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Emission and Environmental Issues of Internal Combustion Engine Using New Fuels

Ruokun Chen[1, *]

[1]Affiliated High School of Fujian Normal University, Fuzhou, China
*Corresponding author: crk.chenruokun@gmail.com

Abstract:

Due to the increasingly serious environmental problems such as the greenhouse effect, this article collects data and analyzes and summarizes multiple documents, aiming to assess the impact of different fuels' use in internal combustion engines on gas emissions and the environment protection by analyzing four types of fuels: electricity, hydrogen energy, biodiesel, and compressed natural gas. Through statistics and analysis, the results show that electric vehicles are the most mature and environmentally friendly in current applications, and compared with other energy vehicles, electric vehicles generate the least gas emissions during manufacturing and combustion, being the most environmentally friendly; hydrogen energy vehicles have significant advantages and potential in terms of environmental protection due to their zero emissions and abundant sources, but currently, the proportion of low-carbon hydrogen production among all hydrogen is still very small, and the related application technologies are not yet mature. Further development of hydrogen production, manufacturing, transportation and storage is still needed to make hydrogen energy available for use in vehicles. Biodiesel cannot become a mainstream fuel option due to issues such as limited raw materials. Similarly, compressed natural gas, as a non-renewable resource, is also difficult to be widely used in the future.

Keywords: environment protection; new fuels; gas emission.

1. Introduction

Nowadays, with the development of automobiles and industry, the greenhouse effect is becoming increasingly severe. The greenhouse effect is caused by the emission of greenhouse gases, the main ones being carbon dioxide, methane, nitrous oxide and ozone. Among all the greenhouse gases emitted, carbon dioxide has the largest volume and causes the most severe greenhouse effect. Since 2010, the annual carbon

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dioxide emissions worldwide have been over 50 billion tons and are showing an increasing trend [1]. According to the World Meteorological Organization, the concentration of CO2 has increased by 11.4% in just 20 years [2]. Most of the carbon dioxide emissions come from the energy system, that is, from the combustion of fossil fuels. The further aggravation of the greenhouse effect will lead to a global temperature rise, which in turn will cause the melting of glaciers, a rise in sea levels, and the submersion of coastal cities or even countries. In addition, global warming will also lead to more and more extreme climates and natural disasters. From the data, the global temperature has risen by more than one degree, and some regional natural disasters may also be related to global warming, such as the wildfires in Australia in 2019. From this, it can be seen that there is an urgent need to reduce the emission of greenhouse gases. Considering the largest quantity and greatest impact of carbon dioxide, the main source of carbon dioxide is vehicle exhaust. Therefore, it is necessary to summarize the issue of vehicle exhaust emissions.

The exhaust from gasoline-powered vehicles mainly contains carbon dioxide, water, and a small amount of sulfur oxides and nitrogen oxides. Among them, sulfur oxides and nitrogen oxides also have significant negative impacts on the environment and cannot be ignored. Specifically, they may cause acid rain and other serious environmental problems.

2. Composition and Working Principle of Internal Combustion Engines

The engine of a car is composed of many components. Specifically, there are spark plugs, intake manifolds, exhaust manifolds, idle control valves, throttle valves, multiple cooling hoses, coolant outlets, fuel injectors, oil filters, starting motors, various pulleys and belts for power transmission, cooling system water pumps, air conditioning compressors, power steering pumps for assist in steering, flywheels, cylinder blocks, pistons, connecting rods, main bearings, crankshafts, oil rings, and various sensors.

Each component plays an important role. Spark plugs are responsible for igniting the mixture of gasoline and air. Intake and exhaust manifolds are used for the entry of air and the expulsion of exhaust gases respectively. Throttle valves control the amount of air entering the combustion chamber, determining the power of the internal combustion engine. Cooling hoses are responsible for the circulation and transportation of coolant. The cylinder block contains many holes and pipes for the circulation of coolant, absorbing the heat generated by the cylinder operation. Fuel injectors provide fuel to the combustion chamber. Starting motors provide inertia to the flywheel when the engine starts. Oil rings prevent engine oil from entering the combustion chamber, preventing the phenomenon of oil burning. Sensors monitor the engine's operating conditions in real time and coordinate their work.

