
Taguchi's Parametric Optimization of CIDI Engine Emissions Fueled with Azadirachta Indica Biodiesel and its Blends

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Abstract

The scrupulous dangerous environmental pollution from automotives and declining reserves of fossil petroleum fuels, the raised usage of diesel triggered to discover a cost-effectively renewable available and environ friendly fuel to replace the fossil fuel. Recently, the past research reviews revealed that biodiesel that was prepared from vegetable oil as one of the replacements of fossil diesel fuel. But the engines are not producing sufficient power as well as not reducing the exhaust emissions as expected. Hence the objective the present paper to identify the optimized combine engine parameters to decrease the exhaust emissions of a 4-stroke, single cylinder, direct injection(DI) diesel engine using Taguchi optimization technique when fueled with methyl ester of Azadirachta indica oil (AIOME). The research explores the effect of fuel injection pressure (FIP), AIOME percentage in blend and engine load was considered as the controlled factors for the objective and CO emission and Smoke density measured as the response variables. The Taguchi method's L16 orthogonal array was systematically decided using design of experiments (DoE) methodology and a progressive experimental tests were carried-out as designed with different combination of influencing factors. Taguchi method employed to evaluate the influencing factors and significance of impact on response variables. The analysis based on Taguchi method revealed that that injection pressure 220 bar, blend B40A of AIOME at 25% of engine load were optimum parametric combination setting to reduce the CO emission and smoke opacity to the lowest level. Engine's exhaust emissions are mainly influenced by engine load, followed by percentage of AIOME in blend and is least influenced by injection pressure. .

Keywords:

Biodiesel;
Taguchi Method;
Optimization;
Azadirachta Indica;
Engine Emissions.

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1. Introduction

The passenger vehicles and heavy duty vehicles are one of the leading causes of environmental pollution. The increased consumption diesel fuel is boosting the severely impacting on environment such as global warming, acid rains and other perilous environmental impacts. In order to reduce the hazardous environmental pollution due to hefty usage of fossil fuels in the fields of transportation and industries foster the research on renewable alternative fuel source(s). The previous research studies revealed that plant based oils, waste cooking oils, and animal fats can be used as biodiesel to reduce the dependence on fossil fuels, lower the green gas emissions and uplift the rural economies. It also revealed that vegetable oil based

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biodiesel as one of the replacements of fossil diesel completely or partially. Competition of renewable liquid fuels to the petroleum fuels is significant in the near future. Renewable energy is a promising alternative solution because it is clean burning, non-toxic, eco-friendly and safe. Moreover it can be prepared at any geographic location, because it requires either vegetable oil or animal fat as biodiesel feedstock.

The biodiesel is principally mono-alkyl ester of long chain fatty acids derived from a alternative renewable feed stock. The plant based vegetable oils can be directly used as fuel for diesel engine without modifications, but pure or partially esterified oils may lead to distinctive engine problems such as injection plugging, piston ring sticking, carbon deposits which can cause engine failure or require more frequent maintenance and clean the engine [1-4]. Generally the neat vegetable oils releases very hazardous exhaust emissions than using diesel fuel that adversely impact the environment [5]. To overcome this problem, transesterification process will be used to produce biodiesel in the form of methyl ester using vegetable oils and methyl or ethyl alcohol [6]. Recently, a quiet few number of research studies revealed that small changes in the engine design parameters such as fuel injection timings, fuel injection pressure, compression ratio, combustion chamber design, combustion chamber type, etc., increases the engine performance and also reduces the emissions [9–11]. Jaichandar et al. conducted series of experimental test to find the optimized the combination of injection timing and combustion chamber geometry to achieve maximum performance and reduce the exhaust emission characteristics of single cylinder, diesel engine when fueled with a blend of 20% by vol. pongamia oil methyl ester (POME) in diesel fuel (B20). The engine was prepared with pistons containing hemispherical and toroidal reentrant combustion chamber (TRCC) geometries. They noticed increased brake thermal efficiency, NO_x for retarded fuel injection timing and the highest performance and lowest emissions at 21° bTDC of fuel injection timing [12]. Bhaskor et al. Have experimentally evaluated the influence of compression ratio on performance, emission and combustion characteristics of a dual fuel, single cylinder, natural aspirated, water cooled CI engine fuelled with rice bran biodiesel-biogas. They noticed higher BTE at higher compression ratios (CRs) at fixed fuel injection timings of 23° bottom top dead centre (bTDC) with the reduced CO, hydro-carbon emissions, but increased CO₂ and NO_x emissions [13]. Hence, the purpose of the present research study focussed on to evaluate the optimum blend of AIOME biodiesel that has optimum exhaust emission values and the level of impact of engine parameters such as load, blend percentage in biodiesel and injection pressure based on the actual experimentation.

