Engineering Science and Technology, an International Journal xxx (2016) xxx–xxx

HOSTED BY

ELSEVIER

Contents lists available at ScienceDirect

Engineering Science and Technology, an International Journal

journal homepage: www.elsevier.com/locate/jestch

JESTECH

Full Length Article

Experimental investigation on CI engine performance using steam injection and ferric chloride as catalyst

P.P. Patnaik, S.K. Acharya *, D. Padhi, U.K. Mohanty

Department of Mechanical Engineering, S'O'A University, Bhubaneswar, Odisha, India

A R T I C L E I N F O

Article history:
Received 26 April 2016
Accepted 15 July 2016
Available online xxxx

Keywords:
Diesel
Ferric chloride
Steam injection
Performance
Combustion
Emission

A B S T R A C T

The present investigation pertains to running a diesel engine with diesel as the main fuel and diesel-ferric chloride ($FeCl_3$), diesel-steam injection, and diesel-$FeCl_3$-steam injection combinations. In order to conduct the experiment, engine exhaust energy and saturated steam generated from shell and tube heat exchanger were used. A heat exchanger was designed to maintain 3% and 5% of steam flow rate respectively at 60% and 80% engine load. The results showed that in diesel-ferric chloride ($FeCl_3$), diesel-steam injection, and diesel-$FeCl_3$-steam injection combinations, the brake thermal efficiency increases by 8%, 4%, and 3% respectively as compared to diesel mode. In diesel-$FeCl_3$-steam injection combination, maximum combustion gas temperature and maximum cylinder pressure decreased up to 4% when compared to diesel mode. Emissions such as NO, CO_2, O_2, and HC were reduced when the engine was run with diesel-$FeCl_3$-steam injection combinations as compared to diesel mode and the diesel-ferric chloride combination resulted in decreased emission of CO, HC and smoke when compared to diesel mode.

1. Introduction

Several hazardous gases are generated when a combustion process takes on irrespective of the fact whether the process is efficient or not. These injurious gases include HC, CO, CO_2 and NO_x.

In this paper, particular attention has been focused on diesel engine performance combustion and pertaining to emission from automobiles because diesel engines emit more pollutants than gasoline engines. It is heartening to note that the performance and emission from automobile engines have attracted the attention of many investigators. Laboratory experiments conducted concerning performance and emission from diesel engines using various additives to diesel adopting various techniques have been reported in the literature.

Kannan et al. added ferric chloride ($FeCl_3$) to biodiesel at a dose of 20 μmol/L. Brake specific fuel consumption was decreased by 8.6% and brake thermal efficiency increased by 6.3% when $FeCl_3$ as a fuel borne catalyst (FBC) is added with biodiesel. Gases like Carbon monoxide (CO), total hydrocarbon (THC) emission decreased by 52.6%, 26.6% respectively at optimum operating pressures and temperatures [1].

"Sahin et al. [2]" observed that the water injection into intake air does not create any significant change in the brake specific fuel consumption and brake effective efficiency of the engine. At specific ratios of water injection it was found that there was decrement in smoke index and NO_x emission with improved engine performance at higher RPMs like 2000, 2500 and 3000. Maximum reduction ratio in smoke index was obtained to be 41.75% for 11.71% water injection at 3000 rpm. Similarly, maximum decrement in NO_x emission was obtained as 12.489% for 9.4% of water injection at 2500 rpm. Due to addition of water inside the combustion chamber, the temperature is reduced and with the increasing specific heat of charge may reduce the soot formation process [3]. Micro-explosion of water vapor may help to mix diesel fuel and air rapidly. With 20% steam injection rate (S20) into an engine cylinder at full load condition, it was found that the torque and effective power increased to 2.5% at 1200 rpm and specific fuel consumption increased to 6.1% at 2400 the rpm [4]. Even the NO_x, CO and smoke density decreased to 22.4%, 4.3% and 45% respectively at different rpm of engines. Due to thermal effect of intake manifold water injection (IMWI) the ignition delay and the peak heat release rate of oxygen replaced by water, is longer than nitrogen [5]. These days, for the sake of reducing NO and particulate matter by direct water injection method [6] is giving popularity over the use of water-diesel emulsion and fumigation. "Murthy et al. [7]" concluded that reduction of NO emissions and exhaust temperature takes place and increment of soot emissions,

* Corresponding author at: Dept. of Mechanical Engg, ITER, SOA University, Bhubaneswar 751030, India.

E-mail address: saroj.acharya76@gmail.com (S.K. Acharya).

Peer review under responsibility of Karabuk University.

http://dx.doi.org/10.1016/j.jestch.2016.07.006
2215-0986/© 2016 The Authors. Published by Elsevier B.V. on behalf of Karabuk University.

Power and SFC takes place when solar generated steam is injected into diesel engine. As alternative fuel is renewable & environment friendly fuel, it has been identified to solve problems related to dwindling supply and emissions [8].

The effect of Fe_3O_4 magnetic nano particles dispersed in the diesel fuel at different concentrations (0.4 and 0.8 vol%), on performance and emission characteristics of diesel engine has been reported by Sarvestany et al. [9]. Break thermal efficiency is increased with the increasing fuel injection pressure, while brake specific fuel consumption (BSFC) and exhaust gas temperature reduced significantly [10]."Subramanian et al. [11]"studied performance and exhaust temperature of diesel engine by taking water-diesel emulsion with different ratio of 0, 5, 10, 15 & 20 and concluded that brake thermal efficiency increases approximately 3.5% for 20% water-diesel emulsions. "Senthil kumar et al. [12]" studied the impact of oxygen enrichment on pollution and performance parameters by increasing the oxygen concentration of intake air. Due to increased combustion temperature and extra oxygen available there is decrease in unburned hydro carbon, carbon monoxide and smoke density levels and increase in nitrogen oxide. "Dharmbir Prasad et al. [13]" studied the fuel cost minimization, transmission active power loss minimization, emission reduction and minimization of combined economic and environmental cost.

