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Experimental Research on Oxygen-enriched Air Supply System for Gasoline Engine

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Abstract: The paper designs and establishes a set of membrane oxygen-enriched air supply system. Experimental research is conducted for LTV-PS roll-type oxygen-enriched membrane module, results of which show that oxygen-enriched concentration is on the rise with the increase of pressure and air flow. Under normal operating temperature, the concentration of O_2 in membrane enriched air can reach 28.3 % when the operating pressure and air flow are respectively 102.7 kPa and 24 m^3/h. *Copyright © 2013 IFSA.*

Keywords: Membrane separation, Oxygen enrichment, Air supply system, Experiment.

1. Introduction

Power of automobile comes from heat energy emitted by fuel combustion within engine cylinder. When fuel combustion's heat energy provides power for engine, waste gas after the combustion will cause air pollution [1, 2]. In recent years, because of skyrocketing of oil price and environmental pollution caused by exhaust emission of automobiles, high requirements are imposed on combustion technology of engine. Therefore, from the perspective of engine combustion technology, experts and scientific research academies and institutes of all countries now make great effort to find out the most effective method that can improve engine power, reduce fuel consumption and exhaust pollution [3-6].

During combustion process of engine, the fuel can give off all heat only when it is under complete oxidation and combustion. It is easy to provide cylinder with sufficient fuel, but it is difficult to provide cylinder with sufficient oxygen for combustion. Therefore, it is believed that main factor for power level of engine lies in air (oxygen) amount instead of fuel supply for combustion. In this way, focusing on characteristics of engine combustion, certain technology that increases oxygen content in total air amount entering the cylinder can meet requirements of complete fuel combustion on oxygen content without change of engine displacement. Such technology will improve power performance and economic efficiency of engine without deteriorating emission, which is endowed with important research significance.

The paper applies the method of membrane separation to produce oxygen-enriched air and carries out experimental research on membrane oxygen-enriched air supply system so as to promote complete fuel combustion in engine and improve power performance and economic efficiency of the engine.

2. Experimental System

Oxygen-enriched air supply membrane experiment system applies one Φ100×1000 mm LTV-PS roll-type oxygen-enriched membrane module. Membrane material is polysulfone-silane rubber composite membrane, which brings better effect of oxygen enrichment. Ventilation property of oxygen enrichment is 1.0×10^{-12} $m^3/(m^2\cdot s\cdot Pa)$. Oxygen enrichment membrane apparatus is operated under vacuum conditions. Differential pressure of operation at two sides of the oxygen enrichment membrane will be maintained by air blower and vacuum pump. Experiential equipment can be seen in Fig. 1.

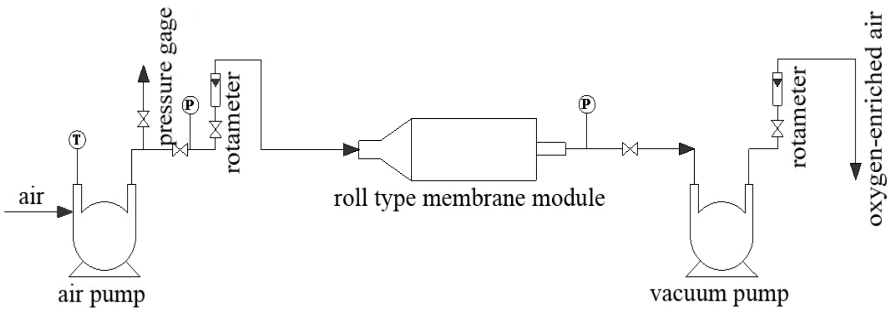

Fig. 1. Schematic diagram on oxygen-enriched air supply membrane experiment system.

When fresh air passes through filter, it will be transported to surface of high-pressure side of membrane module after mechanical impurity is removed. Vacuum pump is used for suction at low-pressure side of oxygen enrichment membrane. Gas discharged by vacuum pump is oxygen -enriched air. Impermeable gas discharged by membrane module is nitrogen-enriched air, which will be directly emitted into the atmosphere.

3. Experimental Results

Feed of experiment will be provided by air in the environment. Certain content of air enters membrane module and oxygen-enriched air will be obtained through membrane separation. After measurement, mass fractions of air are N_2 80.233 % and O_2 19.767 %. Feed quantity of air is 15 m^3/h.

Table 1. Oxygen enrichment operating parameters under different operating conditions after calibration.

