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Effect on gasoline engine emission characteristics of variable composition oxygen-enriched intake air

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ABSTRACT

In this paper, taking air-cooled, four-stroke, single cylinder gasoline engine as the research object, oxygen-enriched intake air systems and gasoline engine performance test bed was built. In the range of 21% to 26% enrichment ratio, based on MAP chart of variable component enriched intake, control parameters was adjusted according to the PWM principle, mixture gas of different oxygen and nitrogen components was prepared for the test engine. Under the conditions of different components intake air, an HC, CO and NOx emission characteristic of gasoline was comparatively analyzed through universal characteristic test. The results show that the lowest HC emissions and CO emissions under conditions of variable component of the oxygen-rich intake air were reduced by 17.59% and 17.14% compared with the normal intake, the lowest NOx emissions was 53×10^{-6}, it increased 7.55%. Under conditions of variable component oxygen-rich intake air, HC and CO emissions of gasoline engine significantly reduced, NOx emissions deteriorated slightly, which improved relatively integrated emission performance of gasoline engine.

KEYWORDS

Variable composition; Oxygen-enriched intake air; Gasoline engine; Emission; Universal characteristic.

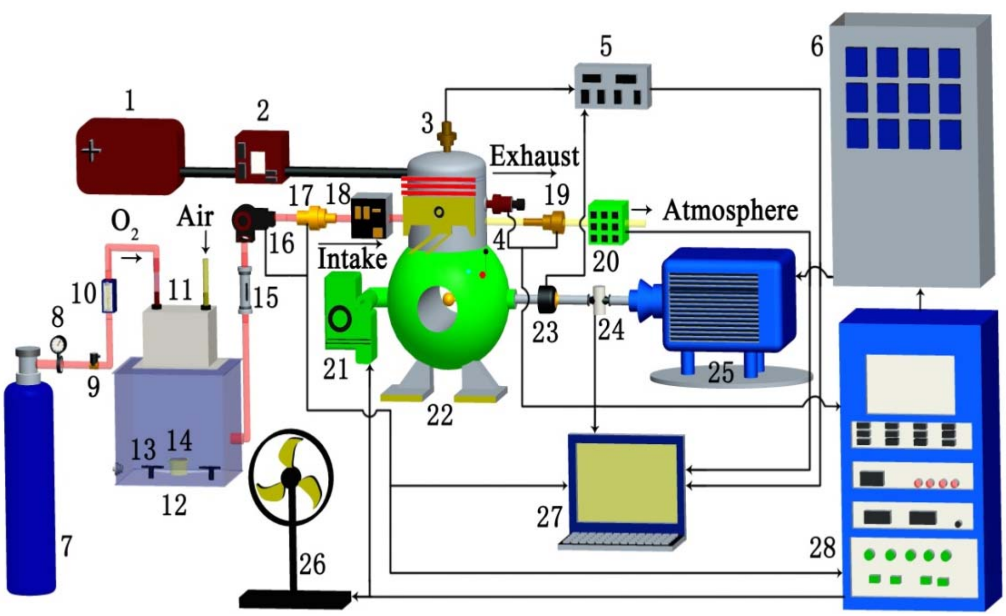
INTRODUCTION

Nitrogen-based flame-retardant component and oxygen-based combustion component constitute flame-retardant and combustion-supporting characteristics constrained engine combustion[1]. Combustion control of variable component intake is an active control method proposed to save fuel for the engine, strengthen power and improve the emissions, and it of is a new way to achieve energy savings[2,3]. Variable component oxygen-rich intake air can directly affect the combustion characteristics and the working process of the engine, effectively improve engine combustion temperatures, decrease ignition delay and promote fuel combustion[4,5]. Meanwhile, it can effectively improve output power of the engine, reduce its fuel consumption and improve its dynamic performance and economic performance[6]. It can reduce CO and HC emission produced from incomplete combustion, but it will also lead to the deterioration of NOx emissions[7,8].