The operation of an internal combustion engine consists of four strokes: the intake stroke, the compression stroke, the power stroke, and the exhaust stroke. At the starting stage, the starting motor makes the flywheel rotate at high speed. In the intake stroke, the piston moves downward, increasing the volume of the combustion chamber, opening the intake valve and closing the exhaust valve, allowing air to be sucked in, while the fuel injector works; in the compression stroke, both the intake valve and the exhaust valve are closed, and the piston moves upward under the inertia of the flywheel, compressing the mixture of gasoline and air, causing its temperature to rise; in the power stroke, both the intake valve and the exhaust valve are closed, and the spark plug ignites the mixture of fuel and air, causing the gas volume to expand, pushing the piston downward, driving the crankshaft and main bearings, and transmitting the power to the tires to drive the car to move; in the exhaust stroke, the piston moves upward due to the inertia of the flywheel, expelling the burned exhaust gases.

3. Factors Affecting Engine Emissions

3.1 . Fuel Type and Prospects

Obviously, the type of fuel plays a decisive role in the emissions of internal combustion engines. The most obvious examples are electric vehicles and hydrogen energy vehicles, as they emit no exhaust gases during driving. The operation of electric vehicles is a closed system that does not use any fuel and does not generate power through a heat engine, and there are no by-products; the main gas emission of hydrogen energy vehicles is water, which has no harm to the environment. However, in addition to this, the large amount of heat produced by hydrogen combustion will cause chemical reactions between oxygen and nitrogen in the air, producing nitrogen oxides, which may cause environmental problems such as acid rain.

But we must also pay attention to the environmental impact generated during the production and transportation steps outside of driving.

The first is electricity. The way and scenario of power generation determine the pollution of the power generation process. According to the statistics in Table 1 [3].

Table 1. Greenhouse gas and air pollution emissions per MJ of electricity produce

Scenario	GHG emission(g)	AP emission(g)
Scenario 1	5.11	0.0195
Scenario 2	77.5	0.296
Scenario 3	149.9	0.573

(1) electricity is produced from renewable energy sources including nuclear energy;
(2) 50% of the electricity is produced from renewable energy sources and 50% from natural gas with an efficiency of 40%;
(3) all electricity is produced from natural gas with an efficiency of 40%
Obviously, Scenario 1 shown in Table 1, which is the electricity derived from renewable energy sources, is the most environmentally friendly and has the least emissions. Therefore, expanding the generation of electricity based on renewable energy is the inevitable way to protect the environment. However, these data were collected in 2006, so we must consider whether new power generation technologies or methods of storing electricity might lead to changes in the data.
From Ember Energy's data [4], as of 2024, the proportion of electricity generated by renewable energy worldwide has exceeded 40%. This is a major milestone in the development of electricity and electric vehicles, and the proportion of electricity generated by renewable energy is showing an increasing trend. Among them, hydropower accounts for the largest share, while solar and wind energy are experiencing the most vigorous development. This undoubtedly indicates a promising future for electric vehicles in terms of environmental protection.
Secondly, hydrogen, as the "ultimate energy source" of the 21st century, has attracted much attention. However, its production process is not environmentally friendly. Currently, the main method of hydrogen production is based on fossil energy, with about one-sixth of the hydrogen as a by-product of oil extraction, two-thirds from natural gas hydrogen production, and one-fifth from coal hydrogen production [5]. Clearly, these hydrogen production methods are not based on renewable energy, and low-carbon hydrogen accounts for less than 1% of all hydrogen sources [5]. The low-emission hydrogen production technology still needs to mature.
In addition, the storage and transportation of hydrogen are also major problems in the industry. In a distance of 2500 to 3000 kilometers, pipeline transportation has the lowest cost and is the most effective, making it the best choice. This method has been chosen by many countries. The European Hydrogen Backbone Initiative brings together 33 natural gas infrastructure operators, aiming to establish a pan-European hydrogen pipeline network. The first 30 kilometers of the Dutch hydrogen backbone network started construction in October 2024, which is part of the planned 1200-kilometer network. In Germany, the German Reinsurance Bank provided 24 billion euros in loans to support the development of the country's 9040-kilometer hydrogen network. The first 525 kilometers (mainly reused natural gas pipelines) are expected to be completed by 2025. China has initiated the construction of a 737-kilometer hydrogen pipeline from Zhangjiakou Kangbao to Caofeidian [6], which is expected to be completed by the middle of 2027 [5]. The storage of hydrogen can be placed underground. In this regard, the United Kingdom, Germany, and Sweden have conducted relevant research. All these facts indicate that many countries have begun to build hydrogen energy transportation and storage networks to support the future development of hydrogen energy.
From the above data, hydrogen energy and electric vehicles both have great potential for future development. However, hydrogen energy still needs to be developed, while the power system has already matured worldwide.
Biodiesel is diesel extracted from plants, animal oil, and daily edible oil and can be used as vehicle fuel. To extract biodiesel, the first step is to filter the crude oil, then add methanol and sodium hydroxide for catalysis, and then heat and pressurize to promote the reaction. This technology is simple and mature. Moreover, this is not the only way to produce biodiesel. By 2020, there will be 7 mature ways to produce biodiesel. Biodiesel has been widely used in aviation and has not caused serious problems. However, biodiesel does have drawbacks. One major limiting factor is insufficient production capacity, which is mainly due to scale limitations and insufficient raw materials. The latter is the most restrictive factor. Its raw material, waste cooking oil, has the characteristic of being difficult to collect and utilize. For example, waste cooking oil in Europe and America even has a phenomenon of insufficient supply, and there has even been a black market for waste cooking oil, leading to the import of waste cooking oil from Asian countries. The industry for utilizing and recycling waste cooking oil in countries with relatively large production volumes is not yet mature, which has led to the predicament of biodiesel. In addition, the price of biodiesel is higher than that of diesel refined from petroleum, and it requires government or foundation subsidies to have a

