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# *Diesel Engine Exhaust Gas Recirculation Technology Based on Machine Learning*

**Vempaty Saini***
*New Valley University, Egypt*
**corresponding author*

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***Abstract:*** Recycling technology has the characteristics of high efficiency, recyclability and reuse. At the same time, it can be widely used in industrial production as an environment-friendly technology. At present, the waste gas treatment methods adopted in China mainly include mechanical (heat treatment) or chemical methods. These methods do great harm to the environment. In order to improve the environmental protection of diesel engines, this paper intends to study the application of machine learning in exhaust gas recirculation technology, and propose the method of exhaust gas recirculation technology. This paper mainly uses the experimental method of EGR scheme design and changes the variables to compare the data difference to realize the research on the influence of internal EGR on emission performance and combustion characteristics. The experimental results show that the NOx emissions of the internal EGR scheme are lower than 10/g•h-1 at 2200r/min and 10% load conditions. The internal exhaust gas recirculation technology has great potential to improve the harmful exhaust gas and total fuel emissions of diesel engines.

## 1. Introduction

With the continuous development of industry, the demand for energy is growing. However, traditional fossil fuels produce a lot of pollution in the use process, which is a big problem. Therefore, people began to seek new technologies to replace the waste with high combustion efficiency, high emissions and difficult to deal with. In this paper, a new type of efficient energy saving and emission reduction method is obtained by using machine learning recycling method to improve the exhaust gas treatment. It has obvious advantages in reducing energy consumption and improving pollutant emission control environment.

There are many theories about machine learning, and there are also some theories about diesel engine exhaust gas recirculation technology. For example, some scholars summarized the characteristics and control methods of diesel exhaust gas recirculation (EGR) technology and analyzed the existing problems [1-2]. Some scholars suggest that low load diesel engines adopt higher EGR rate. In case of overload, low EGR rate is assumed. EGR can effectively reduce NOx emissions [3-4]. Some scholars use data based machine learning algorithms to predict the carbon load of DPF in passenger car diesel engines [5-6]. Therefore, in the environment of low-carbon development, it is necessary to study the diesel engine exhaust gas recirculation technology based on machine learning in the industrial field.

In this paper, we first study machine learning, and describe the characteristics of machine learning through neural networks and reinforcement learning. Secondly, the paper expounds the exhaust gas recirculation technology in different points, points out the differences between gasoline and diesel engine exhaust gas recirculation, and discusses the recycling technology. Then the organic Rankine cycle system is described. Finally, through the internal EGR scheme design, using experiments, control variables, and obtain relevant data.

## 2. Diesel Engine Exhaust Gas Recirculation Technology Based on Machine Learning

### 2.1. Machine Learning

The composition of artificial neuron is as follows: synapse, adder, activation function, bias signal, output result. The neural network is built by the basic neuron structure. In the structure diagram of the sense memory and the execution memory, there is a forward propagating working signal and a backward propagating error signal [7-8]. Using the above two signals, the MLP neural network can be trained by means of supervised learning. The process is as follows:

In the forward phase, the synaptic weight is fixed, and the output of each neuron is calculated by training known learning samples into the input, and the input signal propagates backward. On the contrary, the synaptic weight of the neural network will change. An error signal is generated by comparing the network output with the expected output. Start from the last layer of the network to calculate the influence of the weight value on the total error (gradient), and change the weight value according to the gradient.

Because BP neural network is used to select waveform parameters, attention should be paid to the selection of training samples in the process of supervision training. The way of neural network is relatively more stable in the process of waveform selection, which makes the system have certain stability. At the same time, it greatly saves computing time and improves computing efficiency. However, this offline training method, to a large extent, depends on the selection of training samples, and also requires sufficient training time. It may be difficult to adapt to unknown environmental scenarios, so an online learning method is required to select waveform parameters [9-10].

The reinforcement of learning system behavior depends on the feedback of the environment. The principle for the decision-making device to choose the action at the next moment is to strengthen the learning system to learn a behavior strategy, so that when the system makes decisions based on this behavior strategy, the behavior obtained by the decision can obtain the maximum cumulative reward value through interaction with the environment. That is, the probability of obtaining positive feedback from the environment increases, and the probability of being punished decreases [11-12].