2. Materials and Methods

2.1 Biodiesel Preparation

The Azadirachta indica oil was bought from local vendor to prepare a biodiesel to reduce the viscosity and density and increase the cetane number using transesterification process. The figure 1 below shows the transesterification chemical reaction to prepare methyl ester biodiesel. In this process, the first step is mix the alcohol for reaction with the catalyst, typically a strong base such as NaOH or KOH. The alcohol/catalyst is then reacted with the fatty acid so that the transesterification reaction takes place. The reaction between the fat or oil and the alcohol is a reversible reaction, so the alcohol must be added in excess to drive the reaction towards the right and ensure complete conversion.

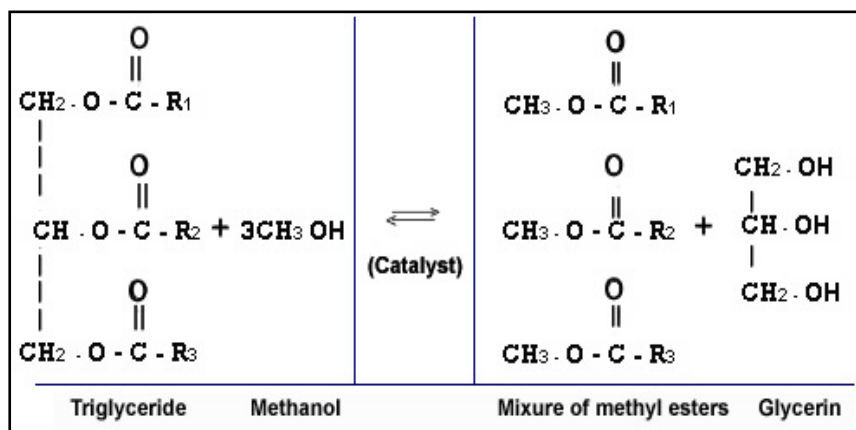


Figure. 1 Chemical Reaction of Transesterification Process

After completion of transesterification process and the separation of the heavy glycerin phase, the producer is left with a crude light biodiesel phase. This crude biodiesel was filtered and further purified prior to use in diesel engine as fuel.

2.2 Application of Taguchi Optimization Technique

In order to employ the Taguchi optimization method, a series of experimental tests should be carried-out after designing the orthogonal array, derived using design of experiments (DoE) methodology. Based the DoE design, 16 experiments should be carried-out in a DI diesel engine using the Azadirachta indica oil methyl ester (AIOME) and its blends at various injection pressures and engine loads.

2.3 Orthogonal Array of Taguchi

For the present research study, three factors and four levels were selected for this research study to evaluate the effect of these three factors on objective parameter which is engine exhaust emissions. The engine parameters of diesel engine: fuel injection pressure, percentage of AIOME in biodiesel blend, and engine load were considered as the factors that influencing the CO emission and smoke opacity which are considered as objective responsive parameters. The list of parameters and levels are given in table 1.

Table 1. Control Parameters and Levels

Control Parameters	Level 1	Level 2	Level 3	Level 4
A. Load	25	50	75	100
B. Percentage of AIOME in Blend	20	40	60	100
C. Injection Pressure	210	220	230	240

To identify the optimized engine parametric values to reduce the emissions, huge number of experimental tests should be conducted when the number of process parameters and levels increases. To reduce the number of experimental tests to be conducted a special design of orthogonal arrays to study the entire parameter space with only a small number of experiments [14]. To solve this problem, the Taguchi method uses orthogonal array of L16 was designed for the present research study and presented in table 2.

