Automotive Science and Engineering, Vol. 11, No. 3, (2021),3566-3578

Iran University of Science and Technology

Automotive Science and Engineering

Journal Homepage: ase.iust.ac.ir

ISSN: 2717-2023

Effect of fuel filter life on exhaust emissions parameters of a gasoline engine: RSM optimization approach

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ARTICLE INFO

Article history:
Received: 13 June 2021
Accepted: 28 Aug 2021
Published:1 Sep 2021

Keywords:
Gasoline Engine
Fuel Filter
Lambda
Exhaust Emission

ABSTRACT

The fuel system in internal combustion engines is one of the most accurate and sensitive parts and its operation has a significant effect on the quality of combustion process and the content of exhaust emissions. In this study, the effect of fuel filter life on lambda and exhaust emissions of engine has been investigated using the response surface method (RSM). The results showed that the elevated values of lambda (1.042) and CO (0.88%) occur at the engine speed of 5000 rpm with a fuel filter life (FFL) of 60,000 km. Also, the highest CO_2 content was obtained as 14.9% at 1000 rpm with a new fuel filter (0 km). Moreover, the highest amount of HC emission (215 ppm) was measured at 1000 rpm and using FFL of 60,000 km. The results showed that increasing the fuel filter life increases the exhaust emissions of the engine. Therefore, timely replacement of the fuel filter, in addition to increasing engine performance, will reduce air pollution, especially in big cities.

[DOI: 10.22068/ase.2021.594]

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https://doi.org/10.22068/ase.2021.594

1. Introduction

Exhaust emissions emitted by gasoline engines play a dominant role in polluting the air especially in large cities. Restricted fossil fuel resources, ever-increasing strict environmental regulations and increasing concerns on health problems have led to extensive research in the field of controlling and reducing such hazardous pollutants.

The fuel system in engine plays the role of blood system in the body and is as essential as such system. The main components of the fuel system include fuel tank, fuel pump, transfer pipes, gasoline filter, fuel rail and injectors. Timely replacement of the fuel filter is always considered as one of the most important vehicle maintenance services and has a great impact on the quality of combustion and increases the life of the fuel system components. It is obvious that the accuracy in fuel purification process in today's injector cars is much more important than the old carburetor fuel system. The reason is that each injector has one or more tiny holes that have less than 0.2 mm diameter, and since each injector opens for less than 0.005 seconds, the existence of external particles in the fuel can easily lead to clogged injector ducts and system malfunction. [1,2]

The main causes of fuel pollution are sediments in fuel transport tanks or suspended particles and sediments deposited in the tanks of fuel distribution stations. Also, the existence of impurity particles in the connection pipes of the fuel system as well as the impurities caused by corrosion of car refueling ducts and air dust particles that enter the fuel are other reasons of fuel pollution. The fuel filter’s task is to prevent all above-mentioned impurities from entering the fuel system and combustion chamber. Some car manufacturing companies have recommended a suitable time to replace the gasoline filter every 15,000 km, but the car kilometer alone is not a good criterion for determining the time to replace the fuel filter. Because the degree of clogging of the fuel filter depends on various factors such as road conditions, traffic, vehicle operation location, gasoline quality of the stations, impurities in the fuel system and sediments in the tank. Over the time and increasing vehicle operation, the gasoline filter becomes clogged due to purification of fuel particles. Dirt and clogging of the gasoline filter reduces engine efficiency, increases starting time, especially in cold weather, dirt and clogged injectors, vehicle shutdown and shortening the life of equipment such as fuel pump, injectors and oxygen sensors, and in some cases lead in engine valves burn [1].

Ghanbari and Mozafari [3] in a study, the effect of increasing the fuel filter life on fuel feeding and ignition systems was investigated. The results showed that the use of long life fuel filter, especially more than 15,000 km, increases the electric current consumption of the fuel pump, the operating temperature of the pump, the fuel temperature in the fuel feeding system and thus shortening the life of the fuel pump. In the ignition system, with the increase of the gasoline filter life, the amount of ignition advance increased, which can cause complications such as premature combustion, knocking in the engine and reducing the useful life of the main engine parts. Carbon monoxide (CO), unburned hydrocarbons (UHCs) and nitrogen oxides (NO_X) are considered as the most important emissions in internal combustion engines [4]. In another study, the effect of changes in fuel pressure and spark time on the emissions of internal combustion engines was investigated. The results depict that at higher diesel injection pressure (IP) operation, the peak of the NMP increases while the AMP peak decreases for neat diesel operation as well as RCCI engine. Nucleation, as well as accumulation mode particles, increases with advanced diesel injection timing in RCCI combustion. An increase in port fuel injected

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mass also leads to an increase in the total particle concentration and total unburned hydrocarbon (THC) emissions [5]. Thomas Durbin et al [6] experimentally investigated the effect of diesel fuel filters and type of diesel fuel on greenhouse gas emissions in medium diesel vehicles. Their results showed that diesel fuel filters (DPFs) are able to reduce the amounts of particulate matters (PMs), UHCs and CO by about 98%, 80% and 90%, respectively. The results showed that the average levels of carbon monoxide, unburned hydrocarbons and nitrogen oxides decreased by 35.3%, 26.1% and 34.3%, respectively [7].