### 2.2. Exhaust Gas Recirculation Technology

EGR technology has become an important technical means to develop efficient and clean internal combustion engines, and the selection of reasonable EGR cycle mode is an important link in the development of EGR system. EGR can be divided into internal EGR and external EGR according to different exhaust gas introduction methods. The internal EGR controls the opening and closing time of the intake and exhaust valves, so that the exhaust gas that has been discharged from the cylinder flows back to the cylinder to participate in the combustion process of the next cycle. By controlling the valve overlap angle or modifying the cam profile, the exhaust valve can be opened during the intake process or the intake valve can be opened during the exhaust stroke. The advantage of internal EGR is that the exhaust gas does not pass through the intake pipe and will not cause corrosion of the intake system. However, the internal EGR control accuracy is low. At the same time, the high temperature exhaust gas entering the cylinder will increase the temperature in the cylinder, reduce the engine inflation coefficient, and affect the engine power. Therefore, the internal EGR is generally only applicable to medium and small load conditions. The external EGR is easier to control the EGR rate than the internal EGR, and the cooled EGR gas entering the cylinder will not have an excessive impact on the inflation coefficient of the cylinder. EGR can effectively reduce the particulate emissions of gasoline engines. On the one hand, EGR reduces the combustion temperature, reducing the soot generated by cracking and dehydrogenation. On the other hand, the introduction of EGR eliminates the over injection area and reduces the particulate matter produced in the anoxic combustion environment. A large amount of carbon dioxide in EGR gas can also reduce the generation of soot [13-14].

EGR rate is usually used as the index to evaluate EGR, that is, the ratio of the recycled exhaust gas volume to the total intake air volume. There are two ways to express it, one is the volume ratio of exhaust gas to the total intake air volume, and the other is the mass ratio of exhaust gas to the total intake air volume. The use of EGR can reduce NOx emissions, but EGR will also have an impact on other engine emissions and its own performance [15-16]. The influence of EGR on engine performance is mainly shown in the following five aspects:

The use of EGR in diesel engines can greatly reduce NOx emissions. However, with the increase of EGR rate, engine performance, effective thermal efficiency and average effective pressure decrease. EGR reduces the maximum growth rate of combustion pressure, so it can effectively improve the roughness of the engine. Excessive EGR will lead to increased fuel consumption and particulate emissions, especially under heavy load. Using EGR will lead to deterioration of engine oil and lubricating oil, wear of cylinder liner and piston ring, and unstable operation of diesel engine. The use of EGR will reduce the combustion temperature and pressure, and the dilution of exhaust gas to oxygen concentration will inhibit the generation of NOx [17-18].

Diesel engine EGR system is more complex than gasoline engine. The pressure difference between the intake pipe and the exhaust pipe of the gasoline engine is relatively large, so it is easy to make the exhaust gas flow back, while the diesel engine is different. The pressure difference is small, so it is difficult for the exhaust gas to flow back, and it is difficult to achieve the optimal EGR rate. Therefore, a throttle valve needs to be installed on the intake pipe to change the pressure difference between the intake pipe and the exhaust pipe through throttling, so that the exhaust gas can be recycled. In the case of idling or cold engine, NOx emissions are very small. To prevent the engine from stalling, sufficient air is required in the cylinder. Therefore, the EGR valve needs to be closed at these times.

In case of low-speed cruise or slight acceleration, low EGR rate is required to reduce NOx emissions and maintain good power performance. In the case of medium load, the NOx emission is relatively high, so it is necessary to use the maximum amount of recycled exhaust gas, so as to greatly reduce the NOx emission. When the engine needs strong power and high speed, it needs enough oxygen and a small amount of recycled exhaust gas, so EGR cannot be used or low EGR rate can be used as far as possible.

