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Performance and Emission Characteristics of an Multi-Fuel Diesel Engine with Variable Compression Ratio (VCR) using PALM Biodiesel

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ABSTRACT:Palm oil/palm oil methyl esters are blends with diesel fuel, the blends were characterized as an alternative fuels for diesel engines. Density, kinematic viscosity, and flash point were estimated according to ASTM as key fuel properties. Palm oil and palm oil biodiesel were blended with diesel. The properties of both blends were estimated. The results showed that the fuel properties of the blends were very close to that of diesel till 30% unless other characteristics are within the limits. This paper aims to optimise the levels of such parameters as compression ratio (CR), injection pres- sure (IP) and palm oil biodiesel blend % of a single cylinder direct injection compression ignition engine on carbon monoxide (CO), hydrocarbon (HC) and nitrogen oxide (NOx) emissions. Taguchi and Analysis of Variance techniques were used to find the optimum levels of the parameters and contribution of the parameters on the emission, respectively. Confirmation tests were performed for predicting the gas emissions to check the adequacy of the proposed model.

KEYWORDS: Palm, Diesel, Bio-oil, Compression ratio, injection pressure, biodiesel blend, emission, Taguchi, ANOVA.

I. INTRODUCTION

It is important to find an alternative fuels to replace fossil fuels based on renewable and natural sources like vegetable oil and fats. Oil and fats are composed of 80–90% triglycerides with small portion of mono and di-glycerides, which contain oxygen in their structure. Diesel fuels from petroleum sources have chemical structure different from chemical structure of vegetable oils. A Diesel fuel has no oxygen compound; it contains carbon and hydrogen arranged in straight and/or branched chain structures. Further research is desired before substituting diesel fuels with vegetable oils. Researchers recognized different complications related to the use of oil in diesel engine, due to their high viscosity and low volatility so they form deposits in the fuel injector of the engine. These problems can be solved by dilution, micro emulsion, pyrolysis, and transesterification. Transesterification is the reaction of oil with an alcohol in presence of catalyst to form ester and glycerol.The application of biodiesel has led a positive impact in resolving the energy crisis. Most of the biodiesel generally pro-vide higher brake thermal efficiency and lower brake-specific fuel consumption. Emission results showed that in most cases, nitrogen oxide (NOx) emission increased and hydrocarbon (HC), carbon Monoxide (CO) and particulate matter (PM) emissions decreased. The performance and emission characteristics of diesel engine using biodiesel fuel produced from hazelnut soap stock/waste sunflower oil mixture. They reported that the hazelnut soap stock/waste sunflower oil methyl ester can be partially substituted for the diesel fuel in terms of the performance parameters and emissions without any engine modification and preheating of the blends. studied the performance, emission and combustion characteristics of a single cylinder four stroke variable compression ratio (VCR) multi-fuel engine when fuelled with waste cooking oil methyl ester and its 20%, 40%, 60% and 80% blends with diesel (on a volume basis) and compared with standard diesel. They observed that reduction in CO, HC and increase in NOx emissions when the engine is fuelled with the biodiesel blends. Limited attempts have been made to investigate the emission characteristics of CI engine using palm biodiesel. Moreover, there is no clear understanding in the literature regarding the contribution of CR, IP and biodiesel blend on the CO, HC and NOx emission of the engine. Hence this work aims to determine the optimum level of CR, IP and percentage of palm biodiesel blend and their contribution on a single cylinder CI engine using Taguchi and Analysis of Variance (ANOVA) methods in achieving lower emissions.

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International Journal of AdvancedResearch in Science, Engineering and Technology
Vol. 5, Issue 3 , March 2018

II. MATERIALS AND METHODS

A. Materials

Palm oil and diesel were obtained from local market. All chemicals (methanol, potassium hydroxide and acetic acid) used in this study are analytical grade.

B. Biodiesel production

Experiments were done in a laboratory scale apparatus. Transesterification was carried out in 2000 ml flask equipped with reflux condenser, thermometer and magnetic stirrer. 1000 ml of oil was heated in the flask to 65 C. Potassium hydroxide (12.75 gm) was dissolved in (255 ml) of methanol and was added to the heated oil. After 2 h, the mixture was transferred into separating funnel to separate the glycerol layer. Esters were washed twice using warm water with 5% acetic acid then with water and left to separate methyl esters. Then ester was dried at 100 C to remove excess alcohol and water.