In many research studies, the RSM has been applied to investigate the performance parameters of internal combustion engines. In order to optimize the EGR ratio, Jalilian Tabar *et al* [8] studied the operating conditions of a diesel engine and the amount of pollutants emitted from the exhaust using the RSM method. Dole et al [9] proposed a mathematical model to investigate the relationship between pollutant emissions and performance parameters of a dual-fuel diesel engine such as engine load, engine speed and the amount of hydrogen-replaced fuel.

Omi et al [10] in a numerical study using the KIVA-3V simulator program investigated the effect of fuel injection time on the rate of fuel evaporation and emissions in a gasoline engine. The results showed that late spraying of fuel will reduce fuel evaporation. On the other hand, increasing the rate of fuel evaporation reduces CO and HC emission. But to reduce NOx emission, spark time adjustment should be used. In a theoretical study using AVL-Fire software investigated the effect of time and fuel injection pressure on the performance and emissions of the diesel engine. The results showed that increasing fuel injection pressure will increase NOx and decrease PM[11].

A review of previous research shows that there is a lot of research on reducing exhaust emissions from internal combustion engines by changing the engine design, replacing new parts in different engine systems, using filtration systems in exhaust outlets such as catalysts and changing the type of fuel used, is done. In our previous research work, the effect of FFL on many of the main characteristics of the engine such as engine power, air to fuel ratio and the combustion quality were envisaged. Since the amount of pollutants emitted from the exhaust has not been studied so far, in this study, the effect of FFL and engine speed on such characteristics will be addressed.

2. Materials and Methods

A four-stroke engine with a linear cylinder block was used for this research. The technical specifications of the engine used in this research are given in Table 1. The use of this engine in many cars, which play a major role in air pollution in big cities in West Asian countries, is the reason for choosing the engine. Five filters made by Perflex company with the same degree of filtration was applied in this study. They include one new filter (0 km) and four used filters in different lives of 15,000 km, 30,000 km, 45,000 km and 60,000 km, respectively. Indeed, the hypothesis is that the condition and operation of a filter will have a significant effect on the amount of fuel passing through the filter. A sample of a fuel filter and exhaust gas analyzer can be seen in Figure 1. In order to measure the ratio of air to fuel (lambda) and exhaust gases (CO, CO_2 and UHCs), the exhaust gas analyzer MAHA-MGT5, Germany, was used. The specifications of the gas analyzer are presented in Table 2. Various engine parameters such as engine speed, manifold inlet air pressure, oxygen sensor voltage, spark advance, injector injection, throttle angle, air to fuel ratio and engine temperature were carefully controlled in the laboratory. The experiments were performed at a temperature of 30 °C and the laboratory temperature was controlled with an accuracy of 1 °C.

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Table 1. Main specifications of four-cylinder gasoline engine.

Type	SI engine, 4 Cylinder
Company	SAIPA, Iran
Number of cylinder	4
Maximum torque (N.m)	103
Displacement volume (cc)	1323
Combustion order	1-3-4-2
Type of ECU	Siemens
Type of fuel system	Single spray injector
Maximum power	63 hp

(a) **(b)**

Figure 1. The exhaust gas analyzer (a) and Sample of the gasoline filter used (b) in the tests

Table 2. Specifications of the exhaust gas analyzer

Parameters	Measurements range	Measurements Accuracy
CO	0–15% vol.	0.01% vol
CO_2	0–20% vol	0.01% vol.
HC	0–9999 ppm	1 ppm
Lambda	0.5–9.99 ppm	0.01

At each stage of the tests, after installing the fuel filter, the engine runs for about five minutes, then the engine water temperature is monitored, and when the temperature reaches 80 °C, the engine speed was increased to reach the set speed, and after stabilizing the engine conditions, the parameters were measured and information was recorded. A schematic of the engine tests is provided in Figure 2.

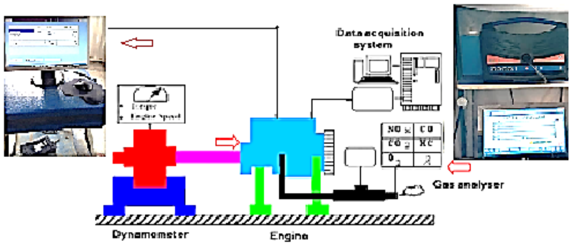


Figure 2. Schematic of performing engine tests and measuring devices

In this study, various engine variables, especially the fuel system, were fully controlled and recorded, but the main purpose of this study was to investigate the effect of fuel filter life on the lambda and exhaust emissions. For this purpose, the effect of FFL on the three important exhaust outlets of a gasoline engine (CO, CO_2 and UHCs) was investigated and analyzed.

