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ANALYSIS OF EXHAUST EMISSION AND ENGINE PERFORMANCE FOR A VARIABLE COMPRESSION RATIO ENGINE OPERATING ON ETHANOL-GASOLINE FUEL FRACTIONS.

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Abstract:

Fossil fuels are depleting fast and ethanol is proving as a fast and best alternative to fossil fuel. Presently ethanol is blended with gasoline upto 10% in India. It is required to find the effects of blending higher ethanol percentage in gasoline and running the existing engine without any modifications in it. In this study, various fuel fractions of ethanol with gasoline from 0% to 40% are tested in a variable compression ratio research engine at the interval of 10%. The engine is run for compression ratios from 7 to 10 Exhaust gases are measured with the help of a Non-Dispersive Infra-Red exhaust gas analyser. Analysis of the exhaust gases is done using Minitab 17 software by Multi-Vari plots. Grey relational analysis is used to find the best operating condition of the engine for reduced exhaust emissions. Engine performance is measured and observed for engine power, specific fuel consumption and mean effective pressures. Engine performance analysis is done using Minitab 17 software by surface plots. These plots are observed for compression ratio 10, as a higher compression ratio leads to better engine powers and mean effective pressures. This study presents the novel concept of understanding emissions behavior using Multi-Vari plots of Quality Tools in Minitab 17. This provides the changes in each exhaust gas with reference to three variables fuel fractions, engine speed and compression ratio.

Keywords: Ethanol-Gasoline Fuel Fractions, Engine Emissions, VCR Engine Performance, Exhaust Gas Analysis, Grey Relational Analysis.

1. Introduction:

Gasoline is widely used as fuel for two-wheelers and cars. With the faster depletion of fossil fuels, ethanol is being blended in gasoline. Ethanol can be produced from feedstocks, corn, cassava etc. Ethanol is also produced as a biproduct in sugar production. It reduces the knocking tendency of the engine and allows use of higher compression ratio [1]. With use of ethanol as a blend in gasoline engine, significant reduction of Carbon Monoxide (CO) and Hydrocarbons (HC) is observed. Ethanol also offers advantage of better Reid Vapour Pressure and higher octane number [2]. Elfasakhany observed that CO and HC emissions are reduced while blending ethanol and methanol with gasoline. He has also noted improvement in volumetric efficiency and engine power with ethanol-gasoline blends [3]. The researcher has also studied the effects of ethanol–methanol–gasoline , n-butanol–iso-butanol–gasoline and iso-butanol–ethanol–gasoline on engine performance and emissions. Reduction of CO and HC were observed with enhancement of engine performance, using these fuel blends [4,9]. Mourad and Mahmoud also observed reduction of harmful emissions but noted reduction of engine power [5]. Researchers have blended other additives in ethanol-gasoline blends to study the effects. Akansu et.al. added hydrogen in ethanol-gasoline blends and have observed that addition of hydrogen increased the engine performance and enhanced the emission from the engine as compared with ethanol-gasoline blends [6]. Chansauria and Mandloi observed that with rising the fractions of ethanol in fuel blends of gasoline engine performance parameters like thermal efficiency, volumetric efficiency, heat release rate and in-cylinder pressure increases. Rise in requirement of compression ratio was also noted [7]. Costa and Sodré conducted engine test at low and high speed of single cylinder engine and it was found that engine power is increased with hydrous ethanol blending with gasoline and engine is tested at high speed [8]. Various engine emissions of CO, Carbon dioxide (CO_2), Nitrogen Oxides (NO_x) and HC are different at low and high temperatures of engine. These emissions are high at low temperatures and reduces with increase in engine temperature [10]. Increase in ethanol addition also affects the engine performance. Increase in ethanol percentage reduces the engine torque and power, whereas Brake Specific Fuel Consumption (BSFC) increases. This increase in BSFC is primarily due to lesser Calorific Value (CV) of ethanol [11]. Brake thermal efficiency and volumetric efficiency of the engine also increases with increase in ethanol content in the

fuel. This enhancement in the performance of the engine gives added advantage over reduction in harmful exhaust gases [12-14]. Some researchers have also experimented different fuel blends and observed the difference with the ethanol-gasoline blend. Fagundez et.al. blended n-butanol with ethanol and observed that n-butanol is a potential surrogate for gasoline when blended with ethanol [15]. Abdu and Inambao observed that ethanol-gasoline blends are more effective in terms of engine performance when compared with methanol-gasoline blends [16]. Hatte and Bhalerao tested the performance of ethanol-gasoline blends and noted a reduction in engine power and torque. They also noted the need to run the engine at high speed and high compression ratio [17]. The dimensional approach is also used for developing the mathematical model to predict the engine performance.
Researchers have done experimentations by changing various engine operating parameters. It becomes difficult to visualise the effect of engine performance and engine emissions with respect to the operating parameters. This study is based on plotting surface plot for engine performance to observe the variations with respect to three operating conditions engine speed, compression ratio (CR) and fuel blends (E). Multi-vari charts are used for analysis of exhaust gases for same operating conditions of engine.

2. Experimentation:

A Variable Compression Ratio (VCR) engine is used in the experimental test setup. It has a facility of varying the compression ratio in the from 7 to 10. This engine can run on various fuels. This is computerised engine setup having a facility to gather data of engine performance parameters. It can compile and analyze the data to plot the graphs of the result. EngineSoft is engine performance analysis software used for engine control and real-time engine performance evaluation. Control panel has the provision of USB port for connecting to a computer. Measurement of various engine performance parameters like engine efficiencies, various powers, fuel consumption, heat balance sheets and combustion analysis are possible using the computerised engine test setup.

The engine can operate on any liquid fuel and operation can be shifted from one fuel to other with exchange of some components in engine setup. The setup has a facility of varying the volume of combustion chamber by specially designed cylinder block having the facility of tilting. It is possible to tilt the cylinder block, even in engine running condition.

