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AN INVESTIGATION ON THE MALFUNCTIONING OF FUEL INJECTORS DUE TO CONTAMINATION OF WATER IN DIESEL FUEL

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ABSTRACT

The operation of compression ignition engines is largely dependent upon a smooth supply of fuel from fuel injectors. Recently an increase in malfunctioning of fuel injectors in compression ignition engines of automobiles has been noticed. Statistics show that these failures are mainly attributed to the poor quality of diesel fuel available in local markets. A fundamental reason in this regard is the presence of extra water content in diesel fuel. The unwanted water content in diesel disturbs the performance of fuel injectors and renders them malfunctioning or pre-mature failure. Since modern electromagnetic fuel injectors are compact and enclosed assemblies, therefore, any observation in their internal mechanism is always difficult to measure. Most studies have been conducted to only approximate malfunctioning of fuel injectors with the help of simulations and corresponding results. Here, we have established an experimental setup using a 2KD engine of Toyota Hilux fitted with DENSO electromagnetic fuel injectors and onboard diagnostic equipment. The setup experimentally proves that fuel injectors malfunction due to high percentage of water in diesel fuel. This study will assist future equipment designers to optimize the design of fuel injectors so that the high percentage of water in diesel fuel may be catered for before production.

1. INTRODUCTION

The performance of compression ignition engines requires a prescribed supply of diesel fuel into engine cylinders [1]. This supply of fuel depends fundamentally on the accurate performance of fuel injectors [2]. In the case of common rail fuel supply systems, it has been observed that 40% of engine failures occur due to malfunctioning of fuel injectors [3]. Many cases of premature malfunctioning of

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fuel injectors have been observed recently [4]. There are many reasons which contribute towards malfunctioning of fuel injectors. Some of most prominent are poor quality of material, operation at undesirable temperature and pressure, manufacturing faults and use of contaminated fuel in fuel injectors [5]. Contamination of fuel particularly diesel fuel existed even 50 years ago [6]. Due to exponential increase in fuel consumption in recent past, the contamination of diesel fuel has also increased significantly [7]. The main constituent of the contamination is water which exists in diesel fuel in the form of small droplets [8]. There is a certain limit up to which water can be added in the diesel fuel. This limit is 500 ppm for small to medium size engines i.e it is safe to add 0.05% water in diesel fuel [9]**.** If water content in diesel fuel exceeds 0.05%, it is likely that in addition to poor performance of engine, the components associated with fuel supply system will also be affected adversely. Fuel injectors are therefore vulnerable to malfunction due to high percentage of water in diesel fuel. Since the modern fuel injectors are compact and fully enclosed assembles [10] hence investigating the malfunctioning within the internal mechanism of fuel injectors is still an unsolved issue in the automotive industry. In this regard, many pieces of research have been done to approximate the malfunctioning of fuel injectors with the help of simulations. Practical demonstration with test equipment to ascertain the poor performance of fuel injectors due to high water content in diesel is still a worth considering idea. Here, we have set up an experimental setup that investigates the malfunctioning of fuel injectors due to high percentage of water in diesel fuel.

2. DESCRIPTION OF EXPERIMENTAL SETUP

An experimental setup is established as shown in figure 1. The setup investigates the performance of diesel fuel injectors with an increase in water content in diesel fuel. The setup is organized by connecting a commercially available OBD test equipment LAUNCH X431 MASTER with a common rail diesel engine (2KD-FTV engine of Toyota Hilux model 2012). The engine uses multi-hole electromagnetic fuel injectors of DENSO Corporation [11]. The fuel injectors were tested with four samples of diesel fuel having a water content ranging from 0.05% to 4%. The behavior of fuel injectors was noted at no load and 50% load conditions. The detailed specification of the experimental setup is mentioned in Table 1.

