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Research Article

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Nanoparticle-Enabled Reduction of Emissions and Fuel Consumption in Compression Ignition LHR Engines

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ABSTRACT
This study examined how adding nanoparticles affected the diesel engine's performance parameters. Aluminum and cerium are two of the metallic nano additives used in this field thus far. Moreover, a wide range of work in this field is manifested by the potential to use different metals, modify additive structures, and enhance or alter the fundamental fluid. The silver nanoparticles were added to the net diesel fuel for this reason. The data show that the engine power, oil temperature, and percentage of pollutants released significantly changed. By quickening the burning process, the metallic nanoparticles inside the combustion chamber increase heat transfer to fuel and reduce the ignition delay. In the meantime, during the spraying stage, these particles may help fuel particles penetrate even deeper into the compressed air. The combination of all these characteristics will enhance combustion, resulting in a reduction of unburned carbons and other pollutants. These findings would result in a considerable decrease in the rate of CO and NOx, to 20.5 and 13%, respectively, with the net diesel and HC levels experiencing the greatest change, up to 28%. The outcomes also show a 3% decrease in fuel consumption and a 6% increase in engine power, with nanoparticles being used in most of these instances. Chugh et al. investigated the green synthesis of silver nanoparticles (AgNPs) using algae as a sustainable and eco-friendly approach. The study highlights the crucial role of capping agents in controlling the size, shape, and stability of AgNPs. The authors explored various capping agents, including polysaccharides, proteins, and polyphenols, to optimize AgNP synthesis [1].

Keywords: Emissions, Fuel, Diesel, Engine, Nanoparticle, Additive

Introduction

Nanotechnology has transformed numerous scientific disciplines, driving innovation and advancement. The intersection of nanoscience and nanotechnology enables the development and utilization of nanoparticles, offering vast potential across diverse fields. Silver nanoparticles (AgNPs) have garnered significant interest due to their exceptional properties and far-reaching applications [2]. The green synthesis of silver nanoparticles (AgNPs) has emerged as a promising approach to developing eco-friendly, cost-effective, and sustainable antibacterial agents. This review highlights the significance of bioactive AgNPs in combating bacterial infections, showcasing their potential applications in various fields, including medicine, healthcare,

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and biomedical engineering. The authors demonstrate that plant-mediated synthesis of AgNPs offers a viable alternative to conventional methods, ensuring reduced toxicity and environmental impact. Demonstrated the green synthesis of silver nanoparticles (AgNPs) using Ocimum canum (Holy Basil) leaf extract [3,4]. The study investigated the antibacterial activity of these AgNPs against various bacterial strains. Salayová et al. investigated the green synthesis of silver nanoparticles (AgNPs) using extracts from various medicinal plants. Kao et al. CNTs in diesel fuel reduced PM emissions by 30%. Sajjad et al. CeO_2 nanoparticles in engine oil reduced NOx emissions by 25%. Rajak et al. TiO_2 nanoparticles in diesel fuel improved fuel efficiency by 12% [5].

Engine Oil Additives: Huang et al. Copper (Cu) nanoparticles in engine oil improved lubricity by 40% and reduced wear by 30%. Li et al. Silver (Ag) nanoparticles in engine oil enhanced antimicrobial properties by 90%. Wang et al. Molybdenum disulfide (MoS_2) nanoparticles in engine oil improved lubricity by 50%.

Coolant Additives: Kim et al. Aluminum oxide (Al_2O_3) nanoparticles in coolant enhanced heat transfer by 20%. Lee et al. Zinc oxide (ZnO) nanoparticles in coolant improved corrosion resistance by 30%. Nanocoating's: Tang et al. Titanium nitride (TiN) nanocoating's improved engine component durability by 50%. Chen et al. Chromium nitride (CrN) nanocoating's enhanced corrosion resistance by 40%. Liu et al. Diamond-like carbon (DLC) nanocoating improved fuel efficiency by 15%. Wang et al. Nanofiltration removed impurities from fuel, improving engine performance. Li et al. Nano catalysts enhanced fuel combustion, reducing emissions. Kumar et al. Nano sensors monitored engine performance, detecting faults. Taylor. Investigated LHR engines with ceramic coatings, achieving a 10% efficiency improvement. Kamo et al: Demonstrated 15% efficiency gain using ceramic-insulated pistons. Jiang et al. Developed an LHR engine with thermal barrier coatings, achieving 12% efficiency improvement. Singh et al: Investigated an LHR engine with a ceramic-coated cylinder head, reducing heat rejection by 25% [6-9]. Kumar et al: Analyzed LHR engine with advanced insulation materials, achieving 18% efficiency gain [10].

