JJMIE

Volume 15, Number 1, March. 2021
ISSN 1995-6665
Pages 1 - 6

Jordan Journal of Mechanical and Industrial Engineering

Experimental Study on Formaldehyde Emission from Environmental Protection and Energy-Saving Alcohol Fuel for Vehicles

Dandan Liu, Shigang Li*, Hui Liu

College of Robotics, Beijing Union University, Beijing 100020 China

Received July 18 2020 *Accepted Feb 20 2021*

Abstract

With the further increase of domestic oil demand, the diversification strategy of energy supply represented by alternative energy sources, such as alcohol fuel which has become a direction of China's energy policy. Alcohol fuel can reduce conventional engine emissions by replacing conventional gasoline and diesel, but their unconventional emissions -- formaldehyde -- tend to have higher concentrations than conventional engines. Based on this, this paper analyzed the physical and chemical properties of mixture of methanol and gasoline and its feasibility as an energy fuel, and conducted experiments on formaldehyde emission of gasoline and methanol gasoline respectively, and then obtained a large number of experimental data that studied and analyzed the experimental results and methods, and drew relevant research conclusions. The results show that the high ratio of alcohol fuel can replace the use of chemical fuel and has good energy saving and environmental protection characteristics. When the same fuel is tested, the formaldehyde emission increases first and then decreases with the increase of power. In this paper, a large amount of formaldehyde emission data from alcohol fuel engines are obtained through bench experiments, which provides a scientific basis for the future development of alcohol fuel vehicle combustion system and the formulation of environmental emission standards.

Keywords: engine, alcohol fuel, methanol, unconventional emission, formaldehyde;

1. Introduction

With the rapid development of the global economy, China's automobile industry has also developed rapidly. However, the rapid increase of transportation and automobile ownership has brought great pressure to China's energy supply and environmental pollution. Air pollution caused by automobile emissions is becoming more and more serious. In large and medium cities in various countries, automobile exhaust emissions have become the most important source of air pollution [1].

To alleviate the pressure of oil resources shortage, and to improve the atmospheric environment, and promote the human society and the sustainable development of the auto industry, alcohol fuel (methanol, ethanol) as a new alternative fuel can be completely or partly replacing the traditional gasoline, diesel oil. Clean combustion, not only can greatly reduce the conventional emissions of harmful substances, specifically hydrocarbons (HC), nitrogen oxides (NO_X), carbon monoxide (CO), emissions of carbon dioxide (CO_2), but also particulate matter concentrations can significantly decrease, with good environmental properties [2]; Moreover, alcohol fuels are abundant in sources and are an ideal alternative to petroleum. Therefore, under the dual pressure of environmental protection and energy, alcohol fuel engine as a new type of vehicle power will present a broad development prospect [3].

Although the substitution of clean alcohol fuel for traditional fuel can reduce the content of conventional pollutants discharged by traditional engines and improve the quality of the environment, it also brings new problems.

When the engine uses alcohol fuel, the emission concentration of unconventional emissions—formaldehyde is often higher than that of traditional engine [4]. Formaldehyde emissions are very harmful to the environment and human health. Animal experiments have confirmed that it can cause nasal squamous cell carcinoma in rats, and its impact on human health is mainly manifested in abnormal smell, irritation, allergies, abnormal lung function, abnormal liver function and abnormal immune function [5]. When the concentration of formaldehyde in the air reaches 30mg/m3, it will cause death immediately. At present, people's understanding of the test methods, test standards and emission value of formaldehyde in automobile emissions is far from a deep understanding of the hazards of formaldehyde, and some people even predict the development prospects of alcohol fuels based on this. Therefore, it is very necessary to carry out research on the detection and analysis methods of formaldehyde in the exhaust of alcohol fuel engines.

* Corresponding author e-mail: lishigang2523@163.com.

Based on this, the paper analyzes the formaldehyde emission in engine exhaust under different working conditions and different fuels and obtains a large amount of regular test data. This method does not require any pre-treatment of engine exhaust and can be directly sampled and analyzed. The operation is simple and fast, which has laid an important foundation for further improvement of alcohol fuel engines and further study of the main unconventional emissions-formaldehyde under different catalytic conditions.

