Journal of Multidisciplinary Engineering Science and Technology (JMEST)
ISSN: 3159-0040
Vol. 2 Issue 12, December - 2015

Cross Gas Pulse With Fuel Spray In Diesel Engine During Injection

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***Abstract*— The diesel engines emissions and soot are considered a serious problem to engine manufacturer and to the environment. Many techniques are used to treat with these problems, such as EGR, dual fuel diesel engines, fuel additives, atomization improvement, dissolved oxygen etc. The present study is a new technique to improve diesel engines emissions and performance. The new technique is designed by entering a high pressure oxygen pulse directly inside the combustion chamber. The oxygen pulse is synchronized with fuel injection as a cross flow with the diesel spray. The oxygen pulse and the diesel injection durations are the same. The high speed of the oxygen pulse works as a wave which can disintegrate the diesel droplets and enhancement the mixing process. To segregate the effect of oxygen as an oxidizer gas on the combustion process, another inert gas (nitrogen) was tested instead of oxygen while keeping all the other test parameters (gas pressure, pulse timing, and pulse duration) the same. The study was carried out on a single cylinder direct injection diesel engine. The gas pulse technique consists of an electro-mechanical system integrated with electronic control circuit designed especially for this purpose. The results reveal that the kind of gas has negligible effect on NOx, good NOx, CO, soot and hydrocarbons reduction, as well as improving the engine performance.**

Keywords— Wave atomization - NOx formation – Spray – Mixing – Oxygenated fuel

Introduction

Worldwide emissions standards are getting stricter in the courses of time, and therefore there is a continuous effort to develop a new generation of clean internal combustion engines.

To treat the emission problems there are two ways the researchers are following, alternative fuels or fuel additives and the modification of the combustion system design. This means that the treatment may be chemically or physically.

The application of oxygen enriched intake air is considered one of the methods that are used to meet the challenges of reducing the smoke, unburned hydrocarbons and carbon monoxide. The oxygen enriched air method is the scope of research for many investigators in the last decades. They found that by increasing the oxygen content in the air leads to faster burn rates and the ability to burn more fuel at the same volume. Added oxygen in the combustion air leads to shorter ignition delays and offers more potential for burning diesel.

The oxy-fuels combustion reduces the volume of flue gases and reduces the effects of greenhouse gas emissions, and rise in the peak pressure and a reduction of combustion duration and ignition delay, the performance is improved, HCs and CO emissions decreased and smoke levels dropped substantially, while NOx emissions increased, also a large decrease in combustion noise [1, 2, 3, 4].

In the direct injection compression ignition engine (CI) the liquid fuel is applied in a form of fuel sprays which is supplied to the engine combustion chamber right before the piston top dead center (TDC). Thus a complete process of preparing the mixture for being burnt, i.e. a disintegration of the fuel spray into drops, their evaporation and mixing with air needs to be performed in a very short time. For such a way of the engine has some local and very significant differences of the air fuel ratios are met. The values met in the combustion chamber range from the infinite high one in the area which is not covered by the fuel spray, throughout near stoichiometric at the edges of the fuel spray initializing the ignition to ≈ 0 being recorded in the spray core. The local deficiencies of oxygen occur despite the high values of the overall air fuel ratios which changes with the engine load and ranges from ≈ 100 at the engine idle running to ≈ 18 at the engine full load.

In case of the combustion process the local deficiencies of oxygen are one of the most important reasons for forming carbon monoxide, hydrocarbons, and partly of forming the particulate matter, where the formation of thermal nitrogen oxides is due to two main mechanisms the prompt one which is formed in the fuel rich zones with high concentrations of radicals [5] and the thermal mechanism which connected with the kinetics of developing the flame which generates the value of the produced heat as the heat delivery speed determines the level of temperature in a combustion chamber. All of it causes that the fuel spraying, in addition to the air swirl, is of the decisive importance for preparing the mixture [7].

The quality of spraying is determined by two basic physical factors: the pressure existing in the nozzle area right before the nozzle whole and the pressure in the combustion chamber where the fuel spray is directed to. An increase in the injection pressure values improves the fuel spraying and it is a current preferred tendency of the developments of the injection systems for the CI engines. The changes which are done in the Common Rail (CR) system confirm the above statement. Every next generation of this system is characterized by the injection pressure values that are higher than that one's of the previously generation.

