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REVIEW

Environmental Solutions and Economic Benefits for Using Natural Gas in Agricultural Engines

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ABSTRACT

The agricultural sector relies heavily on diesel-powered engines for irrigation, tillage, and transportation, contributing to environmental pollution and high operational costs. The transition to natural gas as an alternative fuel offers significant environmental and economic benefits. Natural gas combustion results in lower greenhouse gas emissions, reduced particulate matter, and decreased nitrogen oxides compared to diesel, thereby improving air quality and mitigating climate change. Economically, natural gas is often more cost-effective than diesel, providing farmers with long-term fuel savings and reduced maintenance costs due to cleaner engine operation. This paper explores the environmental advantages and financial feasibility of using natural gas in agricultural engines, emphasizing technological advancements that facilitate its adoption.

Keywords: Natural gas consumption; Agricultural economy; NG engine; Environmental effect

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INTRODUCTION

The use of gasoline and diesel engines entails a number of problems. Especially since the dependence of developing and developed economies on fossil fuels is increasing exponentially. For instance, the consumption of petroleum products among Egypt, Angola, Algeria, Nigeria and Gabon rose from 116.4 thousand barrels/day in 1980 and 213.2 thousand barrels/day in 2000 to an average of 339.2 thousand barrels/day in 2015, which represents an increase of 191% and 59% over their 1980 and 2000 values respectively (Awodumi and Adewuyi, 2020).

One of the most important of these problems is that oil belongs to non-renewable energy a source which is extracted on such a scale that in the near future its reserves will be completely depleted. The second, no less serious problem is the negative impact of transport and technology on the environment. Exhaust gases are one of the most serious causes of air pollution. In Russia, the emissions of transport sector into the atmosphere reach 42% of its total pollutants emissions (Smurov, 2012). Transportation plays an important role in the economic costs of the product, for example, transportation costs 20% of agricultural production costs. Therefore, the continuous increase in the price of conventional fuels (gasoline and diesel) represents a threat to food security (Zingbagba *et al*. 2019; Ivanova and Dospatliev, 2023). Therefore, reducing the cost of agricultural products is a priority for most countries. One of the successful ways to reduce costs is to switch to more sustainable fuel options from both economic and environmental perspectives.

To eliminate these problems of traditional fuels and limit their influence in the world, there is a constant search for a more sustainable alternative to fueling equipment. The possibility of obtaining alternative fuels with the required standards and physical and chemical properties will make it possible to improve the working processes of engines and thus improve their environmental and economic performance.

Prospects for Converting Agricultural Diesel Engines to Natural Gas Engine

Globally, natural gas reserves increased from 123.5 trillion cubic meters in 1996 to 186.6 trillion cubic meters in 2016, representing an increase of 51.1% (Chen et. al., 2019). In South America, Brazil has continued its policies requiring the inclusion of at least 22% ethanol in motor fuels and encouraging the use of hydrous ethanol vehicles instead of gasoline. Over the past decade, biofuel use has increased dramatically, reaching a total volume of nearly 30 billion liters (30,109) in 2003. Biodiesel use has grown significantly, rising from almost zero in 1995 to over 1.5 billion liters in 2003 (Demirbas and Balat, 2006). The natural gas market is actively developing in Russia, covering a large number of vehicles. Currently, compressed natural gas (CNG) is used in more than 14.7 million cars, which is 1.5% of the world market (900 million). Every year, the number of cars running on compressed natural gas is growing by 25-30% according to the forecasts of the International Gas Union, and will reach 50 million units by 2020 and 10030 by 2030 (Figure 1) (Makarova, 2013). Many global concerns are implementing the production of a number of gas-powered cars (Audi, BMW, Cadillac, Ford, Mercedes-Benz, Chrysler, Honda, Kia, Toyota, Volkswagen and others).

