AN EXPERIMENTAL NO_X REDUCTION POTENTIAL INVESTIGATION OF THE PARTIAL HCCI APPLICATION, ON A HIGH PRESSURE FUEL INJECTION EQUIPPED DIESEL ENGINE BY IMPLEMENTING FUMIGATION OF GASOLINE PORT INJECTION

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Abstract
This work investigates the effects of partial HCCI (Homogeneous charge compression ignition) application on today's modern diesel engine tail pipe NO_x emissions. Gasoline fumigation is supplied via a port fuel injection system located in the intake port of DI(Direct injection) diesel engine to maintain partial HCCI conditions and also diesel fuel injected directly into the combustion chamber before TDC(Top dead center). A single cylinder direct injection diesel research engine equipped with a high pressure injection system was used. Engine performance, fuel consumption, tail pipe emissions and in cylinder pressure measurements were recorded during tests. Rate of heat release and bulk temperature of medium calculated with implementing thermodynamic and gas laws to measured pressure signals. Experiments divide into two main phases which are diesel fuel tests and fumigation tests. Before the tests, maximum injectible quantity of diesel fuel was determined by considering the soot limit of the engine and fumigation ratio was 10% by volume of pre-determined diesel injection quantity. Gasoline fumigation slightly decreased engine performance at low speeds and brake specific fuel consumption increased relatively. Exhaust temperature of fumigation test was higher than that of diesel fuel tests also diffusion phase of rate of heat release curve were similar for both fuels. Depending on in cylinder pressure measurements and heat release calculations, lower heat loss from medium to the walls obtained with gasoline fumigation. Despite higher peak premixed combustion values, NO_x emissions decreased significantly. On the other hand unburned hydrocarbons increased dramatically.
Keywords: *HCCI,Gasoline Fumigation,Diesel Engine,NO_x emission*

1. Introduction

Energy use has been central of the development of the world economy over many centuries, and remains crucial for alleviating poverty, expanding economic opportunities, providing light, heat and mobility, and enhancing the welfare of us all. To the fore are fossil fuels that provide more than 90% of the worldôs total commercial energy needs, with oil the leading source in the global energy mix (5). The oilôs share by the means of the total world final energy consumption is %43.4 . The transportation sector has 60,3% and the biggest share of the this total oil consumption (6). Today, diesel engines are the axis of this world industry and transportation sector with high torque, durability and economical on fuel under several conditions. Researchers are working on diesel engines for many years in the perspective of performance and exhaust emissions. Especially , the out coming stringent exhaust emission regulations that are served at the last quarter of the 20^{th} century forced the researchers finding an optimized solution in terms of both performance and emissions. One of the key technology that is improved for this purpose is homogeneous charge compression ignition (HCCI) process which has the potential to provide the best features of both spark ignition and compression ignition. As in spark ignition (SI) engine, the charge is well mixed, which minimizes particulate emissions, and as in compression ignition engine ,the charge is compressed and ignited spontaneously and also has no throttling losses which leads high efficiency(2). HCCI engines have been proven potential to reduce nitrogen oxides (NO_x) and smoke emissions simultaneously (7,8). On the other hand, considering to the homogenous charge formation in the combustion chamber the low volatility of diesel fuel comes out as a problem for the HCCI process. Also the high cetane number of diesel fuel can result as early auto ignition which makes the control of combustion process difficult(4). The concept of partial homogeneous charge compression ignition (p-HCCI) has been proposed to resolve these difficulties in HCCI engines under several names, including external mixture formation, dual injection and multi injection (2,4). One category of these solutions that has been proposed for HCCI process problem is the concept of forming premixed air-fuel charge at the intake port or over the intake valve with an additional port fuel injector .First the premixed charge that was formed outside of the combustion chamber is taken in to the combustion chamber during the intake stroke .Then the charge is ignited by a predefined amount of fuel with a high cetane number which is directly injected to the combustion chamber at the predefined injection advance of crank angle degree(°CA). Suzuki et. Al.(3) investigated the gasoline

port injection on a single cylinder direct injection (DI) diesel engine with injection pressure of 18 MPa.