2.1. Design of experiments

Due to the large number of tests, the complexity of the engine tests and its high cost, RSM was employed for statistical modeling and analysis using Design-Expert® Software (version10). Therefore, the influence of the independent variables on the lambda and exhaust emission parameters were assessed using the central composite design (CCD). RSM includes a set of mathematical and statistical techniques that are useful for designing experiments, modeling and optimizing processes [12].

Two independent variables of FFL and engine speed were considered as independent variables and the ratio of air to fuel (lambda) and exhaust emissions including CO, CO_2 and UHC were set as dependent variables (response). FFL factor was set at 5 levels with values of 0 km, 15000 km, 30000 km, 45000 km and 60,000 km and engine speed factor was also at 5 levels with 1000 rpm, 2000 rpm, 3000 rpm, 4000 rpm and 5000 rpm (Table 3). The design of the experiments by the software for research is shown in Table 4.

Table 3. The experiment matrix.

Independent variables	Symbols	Levels of each factor (×1000)				
Fuel Filter (km)	A	0	15	30	45	**60**
Engine Speed (rpm)	B	1	2	3	4	**5**

Table 4. Experimental design proposed by RSM

Std	FFL	rpm	CO	CO_2	UHC	lambda
1	60000	3000	0.78	13.8	120	1.032
2	60000	1000	0.72	14.2	215	1.021
3	30000	3000	0.74	14.4	117	1.028
4	0	5000	0.82	14.1	88	1.031
5	0	1000	0.55	14.9	196	1.017
6	0	3000	0.69	14.6	109	1.021
7	30000	3000	0.74	14.4	118	1.029
8	30000	1000	0.6	14.6	205	1.018
9	30000	3000	0.75	14.2	115	1.03
10	30000	3000	0.76	14	114	1.027
11	60000	5000	0.88	13	110	1.042
12	30000	5000	0.85	13.9	101	1.038
13	30000	3000	0.74	14.4	117	1.028

3. Results and discussion

3.1. Lambda

The ideal ratio of air to fuel can be obtained based on the chemical balance of the gasoline combustion relationship. This ideal mass ratio has a value of 1:14.7 and is known as the stoichiometric ratio. On the other hand, for air-to-ideal fuel mixing ratios, a coefficient called lambda (λ) is defined and calculated by the following equation:

$$\lambda = \frac{(A/F)_{Actual}}{(A/F)_{Theoretical}} \quad (1)$$

According to the above definition and eq. (1), there are three limits for the origin. If $\lambda<1$, the mixture is rich and the amount of fuel is greater than the stoichiometric ratio. If $\lambda=1$ is the same as the ideal mixture and $\lambda>1$ states that the mixture is diluted and fuel is less than the stoichiometric ratio [13]. Figure 3 shows a surface diagram of the interaction between FFL and engine speed on the air-to-fuel ratio. According to the three-dimensional diagram, it can be seen that with increasing the FFL and engine speed, the air to fuel ratio increases slightly. The reason for the increase in air-to-fuel ratio is that with increasing filter life and clogging, the fuel pressure in the fuel rail decreases and it reduces fuel atomization, increases the ratio of air to fuel, impoverishes the mixture and reduces the quality of combustion [1]. According to Figure 3 and the results of analysis of variance in Table 5, it is clear that the two variables of FFL and engine speed have a significant effect on the air to fuel ratio at the level of 1%, respectively. The regression equation between independent variables and dependent variables is shown in Equation 2. In

[DOI: 10.22068/ase.2021.594]

this equation, variable A is the amount of FFL (km) and variable B is engine speed (rpm).

