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PAPER

ANALYSIS OF TECHNOLOGIES AND DEVICES FOR BURNING ALTERNATIVE BIOMASS-DERIVED FUELS

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Abstract

In this study, the authors analysed the importance of spraying and atomisation in the combustion of alternative liquid fuels derived from biomass pyrolysis. They scientifically substantiated the formation of droplets resulting from the primary and secondary decomposition of alternative liquid fuels exiting the injector, their spatial distribution and the evaporation processes. The study found that the spray cone angle, spray distance and formation of spray zones can ensure effective fuel-air mixing in the combustion chamber. The results demonstrate the importance of optimising atomisation processes in increasing the combustion efficiency of alternative liquid fuels obtained from biomass pyrolysis and reducing fuel consumption and harmful emissions into the atmosphere.

Key words: Biomass pyrolysis fuel, alternative liquid fuel, spraying process, atomization, vaporization zone, sprayer (injector), combustion efficiency.

Introduction

Fossil fuels - natural gas, coal, shale and oil - currently form the basis of the world's energy balance as traditional energy sources. However, these resources are becoming depleted every year due to increased extraction, processing and consumption. Therefore, the rational use of fuel and energy resources, as well as finding new sources to replace them, is considered one of the most urgent global problems today [1-3]. Solving this problem will not only serve the sustainable development of the global community, but also help to maintain ecological stability and reduce the impact of human activity on the environment. In recent years, interest in the creation of energy-saving technologies based on renewable energy sources has increased significantly due to the depletion of traditional fossil fuel and energy reserves and the increasing emissions of greenhouse gases and harmful compounds resulting from their combustion. These include solar, wind and

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biomass energy, as well as other natural sources. Alternative fuels derived from biomass, such as gaseous, liquid (e.g. bioethanol and biodiesel) and solid (e.g. pyrolysis coal) fuels, are recognised as environmentally friendly, renewable and promising sources for ensuring energy independence [4-5].

The high energy potential of biomass, its renewable nature, and the possibility of converting waste biomass from various sources (agricultural residues, livestock waste, household and food industry waste) into an energy source further increase the relevance of this direction. Biomass resources are widely distributed in the territory, and a large part of them is currently not sufficiently involved in the energy cycle. However, by directing these wastes to the production of biofuels (biogas, bioethanol, biodiesel, biosolid fuel), on the one hand, energy supply is diversified, and on the other hand, environmental problems - waste accumulation, atmospheric and soil pollution - are significantly reduced.

At the same time, the development and use of alternative fuels based on biomass will allow reducing greenhouse gas emissions, gradually implementing the principles of carbon neutrality, increasing the share of organic waste recycling, and effectively using local energy resources. These processes serve as an important factor in strengthening the country's energy security, reducing dependence on imported fuels, and ensuring the energy independence of regions. In addition, biomass energy also serves to create new jobs in rural areas, develop small and medium-sized energy facilities, and accelerate regional socio-economic development.

Thus, the development of alternative fuels derived from biomass, their integration into practical energy systems, and improvement of existing technological processes is one of the important scientific and practical directions within the framework of the sustainable development strategy of Uzbekistan. This direction requires not only the introduction of energy-saving and resource-saving technologies, but also creates a solid scientific and technological basis for ensuring environmental safety, developing waste-free and low-waste production systems, and accelerating the "green" transformation of the economy. As a result, biomass energy is emerging as one of the priorities in Uzbekistan's long-term energy policy and climate change mitigation strategies [6-8].

Methods and materials

This research study examined methods of obtaining alternative fuels from biomass and technologies for burning these fuels, based on widely accepted scientific principles. During the research process, widely accepted analytical methods were employed to analyse technologies for converting biomass energy into other forms of energy, such as anaerobic decomposition, pyrolysis, gasification, fermentation and briquetting, as well as methods for obtaining energy from biofuels. These methods included comparative analysis, a systematic approach, statistical processing and energy-technical assessment.

In recent years, countries around the world have introduced strict emission standards due to the increasing harm caused by global warming to human health, encouraging researchers to search for alternative renewable fuel sources. With the depletion of oil and gas reserves and the intensification of environmental problems, the development of alternative fuels and practical solutions for their global use is accelerating.

According to the International Energy Agency (IEA), biofuels are expected to account for around 5.4% of fuel and energy resources consumed in the transport sector by the end of 2025 [10]. From an economic and energy security perspective, integrating alternative fuels into the energy system reduces dependence on traditional oil imports and contributes to domestic economic development.

In particular, alternative fuels allow for the reduction of NO_x, SO_x and greenhouse gas emissions. They contain very little sulfur, making them more easily biodegradable than petroleum products.

Biofuels similar to diesel, such as vegetable oil, essential oil and pyrolysis oil, can be used in existing diesel engines without further processing or the need for new infrastructure [10].

However, alcohols, gaseous fuels, bioethanol, biomethanol, liquefied biogas and bio-DME (dimethyl ether), which are obtained from the thermal processing of biomass and biofuels, require modifications to be made to internal combustion engines, storage and refuelling infrastructure. This leads to additional costs.