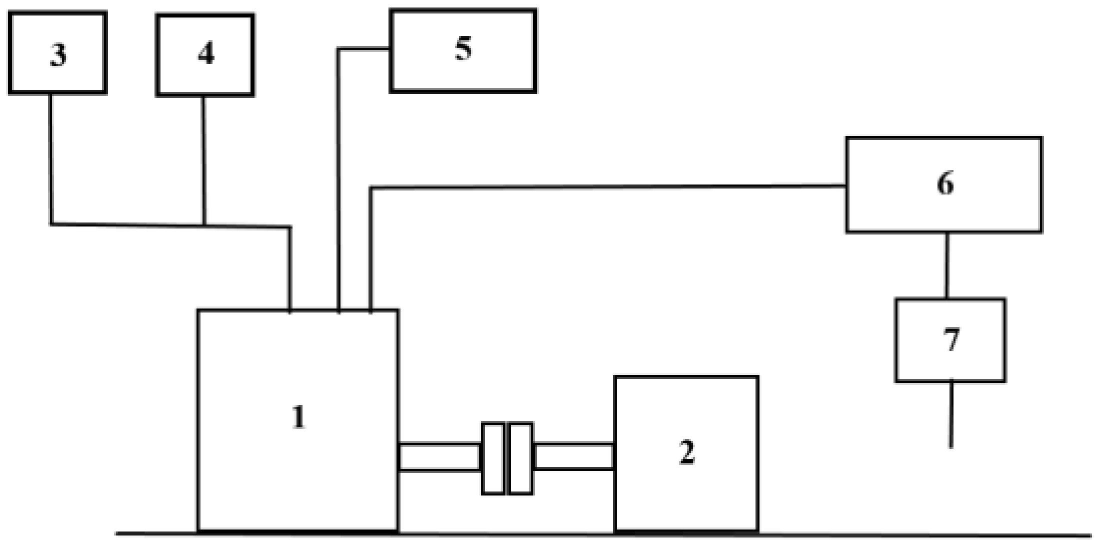

Fig. 1. Engine Experimental Setup

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As shown in Fig.1, Engine 1 is connected to Eddy Current Dynamometer 2 through the coupling. The load is applied on engine through this dynamometer. The test setup has two fuel tanks 3 and 4. These fuel tanks supply two different fuels to the engine. Tank 3 supplies pure gasoline, while tank 4 supplies gasoline-ethanol blends. Engine load and water flow controllers are fitted in Panel 5 along with the surge tank for air inflow. This panel also has sensors for air flow and fuel flow measurements. It has displays of various engine parameters like engine load, water flow rate, various temperatures, engine speed, air and fuel flow rates etc. Exhaust gas calorimeter 6 is used for finding the heat losses to exhaust gases. Water circulated in this calorimeter absorbs the heat from the exhaust gases. After this calorimeter, exhaust gases are tapped in exhaust gas analyser 7 for measurement of contents of exhaust gas.

Engine steady state is attained by running the engine for 15 to 20 minutes.. All the readings are taken after steady state. Fuel fractions of ethanol and gasoline are taken by volume to prepare fuel blends. 10 % ethanol mixed with 90% gasoline by volume is treated as E10. Similarly, fuel fractions are prepared for E20, E30 and E40. Observations of various parameters are recorded at Wide Open Throttle (WOT) condition. Engine is loaded by applying the load through eddy current dynamometer. The speed of the engine at the beginning is matched with its highest rated speed and gradually the speed of the engine is reduced by increasing the load on the engine. Readings are taken from 1700 rpm to 1300 rpm in the interval of 100rpm. For each single fuel fraction, the compression ratio of the engine is also changed from 7 to 10 at the interval of 1 by tilting the cylinder head. Performance of the engine is observed for each fuel fraction, compression ratio and speed of the engine. The data collected after tests is used for analysis of engine performance.

3. Emissions:

Engine is allowed to run idle for 15 to 20 minutes for taking it to steady state conditions. Readings of exhaust gases are recorded by NDIR type exhaust gas analyser. NO_x, CO, CO_2 and HC are measured in this gas analyser. The data collected is compiled in Minitab 17 software for plotting the graphs and further analysis. The following graphs are observed.

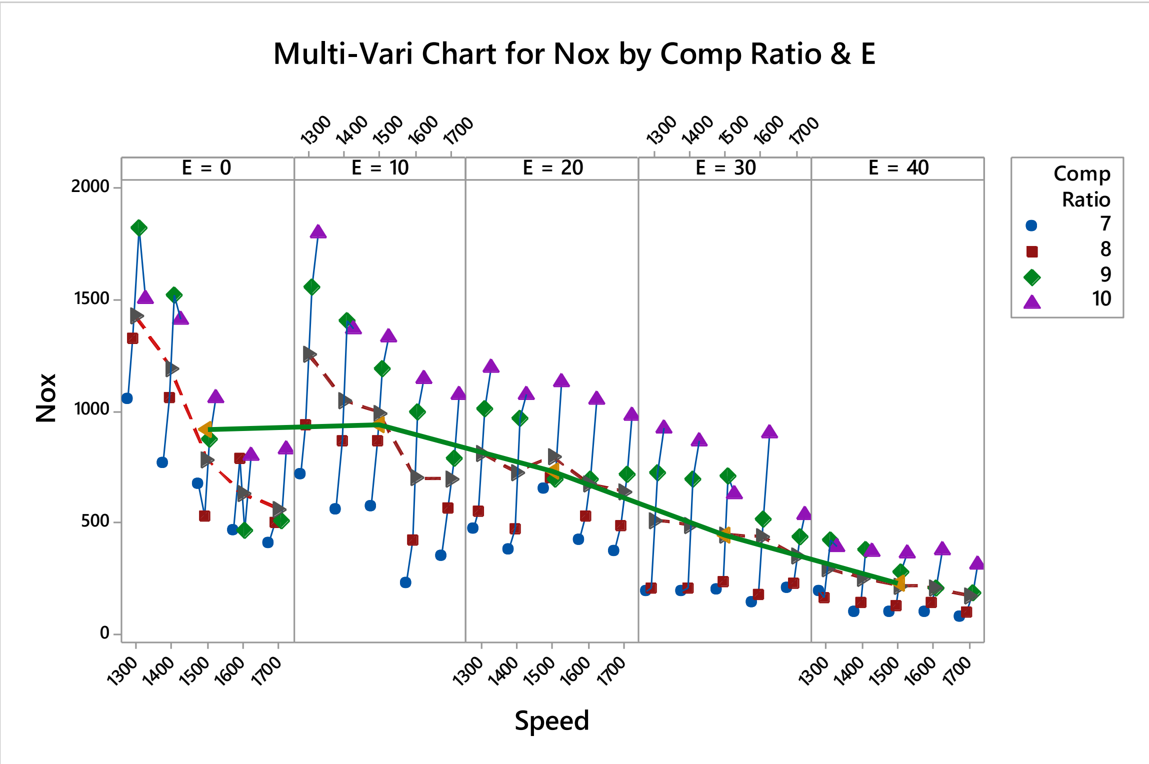

Fig. 2. Multi-Vari chart of NO_x

NO_x is formed due to reactions of nitrogen with oxygen. With the increase in the engine speed, the time required for the reaction of nitrogen reduces and the formation of NO_x reduces. With the further rise in speed, NO_x increases again. It is also noted that with an increase in ethanol contents, the mean values of NO_x dropdown. This is because, with an increase in the percentage of ethanol, engine temperature drops down. At each ethanol-gasoline fuel fraction, with an increase in compression ratio, NO_x increases with rise in engine speed. With rise in engine speed the temperature of the engine increases. Rise in temperature increases the formation of NO_x. The variations of NO_x concerning speed at each fuel fraction and compression ratio are shown in Fig. 2.