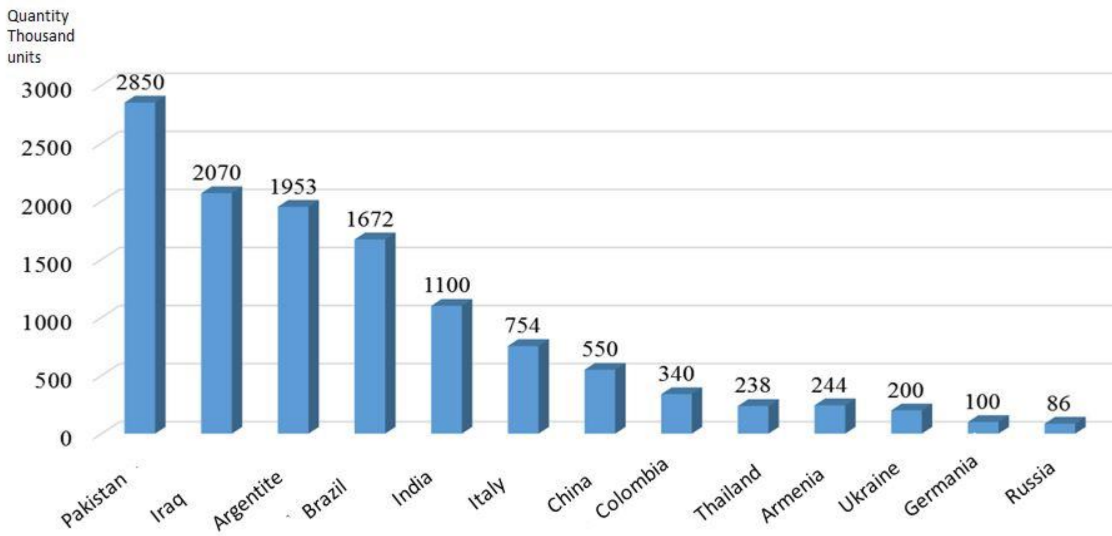

Figure (1) Global vehicles operating on compressed natural gas

By analyzing the graph shown in Figure (1), it can be concluded that Russia is in the first stage of the development to CNG transportation and lagging behind other countries, while Iraq is much higher in the use of methane as a fuel for cars for transportation.

The use of compressed natural gas as a fuel for cars has a number of advantages:

- Methane does not cause corrosion of metals.
- Non-toxic at low concentrations.
- Methane has a relatively low boiling point, which ensures complete evaporation of the gas at low temperatures.
- It burns almost completely and does not leave residues.
- Exhaust gases do not contain sulfur impurities.
- Safer compared to other types of fuel, since methane is lighter than air, and in the event of an emergency spill it evaporates quickly, preventing an explosion.
- Natural gas is much cheaper than gasoline and diesel fuel as shown in (Figure 2) by (Bebenin, 2009).
- Extracted natural gas is not subject to further processing.
- World reserves of natural gas far exceed oil reserves.

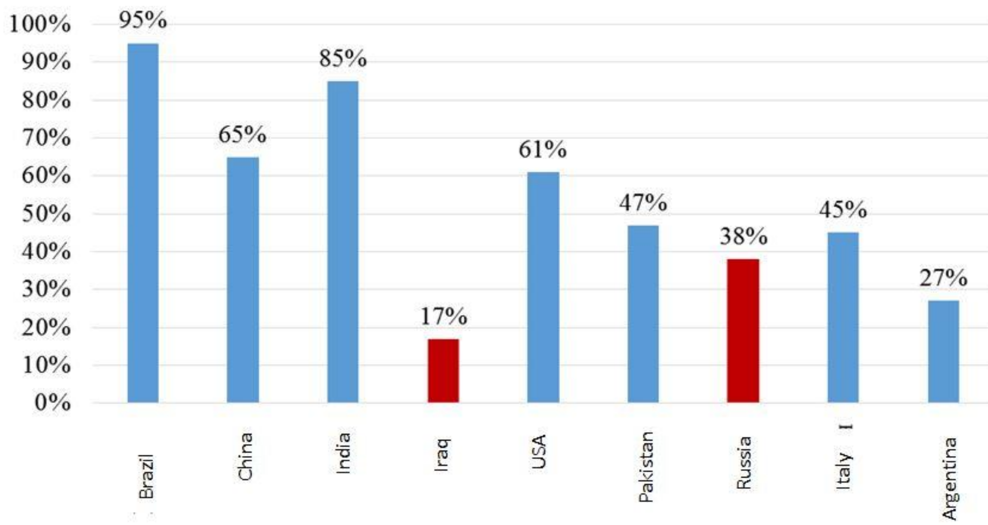

Figure (2) Ratio of natural gas prices to diesel fuel prices in major markets.