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significant competitive advantage. Meanwhile, biodiesel is still a hydrocarbon. Compared with diesel, it does not have significant advantages in terms of exhaust emissions. On the contrary, due to its imperfect extraction process, it may lead to even more severe exhaust emissions.

In addition, compressed natural gas is also a fuel option for internal combustion engines nowadays. As early as 1930, Italy discovered the use of compressed natural gas as a fuel [7]. In recent years, the number of natural gas vehicles has gradually increased, as shown in Figure 1. The most significant growth has occurred in the Asia-Pacific and Europe and America regions. Among them, India has designated compressed natural gas as one of the environmentally friendly fuels for public transportation in its new environmental policy, in an effort to improve air quality.

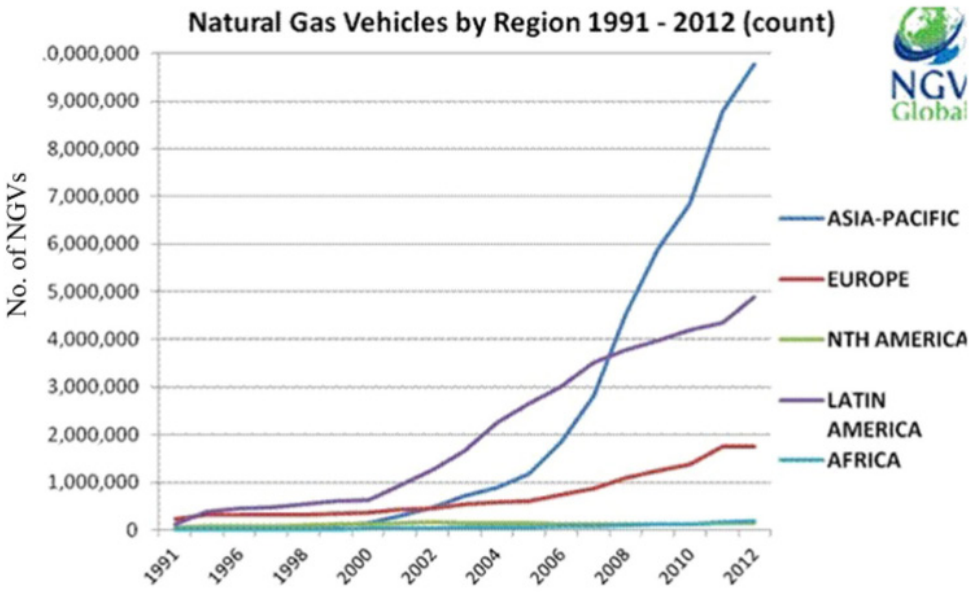

Fig. 1 Worldwide NGVs Growth [8]