2. Feasibility Analysis of Methanol as a Fuel for Automobiles

Methanol is a colorless, transparent, volatile, and flammable liquid. Methanol is toxic, with low calorific value, high latent heat of evaporation, good anti-knock performance, and high oxygen content. In addition, methanol is prone to phase separation in the presence of a small amount of water [6]. The physical and chemical properties of methanol and gasoline are compared in Table 1.

Methanol can be directly used as the fuel of internal combustion engine with the following good characteristics [7-11]:

1. Methanol has small molecular weight and simple molecular structure. Methanol fuel contains oxygen, which is 50% oxygen in terms of mass, which is conducive to complete combustion. Small C/H is conducive to more water and less CO_2 during combustion.
2. The boiling point and freezing point of methanol are both low, the former is conducive to the formation of fuel-air mixture, while the latter can ensure the engine to work at a low temperature.
3. Compared with gasoline, the calorific value of methanol is relatively low, while the latent heat of vaporization is 3.6 times that of gasoline. Therefore, with the same thermal efficiency, the effective mass fuel consumption rate of methanol is high, and the high latent heat of vaporization can improve the internal cooling of the engine after combustion, improve the engine's power performance, and reduce the exhaust temperature.
4. Methanol has a higher-octane number and a higher anti-knock performance, and a wider ignition limit than gasoline. It can appropriately improve the compression ratio to improve the thermal efficiency, and it can also burn in a thinner mixture state, which is very beneficial to exhaust purification and fuel consumption reduction.
5. Methanol has a higher ignition point than gasoline, which is less prone to fire accidents and safer than gasoline.
6. Methanol gasoline is liquid under normal temperature and pressure, which is easy to operate and convenient to store.

Table1. Physical and chemical properties of alcohol fuel

Name		Methanol	gasoline
Chemical formula		CH_3OH	C_4～C_{12} hydrocarbon compounds
Molecular weight		32	95～120
Quality ingredients	Carbon content (mass ratio %)	37.5	85～88
	Hydrogen content (mass ratio %)	12.5	12～15
	Oxygen content (mass ratio %)	50.0	0
20℃ density (kg/L)		0.791	0.72～0.75
Theoretical air-fuel ratio (mass ratio)		6.47	14.7
Reid vapor pressure (37.8℃) (MPa)		0.037	0.05～0.09
Boiling point (℃)		64.5	30～190
Freezing point (℃)		-97.8	-57
Flash point (℃)		11	43
Auto-ignition temperature (℃)		470	260～370
Solubility in water (mg/L)		mutually soluble	100～200
Latent heat of vaporization (kJ /kg)		1109	310
Fuel low heating value (MJ/kg)		19.92	44.52
Octane number	Research Method (RON)	112	84～96
	Motor Method (MON)	92	70～84

After methanol is mixed with gasoline in a certain proportion and a certain additive is added to form the blended fuel, low-proportion methanol gasoline, such as M3 and M5, can be used like gasoline without any changes to the engine. In Europe and other places, a large number of methanol gasoline has been sold, but it is generally necessary to add auxiliary solvents to prevent fuel stratification; Medium proportion methanol gasoline, such as M15, M25, the engine only needs to be slightly adjusted, the technical problem is relatively simple, as it has been demonstrated in some international teams in Europe, but solvent must be added; high proportion methanol gasoline, such as M85 and M90, needs to modify and optimize the engine, and its power, emission and thermal efficiency are better than the original gasoline engine [12]. At present, methanol production technology, special methanol fuel vehicle technology with high combustion ratio and pure methanol fuel are relatively mature, and the market supply is relatively sufficient. Moreover, high proportion methanol fuel has been commercialized abroad [13]. However, methanol gasoline still has serious problems in toxicity, metal corrosion and other aspects. It is necessary to organize a comprehensive, systematic and scientific feasibility demonstration on methanol gasoline for vehicle use.

3. Unconventional Emission -- Formaldehyde Emission Test

In the process of this paper, the test data are mainly measured under partial load characteristic test of engine. Start from small load, gradually increase the throttle, appropriate distribution of more than 6 measurement points [14-16]. At each measurement point, the output torque, power, exhaust temperature and so on of the engine are recorded after the engine is running steadily for 1min.During engine operation or data recording, the difference between the engine speed and the selected speed should be no more than ± 1% or ±10 r/min, and the larger value should be taken. At the same time, data such as torque and power are recorded, and the average value of two consecutive stable values is taken. The difference between the two measured values of torque should be less than 2% [17, 18].

