Study of Modified Fuel and Advanced Zeolite-Copper Oxide Nanocomposite Catalytic Converter in a Diesel Generator

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Abstract. The issue of environmental pollution from diesel engines is a cause of major concern, even though diesel engines provide high thermal efficiency. This problem can be reduced to an extent through the use of modified fuel and catalytic converters. This study focus on improving the energy density of fuel by blending it with metal particles and hence increasing the thermal efficiency and ignition within the combustion chamber. Diesel was blended with nano and micron aluminium particles separately using ultrasonicator. Sorbitan monooleate was used as the surfactant. The catalytic converter was developed by making modification inside the silencer by placing stacks of mesh, which were coated with zeolite copper oxide nanocomposite. The nanocomposite matrix was prepared using copper nitrate solution and zeolite powder in an alcoholic medium, treated with a reducing agent. Engine performance test was carried out separately for both nano and micron aluminium blended diesel in a single cylinder four stroke, air cooled, direct injection Kirloskar engine. The experiment was carried out by varying the load at a constant speed of 1500 rpm to evaluate the performance characteristics. Emissions from the diesel generator fuelled by diesel and modified fuels were recorded by OPAX gas analyser both in the presence and absence of catalytic converter. The results indicated an increase in brake thermal efficiency by 8% and 72% for micro Al blended diesel and nano Al blended diesel respectively, in comparison with ordinary diesel. The emission test using catalytic converter gave 50%, 34% and 17% decrease in CO emission for ordinary diesel, micro-Al blended diesel and nano Al blended diesel respectively.

1. Introduction

Air pollution generated from mobile source is a cause of great concern. This environmental problem is due to the fact that, most of the engines employ combustion of fuels derived from crude oil as the
source of energy. Burning of hydrocarbon ideally leads to the formation of water and CO₂ but due to imperfect combustion control and the high temperatures reached during combustion, exhaust contains significant amount of pollutants which need to be converted to harmless compounds. The concept of making alternative fuels is aimed at reducing the percentage emissions of such harmful gases and to increase the efficiency of engine. Diesel is a liquid fuel derived from crude oil. It has an average reported density of 840kg/m³ and calorific value of 36.9 MJ/L. Diesel engines are self-ignition and do not require any spark to start. Diesel engines produce high torque at low engine speeds and are more reliable than petrol engines. The main concern of a diesel engine is its emission rate of greenhouse gases and hydrocarbon soot due to incomplete combustion. Diesel can be used as a base fuel for the preparation of alternative fuel. Aluminium is the most abundant metal in the earth’s crust and is relatively safe to use. Aluminium is known for its reaction with oxygen in the presence of heat leading to an exothermic reaction. It also has high combustion energy. Due to these factors, aluminium of various size ranges (nano and micron) can be used as an additive in the base fuel to form the alternative fuel. Nano aluminium (n-Al) and micron aluminium (μ-Al) were separately dispersed in diesel in an ultrasonicator to form modified fuels[1]. Sorbitan monooleate (span 80) was used as surfactant[2]. One of the main issues in the combustion of μ-Al particles is its high ignition temperature. For a particle with a diameter greater than 100-micron metre, ignition is achieved only upon the melting of oxide shell at high temperatures[5]. The molten oxide shell forms a cap because of surface tension and exposes the aluminium core, thereby allowing ignition of the particle. The application of micron scale energetic metal particle additives in liquid fuel is a concept yet to be explored to its full potential.

Higher energy density of metal particles results in the increase of overall calorific value of the liquid fuel, eventually improving the performance of the engine by boosting power output. The study on evaporation and ignition probability hints to a very important role in determining two critical properties, viz; ignition delay and ignition temperature which probably characterizes the performance of a diesel engine, very much instrumental in controlling emissions.