The present work is a humble attempt at address the performance, combustion and emission related problems pertaining to diesel automobile engine using different combinations of fuel and additives. The investigators have assessed the performance, combustion and emissions from a diesel engine under laboratory conditions with three different sets of experiments using diesel with $FeCl_3$ as catalyst, diesel with steam injection, and diesel with $FeCl_3$ and steam injection combinations. The results are evaluated and thoroughly examined, and are presented in a systematic manner.

2. Experimental

2.1. Experimental setup

The engine used in this study is a Kirloskar make, single cylinder, 4 stroke, naturally aspirated diesel engine with power 3.5 kW at 1500 rpm connected to eddy current dynamometer for loading. By rotating the knob on dynamometer loading unit, the engine is gradually loaded observed in the load indicator.

The setup has a panel box consisting of air box, one fuel tank with capacity of 15 liters for fuel test, manometer, fuel measuring unit, transmitters for air and fuel flow measurements, process indicator and engine indicator. Air flow rate was calculated from the head difference in the manometer. In order to measure the in-cylinder pressure a Piezo sensor range of 5000 psi was used. Rota-meter is provided for measuring the flows of cooling water. A Kubler make digital rotary encoder was used for measurement of the engine rpm. This rotary encoder is capable of measuring 1 to 10,000 rpm of the engine.

The capacity of engine is 661 cc with compression ratio varying from 12 to 18. Compression ratio is changed by changing the clearance volume using incline cylinder head. The detailed specification of the engine is shown in Table 1. Software package "Engine soft-LV" of version 8.51 is employed for online performance and combustion analysis. The tests have been conducted at the rated speed of 1500 rpm and at constant compression ratio 18:1 under different loading condition. Compression ratio 18 is chosen because of better engine performance. Fig. 1 shows the diagram of the actual experimental setup of diesel engine with modification. A shell and tube heat exchanger is attached with the existing setup for transferring heat from engine exhaust to water inside the tube. Several 'K' type thermocouples are used to measure different temperatures. Temperatures were measured at different points such as at the outlet of the Heat Exchanger (T3, T4, and T5), temperature of exhaust gas in and exhaust gas out (T1 and T2). The engine was operated in standard diesel mode. The exhaust emissions are measured by online AVL- 444 model, multi-gas analyzer which is capable of measuring CO, HC, CO_2, O_2 and NO_x concentrations in the exhaust. Smoke opacity is measured with AVL-437 model smoke meter (measuring range 0 to 100% with resolution 0.1% and uncertainty of ±1.2). Uncertainty analysis for cylinder pressure and combustion temperature is ±1.2 and 64.78 K. A computerized data acquisition system is used in order to collect, store and analyze the data during the experiment by using various sensors.

Table 1
Specification of the engine.

Make	Kirloskar
General details	Diesel Engine test setup 1-cylinder, 4-stroke, water cooled
Rated power	3.5Kw at 1500 rpm
Speed	1500 rpm(constant)
Number of cylinder	Single cylinder
Compression ratio	12:1 to 18:1(variable)
Bore	87.5 mm
Stroke	110 mm
Ignition	Compression ignition

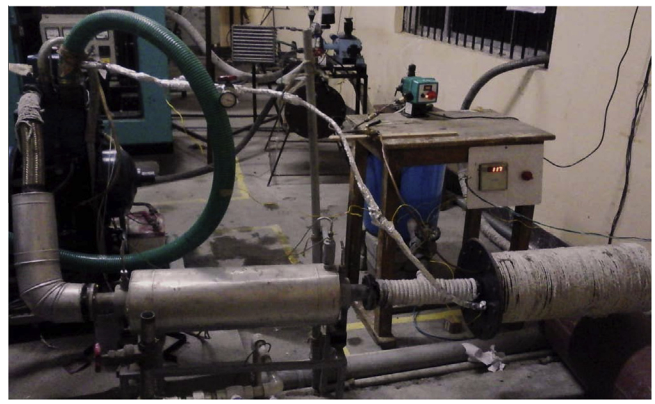

Fig. 1. Actual engine setup after modification.

At each loading conditions the required emission parameters are measured and recorded after allowing sufficient time for the engine to reach its steady state condition. The performance, combustion and emission characteristics of the engine were measured for the steam injection method and the results are compared with standard diesel.

2.2. Experimental procedure

The block diagram of the experimental setup is shown in Fig. 2. The water is required to be circulated through heat exchanger as a medium to carry heat. An electronic metering "gaint-01" model pump with the capacity of 4 lph, pressure 4 kg/cm^2 is taken for circulation of water. The water through the pump flows to the inlet tube of the heat exchanger. The circulated water in the heat exchanger gains heat from the exhaust and converts to saturated steam at the outlet. Flow rate is decided by maintaining the flow rate of water as per the air flow rate using an electronic dosing pump. Water from liquid state is converted to saturated steam in the designed heat exchanger which is shown in Fig. 3 depending