$$\text{Lambda} = 1.03 + 0.0043\,A + 0.0091\,B + 0.0017\,AB \qquad (2)$$

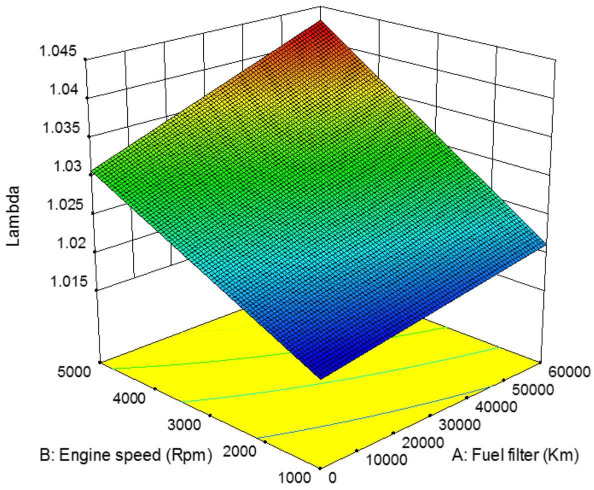
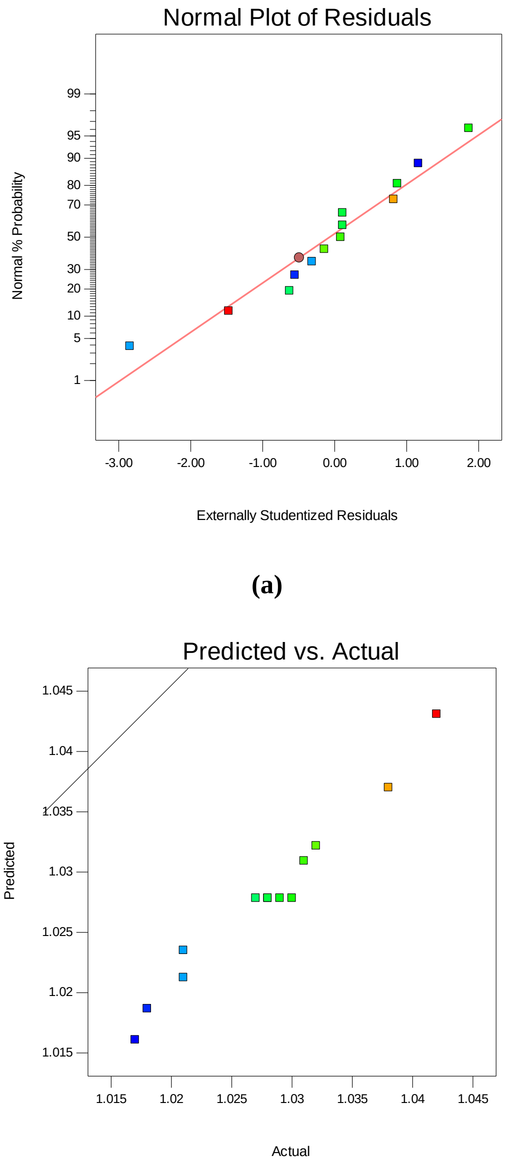


Figure 3: Interaction of FFL and engine speed on lambda

Examining the diagrams in Figure 4, it can be seen that the results obtained experimentally correspond to the results predicted by the software. Also, the value of R^2= 0.96, shows a satisfying agreement between the predicted results and the actual data. That is, 96% of the dependent variables depend on independent variables, and only 4% of the dependent variables cannot be explained using independent variables, which proves the validity of the model. As can be seen, the residues are distributed normally and similarly to a straight line.



(a)

(b)

Figure 4: Normal probability diagram (a) and Comparison of actual results with the predicted results of lambda (b)

Table 5 presents the results of analysis of variance to evaluate the tested variables. The p-value in the analysis of variance table shows the significant effect of each of the independent variables on the dependent variables. P-value <0.05 indicates the significance of the effect of variables on the response. But P-value> 0.1 indicates that the effect of variables on the

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response is negligible. According to the results of analysis of variance in Table 5, it can be seen that the model used to investigate the effect of independent variables on dependent variables is significant and it can be predicted using the first-order polynomial equation. Examining the p-value for different sources in Table 5, it can be concluded that the FFL (A), engine speed (B) at the level of 1% and the interaction of FFL and engine speed (AB) have a significant effect on the lambda.

Table 5: Analysis of variance of lambda.

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F
Model	6.291E-004	3	2.097E-004	113.63	< 0.0001
A: Fuel filter life (FFL)	1.127E-004	1	1.127E-004	61.05	< 0.0001
B: Engine speed	5.042E-004	1	5.042E-004	273.20	< 0.0001
AB	1.225E-005	1	1.225E-005	6.64	0.0299
Residual	1.661E-005	9	1.845E-006		
Lack of fit	1.141E-005	5	2.282E-006	1.76	0.3028
Pure error	5.200E-006	4	1.300E-006		
Cor Total	6.457E-004	12			

3-2- CO emission

Figure 6 shows the interaction between fuel filter and engine speed on changes in carbon monoxide emissions. According to the surface diagram, it is observed that with increasing the fuel filter and engine speed, CO emission increases. Increase in air to fuel ratio, poor mixture and decrease in combustion quality are the reasons for increasing CO emission [14,15]. According to Figure 6 and the results of analysis of variance in Table 6, it is clear that the two variables of FFL and engine speed have significant effects on CO emission, respectively. The regression equation between independent variables and dependent variables is shown in eq. 3, which can also predict and detect different values of variables. In this equation, variable A is the amount of FFL (km) and variable B is the engine speed (rpm).

$$CO = 0.74 + 0.053\ A + 0.11\ B - 0.27\ AB \quad (3)$$

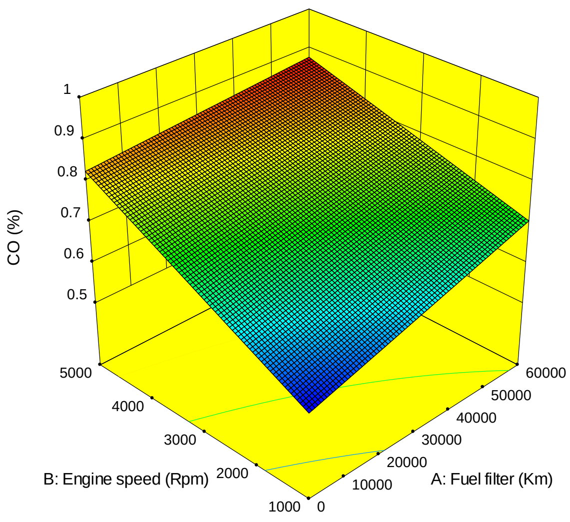

Figure 6: Interaction of FFL and engine speed on CO emission.