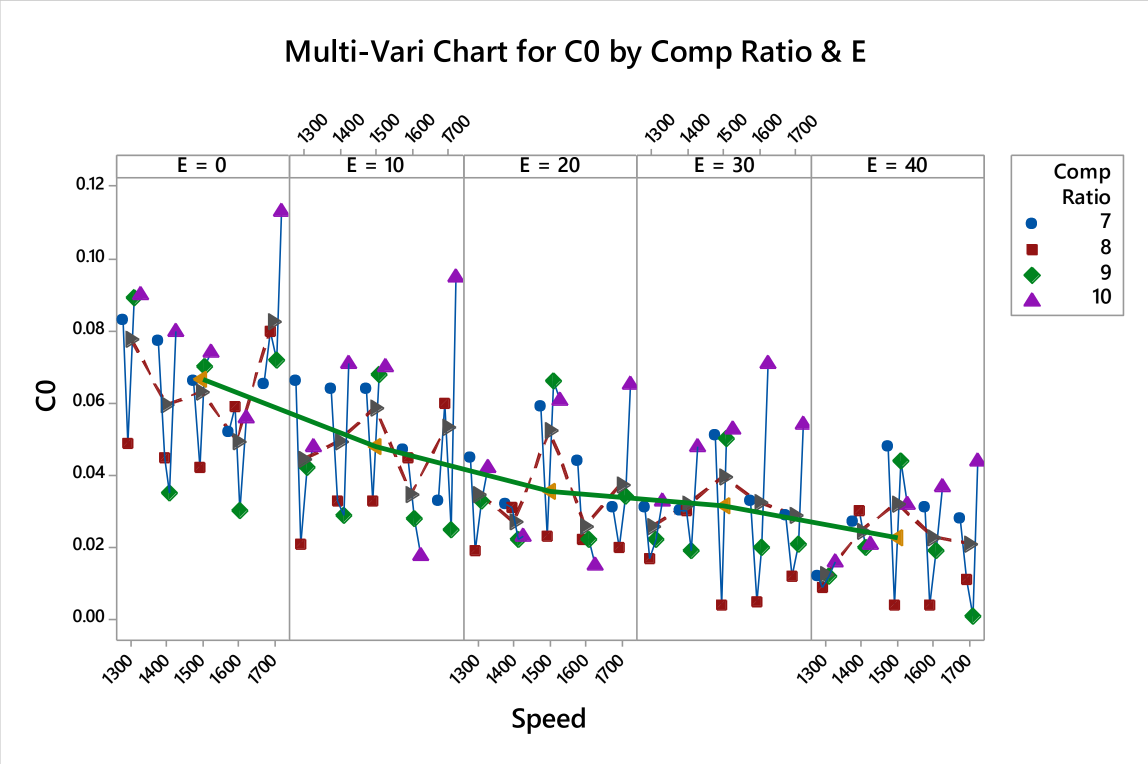

Fig. 3. Multi-Vari chart of CO

Variation of CO with reference to engine speed at various fuel fractions and compression ratio is shown in Fig 3. The addition of ethanol in fuel leads to adding extra oxygen atoms in the fuel and a reduction of engine temperature. Mean of CO is noted to decrease with increase in ethanol contents in the fuel. CO decrease first with increase in compression ratio from 7 to 8 and then increases at constant speed. At a specific compression ratio, CO increases from 1300 to 1400 rpm and then falls down. At any specific fuel blend, higher value of CO is noted at 1500 rpm. Considering the environmental impact, it is expected to reduce CO.

Changes in CO_2 with reference to engine speed at various fuel fractions and compression ratio is shown in Fig 4. At any particular engine speed and fuel fraction, it noted that CO_2 reduces first then increases up to 1600 rpm and then a slightly reduces up to 1700 rpm. For a specific compression ratio, CO_2 decreases with engine speed at a particular fuel fraction. The mean of CO_2 gives a slight rise from E0 to E20 and then it reduces up to E40. Overall changes in mean values of CO_2 is small.