The improvement of the fuel spraying can be achieved not only by increasing the injection pressure but also by modifications to the mechanism causing the disintegration of the fuel spray. The velocity of the fuel outflow from the nozzle is a single physical stimulus which causes the disintegration of fuel spray in the currently used mechanism of spraying. In order to achieve the improvement of spraying it is proposed to use an additional physical stimulus resulting from the physical properties of the gas-in liquid solution [8, 9, 10, and 11]. The amount of gas that can be dissolved in a liquid significantly depends on the pressure. A spontaneous release of gas at the non-equilibrium state caused by the pressure fuel is very characteristic for such a solution. The process of releasing the gas from a liquid is of a volumetric nature, i.e. the gas is being released simultaneously from the whole liquid volume. The energetic effects which accompany that process depend on the speed of the stimulus modifications and the gas which is released always presents a tendency to break the bonds of liquid molecules. Under such conditions the state of liquid is similar to that state of boiling [6]. The presented properties of a liquid are very desirable in the injection system of the diesel engine, thus a concept of using the effect accompanying the process of releasing the gas from a liquid for improving the existing mechanism of fuel oil spraying [7].

This concept consists in adding the appropriate amount of air to the fuel, its dissolving under high pressure conditions (in a high pressure pump) and keeping it in a form of solution in a high-pressure section of the engine supply system (up to the nozzle) until the moment of injection, occurs. A detailed description of this concept is presented in [9].

In the present study a novel technique was used which summarized in simultaneous oxygen pulse is injected cross with the diesel fuel injection spray to intersect with each other. The oxygen exit speed is more than sonic speed and its duration is the same as diesel injection duration. This process has physical and chemical effects, the physical effect is the disintegration of the fuel droplets into more fine in a wider distribution volume, to become more homogeneous mixture in the combustion space. Also due to the high speed of oxygen pulse it can penetrates the fuel droplet to form a semi oxidized fuel. The chemical effect is the availability of more oxygen in the combustion local rich zone which enhance faster and efficient combustion reactions.

Experiment Facilities and Conditions

The present study has been conducted on a Petter PH1W single cylinder, naturally aspirated, four-stroke, water cooled, DI diesel engine with a bowl-in-piston combustion chamber. The engine specifications are given in Table 1. The engine is equipped with a hole for the measurement the in cylinder pressure.

The used dynamometer is a direct current generator of 22 kW. The dynamometer was used as a starting motor at the beginning and after that as a generator.

Table 1 the engine specifications

Model	Petter PH1W diesel engine
Engine configuration	Single cylinder, four-stroke, naturally aspirated, water cooled
Bore	87.3 mm
Stroke	110 mm
Compression ratio	16.5:1
Rated power	8.2 bhp @ 2000 rpm
Fuel injection system	Direct injection (DI)
Injection pressure	200 bar
Number of nozzle holes	3
Nozzle hole diameter	0.25 mm
Spray angle	120^o

The test bed was equipped with settling chamber and a standard orifice plate for measuring the naturally aspirated air with the aid of a standard inclined manometer. The fuel flow rate was measured by the use of time and certain volume. Engine speed was measured with the use of magnetic pickup and a gear mounted on the engine shaft and an electronic unit to convert the signal to rational speed. The fuel pressure was measured with a piezo pressure transducer mounted on the HP (high pressure) line and a charge amplifier to convert the charge to voltage, the fuel pressure signal was presented and stored on a digital storage oscilloscope. The engine can be loaded by the use of an eclectic bank of heaters, and the load can be controlled with control unit. The engine torque was measured by the use of a spring balance. The exhaust gas analysis was carried out by the use of a flam ionization detector for hydrocarbon, a paramagnetic for oxygen, a non-dispersive infra-red for CO, CO2, and NOx, and opacity for smoke level.

The oxygen pulse system consists of high pressure oxygen bottle 100 to 150 bar, a high pressure pipes and connections. A high pressure high temperature electric injector, and an electronic control unit which can control the injector valve opening and close (pulse width), this was linked to the diesel injection pressure. This system is a patent of the author. Fig. 1 is a schematic diagram of the test rig, gas injector photo and gas assembly facility.

The test conditions were carried on constant engine speed of 1500 rpm and different engine load percentage from 10 to 90 %, the oxygen pressure was kept constant all over the test. Two conditions were compared with each other, the normal diesel running condition and the diesel running with the cross oxygen pulse with the injected diesel in the cylinder during the injection duration. The oxygen pulse width is adjusted to be equal the diesel injection duration.