Table 1
Chemical composition of palm oil and palm oil methyl ester using GC-MS.

Palm oil methyl ester [21]	Palm oil	Fatty acid
0.64	0.190	Lauric (12:0)
1.02	1.01	Myristic (14:0)
40.2	38.88	Palmitic (16:0)
42.4	55.86	Oleic (18:1)
0.08	–	Arachidic (20:0)
0.36	–	Palmitoleic (16:1)
9.9	–	Linoleic (18:2)
0.47	–	Linolenic (18:3)
4.6	4.07	Stearic (18:0)
0.33	–	Gadolic (20:1)

C. Blend preparation

Palm oil/palm oil methyl ester was added to diesel at low stirring rate. The mixture was stirred for 20 min and left to reach equilibrium before analysis. Palm oil/palm oil methyl ester was added in volume percentages of 5%, 10%, 15%, 20%, and 30%. In order to measure the properties of the oil diesel fuels, the test methods were used as follows; Density (ASTM D941), Viscosity (ASTM D445) and Flash point (ASTM D93).

Table 2
Comparison of fuel properties according to ASTM [22].

Fuel Property	Diesel	Biodiesel
Fuel composition	C_{10}-C_{21} HC	C_{12}-C_{22} FAME
Density @15 °C, g/ml	0.848	0.978
kin viscosity @40 °C, mm^2/s	1.3–4.1	1.9–6
Flash point, °C	60–80	100–170

Table 3
Properties of diesel fuel, palm oil and palm oil biodiesel.

Property	Palm oil	Palm oil Methyl ester	Diesel
Density @15 °C, g/ml	0.925	0.877	0.827
Kin. Viscosity @40 °C, mm^2/s	41	4.56	2.28
Flash point, °C	260	196	64

ISSN: 2350-0328
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Vol. 5, Issue 3 , March 2018

Table 4
Properties of oil with different blends and diesel.

Fuel	Density @15 °C g/ml	Kinematic viscosity @40 °C mm^2/s	Flash point, °C
Diesel	0.827	2.28	64
B5	0.827	2.48	66
B10	0.835	2.73	69
B15	0.84	3.06	70
B20	0.845	3.33	72
B30	0.8553	3.4	74
B100	0.925	41	260

Table 5
Properties of methyl esters (Biodiesel) with different blends and diesel.

Fuel	Density @15 °C g/ml	Kinematic viscosity @40 °C, mm^2/s	Flash point, °C
Diesel	0.827	2.28	64
B5	0.83	2.34	66
B10	0.833	2.49	69
B15	0.834	2.67	70.5
B20	0.835	2.82	71.5
B30	0.841	2.85	82.0
B100	0.877	4.56	196

III. EXPERIMENTALPROCEDURE

The pyrolysis method was used to reduce the viscosity of palm oil to suit the CI engines. The properties of the normal diesel and pyrolysed palm biodiesel are presented in Table 6. The present study was carried out in a four stroke VCR multi- fuel testing engine which is shown in Figure 1. The engine was tested at 20 Nm at a rated speed of 1500 rpm. The engine was tested using normal diesel and palm biodiesel blend (B10 and B20) for different CRs (14:1, 17:1, 20:1) and IPs (140,160,180 bar), respectively. The exhaust emissions were measured by an AVL multi-gas analyzer which is capable of measuring CO, HC and NOx concentrations in the exhaust gas. The emission data were recorded for each test after 10 min.