Pressure for entering membrane, kPa	Pressure for exiting from membrane, kPa	Pressure ratio	Oxygen-enriched concentration, %	Flow for entering membrane, m^3/h	Amount of oxygen-enriched air, m^3/h
97.672	61.472	0.629	20.015	6.131	5.705
97.872	61.472	0.628	21.769	9.241	5.753
98.472	61.472	0.624	22.615	12.359	5.788
98.972	61.472	0.621	23.888	15.504	5.842
100.172	61.472	0.617	24.040	18.604	5.858
101.272	62.472	0.614	25.134	21.792	5.921
102.672	62.472	0.608	26.320	24.965	5.966
103.472	62.472	0.606	27.272	28.107	6.037
103.872	63.472	0.605	28.269	31.299	6.077

3.1. Relations of Pressure Ratio with Oxygen-Enriched Concentration and Amount of Oxygen-enriched Air

It can be seen from Fig. 2 and Fig. 3 that pressure ratio of pressure at two sides of oxygen enrichment membrane can vary with the vacuum degree under vacuum conditions for operation. When the pressure ratio decreases, flow of passing air (oxygen-enriched air) increases accordingly, but oxygen-enriched concentration firstly increases and then decreases slightly. The reason is that increase of vacuum degree causes greater differential pressure at the front and rear side of membrane module, resulting in increase of permeability and decrease of selectivity of the membrane, which causes increase of permeable air amount that affects oxygen-enriched concentration. Therefore, in order to improve oxygen-enriched air or concentration, differential pressure at two sides of separation membrane can be appropriately improved, but if the differential pressure is too high, it will result in increase of equipment power and power consumption.

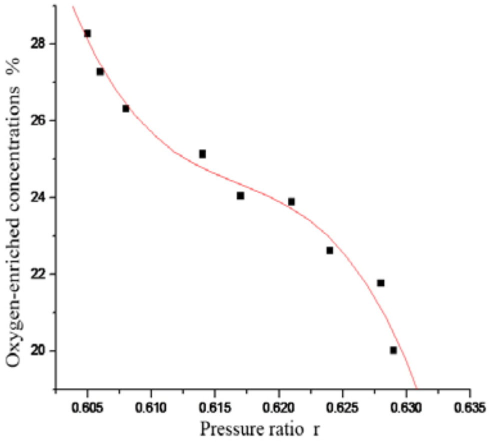

Fig. 2. Relations of pressure ratio with oxygen-enriched concentration.

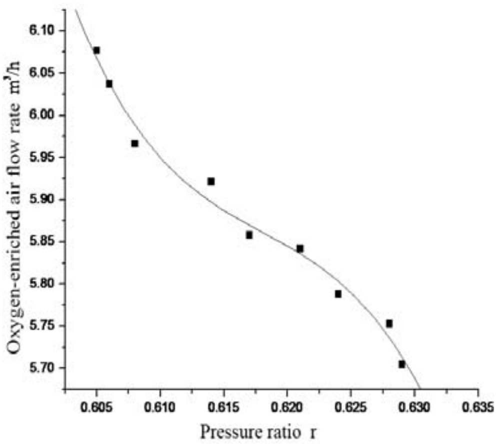

Fig. 3. Relations of pressure ratio with amount of oxygen-enriched air.

3.2. Relations of Air Supply Amount with Oxygen-enriched Concentration and Amount of Oxygen-enriched Air

It can be seen from Fig. 4 that change of flow supplied by air pump has little effect on the amount of oxygen-enriched air (in a certain range of air supply amount), but the change still affects oxygen content in oxygen-enriched air. With the increase of air supply amount, amount of oxygen-enriched air increases accordingly, but oxygen-enriched concentration firstly increases and then decreases slightly. The main reason is that under vacuum conditions for operation, limit of vacuum pump's characteristics and increase of air supply amount result in greater differential pressure at the front and rear side of membrane module, causing increase of permeability and decrease of selectivity of the membrane, which leads to the increase of permeable air amount that affects oxygen-enriched concentration. Actually, after oxygen-enriched concentration increases to a certain degree with the increase of air supply amount, it will be free from effect of air supply amount and it will mainly be controlled by vacuum degree. However, increase of air supply amount will still result in low recovery rate and high power expense.

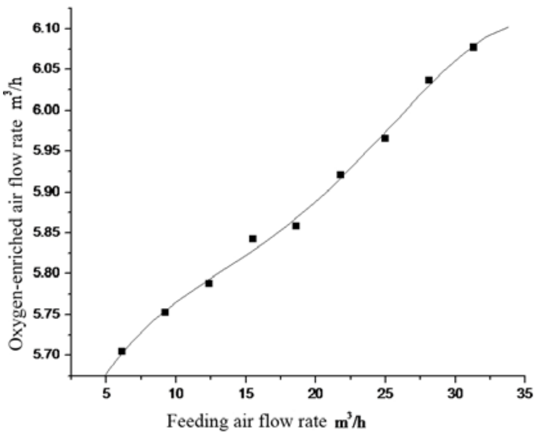

Fig. 4. Relations of air amount of feed with amount of oxygen-enriched air.

3.3. Permeation Coefficient and Separation Coefficient [7]

Gas permeation coefficient and separation coefficient are the main performance indexes of oxygen enrichment membrane. They respectively indicate the separation property and permeability of the membrane and they are both related to membrane materials.

Permeation coefficient of oxygen enrichment membrane can be obtained through calculation in accordance with active area of membrane module, flow of permeable gas and differential pressure at two sides of membrane. The formula is as follows:

$$P = \frac{Q_2}{(\Delta P \cdot A)} \tag{1}$$

where P refers to permeation coefficient of oxygen enrichment membrane, $cm^3/(m^2 \cdot s \cdot MPa)$;A refers to active area of membrane, m^2; Q_2 refers to amount of oxygen-enriched air, m^3/s; ΔP refers to differential pressure of gas at two sides of membrane, MPa.