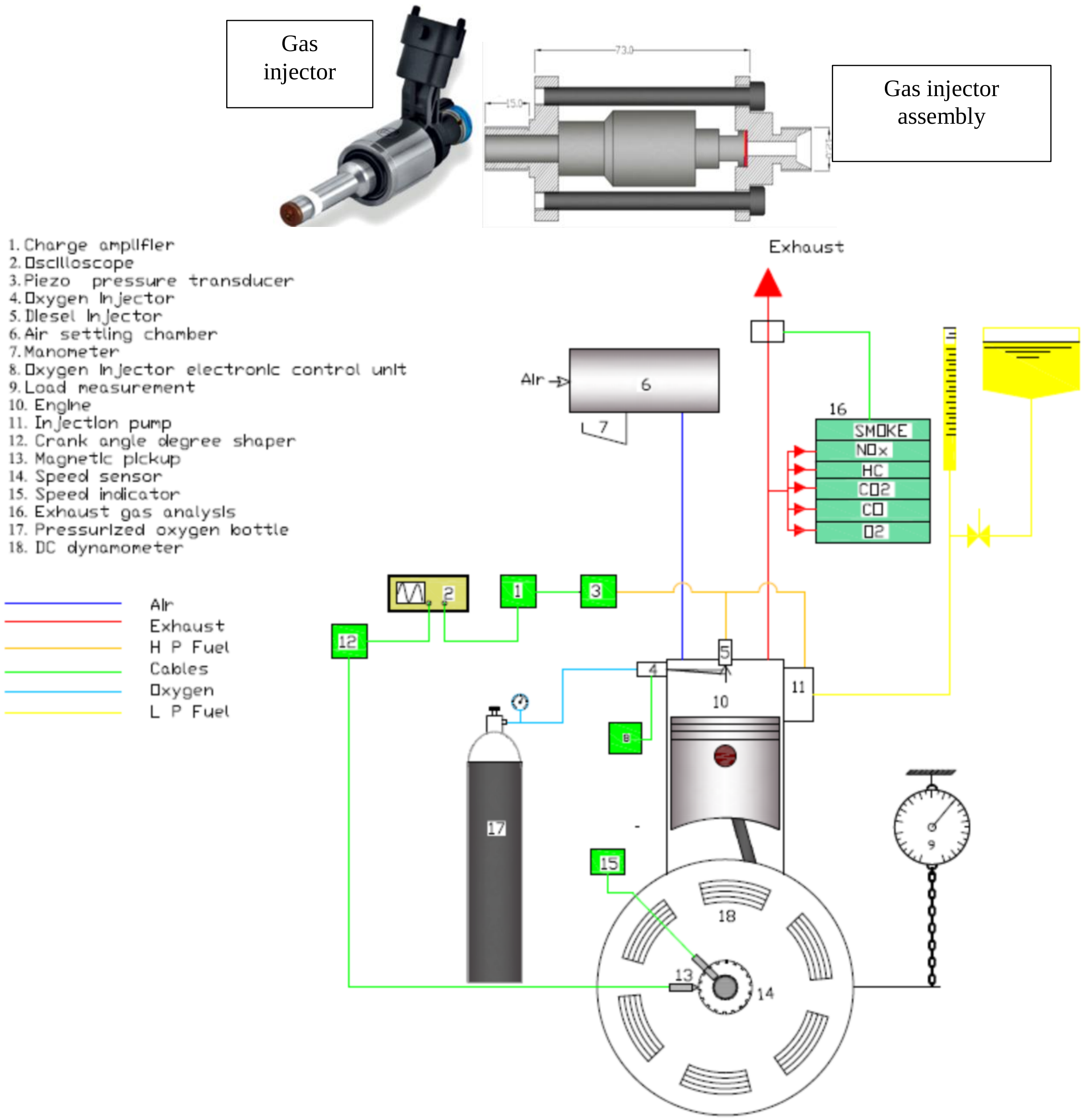


Figure 1 Schematic diagram of the test rig

Accuracy of Measurements and Uncertainty Analysis

To ascertain the accuracy of measurements, all the instruments used are tested and calibrated, under the same operating conditions of the actual tests, before conducting the experiments. Special emphasis is given to the exhaust gas emissions measurements. All gas analysers are purged after each measurement, and then calibrated before the next measurement using reference gases from a certified source.