Sl. No.	Properties	Diesel	Pyrolysed palm biodiesel
1	Density (g/cc)	0.825	0.880
2	Calorific value (kJ/kg)	45,000	44,810
3	Flash point (°C)	53	128
4	Cloud point (°C)	−9	−20
5	Ash Content (gm)	0.01	0

Table 6

ISSN: 2350-0328
International Journal of AdvancedResearch in Science, Engineering and Technology
Vol. 5, Issue 3 , March 2018

VCR multi-fuel testing engine

IV. EXPERIMENTATION

A . Taguchi and ANOVA analysis

An L9 (33) orthogonal array was employed for the present investigation. The notation 33 implies that 3 factors, each at 3 levels can be investigated using the orthogonal array. In this study, 'smaller is better' S/N ratio was used to predict the optimum levels of parameters because lower CO, HC and NOx were preferred for this study.
The mathematical equation of the S/N ratio for 'smaller is better' can be expressed as follows (Equation (1))

$$\frac{S}{N} = -10\,\mathrm{Log}\left(\frac{1}{n}\sum_i \frac{1}{Y_i^2}\right), \qquad (1)$$

Where Y is the observed data and n is the number of observations.
The selected factors and the corresponding levels are presented in Table 8. Moreover, the test results were analyzed using ANOVA to evaluate the influence of the factors on the performance measure.

B . Results of S/Nratio

Emission tests were conducted as per the L9 orthogonal array and the corresponding values and S/N ratios for the emissions of CO, HC and NOx are presented in Table 9. The S/N ratio for each parameter level is computed by averaging the S/N ratios at the corresponding level. The parameter with the highest S/N ratio would give minimum emission. From the response diagram of S/N ratio (Figures 2 and 3), it was found that the optimum parameter levels were CR (20), IP (180 bar) and biodiesel blend (B20) in reducing the emission of CO and HC. On the other hand, it was found from the response diagram of S/N ratio (Figure 4) that the optimum parameter levels were CR (14), IP (140 bar) and biodiesel blend (0%) in reducing the NOx emission.

Level	CR (A)	IP(bar) (B)	Biodiesel blend % (C)
I	14	140	0
II	17	160	10
III	20	180	20

Table 8 Factors and levels.

ISSN: 2350-0328
International Journal of AdvancedResearch in Science, Engineering and Technology
Vol. 5, Issue 3 , March 2018

				Measured values			S/N ratios		
Test no	CR (A)	IP (bar) (B)	Biodiesel blend (%) (C)	CO (% Vol.)	HC (ppm Vol.)	NO_x (ppm Vol.)	CO	HC	NO_x
1	14	140	0	0.06	40	2	24.4370	−32.041	−6.0206
2	14	160	10	0.05	32	5	26.0206	−30.103	−13.9794
3	14	180	20	0.02	27	9	33.9794	−28.627	−19.0849
4	17	140	10	0.04	28	5	27.9588	−28.943	−13.9794
5	17	160	20	0.02	17	10	33.9794	−24.609	−20
6	17	180	0	0.03	21	8	30.4576	−26.444	−18.0618
7	20	140	20	0.02	16	11	33.9794	−24.082	−20.8279
8	20	160	0	0.03	20	9	30.4576	−26.020	−19.0849
9	20	180	10	0.01	11	13	40.0000	−20.827	−22.2789