Premixing ratio of this research was increasing up to 1 with 0.2 equal intervals. Authors reported that the decrease in both NO_x and smoke emissions were greater than ordinary diesel engines. Also smoke reduced near-uniformly as pre-mixed fuel ratio was increased. Increasing the pre-mixed fuel ratio, increases hydrocarbon (HC) emission remarkably. Authors considered a part of pre-mixture was left unburned in the flameless area in the combustion chamber such as top clearance. Kim et. Al.(2) applied gasoline fumigation on single cylinder DI research engine with two different gasoline injection pressure for enhancing the premixing quality. They reported that the high pressure injection of gasoline fuel from intake manifold resulted better HC and carbon monoxide (CO) emissions also NO_x concentrations in the exhaust gases reduced linearly as the premixed ratio increases. This work uses gasoline-air charge as a premixed charge. Gasoline fumigation is supplied via a port fuel injection system located in the intake port of DI diesel engine to maintain p-HCCI conditions and also diesel fuel injected directly into the combustion chamber before top dead center (TDC) for igniting the gasoline-air charge.

2.Experimental Apparatus and Procedure

The schematic description of experimental apparatus is shown in figure 1. A single cylinder, DI(direct injection), naturally aspirated, air cooled diesel engine has modified for p-HCCI application. Specifications of the test engine are listed in the Table 1. A high pressure (2000 bar of injection pressure) common-rail traditional fuel injection system has adopted to test engine, multi-point injection gasoline fuel injector positioned directly to the upstream of intake valve. Both fuel injection systems were controlled from an external Programmable logic control unit(PLC). Gasoline injection was started at the end of

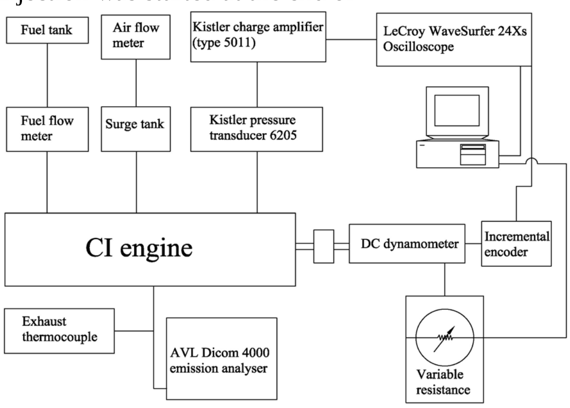

Fig. 1: Scheme of Test Bench.

compression stroke to obtain required time for injecting

Table 1: Test Engine Specifications

Manufacturer	Lombardini
Model	3ld450
Type	4-cycle air cooled diesel
Number of of cylinders	1
Combustion chamber	Direct injection MAN
Aspiration	Natural
Bore "mm"	85
Stroke "mm"	80
Displacement "cm^3"	454
Compression ratio	17,5:1
Rated power "kW"	6,6

desired quantity of gasoline. Diesel injection advance was 17 °CA before top dead center(BTDC) and kept constant during the tests. In cylinder pressure measurements were recorded with using Kistler 6011 pressure transducer, Kistler 5011 type charge amplifier and LeCroy brand digital oscilloscope. Injection, pressure and incremental encoder signals recorded simultaneously with 0,1 °CA intervals. Mean of 100 consecutive cycles calculated externally by using a signal processing computer code. ROHR analysis were made according to Kriger-Borman approach while post-processing. AVL Dicom 4000 exhaust gas analyzer and electronically controlled direction valve integrated on exhaust system for measuring NO_x and HC emissions. Exhaust temperature measured by using K-type

Table 2: Test Conditions

Engine Speed	1000-1800 rpm
Engine Load	0-30 Nm
Intake Air Temperature	23 C
Fuel(Premixed)	Gasoline
Fuel(Directly Injected)	Diesel
Gasoline Injection Pressure	4 bar
Diesel Injection Pressure	1200 bar
Gasoline Injection Timing	TDC
Diesel Direct Injection Timing	BTDC, 17 °CA
Premixed Ratio	10%

thermocouples.
The fuel quantity of each injection, which is a function of the common-rail pressure and the injection pulse width, was calculated from the alibration map in this study. Common-rail fuel injector was calibrated at 1200 bars of injection pressure and gasoline injector calibrated at 4 bars