The process of spraying liquid alternative fuels into the combustion chamber is precisely timed to create the optimal mixture at the desired stage of combustion. The spraying and atomisation of fuel (the process of dividing liquid fuel into very small droplets) have a significant impact on combustion efficiency and the amount of combustion products. In this process, it is necessary to strike a balance between maximising efficiency and minimising the amount of combustion products [11].

The spraying of liquid alternative fuels occurs in two main stages:

Primary spraying: in this stage, the liquid fuel flow is separated into small droplets and particles due to turbulent flow conditions and cavitation phenomena. This process occurs particularly during spraying under high pressure.

Secondary spraying: in this stage, the resulting droplet particles are broken down into smaller particles due to collisions and coalescence in a gaseous environment [9,10,12].

Many researchers have studied the effect of biodiesel produced by biomass pyrolysis and its blends with diesel on the efficiency of diesel engines, as well as the amount of waste products generated during the combustion process [13].

G. J. Cong et al. conducted an experimental study investigating the impact of a blend of canola oil-based biodiesel and diesel on the performance of a diesel engine. Their study showed that the presence of oxygen in the biodiesel was important for the combustion process of canola biodiesel. The results showed that the maximum pressure values during combustion were lower for pure biodiesel (B100) and a 20% biodiesel + 80% diesel blend (B20) than for diesel fuel. Additionally, the combustion delay of pure biodiesel (B100) and the B20 blend was shorter than that of diesel. The experiments also showed that the amount of CO (carbon monoxide) and exhaust gases decreased during the combustion process, but the amount of NOx compounds increased. In their studies on biodiesel, Can et al. determined the fatty acid composition of purified biodiesel. Many studies have shown that the higher viscosity and density of biodiesel compared to diesel fuel affects the fuel's injection properties, resulting in lower engine efficiency with biodiesel than with diesel fuel [14].

Consequently, researchers are keen to study liquid fuel injection processes and optimise the combustion efficiency of alternative liquid fuels by analysing injection behaviour.

An important feature of alternative liquid fuels is that changes in their physicochemical properties affect the formation of the fuel spray and, consequently, the efficiency of fuel vaporisation and the structure and nature of the flame.

Results and discussion

Figure 1.1 illustrates the process and device for the combustion of alternative liquid fuels by spraying.

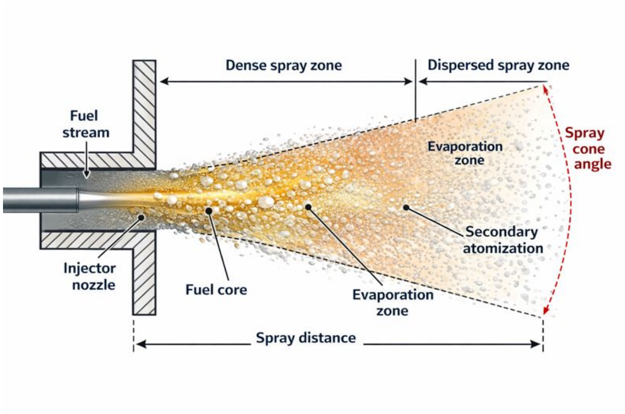

Figure 1. Process and device for the combustion spraying of alternative liquid fuels.

The figure 1 schematically depicts the exit of alternative liquid fuel from the injector nozzle, its separation into droplets, and the spatial distribution of these droplets during the spraying process. Initially, the liquid fuel flows out of the injector in a liquid core state, and primary atomisation occurs near the nozzle mouth. Here, the flow becomes unstable, separating into large droplets and forming a dense spray zone.

As the liquid fuel continues to flow, the droplets become smaller due to aerodynamic forces, turbulence and interaction with the environment. This stage is known as secondary atomisation, characterised by the formation of a dispersed spray zone. Here, the diameter of the droplets decreases sharply, their total surface area increases, and heat and mass transfer processes accelerate.

The figure 1 also shows the evaporation zone of the liquid fuel, where small droplets evaporate intensively and the fuel mixes with the air more readily. The spray distance and spray cone angle depend on the design features of the sprayer and the physical and thermal properties of the liquid fuel. These parameters are important for determining the efficiency of the combustion process.

Conclusions

The analysis conducted during the research shows that the spraying and atomisation stages are crucial for the efficient combustion of liquid, biomass-based alternative fuels obtained from biomass pyrolysis. The primary and secondary decomposition processes of the liquid alternative fuel exiting the injector result in crushed droplets and an increased total surface area, ensuring an optimal evaporation rate and degree of mixing with air for complete combustion. The spray cone angle of the liquid alternative fuel, spray distance and formation of spray zones ensure a uniform distribution of the combustible mixture in the combustion chamber.

According to the analysis results, the consistent formation of thick and thin spray zones of liquid alternative fuels, as well as the development of the vaporisation zone, indicates active preparation for combustion. In particular, the small droplets formed during the secondary decomposition stage evaporate rapidly due to intensive heat and mass transfer, leading to increased flame stability and combustion efficiency.

Therefore, improving alternative biomass-based fuel combustion technologies requires optimising atomiser design and controlling atomisation parameters, as well as conducting in-depth studies of atomisation processes. This provides a scientific and technical foundation for increasing fuel combustion efficiency, reducing harmful emissions into the atmosphere, and effectively integrating biofuels into practical energy systems.

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