In addition, according to the decision of the Government of Russia, the price of natural gas cannot exceed 50% of the price of gasoline. At the moment, the average retail price of CNG in the Russian Federation is 14 rubles / m3. These advantages contribute to the rapid transition to natural gas transportation: road, rail and air. But there are also restrictive factors that determine the intensity of the introduction of gas-fired fuel.

In Iraq, due to the ongoing hostilities, as well as the emergence of the Islamic State of Iraq and Syria (ISIS), the capitalization of oil and gas companies has been reduced by external countries, which helps to limit the development of new gas fields, as well as support for already existing ones. Russian companies "Lukoil", "Gazprom Neft" and "Bashneft" are actively investing in the development of the oil and gas industry in Iraq, as well as implementing joint projects and exchanging experience and technologies for the transfer of equipment to gas fuel.

Currently, about 20% of the costs of agricultural projects are fuel costs. The share of gas does not exceed 1% in the total amount of fuel used. At the same time, the use of natural gas is more economical and environmentally friendly. In agriculture sector of Russia, this technology still operates mainly on diesel fuel shown in (Figure 3) by (Bebenin, 2009). This is due to an underdeveloped network of gas stations.

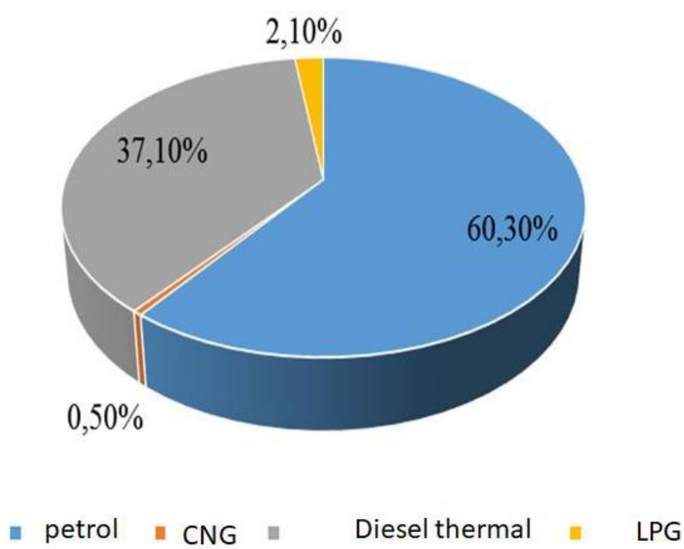

Figure (3). Scheme of fuel consumption in Russia

The lack of filling stations for this type of gas near agricultural areas is a serious obstacle to the conversion of agricultural equipment to natural gas, as it is very difficult to transport economical gas equipment to receive gas fuel from relatively distant places. Also, one of the problems is the imperfection of the design of the gas-diesel power supply system; besides the conversion cost is still high enough and does not allow small farms to convert agricultural machinery. Despite these problems, Gazprom expects a 10-times increase in demand for gas-diesel fuel in Russia for the period from 2015 to 2023 (Figure 4) (Gazprom report, 2013). The network of refueling stations of CNG increased to 314 units at the beginning of 2017, compared to 270 at the beginning of 2016. Approximately, 80% of gas stations in Russia are under the control of Gazprom. Thus, by January 1, 2017, Gazprom's LNG network totaled 254 units, compared to 220 units at the beginning of 2016. Gazprom's market share in terms of gas sales is even higher: in 2016, the company, through KNEX, delivered 478 million cubic meters of gas, or 89% of the country's total (Al-Maidi at al., 2017).

