BIOFUEL: ALTERNATIVE FOR APPLICATIONS IN OXI-COMBUSTION THERMAL PROCESSES

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ABSTRACT: Bioenergy, as a form of regenerable power, is an excellent alternative to ensure a clean and healthy environment and at the same time, to preserve natural energy resources that are constantly decreasing. Due to their biological origin, biofuels used in combustion processes contribute to the releasing of non-polluting gases in ambience with low percentages of CO_2, CO, NO_x, etc. The paper presents the project of an oxy-biological fuel burner using glycerin and ethanol as biofuels, suitable for industrial thermal processes at high temperature. The project was based on the own outcomes previously obtained in 2022, adding new contributions to improve the combustion process. Keeping the heat power of the burner at 60 kW, the glycerin and ethanol flows were adopted at 10 and 1.11 $kg \cdot h^{-1}$, i.e. a mass ratio of 9.0 than 8.1 used in the previous experiment. Residual gas composition measured under these conditions showed under 0.05 vol. % CO_2, 0 vol. % CO as well as below 183 $mg \cdot m^3 N^{-1}$ NO and under 200 $mg \cdot m^3 N^{-1}$ NO_2.

KEYWORDS: burner, biofuel, glycerin, ethanol, oxygen, fire steadiness.

1. INTRODUCTION

In the last decades, regenerable power, including bioenergy, has come to constitute an important alternative for reducing emissions of pollutants in the atmosphere and preserving the current natural energy resources that are in sharp decline.

Biological mass as a provenance of regenerable power has the particularity of being able to be turned directly into biofuel, unlike other known sources of renewable energy. The most well-known types of liquid biofuel used in transport are ethanol and biodiesel, constituting the basis of biofuel technology [1-3].

Ethanol, having the chemical formula C_2H_5OH, can be made from several vegetal materials known as biomass. By mixing with gasoline, it contributes to increasing its octane number, reducing the emissions of pollutants (mainly carbon monoxide) that generate smog.

In the field of road transport, the most frequently used ethanol-gasoline mixtures contain 10 and 15 % ethanol, but there are also vehicles designed to operate with 51-83 % ethanol depending on the season [1].

The largest amount of ethanol is extracted from starch and sugars available in plants, but there are current researches aiming at the possibility of using cellulose and hemicellulose representing the predominant part of the plant matter.

According to [5], the rapid development of the green diesel production sector led to growing in the glycerin providing and a decrease in the market for this product. On the world level, in 1995 the glycerin on the market was excessive. Currently, there is an estimate by specialists that glycerin manufacturing is much greater (6 times) than the requirement [6]. Thus, the glycerin price dropped suddenly. In these conditions, there was a need to search for new possibilities of using glycerin and scientific investigations were initiated to find uses for glycerin as a product with newly created value [7].

As a consequence of the serious deterioration of the environment quality in the last decades of the last century and the international programs to remedy this situation, the focus of general interest on nonconventional energy sources has experienced an unprecedented increase. In accordance with the provisions of the International Agency of Energy [3] established in 2019, in the next 5 years (until 2024) regenerable power should have developed by 50 percents, of which solar energy should have reached an increase of 30 % compared to the year of reference. Also, sun power should have reached an increase of 25 % and bioenergy was forecast to increase by 4 %.

A viable alternative for reducing greenhouse gas emissions (mainly CO_2) was the utilization of biological fuels especially in internal burning engines in the transportation area. The liquid biofuels used in this sector have the particularity of being derived from vegetable matter and their combustion takes place in environmentally friendly conditions [8-10].

Despite the application of the use of biofuels, last evaluations showed that under 1 percent of the regenerable power usable worldwide arises from the biological fuel applications [11]. Therefore, there are still great reserves and opportunities regarding the use of biofuels in the future.

The objective of this work is the use of biofuels in oxy-combustion thermal processes. According to the information provided by the literature, there are no known works that confirm previous concerns of other researchers in this direction, except for the one published in 2022 [12] by the same authors' team of the current article. The work tested the conditions of using glycerol as a polyol compound together with ethanol as an alcohol. The combustion process was achieved by adding oxygen brought into direct contact with the biofuel mixture. The glycerol/ethanol flow ratio was 8.1, while the biofuel mix/oxygen flow ratio was 0.41 kg/m^{3}N. The composition of the residual gases included 0.06-0.13 vol. % CO_2, 0 vol. % CO, under 199 mg·m^{3}N^{-1} NO and under 210 mg·m^{3}N^{-1} NO_2. The oxy-fuel flame temperature reached a maximum of 1846 °C.

