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Optimal Mixture Ratios of Biodiesel Ethanol Diesel for Diesel Engines*

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Abstract

In this paper, we study the best-mixture ratio of biodiesel-ethanol-diesel for diesel engines. The simulation results show that the integrated indexes including engine power, cost-effectiveness and emission properties are rather better with different optimizing index when the ratio of bio-diesel, ethanol and diesel are 71.58: 2.72:25.70 and 50:2.4127:47.5873.

Keywords: Diesel Engine, Biodiesel, Ethanol, Best-Mixture Ratio, Integrated Indexes

1. Introduction

Developing new energy car is the top research issue in the automobile industry, for the energy crisis and air pollution had become severe global problems [1]. In China, the project of exploring biodiesel as an automobile substitutable fuel has been formulated to achieve the nation energy developing plan in biology liquid fuel. In this paper the ethanol is ejected into the biodiesel-diesel with high mixture ratio, the mixture ratio of biodiesel is over 50%, as an assistant burning material. The power, cost-effectiveness performance and SOOT, NO_x emissions property of diesel engine is analyzed and researched. And the torque fuel consumption rate, NO_x and SOOT emissions are chosen as the integrated indexes for the best mixture ratio of biodiesel-ethanoldiesel.

2. Simulation Test and Uniformity Design Principle

The diesel engine with biodiesel-ethanol-diesel fuel in different mixture ratio is simulated by using GT-Power [2] to research the best mixture ratio of biodiesel-ethanol-diesel for optimizing the power, cost-effectiveness permance and SOOT, NO_x emissions property of diesel engine.

2.1. Introduction of Uniformity Design Principle

Uniformity design principle is an experiment design method, put forward by Professor Fang Kai Tai and Wang Yuan in China Academy of Scientist, Application mathematics department in 1970s. The process of uniformity design principle method includes steps as following, 1) ensuring the experiment aims and evaluation indexes, 2) choosing experiment factors, 3) ensuring the level of each factor, 4) choosing uniformity design table and assign relative factors, 5) making experiment schemes and operations, 6) analyzing the experimental results.

2.2. Choosing of Factors, Level and Optimization Aims

1) Choosing experiment factors, the mass fractions of ethanol and biodiesel are chosen to be experimental factor 1 and 2 respectively. For the diesel ratio in mixture is fixed as soon as the ratios of biodiesel and ethanol are defined, it is needn't to take the mass fraction of diesel as experimental factor as well. Because the engine runs under variable modes practically, it is unreliable to ensure the best-mixture ratio under a single mode [3,4]. Besides, the revolution and load alteration are taken consideration in building math model to ensure the best mixture ratio. The revolution and load are chosen to be factor 3 and 4.

2) Determining the factor level, in this paper that the assistant fuel, ethanol, is ejected in the mixture fuel with high mixture ratio is researched. So the biodiesel factor levels are chosen at 50%, 60%, 70%, 80%, 90%. The ethanol factor levels are at 2.5%, 5%, 7.5%, and 10%. Considering the various practical modes the revolution

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levels are chosen at 800, 1000, 1400, 1800, 2200 r/m. the load levels are at 25%, 50%, 75% and full load.

2.3. Diesel Engine Simulation Model and Fuel-Base

Supercharging & middle cooling diesel engine is researched in this paper, and its technical parameters are shown in **Table 1**.

Table 1. The main technical parameters of diesel engine.

Engine Form	Six-cylinder, Four-stroke, Supercharging & middle cooling diesel engine
Cylinder diameter × Stroke length	114 mm × 135 mm
Compression ratio	18
Total cylinders cubage/L	8.27 L
Maximum torque/Revolution	1000 N·m/1400 r/min
Rating power/Revolution	184 kw/2200 r/min

The diesel engine is predigested different models such intake system, exhaust system, cylinder, crankcase, ejecting device, middle cooler, circumstance and the relative pipe among them based on the parameters above all. The diesel model seems as **Figure 1**.

In this paper the biodiesel composes of saturated and unsaturated fatty acid methyl ester such as, palmitic acid methyl ester, stearic acid methyl ester, oleic acid methyl ester, linoleic acid methyl ester, linolenic acid methyl ester [5-8]. And their structure forms are following as:

$CH_3(CH_2)_{14}COOCH_3$

$CH_3(CH_2)_{16}COOCH_3$

$CH_3(CH_2)_7CH{=}CH(CH_2)_7COOCH_3$

$CH_3(CH_2)_7CH{=}CHCH_2CH{=}CH(CH_2)_4COOCH_3$

$CH_3CH_2CH{=}CHCH_2CH{=}CHCH_2CH{==}CH(CH_2)_7CO$ OCH_3

Their chemical forms and ratios are shown in **Table 2**.