Facts have shown that the air quality in India has significantly improved after the release of new policies [8], with multiple pollution gas indicators having decreased. Specifically, total suspended particulates have dropped by 14%, carbon monoxide by 10%, sulfur dioxide by 22%, and nitrogen oxides by 6% [7]. Compared to gasoline, natural gas has a natural advantage in terms of emissions. The composition of its emissions is roughly the same as that of gasoline, including CO_2, N_2O, CO, and NMH. Multiple experiments have proven that, regardless of the type of emission, compressed natural gas has a significant environmental advantage [8]. The chemical composition of natural gas is CH4, and its carbon-hydrogen ratio is higher than that of gasoline, which may be one of the reasons why it emits less carbon dioxide compared to gasoline. Additionally, natural gas can be mixed with other fuels such as diesel, and diesel vehicles can be modified to run on natural gas. Moreover, natural gas can effectively reduce the operating costs of vehicles. Specifically, it can prevent the dilution of engine oil and extend its lifespan. As a gas, natural gas enters the combustion chamber and avoids washing away the lubricating oil from the piston area, thereby extending the engine's lifespan [8]. Burning in gaseous form, natural gas can diffuse more quickly in the combustion chamber and achieve a faster combustion speed. The lower maintenance costs may promote the sales of compressed natural gas vehicles.

Despite the economic and environmental advantages of natural gas, it also has notable disadvantages. Firstly, due to its low energy density, natural gas vehicles have a shorter range than gasoline or diesel vehicles. Using gaseous fuel also poses safety risks; like hydrogen, a severe collision could ignite the natural gas in the vehicle, causing a serious explosion. Lastly, natural gas, like hydrogen, faces the same issue: although it has been widely used in regions such as India, its transportation and storage systems are not well-developed worldwide, and many areas lack refueling stations for natural gas [7]. Like petroleum, natural gas is also a fossil fuel, and its non-renewable nature means it cannot be widely and extensively used in the future. However, it can still be regarded as a good alternative for environmental protection in a short period of time.

3.2 Exhaust After-Treatment Technology

In the early days of the invention of automobiles, people were completely unaware of the dangers of exhaust

gases. Unprocessed exhaust gases were emitted in some countries and regions for several decades. The photochemical smog in Los Angeles in 1943 was caused by the chemical reactions of components in the exhaust gases when exposed to sunlight. The earliest exhaust after-treatment technology emerged in the 1970s, with its effective catalytic components being Pt and Pd, mainly used to eliminate carbon monoxide and hydrocarbons. Later, Rh was also used [9]. The three-way catalytic converter is the most important exhaust treatment device, responsible for purifying harmful components such as carbon monoxide and nitrogen oxides in the exhaust gas. Through three metals as catalysts (Pt, Pd, Rh), it converts the harmful components in the exhaust gas into harmless ones. The catalytic reaction requires high temperature as a condition, which is generally provided by the combustion heat of the exhaust gas itself. However, during the start-up stage of the car, the exhaust gas temperature is not high, which results in almost zero purification effect. This stage accounts for a large proportion of exhaust emissions among all emissions. Later, this situation was improved. Specifically, installing a heating device in the catalytic converter significantly reduced the emission of unprocessed exhaust gas.

It is worth noting that the metals used as catalysts in the three-way catalytic converter are extremely expensive, even more than ten times that of gold, and their prices are still rising [10]. This has led to some problems. Automakers had to find ways to reduce the cost of the three-way catalytic converter, improve the working efficiency of the catalytic metals to achieve the goal of reducing the use of precious metals, or invest funds in researching substitutes for precious metals. The huge cost of exhaust after-treatment also led to the Volkswagen Diesel gate incident. Volkswagen, despite knowing that its diesel vehicles did not meet emission standards, still used software cheating methods to evade emission tests. This incident not only had a very negative impact on Volkswagen but also caused harm to the environment.

In contrast, electric vehicles have a huge advantage in this aspect because they emit zero emissions. Therefore, nowadays, the three-way catalytic converter and traditional fuel vehicles are leading the choice of the times.

4. Conclusion

To sum up, the author believes that in today's era of increasing fuel demand, petroleum, due to its limited reserves, will inevitably be replaced by new energy sources. Among them, hydrogen energy and electrical energy have the greatest potential, and the development of electrical energy is the most mature, with the most extensive applications and a high degree of low-carbonization. The development of the hydrogen energy industry is not yet complete, and the technologies for storage, transportation, and utilization still need to be mature. However, many countries and policies have been introduced to develop related industries, which have great potential for development. Both hydrogen energy and electrical energy are expected to fully replace gasoline and diesel in the future. Biodiesel is difficult to become a mainstream fuel due to problems such as unstable sources and insufficient raw materials. Natural gas has advantages over gasoline in terms of economy and environmental protection. It can be a sustainable option for short-term use. However, due to its non-renewable nature, it is difficult to become the main fuel in the future.

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