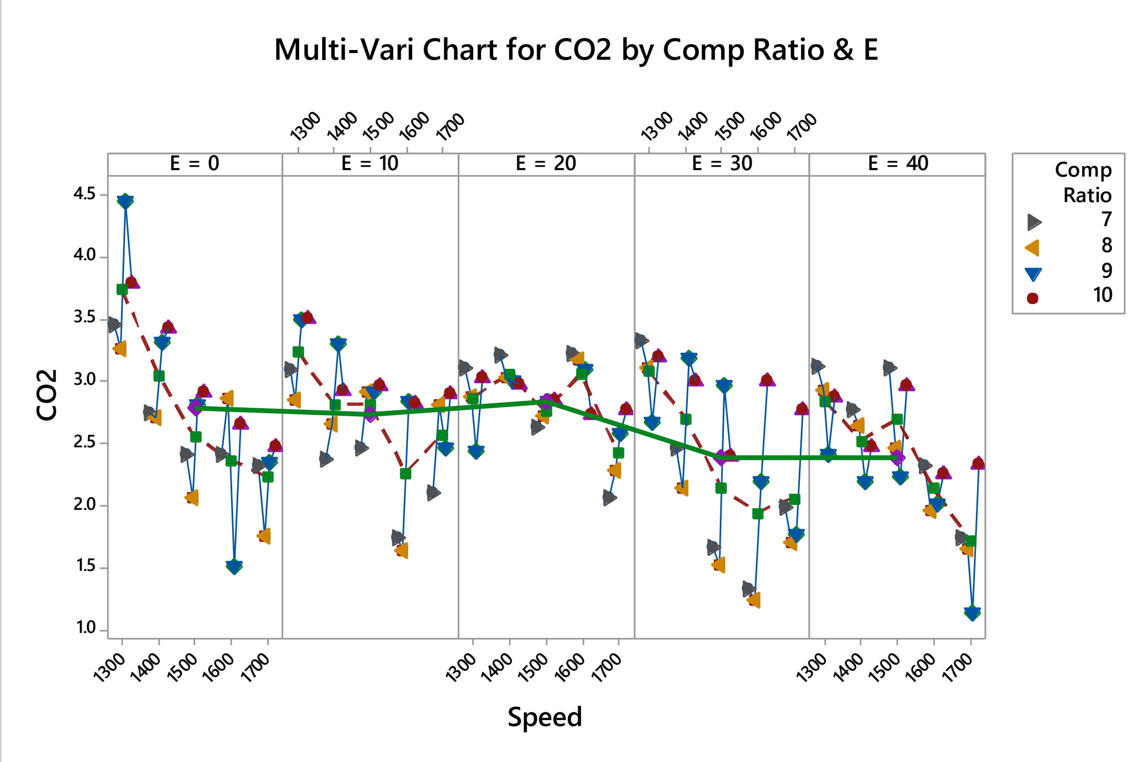

Fig. 4. Multi-Vari chart of CO_2

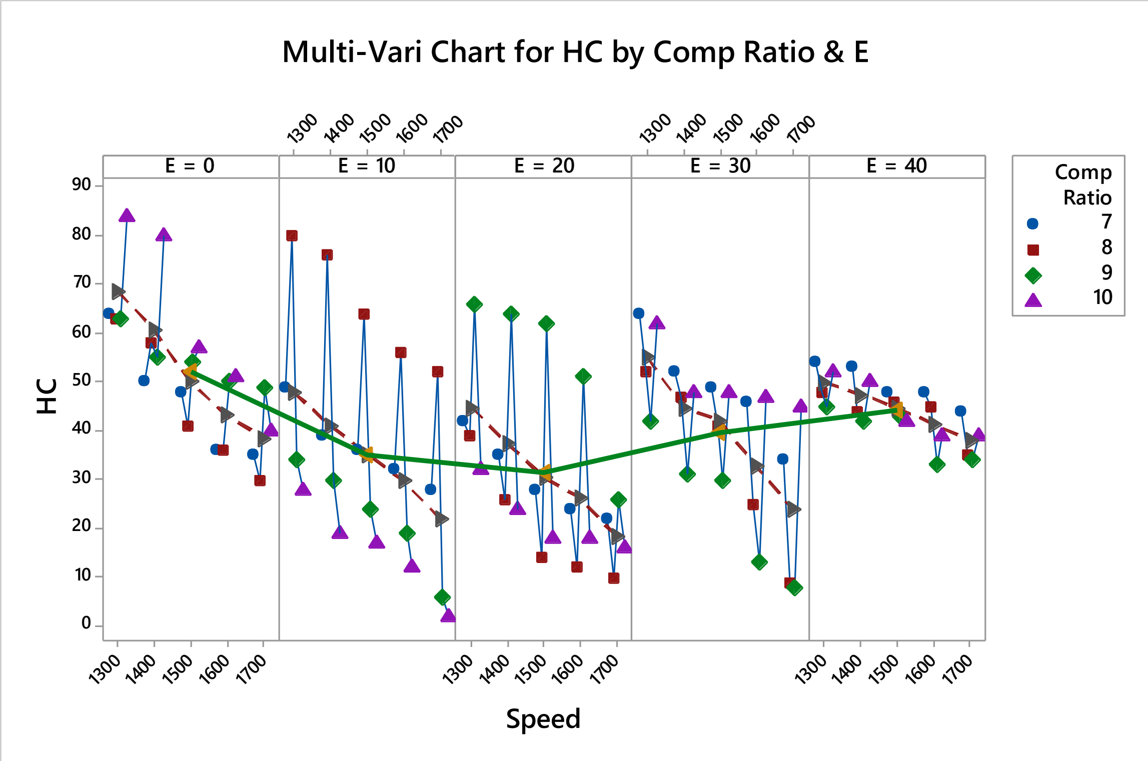

Fig. 5. Multi-Vari chart of HC

The variations of HC with reference to engine speed at each fuel fraction and compression ratio is shown in Fig 5. It is seen that the mean value of HC decreases from E0 to E20 and then increases up to E40. For a specific fuel blend, HC pattern show rise, fall and rise characteristics with engine speed. For a specific compression ratio and fuel fraction, it is noted that HC decreases with increase in engine speed. It is beneficial to increase the ethanol percentage in fuel fraction, as HC is noted decreasing with higher ethanol percentage at any compression ratio till E30.

4. Taguchi Design:

It is expected that all the exhaust gases NO_x, CO, CO_2 and HC should be minimum to reduce the environmental effect. An engineering approach is needed to find the the optimum level of the exhaust gases. Taguchi approach can be used for the optimization of design variables to determine optimum combination with less cost and a minimum number of experimental trials. The Taguchi approach depends on the technique of matrix experiments, known as orthogonal array (OA). To obtain the optimum level of each exhaust gases the orthogonal array was selected. Taguchi approach segregates the objective function into three groups, namely, “smaller the better type”, “larger the better type” and “nominal the best type”. For exhaust gases “smaller the better type” objective function has been selected in the existing study. The selected design variables as per L_{25} OA is shown in Tables 1.Engine is operated at compression ratios from 7 to 10 whereas for analysis using L_{25} OA, readings for CR 6 are extrapolated.

Table 1. L_{25} Orthogonal Array

Expt. No.	Speed	CR	E	Expt. No.	Speed	CR	E
1	1300	6	0	14	1500	9	0
2	1300	7	10	15	1500	10	10
3	1300	8	20	16	1600	6	30
4	1300	9	30	17	1600	7	40
5	1300	10	40	18	1600	8	0
6	1400	6	10	19	1600	9	10
7	1400	7	20	20	1600	10	20
8	1400	8	30	21	1700	6	40
9	1400	9	40	22	1700	7	0
10	1400	10	0	23	1700	8	10
11	1500	6	20	24	1700	9	20
12	1500	7	30	25	1700	10	30
13	1500	8	40				

Table 2 shows the levels of operating parameters used in L_{25} Orthogonal Array

Table 2. Operating parameter levels

	Levels				
	1	2	3	4	5
Speed (rpm)	1300	1400	1500	1600	1700
CR	6	7	8	9	10
E (%)	0	10	20	30	40

5. Grey Relational Analysis (GRA) of exhaust gases:

GRA is optimisation technique used to find the optimum values of the output to decide the best operating condition of the engine. It is used to find the values of operating variables of engine speed, CR and E, where the lowest emission of exhaust gases is possible. The data is first normalised to have uniformity and Grey Relation Grades (GRG) are found out from Grey Relation Coefficients. Ranking is done based on GRG. It is noted that the best operating condition to minimise the exhaust gases is when the engine is operated at 1500 rpm, 8 CR and E40. This result also shows that it is beneficial to use a higher percentage of ethanol in fuel fraction. The highest percentage used in the study is 40. It also shows that the compression ratio should not be kept to the highest value of 10 and the lowest value of 7.

Data of exhaust gases and analysis by GRA is shown in Table 3.

