Water and biofuel application strategy for combustion process in thermal power plants

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Abstract. The article provides an analysis of the use of biofuels and water-based fuels in thermal power plants. The problems of using these types of fuel and biofuel are identified, a new technical solution and water-synthetic fuel in the form of a water-fuel composition, which is patented as a water-containing composition and method for its preparation, are proposed. This composition can be used in various thermal engines and rocket installations. For various kinds of water-fuel composition, components had been calculated and designed for maximum cost efficiency. A feasibility study of one of the options of the use of water and fuel compositions for MAZ - 6601 engines shows the economic feasibility of the use of water and fuel compositions.

1. Introduction

Today, the world power consumption is based on non-renewable energy resources. The main sources of energy are oil, gas and coal. The immediate prospects for the development of the energy use are associated with the search for a better balance of energy use and, above all, attempts to try to reduce the share of liquid fuels. But we can say that today mankind has entered a transition period - from energy based on limited organic resources to the energy sector based on an almost inexhaustible potential.

High hopes are on the world's so-called alternative energy sources, the advantage of which is that they are renewable and that they are eco-friendly energy sources.

Almost all the world is actively engaged in the creation of fuel from biomass, and there are even countries that have already switched to this type of fuel to a certain extent (in Finland, the need for fuel by 20% met by biofuels, and the leader in the EU on the use of biomass as a source of energy is Germany). In Russia, the use of biofuels in the agricultural sector is becoming more and more actual. Agricultural production is known to be experiencing a constant need for high quality fertilizers and requires considerable quantities of fuel. With the help of modern biological technology, sustainability of agricultural production can increase many times. Biotechnology is considered to be the future of the economy of the country as a whole and its individual sectors [1,2].

2. Relevance

Among the alternatives to solve the problem associated with the reduction of energy sources and increasing environmental requirements for fuel, the aqueous fuel is considered. The water-fuel additive compositions change the composition of exhaust gases, which are the main cause of smog. The exhaust gases are improved due to significant reduction of nitrogen oxides, carbon monoxide and soot, thereby decreasing the level of smoke. In this aspect one of the most promising directions is the development of thermal power plants: Engines of internal and external combustion (steam boiler
installations), the use of water in vapor form, water-fuel emulsions, suspensions and aqueous fuel compositions in the combustion process [3,4,5].

3. Formulation of the task
The effectiveness of water-fuel emulsions has been proven by numerous studies of various scientists both within the country and abroad. But the main problem of the possibility of their practical application is the low stability, which cannot even be greatly improved by using expensive emulsifiers. Therefore, the task is a creating the stable water-fuel emulsions without the use of expensive emulsifiers.

4. Theoretical part
The fuel and energy system is a fundamental part of the infrastructure of a civilized society. This is the most important, life-supporting factor in the production of the modern world. The fuel and energy system is a social production, which includes the processing of energy resources into various types of energy.

The amount of energy consumed is constantly increasing. If we draw the link between energy consumption from the 20th century to the present day, then we can see the following trend: in 1900, 950 million tons of fuel equivalent were needed to meet energy demand, then in 1936 this figure became equal to 2000 million tons, that is, over 36 years, the need has increased by more than 2 times. The next increase in the number of used energy sources occurred 22 years later in 1958. Today, the increase occurs every 10 years. This trend may lead to the extinction of traditional fossil energy.

Search and use of alternative energy sources have always been interesting to society, but today the problem of resource exhaustion has become more urgent than ever. The increased interest in renewable energy resources is associated with the gradual reduction of traditional fossil energy sources, with the deterioration of environmental conditions due to emissions of waste gases, which increase the greenhouse effect.

Renewable energy sources are sources that are formed due to periodically arising or constant natural processes and phenomena, as well as the life cycles of flora and fauna, human activity.

The innovative development of today's economy includes three main areas - information, bio-and nanotechnology. In connection with the exhaustibility of energy resources in the future, the development of innovations has become extremely relevant. It is the latest biotechnology that will mark the beginning of a modern bioeconomy. This is one of the fastest growing industries.

The first renewable source of energy was the muscular strength of a person or animal. During the evolution of unconventional energy resources, the following types emerged: tidal energy, solar exploration, energy of radioactive particle splitting and chemical reactions, in other words, geothermal sources, solar and wind energy and biomass became the most common.