The current work continued the research on burning biofuels for applications in oxy-combustion thermal processes, whose results were shown in [12], aiming at improving the specific burning conditions.

2. PROCEDURES AND MATERIALS

2.1 Procedures

In the case of burning a mixture composed of the main known biofuels (glycerol and ethanol), the flame stability is influenced by the concentration in the aqueous solution of the two biological fuels. By comparison, glycerin is low volatile compared to water, and ethanol is higher volatile compared to water. Thus, using glycerin, the water is predominantly turned into vapours, while using ethanol, this is the liquid material predominantly turned into vapours. The operational steadiness of the fire with low vaporousness by comparison with water is hard to obtain under the conditions of high ratio of water for spraying the liquid fuel. In accordance with other articles [13], growing the aqueous solution flame stability is possible by addition of small ethanol ratios. Good outcomes were achieved in the case of 30 % concentration of glycerol in water and 10 % ethanol addition.

In principle, the design of the combustion equipment tested in this experiment (presented in Figure 1) kept unchanged the main constructive characteristics adopted in the paper [12]. One of the basic elements of obtaining the stability of the flame propagation is the recirculation of fuel and oxygen jets at the exit from the nozzle area by creating vortices on the flat frontal surface. This method of obtaining the flame propagation stability is known from the literature [14-16] and constitutes one of the principles of the swirly burner operation.

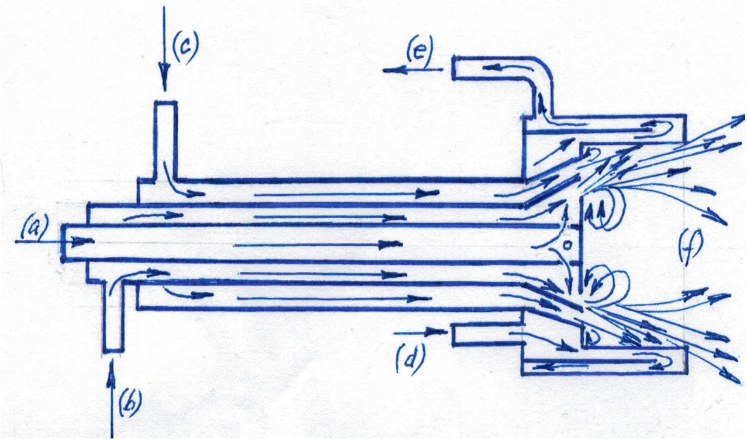

Figure 1. Designed and operational plan of the oxy-biological fuel combustion equipment
a – glycerin and ethanol mix; b – water for atomizing; c – oxygen; d – cold water entrance; e – water exit; f – propagated fire.

By construction, the distribution of the biological fuel mix, the water for atomizing the liquid mixture, and the oxygen required for combustion was carried out on concentric routes. The faster outer jet of oxygen sucked the sprayed fuel jet and thus the proper contact between fuel and oxygen was obtained. In this way, the chemical reactions between glycerol/ethanol and oxygen took place with strong release of heat. The two specific oxidation reactions had the following developments:

$$C_3H_8O_3 + 3.5O_2 = 3CO_2 + 4H_2O \quad (1)$$

$$C_2H_5OH + 3O_2 = 2CO_2 + 3H_2O \quad (2)$$

Testing the oxy-biofuel burner was performed on a burner attempt stand (see Figure 2) in the Romanian Metallurgical Research Institute.

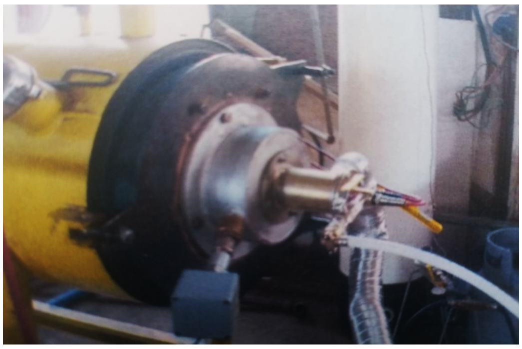

Figure 2. Image of the burner attempt stand

2.2 Materials

Glycerin and ethanol were adopted as biofuels in this experiment, while industrial oxygen was chosen as a pure oxidant having in its composition integral O_2 that participates directly in the oxidation reactions. Also, water as an atomizing agent of the liquid fuel mixture was used in the mentioned combustion process.

