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Utilization of landfill gas from municipal solid waste by co-combustion with hydrogen

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Abstract. Currently, the problem of utilization of landfill gas (LFG) released in landfills and municipal solid waste landfills is becoming increasingly urgent. This is due to environmental pollution and, as a consequence, the level of increase in the incidence of the population. The article provides an overview of currently existing methods of landfill gas utilization. The authors of the present article have conducted research on the utilization of landfill gas from a municipal solid waste landfill by co-combustion with hydrogen. Some experimental data were obtained on the influence of various factors on the stable combustion of a gas mixture. The advantages of the proposed method are discussed, including its potential to reduce air pollution by greenhouse gas, as well as the creation of additional energy sources, and effective utilization of LFG from municipal solid waste landfills.

1 Introduction

The complexity of waste management is associated with their diversity, uneven composition in seasonal and climatic cycles, the level of recycling culture, and the variety of existing methods and technologies for their processing and disposal [1].

One of the main types of anthropogenic impact of landfills and municipal household waste landfills is atmospheric air pollution by landfill gas from natural biological decomposition of organic components stored in waste dumps.

LFG formation continues for decades after the cessation of waste reception and landfill remediation, with the most active phase of gas evolution being 20 - 30 years [2].

It is known that one can swap out conventional natural fuel for landfill gas as an ecologically clean type of fuel having a low level of carbon [3, 4]. Due to increasing energy demand, bioenergy production from biomass and landfill gas will increase in the future. Therefore, the use of landfill biogas to generate electricity should be encouraged by national governments, because it is an alternative source of energy, and it can cut back on CO_2 emissions [5].

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The main components of LFG are methane CH_4 (30 – 50%), carbon dioxide CO_2 (30 – 45%), as well as mercaptans and non-methane organic hydrocarbons (~ 1%).

Methane and carbon dioxide are both greenhouse gases, with the greenhouse effect of methane being 25 times greater than that of carbon dioxide. The calorific value of LFG is ~18–25 MJ/m^3.

Various technologies and equipment are used to utilize landfill gas from municipal solid waste landfills [6-8]. Each technology has its own economic, environmental, and social impact.

Thus, in article [6], the study was aimed at planning the use of landfill gas for the production of renewable energy at the Seelong garbage dump in Johor, Malaysia. Using the GAMS optimizer, the authors selected the most profitable landfill gas utilization technology from the range of series proposed below: gas motor, gas turbine and steam turbine for generation of electric energy or combined heat and power production; steam boiler for steam generation; direct distribution of landfill gas at homes/industrial establishments as a substitute for natural gas. The optimization results showed that a steam turbine operating on low-grade landfill gas is the most appropriate variant in terms of profitability and ecological requirements.

In article [7], incentives for the extraction of landfill gas with a lower methane content were studied and assessed based on a comparison of the Stirling technology and traditional one, and parameters affecting the formation of methane were identified. To evaluate the performance of Stirling engines, the Ronneholm waste storage facility was investigated. When knowing the limitations of different technologies, one can conclude that we can have control over landfill gas in the future. The study shows that Stirling technology works well even at low methane concentrations and low gas streaming. Flaring is also possible in situations of this kind. However, the value of Stirling technology is that both electricity and heat can be produced from gas.

In article [8], greenhouse gas emissions from an uncontrolled landfill filled with municipal solid waste (MSW) are compared with emissions from controlled sites where collected landfill gases (LFGs) are disposed of using various technologies. These technologies include flaring, traditional energy generation technologies such as the internal combustion engine (ICE) and gas turbine (GT), as well as a new technology of solid oxide fuel cell (SOFC). The results show that SOFC is the best variant to lessen CO_2 emissions among discussed technologies.

All of the above technologies the advantages and importance of using landfill gas are shown. The authors of the present article believe that in order to obtain thermal energy, the recycling process should be simplified by means of effective co-combustion of landfill gas with hydrogen in a hot water boiler.

Landfill gases, produced by the decomposition of waste in landfills and municipal household waste landfills, are not only an environmental problem but also a potential source of valuable energy. One approach to managing these gases is to use H_2 when burning them.

The advantages of using hydrogen include:

1. *Energy potential of hydrogen*. Hydrogen is a clean and efficient source of energy. Its combustion does not produce carbon emissions, making it environmentally friendly and an important contributor to strategies to reduce greenhouse gases and combat climate change.

2. *Use of hydrogen to burn landfill gas*. When burning landfill gas together with hydrogen, it produces water and carbon dioxide, which is more environmentally friendly than CH_4 emissions.

3. *Reducing greenhouse gas emissions*. The use of hydrogen in the combustion of landfill gases helps reduce emissions of greenhouse gases such as methane. This is

important for achieving global goals to reduce emissions and reduce negative climate impacts.

4. *Technological progress*. Modern technologies for using hydrogen to burn landfill gases are becoming a real alternative, supported by innovative developments in the energy sector.