Table 2. DoE – L16 Orthogonal Array

Experiment Number	Percentage of AIOME in Blend (%) (A)	Engine Load (%) (B)	Injection Pressure (bar) (C)
1	1	1	1
2	2	1	2
3	3	1	3
4	4	1	4
5	1	2	2
6	2	2	1
7	3	2	4
8	4	2	3
9	1	3	3
10	2	3	4
11	3	3	1
12	4	3	2
13	1	4	4
14	2	4	3
15	3	4	2
16	4	4	1

Taguchi has four categorization of response variables for S/N ratio and are Larger is better to maximize the response, Nominal is best when the goal is to target the response and S/N ratio on standard deviations are required, Nominal is best when the goal is to target the response, the S/N ratio on means and standard deviations are required, and smaller is better when the S/N ratio should be selected that best meets the objective of the optimization [14]. In this study, the goal is to minimize the response variables viz., CO emission and smoke opacity, and hence *Smaller is Better* was selected to minimize the diesel engine emissions when fuelled with AIOME biodiesel.

2.4 Experimental Test Setup

The series of experimental tests were conducted using single cylinder, 4-stroke water cooled direct injection diesel engine fuelled with Azadirachta indica oil methyl ester (AIOME) after the designing of L16 orthogonal array. The experimental setup in schematic diagram is presented in figure 2 and photographic view is presented in figure 3.

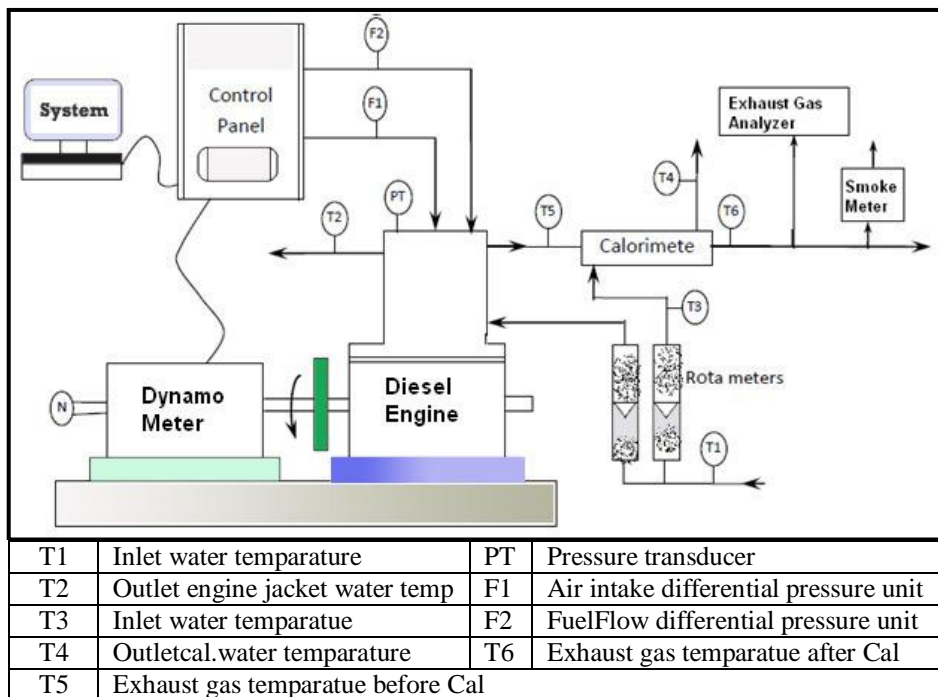


Figure. 2 Schematic Diagram of Experimental Test Setup



Fig. 3 Photographic View of Experimental Test Rig

The test setup consist of 3.7 KW (5HP) Kirloskar diesel engine, eddy current dynamometer, smoke meter, and exhaust gas analyzer with computer test rig. The specifications of the test engine are given in table 3.

Table 3. Specification of Test Engine

Type	Kirloskar
Details	Single cylinder, Four stroke, DI, Water cooled
Bore & Stroke	80 × 110 mm
Rated Power	3.7 KW (5 HP)
Engine Speed	1500 rpm
Rated Injection Pressure	200 bar
Dynamometer	Eddy Current

3. Results and Analysis

The Taguchi method was employed for the optimization of the mentioned three process parameters. The different combinations of three input variables: fuel injection pressure, AIOME percentage in blend, and engine load were selected to evaluate the effect on two output response parameters: CO emission and smoke opacity. In order to search for the optimal process condition with a limited number of experiments, L16 orthogonal array had been used as part application of Taguchi optimization technique using DoE methodology.