Table 3. GRA Data

Data							**Normalising**				**Grey relation coefficient**				**Grey relation grade**					
E	Speed	CR	HC	C0	CO2	Nox	HC	C0	CO2	Nox	HC	C0	CO2	Nox	HC	C0	CO2	Nox	GRG Average	Rank
0	1300	6	53	0.071	3.2	699	0.428571	0.118421	0.121693	0.543116	0.571429	0.881579	0.878307	0.456884	0.466667	0.361905	0.362764	0.52253	0.428466	23
10	1300	7	49	0.066	3.1	718	0.492063	0.184211	0.174603	0.528744	0.507937	0.815789	0.825397	0.471256	0.496063	0.38	0.377246	0.514798	0.442027	22
20	1300	8	39	0.019	2.88	556	0.650794	0.802632	0.291005	0.651286	0.349206	0.197368	0.708995	0.348714	0.588785	0.716981	0.413567	0.589127	0.577115	12
30	1300	9	42	0.022	2.67	722	0.603175	0.763158	0.402116	0.525719	0.396825	0.236842	0.597884	0.474281	0.557522	0.678571	0.455422	0.513199	0.551178	16
40	1300	10	52	0.016	2.88	393	0.444444	0.842105	0.291005	0.774584	0.555556	0.157895	0.708995	0.225416	0.473684	0.76	0.413567	0.68926	0.584128	10
10	1400	6	38	0.067	3.3	424	0.666667	0.171053	0.068783	0.751135	0.333333	0.828947	0.931217	0.248865	0.6	0.376238	0.349353	0.667677	0.498317	18
20	1400	7	35	0.032	3.21	384	0.714286	0.631579	0.116402	0.781392	0.285714	0.368421	0.883598	0.218608	0.636364	0.575758	0.361377	0.695789	0.567322	13
30	1400	8	47	0.03	2.15	209	0.52381	0.657895	0.677249	0.913767	0.47619	0.342105	0.322751	0.086233	0.512195	0.59375	0.607717	0.852903	0.641641	7
40	1400	9	42	0.02	2.19	378	0.603175	0.789474	0.656085	0.78593	0.396825	0.210526	0.343915	0.21407	0.557522	0.703704	0.592476	0.700212	0.638479	8
0	1400	10	80	0.08	3.43	1417	0	0	0	0	1	1	1	1	0.333333	0.333333	0.333333	0.333333	0.333333	25
20	1500	6	50	0.048	1.54	210	0.47619	0.421053	1	0.913011	0.52381	0.578947	0	0.086989	0.488372	0.463415	1	0.851804	0.700898	2
30	1500	7	49	0.051	1.67	203	0.492063	0.381579	0.931217	0.918306	0.507937	0.618421	0.068783	0.081694	0.496063	0.447059	0.87907	0.859558	0.670437	3
40	1500	8	46	0.004	2.47	133	0.539683	1	0.507937	0.971256	0.460317	0	0.492063	0.028744	0.520661	1	0.504	0.945637	0.742574	1
0	1500	9	54	0.07	2.81	875	0.412698	0.131579	0.328042	0.409985	0.587302	0.868421	0.671958	0.590015	0.459854	0.365385	0.426637	0.458709	0.427646	24
10	1500	10	17	0.07	2.97	1334	1	0.131579	0.243386	0.062784	0	0.868421	0.756614	0.937216	1	0.365385	0.397895	0.347895	0.527794	17
30	1600	6	49	0.044	2.21	95	0.492063	0.473684	0.645503	1	0.507937	0.526316	0.354497	0	0.496063	0.487179	0.585139	1	0.642095	6
40	1600	7	48	0.031	2.33	101	0.507937	0.644737	0.582011	0.995461	0.492063	0.355263	0.417989	0.004539	0.504	0.584615	0.544669	0.991004	0.656072	4
0	1600	8	36	0.059	2.86	787	0.698413	0.276316	0.301587	0.476551	0.301587	0.723684	0.698413	0.523449	0.623762	0.408602	0.417219	0.488544	0.484532	20
10	1600	9	19	0.028	2.84	998	0.968254	0.684211	0.312169	0.316944	0.031746	0.315789	0.687831	0.683056	0.940299	0.612903	0.420935	0.422634	0.599193	9
20	1600	10	18	0.015	2.73	1053	0.984127	0.855263	0.37037	0.27534	0.015873	0.144737	0.62963	0.72466	0.969231	0.77551	0.442623	0.408277	0.64891	5
40	1700	6	45	0.067	2.21	332	0.555556	0.171053	0.645503	0.820726	0.444444	0.828947	0.354497	0.179274	0.529412	0.376238	0.585139	0.73608	0.556717	15
0	1700	7	35	0.065	2.33	407	0.714286	0.197368	0.582011	0.763994	0.285714	0.802632	0.417989	0.236006	0.636364	0.383838	0.544669	0.679342	0.561053	14
10	1700	8	52	0.06	2.81	566	0.444444	0.263158	0.328042	0.643722	0.555556	0.736842	0.671958	0.356278	0.473684	0.404255	0.426637	0.583922	0.472125	21
20	1700	9	26	0.034	2.58	720	0.857143	0.605263	0.449735	0.527231	0.142857	0.394737	0.550265	0.472769	0.777778	0.558824	0.476071	0.513997	0.581667	11
30	1700	10	45	0.054	2.77	541	0.555556	0.342105	0.349206	0.662632	0.444444	0.657895	0.650794	0.337368	0.529412	0.431818	0.434483	0.597109	0.498206	19

6. Engine Performance Analysis:

The performance of the engine is found out by measuring engine parameters like Brake Power (BP), Indicate Power (IP), Brake Mean Effective Pressure (BMEP), Indicated Mean Effective Pressure (IMEP) & BSFC. These parameters are observed by plotting the surface plots using Minitab17 software. Compression ratio is changed from 7 to 10 in the interval of 1 each. It is noted that engine performance is better at CR 10. The surface plots are plotted for CR10 to understand the best performance of the engine.

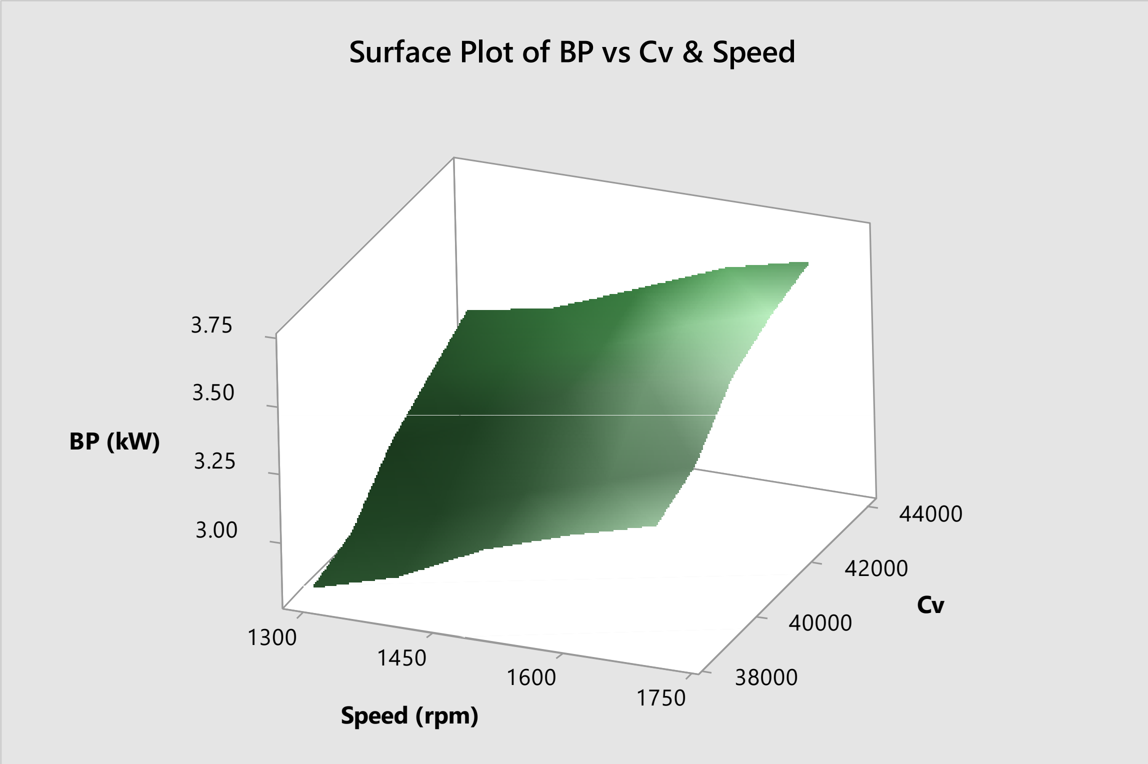

Fig. 6. Variation of BP with respect to engine speed and CV at CR 10

It is noted from Fig 6 that BP increases with an increase in engine speed. It is also noted that BP increases with increase in calorific value. Highest BP is observed at CV 44000 kW/Kg and 1700 rpm. This signifies the use of lower ethanol percentages in fuel fractions. BP decreases with increase in ethanol percentage in fuel fraction as CV of ethanol is less than CV of gasoline.