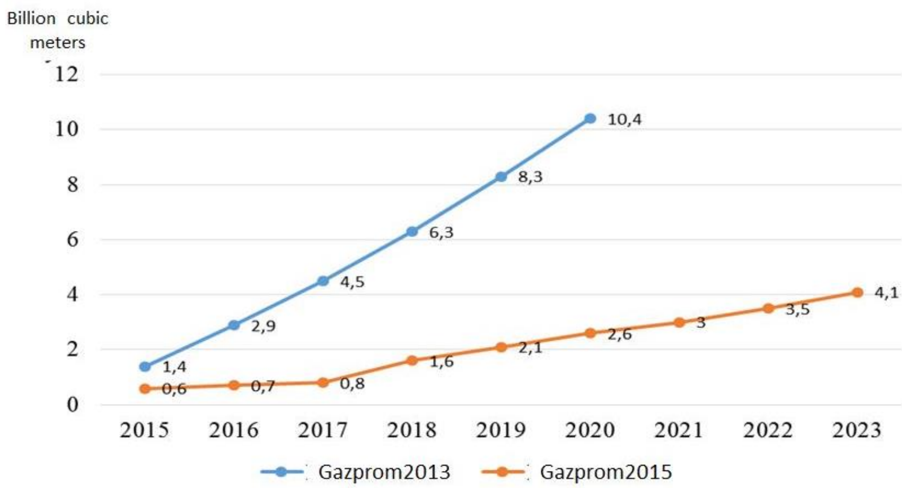

Figure (4). Forecast of CNG demand in Russia.

Thus, it can be concluded that many measures must be taken to ensure planned forecasting, and the most important of these measures are:

1. To conduct research and improve the design of casting systems for gas engines: both diesel and gas engines. Since the existing tug engine runs mainly on diesel fuel, it is more economical and faster to upgrade the existing engines to gas by adding a gas feeding system, gas cylinders and spark plugs. It should be noted that gas is easier to feed the engine with air, in contrast to the separate supply of reagents in diesel.
2. The development of small gas-powered compressor stations which will be available to small agricultural producers, as well as mobile fueling complexes which will ensure the supply of fuel gas directly to the workplaces of the machinery and tractors.
3. It is necessary to support the state enterprises of the agro-industrial complex, which consists of developing programs for converting agricultural machinery to natural gas-powered machines, and supporting farmers when purchasing machines that operate on compressed natural gas. Implementation of a program for the development of mobile fueling stations and complexes.

Analysis of methods of converting mobile agricultural machinery into compressed methane

The combustion temperature of diesel fuel is 320°C, and for compressed methane is much higher- about 700°C. In this regard, the combination of a compressed gas engine on a diesel cannot work, because the temperatures of the compressed air in the cylinders are not sufficient for self-ignition of compressed methane.

There are two main ways to adapt diesel engines to run on compressed natural gas (CNG):

1. Re-engineering the spark ignition engine (conversion).

2. Transition to a diesel fuel operation.

Reducing the compression ratio leads to a decrease in the efficiency index of the gas engine compared to the basic diesel engine. Increased throttle loss leads to a decrease in effective efficiency, especially at low loads. All this leads to deterioration (up to 30%) of operating costs of gas fuel (in volume units) on mobile equipment with a gas engine compared to a diesel analogue (Luksho, 2015).

Another method that has been used for a long time but is not widespread is the transition to the diesel fuel process. The basis of this method is adapting a diesel engine to operate on a mixture of diesel fuel and methane (gasoline diesel engine). With this method, it is necessary to supply the engine with a certain amount of diesel fuel as the ignition dose. This method involves mixing 70-85% natural gas with diesel. Consequently, the engine produces no black smoke, but the amount of hydrocarbons in the exhaust increases somewhat. But this is not carcinogenic which is emitted by diesel engine but only a small amount of unburned methane which is absolutely harmless. In addition, there is no strict check of the toxicity of exhaust gases in daily operation and no significant deviations from the established norm toxicity parameters (less sensitive, compared to fixed ones) have been detected (Bebenin, 2009).

Analysis of the toxicity of exhaust gases and smoke from diesel and gas fuel showed that the exhaust gases of gas fuel are 40% or more lower than that of diesel engine. The concentration of nitrogen oxides in the exhaust gases decreases by 20%. At the same time, the content of carbon dioxide emissions changes significantly (Dyachenko, 2004). Modern methods allow us to estimate the amount of emissions of harmful substances that contain exhaust gases of automobiles, but the environmental hazard of these emissions for humans (GOST, 1989). It should be noted that mechanical systems, due to their relative cheapness, represent a large market size. First of all, we should mention the countries where large quantities of pre-electric generation cars are produced under license and some of them will be produced in the near future (such as Argentina, Brazil, Egypt, India, Iran, China and Turkey). Also, the systems based on electric vehicles retain a large financial market share in Europe (Nigmatulin, 2014). The scheme of diesel fuel equipment of tractors K-700A and K-701 with microprocessor control system of gas supply SERG-500 produced by LK-DEEP "Diesel Automation" (Saratov) is shown in Figure 5, (Gyulmaliev *et al*., 2007).