3.1 CO Emissions

The signal-to-noise (S/N) ratios for the output response parameters: CO emission and smoke opacity were calculated using sing Minitab software. The calculated S/N ratios for the selected output parameters are presented in Table 4. Figure 4 presents the graphical representation of ratio for three influencing factors in the main effect plot for S/N Ratios and Figure 5 shows the main effect plot for Mean of CO emission.

Table 4. Experimental Results – S/N Ratio

AIOME Percentage in Blend (%)	Engine Load (%)	Injection Pressure (bar)	S/N Ratio-CO Emission (%)	S/N Ratio-Smoke Opacity (%)
20	25	210	18.4164	-20.0864
20	50	220	17.7211	-22.0074
20	75	230	15.3910	-25.756
20	100	240	13.1515	-27.8539
40	25	220	23.0980	-19.1808
40	50	210	17.7211	-21.7981
40	75	240	14.4249	-25.8451
40	100	230	14.8945	-27.3098
60	25	230	23.0980	-19.4626
60	50	240	18.4164	-21.5109
60	75	210	15.9176	-24.1365
60	100	220	16.4782	-26.9661
100	25	240	21.9382	-20.172
100	50	230	20.9151	-20.7485
100	75	220	20.0000	-23.2274
100	100	210	15.9176	-26.6083

If a line for a particular influencing parameter is almost horizontal, the impact of input parameter on response less significant effect will be presented as almost horizontal line in the graph. Conversely, a parameter for which the line has the highest inclination will have the most significant effect. As shown in plots at figure 4 and 5, it has been noticed that engine load had the most significant effect among the three parameters followed by blend percentage of A1OME. The optimum process parameter combination corresponding to minimum emission was indicated by the maximum value for signal-to-noise (S/N) ratio for each input parameter. The B40A biodiesel blend of A1OME at 25% of engine load with 220 bar injection pressure and B60A biodiesel blend of A1OME at 25% of engine load with 230 bar injection pressure were found as optimum process parameter combination to reduce the CO emission based on the data presented in Table IV. As shown in Table V, the data of response for means indicating that engine load highest effect followed by A1OME percentage in blend and least impact by fuel injection pressure.