IP of the engine also shows a similar nature compared with BP. It is higher for CV 44000 kW/Kg and 1700 rpm. As shown in Fig 7, surface plot of IP is not smooth and shows little drop for E10 and rise for E20. This may be due to unaccounted engine losses. Reduction in IP with increase in ethanol percentage in fuel fraction is due to lesser CV of ethanol.

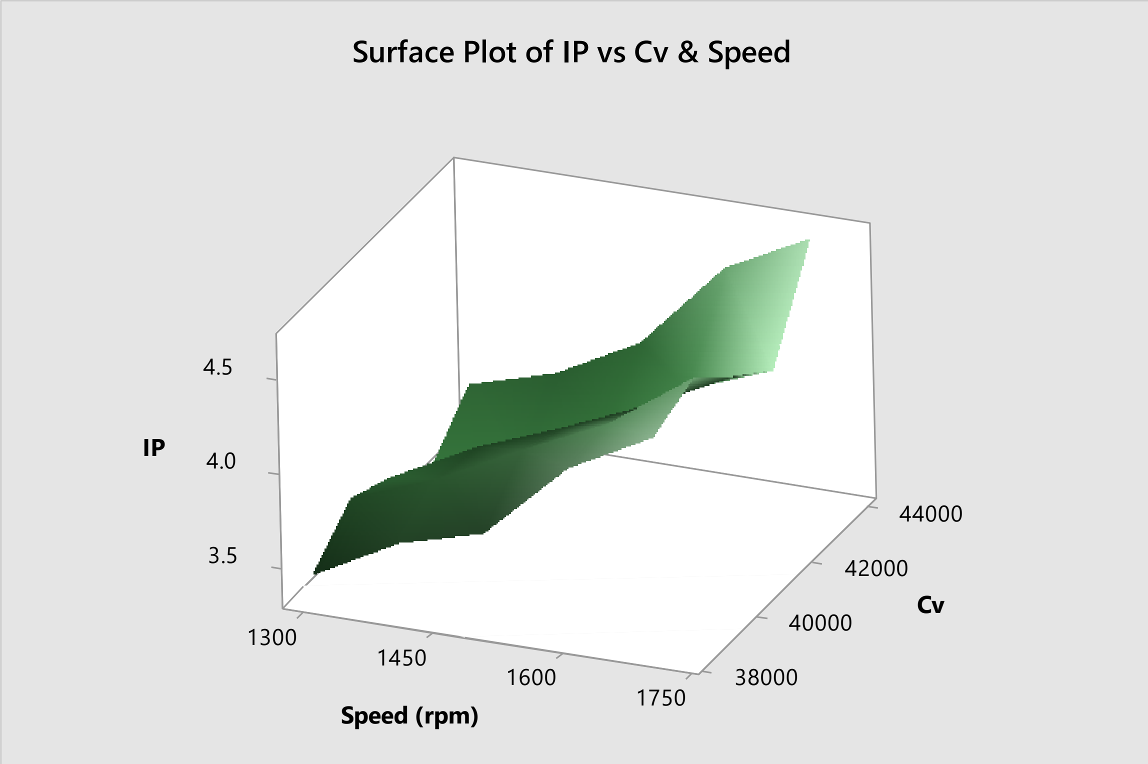

Fig. 7. Variation of IP with respect to engine speed and CV at CR 10

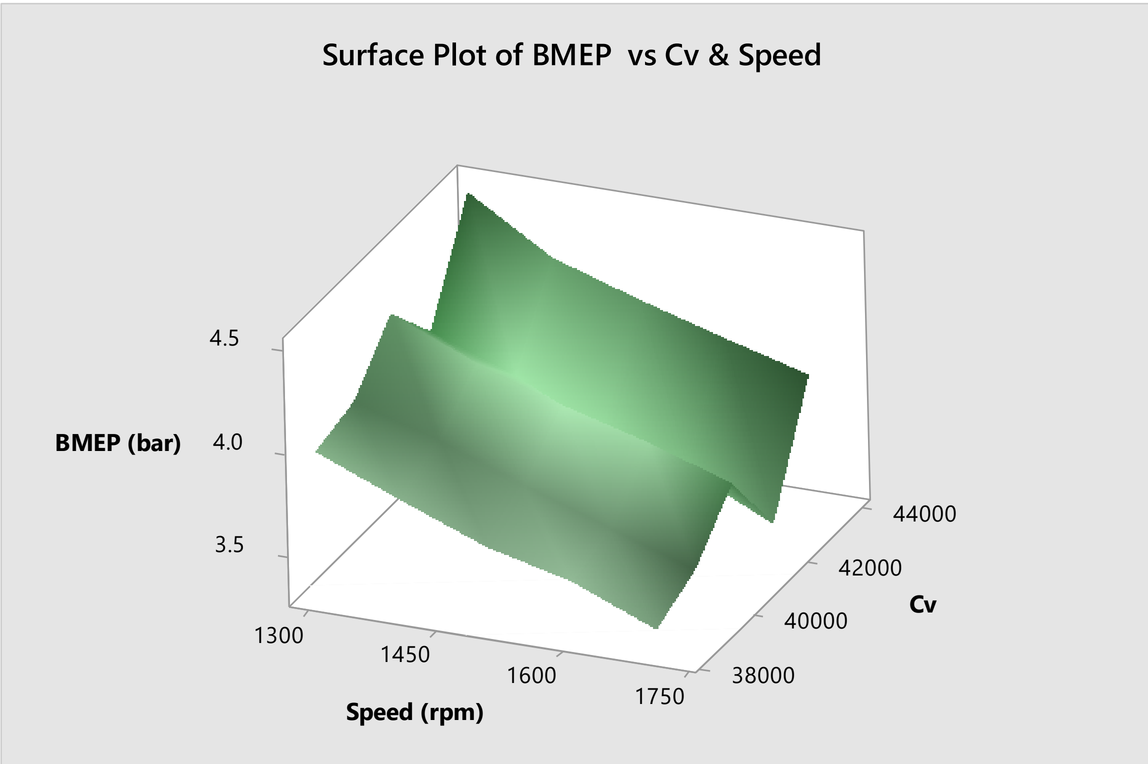

Fig. 8. Variation of BMEP with respect to engine speed and CV at CR 10

BMEP changes with respect to fuel fraction and corresponding CV to a larger extent. It's variation with reference to CV and engine speed is shown in Fig 8. BMEP is more for E0 and E20 as compared with other fuel fractions. BMEP is observed to decrease with an increase in engine speed at all the fuel fractions. It is noted that the engine

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develops more BMEP at a slow speed and with no blends of ethanol in fuel fraction. As the CV of ethanol is less than gasoline, the pressure developed is less with increase in ethanol percentage in fuel fractions. It is desirable to run the engine at high compression ratio, to compensate for loss of pressure due to adding ethanol in fuel fractions.