According to Figure 7, it can be seen that the results obtained experimentally correspond to the results predicted by the software. Also, the correlation coefficient was equal to $R^2 = 0.97$, which shows a very good agreement between the predicted results and the actual data.

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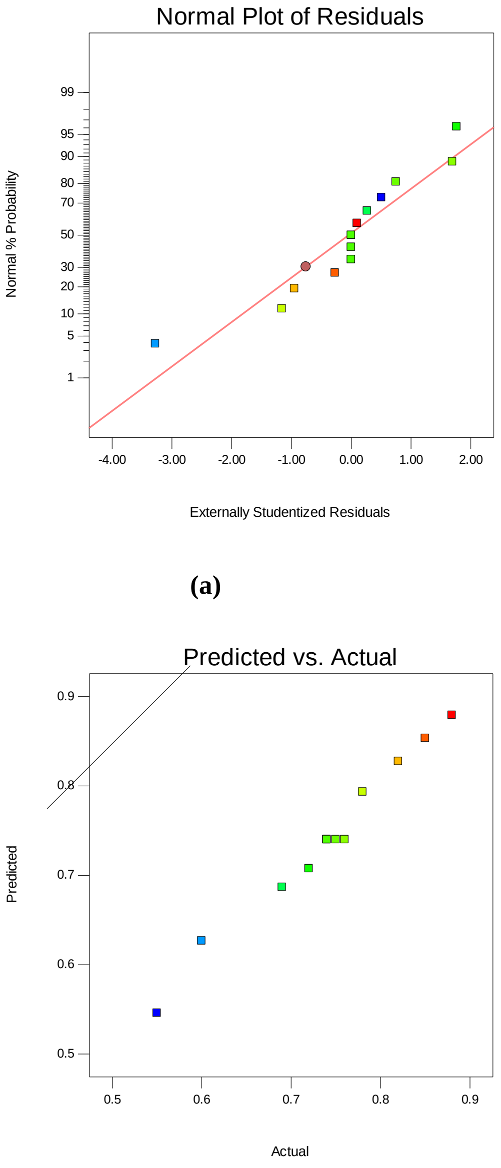
Accordingly, 97% of the dependent variables depend on independent variables and only 3% of the dependent variables cannot be explained using independent variables, which proves the validity of the model. The normal residual probability diagram for carbon monoxide is shown in Figure 7, which shows the residual normality.



(a)

(b)

Figure 7: Normal probability diagram (a) and Comparison of actual results with the predicted results of CO (b)

According to the results of analysis of variance in Table 6, it can be seen that the model used to investigate the effect of independent variables on dependent variables is significant and can be predicted using a linear equation. By examining the p-value for different sources in Table 6, it can be concluded that the FFL (A), engine speed (B) and the interaction of FFL and engine speed (AB) at level 1 % have a significant effect on CO emission.

Table 6: Analysis of variance of CO emission

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F
Model	0.097	3	0.032	177.55	< 0.0001
A: Fuel filter	0.017	1	0.017	93.56	< 0.0001
B: Engine speed	0.077	1	0.077	422.50	< 0.0001
AB	3.025E-003	1	3.025E-003	16.58	0.0028
Residual	1.642E-003	9	1.824E-004		
Lack of Fit	1.322E-003	5	2.643E-004	3.30	0.1350
Pure Error	3.200E-004	4	8.000E-005		
Cor Total	0.099	12			

3-3- CO_2 greenhouse gas

Figure 8 shows the interaction between FFL and engine speed on carbon dioxide gas changes. According to this figure, it can be seen that CO_2 is reduced by increasing the FFL and engine speed. Decreased combustion quality and increased carbon monoxide emissions are the reasons for the increase in CO_2 [16]. According to Figure 8 and the results of analysis of variance in Table 7, It can be seen that the two variables of fuel filter and engine speed have a significant effect on CO_2 at the level of 1%. The regression equation between independent variables and dependent variables is shown in Equation 4, which can also predict and detect different values of variables. In this equation, variable A is the amount of fuel filter life (km) and variable B is engine speed (rpm).