5. *Economic incentive*. The adoption of hydrogen technologies can create new markets and business opportunities, encouraging economic and industrial development. Economic incentives can be a powerful driver for innovation in landfill gas management.

Controlling co-firing requires careful monitoring and constant updating of technology to accommodate a variety of gas compositions.

In articles [9-11], a positive effect is described when adding hydrogen. Thus, in article [9] the results of combustion of mixtures of low-emission and high-efficiency liquefied petroleum gas enriched with hydrogen are presented. To maintain equal calorific value of the fuel mixture, the amount of liquefied petroleum gas was reduced as hydrogen was gradually added. The results showed that the duration of rapid combustion shortened and the rate of heat release increased as the proportion of hydrogen in the fuel mixture increased.

Conducting research [10, 15] on introducing hydrogen into methane will make a big difference in converting power plants to hydrogen combustion. The effect of this additive on flame structure and CO emissions was evaluated on two various atmospheric burners. Four types of fuels of the following composition were used: 100%CH4, 98%CH4 + 2%H2, 94%CH4 + 6%H2 and 85%CH4 + 15%H2. In a single-pass atmospheric burner, the blue cone height tends to decrease when hydrogen is added. An increase in laminar combustion rate was identified as the main influence on the response of this parameter. The results obtained are consistent with previous experimental studies. This decrease is explained by a higher concentration of OH radicals by a process of hydrogen addition.

Of scientific interest are studies on the gradual conversion of internal combustion engines to hydrogen [11]. The effect of LPG + H2 emissions (0%, 15%, 30% and 45%) with different energy content at full load and the same torque (70 Nm) at a constant engine speed of 1200 rpm is investigated on CO, THC, NOx and smoke emissions. The results showed small increases in brake thermal efficiency, CO and THC emissions, but significant improvements in NOx and smoke emissions. By using small amounts of hydrogen (20% of the total gas mixture) and liquefied petroleum gas, one can be achieve significant improvements, and the damaging action of diesel engines can be reduced due to the unique properties of hydrogen fuel.

2 Materials and methods

In article [12], a series of experiments are described concerning the combustion of gaseous fuel in a burner unit shown in Figure 1. The burner consists of internal blades, a tapering channel, a fuel supply tube with holes, holes for hydrogen supply and an outer ring of blades. During the experiment, the blades took positions of 30°, 40°, and 60° relative to the axis of burner.

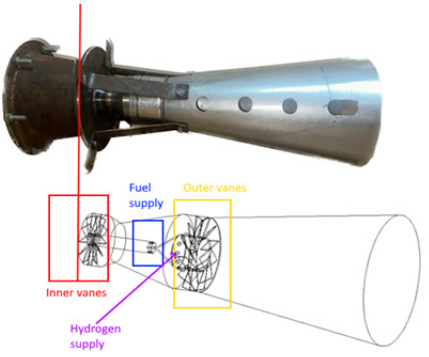

Fig. 1. Burner unit.

Figure 2 shows an experimental setup for studying combustion processes in burner devices.