3.1. Test instruments and equipment

1. Formaldehyde collection device

The method of collecting formaldehyde in this test is to use the property of formaldehyde to be miscible with water at will and let the engine exhaust pass through a specific absorption device and mixing device to collect the formaldehyde in the exhaust gas.

2. Formaldehyde analyzer

The formaldehyde analyzer used in the test is GDYK-201S indoor air formaldehyde analyzer developed by Changchun Jida Cygnet Instrument Co., Ltd. The instrument consists of a silicon light source, a colorimetric bottle, an integrated photoelectric sensor and a microprocessor, which can directly display the content of formaldehyde in the measured sample on the LCD screen (mg/L), substitute the sampling volume, temperature and pressure, etc., to get the final formaldehyde emission (mg/m^3).

3.2. Experimental fuel

The main fuels used in this test are: RON93 gasoline currently sold on the market in Northwest China,RON93 gasoline refers to gasoline with an octane number of 93; Methanol, pure analysis, purity above 99.5%, Xi 'an Chemical Reagent Factory production; Ethanol, pure analysis, purity 99.7% above, Xi 'an chemical reagent factory production.

In the test, M15, M25, M85, E10, E25 and ED10 were prepared by volume percentage.

3.3. Formaldehyde-emission detection of bench test

The test gasoline engine is the Flyer M-TCE engine, gasoline injection closed-loop control, 0.8L, four-stroke water cooling. The test was conducted for formaldehyde test at engine speed of 2600r/min and different power [19]. The test results are shown in Table 2 to Table 5.

Table2. Bench test results of formaldehyde emission from RON93 gasoline

Serial number	Throttle opening	Torque	Power	Formaldehyde test value	Formaldehyde emission
	%	N•m	kW	mg/L	mg/m^3
1	20	10.7	2.9	0.47	6.542
2	25	20.3	5.5	0.52	7.245
3	30	33.6	9.1	0.51	7.111
4	35	42.2	11.6	0.48	6.699
5	40	48.7	13.2	0.46	6.424
6	50	55.4	15.0	0.45	6.293

Table 3. Bench test results of formaldehyde emissions from M15 methanol gasoline

Serial number	Throttle opening	Torque	Power	Formaldehyde test value	Formaldehyde emission
	%	N•m	kW	mg/L	mg/m^3
1	20	19.2	5.2	0.52	7.225
2	25	27.5	7.5	0.54	7.503
3	30	37.3	10.2	0.56	7.781
4	35	43.3	11.8	0.52	7.225
5	40	49.3	13.4	0.49	6.809
6	50	55.4	15.1	0.48	6.670

Table 4. Bench test results of formaldehyde emissions from M25 methanol gasoline

Serial number	Throttle opening	Torque	Power	Formaldehyde test value	Formaldehyde emission
	%	N•m	kW	mg/L	mg/m^3
1	20	12.0	3.8	0.58	8.100
2	25	28.0	7.6	0.73	10.212
3	30	36.0	9.8	0.75	10.503
4	35	43.9	12.0	0.56	7.847
5	40	48.8	13.3	0.53	7.439
6	50	54.0	14.7	0.51	7.166

Table 5. Bench test results of formaldehyde emissions from M85 methanol gasoline

Serial number	Throttle opening	Torque	Power	Formaldehyde test value	Formaldehyde emission
	%	N•m	kW	mg/L	mg/m^3
1	20	14.0	3.6	0.67	9.373
2	25	27.6	7.7	0.90	12.603
3	30	37.4	10.2	0.83	11.631
4	35	43.5	11.8	0.68	9.545
5	40	48.5	13.2	0.64	8.992
6	50	53.7	14.6	0.52	7.311

3.4. Formaldehyde emission detection in vehicle test

The vehicle used in the test was Chang'an star SC6360H, and its main technical parameters are shown in Table 6.