Fuel Properties; Cetane number: affects engine performance and emissions [11]. Viscosity: influences fuel atomization and combustion, Sulfur content: impacts emissions and engine durability, Biodiesel: reduces greenhouse gas emissions Yan et al. Hydrogenated vegetable oil (HVO): improves engine efficiency Liu et al. Synthetic diesel: enhances fuel properties Wang et al. Detergents: improve fuel cleanliness Kao et al. Dispersants: reduce sludge formation Sajjad et al. Anti-corrosion additives: protect engine components [12,13].

Emissions

1. **Particulate matter (PM):** influenced by fuel properties and engine design Kim et al.
2. **Nitrogen oxides (NOx):** affected by combustion temperature and timing Lee et al.
3. **Carbon monoxide (CO):** impacted by fuel-air mixture and combustion efficiency [10].

Materials and Methods

Preparation of Diesel Fuel and Nanoparticle

To prepare the fuel and nanoparticle combination, 30–50 nm diameter silver powder, produced by the US Nano American company, was first chosen. Moreover, the surfactant sorbitan monooleate produced by to ensure the stability of the nanoparticles in the diesel fuel, Sigma-Aldrich was consulted. Silver nanoparticles were added after the homogenizer had solved only 2% of the surfactant per volume in the diesel fuel. The prepared mixture was then placed in the German company Hielscher's ultrasonic UP400 s for 10 minutes. For the experiment, three different fuel combinations were ready. First, a mixture containing 10 ppm of nanoparticle and fuel was prepared. Following this, a mixture containing 20 ppm of nanoparticle and fuel was obtained. Lastly, a mixture containing 40 ppm of nanoparticle and fuel was prepared. In the aforementioned procedure, three different types of fuel mixture were identified in the diagrams by the letters D10, D20, and D40, respectively [11].

Coating of Diesel Engine Parts

Thermal Insulation of Diesel Engine Components; To minimize heat rejection, various engine elements were insulated using diverse materials. This study involved:1. Cleaning: Valves, piston crowns, cylinder heads, and grit-blasted surfaces were disinfected with ethyl alcohol and dried.2. Base Coating: A 0.16 mm layer of NiCrAl was applied to engine components.3. Top Coating: A 0.5 mm layer of ceramic composites (PSZ and TiO_2) was added, using particle sizes of 8-60 µm.4. Machining: Excess material was removed from piston crowns.5. Surface Treatment: Grit blasting enhanced bond strength of aluminum alloy. Coating Process coating steps were performed at Ideal Engine Coating Private Limited's facility in Chennai, India. To Reduce heat rejection rate in diesel engines through insulation [12-15].

Configuration of Diesel Engine

This experiment uses a Low heat rejection compression ignition engine, which has the characteristics listed in Table 1. The fuel flow was measured using an FTO flow meter, which has a measurement range of 37 to 1,514 milliliters per minute, manufactured by the American company Flowtech. The flow meter uses a magnetic sensor in conjunction with a turbine to function. The eddy dynamometer was used to conduct the experiments and regulate the speed and load. Based on the dynamometer printout, the given power in the graph is written. The standard power takes off (PTO) speed with a 6-gear shaft is 540 rpm at 1,893 engine speed, and 1,000 rpm at 1,900 engine speed with a 21-gear shaft. Stated differently, the engine RPM to PTO shaft ratio through a 6-gear shaft is 3.51:1, while a 21-gear shaft has a ratio of 1.9:1. Given that the empowerment shaft specification of the engine favors a 21-gear and 1,000 rpm mode, the 21-gear interface shaft was selected. The experiment used an emission analyzer (made in Germany) that measures the number of pollutants such as O_2, HC, NOx, CO, and CO_2 exhaust products from the exhaust and indicates the temperature of the oil. The dynamometer conducted tests in seven different modes (Table 2), and each test was run twice to guarantee repeatability and consistency in the results. A schematic of the experimental setup is shown in Figure 1. Table 3 provides an expression of the machine's measurement precision.