10% by volume of total injected diesel quantity determined
and equal gasoline injected from intake port to maintain partial HCCI conditions. Thus injected fuel ratio kept constant for both tests. EN 590 convenient diesel fuel and EN 228 convenient gasoline fuel used as test fuels and technical specifications of test fuels listed in table 3 and table 4*. Engine load varied with resistance group, regime speeds of the engine was determined from previous experiments with considering stability. Each test performed three times consecutively then results averaged. Details of the test conditions in this research are summarized in Table 2.

*Gasoline fuel specifications obtained from Turkiye Petrol Rafineleri Corporationôs web page that the manufacturer indicates the product meets the EN 228 standard. .

3.Result and Discussion

Engine torque was decreased with gasoline fumigation at low speeds. Although both BSFC and torque outputs of engine almost same at medium and high speeds. Intake air passes across several restrictions(throttle body, valve-cylinder head gap) in a conventional throttled gasoline engine this phenomenon creates higher pumping loses for gasoline engines, this loses decreases the engine efficiency although higher speed of intake medium through the intake valve region reveals better premixing for fuel. Premixing quality directly effects homogeneity of air-fuel mixture and unburned hydrocarbon emissions
Several methods such as heating and injection pressure increasing were applied to increase the premixing ratio of the air fuel mixtures on HCCI engines (2,3). Peak heat release of premixed phase of gasoline fumigation combustion process is 5% higher than diesel combustion while diffusion parts are both similar as indicated in figure 3. This can be related to lower wall heat transfer of the medium as shown in figure 5. Total combustion duration of fuels remained same but, according to figure 4, exhaust temperature results of

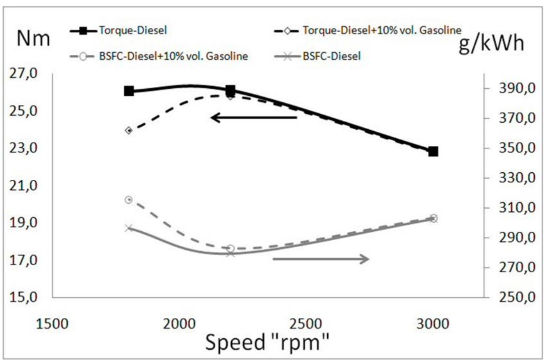

Fig. 2: Engine torque and BSFC variation with engine speed.

fumigated experiments are higher than diesel experiments. This situation indicates that, the combustion extended to exhaust valve opening. In conventional diesel combustion higher premixed peak values, results higher NO_x emissions. But depends on the Zeldovichôs mechanism of NO_x formation, reverse reactions keep formation at lower temperatures (1).In this experimental study, significant NO_x reduction has obtained with gasoline fumigation as shown in figure 6. Higher exhaust gas temperature can contribute to reduce NO_x emission, also gasoline evaporation at the initial stage of diesel combustion reduce flame temperature. Gasoline fuel has significantly lower amount of nitrogen than diesel, but in this study any measurement wasnðt applied. Crevice mechanism is a dominant factor for unburned hydrocarbon emissions and this type of emission is dramatically lower at diesel engine when compared to the gasoline engines.

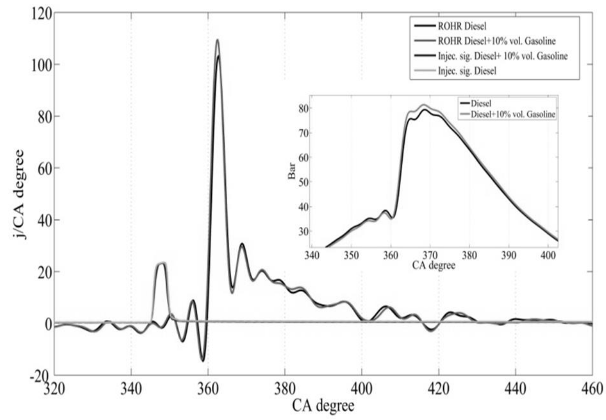

Fig. 3: ROHR and Pressure curves of diesel and fumigated operations at 2200 rpm engine speed

HC emission results are in harmony with BSFC, from this point of view one can clearly indicate that, the homogeneity of the fuel-air mixture are not enough at low speeds.

