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Performance and emission characteristics of CIE using hydrogen, biodiesel, and massive EGR

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ABSTRACT

Hydrogen is considered as an excellent energy carrier and can be used in diesel engines that operate in dual fuel mode. Many studies have shown that biodiesel, which is sustainable, clean, and safe, a good alternative to fossil fuel. However, tests have confirmed that using biodiesel or hydrogen as a fuel or added fuel in compression ignition engines increases NOx concentrations. Cooled or hot exhaust gas recirculation (EGR) effectively controls the NOx outflows of diesel engines. However, this technique is restricted by high particulate matter PM emissions and the low thermal efficiency of diesel engines.

In this study, gaseous hydrogen was added to the intake manifold of a diesel engine that uses biodiesel fuel as pilot fuel. The investigation was conducted under heavy-EGR conditions. An EGR system was modified to achieve the highest possible control on the EGR ratio and temperature. Hot EGR was recirculated directly from the engine exhaust to the intake manifold. A heat exchanger was utilized to maintain the temperature of the cooled EGR at 25 °C.

The supplied hydrogen increased NOx concentrations in the exhaust gas emissions and high EGR rates reduced the brake thermal efficiency. The reduction in NOx emissions depended on the added hydrogen and the EGR ratios when compared with pure diesel combustion. Adding hydrogen to significant amounts of recycled exhaust gas reduced the CO, PM, and unburned hydrocarbon (HC) emissions significantly. Results showed that using hydrogen and biodiesel increases engine noise, which is reduced by adding high levels of EGR.

Introduction

The three principal global issues are global warming, air contamination, and fossil fuel dependency. All studies indicate that fossil fuel reserves are being depleted at an alarming rate [1]. Diesel engines have higher thermal efficiency and emit less CO_2 than gasoline engines, thereby becoming an attractive choice. However, diesel engines emit high levels of NOx and smoke. New technologies are being developed to reduce these emission levels [2,3]. Many techniques have been developed to meet the restricted emission legislation for the competitive fuel economy, reduce exhaust gas after-treatment emissions, and establish optimal combustion. However, the success of these methods is uncertain [4].

Biodiesel is produced from sources such as vegetable oils, animal fats or used cooking oils by a process called transesterification. It is an attractive fuel for diesel engines because of its high oxygen content, which enhances its burning efficiency [5,6]. Biodiesel combustion also emits less hydrocarbon (HC), carbon monoxide (CO), and particulate matter (PM) than

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Notation

BTDC	before top dead center
bmep	brake mean effective pressure
bp	Brake power
bsfc	Brake specific fuel consumption
BTE	brake thermal efficiency
CA	crank angle
CO	carbon monoxide
CO_2	carbon dioxide
CN	cetane number
CR	compression ratio
dB	decibel
DI	direct injection
$\frac{\partial R}{\partial V_1}$	a measure of the sensitivity of the result to a single variable
HC	unburnt hydrocarbon
e_i	uncertainty interval in the nth variable
e_R	Uncertainty in the results
IT	injection timing
LCV	Lower calorific value
$\dot{m}_{a,act.}$	actual air mass flow rate
$\dot{m}_{a_{theo.}}$	Theoretical air mass flow rate
$\dot{m}_f$	Fuel mass flow rate
NOx	nitrogen oxides
N	engine speed (rpm)
R	a given function of the independent variables $V_1, V_2, \ldots, V_n$ or $R = R(V_1, V_2, \ldots, V_n)$
T	engine torque
V_{sn}	swept volume
Q_t	The total fuel heat
Ø	Equivalence ratio

diesel. However, biodiesel has lower heat content than diesel resulting in less power, torque, and fuel economy. Furthermore, oxygenated fuels, such as biodiesel, tend to increase nitrogen oxide (NOx) emissions. B100 (100% biodiesel) increases NOx emissions by approximately 10% [7,8].