3. Analyzing Simulation Results

Simulation experiment is carried out with GT-Power according the experiment scheme, and experimental re-

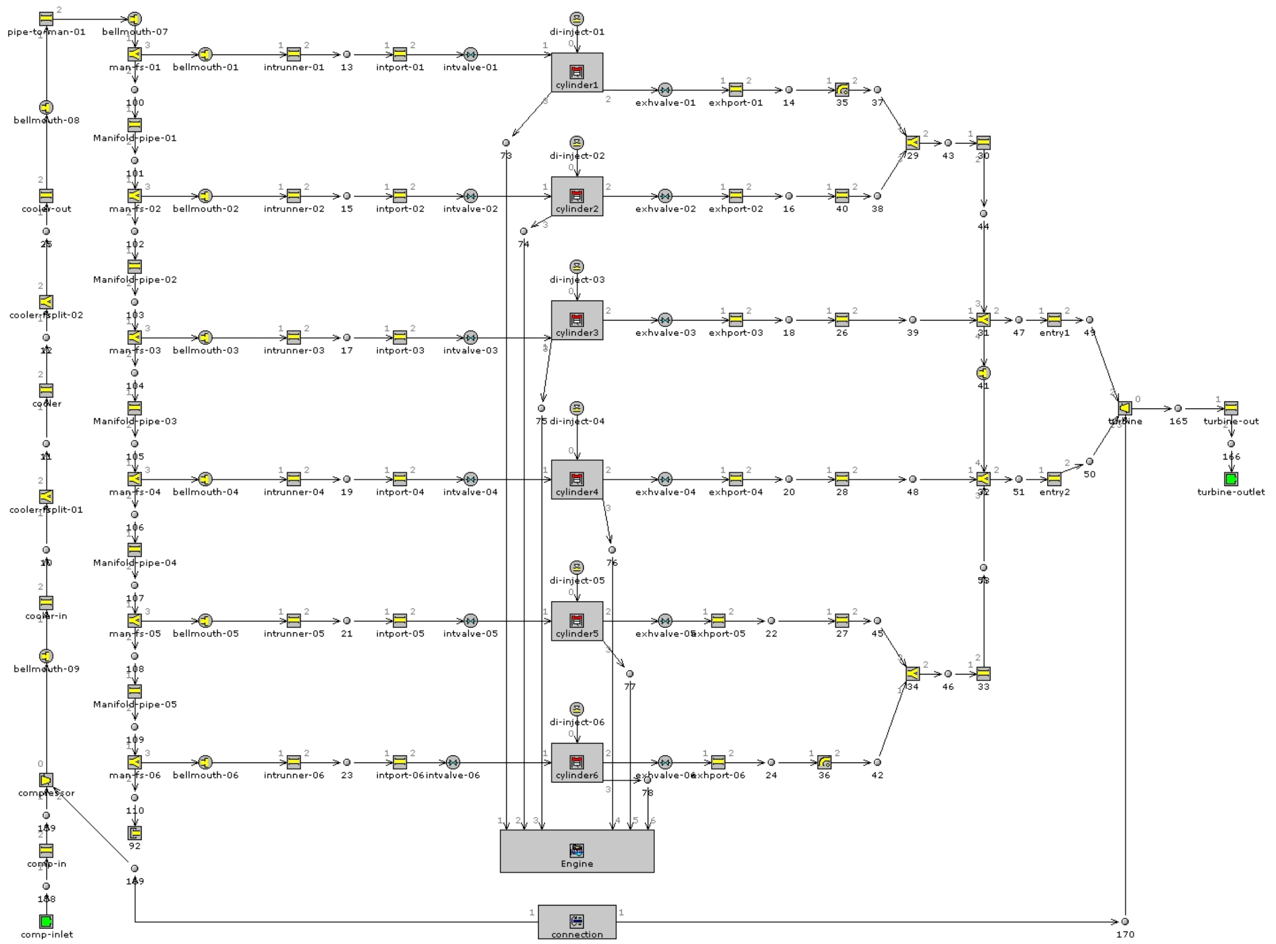

Figure 1. Diesel engine simulation model diagram.

sults (torque, BSFC, NO_x, SOOT) are shown in **Table 3**.