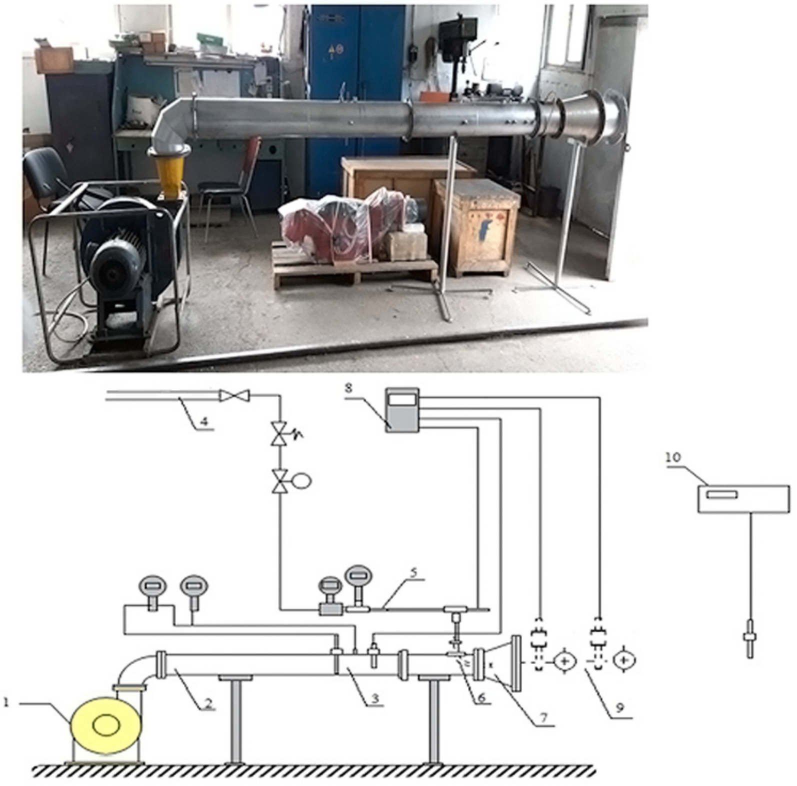

Fig. 2. Photograph and diagram of the experimental setup: 1 – compressor; 2 – stabilizing pipe; 3 – dimensional section at the air inlet; 4 – gas pipeline; 5 – measuring section on the fuel supply; 6 – fuel supply pipe; 7 – front device diffuser with burner; 8 – multi-channel meter; 9 – dimensional area behind the diffuser; 10 – gas analyzer.

Research by the authors [13, 14] shows that when developing new burner devices, it is important to take into account many factors that are important when burning H2. Strong swirling of the flow due to the large angle makes it possible to achieve higher flame stabilization and reduce CO concentration. However, it also leads to an increase in NOx concentration. Another important issue is combustion characteristics. With poor fuel concentrations and diffusion combustion, fairly low NOx values can be achieved by adding hydrogen. The most optimal twist angle is 45°, and the proportion of hydrogen is 30-40%.

3 Results and discussion

We have conducted research on the combustion of landfill gases with the addition of hydrogen. The research was carried out on a burner unit shown in Figure 1 at different temperature conditions. The results for co-combustion are presented in Table 1.

Table 1. Effect of temperature on the yield of combustion products.

Combustion products	**Temperatures, °C**				
	588.8	**615.6**	**687.5**	**722.0**	**721.1**
CO, %	49	39	33	29	24
CO_2, %	8.72	8.47	5.42	3.21	3.13
NO, %	8.0	10.0	15.0	18.0	19.0
NO_2, %	0.2	0.1	0.1	0.1	0.1
NO_x, %	8.2	10.1	15.1	19.1	19.2

A comparative analysis of the experimental results is presented in the form of graphs of the emission yield in flue gases versus temperature in Figure 3.

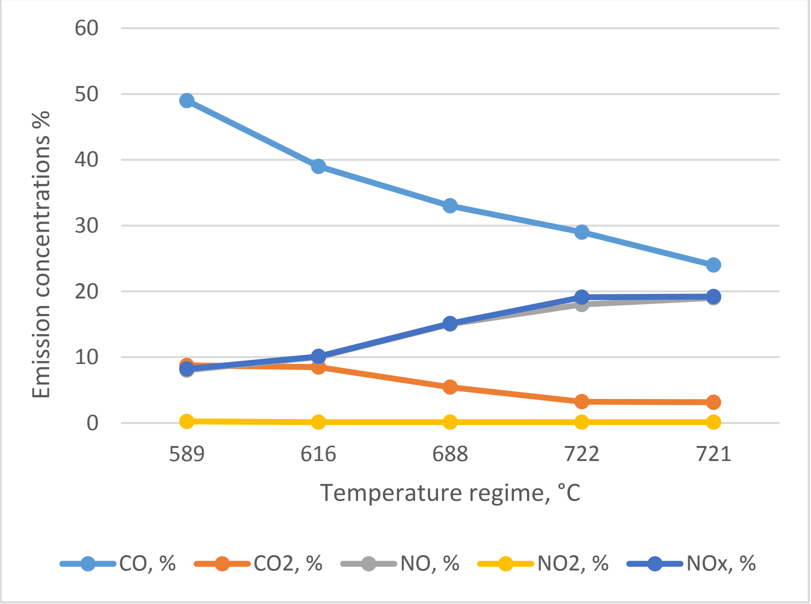

Fig. 3. Effect of temperature on the concentrations of emission components when burning landfill gas with hydrogen.

The Table 1 and Figure 3 show that CO and CO2 emissions decrease while the temperature increases, and for NO and NOx there is a significant increase in their concentrations. No significant changes are observed for NO2.

The results confirm that co-combustion of landfill gas with hydrogen is a more environmentally friendly option that reduces the harmful impact on the environment.

The experimental results highlight the importance of further research to optimize the process, including studying the effect of different gas ratios.

The results and discussion prove the importance of co-combustion of landfill gas with hydrogen as a promising and environmentally sustainable method of waste disposal and energy production.

4 Conclusion

The authors obtained the results that prove the prospects of using hydrogen as an additive when burning landfill gas. Co-firing landfill gas with hydrogen represents an important step towards sustainable energy and reducing environmental impacts. The research results support the assumption that co-combustion of landfill gas with the addition of hydrogen can significantly improve the energy efficiency of LFG and reduce the concentration of greenhouse gas emissions into the atmosphere. The findings can serve as a basis for further steps towards sustainable energy production and LFG recycling. Researchers face a promising future where efficient co-firing technologies could be a key element of a sustainable energy future.

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