The behaviour of changes in IMEP with reference to engine speed and CV is shown in Fig 9. The behaviour is similar to BMEP. The engine develops more IMEP at slow speed of 1300 rpm and at E0. IMEP decreases with an increase in engine speed. It is also noted that IMEP is low at E30 and then it further increases for higher ethanol blends.

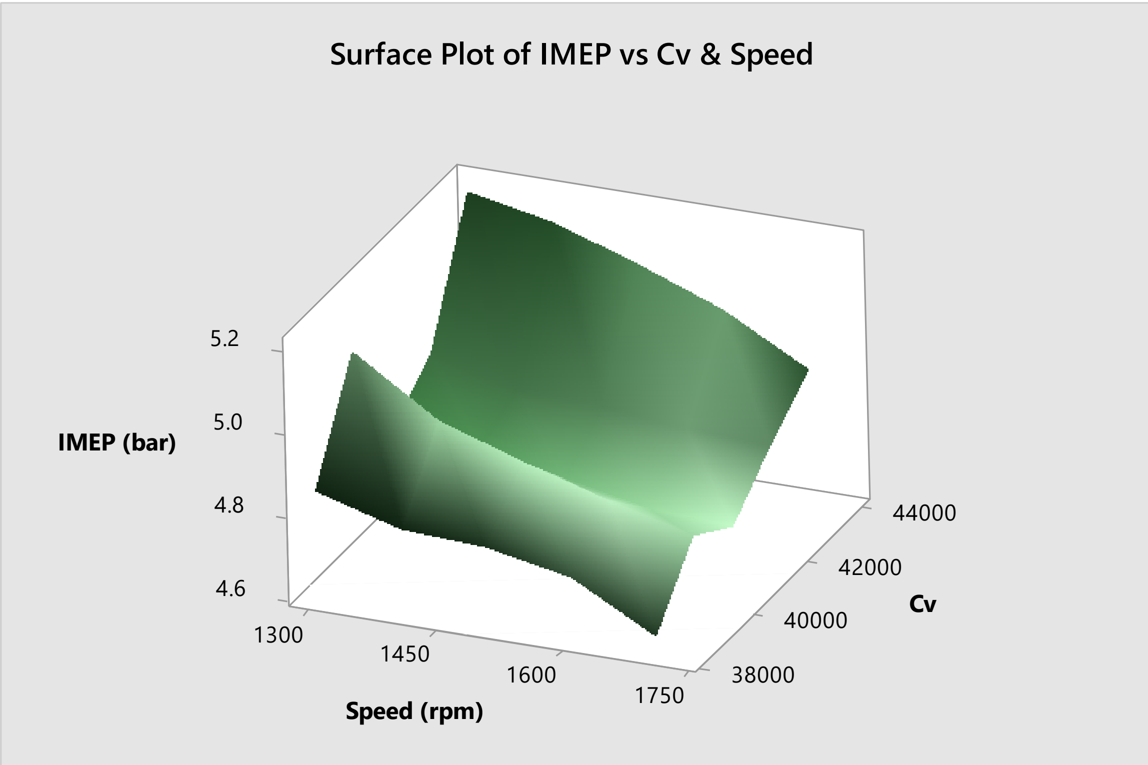

Fig. 9. Variation of IMEP with respect to engine speed and CV at CR 10

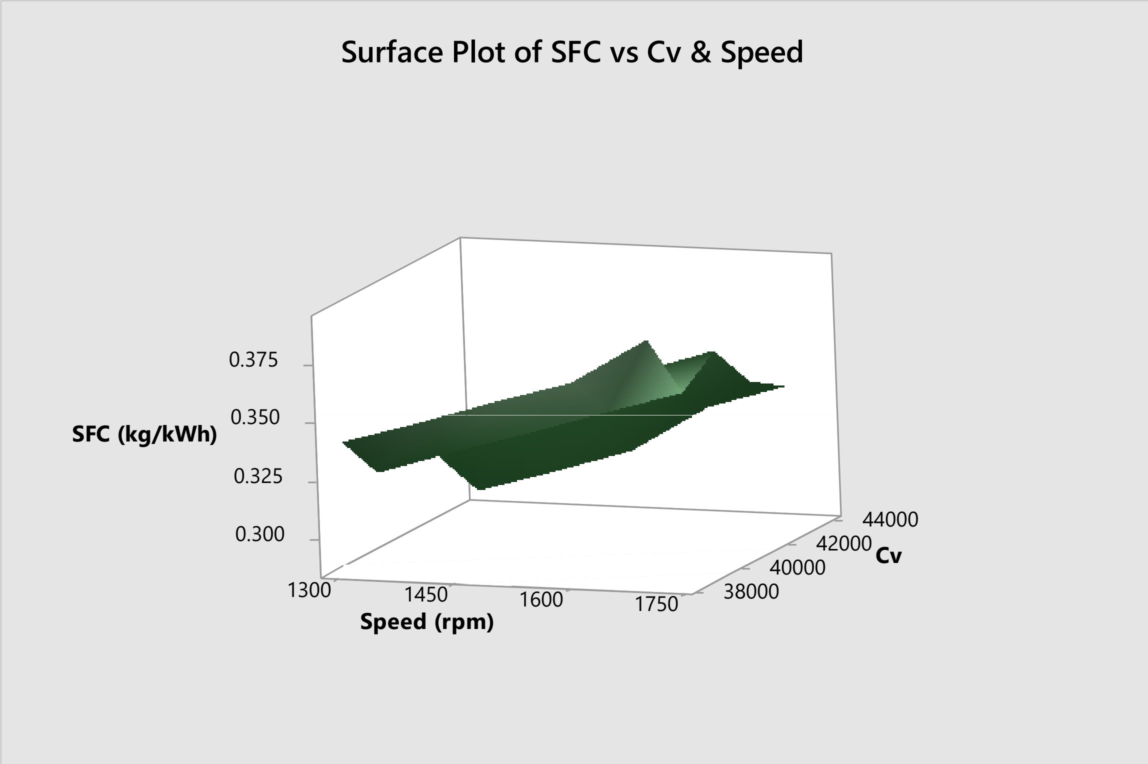

Fig. 10. Variation of BSFC with respect to engine speed and CV at CR 10

Brake specific fuel consumption shows the fuel consumption with reference to engine brake power. This factor is important to understand the variations in fuel consumption with different operating conditions of engine speed and CV of fuel. The total variations for CR 10 is shown in Fig 10. It is noted that BSFC increases with increase in engine speed due to part of the fuel going unburnt in the exhaust. CV of ethanol is less in comparison with gasoline. Hence more fuel is required with increase in ethanol percentage. With reference to the same, it is noted that BSFC increases with increase in ethanol percentage.