Table 1: Experimental Setup Data

Engine Model (1 Ton Toyota Hilux)	2KD FTV CI Engine
Model Year	2012
Fuel Injectors fitted with Engine	DENSO Corporation
Fuel Injector Type	Electromagnetic multi-hole Injectors
Fuel Injection Type	Common Rail Injection
Sample Sizes of Fuel	Four samples of two liters each with following water concentration in diesel:- 1st Sample – 0.05% water 2nd Sample – 1% water 3rd Sample – 2% water 4th Sample – 4% water
Measurement Apparatus	LAUNCH X431 MASTER
Number of Experiments Conducted	Two

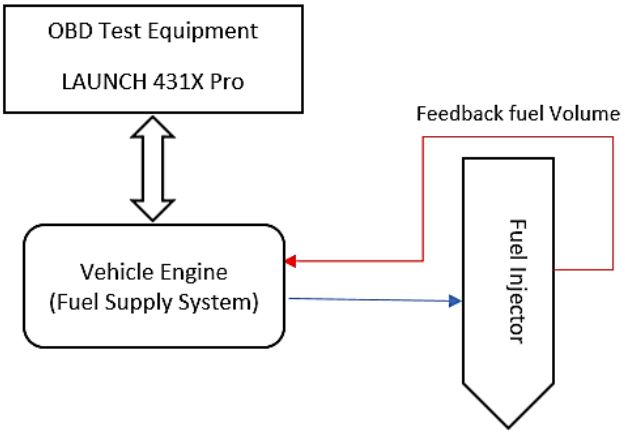

Figure 1: Schematic of Experimental Setup.

3. RESULTS AND DISCUSSIONS

3.1 PERFORMANCE PARAMETERS OF FUEL INJECTORS

The performance of an electromagnetic DENSO fuel injector for the 2KD engine is measured by the volume of fuel sprayed into the cylinder at respective pressure and temperature [12]. Likewise, extra fuel which is not sprayed into the cylinder is returned back to common rail storage through a feedback exit [13]. Ideally, this feedback fuel volume shall be zero [12]. As this feedback volume increases it reaches a tolerable limit. The engine starts misfiring and wobbling above this limit [14]. The inlet and feedback exit of an electromagnetic fuel injector of DENSO corporation (for 2KD engines) are shown in Figure 1.

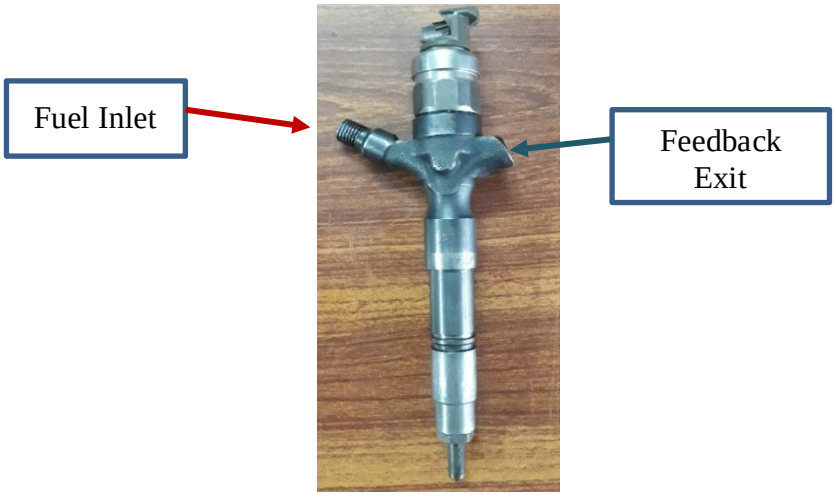

Figure 2: Multi-hole DENSO Fuel Injector.

3.2 FUEL FEEDBACK READINGS ON TEST EQUIPMENT

The engine was operated on four different samples of fuel at both no-load and 50% load conditions. New DENSO fuel injectors were used for each fuel sample. Readings of both experiments are given in Figures 3 and 4. A graphical representation of all four samples is given in Figures 2 and 3 at no load and 50% load conditions respectively. From Figures 3 and 4, as the water content in diesel fuel increases, the feedback volume of fuel injectors also increases in direct proportion. In the fourth sample i.e. sample having water content equal to 4%, the feedback volume increases drastically depicting a negligible fuel spray in the cylinders. In said case, almost all of the

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fuel supplied to fuel injectors has been returned back to common rail storage as feedback volume. This pattern is observed for both no-load and 50% load conditions. A high feedback volume of fuel shows the poor performance of fuel injectors which occurred mainly due to high percentage of water in second, third and fourth samples respectively.