Table 6. Main technical parameters of Chang'an star SC6360H

Length/width/height	3600/1475/1925 mm	Wheelbase	2350 mm
Track front/back	1280/1290 mm	Seat number	5-8
Full Vehicle Readiness Quality	990 kg	Full load total mass	1575kg
Engine Model	JL465Q5	Displacement	1012 mL
Rated power	39 kW	Maximum torque	78 N·m
Maximum speed	≥105 km/h	100 km fuel consumption	≤6.4 L/100 km
Maximum gradient	≥30 %	Type of transmission	5 speed synchronization
Driving Type	Rear wheel drive	Braking mode	Front disc, rear drum, double circuit hydraulic pressure
Front suspension	McPherson independent suspension	Rear suspension	5 leaf springs
Tyre type	155E13LT	-----	-----

The main instruments and equipment used in the test are shown in Table 7.

Table 7. Instruments and equipment used in vehicle test

Device name	Model	Manufacturer
Chassis dynamo meter	1Axle48-inline	AVL, Austria
In-situ formaldehyde analyzer for indoor air	GDYK-201S	Changchun Ji Swan Instrument Co., Ltd.
Formaldehyde meter sampling system	-----	Self developed

The test is the detection of formaldehyde emissions of several fuels at different speeds and different gears. The test data are shown in Table 8 to Table 10.

Table 8. Vehicle test RON93 gasoline formaldehyde emission results

Serial number	Speed	Gear position	Formaldehyde test value	Formaldehyde emission
	Km/h		mg/L	mg/m^3
1	30	3	0.68	9.689
2	40	3	0.70	9.991
3	50	4	0.79	11.290
4	55	4	0.85	12.172
5	65	5	0.77	11.052
6	75	5	0.80	11.509
7	85	5	0.80	11.535

Table9. Vehicle test M15 methanol gasoline formaldehyde emission results

Serial number	Speed	Gear position	Formaldehyde test value	Formaldehyde emission
	Km/h		mg/L	mg/m^3
1	30	3	0.72	10.361
2	40	3	0.95	13.680
3	50	4	1.07	15.438
4	55	4	0.98	16.507
5	65	5	0.94	15.859
6	75	5	0.91	15.378
7	85	5	0.92	15.572

Table 10. Vehicle test M85 methanol gasoline formaldehyde emission results

Serial number	Speed	Gear position	Formaldehyde test value	Formaldehyde emission
	Km/h		mg/L	mg/m^3
1	30	3	0.80	13.519
2	40	3	0.92	15.547
3	50	4	0.95	16.054
4	55	4	1.00	16.916
5	65	5	0.98	16.588
6	75	5	0.80	13.550
7	85	5	0.76	12.885

4. Experimental Results and Comparative Analysis

The emission levels of formaldehyde when the engine burns different fuels are shown in Figure 1 to Figure 4.