Commonly membrane-enriched and oxygen cylinders was used to achieve enriched-oxygen intake air of the engine, but the oxygen-rich air intake components provided is not stable, it is difficult to fully grasp the actual working conditions and performance parameters of engine[9-11]. In this paper, taking air-cooled, four-stroke, single cylinder gasoline engine as the research object, oxygen-enriched intake air systems and gasoline engine performance test bed was built. Which prepare different components of oxygen and nitrogen enriched for the test engine, precise control of oxygen concentration ensure that the engine can be stable operation under conditions of the target component, to analysis HC, CO and NOx emission characteristics of gasoline engine.

BUILDING TEST BED OF OXYGEN-ENRICHED INTAKE AIR

Oxygen-enriched intake air test bed of gasoline engine was composed by air-cooled, four-stroke, single cylinder gasoline engine, gas distribution systems, fuel tank, smart fuel consumption, cylinder pressure sensor, cylinder temperature sensor, combustion analyzer, control cabinet, oxygen bottles, oxygen bottle pressure reducer, oxygen flow control valve, oxygen flow meter, pre-mixing chamber, gas chamber, gas mixing fan, temperature hygrometer, gas flow meter, etc. The structure of test bed was shown in Figure 1, and key technical parameter of test engine was listed in TABLE 1.



1-fuel tank, 2-smart fuel consumption, 3-cylinder pressure sensor, 4-cylinder temperature sensor, 5-combustion Analyzer, 6-control cabinet, 7-oxygen bottles, 8-oxygen bottle pressure reducer, 9-oxygenflow control valve, 10-oxygen flow meter, 11-pre-mixing chamber, 12-gas chamber, 13-gas mixing fan, 14-temperature hygrometer, 15-gas flow meter, 16-throttle position sensor, 17-intaketemperature sensor, 18-oxygen analyzer, 19-exhaust gas temperature sensor, 20-exhaust gas analyzer, 21-throttle actuator, 22-engine, 23-incremental encoder, 24-speed torque sensor, 25-DC electric dynamometer, 26-cooling fan, 27-monitor and collection system, 28-engine automatic monitoring and control system.

Figure 1 : Diagram of Oxygen-enriched intake air test bed

TABLE 1 : The key technical parameters of engine test

Parameters	index	Parameters	index
Cylinder diameter route/mm	56.5×49.5	max power/kW	7.5/(7500 r/min)
Displacement/mL	124	rated power/kW	6.5/(6500 r/min)
Compression ratio	9:1	max torque/(N·m)	8.5(5500 r/min)
Fuel	93#Gasoline	Max Speed/ r/min	8500

PREPARATION OF VARIABLE COMPOSITION OXYGEN-ENRICHED INTAKE AIR

Valve-train

Valve-train is an important part of oxygen-enriched intake air test bed of gasoline engine, it was composed by pre-mixing chamber, gas chamber, oxygen bottle, oxygen bottle regulator, and oxygen flow control valve, oxygen flow meter, mixing fan, temperature hygrometer, gas flow meter, oxygen analyzer and oxygen intake monitoring system. The main instruments and types were shown in TABLE 2. Among them, the monitoring system of oxygen-rich intake air consists of a microprocessor, PC host computer, programmable DC power supply, crystal oscillator circuit, PC control unit, data acquisition unit and the communication unit, etc. Mainly electronic components and types were shown in TABLE 3.

TABLE 2 : Main instrument and type of rich oxygen intake and valve system

Name	Type	Name	Type
Oxygen bottle	QR1114X-40	Oxygen analyzer	KY-2F
Oxygen bottle regulator	QD-3A	Gas flow meter	EF80
Oxygen flow control valve	PVD1-08D	Mixing fan	8025
Oxygen flow meter	GR-LUGB	Temperature hygrometer	TH603A

TABLE 3 : Main electronic component and type

No.	Name	Type
1	Programmable DC power	IPD-3303SLU
2	Microprocessor	MC9S12DP256
3	PC host computer	IBM-R400
4	Data acquisition unit	PCI1710L