Table 1: Properties of engine

Type	Kirloskar, four stroke, single cylinder DI diesel engine
Bore x Stroke	87.5 mm x 110 mm
Compression ratio	17.5: 1
Injection timing	23deg. before TDC (static)
Number of nozzles	3
Nozzle spray hole diameter	0.3 mm
Angle of fuel spray (cone angle)	120 deg
Piston geometry	Hemispherical
Swept volume	661 cc
Rated Power	4.4 kW
Rated Speed	1500 rpm

Table 2: Engine test models

SI NO	MODE	Engine speed (RPM)
1	1	1330
2	2	1425
3	3	1520
4	4	1615
5	8	1710
6	6	1805
7	7(Idle)	1900

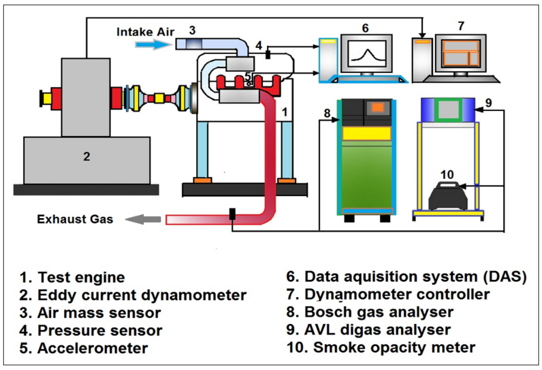

Figure 1: Schematic layout of Engine experimental setup

Table 3: Measurement Precision

SI NO	PARAMETERS	ACCURACY
1	Engine speed	+/_1rpm
2	Engine torque	+/_1Nm
3	NOx emissions	+/_5%
4	CO emissions	+/_1 %
5	CO2 emissions	+/_2%
6	HC emissions	+/_2%
7	Fuel flow rate measurement	+/_1%
8	Lower heating value of the fuel	+/_4%

Results and Discussion:

Fuel Consumption

Figure 2 illustrates, the largest reduction in fuel consumption occurs when 10 and 20 parts per million of nanoparticles are added to the fuel. The sixth mode has the highest fuel consumption for all fuels, while the seventh mode has the lowest fuel consumption, according to the results of comparing various combinations between modes. Diesel and nano silver blends with ratios of 40 ppm in mode 6 and 10 ppm in mode 7 are associated with maximum and minimum fuel consumption, respectively, of 385 (ml/min) and 116 (ml/min), respectively. In terms of the declining trend of the diesel fuel consumption rate, most of the compounds saw a decrease of roughly 1-2%. As shown in Figure 2, adding up to 20 parts per million of nanoparticles reduced the amount of fuel used. One of the ways that the addition of nanoparticles reduces fuel consumption is by improving fuel distribution in the combustion chamber, reducing the ignition delay, and enhancing the physical properties of the fuel. It demonstrates a slight decrease from base diesel to DAG10, which is explained by the introduction of nanoparticles, which reduces the cohesion force between diesel fuel molecules. This causes a decrease in fuel injection from the injector due to a decrease in fuel viscosity. On the other hand, higher nanoparticle concentrations (10–40 ppm) result in denser droplets and ligaments because of stronger bonds between fuel molecules and nanoparticles, which makes it possible for the injector's nozzle tip to release more fuel. By adding nanoparticles to diesel fuel, it is possible to increase the fuel injection momentum and the rate at which fuel enters the cylinder, leading to a more even distribution of the fuel/air mixture in the combustion chamber. This result is consistent with similar studies involving nanoparticles that reported improved charge characteristics Yang et al. Kao et al. Selvan et al [16-20].