Table 9. Measured values and S/N ratios

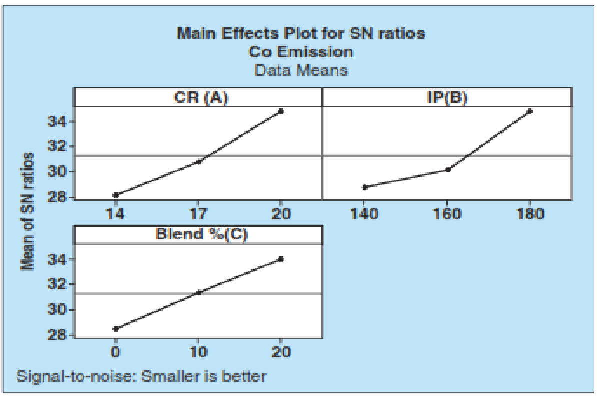


FIGURE2.RESPONSEDIAGRAMOF S/*N*RATIOFORCO EMISSION

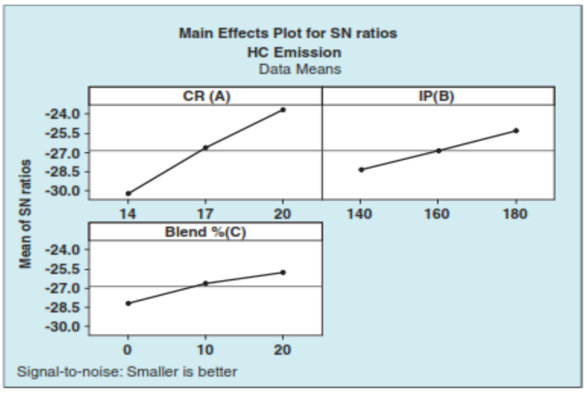
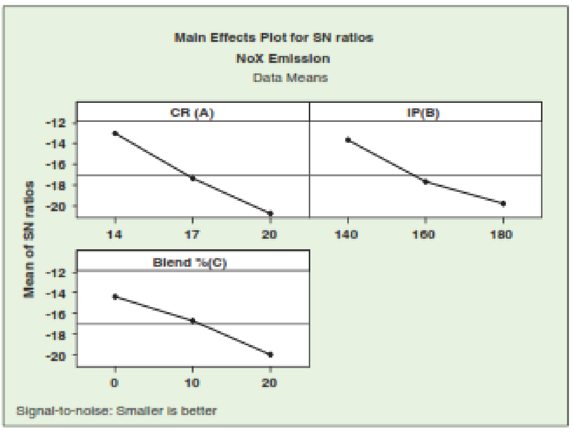


FIGURE 3. RESPONSE DIAGRAM OF S/N RATIO FOR HC EMISSION

C . Results of ANOVA

The analysis of variance was employed to find the statistically significant parameters and the contribution of these parameters on the emission. In the ANOVA(Table10),the re is a *P*-value for each independent parameter in the model. When the *P*-value is less than.05,then the parameter can be considered as statistically highly significant .CR(39.36%) was them a jor contributing factorfollowedbyIPandfinallybiodieselblend(29.78%)ininfluencingtheCOemission.CR(70.98%) was them ajor contributing factor followed by IP(16.23%)and finally biodiesel blend (11.31%)in influencing the HC emission. The similar trend was observed in case of NO_X emission.



ISSN: 2350-0328
International Journal of AdvancedResearch in Science, Engineering and Technology
Vol. 5, Issue 3 , March 2018

FIGURE 10. RESPONSE DIAGRAM OF S/N RATIO FOR NOX EMISSION

The e variation of CO emission with three different CRs and IPs for diesel and B20 blend of palm oil is shown in Figure5. It shows that the CO emission was found to be decreasing with the increase in CR and IP for both diesel and bio diesel. The CO emission of B20 decreased from 0.02 to 0.01ppm when the CR was increased from 14 to 20 at a high IP of 180 bar. This can be attributed to the fact that better atomization of fuel at higher CRs and IPs leading to better combustion. Lower IP(140bar) leads an incomplete and improper atomization of the fuel which increases the CO emission. It can also be inferred that CO emission of B20 biodiesel reduced by 50% compared to diesel when engine was run at higher CR(20:1) and IP(180bar).It may be due to the additional oxygen molecule in the biodiesel blends which improves the combustion resulting in a decrease in the CO emission.Similartr ends were reported by BahattinCelikandSimsek (2014).

The unburned fuel which is the outcome of incomplete combustion, present in exhaust gas can be termed as HC emission. The effect of HC emission with different CRs and IPs for diesel and B20 blend of palm oil is illustrated in Figure6.The HC emission of B20 decreased from 16t o 8ppm when the IP was increased from 140 to 180 bar at a high CR of 20.It indicates that higher IP increases the better mixing ability of fuel with air and reduces the HCemission.TheHCemissionofB20decreased by about 33% compared to diesel when the engine was operated at higher CR (20:1)and higher IP(180bar).It was found that the combined

Table 10.ANOVAanalysis

		CO			HC			NO_x		
Factors	DoF	*F*	*P* value	Pc%	*F*	*P* value	Pc%	*F*	*P* value	Pc%
CR (A)	2	37	0.026	39.36	48.30	0.020	70.98	73	0.014	51.77
IP (bar) (B)	2	28	0.034	29.78	11.05	0.083	16.23	36	0.027	25.53
Biodiesel blend (%) (C)	2	28	0.034	29.78	7.70	0.115	11.31	31	0.031	21.98
Error	2			1.062			1.470			0.709
Total	8			100			100			100

Notes: DoF, degrees of freedom; *F*, *F* ratio; Pc %, percentage of contribution.