### 2.3. Organic Rankine Cycle System

Low boiling point organics are used as working medium to effectively convert low temperature waste heat into electrical energy. The basic organic Rankine circulation system mainly includes five parts: evaporator, expander, condenser, liquid storage tank and working fluid pump, as shown in Figure 1:

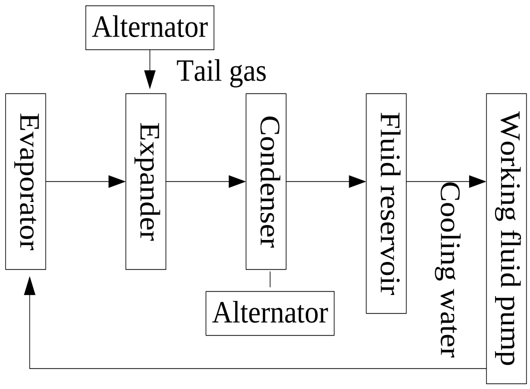


*Figure 1. Basic organic langken cycle system*

During the cycle, the low temperature exhaust gas expanded in the expander becomes saturated liquid after being cooled by the condenser; The liquid organic working liquid then returns to the tank. The working medium pump extracts and prints organic working medium from the tank and sends it to the evaporator. The organic fluid in the evaporator is converted into saturated steam after heat exchange with diesel exhaust. Saturated steam enters the expander and drives the expander to operate; So far, a work cycle has been completed. The liquid organic fluid becomes saturated steam after heat exchange with the diesel engine outlet in the evaporator. It is assumed that the heat absorbed by the organic working medium is equal to the heat released by the engine exhaust during this process. Heat exchange:

$$\dot{P}_f = d_q \dot{x}_q (s_{v1} - s_{v2}) = \dot{x}(g_1 - g_4) \tag{1}$$

Where, $\dot{P}_f$ is the heat exchange capacity in the evaporator (kW); $\dot{x}$ is the mass flow rate of working medium (kg/s). The heat exchange loss in the condenser is negligible, the heat absorbed by the cooling water is equal to the heat released by the organic working medium, and the heat exchange is:

$$\dot{P}_f = \dot{x}(g_2 - g_3) \tag{2}$$

Wherein, $g_3$ is the enthalpy value of the working medium at the outlet of the condenser.

Compared with Rankine organic cycle, Rankine organic preheating cycle is completed by heater and primary expander. Rankine regeneration organic circulation system adds a regeneration device at the outlet of expander and the inlet of evaporator, compared with Rankine alkaline organic circulation system. The task is to transfer part of the heat energy of low-pressure superheated steam to the expander that completes the work in the low-temperature liquid working medium at the evaporator inlet. The principle of residual circulation is the same as that of organic Rankine circulation system. Rankine organic circulation system has a simple structure, and the waste heat recovery efficiency of vehicle diesel engine exhaust gas is low. The system structures of heated and regenerated organic Rankine rings were optimized. Both of these systems have high efficiency of diesel engine waste heat recovery and have good application value, but the system structure is complex.

## 3. Internal EGR Scheme Design

### 3.1. Determination of Internal EGR Implementation Mode

Internal EGR is generally achieved by changing the valve timing. The exhaust valve can be closed in advance by adjusting the closing angle of the exhaust valve, forming a negative valve overlap angle, so that the exhaust gas stays in the cylinder to achieve internal EGR, so as to participate in the next stage of combustion. In order to avoid the disadvantages of the above two internal EGR methods, a bimodal cam can be used to achieve internal EGR. This method can not only avoid the condition that the exhaust valve will encounter the piston when the exhaust valve is closed late, but also prevent the high temperature exhaust gas from entering the intake duct and heating the intake too much. It can not only minimize the impact on the intake charge, but also reduce the exhaust back pressure.

### 3.2. Feasibility Analysis of Secondary Opening Scheme of Exhaust Valve

This work calculates and analyzes the exhaust pressure and cylinder pressure of the original engine speed calibration point. During the intake stroke, the exhaust pressure in the exhaust pipe is always higher than the cylinder pressure. Since the pressure difference between the exhaust pipe and the cylinder is within the range after the exhaust valve is closed and the inlet valve is opened. Therefore, the gas return in the exhaust pipe with the secondary opening of the exhaust valve can effectively achieve internal exhaust gas recirculation.