Separation coefficient can be calculated through following formula in accordance with oxygen concentration of gas supplied and permeable gas as well as pressure ratio for two sides of oxygen enrichment membrane.

$$\alpha = \frac{X_2[1 - X_1 - \gamma(1 - X_2)]}{(1 - X_2)(X_1 - \gamma X_2)} \tag{2}$$

where α refers to separation coefficient of oxygen enrichment membrane; γ refers to pressure ratio for two sides of oxygen enrichment membrane; X_1 is the oxygen concentration of gas supplied; X_2 is the oxygen concentration of permeable gas.

The first group of data in Table 1 will be used as calculation example and other data calculation will applies the same method. Calculation results will be listed in Table 2.

According to experimental data, average permeation coefficient of the oxygen enrichment membrane is 8.14×10^{-9} cm^3/(m^2·s·MPa) after being calculated with Formula (1) and (2). The value is larger than theoretical permeation coefficient (which is 1×10^{-9}cm^3/(m^2·s·MPa) of the membrane. The main reason is that the vacuum degree of vacuum pump is too large. Average separation coefficient is 1.397 that is lower than theoretical separation coefficient (which is 2) of the membrane. The reason is that there is bias current, slight concentration polarization and loss of pressure in oxygen-enriched membrane module.

Table 2. Data for performance experiment of oxygen enrichment membrane apparatus.

ΔP [kPa]	Q_2 [m^3/h]	X_2	γ	P×10^{-9} [m^3/(m^2·s·MPa)]	α
36.200	5.705	20.015	0.629	8.44	1.045
36.400	5.753	21.769	0.628	8.41	1.188
37.000	5.788	22.615	0.624	8.38	1.375
37.500	5.842	23.888	0.621	8.32	1.440
38.700	5.858	24.040	0.617	8.09	1.468
38.800	5.921	25.134	0.614	8.05	1.497
40.200	5.966	26.320	0.608	7.92	1.530
41.000	6.037	27.272	0.606	7.86	1.522
41.400	6.077	28.269	0.605	7.82	1.510

3.4. Main Factors Affecting the Oxygen-enriched Concentration

Influence of oxygen enrichment membrane performance. For oxygen enrichment by means of membrane, it is very important to improve the oxygen-enriched performance; the performance of oxygen enrichment membrane is measured by the permeability coefficient and separation coefficient [8]. However, the permeation coefficient and separation coefficient are mainly influenced by the fore-and-aft differential pressure, pressure ratio of membrane module, the effective area of the membrane, the amount of oxygen-enriched air, and oxygen-enriched concentration. This experiment is mainly affected by influence of the vacuum pump characteristics; the degree of vacuum does not achieve the requirements of the experiment; the degree of vacuum is too high so that the pressure ratio is too high, which leads to the permeability coefficient of membrane becomes large, and the separation factor becomes smaller, that is to say, the increasing amount of passing air will reduce the concentration of oxygen enrichment. We can see from the above analysis, if the permeability coefficient and separation factor of membrane are increased, it will not only reduce the motive power of the device, but also reduce the cost of the oxygen-enriched air, and make the oxygen-rich device miniaturization at the same time.

Influence of operating condition. The running state of oxygen enrichment membrane experimental apparatus is closely related to the operating condition; its operating condition mainly includes pressure ratio (differential pressure) and feed air quantity. Seen from the data analysis of the experimental results, the oxygen-enriched concentration increases with the increasing of pressure, feed flow capacity in a certain operating temperature; but this experiment is operated under vacuum conditions; the influence of the vacuum pump is particularly serious; the oxygen-enriched concentration has a slight decrease with their increasing, that is because the degree of vacuum is too large, which makes the differential pressure before and after the membrane module becomes large and permeation of gas is increased; this leads to the deterioration of the efficiency of membrane separation, thereby reducing the oxygen-enriched concentration. In a word, changes in the degree of vacuum have great impact on the experiment. So in the experiment, the amount of feed air should be appropriate, in order to fully reflect the performance of oxygen enrichment membrane, this not only can get a higher oxygen-enriched concentration and oxygen-enriched air volume, but also reduce the running power costs of oxygen-rich membrane apparatus, making the best of economic benefits.

4. Conclusions

(1) This paper designs and establishes a membrane oxygen-enriched air supply experimental system; the system is running under vacuum conditions.

(2) Through experimental research on separation characteristics of LTV-PS membrane module, we understand that: with the increase of pressure and air

flow, oxygen-rich concentration tends to increase. Under operation in normal temperature and pressure (under the test condition, the atmospheric pressure is 102.7 kPa), when the air flow rate is 24 m^3/h, the concentration oxygen in membrane enrichment air is up to 28.3 %.

(3) In the research, we have analyzed that the main reasons that influenced the oxygen enrichment concentration are oxygen enrichment membrane performance and operating conditions; with the improvement of separation performance of domestic membrane, the performance of the existing oxygen-enriched air supply process program will subsequently be improved and enhanced.

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