$$CO_2 = 14.19 - 0.43\ A - 0.45\ B \qquad (4)$$

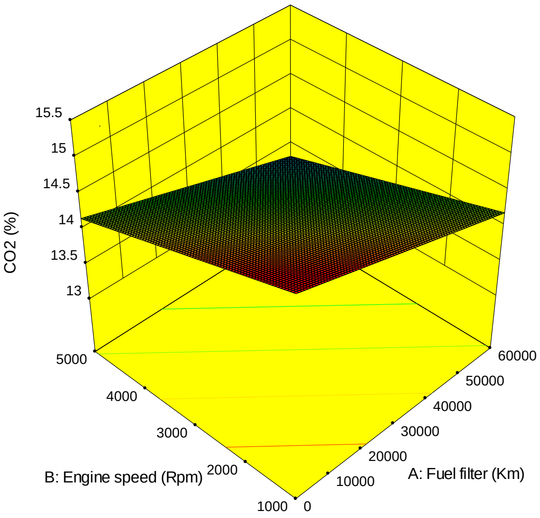
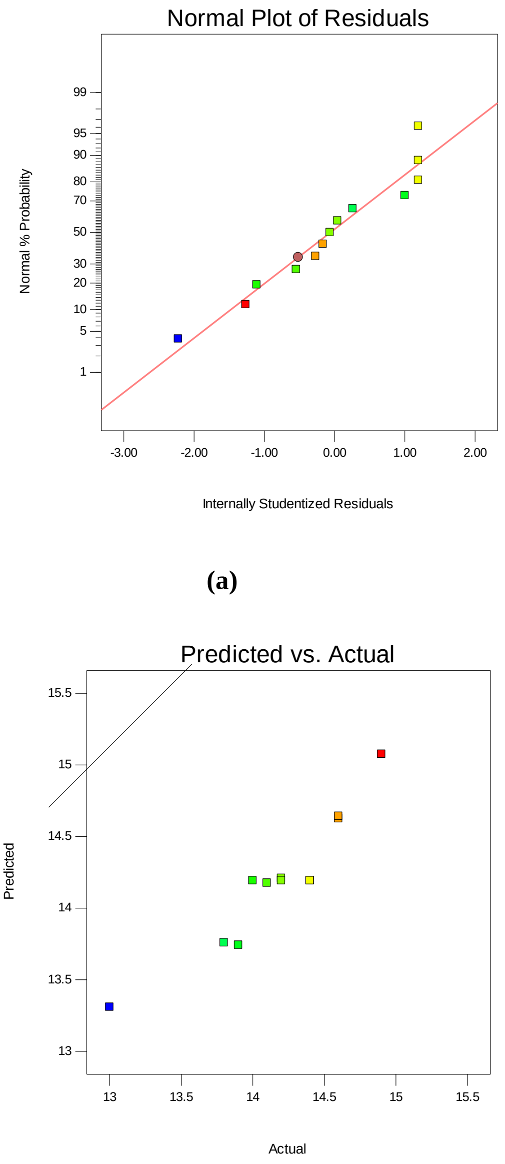


Figure 8: Interaction of FFL and engine speed on CO_2 emission

As can be seen in Figure 9, the results obtained experimentally correspond to the results predicted by the software. Also, the correlation coefficient was calculated as $R^2 = 0.85$, which shows the closeness of the predicted results to the real data. That is, 85% of the dependent variables depend on the independent variables, and only 15% of the dependent variables cannot be explained using the independent variables. The normal residual probability diagram for carbon dioxide is shown in Figure 9, which shows the residual normality.



(a)

(b)

Figure 9: Normal probability diagram (a) and Comparison of actual results with the predicted results of CO2 (b)

Observing the results of analysis of variance in Table 7, it can be seen that the model used to investigate the effect of independent variables on dependent variables is significant and can be predicted using a linear equation. The p-value for different sources in Table 7 shows that FFL (A), engine speed (B) at the level of 1% have a significant effect on carbon dioxide gas.

Table 7: Analysis of variance of CO_2 emission

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F
Model	2.34	2	1.17	35.74	< 0.0001
A: Fuel filter	1.13	1	1.13	34.40	0.0002
B: Engine speed	1.21	1	1.21	37.09	0.0001
Residual	0.33	10	0.033		
Lack of fit	0.20	6	0.033	1.04	0.5088
Pure error	0.13	4	0.032		
Cor total	2.67	12			

3-4- UHC emission

The emission changes of unburned hydrocarbons due to the interaction of the FFL and engine speed are shown in Figure 10. According to the diagram, it can be seen that increasing the fuel filter life causes a slight increase in the amount of UHC emission and decreases with increasing engine speed [17]. Figure 10 and the results of analysis of variance in Table 8 show that the two variables of fuel filter and engine speed have a significant effect on UHC emission at the level of 1%. The regression equation between independent variables and dependent variables is shown in Equation 5, which can also predict and detect different values of variables. In this equation, variable A is the amount of FFL (km) and variable B is engine speed (rpm).

$$UHC = 116.07 + 8.67\,A - 52.83\,B + 0.75\,AB - 1.24\,A^2 + 37.26\,B^2 \qquad (5)$$