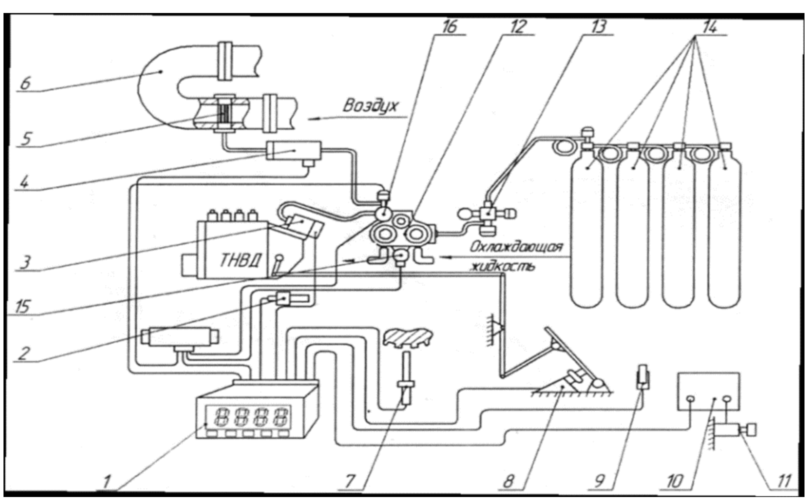

Figure (5) Gas diesel power supply system (SERG-500). 1- mixer; 2- intake manifold; 3- throttle body pipe; 4- Distributor; 5- dispenser;

6- valve; 7- cylinders; 8- temperature sensor; 9- stepper motor; 10- Electronic control unit; 11- control lever position sensor; 12- speed sensor; 13- Throttle Position Sensor; 14- fuel injection pump.

Unlike mechanical gas supply control system, the microprocessor system is equipped with a high-pressure reducer and two (parallel low-pressure) reducers of JSC "Autosystem" production. Parallel connection of two gears allows achieving the required gas flow at maximum power of the gas diesel engine (50- 55 m3/h). It is possible to install one two-stage gearbox with higher capacity. In this version the gearbox has two stages of high and medium pressure.

The amount of gas delivered in this scheme is regulated by the gas sterilizer controlled by the above electronic regulation system which includes the automatic control unit of the system and a number of necessary sensors (Expert analytical report, 2015). However, this system does not eliminate the disadvantage of the previous system because the ignition dose value remains constant, and the load regime is maintained by regulating the gas flow rate, i.e. a qualitative regulation implemented by diesel power. With this regulation, partial fuel media produce poor air-gas mixtures, i.e. worse combustion than that based on diesel fuel, which leads to an increase in fuel consumption and emissions of incomplete combustion products (Vibe, 1962).

It should be noted that electronic control of various parameters is now widely used on diesel and gas-gas engines. During the tests of this system, the following shortcomings were revealed (Lukanin *et al*., 2007):

- Significant system failures due to the presence of large amounts of impurities in the receiver;
- Release of unburned methane into the exhaust system due to significant overlap of the intake and exhaust valves (reducing efficiency and increasing HF emissions);
- Impossibility of dosing the fuel mixture individually for each cylinder and, as a result, inconsistency of the mixture composition in the combustion chamber.

In recent years, many regions of Russia (Ryazan, Vladimir, Penza, Samara, Saratov regions, Stavropol and Krasnodar regions) are actively implementing programs for converting agricultural vehicles and tractors to gas fuel. In separate farms of these regions tractors (K-700A, T-150K, MTЗ-80/82, DT-75M, PTM-160) with gas-cylinder equipment operate (Al-Maidi, 2017).

It is noted that it is more effective to re-equip powerful tractors (such as K-701) due to greater savings of diesel fuel. At the same time, the constant increase in prices for gas-cylinder equipment and fuel affects the efficiency of using tractors. The increase in the cost and installation of gas-cylinder equipment for the K-700A tractor with a gas-distributed injection system of the ejection principle, in comparison with the system with central injection, is compensated by 3.5 times. Compensation by increasing the difference in prices for diesel and gas fuel by 2.5 times allows increasing the net discounted income by 2.4 times.

