EFFECTS OF NANO-CERIA BASED FUEL BORNE CATALYST ON SINGLE CYLINDER DIESEL ENGINE CHARACTERISTICS

NGHIÊN CỨU ẢNH HƯỞNG CỦA XÚC TÁC NHIÊN LIỆU ÔXÍT NANO XÊRI ĐẾN ĐẶC TÍNH CỦA ĐỘNG CƠ DIESEL 1 XILANH

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ABSTRACT

Aiming to reduce the fuel consumption and exhaust emissions of internal combustion engines, nano-ceria (CeO_2) based Fuel Borne Catalyst (ηFBC) developed by NanoScience Innovation Pte Ltd, Singapore has been directly blended with Vietnam's market diesel fuel in the ratio of 1:5,000. This blended diesel consists of more than 99.99% diesel, less than 0.01% surfactant (hydrocarbon), and less than 10ppm (10mg/liter) of CeO_2 nanoparticles.

Comparative experiments were conducted on single cylinder research engine AVL 5402 to find the impacts of this ηFBC additive on engine's performance, exhaust emissions and combustion profile. The experimental results show that there are no adverse effects on the engine after 56-hours running with ηFBC. The reduction of fuel consumption increases gradually and reaches 7.7% after 56-hours running with ηFBC additive. The soot concentration has declined on the averaged of 10-20%. The carbon monoxide (CO) emission has increased significantly in the early engine running stage (less than 20-hours) which might be due to the burning off the deposited carbon through catalytic cleaning effect. However, after 20-hours running with ηFBC additive, the CO emission has decreased dramatically. The total hydro-carbon (THC) emission has decreased by more than 10% in various operating regimes. However, nitrogen oxides (NO_x) emission reduction has not been as significant as expected. The peak of combustion pressure profile has moved closer to firing top dead center at the positive crank angle regime after adding ηFBC into the fuel. This phenomenon has been observed most prominent at low engine speed (1,400rpm). However, at higher engine speeds, the time point of pressure peaks has not changed significantly.

Keywords: Nano fuel's additive, combustion characteristics, single cylinder diesel engine.

TÓM TẮT

Hướng tới giảm tiêu thụ nhiên liệu và phát thải độc hại của động cơ đốt trong, xúc tác nhiên liệu dựa trên cơ sở ôxit xêri dạng nano (ηFBC), phát triển bởi Công ty NanoScience Innovation, Singapore được trộn với nhiên liệu diesel thị trường ở Việt Nam với tỷ lệ 1:5.000. Hỗn hợp diesel này bao gồm trên 99,99% diesel, dưới 0,01% chất bề mặt (hydrô cácbon) và dưới 10ppm (10mg/lít) hạt ôxít xêri dạng nano.

Các thử nghiệm đối chứng được thực hiện trên động cơ tiêu chuẩn AVL 5402 nhằm đánh giá ảnh hưởng của phụ gia ηFBC đến tính năng, phát thải và diễn biến áp suất trong xilanh động cơ. Các kết quả thực nghiệm cho thấy, động cơ vận hành ổn định với phụ gia ηFBC; tiêu thụ nhiên liệu giảm dần và đạt 7,7% sau 56 giờ vận hành; độ mờ khói giảm trung bình 10-20%; phát thải mônôxit cácbon (CO) chỉ giảm sau 20 giờ vận hành, trước thời gian này CO tăng mạnh do hiệu ứng làm sạch buồng cháy của chất xúc tác; phát thải hydrô cácbon tổng giảm trên 10% đối với hầu hết các chế độ vận hành. Tuy nhiên, phát thải NO_x không được cải thiện như dự tính. Thời điểm áp suất cực đại trong xilanh được dịch chuyển theo chiều hướng gần với điểm chết trên trong hành trình giãn nở khi có mặt phụ gia ηFBC. Hiện tượng này được thể hiện rõ ở tốc độ vòng quay thấp của động cơ (1400 v/ph), tuy nhiên, ở tốc độ quay cao, thời điểm áp suất cực đại không có nhiều thay đổi khi có sử dụng phụ gia ηFBC.

Từ khóa: phụ gia nano cho nhiên liệu, đặc tính cháy, động cơ diesel 1 xilanh.