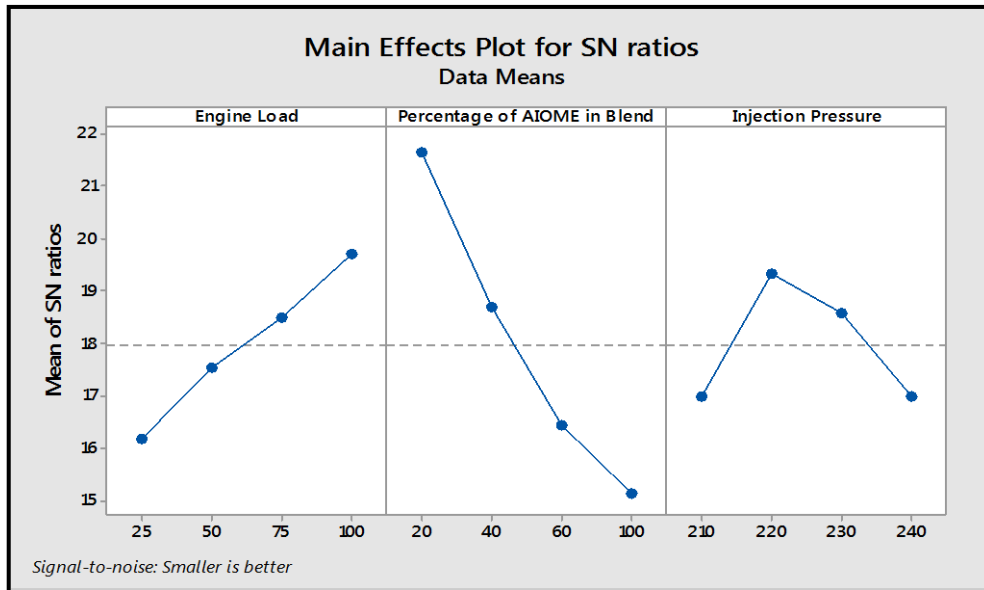


Figure.4 Main Effects Plot for S/N Ratios of CO Emission

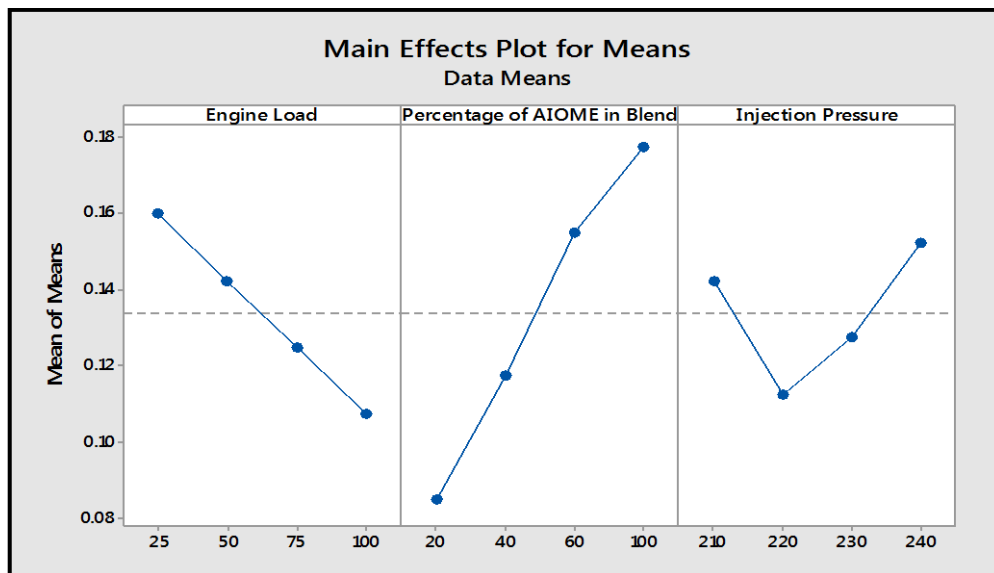


Figure.5 Main Effects Plot for Means of CO Emission

Table 5. Response Table For Means of CO Emission

Level	AIOME Percentage in Blend	Engine Load	Injection Pressure
1	0.16000	0.08500	0.14250
2	0.14250	0.11750	0.11250
3	0.12500	0.15500	0.12750
4	0.10750	0.17750	0.15250
Delta	0.05250	0.09250	0.04000
Rank	2	1	3

(Smaller is better)

3.2 Smoke Opacity

The signal-to-noise (S/N) ratios for the output response parameter: smoke opacity were calculated using sing Minitab software and the calculated S/N ratios are presented in Table 6. Figure 6 presents the graphical representation of ratio for three influencing factors in the main effect plot for S/N Ratios and Figure 7 shows the main effect plot for Mean of Smoke Opacity. The data shown in Table 4, the B40A biodiesel blend of AIOME at 25% of engine load with 220 bar injection pressure found to be optimum parameter combination to reduce the smoke opacity emission. As shown in Table 4, the data of response for means reflecting that engine load highest effect followed by AIOME percentage blend and least impact by fuel injection pressure.

