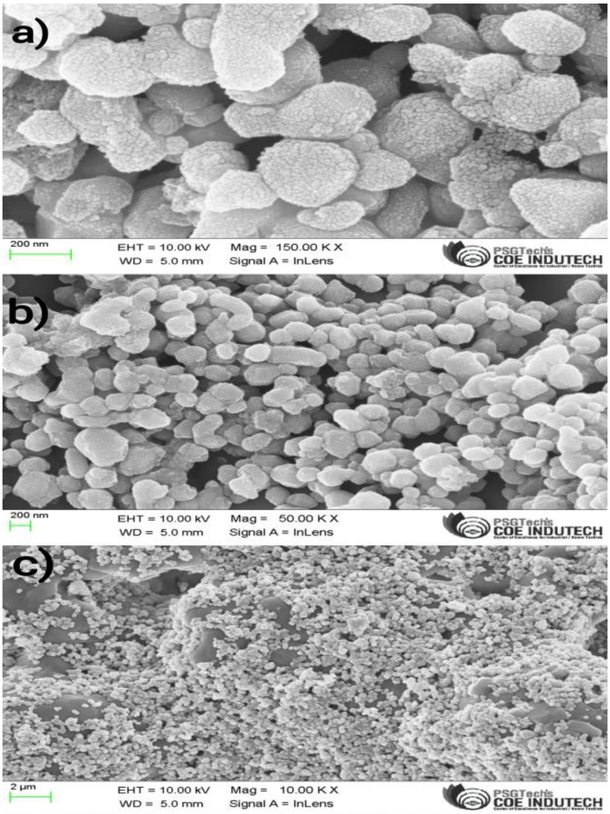


Figure 3. SEM micrographs of the nanocoating. a), b) images are showing Ti-doped zinc nanoparticles c) images show the nanosphere particles of Ti-doped zinc.

4.3. Emission Test

The AVL 444L five-gas apparatus was used for the emission test to measure CO, HC and NOx in CI engine with standard diesel fuel.

4.3.1. Carbon Monoxide Emission

In this instance, a titanium and zinc-coated catalytic converter was utilized to investigate a conventional CI engine's emission characteristic under several loading scenarios. CO emissions are often produced during and after the combustion process because of the decreased O_2 concentration and the lower in-cylinder temperature during the oxidation process. These emissions were formed in rich zone of combustion. The CO values were gradually increases with increase in engine loading due to more fuel consumption at high loads with low air-fuel ratio (Udhayakumar et al. 2021). The variation of CO emission (g/kW-hr) values under various load scenarios is shown in figure 4. As an oxidizing agent, titanium seems appealing. It transforms into carbon dioxide through a reaction with carbon monoxide.

$$CO + \frac{1}{2} O2 \rightarrow CO2 \quad (1)$$

Analyzing emissions from the CI engine without a catalytic converter is also being done. A 57% reduction in CO emission in fully loaded situations is obtained by comparing the two outcomes.

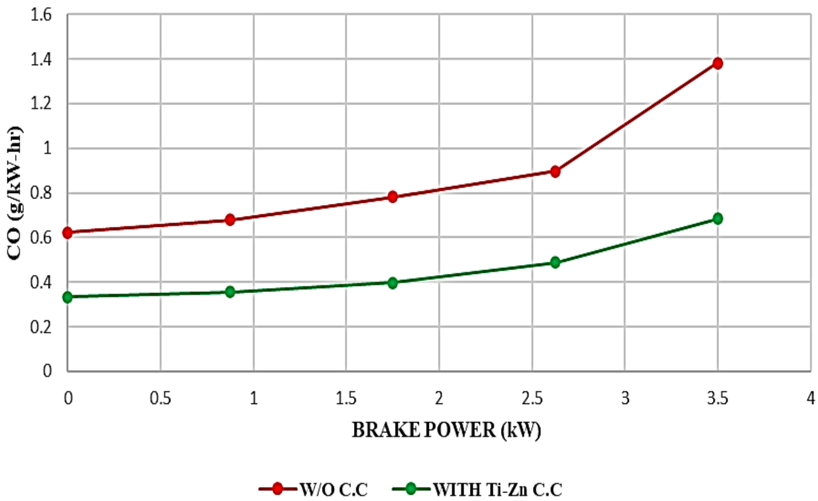


Figure 4. Variation of CO emission with respect to brake power

4.3.2. Hydrocarbon Emission

The unburnt fuel produces hydrocarbon gas. Emissions of Unburnt Hydrocarbons (UBHC) at the exhaust were a result of the lower in-cylinder temperature and improper combustion. An incomplete combustion causes due to improper mixing of fuel and air, wall wetting, blow by due to wear and tear in oil rings and local cooling(Sanjeevan et al.2013). UBHC gases significantly impact human health. An emission analysis was conducted on a conventional Compression Ignition (CI) engine, both without a catalytic converter and with one coated in titanium and zinc. Variation of HC emission with respect to load conditions is shown in figure 5. It was found that the emissions of UBHC were significantly reduced by the catalytic converter that was coated with titanium and zinc. Titanium, being an effective agent for oxidation reactions, facilitates the conversion of hydrocarbons into carbon dioxide and water vapor.