1. INTRODUCTION

Cerium Oxide, CeO_2, has been known for its redox (reduction and oxidation) catalytic effects in various internal combustion engines and has been studied over the last decade. When nano-ceria (CeO_2) based Fuel Borne Catalyst (ηFBC) is mixed in fuel at very low concentration, they can oxidize carbon-soot (C-soot) and total hydrocarbons (THC) at lower temperatures to become CO_2 and H_2O. Furthermore, C-soot attached to engine's wall can also be removed through burning due to the catalytic activities of CeO_2, allowing the engine to work more efficiently. Very little amount (5-10ppm) of ηFBC with size of 5-10nm would have sufficient surface area for catalytic effect to reduce fuel consumption and all types of emission from the internal combustion engine. This series of tests is done on diesel internal combustion engine. This type of fuel additive is considered as one of the most advanced nanotechnology additive available which is being developed, tested and used in several countries like UK, USA, Singapore, and Australia etc [1].

Figure 1 shows the particulates distribution from a standard diesel engine exhaust. It is observed that significant amount of particulates is in nano-scale (<50nm) [2]. So the additional of 10ppm ηFBC would not significantly change the nanoparticles population. However, its effect on reducing these carbon based particle is significant.

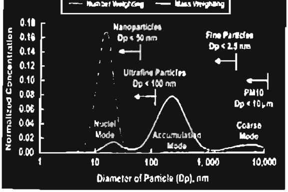

Fig. 1 The size distribution of typical diesel exhaust particles ranges from nano-scale particles up to coarse soot particles [2].

2. BACKGROUND OF CEO_2 CATALYTIC EFFECTS

It is beneficial to discuss the roles that ηFBC plays in each reaction which may influence the fuel consumption, CO_2, CO, NO_x, THC emissions and opacity separately and concurrently.

It is well known that CeO_2 nanoparticles provide the catalytic activities on oxidation and reduction which can be expressed in the following reaction equations [3],[7]:

$$2CeO_2 <=> Ce_2O_3 + V_O^{\bullet} + O^{\bullet} \quad (1)$$

$$(2x+y)CeO_2 + C_xH_y => [(2x+y)/2]Ce_2O_3 + xCO + y/2H_2O \quad (2)$$

$$2CeO_2 + C_{soot} => Ce_2O_3 + CO \quad (3)$$

$$4CeO_2 + C_{soot} => 2Ce_2O_3 + CO_2 \quad (4)$$

$$2CeO_2 + CO => Ce_2O_3 + CO_2 \quad (5)$$

$$Ce_2O_3 + NO_x => Ce_2O_{3+x} + 1/2N_2 \quad (6)$$

Eq-1 describes oxygen storing/releasing effect of CeO_2 nanoparticles. These oxygen ($O^{\bullet}$) are in atomic form, reside on surface of CeO_2 nanoparticles and is more active than molecular oxygen in air (O_2). As a result, $O^{\bullet}$ can reduce the temperature of oxidation reaction in Eqs-2, 3, 4, and 5 to as low as 300^0C. Eq-6 shows the reduction process of NO_x to N_2. However, NO_x can be also formed through combining N_2 and oxygen from either air or $O^{\bullet}$ from CeO_2 at elevated temperatures.

Under normal circumstances, the engine wall temperature is lower than the carbon combustion temperature, part of the unburnt carbon would deposit onto wall when the engine runs. This wall deposit would slowly accumulate leading to engine performance degradation. With the presence of CeO_2 in the system, the catalytic effect would lower the carbon combustion temperature which leads to burn-off the carbon deposit on the wall. In other words, the CeO_2 nanoparticles would deposit on and clean the wall. The CeO_2 deposition would reach an equilibrium amount and the engine is then expected to run in more efficient mode.

From the processes described above, detailed analysis of combustion process involving CeO_2 becomes very complex as the CeO_2 particles can either participate in oxidation or reduction reaction. Concentration of the various exhaust emissions such as CO, C-soot, THC and NO_x are expected to fluctuate widely, especially in the early stage of the test. The stability of the exhaust can only be established after relatively long hours of operation until some kind of equilibrium between the surfaces of combustion chamber and the combustion process. This is one of the purposes to make 3 different measurements at different time frame in this test.

In general, CO, C-soot, THC can be classified in a same category and oxidation reaction is favorable in terms of energy oxidation of these gases to become CO_2 is one way reaction (releasing energy) at all working temperatures. In other words, by adding the CeO_2 nanoparticles, these emissions will decrease eventually and they occur either inside or outside the combustion chamber.

3. EXPERIMENTAL

The purpose of the test was to systematically investigate the time history on the effect of ηFBC on diesel engine combustion. It is expected that the engine will run more efficient and discharge less pollutant gases. Adversary effects, if any, to the engine due to the additive will also be reported in this long duration of running of the engine.