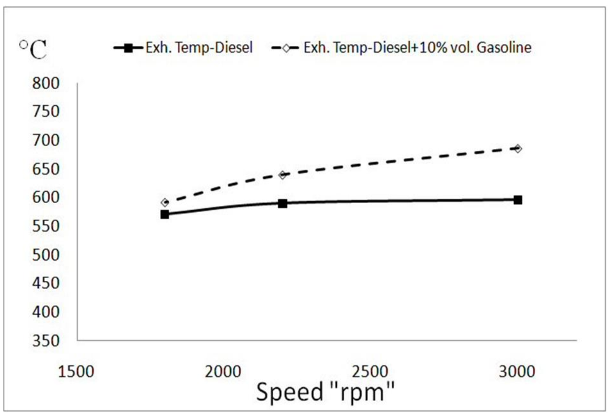

Fig. 4: Exhaust temperature variation with engine speed.

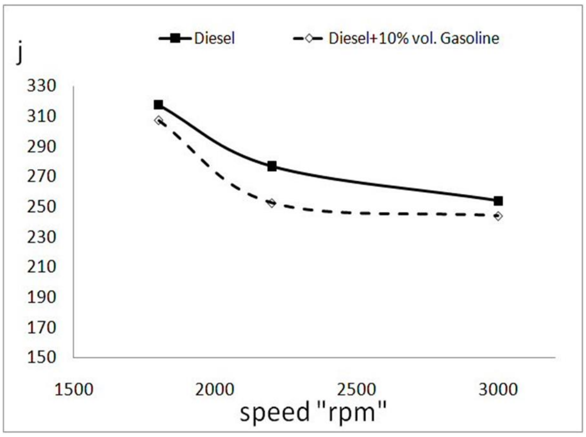

Fig. 5: Wall heat transfer variation with engine speed.

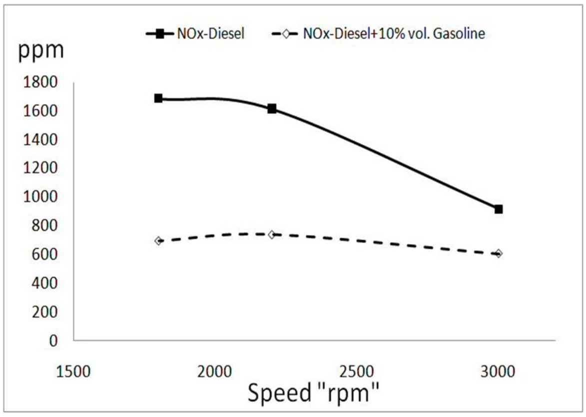

Fig. 6: NO_x emission variation depends with engine speed.

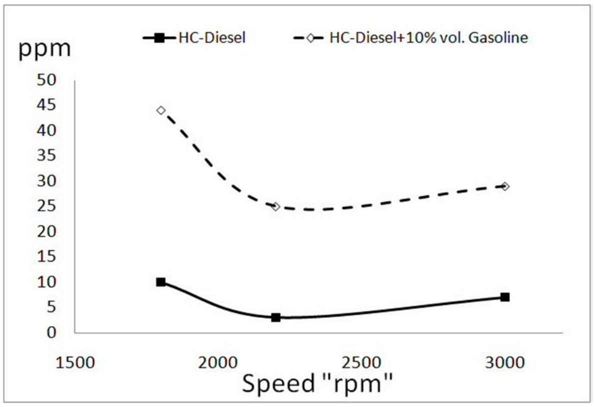

Fig. 7: HC emission variation with engine speed.

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