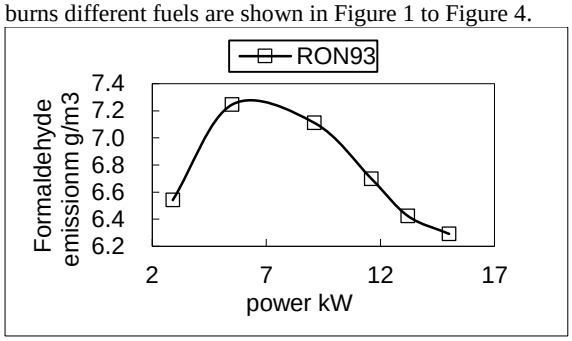

Figure 1. RON93 gasoline formaldehyde emission

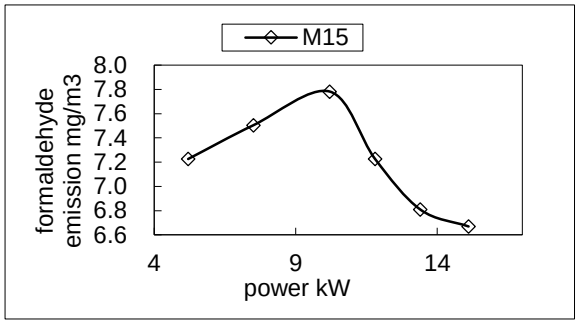

Figure 2. M15 methanol gasoline formaldehyde emission

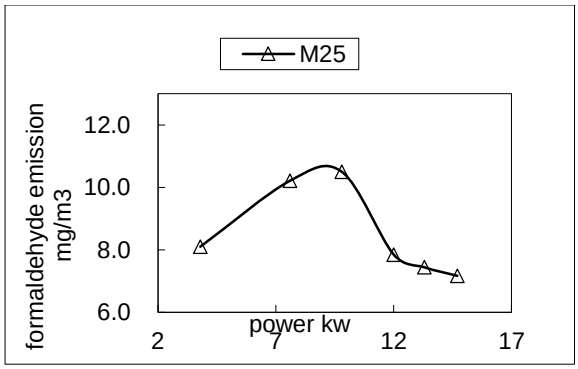

Figure 3. M25 methanol gasoline formaldehyde emission

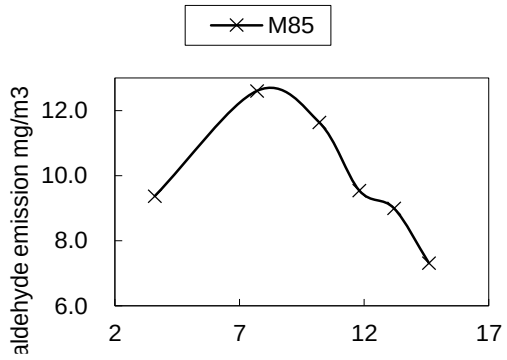

Figure 4. M25 methanol gasoline formaldehyde emission

4.1. Influence of methanol content on results

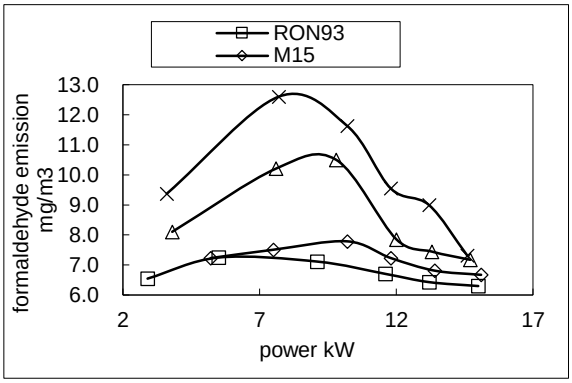

Figure 5. Comparison of Methanol Gasoline and RON93 Formaldehyde Emissions

As can be seen from Figure 5, with the increase of methanol content in the fuel, the emission of formaldehyde is generally increasing. Moreover, at the same speed, with the increase of throttle opening, the formaldehyde emission generally shows a trend of first rising and then falling, and the formaldehyde emission is the largest near the throttle opening of 30%. The reason is that in the case of small load, the amount of mixture filled in the engine cylinder is less, the combustion is more complete, and the emission of formaldehyde is less. The decrease of formaldehyde emission under heavy load is mainly due to the rise of temperature, and high temperature is not conducive to the formation of formaldehyde. This is also verified by analyzing formaldehyde emission concentration at different sampling points in the exhaust system.

Table 11 shows the comparison of the maximum, minimum and average formaldehyde emission of the selected fuels within the range of engine test conditions. It can also be seen that the emission of formaldehyde shows a gradual rising trend with the increase of methanol or ethanol in the fuel.

Table 11. Comparison of formaldehyde emission averages of several fuels

Fuel	Maximum value	minimum value	average value
RON93	7.11	6.29	6.72
M15	7.78	6.67	7.20
M25	9.80	7.12	8.31
M85	11.07	7.31	9.49

5. Conclusion

Through the experimental study, the following conclusions are drawn:

1. When the engine uses gasoline and alcohol fuel, formaldehyde pollutants are present in the exhaust gas.
2. When the engine uses a mixed fuel of alcohol and gasoline, as the alcohol content in the mixed fuel increases, the amount of formaldehyde emissions in the exhaust also increases.

3. When the engine uses gasoline and alcohol fuels, formaldehyde emissions first increase and then decrease with the increase of load.
4. The combustion characteristics and combustion speed of M85 methanol gasoline are similar to that of RON93 gasoline, which can be used as fuel for ignition engine, and has good energy-saving and environmental protection characteristics.
5. M85 methanol gasoline has a very strong anti-knock performance, and its octane number is about 103. When M85 methanol gasoline is used as fuel, the engine runs smoothly with extremely low noise.
6. Due to the limitation of adjustment of the oxygen sensor of the engine, the adaptability of the engine is poor when using methanol gasoline above M50, or even the engine may not work. In order to ensure the good combustion of the engine, it is very necessary to develop the flexible fuel controller, which is beyond the scope of this article.