In the fuel supply system in (Figure 6) the gas is distributed between the engine cylinders through gas valves installed in the intake manifold, and the system also differs from its existing counterparts in the presence of an electronic regulator that moves the fuel rail of the fuel injection pump depending on the operating mode of the internal combustion engine (Volodin *et al*., 2011). To increase the efficiency of gas fuel utilization by increasing energy, the system uses expulsion, where the energy of the gas is transferred to the incoming air when mixed, which leads to an increase in the combustion chamber filling coefficient (Volodin *et al*., 2012).

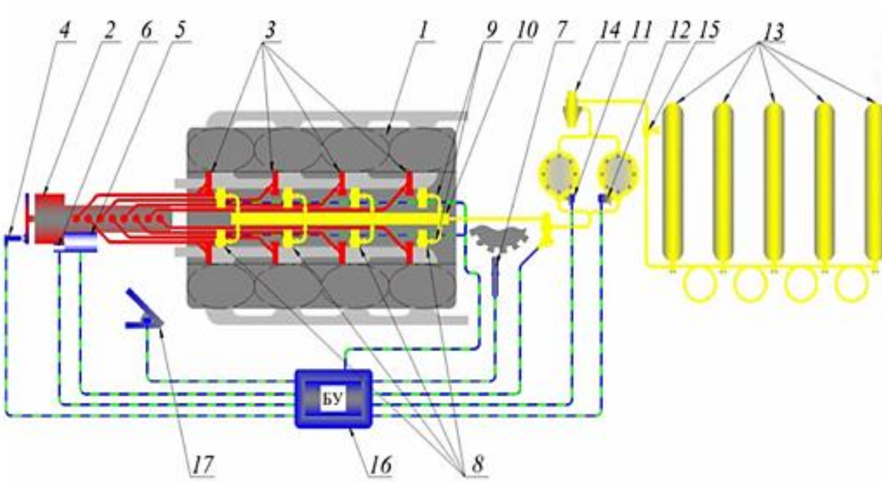

Figure (6) Distributed fuel gas inlet system. 1- Engine, 2 - High pressure fuel pump, 3 - Diesel injection, 4 - Phase sensor, 5 - Electronic controller, 6 - Fuel rail position sensor, 7 - Crankshaft speed sensor, 8 - Engine gas fuel ejector, 9 - Gas hoses, 10 - Gas manifold, 11 - Temperature sensor, 12 - Gas pressure sensor, 13 - Gas cylinders, 14 - High pressure gas pressure reducer, 15 - Valve group, 16 - Electronic control unit, 17 - Electronic master pedal.

One of the important advantages of using compressed natural gas as a fuel for vehicle is undoubtedly its economic feasibility, because the use of gas fuel allows you to save 80% of diesel fuel, provided that an ignition dose of 20-25% is provided. It is noted that the maximum economic effect is achieved when the most powerful tractors (type K-701) are transferred to work on a diesel fuel cycle, since they have the highest diesel fuel consumption. Despite the increase in prices for installing and purchasing gas equipment, the difference in prices for diesel fuel and CNG allows you to quickly pay for the cost of re-equipment and reduce the cost of diesel fuel by 3.5 times (Savelyev *et al*.,1997; Volodin *et al*., 2012; Savelyev and Gaivoronsky, 2006). The main advantage of CNG is its environmental friendliness, i.e. low harmful effects on the environment. Since CNG refueling consists mainly of methane, which, when burned in the engine cylinders, saves the content of hydrocarbons and water in the exhaust gas, therefore, replacing 80% of diesel fuel with methane leads to a corresponding reduction in soot emissions, which is a carcinogen. The exhaust gases of engines operating in the diesel and natural gas methane cycle are several times less toxic than the exhaust gases of diesel or gasoline internal combustion engines. In addition, natural gas does not contain sulfur, which has a harmful effect on water, soil and human health (Lukanin *et al*., 2007; Vasiliev *et al*., 1992).

Analysis of CNG properties

CNG types available on the European market (high-calorie H-gas with suitable calorific value tolerance) are simulated with reference fuel during experimental studies (Table 1), (UNECE Regulation, 2008).