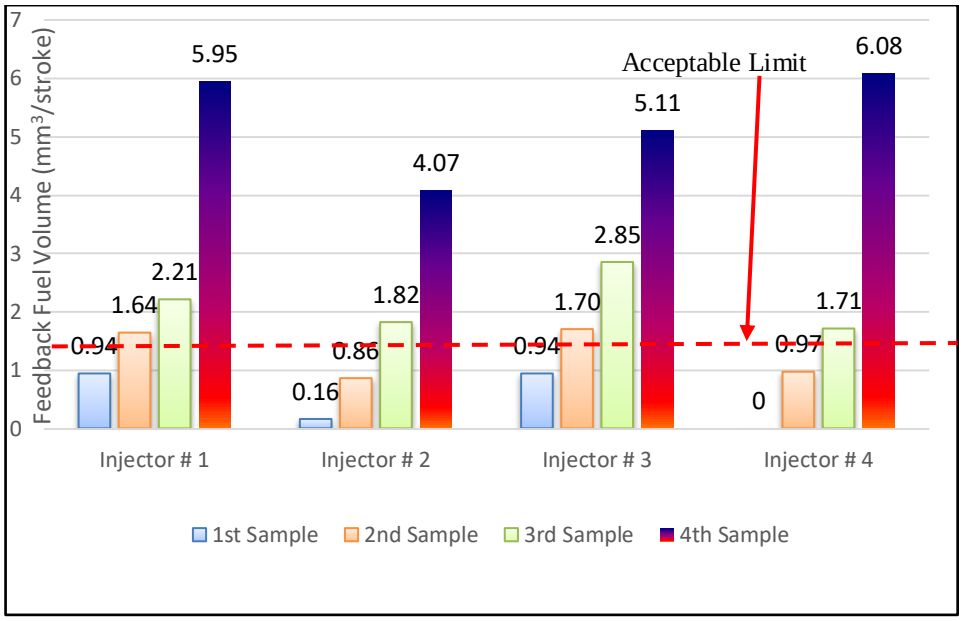

Figure 3: Injectors feedback volume with an acceptable limit (no-load condition) from four diesel fuel samples.

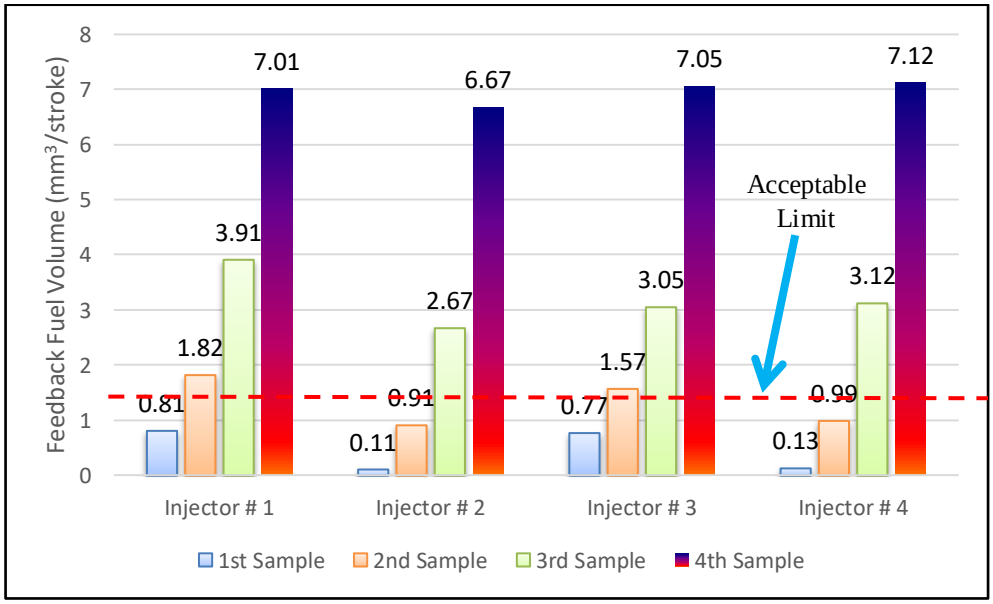

Figure 4: Injectors feedback volume with an acceptable limit (@ 50% load condition) from four diesel fuel samples.