To examine the repeatability of measured values, the experiments have been conducted such that five measurements of each parameter have been recorded; for each operating point. The values reported for all measured parameters, which are then used for further computations, are the arithmetic mean ones of the five measurements. The coefficient of variance (COV) for each measured value is computed, to estimate the repeatability of measurement and the accuracy of procedure. It has been found that the value of COV of each main measured parameter is less than 0.5%. Accordingly, the measurements precision is quite high.

To estimate the limiting error associated with each measured parameter, comprehensive uncertainty analysis is conducted; based on the accuracy of the instrument used and the measured value [12].

Table 2 Absolute error and uncertainty of measured parameters

Measured parameter	Absolute error	Uncertainty
Inlet air flow rate	0.357 m3/h	2.05 %
Diesel fuel flow rate	8.27 x10-3 kg/h	2.7 %
Engine speed	0.25 rev/s	1 %
Engine torque	0.6 Nm	2 %
Smoke opacity	0.2%	3.08 %
NO emission	2 ppm	2.35 %
CO emission	0.002%	2.5 %
O2 concentration	0.025%	0.69%
HC emission	3 ppm	3.06 %

RESULTS AND DISCUSSION

To evaluate the present new technique (oxygen pulse) the authors have gathered extensive comparative material. The results presented here are comparison between the normal diesel engine operation as a reference data and that results of the diesel engine running with the oxygen pulse technique. The engine performance and exhaust gas compounds which they are nitrogen oxides NOx, hydrocarbons HCs, carbon monoxide CO, oxygen O2, and opacity.

The engine break thermal efficiency versus engine load percentage was presented in fig. 2 for normal diesel, diesel with N2-pulse, and Diesel with O2-pulse. The figure indicates that the oxygen pulse technique improves the engine performance than that of normal diesel of N2-pulse especially in the high load zone.

The presence of oxygen itself in the combustion zone in DI diesel engine improves the combustion kinetics and decrease the chemical delay period which affect the combustion positively. The effect of oxygen in the high load zone is dominant because the air-fuel ratio is become lower as the load increases. Therefore, the presence of O2 enhances and accelerates the reaction rates.

The gas wave acts as a collision of projectile to the diesel spray droplets with a high speed. This resulting in more disintegration of the droplets, redistribution and enhance mixing of the droplets with the oxidizer.

Fig. 3 represents the oxygen percentage content in the exhaust gases for both normal diesel and diesel with oxygen pulse technique. The residual oxygen in the exhaust is due to the oxygen pulse, and the difference in the values between diesel and diesel with O2-pulse represents the O2 amount injected. One can notice that the difference with the engine load is increasing. This is due to that the oxygen pulse duration was synchronized with the diesel injection duration. Therefore, as the engine load increases the diesel injection duration increases and hence the oxygen amount increases.