The oxygen-enriched proportion of intake air

Using valve-train to prepare oxygen-enriched intake air of different components of oxygen and nitrogen for the test engine, industrial oxygen whose purity was higher than 99.2%, and filling pressure was 13 ± 0.5 MPa, was provided by oxygen bottles. After its pressure drops to standard atmospheric pressure by oxygen cylinder regulator, it was passed into the pre-mixing chamber; another inlet of the pre-mixing chamber was connected to the atmosphere. Using a plurality of mixing fans, industrial oxygen and air are premixed in a pre-mixing chamber, and then it was passed into the gas chamber to mix sufficiently. By oxygen flow meter and oxygen flow meter control valve, the flow of industrial oxygen and proportion of intake oxygen concentration were controlled precise to form the target variable component mixing gas of oxygen-enriched intake air. Then it was naturally aspirated way to provide the test engine. Based on the pulse-width modulation (PWM) principle, using MC9S12DP256 microprocessors, by matching duty ratio to control on or off of oxygen flow control valve. Precise control of industrial oxygen flow and proportion of intake oxygen concentration of the engine prepare intake air for the test gasoline engine under different conditions.

Oxygen-enriched intake air can promote rapid ignition, shortened delay period, increase burning speed, accelerate low-temperature burning, rise combustion temperature and promote fully combustion, which have a significantly effect on power, economy and emissions performance of gasoline engine. When the proportion of oxygen-enriched intake air increased to a certain extent, the amplitude of flame temperature in cylinder gradually slowed, but the corresponding costs of continuing to increase the oxygen-enriched proportion has increased significantly. If the proportion of oxygen-enriched is too high, it can cause knocking of the engine, unstable output torque and deterioration of NOx emissions, etc. The selected proportion of oxygen-enriched intake was 22% ~ 26% in this paper.

Principle of of variable composition oxygen-enriched intake air

According to the PWM principle, adjusting the period and single-period on-time of oxygen flow control valve match oxygen concentration control amount of target compound for each node, and the matching results were shown in TABLE 4. Corresponding period and the control amount of single-cycle on-time were shown in TABLE 5, the MAP chart of variable component oxygen-rich intake air was shown in Figure 2. By the PC host computer, the MAP chart of oxygen-enriched intake air, the corresponding period of oxygen flow control valve and to single-period on-time previously were stored in MC9S12DP256 microprocessor. During actual engine operation, the operating condition of the engine was determined in accordance with various sensor acquisition speed, throttle opening degree, etc. According to MAP chart of oxygen-enriched intake air, the basic control volume of oxygen concentration can be obtained. Adjusting the control parameters of PWM and controlling flow of industrial oxygen provide a stable oxygen-enriched intake of target component for test gasoline engine.

TABLE 4 : Duty ratio match of MAP control amount under condition of variable components oxygen-rich intake air

Throttle opening degree (%) N (r/min)	0		20		40		60		80		100	
	Oxygen (%)	Duty ratio (%)	Oxygen (%)	Duty ratio (%)	Oxygen (%)	Duty ratio (%)	Oxygen (%)	Duty ratio (%)	Oxygen (%)	Duty ratio (%)	Oxygen (%)	Duty ratio (%)
1500	22	1.82	22	2.00	23	2.32	23	2.55	24	2.78	24	2.94
2500	22	1.94	22	2.19	23	2.44	24	2.67	24	2.89	25	3.18
3500	22	2.19	22	2.38	24	2.71	24	2.76	25	3.06	25	3.29
4500	22	2.29	23	2.53	24	2.75	25	2.95	25	3.18	26	3.56
5500	22	2.31	23	2.74	24	2.82	25	3.22	26	3.50	26	3.76
6500	22	2.40	23	2.94	25	3.25	26	3.44	26	3.87	26	4.13
7500	22	2.50	24	3.22	25	3.50	26	4.12	26	4.29	26	5.43
8500	22	3.47	24	4.47	25	4.83	25	5.14	26	6.83	26	7.64

TABLE 5 : Period and single-period on-time of MAP controlled amount under variable component oxygen-enriched intake air