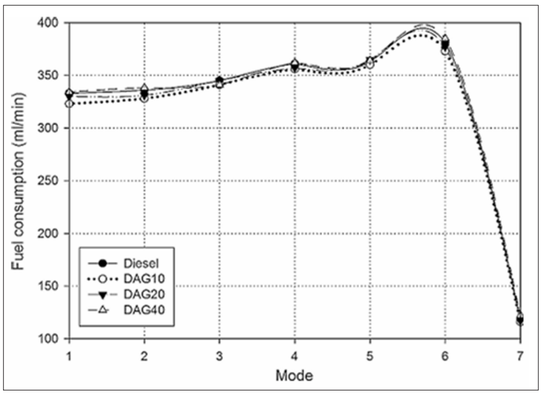

Figure 2: Variation of FC with respect to speed modes

The rise in viscosity and subsequent increase in droplet diameter during the 40-ppm mode are the causes of the increased fuel consumption. Spraying of fuel. D10 fuel was linked to the highest reduction rate of 3%, while D40 fuel in modes 7 and 6 was linked to the highest increase rates of 4.3% and 1%, respectively. The maximum values for engine torque and power are suggested by the dynamometer's indicated values in modes 3 and 5. When tests are conducted in these modes, the aforementioned scenarios outperform the others in terms of fuel consumption.

CO Emissions

Figure 3 illustrates how the enhanced mixture by nanoparticles significantly reduces CO emissions when compared to the base fuel mode. The results of similar studies using nanoparticles in fuel composition Basha and Anand. Selvan et al. Solero is consistent with this finding. Fuel free of nanoparticles emits significantly more CO, which is explained by the cohesiveness of diesel's intermolecular bonds. By decreasing the homogeneity of the base fuel composition, increasing the percentage involvement of nanoparticles speeds up fuel disintegration and breakup during fuel injection. With a DAG40-fueled engine, more fuel breakdown results in a better air-fuel mixture and a lower equivalency ratio, which can eventually reduce CO emissions. Under dynamometer loading conditions and idle mode (mode 7), the fuel consumption was typically reduced by about 20.48 and 40–70%, respectively, when compared to the base diesel fuel for D40. As a result of the engine reaching the smoke limit under high dynamometer loads, all fuels see an increase in CO and UHC (unburned hydrocarbon) emissions. This is because the engine needs oxygen to operate in air/fuel ratios greater than unity, or stoichiometric ratios. After D20, changes occur very slowly, and the addition of additional nanoparticles has no appreciable impact.

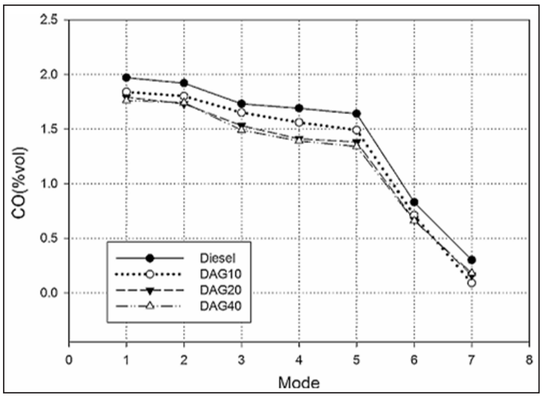

Figure 3: Variation of CO with respect to various speed modes

NOx Emissions

As can be seen in Figure 4, silver nanoparticles have a decreasing effect on NOx, which continues to decrease up to 13% for D40 under dynamometer loading conditions and 20–23% in idle mode (mode 7). The lowest NOx of 250 ppm is connected to the combination of diesel and nanosilver with a ratio of 20 ppm in mode 7, while the maximum NOx of 1,427 ppm is related to diesel fuel in mode 1. There are several factors that contribute to the specific formation of NOx emissions. The Zeldovich mechanism states that temperature, residence time, and oxygen concentration all affect the production of NOx Benson and Whitehouse. The NOx reduction is caused by the temperature drop in the combustion chamber brought on by the addition of nanoparticles. Similar studies conducted for nanoparticles Yang et al. Kao et al. Basha and Anand. Selvan et al. Sajith et al. Basha and Anand are consistent with this result. As is well known, the nanoparticles have remarkable heat-transfer capabilities. The ability of nanoparticle addition to lower combustion chamber temperature through high convective heat transfer rates and increase fuel's nano fraction to reduce NOx emissions is one of its main benefits [21-25].

UHC is regarded as an emission that negatively impacts engine efficiency. Insufficient air available during fuel combustion resulted in the generation of partially or completely burned hydrocarbons. The most significant impact of metallic nanoparticle application has been on HC emission.