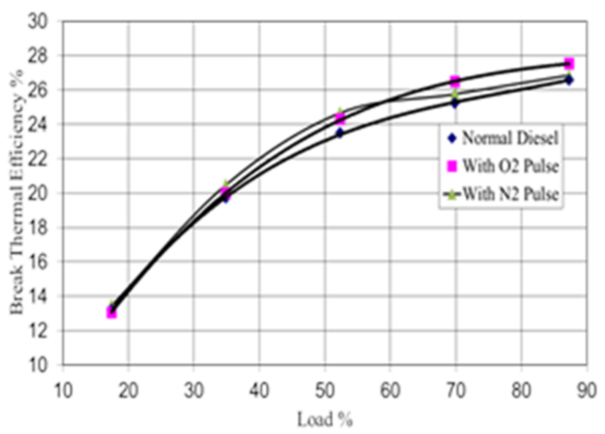


Figure 2. Break efficiency versus engine load %

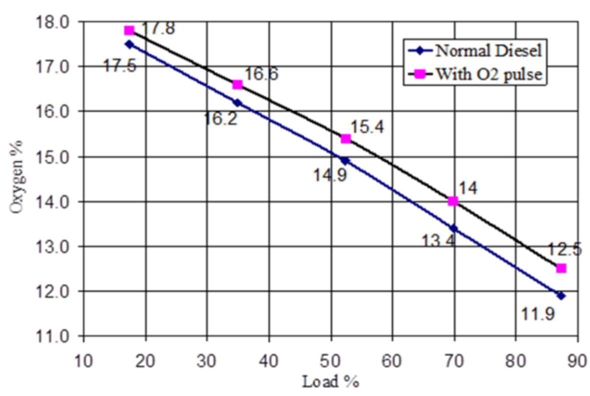


Figure 3. Emitted oxygen versus engine load %

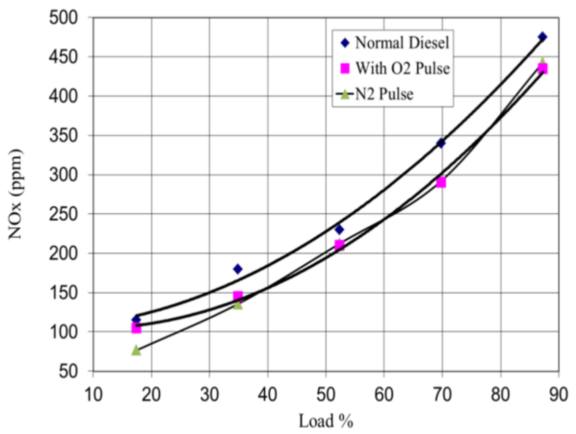
The improvement of the fuel spray and mixing were expected to affect positively the engine emissions. In order to verify the improvement of oxygen pulse mechanism, the exhaust gas analysis released at particular engine operation points were compared with the emissions caused by the engine with normal diesel operation.

The changes in exhaust gas compounds concentrations are given in figures 4,5 & 6. On the basis of the comparative analysis, it can be concluded as follows, firstly, better fuel spraying and droplet distribution causes the temperature in-cylinder peaks to be reduced which is responsible for the formation of the thermal NOx emission reduction. Also the more homogeneous mixture reduces the local high concentration of the fuel which is responsible for the prompt NOx formation, therefore it was reduced. The values of NOx reduction through all over the engine different loads percentage are varied from 8.5% to 14.7% with respect to normal diesel results. The figure also indicates the behavior of the N2-pulse. The results of NOx with N2-pulse is almost the same like O2-pulse, this means that the dominant effect on NOx emissions are the physical processes i.e. droplet disintegration and mixing.

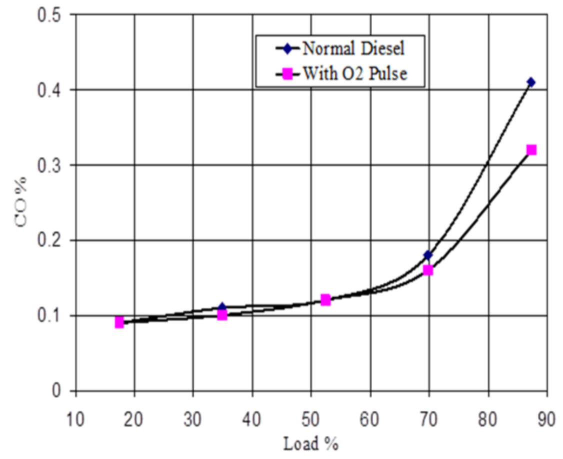
Secondly, the carbon monoxide and hydrocarbons concentrations in the exhaust gas almost reduced, which indicates that the oxygen pulse mechanism has a positive effect on combustion kinetics, delay period, and the temperature distribution.

Fig. 7 represents the comparison of opacity at different engine loads for both normal diesel operating condition and the diesel with oxygen pulse technique. The opacity is a good indication to the smokiness. The oxygen pulse affects positively the soot formation reduction; the percentage reduction in soot varies from 21% to 42% with respect to normal diesel operation.

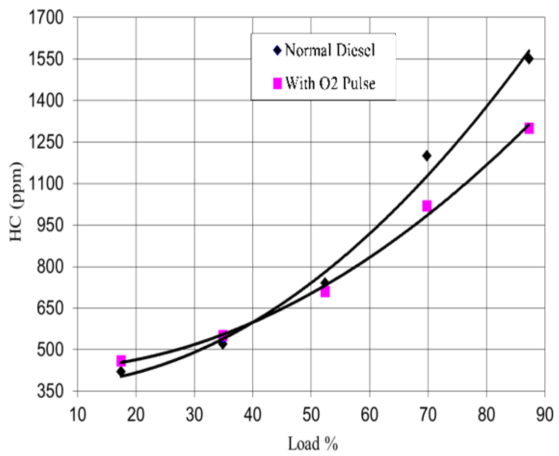
The amount of formulated soot depends on the physical conditions in which hydrocarbon liquid phase is maintained void of oxidizer as well as the droplet size in conjunction with the residence time of the droplet in combustion space.