Throttle opening degree (%) n (r/min)	0		20		40		60		80		100	
	T (ms)	t (ms)	T (ms)	t (ms)	T (ms)	t (ms)	T (ms)	t (ms)	T (ms)	t (ms)	T (ms)	t (ms)
1500	1100	20	1050	21	950	22	1100	28	900	24	850	25
2500	1800	35	1050	23	900	22	1050	28	900	26	850	27
3500	1600	35	1050	25	850	23	1050	29	850	26	850	28
4500	1400	32	950	24	800	22	950	28	850	27	900	32
5500	1300	30	950	26	850	24	900	29	800	28	850	32
6500	1250	30	850	25	800	26	900	31	750	29	800	33
7500	1200	30	900	29	800	28	850	35	700	30	700	38
8500	1500	52	850	38	600	29	700	36	600	41	550	42

***T stands for period, t stands for single-period on-time.**

EMISSION CHARACTERISTIC TEST ANALYSIS OF GASOLINE ENGINE

According to test methods of engine universal characteristic reported in national standards, "car engine performance test method (GB / T 18297-2001)", under the condition of oxygen-rich ratio of 22% to 26%, universal characteristic test of HC, CO, NOx emissions was conducted. 1500 r/min, 2500 r/min, 3500 r/min, 4500 r/min, 5500 r/min, 6500 r/min, 7500 r/min and 8500 r/min was selected, and 0%, 20%, 40 %, 60%, 80% and 100% load point was selected. Normal intake air and variable component oxygen-enriched intake air were used, respectively. Oxygen volume fraction was 21% under condition of normal intake air, and Oxygen volume fraction can be calculated by the MAP chart shown in Figure 2 under condition of variable component oxygen-enriched intake air. After the gasoline engine is stable, HC, CO, NOx emissions was measured and comparative analyzed, controlled amount of MAP and the corresponding experimental data were shown in TABLE 6 and TABLE 7.

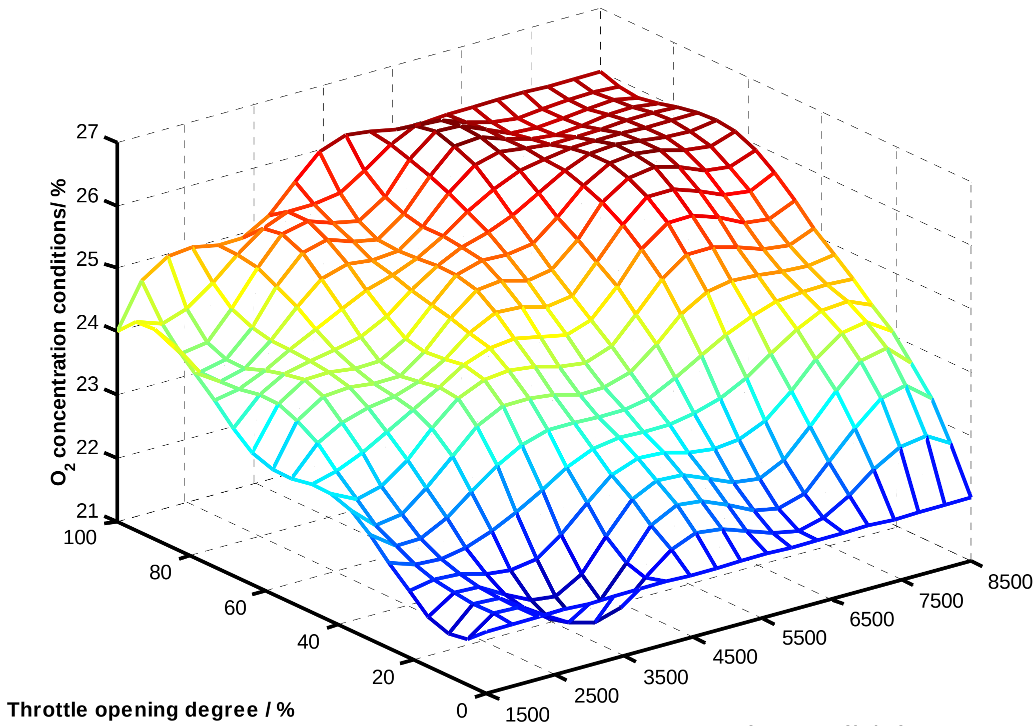


Figure 2 : MAP figure of variable composition oxygen-enriched intake air

TABLE 6 : Controlled quantity and HC emission of variable composition oxygen-enriched intake air