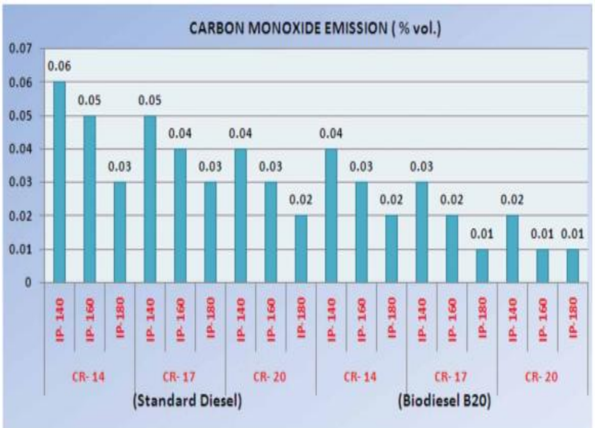


FIGURE 5. VARIATION OF CO EMISSION WITH DIFFERENT CRS AND IPS

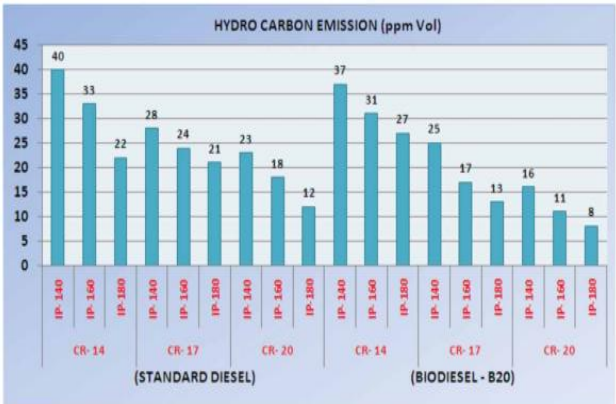


FIGURE 6. VARIATION OF HC EMISSION WITH DIFFERENT CRS AND IPS

The effect of NO*x* emission with respect to different CRs and IPs for diesel and B20 blend of palm oil is shown in Figure 7. It shows that the NO*x* emission is found to be increasing with the increase in CR and IP. NO*x* of B20 increased from 9 to 16 ppm

ISSN: 2350-0328
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Vol. 5, Issue 3 , March 2018

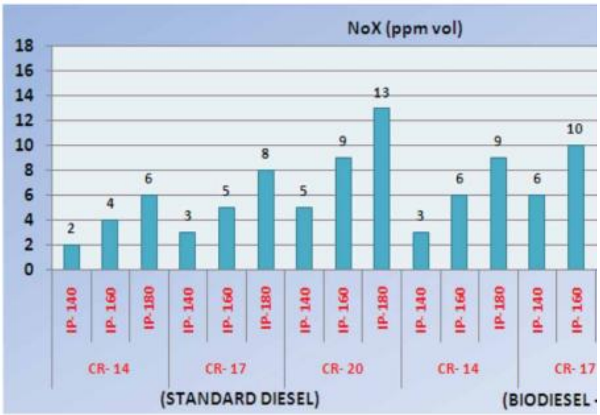

FIGURE 7. Variation of NO*x*emission with different CRs and IPs.

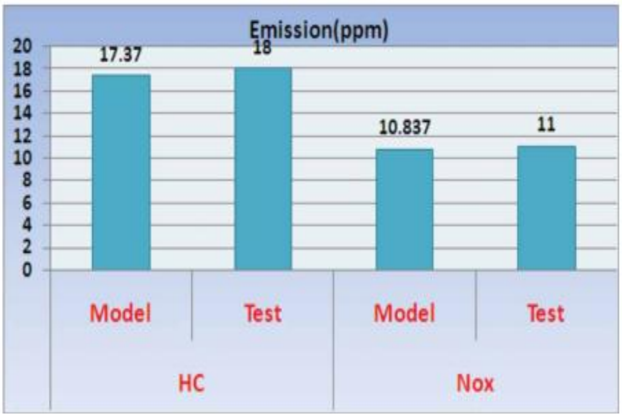

Figure 8. Result of confirmation experiment and their comparison with regression model.