### 3.3. Exhaust Valve Secondary Opening Scheme Design

In order to obtain a reasonable internal EGR, the parameters of the exhaust cam are designed, namely the starting point, the cam stroke and the second exhaust valve opening time. In order to find a suitable starting point for the secondary exhaust valve opening, the cam stroke of the secondary exhaust valve opening is 1.0 mm, as a simulation limit. The opening time of the secondary exhaust valve has little effect on the EGR internal speed, power and fuel economy. Therefore, in the process of cam profile design, combined with the dynamic characteristics, the secondary opening time of the exhaust valve can be reasonably selected.

## 4. Effect of Internal EGR on Emission Performance and Combustion Characteristics

### 4.1. Effect of Internal EGR on Emission Performance

In order to find out the influence of the internal EGR scheme on the emission performance of the test prototype, the four condition emission test was conducted under the condition that the internal

EGR scheme and the original engine have the same power and the injection timing is unchanged. The speed under four working conditions shall be consistent, and the load shall be from 100% to 10%. By comparing and analyzing the emission performance of diesel engines before and after the implementation of internal EGR, the influence rules of different internal EGR schemes on diesel engine emissions under different working conditions are found. See Table 1 for details:

*Table 1. Comparison of NOx emissions between the original machine and EGR schemes*

| | Original machine | Scheme 1 | Scheme 2 | Scheme 3 |
|---|---|---|---|---|
| 1 | 72 | 64 | 68 | 63 |
| 2 | 55 | 49 | 53 | 52 |
| 3 | 31 | 27 | 31 | 30 |
| 4 | 7 | 6 | 8 | 7 |

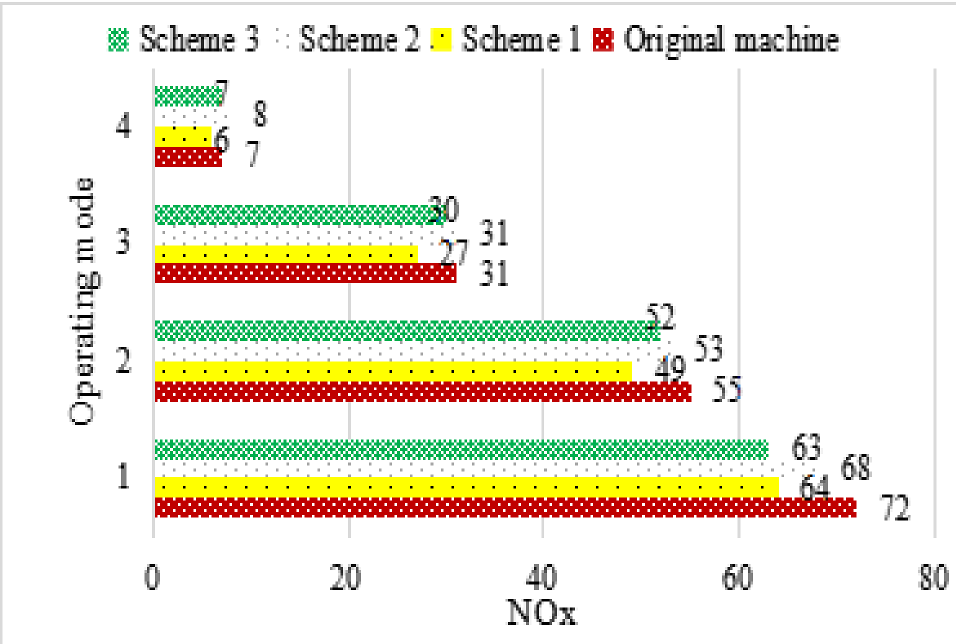


*Figure 2. Comparison of NOx emissions between the original machine and EGR schemes*

As shown in Figure 2, under 2200r/min and 100% load conditions, NOx emissions of internal EGR schemes 1, 2 and 3 decreased by 8, 4 and 7 respectively compared with the original engine. Under this working condition, the reduction of NOx emissions is also related to the internal EGR rate. The larger the internal EGR rate is, the more NOx emissions will decrease compared with the original engine.