3.1. Test procedure

In the beginning, the engine was fueled and run with the diesel acquired from Vietnamese open market. Fifteen different engine running modes with various loads and speeds of 1,400rpm, 1,800 rpm and 3,000rpm were carried out. The fuel consumption and exhaust emissions were measured and recorded for reference. Straight after that, the same diesel was added with 5-10 ppm of ηFBC and another cycle of the same 15 running-mode was carried out on the same engine. Similarly, the fuel consumption and the exhaust emissions were measured and recorded for comparing with test running with and without additive.

Engine was then run for 20 hours continuously with ηFBC added fuel at 1,800rpm and 50% load before the third 15 running-mode cycle test and measurement were carried out.

The final 15 running-mode cycle test was performed after 56 hours of engine running with ηFBC at 1,800rpm and 50% load.

The data of fuel consumption and exhaust emissions at different speeds and loads varied widely. Although running parameters are not exactly the same as standard, it is useful to average over a standard European ECE R49 protocol. Figure 2 shows the engine's operating modes and the weighing factor for each mode of ECE R49 protocol.

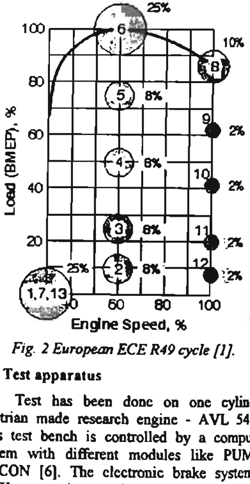

Fig. 2 European ECE R49 cycle [1].

3.2. Test apparatus

Test has been done on one cylinder Austrian made research engine - AVL 5402. This test bench is controlled by a computer system with different modules like PUMA, EMCON [6]. The electronic brake system - AMK, can work at maximum power, torque and speed at 28kW, 150Nm and 7,000rpm respectively. Exhaust emissions were analyzed by CEBII work bench, which is able to monitor different gases like CO_2, CO, NO, NO_x and THC [5]. The control system of the test set up is presented in Figure 3 and the configuration of the test engine is presented in table 1.

Table 1 Specification of the test engine AVL5402

Items	Values	Units
Bore	85	mm
Stroke	90	mm
Displacement	510.7	cc
Compression ratio	17:1	-
Rated power/speed	9/3200	kW/rpm

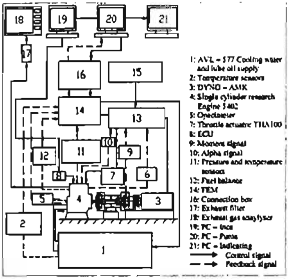

Fig. 3 Control system of the experimental set up.

4. RESULTS AND DISCUSSIONS

4.1. Pressure profiles

Figure 4 shows the combustion pressure profiles for running with and without ηFBC at engine speed of 1,400rpm. The pressure profiles have changed significantly when ηFBC was added into the fuel. The combustion pressure has increased and the pressure front moved forward closer to 0 degree crank angle.

It is believed that ηFBC have catalyzed the ignition of diesel earlier. The pressure increment occurs at the positive crank angle regime where actual useful mechanical work is done. In this circumstance, the ηFBC have promoted combustion within diesel droplets in fuel rich environment. Due to their ability to initiate the combustion at lower temperature, more fuel would be combusted.

On the other hand, for the case of 1,800rpm and 3,000rpm, the changes are not significant although in both cases, higher pressures also move toward positive crank angles. This may be due to both temperature and residence time in favor for catalytic effects of ηFBC for the low rpm (1,400rpm) operation for this particular test engine.

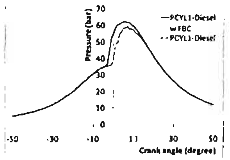

Fig. 4 Pressure profile versus crank angle at 1,400rpm with ηFBC (PCYL1-Diesel w.FBC) and without ηFBC (PCYL1-Diesel).

4.2. Fuel consumption

The measured fuel consumption was weighed-average fuel according to ECE R49 protocol and shown in Figure 5. This figure clearly shows the fuel consumption has reduced over time. It is observed that, after 56 hrs running with ηFBC, the fuel consumption improvement reaches 7.7%.

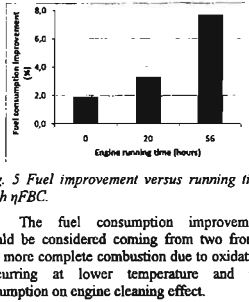

Fig. 5 Fuel improvement versus running time with ηFBC.

The fuel consumption improvement could be considered coming from two fronts, i.e. more complete combustion due to oxidation occurring at lower temperature and the assumption on engine cleaning effect.

4.3. Exhaust emissions

Total hydrocarbon emission was measured through heated ionization flame detector and the measured and weighed average results are shown in Figure 6. Overall, the THC improvement is higher than 10%.