Hydrogen is being recognized an essential energy carrier for sustained power utilization because it has less negative effect on the environment than commonly used fuels. Hydrogen burning does not produce dangerous substances, such as, HC, CO and sulfur oxides, natural acids or carbon dioxide (CO_2) [9]. Table 1 shows the unique properties of hydrogen contrasted with the attributes of diesel fuel [10]. Sometimes, diesel fuel is difficult to ignite, which diminishes the output power. Elimination of the misfire phenomenon can improve the discharged emissions, performance, and fuel economy by adding hydrogen. Numerous researchers have sought to take advantage of the unique properties of hydrogen by adding it to diesel fuel to improve combustion specifications and reduce emissions. Table 1 presents some of these attempts.

The studies listed in Table 1 indicate that adding hydrogen to diesel fuel improves combustion characteristics by increasing the burning propagation rate, and, consequently, raising the peak cylinder pressure. A variety of methods used by researchers to insert hydrogen into the combustion chamber such as injecting it in the suction manifold, mixing it with the entering air, and injecting it into the combustion chamber. In general, most of them pointed out that adding hydrogen widen the equivalence ratio limits that make the engine run at lean air/fuel ratios and manipulate the injection timing to reduce of engine knocking. Yousif [23] declared that the main (premixed) fuel's energy fraction and pilot fuel injection timing have a significant role in the dual-fuel diesel mode engines. H_2 is carbon-free and has a high calorific value, resulting in low emissions and supply better engine's performance. Most R & D efforts seek to confirm the use of hydrogen as an alternative to energy in dual-diesel engines with minor modifications [24].

Many researchers have also studied the possibility of running a diesel engine using biodiesel and gaseous fuel to take advantage of the both fuels properties. Table 2 lists some of these works.

The use of hydrogen and biodiesel as a dual fuel in diesel engines gives higher thermal efficiency and reduces hydrocarbon contaminants based on two important factors: first, hydrogen is carbon-free fuel, and the second is the presence of extra oxygen in the composition of the biodiesel. Unfortunately, this dual fuel due to the high heat released in the combustion chamber causes higher concentrations of NOx [37]. In addition to hydrogen, several gases that contain a high proportion of hydrogen, such as product gas, biogas, and CNG, were also used in the studies in (Table 2). Hydrogen significantly affects the properties of combustion, but its impact may be limited by additives, such as CNG. Hydrogen has the highest burning speed among all known gases while natural gas has a slow burning rate.

Exhaust gas recirculation (EGR) effectively reduces NOx and avoids engine knocking but increases the amount of emitted smoke. Thus, EGR is added in small amounts to avoid emitting high smoke levels. Currently, smokeless diesel ignition has been achieved by utilizing a considerable amount of EGR [38]. Table 3 lists some studies that added EGR to dual fuel engine operation.

The results in Table 3 clarify that using EGR can increase specific power and control NOx. Adding EGR reduces NOx concentrations, but increases the CO, HC, and smoke opacity levels. In the same time, EGR extends higher load output over the normal operation. Engine fuels with oxygenates, such as biodiesel, reduce CO, HC and PM concentrations but increase NOx levels. The exhaust pollutants resulted from using EGR with biodiesel is the balance of these two factors according to their impact on each other and their combustion characteristics. Adding hydrogen (with its combustion enhancement characteristics) to this group reduces PM, CO, and HC levels but increases NOx rates.

A few scientists reported about dual fuel operation with hydrogen expansion consolidated with EGR [51–54]. These studies showed lower discharge levels and enhanced performance compared with regular diesel burning. Saravanan et al. [55] concluded that NOx levels are reduced by utilizing EGR for different diesel engine loads by burning diesel blended with hydrogen, comparable outcomes were produced by other studies. However, their concentrates seemed to diminish the NOx outflows caused by adding hydrogen. The change in NOx levels by EGR was contrasted with that in the NOx levels of pure diesel burning without EGR. Varde [56] attempted to reduce diesel particulates by aspirating small quantities of gaseous