In the context of the growing shortage of energy sources and the rising cost of all known types of energy, the program of saving classical energy resources becomes actual. It should include the creation of new energy and fuel saving technologies, the rationalization of the use of heat, electricity and fuel.

The most important factors for the use of alternative energy are:
- reduction of harmful effects on the environment;
- wish to keep reserves of fossil non-renewable emergency energy sources for future generations;
- gradual abandonment of energy imports.

Bioenergy is considered one of the most promising areas in solving the problem of exhaustion of energy resources. Since ancient times, man used biomass as an energy source, it all started with making fire.

Biomass is the result of photosynthesis, which in turn is considered the most productive converter of the energy of the Sun. These are products of processing of the animal and plant world, in other words, organic waste, which can be a potential source of energy.

The interest generated by biomass as an energy source is due to a number of positive factors:
- Biomass is a renewable source;
The energy contained in biomass has a long shelf life and processing;
Biomass is converted to any type of fuel, solid, liquid, gaseous state;
Availability of bioenergy technology for the production of biofuels;
Broad prospects in the development of biofuels;
The use of organic waste as an energy source;
Bioenergy is a cost-effective energy source for some regions;
Biomass is a source of environmental energy that does not generate harmful emissions into the atmosphere.

The volume of reproducible biomass, its quality, composition of organic substances, humidity and physical properties have a significant impact on the quantity and types of biofuel produced.

By today's indicators, renewable energy resources make up about 14% in the world energy balance, while the share of biomass is about 2%. The indicators are small, but even minimal fluctuations in the market supply of energy resources entail a significant change in price. This indicates the prospect of a stable development of the alternative fuel market.

There are good arguments in favor of the use of biomass as an energy source. First, biomass recovery will maintain the concentration of carbon dioxide in the atmosphere; secondly, it would be expedient to apply annually appearing changes of agricultural land for the production of energy plants; thirdly, the processing of agricultural, household and industrial waste into energy, it will contribute to solving environmental problems; and finally, fourth, new technologies will ensure more efficient use of biomass.

Like any innovation, the bioenergy industry has its drawbacks.

- Biofuel production requires land, fertilizer, water.
- Often biofuels exceed the cost of classic energy sources.
- Researchers believe that it is better to use biomass locally.
- Water content (more than 50%) makes the processing of biofuels more expensive.
- Most biomass sources are seasonal.
- Photosynthesis has low efficiency.
- And the last disadvantage of biomass is storage difficulty.

Biomass is widely used to produce heat both within the private sector and on industrial scale. Most of the heat generated from renewable sources of energy comes from biomass. The use of biomass as an energy resource is most actively practiced in countries such as Sweden, Finland, Denmark, Austria, Germany and the Netherlands. In Sweden, for example, biomass is the main raw material for heat supply, which is also used in the transport sector.

Biofuels are an alternative to fuels derived from petroleum. The gradual growth of demand for biofuels from the transport sector will significantly change the situation on the energy market.

The World Energy Agency predicts a shortage of oil by 2025. Shortage is estimated at 14%. Biofuel production can cover only ½ of deficit.

The growth rate of alternative fuel productivity is much lower than the need for it, due to the need for cheap raw materials and the need for financing.

I would like to once again mention one of the positive aspects of biotechnology. The operation of biofuels has a beneficial effect on the environment

- Partial replacement of conventional fuels with alternative types will reduce damage from the extraction of mineral resources;
- Biofuels reduce the harmful effects of internal combustion engines.

The feasibility of using biofuels due to the ability to reduce the harmful effects of exhaust gases on the environment. It is impossible not to note the prospects that opens bioenergy for international trade in fuel.

The development of technology for processing of renewable sources will allow avoiding the threat of an energy crisis associated with the exhaustion of natural resources.

The use of alternative fuels will not only increase the level of vehicle safety, which depends on emissions of fuel combustion products into the environment, which negatively affect human health,
but also correct the fire hazard situation. Fuel is the main cause of vehicle fires. An effective way to prevent explosions and fires is to use such fuels that increase the flash point.

The production of alternative fuels, on the one hand, is quite radical, but on the other hand, the most promising method of energy saving, improving environmental performance, as well as reducing fuel prices.