3.1. Ensuring Integrated Index

The experiment results shown in Table 3 dedicate that the optimization aim is a multi-index, which needs to be quantitated firstly, and then optimized comprehensively. Integrated evaluation method based on weighting factor is adopted to acquire the integrated index value y*i* [3,4], whose computing formula is as following.

$$\mathrm{y}i = \mathrm{b}i1 \times \mathrm{y}i1 + \mathrm{b}i2 \times \mathrm{y}i2 + \cdots + \mathrm{b}ij \times \mathrm{y}ij \tag{1}$$

Therein, b*ij* are the coefficient. Y*ij* are the experiment indexes. *i* expresses the *i*th experimental level. *j* expresses the *j*th experiment index.

The total weighting factor is supposed as 100. And then the weighting factor of every index would be evaluated as bij, determined by the index's weight compared with total weighting factor 100. After analyzing the comparative weight of different index comprehensively based on professional knowledge, there are two series of the integrated weighting evaluation are set in this paper. In the first set the weights of torque, fuel consumption rate, NO_x and SOOT all are 25. In the second set the weight of torque is 15, that of fuel consume rate is 35, that of NO_x is 15, and that of SOOT is 35. The values of integrated index Y1 and Y2 are contra posed to the first and second set respectively.

The difference between the maximum and the minimum of every experiment is its variation spectrum k. The k of torque is 670.544, that of fuel consumption rate is 126.504, and that of NO_x is 209.3779, while that of SOOT is 2.101513.

The coefficient is computed by following formula.

$$\mathrm{b}ij = \mathrm{Weight}/\mathrm{k} \tag{2}$$

Computing the integrated evaluation of the weighting factor is corresponded to evaluate every experiment result. The values of different indexes should be supposed as lesser numbers at the same class before calculating the integrated index value in case of wrong in calculating. Besides, the value of torque index should be as larger as possible, and the values of fuel consume rate, NO_x and SOOT are as small as possible. The value of torque is supposed as a minus to acquire the minimums of all indexes unifiedly. The acquired integrated evaluations based on weighting factor are Y1 and Y2, as shown in **Table 3**.

Table 2. Basic information of the biodiesel [6,7].

Name	Chemical Form	Molecular Weight	Ratio (%)
palmitic acid methyl ester	$C_{17}H_{34}O_2$	270.45	10.74
stearic acid methyl ester	$C_{19}H_{38}O_2$	298.50	4.28
oleic acid methyl ester	$C_{19}H_{36}O_2$	296.49	24.03
linoleic acid methyl ester	$C_{19}H_{34}O_2$	294.48	54.23
linolenic acid methyl ester	$C_{19}H_{32}O_2$	292.46	6.72

Table 3. Results of experiment and integrated indexes.

Level/ Factor	Ethanol mass fraction X1/%	Biodiesel mass fraction X2/%	Rev X3/RPM	Load X4/%	Torque y1/N·m	BSFC y2/g/(kW·h)	NO_x y3/ppm	SOOT y4/ppm	Integrated index value Y1	Integrated index value Y2
N1	5	70	1000	75	598.959	235.123	105.002	2.02225	60.7289	92.8554
N2	5	50	1000	25	188.958	235.577	4.93408	1.09812	53.1629	79.5927
N3	2.5	90	800	50	418.092	259.641	30.4608	0.636468	46.9316	75.2649
N4	2.5	80	1800	75	544.014	259.641	93.4912	1.24741	57.0307	87.1386
N5	10	60	800	100	829.374	239.685	214.312	0.529577	48.3345	71.9343
N6	5	90	2200	100	731.667	282.368	130.981	0.775017	53.3824	84.047
N7	2.5	70	2200	25	179.289	361.627	57.3555	2.63109	102.9293	143.97
N8	5	60	1400	50	478.244	240.247	119.896	2.06413	68.5187	98.738
N9	10	90	1400	25	199.145	265.033	17.0314	1.31078	62.5785	91.9229
N10	7.5	60	1800	75	561.163	253.786	87.1341	1.37306	55.9699	86.7723

3.2. Quadratic Multinomial Regression Model

The quadratic multinomial regression models of integrated indexes in **Table 3** are acquired by statistics software and their formula are as following.