Table (1). Characteristics of fuel indicator types

Characteristics	fuel index		
	GR	G25	G23
Methane, mol. %	84-89	86	92,5
Ethane, mol. %	13	-	-
Nitrogen, mol. %	-	14	7,5
Inert gases % mol.	1	1	1
Sulfur content, mg/m3	10	10	10

lower calorific value mj/kg.	49,5	39,0	43,9
Minimum Wobbe number, mj/m3	50,2	39,2	43,4
Lower Heating Value (LHV). mj/m3	3,47	3,38	3,41

Analysis of (Table 1) allows us to conclude that high-quality gas fuel must meet the requirements: the calorific value must be in the specified range, and the minimum value of detonation resistance, determined by the methane number (MCH), 75 (Gnedova *et al*., 2015). The methane number characterizes the fraction of methane throughout the volume, which is concentrated in a mixture of hydrogen and methane and explodes, like a test gas, with a similar compression ratio (Kirillov, 2008). So far, there is no generally accepted methodology for determining the methane number; therefore, the MF may vary from 5 to 8 units, depending on the calculation method used (Gnedova *et al*., 2011). In the study (Chaiyot, 2006), experiments were conducted on a multi-cylinder internal combustion engine, confirming the effect of changes in compression ratio on the performance of the internal combustion engine (Figure. 7).

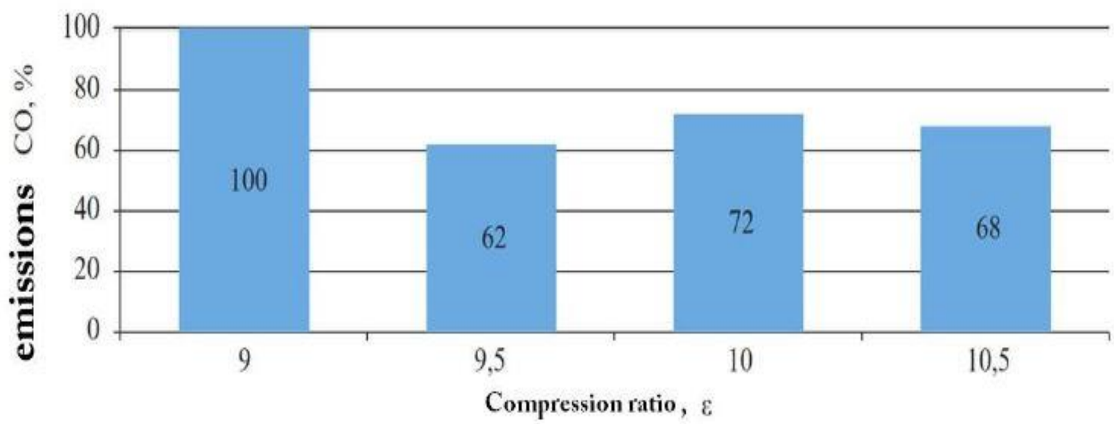

Figure (7) Effect of pressure on carbon monoxide emissions

Analysis of Figure 7 shows that with increasing compression ratio, the fuel combustion process becomes more intense, as a result of which CO emissions are reduced by 38%, which is achieved at η = 9.5 (Chaiyot, 2006). Figures 8 and 9 show a graphical presentation of the results of the studies conducted in (Feist and Deere, 2009; Linke, 2012).