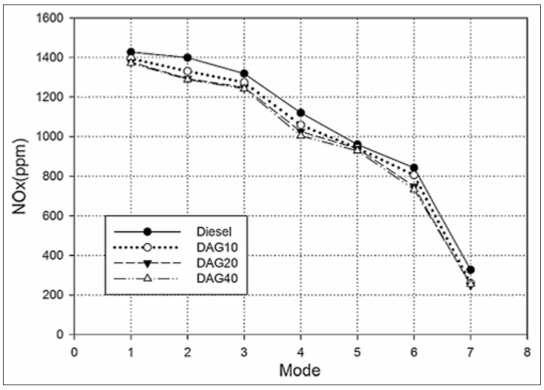

Figure 4: Variation of NOx with respect to various speed modes

HC Emissions

Figure 5 shows that HC emissions can be reduced by 4–28%, and that all fuels will see a decrease in HC emissions relative to the base fuel as the amount of silver increases. The published research of Yang et al. Kao et al. Basha and Anand. Selvan et al. Sajith et al. Basha and Anand. Can all be used to support this conclusion. However, the decrease in HC is not very significant because of the low amount of HC in the diesel engine that is being used. Particularly at higher equivalency ratios, the higher percentage of incomplete combustion in the combustion chamber results in the generation of UHC and a significant reduction in efficiency. As previously stated, the addition of nanoparticles improves the air-fuel mixing process and lowers the equivalency ratio, resulting in full combustion and increased thermal efficiency. Fuel spray droplet interaction and fuel droplet propagation increase with nanoadditiveness. Silver nanoparticles added to the fuel can help the injected fuel disperse in the combustion chamber and increase the spray cone angle. Better spray dispersion is explained by the presence of metallic particles in pure liquid fuel during the injection phase, which have varying densities and velocities and interact with one another. However, the pollutants shown in Figures 5, 6, and 7 would be reduced if a more thorough combustion were established as a result of the increased oxygen availability and silver properties. Applying nanoparticles reduces fuel cohesion, which makes fuel breakup easier and produces smaller droplets or a lower Sauter mean diameter. This exposes more fuel surface to O_2 oxidizer, which raises CO_2 production, as previously discussed.

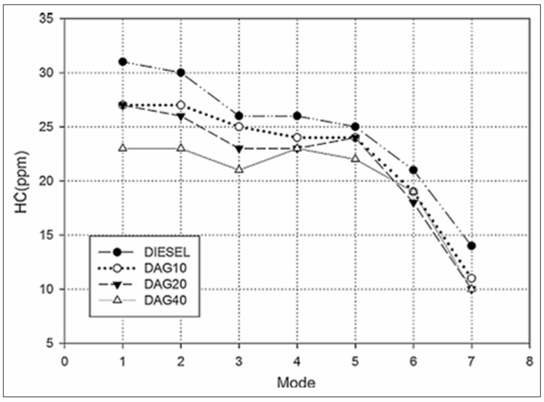

Figure 5 & 6: Variation of HC with respect to various speed modes

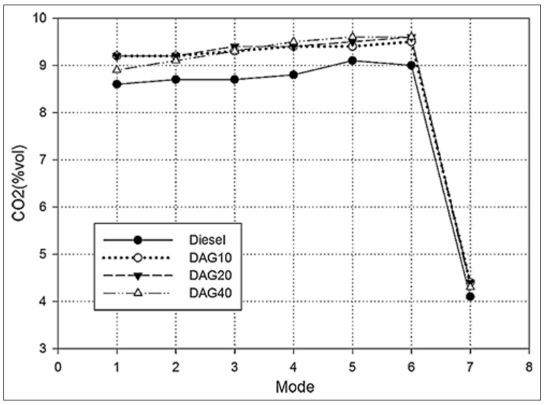

Figure 7: Variation of CO_2 with respect to various speed modes

CO_2 Emissions

Figure 6 shows, CO2 emissions for different fuel blends of nanoparticle portions as a function of different dynamometer loads. As can be observed, at various dynamometer loads, the CO2 emission from fuels containing nanoparticles is higher than that from pure diesel fuel. Existence of a portion of nanoparticles enhances spray quality and combustion phase for increased oxygen availability and catalytic activities. This lowers the amount of CO and UHC incomplete combustion products released into the atmosphere and increases CO2 emission concentration. Rather than being an oxidation catalyst, metals were frequently employed as reducing catalysts. Silver, however, is an anomaly and was additionally employed as an oxidation catalyst Prucek et al. Kvitek and Robert. Claus and Hofmeister [26-28].