Throttle opening degree (%) N (r/min)	0		20		40		60		80		100	
	HC emission ($\times10^{-6}$)	Oxygen (%)	HC emission ($\times10^{-6}$)	Oxygen (%)	HC emission ($\times10^{-6}$)	Oxygen (%)	HC emission ($\times10^{-6}$)	Oxygen (%)	HC emission ($\times10^{-6}$)	Oxygen (%)	HC emission ($\times10^{-6}$)	Oxygen (%)
1500	129	22	109	22	96	23	94	23	110	24	135	24
2500	126	22	105	22	93	23	91	24	106	24	132	25
3500	123	22	102	22	92	24	89	24	103	25	130	25
4500	125	22	103	23	94	24	92	25	107	25	133	26
5500	130	22	104	23	97	24	95	25	110	26	135	26
6500	133	22	107	23	99	25	97	26	112	26	137	26
7500	136	22	110	24	102	25	100	26	115	26	139	26
8500	139	22	113	24	104	25	102	25	117	26	142	26

TABLE 7 : CO and NO_x emission

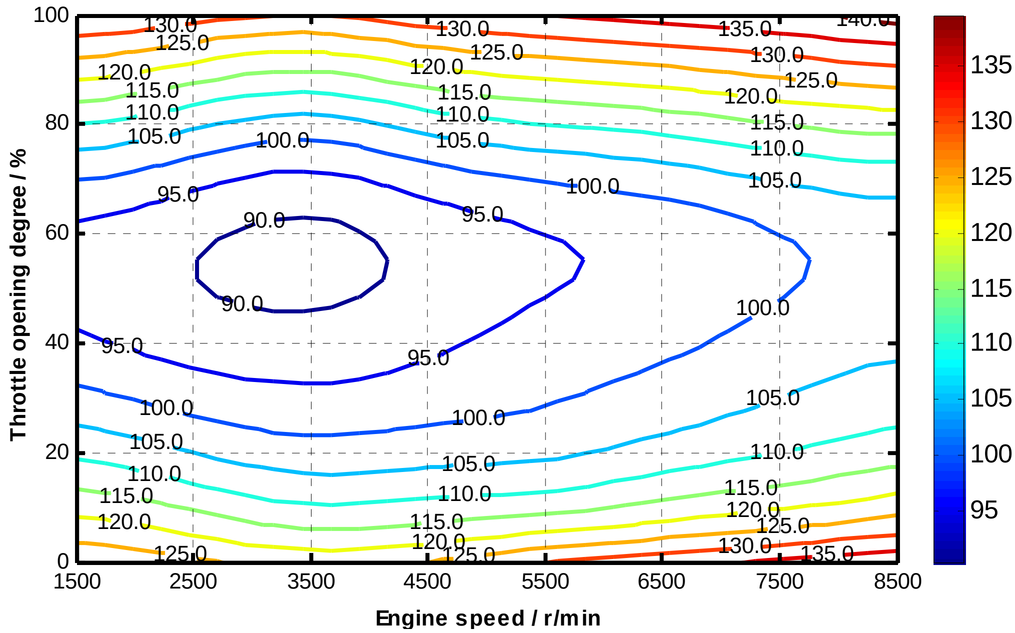
Throttle opening degree (%) n (r/min)	0		20		40		60		80		100	
	CO emission (%)	NO_x emission ($\times10^{-6}$)	CO emission (%)	NO_x emission ($\times10^{-6}$)	CO emission (%)	NO_x emission ($\times10^{-6}$)	CO emission (%)	NO_x emission ($\times10^{-6}$)	CO emission (%)	NO_x emission ($\times10^{-6}$)	CO emission (%)	NO_x emission ($\times10^{-6}$)
1500	1.03	57	0.88	126	0.73	182	0.65	230	0.76	264	1.17	275