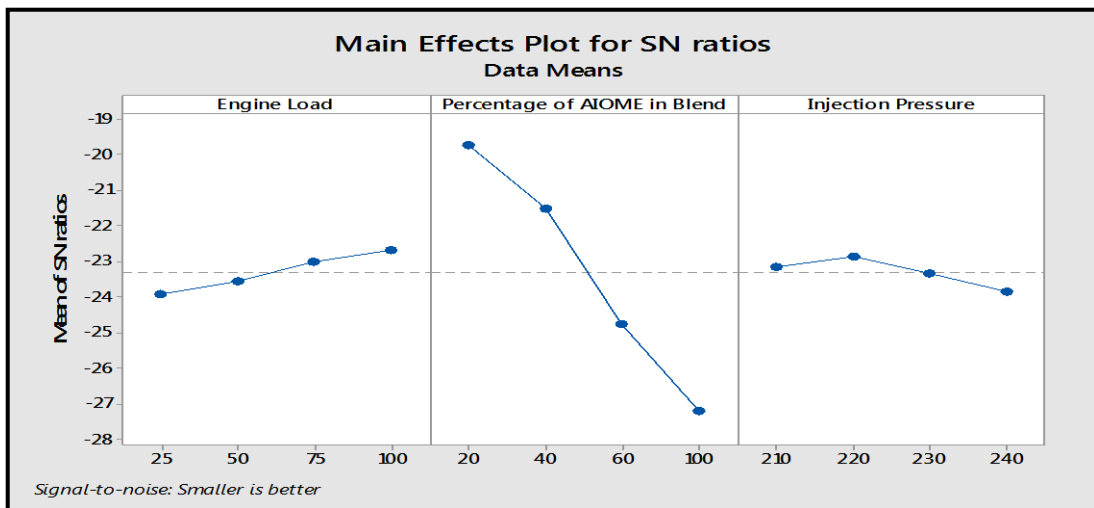


Figure. 6 Main Effects Plot for S/N Ratios of Smoke Opacity

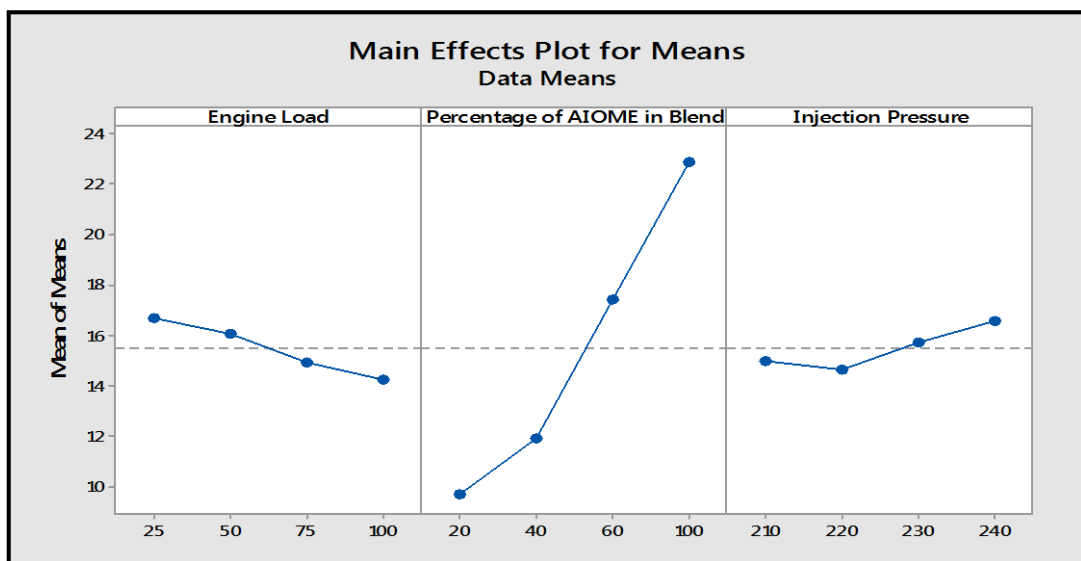


Figure.7 Main Effects Plot for Means of Smoke Opacity

Table 6. Response Table For Means of Smoke Opacity

Level	AIOME Percentage in Blend	Engine Load	Injection Pressure
1	16.700	9.700	14.975
2	16.050	11.925	14.625
3	14.925	17.400	15.725
4	14.250	22.900	16.600
Delta	2.450	13.200	1.975
Rank	2	1	3

(Smaller is better)

4. Conclusions

The research analysis was conducted to establish the optimum level and effect of the engine parameters such as engine load, AIOME biodiesel percentage in blend and fuel injection pressure of diesel engine on carbon monoxide emission and smoke opacity. The experimental tests were carried-out using a single cylinder, 4-stroke compression ignition direct injection engine fuelled with different blends (B20A, B40A, B60A and B100A) of *Adirachta indica* oil methyl ester (AIOME) as biodiesel according L16 orthogonal array. The optimization analysis performed using Taguchi optimization technique and the analysis established that the fuel injection pressure of 220 bar, blend B40A of AIOME at 25% of engine load are the optimum parameteric combination to reduce the CO emission and smoke opacity to the lowest levels. It also revealed that the engine emission characteristics are mostly influenced by engine load, blend and is least influenced by fuel injection pressure.

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