7. Conclusions:

Various fuel fractions of ethanol from E0 to E40 are tested on VCR engine and exhaust gas emissions are noted for different operating conditions of CV, engine speed, and compression ratio. Minitab 17 gives the option to view the graphical behaviour of various emission parameters with three different operating conditions on the same graph using the Multi-Vari chart option under Quality Tools. The following results are concluded from the experimental study.

1. NO_x formation depends on temperature. With the addition of ethanol, the engine temperature was reduced. This also leads to a reduction of NO_x. It is recommended to use higher values of ethanol percentage up to E40. NO_x increases with the rise in engine pressure. A higher compression ratio leads to more engine pressure and temperature. This also promotes the formation of more NO_x. It is recommended to run the engine at lower CR to reduce NO_x.
2. Formation of CO reduces with an increase in ethanol percentage in fuel. Excess oxygen in ethanol allows complete combustion of fuel and decreases the formation of CO.
3. CO_2 formation increases with an increase in ethanol percentage due to complete combustion of fuel. However, this trend is observed till E 20 and then CO_2 formation slightly reduces. Additional oxygen in ethanol ensures complete combustion of fuel.
4. Hydrocarbons reduce with an increase in ethanol percentage till E20 and then slightly increase. The compression ratio can be kept low to moderate and also depends on the fuel fraction being used in the engine.

5. It is difficult to predict the best operating condition of the engine under different values of E, CR and speed for minimising the emissions of gases. GRA has given the solution to find the best operating condition of the engine. It is noted that the best operating condition to minimise the exhaust gases is when the engine is operated at 1500 rpm, 8 CR and E40.
6. Engine powers, IP, and BP are observed higher at lower ethanol percentages and high engine speed. These powers can be compensated for enhancement by running the engine at high compression ratio do develop high pressures in the engine. At high compression ratio knocking is also reduced due to lower engine temperature, as an effect of ethanol presence.
7. BMEP and IMEP are higher at low engine speed and lower ethanol percentages. This is due to the fact that, complete combustion may not happen at high temperatures. It is also to be noted that ethanol presence in fuel reduces the pressure developed as it has lower CV.
8. BSFC increases with an increase in ethanol percentage. More fuel is required in the engine due to lower CV of ethanol. BSFC also increases with an increase in engine speed, as we supply more fuel per power developed in the engine.

It is concluded that adding ethanol in the VCR engine reduces the emissions. With an increase in ethanol in fuel fraction, engine power and mean effective pressures reduce due to lower CV of ethanol. It is also to be noted that the overall performance of the engine even with lower power can be compensated with lower price of ethanol.

References:

1. Xiaokang Deng, Zhenbin Chen, Xiaochen Wang, Haisheng Zhen, Rongfu Xie, “Exhaust noise, performance and emission characteristics of spark ignition engine fuelled with pure gasoline and hydrous ethanol gasoline blends”, https://doi.org/10.1016/j.csite.2018.02.004
2. P. Sakthivel, K.A. Subramanian, Reji Mathai, “Comparative studies on combustion, performance and emission characteristics of a two-wheeler with gasoline and 30% ethanol-gasoline blend using chassis dynamometer”, https://doi.org/10.1016/j.applthermaleng.2018.10.035
3. Ashraf Elfasakhany, “Investigations on the effects of ethanol-methanol-gasoline blends in a spark-ignition engine: Performance and emissions analysis”, http://dx.doi.org/10.1016/j.jestch.2015.05.003
4. Ashraf Elfasakhany, “Performance and emissions of spark-ignition engine using ethanol–methanol–gasoline, n-butanol–iso-butanol–gasoline and iso-butanol–ethanol–gasoline blends: A comparative study”, http://dx.doi.org/10.1016/j.jestch.2016.09.009
5. M. Mourad , K. Mahmoud,“ Investigation into SI engine performance characteristics and emissions fuelled with ethanol/butanol-gasoline blends”, https://doi.org/10.1016/j.renene.2019.05.064
6. Selahaddin Orhan Akansu, Selim Tangoz , Nafiz Kahraman , Mehmet Ilhan Ilhak , Salih Acıkgoz, “Experimental study of gasoline-ethanol-hydrogen blends combustion in an SI engine”, http://dx.doi.org/10.1016/j.ijhydene.2017.07.014
7. Prakhar Chansauria, R. K. Mandloi, “Effects of ethanol blends on performance of spark ignition engine-A review”, Materials Today: Proceedings 5 (2018) 4066–4077
8. Rodrigo C. Costa 1, José R. Sodré, “Hydrous ethanol vs. gasoline-ethanol blend: Engine performance and emissions”, https://doi.org/10.1016/j.fuel.2009.06.017
9. Ashraf Elfasakhany, “Engine performance evaluation and pollutant emissions analysis using ternary bio-ethanol-iso-butanol-gasoline blends in gasoline engines”, http://dx.doi.org/10.1016/j.jclepro.2016.09.016
10. P. Iodice, G. Langella, A. Amoresano, “Ethanol in gasoline fuel blends: Effect on fuel consumption and engine out emissions of SI engine in cold operating conditions., https://doi.org/10.1016/j.applthermaleng.2017.11.090
11. Qian Yejian , Zuo Chengji , Xu Hongming , Tan Jian & Teng Qin. “Experimental investigation of using ethanol-gasoline in electronic control gasoline-injection engine”, http://dx.doi.org/10.1080/1023697X.2007.10668074
12. Y. Varol, C. Öner, H. F. Öztop & Ş. Altun, “Comparison of methanol, ethanol, or n-butanol blending with unleaded gasoline on exhaust emissions of an SI engine”, http://dx.doi.org/10.1080/15567036.2011.572141
13. Amit Kumar Thakur, Ajay Kumar Kaviti, Roopesh Mehra, K.K.S. Mer, “Progress in performance analysis of ethanol-gasoline blends on SI engine”, http://dx.doi.org/10.1016/j.rser.2016.11.056
14. V. Saikrishnan, A. Karthikeyan & J. Jayaprabakar, “Analysis of ethanol blends on spark ignition engines”, http://dx.doi.org/10.1080/01430750.2016.1269678

15. Fagundez JLS, Golke D, Martins MES, Salau NPG, “An investigation on performance and combustion characteristics of pure n-butanol and a blend of n-butanol/ethanol as fuels in a spark ignition engine”, https://doi.org/10.1016/j.energy.2019.04.010
16. Yusuf Abdulfatah Abdu & Freddie L. Inambao, “Progress in alcohol-gasoline blends and their effects on the performance and emissions in SI engines under different operating conditions”, https://doi.org/10.1080/01430750.2018.1531261
17. Prafulla Hatte, Dr. Yogesh Bhalerao, “Influence of Ethanol-Gasoline Fuel Fractions on Variable Compression Ratio Engine” DOI: 10.35940/ijrte.C4792.098319
18. Hatte, Prafulla, and Yogesh Bhalerao. “Prediction of Ethanol-Gasoline Blend Fuelled Spark Ignition Engine Performance Using Dimensional Analysis.” Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, August 4, 2021, 1–15. https://doi.org/10.1080/15567036.2021.1955044