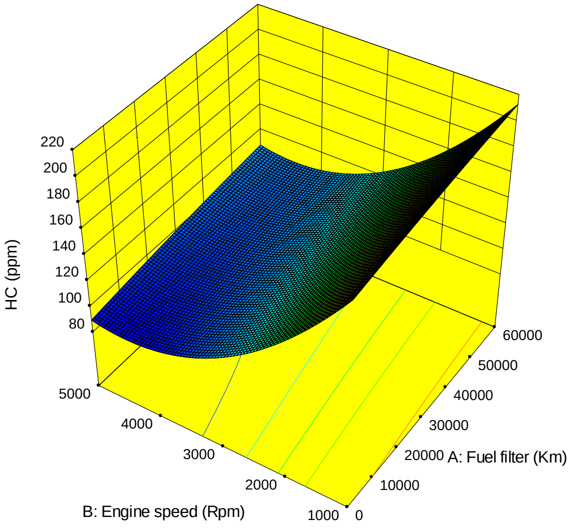
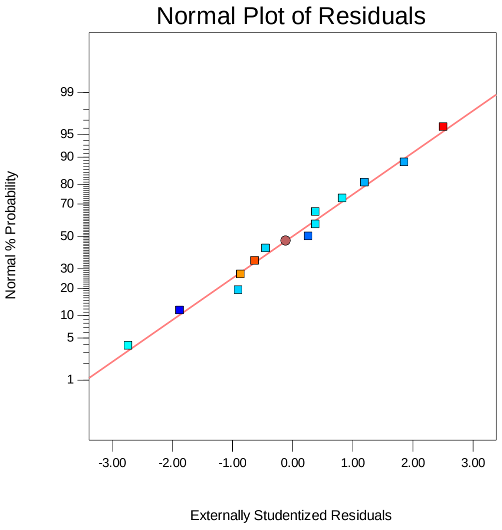
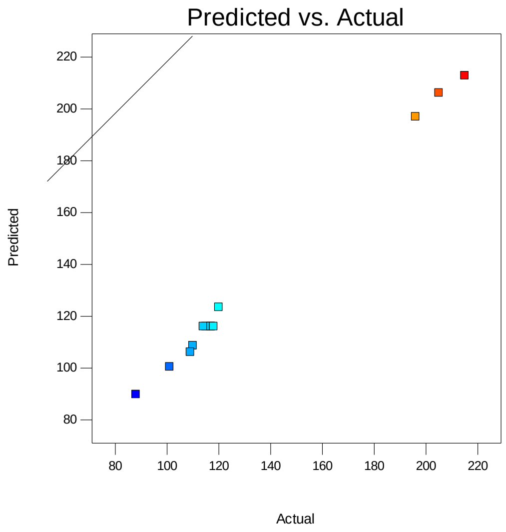


Figure 10: Interaction of FFL and engine speed on HC emission

By looking at the diagrams in Figure 11, it can be seen that the results obtained experimentally correspond to the results predicted by the software. Also, the $R^2 = 0.99$, which shows the closeness of the predicted results to the real data. The normal residual probability diagram for UHC emission can also be seen in Figure 11. In this figure, the remaining residues are distributed normally and in a straight line.



(a)



(b)

Figure 11: Normal probability diagram (a) and Comparison of actual results with the predicted results of HC (b)

The results of analysis of variance in Table 8 show that the model used to investigate the effect of independent variables on dependent variables is significant and can be predicted using a quadratic equation. The p-value for different variables in Table 8 shows that the FFL (A), engine speed (B) and quadratic coefficients of engine speed (B^2) at the level of 1% have a significant effect on UHC emission. The interaction effect of filter type and engine speed (AB) and the effect of quadratic coefficients of filter type (A^2) on the change of UHC emission was not significant.

Table 8: Analysis of variance of HC emission

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F
Model	21577.18	5	4315.44	4315.44	< 0.0001
A: Fuel filter	450.67	1	450.67	450.67	< 0.0001
B: Engine speed	16748.17	1	16748.17	16748.17	< 0.0001
AB	2.25	1	2.25	2.25	0.5667
A^2	4.26	1	4.26	4.26	0.4357
B^2	3834.09	1	3834.09	3834.09	< 0.0001
Residual	43.59	7	6.23		
Lack of fit	32.79	3	10.93	4.05	0.1051
Pure error	10.80	4	2.70		
Cor total	21620.77	12			

4. Conclusions

In this study, the effects of FFL and engine speed on the emission parameters of the gasoline engine (CO, CO_2 and UHC) as well as air to fuel ratio (lambda) were investigated using the RSM method. Following conclusions can be drawn from the current study:

1- Lambda value increased with increasing FFL and engine speed. The maximum value of lambda was 1.042 which occurred at the engine speed of 5000 rpm and FFL of 60,000 km and the lowest value of lambda was 1.017 which measured at engine speed of 1000 rpm and FFL of 0 km.

2- Increasing the FFL and the engine speed increased the amount of CO emission. The highest value of CO emission was 0.88% which occurred at 5000 rpm and FFL of 60,000 km. The lowest CO amount was 0.55% and observed at 1000 rpm by using a new fuel filter (FFL of 0).

3- Increasing the FFL and engine speed reduced the CO_2 gas. The lowest amount of CO_2 gas was 13% and occurred at 5000 rpm and using FFL of 60,000 km and its highest value (14.9%) was recorded at 1000 rpm and FFL of 0.