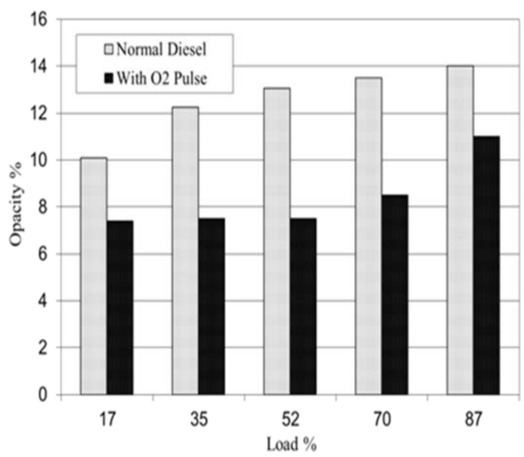
.Figure, 4. NOx versus engine load %



Figure, 5. CO versus engine load %.

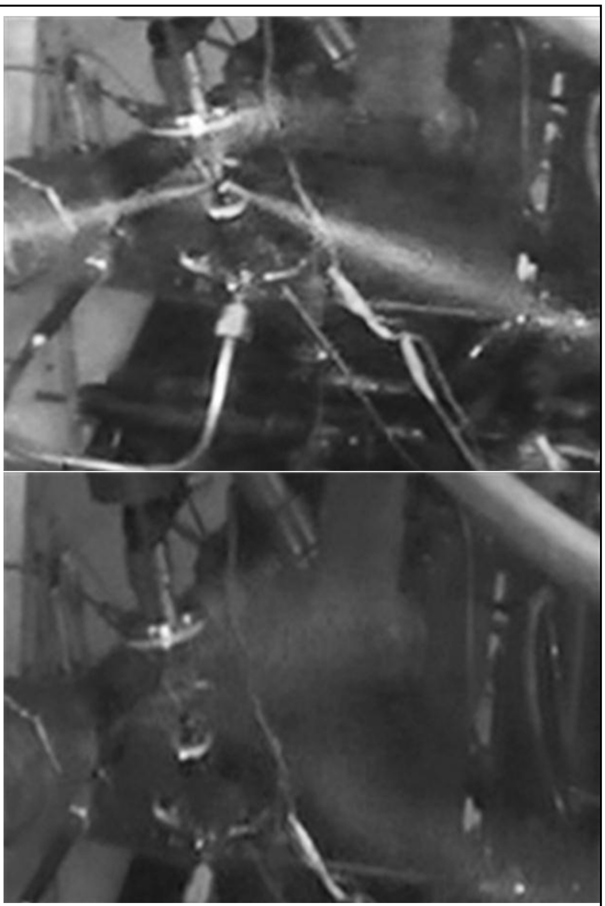


Figure, 6. Hydrocarbons versus engine load %.



Figure, 7. Opacity versus engine load%.

A Trial to get a closer view to what is happened when the diesel injection spray is hitting with cross high speed oxygen pulse. To obtain such an investigation, the diesel injector was prepared to operate outside the engine (with and without the oxygen pulse) by the use of Motoring the engine with the dynamometer, and a video film was taken in both cases. Fig. 8a and 8b are showing the two cases. One can note that in case of normal diesel injection the three fuel sprays are sharp (multi-jet injector); long, clear and distinct from each other, this is due to the high momentum of the droplets. When oxygen pulse is applied the three sprays are become like a cloud, mixed, homogeneous, and shorter. One can conclude that the oxygen pulse disintegrate the droplets by collusion, and the gas speed improves the droplet evaporation and mixing with oxygen. The local dense spray is to a great extent is fades. This is positively affected the combustion and the chemical kinetics of the reaction.



Figure, 8, a) normal diesel injection, and b) diesel injection with cross oxygen pulse.

CONCLUSIONS

In the light of the presented results, the above-described physical process that provides a practical foundation for the new mechanism of fuel spray disintegration, homogeneous distribution and oxygen droplet penetration, can fairly account for the emissions downsizing in direct injection diesel engines. Apparently, oxygen pulse in this case, improves fuel droplet size and distribution and hence modifies the contents of exhaust gas, especially as far as the NOx, HCs, CO, and soot. Furthermore, the temperature peak reduction proves that the fuel disintegration and distribution has become more homogeneous. However, in the other methods like oxygen enriched, air dissolved in fuel, air and Common Rail advancements it cannot help NOx formation reduction with HC, CO and soot reduction as the outcome of the temperature growth caused by the increased oxygen concentration or increased injection pressure. But in the present technique (oxygen pulse) the NOx as well as can be decreased substationally with other toxic gases.

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