The use of bioenergy technologies in agriculture helps to solve a number of problems associated with the use of organic raw materials, including industrial waste. Basic research of this approach will create a new, fairly efficient sector of the economy.

For the introduction of bioenergy in the national economy it is necessary to work in the following areas:

1. Research and formation of sources of bio-raw materials with high productivity. As a raw material, you can use wood, cultures of energy plants and waste of both industrial and man-made;
2. Testing various methods of biofuel production (production of solid, liquid and gaseous fuels). Methods for processing biomass and obtaining energy from it in the form of fuel are presented in Appendix 1.

Today there is a classification of biofuels, approved by the EU Directive of May 8, 2003. 2003/30 ES “On measures to promote the use of biofuels and other types of renewable fuels in the transport sector”. The most common are:

1. Bioethanol is ethyl alcohol obtained from agricultural waste (biomass), grain crops, used as the main component of the fuel;
2. Biodiesel is a methyl ester based on vegetable or animal oils, used as a biofuel.
3. Biogas is a fuel gas based on biomass or agricultural waste, used as biofuel. On quality it is equated to natural gas, it is made with accompanying products, such as organic fertilizers and fuel briquettes.
4. Solid fuels are pellets, briquettes obtained from biomass in the composting process, in the form of fuel for domestic stoves.

World experience has shown that crops of oilseed varieties, crop and livestock waste, and raw materials of plant origin (corn, rape, etc.) are the most famous and productive.

Let's take a closer look at each type of biofuel and its production methods. About 90% of the global consumption of biofuels belongs to bioethanol and biodiesel.

Bioethanol is a liquid alcohol fuel. It is produced from agricultural products, through the processing of sugar and starch containing crops. Unlike ordinary alcohol, on the basis of which alcoholic beverages are produced, water is not included in the composition of fuel ethanol.

Thus, bioenergy can be considered a promising source of energy for our country. Based on the above, it follows that biofuel is a promising direction for the development of the Russian economy in general and the agro-industrial complex in particular.

Unfortunately, in Russia the production of liquid biofuels is still poorly developed. At the end of 2007, there was not even a federal program for the development of biofuels, there were no plants for the production of biodiesel, stations that refuel vehicles with biofuels, while in the world work on the development of biofuels intensified in 1992. Growing rape on a huge scale was the beginning of the production of biodiesel in Russia, but the pace of development of this industry was slowed by the lack of a unified state production program.

Today in Russia, the main source of raw materials for the production of biofuels are food products, about 1.5 billion liters are produced annually from grain crops. But the orientation on the replacement of food raw materials by other equivalents, such as sugar production waste, sweet sorghum and lupine, can prevent the threat of grain shortages.

As it was said earlier, Russia has great potential for the development of this industry, since it has all the necessary components, this includes vast land areas for growing bio-raw materials, and factories for their processing. The disadvantages are that the state has little support for biofuel production. There are no specialized factories for the production of this fuel in the country, in addition, all alcohol-
containing liquids with a fraction of ethanol of more than 2% are subject to excise, and ethanol is the basis of biofuels, as a result of which biofuel production becomes simply not profitable.

Biofuels can be considered not only the most important resource in the development of the agro-industrial complex, but also a way to preserve climatic conditions by reducing emissions to the atmosphere. This fuel has a special place in the structure of energy sources.

With the help of modern biological technologies, it is possible to increase the ecological compatibility of agricultural production several times. Biotechnology can be called the future of the economy as a country as a whole, and its individual sectors.

The Russian agro-industrial complex is the most active consumer of fuel oil, besides diesel requires much more than gasoline. Energy and resource conservation is directly related to global fuel and energy reserves, rising prices for petroleum products, and increased environmental data and reduction of toxic emissions are due to a modern strategy for the protection of the environment.

Bioenergy in Russia plays an important role, it solves the problem of energy independence of agriculture. The main document regulating the development of the bioenergy industry is the “Energy Strategy of Russia for the Period until 2030”, and the strategy was approved by the Government of the Russian Federation in 2009. The main tasks are improving the quality of fuel oil and improving environmental indicators that meet international standards.

The development of alternative fuels and energy, the creation of energy-saving technologies and other ways of solving environmental and energy problems are possible only on the basis of an integrated scientific and experimental approach.

