Research on a New Pretreatment Technology for High Temperature Exhaust of Motor Vehicle

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Abstract. In order to ensure that the vehicle exhaust analyzer can work normally with the harsh conditions of the high temperature exhaust, the sample gas must be dewatered, dedusted and cooled without distortion. A new pretreatment technology for motor vehicle exhaust has been proposed in this paper. On the basis of the principle of cyclone separator with particles filter chamber, cyclone separator, liquid resistance and membrane type dryer as main devices, the particles filter chamber for dedusting, metal spiral pipe for cooling, cyclone separator for dewatering and dedusting, liquid resistance and membrane type dryer for dewatering have been used in the designed system. It can pretreat the exhaust without changing the exhaust composition, so the sample gas clarity can be increased. Field experiment results show that the designed pretreatment system can remove more than 5 um particle diameter. With it the exhaust temperature of range (180,210)°C can drop to around 39°C, the relative exhaust humidity of range (65,75)% can fall to about 25%, which can ensure the long-term stable operation of the online analysis instrument for high temperature exhaust.

1. Introduction
The vehicle exhaust has become one of the major sources of pollution of the atmosphere, and it seriously jeopardizes human health [1]. At present, there are many PEMS devices that analyze the vehicle exhaust [2]. However, the sample gas must be pretreated before using these devices to analyze the content of vehicle exhaust.

For the basic technical requirements of the processing system of the vehicle exhaust sampling, US expert Roberts proposed that the sample processing system should ensure that samples submitted for inspection can accurately reflect the characteristics of industrial fluids, and In addition to the composition of the sample reflecting the characteristics of the industrial fluid sampled and analyzed, the quality of the industrial fluid supplied to the process analysis instrument should be similar to that of the analytical instrument calibration gas. In other words, the sample gas cannot be distorted during the sample sampling process. The sample gas should meet the standard gas requirements (clean, dry, homoeothermic, etc.) before it enters the analytical instrument [3, 4, 5]. At present, there is not much research on the pretreatment of vehicle exhaust. The common methods are physical and chemical methods. The physical method is to install various purification devices in the exhaust system of a car, such as washing. The soot particles in the exhaust of the automobile are washed and filtered through the water tank, and the carbon particles are expanded to give removal [6]. The chemical method is to save hazardous substances by chemical means or use catalysts to purify CO and HC [7]. These two methods are very unfavorable to the analysis of vehicle exhaust composition. Physical methods bring more water vapor, and chemical methods change the original composition of exhaust.
In view of the above problems, based on the principle of cyclone separator, this paper proposes an effective vehicle exhaust treatment technology, and designs a sampling pretreatment system, which can remove the collected sample gas from water, impurities and drop temperature without changing the high-temperature exhaust component content of the vehicle to improve the sample gas clarity. Accurate analysis of the content of vehicle exhaust components has certain reference value.

2. Theory

The working principle of the cyclone separator is shown in Figure 1 (a). The gas enters from the upper side of the cylinder, and the inner wall of the cylinder rotates downward, approaching the bottom of the vertebral body. The droplets of dust particles are pumped away by the pump installed underneath, and the clean gas rotates counter-currently from bottom to top, reaching the air hole at the top center, and it is pulled away by the pump installed at the upper air outlet.

Figure 1. (a) Cyclone working principle; (b) Cyclone structure

The key to design a cyclone separator is to take full consideration of the factors in the design process, such as the characteristics of the separated particles, the flow field parameters and operating parameters. The key to the general design of a typical cyclone separator is to determine the cylinder diameter D of the cyclone separator (Figure 1(b)). As long as the diameter D of the cylinder is accurately calculated, the standard design of other structural parameters can be completed according to the design manual [8]. The pressure loss, which is the basis for designing the cylinder diameter D, is calculated by:

\[
\Delta P = \frac{1}{2} C \rho V^2 N_h
\]

where \(C\) is gas inlet resistance coefficient, straight-cut type is 1, 90° volute type is 0.694, 180° volute type is 0.4, \(\rho\) is gas density, \(V\) is inlet velocity, exponent sign is between (1.5, 2), typically 2, \(N_h\) is inlet velocity head. According to the import speed head formula:

\[
N_h = \frac{11.3 f_1^2 f_2^2}{f_4^4} + 3.33
\]

where \(f_1\) is Cyclone separator inlet height coefficient, \(f_2\) is Cyclone separator width factor, \(f_4\) is the diameter coefficient of the discharge tube of a cyclone separator. It is also know that:

\[
V = \frac{Q}{f_1 f_2 D^2}
\]

where \(Q\) is the inlet air volume, it can be determined by the displacement of the pump. Combine (1),
(2), and (3), we can obtain:

\[
D = \sqrt{\frac{11.3}{f_3^4} \left( \frac{33.3}{f_1^2} + \frac{33.3}{f_2^2} \right) \frac{C^2 \rho Q^2}{2\Delta P}}
\]  

(4)

obviously, after determining the displacement of the pump and the sample gas density, the diameter of the cylinder can be initially determined from equation (4) according to the pressure loss required by the index. Then the other size parameters are further determined.