The most effective treatment for reducing engine emissions is the use of a catalytic converter[13]. Thermal converters require a temperature of about 700°C to oxidise CO & HC to CO₂ and water. But if certain catalysts are present, the temperature needed to sustain these oxidation reactions is reduced to 250-300°C. CuO is a good candidate for replacement of the costly metal catalyst since it is cheap[19]. The effectiveness of the CuO can be heavily improved by making it to nanometer scale. The catalyst is not consumed in the reaction and so it functions indefinitely unless it gets degraded by heat, age or other factors. Catalytic converters consist of chambers mounted in the flow system through which exhaust gases pass through. Catalytic material incorporated in the meshes, which is stacked in the chamber, promotes the oxidation of emissions contained in the exhaust flow.

2. Experiment

2.1 Fuel Preparation

The Aluminium nanoparticles (from Nanoshell LLC) of 100nm average particle size were mixed with liquid fuel by first stirring them vigorously. Sorbitan monooleate was used as the surfactant to promote chemical stabilization of the suspension. It is a typical surfactant used to enhance the stability of metal particles in n-alkanes and it is also commonly used in water/fuel emulsion. Then an ultrasonic disrupter was used to disperse particles evenly and to avoid agglomeration[1]. Sonication was performed in a water bath to maintain a constant temperature for the mixture. The sonication generates a series of 4-s-long pulses 4s apart, was turned on for about 5 minutes. The figure 1 shows the blending of fuel in an ultrasonicator.

Modified diesel was prepared by blending diesel, μ-Al (from Mepco- dust grade du10) of average particle size 40 μm and Sorbitan monooleate in the weight ratio of 200:1:10. The use of 5 (weight) % surfactant will help to improve the settling time of μ-Al in diesel from 5 minutes [1] to 23 minutes,
thus ensuring the stability of the blended diesel. The same procedure is repeated to prepare n-Al blended diesel in the weight ratio of 1000:5:2.

2.2 Zeolite Copper Oxide Nanocomposite Preparation
Zeolite powder was added to 250ml CuNO₃ solution and was constantly agitated for two hours at a temperature of 150-200°C, until the colour of the CuNO₃ solution (blue colour) fades. The supernatant liquid was removed and residue was dried. The resultant matrix was treated with reducing agent (hydrazine hydrate) in an alcoholic medium for 1 hour[18]. It was then vacuum filtered and heated at 250°C. Figure 2 shows the prepared zeolite copper oxide nanocomposites.

2.3 Diesel Generator Modification
For the prevention of coagulation caused by the modified diesel, the nozzle size of the diesel generator was modified to 0.3mm. Modification was made inside the silencer by placing stacks of 4 meshes (with negligible pressure drop) which were coated with zeolite copper oxide nanocomposite as shown in Figure 3.

2.4 Engine Performance Test
A study of engine performance was conducted on a single-cylinder, four stroke, constant speed (1500 rpm) direct injection Kirloskar KBM-108 Diesel Four-stroke, CI, vertical, air cooled, single-cylinder Bore stroke 87.5 mm x110 mm Diesel engine. Compression ratio was 17.5:1. Capacity 661 cc and rated output of 7.5 kVA were at 1500 rpm diesel generator. The engine test was performed initially with pure diesel at fully throttled and no-load conditions and then micron/nano fuel was fed through a separate fuel feed line. During the engine test for μ-Al blended diesel, the stability of the suspension was ensured by conducting the test well before its settling time. All experiments were conducted by varying the loads at a constant speed of 1500 rpm to evaluate the performance characteristics such as specific fuel consumption (SFC), brake power (BP) and brake thermal efficiency (BTE). As the engine was used for electric generation purpose, electric loads were used for testing the engine. Engine was stepped up for each loading and the loading test was carried out. Each step up of 500W was carried out. The engine was started by cranking after taking the necessary precautions. Engine was allowed to run for 5-10 minutes to get heated up. Time was noted for the consumption of 10cc fuel at no load. The load test was carried out for different modified fuels.