Comprehensive use of renewable energy sources will provide livestock feed industry, create additional places in the agricultural sector, as well as increase the competitiveness of agricultural products intended for export.

The future of the fuel and energy complex of our country is for biofuel. For Russia, where the immense expanses of abandoned land, where unemployment among the rural population is rampant with the dissolution of collective farms, the organization of mass production of biofuels can play a positive social role. Such a strategy will allow solving the state program of replacing imported products with gaining a competitive advantage.

The production of biofuels in Russia is at the stage of development and has great potential, which is a very positive fact. Unlike in Europe and the United States, where prices for food resources increase with increasing volumes of biofuel production, biofuels in Russia do not have a negative impact on the grain, feed and livestock market, while this area of agriculture is not at its peak.

Biofuel production is gradually gaining momentum, a factor hampering the advancement of the industry is poorly developed technological equipment, so it is very important to constantly develop equipment for the production of biofuels and gradually introduce it into production. It would be advisable to start producing high-quality equipment for the production of bioenergy products at one of the domestic plants. The organization of its own production will be much cheaper and cheaper than the purchase of imported equipment.

Today, the share of biofuel use in Russia is about 5%. This is due to the fact that most of the ongoing projects for its production are focused on exports to countries where the alternative fuel segment is better developed than in our state.

The use of emulsified fuel in agricultural machinery, today, is the solution to the main question regarding the saving of fuel and energy resources and reducing the harmful effects on the environment during their operation.

The feasibility of using water-fuel compositions is obvious. Today, fuel oil is the main fuel for vehicles. The growing number of vehicles entails an increase in the volume of fuel consumed and the demand for it, which in turn leads to an increase in the prices of petroleum products. In addition, diesel is considered one of the most popular types of motor fuel, its share in the fuel segment of the Russian market is about 30%. In agriculture, diesel fuel requires 5 times more than gasoline.

The most important performance indicator of water-fuel compositions is their stability, i.e. the ability for a long time to maintain the immutability of its structure. But it is this parameter that
determines the main problem of producing high-quality emulsion. Most of the methods for producing water-fuel compositions involve the use of expensive emulsifiers, but even so, the possibility of stratification during the prolonged inactivity of the vehicles in which it is used remains.

All of the above has led to the improvement of diesel fuel through the use of water-fuel compositions while increasing its usefulness and maintaining the level of costs for its production.

To date, no water influence on the combustion process is fully studied, but we have found that, for example, to remove all the water from gasoline available there, and there is always at least tiny amount of water, the gasoline will not burn. It has been known to chemists even in the 19th century.

Recently it was found that for any burning must be at least any tiny but amount of water [6]. For a theoretical justification, that the water involved in the combustion process, you can use the data in Table 1, which provides information about the degree of dissociation of the components of the combustion of hydrocarbon fuel, water and air.

Table 1. Information about the degree of dissociation of the components of the combustion of hydrocarbon fuel, water and air.

| Compound (radical) | Dissociation Equation (disintegration) | The dissociation constant of equilibrium (disintegration) | The degree of dissociation (disintegration) |
|--------------------|----------------------------------------|----------------------------------------------------------|---------------------------------------------|
| The hydrocarbon fuel (gas oil) | C\textsubscript{n}H\textsubscript{m}→ R\textsubscript{1}+R\textsubscript{2}+… | 5.24\times10\textsuperscript{5} | - |
| Water | H\textsubscript{2}O↔OH+H | 2.16\times10\textsuperscript{-6} | 2.1\times10\textsuperscript{4} |
| | H\textsubscript{2}O↔H\textsubscript{2}+O | 6.53\times10\textsuperscript{-6} | 4.4\times10\textsuperscript{4} |
| Hydroxyl | OH↔H+O | 2.57\times10\textsuperscript{-10} | 1.6\times10\textsuperscript{5} |
| Oxygen | O\textsubscript{2}↔O+O | 2.08\times10\textsuperscript{-10} | 7.2\times10\textsuperscript{6} |
| Nitrogen | N\textsubscript{2}↔N+N | 4.4\times10\textsuperscript{-25} | 3.32\times10\textsuperscript{-13} |