$$2CxHY + \frac{1}{2}(4X + Y)\,O2 \rightarrow 2XCO2 + YH2O \qquad (2)$$

$$CxHY + 2O2 \rightarrow H2O + CO2 \qquad (3)$$

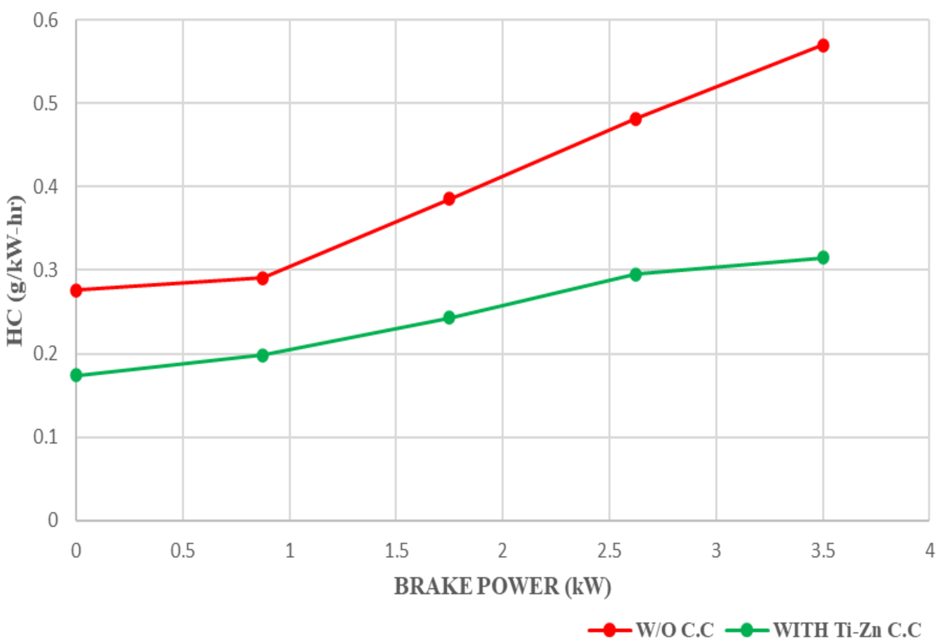


Figure 5. Variation of HC emission with respect to brake power

The Hydrocarbon gas emission is minimized by 59% at full load condition.

4.3.3. Oxides of Nitrogen

High in-cylinder temperature and excess O_2 levels following combustion resulted in the formation of oxides of nitrogen emission in the combustion chamber. When NO_x emissions are high, it can affect people's respiratory systems. NOx emissions vary according to the load as depicted in the figure 6. With traditional engines, the titanium zinc catalytic converter lowers the oxides of nitrogen emissions under various load scenarios. Because titanium zinc-coated converters contain zinc, which functions as an oxi-reduction agent in catalytic converters, the engine emits 60% less NOx. Nitrogen and oxygen are the two products of nitrogen oxide transformation, allowing the oxygen to combine with carbon monoxide.

$$2CO + 2NO \rightarrow 2CO2 + N2 \tag{4}$$

$$\text{CxHx} + \text{NO} \rightarrow \text{XCO2} + \text{2H2O} + \text{N2} \tag{5}$$