2500	1.12	66	0.96	131	0.83	188	0.71	239	0.87	275	1.21	283
3500	0.94	80	0.79	145	0.70	198	0.61	246	0.73	282	1.09	291
4500	0.87	89	0.72	160	0.63	217	0.55	261	0.66	290	1.01	296
5500	0.78	83	0.65	152	0.54	203	0.48	250	0.58	285	0.94	294
6500	0.67	76	0.60	145	0.49	193	0.40	244	0.52	278	0.83	286
7500	0.59	68	0.46	128	0.40	187	0.34	237	0.44	270	0.79	279
8500	0.53	63	0.42	122	0.34	181	0.29	230	0.35	269	0.72	274

HC emission analysis

Taking rotational speed (r/min) as the x-axis, throttle opening degree (%) as y-axis, the universal characteristic curve of HC emissions was shown in Figure 3.

As can be seen from TABLE 6 and Figure 3, the high HC emissions are mainly concentrated in the middle and high speed zone of low load conditions and large load zone. Part of load operating conditions, HC emission was lower, which reflected better HC emissions of engine. Minimum HC emissions was 89×10^{-6}, when the throttle opening was 60%, and rotate speed was 3500 r/min at part load conditions. Compared with the minimum emissions of normal intake air (108×10^{-6}), it decreased 17.59%, and the decline extent was very significant.

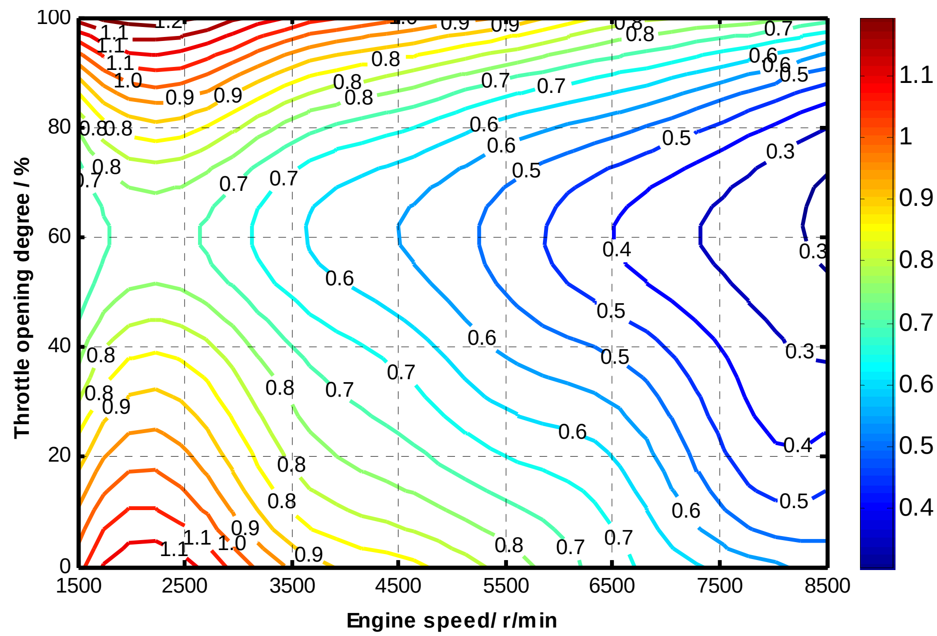


Note: The values marked in the figure represent HC emission (10^{-6}).

Figure 3 : Universal characteristic curve of HC emission

CO emission analysis

Taking rotational speed (r/min) as the x-axis, throttle opening degree (%) as y-axis, the universal characteristic curve of CO emissions was shown in Figure 4.