2.5 Engine Emission Test
The emission test was carried out for the exhaust gas from the single cylinder, four-stroke Kirloskar diesel generator as shown in Figure 4. The emissions from diesel generator fuelled by diesel and modified diesel (μ-Al & n-Al particles blended with diesel) samples was recorded by gas analyzer (OPAX 2000 II/DX) shown in Figure 5. The test was carried out under no load condition. The exhaust gas emission was recorded both in the presence and absence of advanced zeolite-copperoxide nanocomposite catalytic converter.
2.6 Droplet test
The droplet test was carried out for both n-Al & μ-Al fuels. A Silica crucible was heated upto 270°C in a Bunsen burner, the temperature was measured using Arduino program. A drop of nano/micron fuel was introduced into silica crucible. A video camera (Canon power shot A 1800 ISO-1600) was setup to observe the micro explosion of the fuel. Figures 6 and figure 7 shows the images of droplet tests carried out with μ-Al and n-Al blended diesel, respectively.

The droplet test shows that, combustion time is inversely proportional to size of particle. Presence of thicker aluminium oxide coating is the main reason for this. Thickness depends on size of the particle and for lesser size more area is available for reaction[5].

![Figure 4. Emission test with catalytic converter](image1)
![Figure 5. OPAX Gas Analyzer](image2)

![Figure 6. Droplet test for diesel + μ-Al](image3)
3. Result and Discussion

The result of the engine performance test is shown in tables 1, 2 and 3. It is observed that the brake thermal efficiency changes on account of aluminium metal particle size. On comparing the load test values, the efficiency increases from the ordinary diesel values to diesel+ n-Al modified fuel as shown in Figure 8.

Table 1. Engine performance test for ordinary diesel

| Sl. No | Load (kW) | Brake power (kW) | Time (Sec) | Total fuel consumption (kg/hr) | Specific fuel consumption (kg/kw.hr) | BTH (ŋ) |
|--------|-----------|------------------|------------|-------------------------------|--------------------------------------|---------|
| 1      | 0         | 0                | 41.30      | 0.951                         | -                                    | -       |
| 2      | 0.5       | 0.961            | 30.76      | 0.994                         | 1.035                                | 7.688   |
| 3      | 1         | 1.925            | 27.62      | 1.108                         | 0.575                                | 13.83   |
| 4      | 1.5       | 2.886            | 22.19      | 1.378                         | 0.477                                | 16.66   |
| 5      | 2         | 3.846            | 20.25      | 1.511                         | 0.392                                | 20.267  |
| 6      | 2.5       | 4.811            | 15.29      | 2.001                         | 0.415                                | 19.146  |
Table 2. Engine performance test for diesel + μ-Al

| Sl: No | Load (kW) | Brake power (kW) | Time (Sec) | Total fuel consumption (kg/hr) | Specific fuel consumption (kg/kw.hr) | BTH є |
|--------|-----------|------------------|------------|-------------------------------|-------------------------------------|-------|
| 1      | 0         | 0                | 39.43      | 0.776                         | -                                   | -     |
| 2      | 0.5       | 0.960            | 32.11      | 0.952                         | 0.992                               | 8.026 |
| 3      | 1         | 1.925            | 28.78      | 1.063                         | 0.552                               | 14.42 |
| 4      | 1.5       | 2.886            | 23.40      | 1.307                         | 0.453                               | 17.58 |
| 5      | 2         | 3.846            | 21.96      | 1.393                         | 0.362                               | 21.98 |
| 6      | 2.5       | 4.811            | 17.01      | 1.799                         | 0.374                               | 21.29 |

Table 3. Engine performance test for diesel + n-Al

| Sl: No | Load (kW) | Brake power (kW) | Time (Sec) | Total fuel consumption (kg/hr) | Specific fuel consumption (kg/kw.hr) | BTH є |
|--------|-----------|------------------|------------|-------------------------------|-------------------------------------|-------|
| 1      | 0         | 0                | 42.6       | 0.709                         | -                                   | -     |
| 2      | 0.5       | 0.959            | 41.5       | 0.728                         | 0.759                               | 10.484|
| 3      | 1         | 1.923            | 40.4       | 0.748                         | 0.389                               | 20.459|
| 4      | 1.5       | 2.882            | 38.9       | 0.777                         | 0.269                               | 29.527|
| 5      | 2         | 3.842            | 34.5       | 0.876                         | 0.228                               | 34.903|
| 6      | 2.5       | 4.805            | 26         | 1.163                         | 0.242                               | 32.902|

From table 2 and table 3, it is clear that n-Al blended fuel has more brake thermal efficiency than its micron counterpart. The expected reason is that, larger Al₂O₃ coating of μ-Al compared to n-Al hinders the micro explosion of Al metal particle[5]. In case of ordinary diesel there is no micro explosion and the energy density increases with the addition of metal particles[5]. Therefore, efficiency of ordinary diesel is less, compared with the other two.