Thus, the use of this metal is appropriate for reducing nitro compounds, oxidizing organic compounds, and many other processes. Conversely, metallic nanoparticles' high surface area and surface energy will improve their performance. There is no doubt that any substance having catalytic activity has a large contact surface area. Nanomaterials are widely employed in catalysis because their surface area grows as their size decreases. For instance, in a crystal measuring 10 nm in diameter, 15% of the atoms are on the surface, whereas in nanocrystals measuring 1 nm in diameter, every atom is positioned on the surface. Thus, more catalytic activity will be present in a small nanocrystal with a high surface area Claus and Hofmeister. With the exception of HC, it is clear from the charts that emissions for higher nanofractions than D20 vary very little and stay nearly constant. As a result, up to 40 parts per million of nanoparticles were added to diesel fuel.

Brake Power

Figure 7, shows that adding nanoparticles to a fuel mixture improves fuel combustion and increases the rate at which fuel energy is converted into useful work by increasing brake power. When compared to base fuel, the engine power has increased within a tolerance range of 1.1%–7.3%. Similar studies employing nanoparticles have produced results similar to this one Yang et al. Kao et al. Basha and Anand. Selvan et al. Sajith et al. Basha and Anand.

The fifth mode had the highest power for all fuels, and the seventh mode had the lowest power, according to the results of comparing combinations between the modes. In mode 5, the maximum power of 64.2 kW is linked to a blend of diesel and nano silver at a ratio of 40 ppm, while in mode 7, the minimum power of 16.7 kW is linked to net diesel. Regarding the diesel's rate of power increase fuel, the majority of the compounds saw an increase of about 4%. Figure 7 shows that the power has been enhanced by adding more nanoparticles, but this growth rate was shown to be reduced after 20 ppm of nanoparticles were added, and it was shown that adding more nanoparticles above this threshold had no appreciable effect on power. Mode 2 produced the highest growth rates for D40 and D20 fuels, which were 7.3% and 7%, respectively. D40 fuel in mode 6 and D10 fuel in mode 7 were linked to the lowest growth rates of 1.1% and 1.3%, respectively. Better air/fuel mixture is anticipated due to the aforementioned factors and the presence of metallic particles inside the chamber; additionally, a higher rate of energy release is certified due to the silver's catalytic role. This increase may result from the cylinder's increased energy production, which also raises the fuel's nanoparticles' surface to volume ratio and heat transfer coefficient.

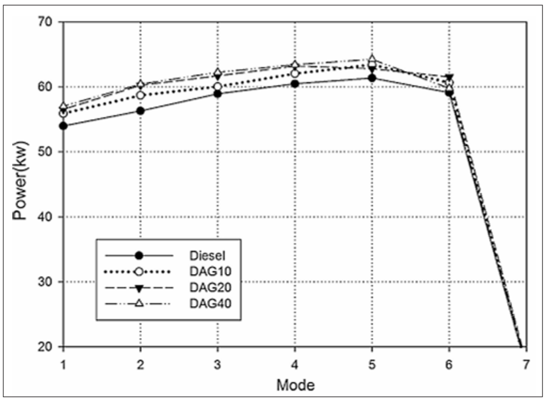

Figure 8: Variation of Brake Power with respect to various speed modes

Conclusion

Drawing from the experiments and diagrams, it was found that the addition of silver nanoparticles will enhance both the amount of pollution released and the fuel consumption when used with diesel fuel. By increasing fuel infiltration and air mixing, the addition of metallic particles will enhance the combustion process. Additionally, the fuel will evaporate more quickly and the ignition delay in the combustion process will be shortened by these metallic particles.

Authors' Contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by [Samuelraj D], [Venkatesh R]. The first draft of the manuscript was written by [Samuelraj D] and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Declaration of Conflicting Interests

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Consent for publication: All the authors have given their consent to publish the paper

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