Glycerin is a polyol originating from plants and animals, being positioned in triglycerides. It is obtained as a by-product from triglycerides through several available processes, the most commonly used being hydrolysis [17]. According to [18], glycerin produced from triglycerides is largely utilized worldwide at a very convenient prix of maximum 5 North American cents per kilogram.

Ethanol as an alcohol, one of main products of the chemical industry, is usable as a cleaner in synthesis techniques and as an additional product for Diesel motor vehicles. It is made by fermentation or hydration procedures of some chemical materials [19, 20].

Both biological fuels were commercially procured and bottled. The burner was supplied with the liquid mix composed of glycerin and ethanol by a suitable hose using a pump. Providing the water for atomizing was made by an adequate hose from industrial water circuit.

Practically, there is the possibility of producing industrial oxygen by some known techniques, the most frequently applied being separating from air by a cryogenic procedure. Usually, industrial oxygen is stored in large containers as well as in cylinders or tanks [21]. In the case of the experiment carried out in a hall of the Metallurgical Research Institute fed through a general pipeline with oxygen produced in a small internal factory, the oxygen supply to the burner took place through a flexible connection and a pressure regulator.

2.3 Methods for determining the technical characteristics of the burner

Main apparatus used for measuring fluid parameters were: Tecfluid flowmeter series DP 65 for glycerin and ethanol, LZQ-7 oxygen flowmeter 3-30 LPM for oxygen, flowmeter rotameter LS32-600 for water. The temperature of the hot gases resulting from the combustion process was measured with a type of radiation pyrometer from the Pyrovar device family and the chemical composition analysis including CO, NO and NO_2 was identified with Testo 350 analyzer.

3. OUTCOMES AND COMMENTS

3.1 Outcomes

The design of the oxy-biofuel burner tested in this experiment generally maintained the constructive principle of the burner previously presented in [12]. Also, the heat power was kept unchanged at the value of 60 kW. The main change in the nominal parameters of the burner was due to the new proportion values of glycerol and ethanol flows: 10 $kg \cdot h^{-1}$ for glycerol and 1.11 $kg \cdot h^{-1}$ for ethanol, i.e. glycerol/ethanol mass ratio of 9.0.

By default, there were changes of values of the hourly flow of industrial oxygen and its speed in the annular section as well as increases in the speed of the biofuel mixture in radial orifices, in the speed of the biofuel spray in the annular section, and also in the speed of the residual gases at the exit from the burner.

The nominal data chosen by the paper's authors for the burner project are presented in Table 1.

Table 1. Nominal design data

Date	Unit	Value
Heat power of burner	kW	60
Glycerin flow rate	$kg \cdot h^{-1}$	10.0
Ethanol flow rate	$kg \cdot h^{-1}$	1.11
Glycerin and ethanol mix pressure	bar	0.4
Water for atomizing flow rate	$kg \cdot h^{-1}$	79.0
Water for atomizing pressure	bar	1.6

Oxygen flow rate	$m^3N\cdot h^{-1}$	27.8
Oxygen pressure	mbar	188
Biological fuel mix speed in radial orifices	$m\cdot s^{-1}$	175
Biological fuel spray speed in the annular section	$m\cdot s^{-1}$	205
Oxygen speed in the annular section	$m\cdot s^{-1}$	212
Residual gas speed at the exit from the burner	$m\cdot s^{-1}$	130
Cooling water flow rate	$m^3\cdot h^{-1}$	1.9
Cooling water speed	$m\cdot s^{-1}$	1.4

During the experimentation of the burner operation, ten thermal regimes (between the maximum and the minimum regime) were tried. The flow of the biological fuel mix had values within the limits of 5.90-11.30 $m^3N\cdot h^{-1}$, the oxygen flow varied in the range of 15.90-27.53 $m^3N\cdot h^{-1}$, and the water for atomizing flow rate fell within the range of 47.50-82.60 $kg\cdot h^{-1}$. The oxide composition of the residual gases after exiting the burner, temperature and length of the flame corresponding to each thermal regime tested are shown in Table 2.