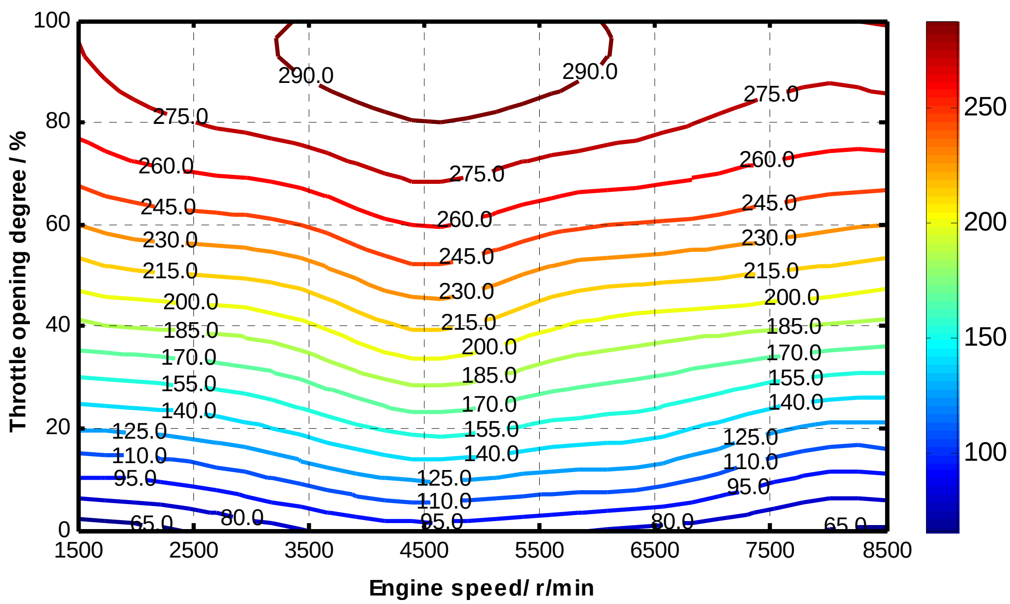
Note: The values marked in the figure represent CO emission (%).

Figure 4 : Universal characteristic curve of CO emission

As can be seen from TABLE 7 and Figure 4, the high CO emissions are mainly concentrated in the low speed zone of low load conditions and large load conditions. Part of load operating conditions, CO emission was lower, which reflected better CO emissions of engine. Minimum CO emissions was 0.29%, when the throttle opening was 60%, and rotate speed was 8500 r/min at part load conditions. Compared with the minimum emissions of normal intake air (0.35%), it decreased 17.14%, and the decline extent was very significant.

NO_x emission analysis

Taking rotational speed (r/min) as the x-axis, throttle opening degree (%) as y-axis, the universal characteristic curve of NOx emissions was shown in Figure 5.



Note: The values marked in the figure represent NOx emission (10^{-6}).

Figure 5 : Universal characteristic curve of NO_x emission

As can be seen from TABLE 7 and Figure 5, the high NO_x emissions are mainly concentrated in the middle speed zone of large load conditions. However, emission values increase in modest compared with the normal condition. Under condition of small load conditions, NO_x emission was lower. Minimum NO_x emission was 56×10^{-6}, when the throttle opening was 0%, and rotate speed was 1500 r/min, compared with the minimum emissions of normal intake air (53×10^{-6}), it increased 17.59%, and the decline extent was not very significant.

CONCLUSIONS

(1)Under condition of Part load conditions, the HC and CO emission was lower. The lowest HC emissions was 89×10-6, when the throttle opening was 60%, and rotate speed was 3500 r/min, and the lowest CO emissions was 0.29%, when the throttle opening was 60%, and rotate speed was 8500 r/min. Compared with the minimum emissions of normal intake air, HC and CO emission decreased 17.59% and 17.14%, respectively.

(2)Under condition of small load conditions, NO_x emission was lower. Minimum NOx emission was 56×10^{-6}, when the throttle opening was 0%, and rotate speed was 1500 r/min. Compared with the minimum emissions of normal intake air (53×10^{-6}), it increased 17.59%, and the decline extent was not very significant.

(3)Variable component oxygen-enriched intake air can significantly reduce HC and CO emissions of gasoline, while deterioration of NO_x emission was not significant, which can improve the overall emission performance of gasoline engine.

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