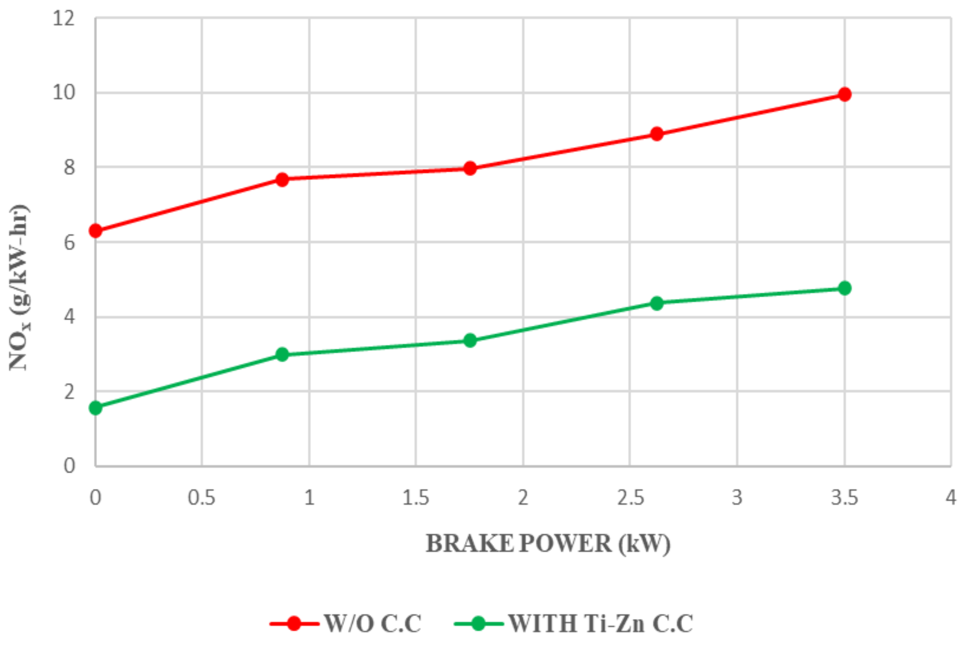


Figure 6. Variation of NO_x emission with respect to brake power

4.4. Cost analysis

In the context of the Indian market, it has been observed that the cost associated with conventional catalytic converters, which utilize noble materials for their operation, typically amounts to approximately INR 35,000. On the other hand, a redesigned version of the catalytic converter, which has been developed as part of this research, is presented as a more cost-effective solution, with an overall expenditure estimated at INR 19,000. This cost encompasses the design expenses, material procurement, and the manufacturing process involved in the creation of the catalytic converter. Through a detailed cost analysis, it has been determined that the redesigned catalytic converter represents a cost reduction of approximately 35% when compared to the traditional models currently available in the market. This significant decrease in cost is attributed to the innovative approach in the design phase, the strategic selection of materials, and the optimization of the manufacturing processes, which collectively contribute to the cost-efficiency of the product without compromising its efficacy or performance. Such findings suggest that the adoption of the redesigned catalytic converter could lead to substantial financial savings for consumers and automobile spare manufacturers in the Indian market, thereby offering a viable and economical alternative to the existing technological solutions.

5. Conclusion

In the research work regarding the emission tests conducted on a Compression Ignition (CI) engine equipped with a titanium-zinc (Ti-Zn) coated catalytic converter, the following conclusions can be drawn:

- **Reduction in Carbon Monoxide Emissions:** It has been observed that at full load, carbon monoxide (CO) emissions were reduced by 57% when a Ti-Zn-coated catalytic converter was employed, in comparison to a conventional CI engine that did not utilize a catalytic converter. This significant reduction can be attributed to the efficiency of titanium as an oxidizing agent, which facilitates the conversion of CO into carbon dioxide (CO_2).

- **Decrease in Oxides of Nitrogen Emissions:** The employment of a Ti-Zn coated catalytic converter resulted in a 60% reduction in the emission of oxides of nitrogen (NO_x) at full load, compared to a conventional CI engine without a catalytic converter. Zinc, acting as a potent oxi-reduction agent, plays a crucial role in converting NO_x into nitrogen (N_2) and oxygen (O_2), thereby contributing significantly to the reduction of NOx emissions.

- **Lowering of Hydrocarbon Emissions:** The application of a Ti-Zn-coated catalytic converter has been associated with a 59% decrease in hydrocarbon (HC) emissions at full load when compared with a conventional CI engine lacking a catalytic converter. This reduction is mainly due to the capability of titanium to act as an effective oxidizer, transforming HC into carbon dioxide (CO_2) and water (H_2O).

- **Cost-Effectiveness of the Catalytic Converter**: The cost analysis reveals that the catalytic converter coated with Ti-Zn is 1.7 times more economical than the currently existing catalytic converters. This cost-effectiveness, along with its enhanced emission reduction capabilities, positions the Ti-Zn-coated catalytic converter as a viable alternative for emission control in CI engines.

The above points underscore the effectiveness of Ti-Zn-coated catalytic converters in significantly lowering emissions from CI engines while being cost-efficient. These findings suggest that titanium and zinc, when used as catalysts, contribute to the substantial reduction of harmful emissions but also present a cost-effective solution for emission control technology.

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Conflicts of Interest

The authors declare that there is no conflict of interest.

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