Since the ability to dissociate the hydrocarbon fuel is significantly superior to other components, it will primarily be the disintegration of hydrocarbon molecules with the formation of radicals. Furthermore, the water dissociation equilibrium constant of the process is four times higher than that of oxygen, and even more — of nitrogen. Therefore, most probably happens a direct interaction with the water dissociation products of hydrocarbon radicals according to scheme

\[ R\textsubscript{1}+H\textsubscript{2}O→R\textsubscript{1}OH+H; \]
\[ R\textsubscript{2}+H\textsubscript{2}O→R\textsubscript{2}H+OH; \]
\[ R\textsubscript{3}+OH→R\textsubscript{3}OH; \]
\[ R\textsubscript{4}H+OH→R\textsubscript{4}+H\textsubscript{2}O. \]

Effective participation of the atoms of water molecules in the combustion of water-fuel mixtures and suspensions is explained in following way. The rate of diffusion of hydrogen atoms (because of their small molecular weight) is many times greater than that of molecules of oxygen and hydrocarbon radicals. Therefore, produced in excess the hydrogen atoms of water will rapidly diffuse into the zone of air excess oxygen and a reaction of their combustion compensates for the cost of the dissociation energy of the water. Involving oxygen of water in the combustion can be also explained burning of soot particles by using water vapor and water-fuel emulsion, which is due to the fact that soot particles are formed as a result of cracking in areas with scarcity of atmospheric oxygen, react with water with oxygen and hydroxyl radicals, and this occurs at the expense of their pre-oxidation. As a result, it prevents coagulation of soot particles and therefore continued their rapid burnout [7].

In experimental studies of the water-fuel emulsions of water based on the prepared oxygen \(^{18}\)O isotopes, it was found that 60% of the oxygen atoms of the water-fuel emulsions of water have been involved in the oxidation of hydrocarbon fuels. This indicates that the water-fuel emulsion is not a simple mixture "nonflammable" hydrocarbon fuel and water but a specific component of the fuel required for combustion, with increases its efficiency.

This is achieved by the fact that the water when getting into the combustion chamber 5 performs positive functions
1. Improves the process of mixing the water due to micro-explosions (explosive conversion of water into superheated steam drops of inverse emulsion).

2. Resource-saving (increases engine life due to lower motor teplonapryazhënnosti caused by the reduction in the average due to the heat consumption cycle temperature on its heating, steam generation and dissociation.

3. Economic (engine efficiency increases due to volume growth of process gases, and their performance because of superheated water vapor. This is explained by the fact that RT of water vapor is higher than that of all the combustion components.

4. Environmental (facilitates the simultaneous reduction of soot and NO\textsubscript{x}) more intensive burning out of soot in the combustion process.

5. Tribological (plunger wear decreases).

In this case the first three functions increase diesel efficiency and reduce soot emissions from the exhaust gases. The fourth feature (factor), mainly contributes to an increase in NO\textsubscript{x} reduction and engine life extension.

As a negative effect of the water should be noted:
- Difficulty of mixture self-ignition due to lowering of combustion temperatures;
- An increase in the time of evaporation of large droplets external emulsion;
- Corrosion of fuel equipment [8].

Despite the fact that the positive tests for use in automotive and locomotive diesels of water-fuel emulsions were conducted by various researchers for a long period of time, they are not practically used because of the instability of emulsions. Thus, there were developed many different emulsifiers that enhance stability, but do not give full effect.

Authors have decided to create a stable water-fuel composition without emulsifiers by establishing equality of densities and water-containing composition of hydrocarbon fuels at the expense of the ratio of components at the same time as the aqueous composition is used a water-alcohol solution.

Let's consider the feasibility study of one example of the use of water and fuel composition.

We analyze and determine the feasibility of use of water and fuel composition for diesel engines in the agricultural enterprise [9,10]. To do this the annual fuel consumption, its purchase costs, implementation costs of the project for the production of water and fuel composition, the break-even period of the event and the expected economic benefits need to be calculated.