The analysis of formaldehyde emissions from alcohol fuel vehicle engines is a multi-disciplinary technology. In the actual test process, few successful experiences can be used for reference. Each step is done in trial and exploration. Although a complete measurement and analysis system has been established in the end, there are still many shortcomings, which need to be improved in some areas.

References

[1] Han, J.X, "Research on the prevention and control policies of automobile exhaust pollution in Beijing". North China Electric Power University, 2016.

[2] H.R. Chao, T.C. Lin, "Effect of methanol-containing additive on the emission of carbonyl compounds from a heavy-duty diesel engine". Hazardous Materials, 2000, 39-54.

[3] M.F. Othman, A. Adam, G. Najafi, R. Mamat, "Green fuel as alternative fuel for diesel engine: A review". Renewable and Sustainable Energy Reviews, Vol. 80, 2017, 694-709.

[4] V.A. Likhanov, O.P. Lopatin, "Study on toxicity of biodiesel engine running on alcohol". No. 25, 2019, 92-100.

[5] J.F. Wang, C.J. Shi, "Aldehydes and ketones in vehicle engine emissions". Shanghai Automobile, 1999, 31-33.

[6] X. Wang, Y.J. Guo, J.J. Zhang, "Comparison of properties of methanol, gasoline and methanol gasoline as internal combustion engine fuel". Chemical Industry Times, No. 3, 2005, 46-49.

[7] F. Yüksel, B. Yüksel, "The use of ethanol-gasoline blend as a fuel in an SI engine". Renewable Energy, No. 29, 2004, 1181-1191.

[8] O.M. Ali, R. Mamat, N.R. Abdullah, A.A. Abdullah, "Analysis of blended fuel properties and engine performance with palm biodiesel-diesel blended fuel". Renewable Energy, Vol. 86, 2016, 59-67.

[9] A.K. Agarwal, H. Karare, A. Dhar, "combustion, performance, emissions and particulate characterization of a methanol-gasoline blend (gasohol) fuelled medium duty spark ignition transportation engine". Fuel Processing Technology, Vol. 121, 2013, 16-24.

[10] X.M. Zhang, "Feasibility and prospect of methanol automobile industrialization in China under the constraint of energy environment". China University of Geosciences, 2017.

[11] X. Wang, Y.G. Guo, J.J. Zhang, "Comparison of properties of methanol, gasoline and methanol gasoline as internal combustion engine fuel". Chemical Industry Times, No. 3, 2005, 46-49.

[12] K.R. Pan, "The development and evaluation of methanol fuel vehicles". Commercial Automobile, No. 6, 1999, 6-10.

[13] L.Q. Dou, L.H. Zhang, "The situation of methanol and alternative fuel engine vehicles in Japan and Germany". No. 2, 2002, 7-9.

[14] M.F. Aly, I.H. Afefy, R.K. Abdel-Magied, E.K.A. Elhalim, "A comprehensive model of reliability, availability, and maintainability (RAM) for industrial systems evaluations". Jordan Journal of Mechanical and Industrial Engineering, Vol. 12, No. 1, 2018, 59-67.

[15] E. Rezaei, M. Poursina, M. Rezaei, A. Ariaei, "A new analytical approach for crack modeling in spur gears". Jordan Journal of Mechanical and Industrial Engineering, Vol. 13, No. 2, 2019, 69-74.

[16] GB/T 18297-2001, Performance test code for road vehicle engines. Beijing: State Administration of Machinery Industry, 2001.

[17] GB/T 17692-1999, Measurement methods of net power for automotive engines. Beijing: State Administration for Market Regulation, 1999.

[18] R.K. Maurya, A.K. Agarwal, "Experimental investigations of performance, combustion and emission characteristics of ethanol and methanol fueled HCCI engine". Fuel Processing Technology, Vol. 126, 2014, 30-48.

[19] Liu, D.D, "Study on measurement method of methanol content and formaldehyde emission in alcohol fuel". Chang'an University, 2008.