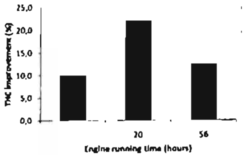

Fig. 6 THC emission improvement versus engine running time with ηFBC.

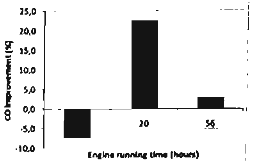

Fig. 7 CO emission improvement versus engine running time with ηFBC.

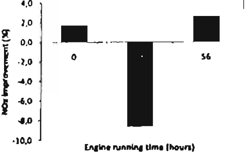

Fig. 8 NOx emission versus engine running time with ηFBC.

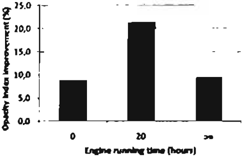

Fig. 9 Opacity index improvement versus engine running time with ηFBC.

The measured and weighed averaged results of CO emission are shown in Figure 7. Comparing the emission between with and without ηFBC, the results fluctuate widely, from worsen to much improved. Immediately after the ηFBC were added to the fuel (0^{th} hour), the CO emission worsen which might be due to engine chamber cleaning cycle The CO emission reduces dramatically by 22.5% at 20^{th} hour of engine running with the additive. However, the improvement of CO emission reduces after 56 hours of engine running.

CO emission come from oxidation process as indicated in Eq-2 and 5. The CeO_2 would assist oxidation of C-soot and THC, especially the carbon deposit on the engine wall. Therefore, it is logical to expect the increase of CO emission in the early stage of engine running. However, the engine will slowly reach its equilibrium state at which CO emission will decrease due to catalytic effects of ηFBC over time.

On the other hand, the CO_2 will not be expected to decline further even if the engine operates more efficiently as final products of all oxidation reactions lead to CO_2.

Figure 8 shows the weighed average of NOx emission at different stages. The emission also fluctuates over time but small percentage of NO_x reduction has been measured after 56 hour engine running.

As discussed on mechanisms of the NO_x formation, it is very difficult to pin-point which mechanism is dominated at the present situation. Theoretically, combustion with ηFBC would lower the temperature and hence the NO_x formation through 'thermal-NO_x' mechanism would decrease. On the other hand, the presence of O• at the nanoparticles surface would increase the 'prompt- NO_x' formation. The 'fuel-NO_x' mechanism is normally important only for biodiesel due to its nitrogen content in the fuel which is not quite relevant here. These competing mechanisms might play different roles at different stages of the test.

When correlate to the CO emission data, the CO emission reduction has caused the NO_x emission to increase. This can be interpreted as that the temperature inside the combustion chamber has increased. Nevertheless, in overall, all emissions have improved over time.

In addition, after the gases discharge from the combustion chamber, there is another opportunity of reducing NO_x to N_2 through reaction described in Eq-6 when the CeO_2 is present. This reaction is commonly used in the combustion-engine's catalytic converter.

Figure 9 shows the averaged opacity index improvement of the engine at different running stages. The improvement was found to be more than10%.

5. SUMMARY AND OUTLOOKS

In summary, no adverse effects were encountered with the engine running with the diesel fuel blended with ηFBC.

The test has shown the reduction of fuel consumption and gases emission of the diesel engine when ηFBC (5-10ppm) are added into diesel fuel. Fuel consumption reduction has eventually reached 7.7% after 56 hour running with ηFBC.

The THC emission has overall declined under using of ηFBC. The CO emission has increased in the early stage but after running for a longer duration, it has decreased to below the level of that in case without ηFBC. Although the NO_x emission has yielded mixed results it seems to be correlated to CO emission. The increment of NO_x emission corresponds to high CO reduction which may due to some changes of the in combustion environment during that stage. However, after 56 hours of utilizing ηFBC, the engine emission level is lower than the emission without ηFBC.

Opacity index, an indirect measurement of particulate matter emission has also shown more than 10% of reduction. Chamber pressure profiles have also shown higher combustion pressure at the positive side of crank angle, leading toward more positive work done

From the emission fluctuation level, it seems that the engine still has not reached its equilibrium state after 56 hours of running with the additive. It is expected to take sometimes for the combustion chamber to be 'cleaned' through canalization of the deposited carbon.

Once the equilibrium amount of ηFBC have deposited onto the engine's wall, this layer of ηFBC would assist not only in removing carbon to be deposited on the wall, but also catalyzing carbon and THC burn-off at as low as 300^{0}C. This will lead to more completed combustion inside the combustion chamber and hence, better fuel efficiency. A further detailed study of this effect will be very useful.

6. ACKNOWLEDGEMENTS

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