$$\begin{aligned} Y1 = &-7045.01+2656.13*X1-197.90*X2 \\ &+5.35*X3+89.84*X4-86.70*X1*X1 \\ &+2.31*X2*X2+0.025*X4*X4 \\ &-12.98*X1*X2-0.31*X1*X3 \\ &-4.41*X1*X4-0.011*X2*X3 \\ &-0.56*X2*X4-0.023*X3*X4 \end{aligned} \tag{3}$$

$$\begin{aligned} Y2 = &-649.08+97.06*X1+5.09*X2 \\ &+0.48*X3-2.81*X4-3.44*X1*X1 \\ &+0.008*X2*X2+0.045*X4*X4 \\ &-0.68*X1*X2-0.002*X1*X3 \\ &-0.12*X1*X4-0.003*X2*X4 \\ &-0.002*X3*X4 \end{aligned} \tag{4}$$

3.3. Obtaining the Best Mixture Ratio

The regression formula shows that the integrated index is related to mixture ratio, revolution and load. It means the integrated index is only related to revolution and load when the mixture ratio is fixed. The function relationship among the integrated index, revolution and load vary from each mixture ratio. In 3D coordinate series, the revolution, load and integrated index are respectively supposed as X axis, Y axis and Z axis. The bend roof cylinder could be computed by $z = f(x, y)$ ($x1 \leq x \leq x2$, $y1 \leq y \leq y2$). Therein, x1 and x2 are the maximum and minimum of revolution respectively. And y1 and y2 are the maximum and minimum of load. The cubage of the bend roof cylinder ($V_{\text{integrated index}}$) can be used to evaluate the value of the integrated index under the prefixed mixture ratio. The smaller the cubage is, the smaller the integrated index value is at the same mixture ratio.

Taking consideration of the various mode of engine, practically, the final integrated index value judged by the above way is comprehensive and comparative reasonable. The $V_{\text{integrated index}}$ with different mixture ratio could be obtained by double integral [9,10]. The relationship among $V_{\text{integrated index}}$, ethanol and biodiesel are shown in **Figures 2** and **3** corresponding to the first and second scheme respectively. The minimum of $V_{\text{integrated index}}$ is X1 = 2.72 and X2 = 71.58 when the first scheme is adopted. And when the second scheme is adopted the minimum of $V_{\text{integrated index}}$ is X1 = 2.4127, X2 = 50. This dedicates the best mixture ratio of bio-diesel, ethanol and diesel are 71.58:2.72:25.70 and 50:2.4127:47.5873 when the torque, fuel consumption rate, NO_x and SOOT emissions are considered under all modes comprehensively.

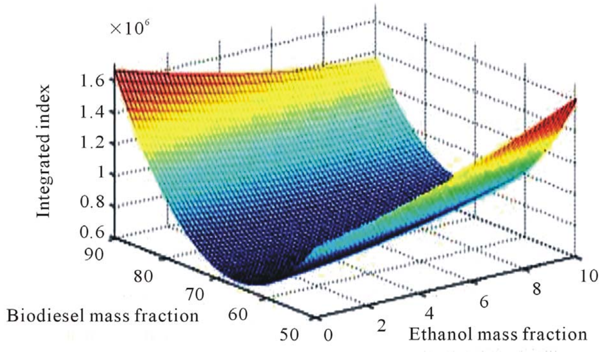

Figure 2. Relation between Integrated optimization index (option one) on all kinds of conditions and the proportion of ethanol and biodiesel.

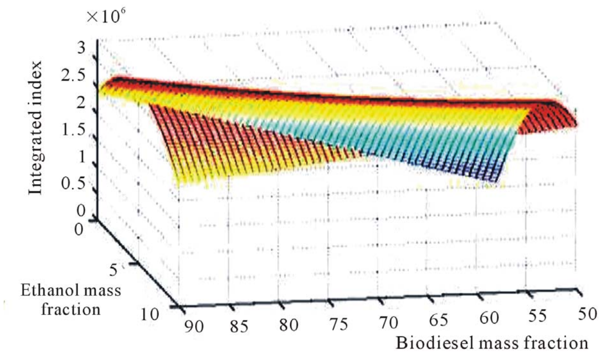

Figure 3. Relation between Integrated optimization index (option two) on all kinds of conditions and the proportion of ethanol and biodiesel.

4. Conclusions

1) The diesel engine power, cost-effectiveness and emission vary between good and bad as the biodiesel-ethanol-diesel mixture with different mixture ratio is burning in it under different revolution and load.

2) After analyzing the torque, fuel consumption rate, NO_x and SOOT emissions with two weighting factor schemes, the results show that the integrated index including engine power, cost-effectiveness and emission properties is rather better with different optimizing index when the ratio of bio-diesel, ethanol and diesel are 71.58:2.72:25.70 and 50:2.4127:47.5873.

5. Acknowledgements

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