3. Design of pretreatment system

The design of high temperature exhaust pretreatment is shown in Figure 2. The high temperature exhaust is filtered into the filter chamber through the sampling tube. After the filter chamber (two stage filtration and dust removal), the metal spiral tube (cooling), the cyclone separator (dewater and dust), the liquid blocking device (dewater) and the dryer (dewater) pretreatment, the high temperature gas enters the gas analysis unit.

![Pretreatment gas circuit of vehicle exhaust](image)

Figure 2. Pretreatment gas circuit of vehicle exhaust

The filter room is divided into two layers and each layer has a filter rod. The filter rod is equipped with PP filter core. Its filtering accuracy reaches 5 \( \mu \text{m} \), and the filter core can be changed according to the usage. The exhaust is filtered through two stages and enters the heat of metal spiral tube and reaches the cyclone separator. The mode of central tangential intake is adopted here.

A double head pump is installed at the top of a cyclone separator, with the maximum free flow of 11SLPM. A single head pump is installed at the bottom of the cyclone separator, with the maximum free flow of 2.5SLPM. The calibrated sample gas density is 1.42kg/m\(^3\). Then, according to the formula (4), the diameter of the cylinder (D) is 20mm. According to the design rules of the cyclone separator in the exhaust treatment device, the other parameters of the cyclone separator can be obtained by combining the characteristics of the gas path.

The separation effect of cyclone separator designed for test: considering the conditions of design pressure and tolerance, more than 5 \( \mu \text{m} \) of the solid particle and droplet diameter greater than 200 \( \mu \text{m} \) can be ignored, in the operating point, the separation efficiency is 99.5%, in the operating point +
15% range, the separation efficiency is 98%; under normal operating conditions, the pressure drop of operating point is less than 20KPa.

The purified sample gas after the separation of the improved cyclone separator is pumped away from the double head pump to the liquid resistance device. The maximum pressure of selected liquid resistance device is 5bar. The moisture of the filtrator is discharged by the proportional valve. The sample gas filtered by the liquid resistance device enters the membrane dryer. The membrane dryer is equipped with a 15L/min of air supply. Its biggest feature is that it does not need to provide external anti blowing to carry out filtered air. It can distribute some of its own gas as a counter blow. The pretreated sample gas is eventually controlled by the solenoid valve to the sample gas analysis module.

The process of pretreatment technology for high temperature exhaust is shown in Figure 3.

4. Experiment and analysis
According to the technology of the high temperature exhaust pretreatment to build the experimental platform, the system is shown in Figure 4.
The experiment was conducted on the basis of the Volkswagen touran to verify the performance of the platform. The basic parameters of the test are shown in Table 1. The operating environment of the field experiment is shown in the Figure 5.

Table 1. The basic information of vehicle being tested on platform

| Date       | Vehicle type | Test conditions | Brand models | Weight(ton) | Average Speed(km/h) |
|------------|--------------|-----------------|--------------|-------------|---------------------|
| 2017/12/20 | MPS          | IG195           | Volkswagen Touran | 1.5         | 21.59               |

The data of the vehicle is analyzed after 1 hour's operation, and the frequency of data collection is 1Hz, with a total of 300 groups. The comparison results of humidity before and after pretreatment of sample gas are shown in Fig. 6.

Figure 6. The comparing of sample gas humidity with exhaust humidity
Figure 7. The comparing of sample gas temperature with exhaust temperature

The relative humidity of exhaust is around (65, 75) % before pretreatment. After pretreatment, the relative humidity of the sample gas is around 25%. Obviously, the pretreatment technology works well on dewatering.

In order to verify the cooling effect of the pretreatment, a portable thermometer was adopted to conduct temperature detection at the inlet of high temperature exhaust and the outlet of the pretreatment sample gas. The comparison results are shown in Figure.7.

The exhaust temperature is between (180, 210) °C before pretreatment, with changing range of around 30°C and downward trend, this is mainly because the environment temperature and road conditions. After pretreatment, temperature of sample gas degrees between (38, 40) °C, range in 2°C and very stable. This is very beneficial to the exhaust composition analysis module.

5. Conclusion
A new pretreatment technology for motor vehicle exhaust has been proposed in this paper. Without changing the exhaust composition, the sample gas can be collected, dewatered, dedusted and cooled by the pretreatment system designed with the proposed technology, which can improve the sample gas clarity, ensure the long-term stable operation of the online analysis instrument for high temperature exhaust. It has good application prospect to meet the requirement of exhaust analysis module.

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7. References
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