[DOI: 10.22068/ase.2021.594]

4- With increasing the FFL, the amount of UHC emission increased, but increasing the engine speed reduces the HC emission. The maximum amount of UHC emission was measured as 215 ppm at 1000 rpm using FFL of 60,000 km and the lowest amount of this pollutant was obtained as 88 ppm at 5000 rpm and using a new fuel filter.

5- The results of this study showed that increasing the FFL and clogging the filter increases the air fuel ratio. Increasing the lambda reduces the combustion quality of the engine, thereby increasing the CO and UHCs and reducing the amount of CO_2.

6- Finally, it can be concluded that timely replacement of fuel filters in gasoline engines, apart from increasing the life of fuel system components and improving engine performance, can significantly reduce exhaust emissions.

References

[1] M. Ghanbari, L. Mozafari, G. Najafi. Investigating the effect of gasoline fuel filter lifetime on fuel pressure and ignition advance using the RSM method, Fluid mechanics and aerodynamics, (2021) Vol. 9(1).

[2] M. Ghanbari, Technology and design of internal combustion engines, Technical and Vocational University (2019).

[3] M. Ghanbari, L. Mozafari. Evaluation of fuel and spark system variables of a gasoline engine due to lack of timely replacement of fuel filter, Karafan (Quarterly Research Journal of Technical and Vocational University), (2021), Vol. 17(4), pp. 133-145.

[4] G. Lenaers, M. Van Poppel, Mobile emission measurements for assessing low emitting vehicles exemplified on a CRT-equipped bus, International Journal of Energy for a Clean Environment, (2005), Vol. 6.

[5] M.R. Saxena, R.K. Maurya, Influence of fuel injection pressure and injection timing on nanoparticle emission in light-duty gasoline/diesel RCCI engine, Particulate Science and Technology, (2020), pp. 1-10.

[6] T.D. Durbin, X. Zhu, J.M. Norbeck, The effects of diesel particulate filters and a low-aromatic, low-sulfur diesel fuel on emissions for medium-duty diesel trucks, Atmospheric Environment, (2003), Vol. 37 , pp. 2105-2116.

[7] T. Pilusa, M. Mollagee, E. Muzenda, Reduction of vehicle exhaust emissions from diesel engines using the whale concept filter, Aerosol and Air Quality Research, (2012), Vol. 12, pp.994-1006.

[8] F.M. Jalilitabar, M. Momeni, E. Optimizing the EGR rate, biodiesel fuel ratio and engine working mode using RSM method, Fuel and Combustion, (2017), Vol. 10.

[9] A. Dhole, R. Yarasu, D. Lata, S. Baraskar, D. Shaw, Mathematical modeling for the performance and emission parameters of dual-fuel diesel engine using producer gas as secondary fuel, Biomass Conversion and Biorefinery, (2015), Vol. 5, pp. 257-270.

[10] F. Omi, Farajpour Kordasiabi, Mehdi, Mir Mohammadi, Ali, Numerical study of the effect of spraying time and spraying angle on fuel evaporation rate and pollutants of a multi-point spraying gasoline engine, Journal of Aerospace Mechanics, (2009), Vol. 5.

[11] K.R. Khabaz Alireza, Theoretical study of the effect of pressure, time and duration of diesel fuel injection on the performance and pollutants of direct injection diesel engine, Engine Research, (2010), Vol. 19, pp. 49-63.

[12] R. Myers, D. Montgomery, Experimental designs for fitting response surfaces -I, Response surface methodology. Process and product

[DOI: 10.22068/ase.2021.594]

optimization using designed experiments. 2a ed. Nueva York: Willey (2002).

[13] S. Aditya, K. Anil, Analysis of emission characteristics of MPFI gasoline engine using the 5 gas analyser, International Journal of Advance Research and Innovative Ideas in Education, (2016), Vol. 2, pp. 1052-1022.

[14] P.C.R. Abhishek Samanta, Pragmatic analysis on performance and emission and a single-zone engine model development with inedible neem and waste vegetable oil biodiesel blend (B10), International Journal of Energy for a Clean Environment, (2021), Vol. 22, pp.53-89.

[15] M. Ghanbari, G. Najafi, B. Ghobadian, T. Yusaf, A. Carlucci, M.K.D. Kiani, Performance and emission characteristics of a CI engine using nano particles additives in biodiesel-diesel blends and modeling with GP approach, Fuel, (2017), Vol. 202, pp. 699-716.

[16] M. Ghanbari, G. Najafi, B. Ghobadian, Experimental studying the effect of nano particles additives in diesel-biodiesel blends on the emission characteristics of a CI engine, Automotive Science and Engineering, (2020), Vol. 10, pp. 3408-3420.

[17] S. Babazadeh Shayan, S. Seyedpour, F. Ommi, S. Moosavy, M. Alizadeh, Impact of methanol–gasoline fuel blends on the performance and exhaust emissions of a SI engine, International Journal of Automotive Engineering, (2011), Vol. 1, pp. 219-227.

[DOI: 10.22068/ase.2021.594]