when the CR was increased from 14 to 20 at a higher IP of 180 bar. This may be due to better mixing of fuel and air at higher CRs and IPs which improves the combustion thereby combustion temperature increases. It can also be noted from Table 5 that biofuel blend was found to be the one of the important parameters which has about 22% contribution on the NO*x* emission of a diesel engine. It can also be seen from Figure 7 that B20 gives comparatively more NO*x* emission than diesel at all CRs and IPs. The results revealed that the NO*x* emission for B20 increased by 23% compared to diesel when the engine was run at the CR of 20 and IP of 180 bar. This could be explained by the fact that the presence of more oxygen molecules in the biodiesel improves the combustion which increases NO*x* emission. Since cetane number of palm biodiesel has higher than diesel, the air–fuel mixture and initial combustion products have a longer residence time at higher temperature that triggers NO*x* forma- tion. A similar trend was observed by Ashrafur Rahman et al. (2014).

D. MULTIPLE LINEAR REGRESSION MODEL

A multiple linear regression equation was generated to establish the correlation among the factors on the outcome of the process.
The regression equation for

CO = 0.187 – 0.00389 CR – 0.000500 IP
- 0.00100 Blend %.

The regression equation for

HC = 110 – 2.89 CR – 0.208 IP – 0.350 Blend %.

It can be observed from 'Equation (2)' and 'Equation (3)' that the coefficients associated with CR and IP and biodiesel ratio (blend) are negative. It indicates that the CO and HC decrease with increasing CR, IP and biodiesel blend with in the observed range. The CR has a larger effect compared with biodiesel blend and IP according to its coefficient value.

The regression equation for

NOx = −25.9 + 0.944 CR + 0.100 IP + 0.183 Blend %.

ISSN: 2350-0328

International Journal of Advanced Research in Science, Engineering and Technology

Vol. 5, Issue 3 , March 2018

It can be seen from 'Equation (4)' that NOx increases with increasing CR, IP and biodiesel blend, since the coefficient associated with them are positive. CR is the major contributing factor compared with biodiesel blend and IP according to its coefficient value.

V. CONFIRMATION TEST

The confirmation tests were performed to predict the emission of B15 biodiesel at the CR of 18 and IP of 170 bar. The results are given in Figure 8. The testing values for the emission of HC and NOx and calculated values from the regression equations are nearly same with least error (±4%). The regression equations can be used to predict the emission of HC and NOx to the acceptable level of accuracy within the observed range.

VI. CONCLUSION

The objective of this study is to investigate the key properties (density, kinematic viscosity and flash point) of palm oil, palm oil methyl ester in a blend with diesel fuel. The properties of palm oil/palm oil biodiesel blends showed that there is no significant difference in fuel properties of the blends up to 30% volume of oil/biodiesel of palm oil. The emission characteristics of single cylinder VCR engine fuelled with palm biodiesel and its blends were analysed and compared to the normal diesel fuel at various IPs (140, 160, and 180 bar) and CRs (CR 14:1, 17:1, and 20:1). Based on the experimental results the following conclusions were obtained.

From the Taguchi results, it was found that the optimum parameters levels were CR (20:1), Bio fuel blend (20%) and IP (180 bar) in reducing the emission of CO and HC. From the ANOVA analysis, it was found that, the most influencing param- eter on the emission of CO is the CR, which accounts for 39.36% of the total effect, followed by the IP (29.78%) and the biodiesel blend (29.78%).

The CR which accounts for 70.98% of the total effect was the most dominant factor in HC emission. On the other hand, the most influencing parameter on the emission of NO*x* is CR, which accounts for 51.77% of the total effect, followed by the IP (25.53%) and the biofuel blend (21.98%).

It was observed that the CO and HC emissions decreased with increase in the CR and IPs, while the exhaust NO*x* emission increased with the increase in the CR and IP. The proposed model equations can be used successfully to predict the CO, HC and NO*x* emission to the acceptable level of accuracy. On an average, the CO emission of B20 decreased by 50% and the HC emission reduced by 33.33%, compared to diesel when the engine was operated at CR of 20:1 and an IP of 180 bar. Finally it can be con- cluded that 20% biodiesel blend could be used as alternative fuel in a diesel engine for lower HC and CO emissions.

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