### 4.2. Effect of Internal EGR on Fuel Consumption

The effective fuel consumption rate of the original engine and different internal EGR schemes are different under different working conditions. Under 2200r/min and 100% load conditions, the fuel consumption rate of Scheme 1 is 2 higher than that of the original engine, and Scheme 2 and Scheme 3 are the same as that of the original engine. Under this condition, the fuel consumption rate of the three schemes has little change compared with that of the original engine. See Table 2 for details:

*Table 2. Comparison of the fuel consumption ratio of the prototype and EGR schemes*

| | Original machine | Scheme 1 | Scheme 2 | Scheme 3 |
|---|---|---|---|---|
| 1 | 250 | 252 | 250 | 250 |
| 2 | 246 | 248 | 245 | 253 |
| 3 | 253 | 253 | 250 | 260 |
| 4 | 540 | 550 | 530 | 590 |

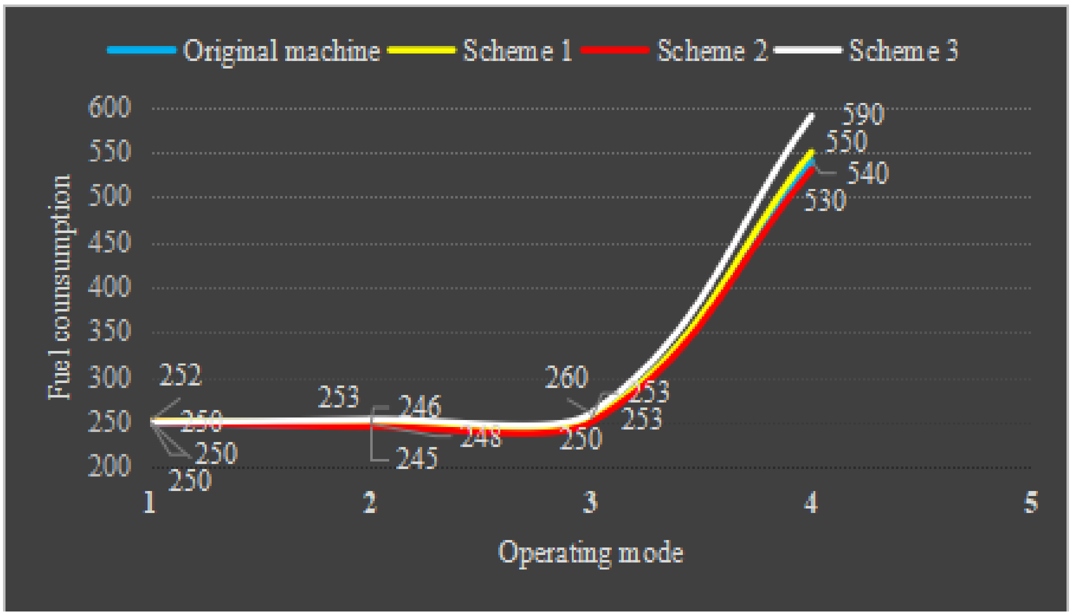


*Figure 3. Comparison of the Fuel Consumption Ratio of the Prototype and EGR Schemes*

As shown in Figure 3, under 2200r/min and 75% load conditions, the fuel consumption rate of Scheme 1 and Scheme 3 has increased by 2 and 7 respectively compared with the original engine. Under this condition, the fuel consumption rate of Scheme 3 has increased significantly. Under 2200r/min and 50% load conditions, the fuel consumption rate of Scheme 1 is the same as that of the original unit, while that of Scheme 3 is increased by 7. Under this condition, the fuel consumption rate of Scheme 3 is still deteriorated.

## 5. Conclusion

Machine learning has a wide range of applications, is easy to implement large-scale computing, and can well handle problems that are difficult to solve in traditional models. The core idea of machine learning is to use computer technology and program to process complex data sets, so as to obtain more useful information. This paper mainly studies the basic structure of the recirculation system, and obtains the relevant data of the device under different working conditions by analyzing the diesel engine exhaust gas reheat regeneration technology. And use the machine learning function to improve the computing ability of the system. Through the analysis and verification of the experimental data, we can draw a conclusion that the internal exhaust gas recirculation technology can achieve something to a certain extent. However, due to the instability of the experimental object and the inadequacy of the theory, the conclusions of this study need to be further confirmed.

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## Data Availability

Data sharing is not applicable to this article as no new data were created or analysed in this study.

## Conflict of Interest

The author states that this article has no conflict of interest.

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