Figure 8. Break thermal efficiency vs load
Figure 9 shows the SEM image of CuO-Zeolite mixture and it reveals the nature of the matrix. The CuO particles have a size range of 1000nm to 50nm. Here nano particles are incorporated into Zeolite sites. From XRD shown in Figure 10, it can be seen that the crystallite formations are in the range of 27 to 45 nm size.
Table 4 shows the pollution assessment of the studied system. There is a decrease in the pollutant level with the use of diesel containing metal Al (μ-Al, n-Al) due to the increased combustion rate and the performance of the catalytic converter. n-Al blended fuel has lowest CO emission, because of effective air mixing due to increased turbulence as a result of micro explosion than its micron counterpart[4].
Table 4. Pollutant assessment

|                  | Without catalytic converter | With catalytic converter |
|------------------|----------------------------|--------------------------|
|                  | % Smoke | % CO | % Smoke | % CO |
| Ordinary diesel  | 58.2    | 1.2  | 26.3    | 0.8  |
|                  | 47.1    | 1.2  | 24      | 0.7  |
|                  | 49.5    | 1.2  | 22.1    | 0.7  |
|                  | 42.2    | 1.1  | 20.2    | 0.7  |
|                  | 35.7    | 1    | 21.2    | 0.7  |
| Average:         | 46.54   | 1.14 | 22.76   | 0.72 |
| Diesel + μAl     | 36.6    | 0.9  | 26.6    | 0.8  |
|                  | 30.4    | 0.8  | 25.7    | 0.7  |
|                  | 36.3    | 0.9  | 22.6    | 0.7  |
|                  | 34.8    | 0.9  | 20.1    | 0.7  |
|                  | 33.9    | 0.8  | 18.5    | 0.6  |
| Average:         | 34.4    | 0.86 | 22.7    | 0.7  |
| Diesel + n-Al    | 26.07   | 0.8  | 24.5    | 0.7  |
|                  | 23.6    | 0.7  | 24      | 0.7  |
|                  | 27.3    | 0.7  | 26      | 0.6  |
|                  | 30.1    | 0.8  | 20      | 0.74 |
|                  | 29      | 0.8  | 18      | 0.6  |
| Average:         | 27.214  | 0.76 | 22.5    | 0.668|

4. Conclusion

The use of the nano-particles improved the functioning of diesel fuel. The droplet test gave more details about micro explosions occurred in engine cylinder. There is a large difference between the combustion behaviours. A sharp increase in efficiency can be seen, while using nano fuel as compared with other fuels due to its higher combustibility and the promoter action of nano aluminium and its oxides.

Aluminium particles have significant effect on the combustion of diesel. Its ability to decrease the delay in combustion is reported in literature. The experiment shows that, application of aluminium particles could increase the break thermal efficiency (BTE) by 8% and 72% for micron and nano aluminium fuels respectively.

Copper acts as a catalyst for the conversion of pollutants in exhaust but in a limited proportion. Experimental results show that, by using copper oxide zeolite based catalytic converter, CO reduces by 51% for ordinary diesel. Experiments show that catalytic converter always makes emissions at a range of 22.5-22.7 (volume)% smoke concentration and 0.65-0.73 (volume)% CO concentration.
Therefore, it can be concluded that, development of copper oxide zeolite based catalytic converter is feasible since it gives satisfactory results for given operating conditions and reduction of CO emissions. Thus, the copper oxide catalyst system can be the effective approach instead of expensive noble metal based catalytic converter.

5. References
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