3.3 ACCEPTABLE LIMIT

During the experiment, it was observed that an acceptable limit of feedback volume is around 1.5 mm^3/stroke because the engine started wobbling above this limit for both no-load and full load conditions. The fuel samples with 1%, 2% and 4% water content gave feedback fuel volumes which were beyond the acceptable limit and therefore caused wobbling in the engine. Only the first fuel sample with 0.05% water content gave feedback fuel volumes within acceptable limit i.e. less than 1.5 mm^3/stroke. This acceptable limit is highlighted for the conducted experiment in Figures 3 and 4.

3.4 VALIDATION OF MALFUNCTIONING OF FUEL INJECTORS DUE TO HIGH PERCENTAGE OF WATER IN DIESEL FUEL

In order to validate the malfunctioning of fuel injectors, the feedback volume of fuel from injectors was noted for another time for only the fuel sample with 0.05% water content. All four fuel injectors were kept the same to compare the difference between the reading of 1st and 2nd experiments. The readings observed are mentioned in Figure 5.

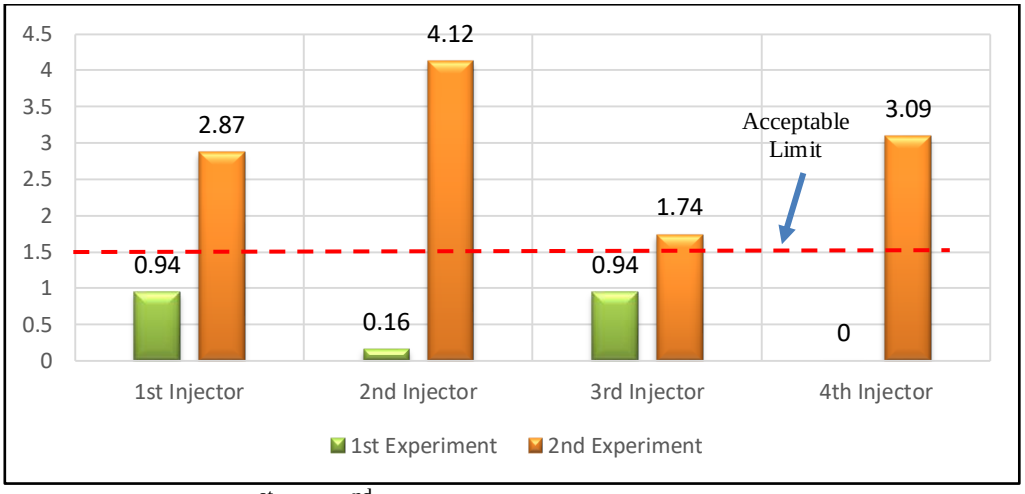

Figure 5: Comparison of 1st and 2nd experiments for fuel sample having 0.05% water content.

3.5 COMPARISON OF 1ST AND 2ND READINGS

After the first experiment, obtained fuel feedback volume is well within the acceptable limit whereas, after the second experiment, the obtained fuel feedback volume surpassed the acceptable limit for injectors. The second experiment was only carried out for the fuel with 0.05% water content. Thus, same fuel injectors that had undergone tests with 1%, 2% and 4% water content had deteriorated to an extent that they could not be used for another experiment. This was manifested with their unusual high feedback fuel volume depicting that fuel injectors have got faulty due to high content of water in diesel fuel.

4. CONCLUSION

An over-addition of water in diesel fuel affects the operational life of fuel injectors. In the case of small to medium-sized automobile engines, the maximum allowable percentage of water in diesel fuel is 0.05% (i.e. 500 ppm). Above this limit, the engines start wobbling and the operational performance of fuel injectors is affected. Moreover, it has been concluded that fuel injectors operated with diesel fuel having high water content (i-e 4% or above water in diesel fuel) malfunctions prematurely. This study provides substantial evidence to fuel injector designers to accommodate the unwanted increase of water content in diesel fuel while designing the fuel injectors for automotive industry.

5. MATERIAL AND DATA AVAILABILITY

Information regarding this study is available from the corresponding author.

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