Table 2. Operational frameworks of the oxy-biological fuel burner

Framework	Heat regime									
	1	2	3	4	5	6	7	8	9	10
Hourly flow of biofuel mix ($m^3N\cdot h^{-1}$)	11.30	11.11	10.60	9.90	9.20	8.50	7.80	7.10	6.40	5.90
Hourly flow of oxygen ($m^3N\cdot h^{-1}$)	27.53	27.40	25.80	24.30	22.90	21.50	20.10	18.70	17.30	15.90
Water for atomizing flow rate ($kg\cdot h^{-1}$)	82.60	79.00	75.00	71.10	66.00	62.10	58.20	54.30	50.40	47.50
Waste gas oxide composition - NO ($mg\cdot m^3N^{-1}$) - NO_2 ($mg\cdot m^3N^{-1}$) - CO_2 (vol. %) - CO (vol. %)	183 200 0.05 -	180 196 0.05 -	175 190 0.03 -	169 182 0.03 -	166 184 0.04 -	164 179 0.02 -	160 175 0.03 -	158 171 0.02 -	155 165 0.01 -	153 163 0.01 -
Fire temperature (°C)	1850	1840	1832	1824	1813	1805	1790	1786	1782	1780
Fire length (mm)	572	560	550	540	528	515	500	487	475	463

Previous research showed that a burning process at high temperature has the effect of increasing the NO_x emission, important atmospheric pollutants [22]. Therefore, an oxy-fuel fire, whose temperature is significantly higher compared to the fire resulting from the combustion of fuel with air, is prone to high NO_x contents. A method whose application is useful in this case is the design of the realization of fuel-oxidizing mixture in stages, procedure adopted in this work [23].

According to the data in Table 2, CO was not identified at all among the components of the combustion gases. Due to the operation of the industrial oxygen burner under the conditions of an oxygen excess very close to the stoichiometric value, the CO_2 content in the combustion gases was very low, reaching the maximum value of 0.05 vol. % only in the case of the nominal thermal regime (no. 2) and the maximum regime (no. 1). Although the temperature of the combustion process reached high levels (between 1780-1850 °C), which favours the formation of nitrogen oxides (NO_x), the content of NO and NO_2 measured in the combustion gases remained within acceptable ranges (under 183 and under 200 $mg\cdot m^3N^{-1}$, respectively) from the point of view of the legislation regarding emissions of these atmospheric pollutants [24, 25].

The fire resulting from the industrial oxygen combustion process of the biofuel mix had excellent steadiness in operation and strong radiant appearance in all tested thermal regimes. The picture containing the development of the oxy-biofuel fire corresponding to the nominal heat regime is indicated in Figure 3.

Figure 3. Picture of the fire propagation in the nominal heat regime

3.2 Comments

In accordance with the literature [26, 27], a suitable burning of singular glycerin is impossible due to its high values of cohesiveness and auto-ignition potential as well as releasing dangerous emissions. Manifesting obvious instability of fire propagation characterizes the combustion process of glycerin as an only fuel.

It has been experimentally found that the addition of some biofuels (such as methanol, butanol or ethanol) together with glycerol would allow to reach the necessary stability of the combustion process. The addition of about 10 % ethanol mixed with glycerol was tested two years ago [12] by the authors' team of this work and the expected result was obtained.

A major role in ensuring the constructive conditions imposed on the oxy-biofuel burner for maintaining the stability of the flame propagation is played by the method of recirculating the combustion gases at the exit from the burner body. This method, known since 1960s, was applied by the authors in the paper [12] as well as in other previous works with reference to the design of traditional burners for fossil fuels.

Burner performances were: the excellent operation steadiness of the burner, obtaining fire temperatures within the limits of 1780-1850 °C in the minimum-maximum operation domain and, despite the high level of the combustion temperature, low level values of nitrogen oxides according to the requirement of pollutant emission limits.

4. CONCLUSION

The design and investigations of an oxy-biological fuel burner for usual open fire-warming processes of industrial ovens was the objective of this work Different types of liquid biofuels (methanol, butanol, ethanol, vegetable oil, glycerin, etc.) have been tested and are used for burning processes in internal burning engines. The originality of the work is the research of a little-investigated field regarding the application of biofuels in open fire combustion processes. The authors' team initiated this direction of approach two years ago, the current paper being a continuation of these concerns. The principal challenge in the case of using glycerin as the main fuel was obtaining the operation steadiness of the fire and low emissions of pollutants (NO, NO_2,, and CO). For this purpose, the mix of glycerin and ethanol in the 9/1 mass proportion was adopted and also the choice of the recirculation principle of combustion gases at the exit from the burner body. Outcomes were excellent both in terms of fire steadiness and of level pollutant emission level into the atmosphere.

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