In the agricultural car park there are 25 machines of type "MAZ 6601". Fuel consumption of the car "MAZ-6601" is 80 liters per 100 km, the average mileage of the car is 90 000 km, it is necessary to take into account the fact that these figures relate to engines that are in operation for the short periods of time. Calculate the annual consumption of diesel fuel for the entire fleet of vehicles:

\[ \text{Fuel consumption} = 80 \times 900 \times 25 = 1800000 \text{ l.} \]

Today, the market price of diesel fuel is 32 rubles per liter. Therefore, diesel fuel costs will be equal to 57.6 million rubles for the year:

\[ C_{DF} = 1800000 \times 32 = 57.6 \text{ million rubles.} \]

For further calculations it is necessary to convert liters to kilograms, so that fuel consumption will amount to 1 512 000 kg, the price of 1 kg of fuel 38,1rub.

It is proposed to replace diesel fuel with a water-fuel composition and therefore reduce fuel costs.

The market price of bioethanol is 18 RUB / Ltr or 22.8 RUB / kg, water costs, including the cleaning and recycling, we take equal to 7 RUB / kg.

According to the initial data we calculate the cost of the preparation of water-fuel composition, which will be 42635800 RUB.

Thus calorific value of conventional diesel fuel is 44.8 MJ / kg. It is necessary to determine the heat of combustion of the fuel-water compositions to be compared with the conventional fuel efficiency.

The calorific value of bioethanol is 33 MJ / kg., and the calorific value of biofuel composition, consisting of diesel fuel and bioethanol is 39.84 MJ / kg., which is lower than calorific value of diesel fuel by 11.07%. Based on the experimental data on aqueous fuel composition it was discovered that
the content of 15% water in the composition increases the combustion efficiency for 7% - 12%, this is
due to the burning of carbon more effective CO

To be safe, we will calculate the lower boundary of 7%. As a result, the calorific value of the water-
fuel composition is to increase to 42.6 MJ / kg. The remaining 4.9% are achieved by increasing the
amount of aqueous fuel composition.

As a result, the cost of water and fuel composition will be 44724954 RUB.

At the same time profit from the fuel will be 12875046 RUB.

To determine the cost-effectiveness, it's necessary to calculate capital investments, which include
the purchase of a mixing liquids' system, construction of facilities and preparation for the operation as
well as other expenses.

Consider mixer with a capacity of 2.8 tons / hr. Calculate the time (T), for which a specified
amount of emulsion will be made:

\[ T = \frac{\text{volume}}{\text{performance}} = \frac{1656}{2.8} = 591 \text{ hours} \]

With a six-hour working day it will take about 4 months. Thus, we can conclude that for this to
work is enough to get one mixer of such capacity but if it breaks an additional mixer will have to be
purchased. So, taking into account other costs, such as delivery and installation of equipment,
maintenance and repair, as well as additional equipment for determining the density and temperature
of liquids, for the purchase of the equipment costs will be equal to 710 000 RUB.

The construction costs of the premises and its equipment will amount to 1 910 000 RUB thus
require capital investment \( I_0 \) in the amount of 2 620 000 RUB.

It is necessary to take into account the current expenditures on wages per worker, which annually
equal of 360 000 RUB.

It is very important to determine the result of the effect of introduction of new technology. The
economic rationale lies in the calculation of the economic effects. The economic effect characterized
by the NPV (net present value). Net present value - the sum of the current values of all predicted,
based on a discount rate of cash flows.

When discount- \( k = 0.32 \) \( (k = k_1 + k_2 + k_3) \):
\( k_1 \) - bank interest rate on the deposit, \( k_1 = 0.13; \)
\( k_2 \) - coefficient that takes into account the losses arising from changes of
the value of money due to inflation, \( k_2 = 0.09; \)
\( k_3 \) - coefficient taking into account potential losses from risk
associated with the implementation of this project, \( k_3 = 0.10; \)

1. Within the % year implementation average annual economic effect of the project will be
5355000 RUB with a break-even period of 3.5 months.

5. Conclusion
Biofuel holds a special place in the structure of energy sources. Being an alternative fuel, biofuels can
be considered the most important resource in the development of agriculture, as well as climate
protection by reducing emissions.

To improve the effectiveness of the use of biofuels, a new method is proposed of making them in
the form of water-fuel composition that provides increased efficiency and environmental friendliness
when used.

Feasibility study of one example of the use of water and fuel composition for the enterprise which
has 25 "MAZ-6601" cars showed the expected average annual economic effect of 5355000 RUB with
a break-even period of 3.5 months, which indicates the practicability of implementing of the proposed
method.

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