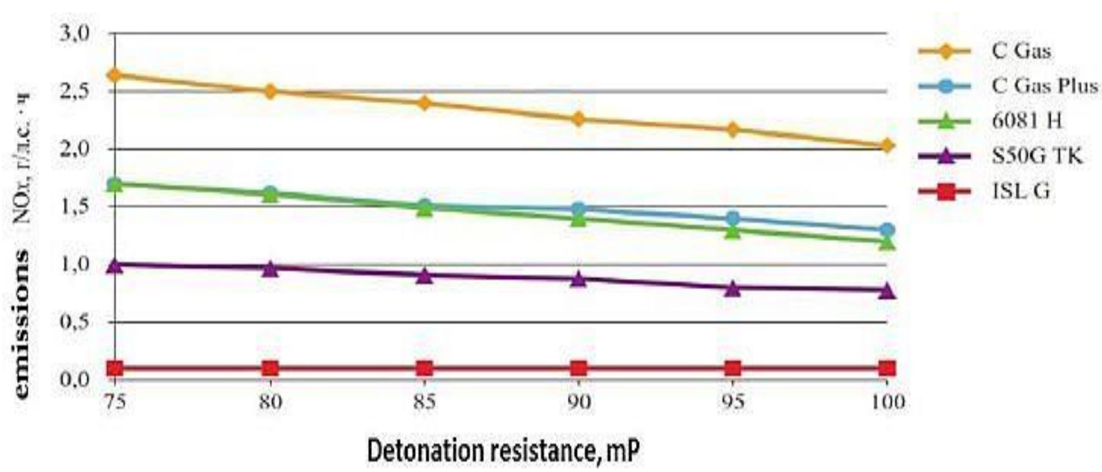

Figure (8) Specific NOx emissions during ICE operation on different gases

Analysis of Figure 8 showed almost the same dynamics of NOx emissions for different engines. According to the figure, the concentration of NOx in the exhaust gases is minimal at the highest explosion resistance of the gas, and increases with its decrease. Figure 9 shows the dependence of hydrocarbon emissions during gas engine operation on the detonation resistance of the gas used (Chaiyot 2006; Linke, 2012).

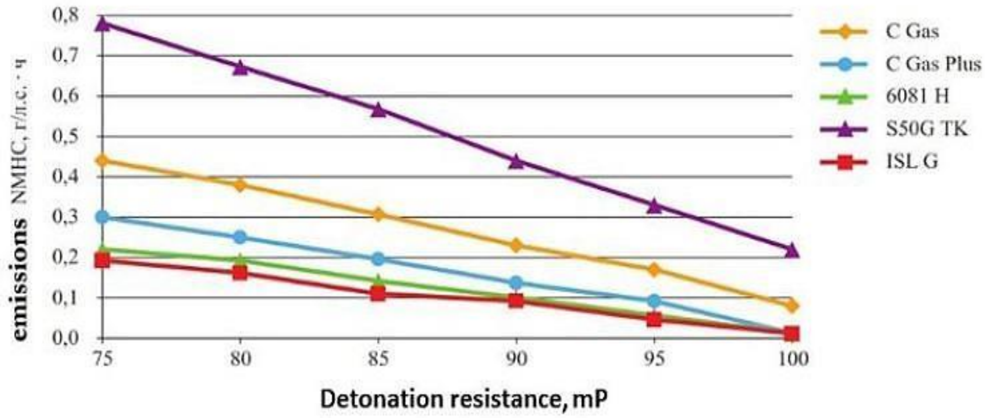

Figure (9) Dependence of specific hydrocarbon emissions on the detonation resistance of the gas used as fuel

Analysis of Figure 9 shows that with increasing gas detonation resistance, hydrocarbon emissions from engine exhaust gases are proportionally reduced, which is due to more complete combustion in the engine cylinders. Microprocessor control systems for internal combustion engines equipped with a knock sensor allow the engine operating parameters to be adjusted to ensure operation on gas fuel with lower detonation resistance (Chiu, 2005; Feist and Deere, 2009).

Conclusions:

The analysis of fuel supply systems for diesel and gas engines of agricultural machinery shows the following:

1. The search for ways to ensure fuel economy and environmental safety of agricultural machinery in the country leads to the need to use alternative types of fuel, to improve the design of modern engines and to develop devices to reduce the toxicity of engine exhaust gases. Therefore, the use of compressed natural gas as a fuel for vehicles is becoming increasingly practical.
2. Based on the analysis of existing methods of converting engines of agricultural machinery to CNG, it was found that the equipment in operation is optimally transferred to the diesel fuel cycle, since this method allows you to switch to a gas fuel system without significant changes in the design parameters of the internal combustion engine.
3. The analysis of existing methods of fuel supply through the gas and diesel cycle showed that the promising system, like other systems, is not ideal.
4. The distributed fuel feeding in engines operating with a gas-diesel cycle is not well understood: studies in the field of fuel economy and environmental friendliness are at the initial stage, so further study is necessary. The aim of this study is to improve the environmental and economic indicators of gas and diesel engines for mobile equipment in the agricultural sector.

Recommendations

It is recommended to use the developed fuel feeding system for diesel engines with a capacity of 150-400 kW for use in mobile agricultural equipment for the economic advantages provided by using gas fuels as well as the other advantage of its environmental friendliness, i.e. low harmful effects on the environment that preserve the safety of humans, animals and plants. In the future, it is necessary to develop a fuel temperature control program for high-power engines, and to use stationary equipment and convert it to natural gas engines to reduce its toxicity and maintain a clean environment.

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