Study on the brewing industry waste combustion

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Abstract. The combustion of the waste from the brewing industry was investigated. Using the elemental analyzer and standard techniques, the elemental composition and technical characteristics of the studied sample were determined. The ignition and combustion of samples were carried out in a combustion chamber at heating medium temperatures (Tg) within the range of 500-700 °C. Gas-phase combustion products were analyzed using an in-line gas analyzer. The minimum ignition temperature of the sample was 337 °C. With an increase in the temperature Tg, a significant decrease in the ignition delay time of the sample was observed (by 9.7 times). The combustion process was accompanied by the formation of an intense flame near the sample surface. It was also found that, with increasing temperature of heating medium, the concentration of CO emission decreased with an inverse increase in the extremum value of CO2 emission.

1. Introduction

The brewing industry plays a key role in the formation of economic resources in many regions (including Russia). According to [1], annual beer production in Europe is close to 400 million hl. The most significant environmental burden in this industrial sector is the consumption of water and its processing, as well as the formation of solid and other kinds of secondary waste (like brewer's yeast). The share of the latter is about 85% [2]. Solid waste includes wet grounds (from seeds and grain shells) in the form of a biological residue formed after the brewing process and subsequent settling of barley (corn, rice, or oat) raw materials after the production of wort. In conditions of the development of a closed-cycle economy, one of the potential ways to use this type of waste is its direct burning in the furnaces of energy boilers as the main type of fuel. The application of this fuel type (waste) by an enterprise will make it possible to cover partially or completely its energy costs for in-house needs and get additional benefits when directly selling this type of fuel or generated energy in the form of heat and electricity. According to [3], 75% of the energy consumed by the brewery is used in the form of steam and hot water, and only 25% – in the form of electricity. This paper presents the results of an experimental study of the combustion process of brewing industry waste and their physicochemical characteristics.

2. Experimental section

2.1. Sample characterization

The industrial waste from the Tomsk brewery was used as the initial sample. It was previously dried in natural conditions to a moisture value not exceeding 10 wt.%. Then the sample was crushed using an
automatically cutting tool and fractionated on sieves to receive fraction with a size of particles less than 200 μm. Technical characteristics and elemental composition of the studied sample were determined using standard methods [4] and the Euro EA 3000 analyzer, respectively. The results are presented in Table 1.

| Table 1. Characteristics of the studied sample of brewing industry waste. |
| W<sup>r</sup> | A<sup>r</sup> | V<sup>r</sup> | C<sup>daf</sup> | H<sup>daf</sup> | N<sup>daf</sup> | S<sup>daf</sup> | O<sup>daf</sup> | Combustion heat Q<sub>z</sub> | \( \text{wt, \%} \) | \( \text{kcal/kg} \) |
| 6,6 | 7,2 | 66,5 | 51,4 | 6,1 | 5,7 | 0,6 | 36,1 | 4678 |

*<sup>r</sup> – as-received basis, \( \text{daf} \) – dry ash-free basis.

As it is seen from Table 1, the sample has a high content of volatile compounds and relatively low carbon content. It is important to mention that the obtained value of combustion heat is comparable with other types of solid biofuels (including briquetted peat). In general, presented in Table 1 physicochemical characteristics of the studied sample are in good correspondence with previously published data for similar samples [2].

2.2. Granulation
Granulation of the fuel pellet was carried out by a cold pressing method via a manually operated hydraulic press [5]. A hinge (average weight \( \approx 0.75 \pm 0.01 \) g) of the crushed sample of brewing industry waste was placed in a matrix with through-hole 8 mm in diameter and restraining glass fixed to the base. Pressing was carried out by a punch with the corresponding diameter, mounted on the hydraulic mechanism of the press. The 2 metric ton-force was used for granulation.

2.3. Combustion experiment
The study of the combustion process of a brewing industry waste sample was carried out using an experimental setup whose description and circuit diagram is presented in detail in [5-6]. The methodology for studying the combustion process included several stages. First, in a thermostatic furnace, the required heating temperature (500-700 °C) was set. The fuel pellet was placed on the holder of the coordination mechanism and then moved to the center of the combustion chamber. Using a high-frequency video camera, the moment of ignition and the later combustion of the pellet were recorded. The combustion chamber exhaust was connected to the ventilation system. The composition of releasing flue gases (consisting of CO, CO<sub>2</sub>, NO<sub>x</sub> and SO<sub>2</sub>) was determined using a BONER in-line gas analyzer (Russia) which was included in this line.

2.4. Minimal ignition temperature determination
Determination of the minimal ignition temperature (T<sub>imin</sub>) was carried out by setting the desired temperature in a muffle furnace, where a sample was introduced using a coordinate mechanism. The main condition for determining T<sub>imin</sub> was the residence time of the sample in the combustion chamber (5 minutes). The corresponding temperature was assumed to be T<sub>imin</sub> when a visible glow appeared on the surface of a fuel pellet during this exposure time. The temperature in the muffle furnace was chosen to determine this parameter using the half division method.

3. Results and discussion
Figure 1 illustrates the results of measuring the ignition delay time for a brewing industry waste sample within the temperature range of 500-700 °C.

The largest ignition delay time of the studied samples was 38.7 s, and was observed at T<sub>f</sub>=500 °C. Figure 1 illustrates that with increasing temperature of the heating medium (up to 700 °C), the ignition delay time was decreased exponentially by 9.7 times. The obtained dependence of the ignition delay time on the temperature of the heating medium is completely consistent with the data of other studies on biomass combustion [5, 7]. At the same time, the minimal ignition temperature T<sub>imin</sub> for pellets was
337 °C. Figure 2 illustrates high-frequency video frames of the ignition and subsequent combustion of a fuel pellet at various temperatures (within the range from 500 to 700 °C). After some exposure to the sample in the atmosphere of the heating medium, the formation of the growing flame was observed. It was likely caused by the intensification of the release of the volatile compound from the surface and inner volume of the fuel granule. The shape of the flame had an oblong and spherical shape near the bottom of the granule, whose volumetric size was 2-3 times greater than that of the studied sample. The uniformity of the flame could be explained by the lack of intense air movement in the vicinity of the fuel pellet.

Based on the results obtained earlier, and published data [8], several stages of the physicochemical transformation of the sample could be distinguished, namely, inert heating; moisture desorption; thermal destruction of sample, and the beginning of the release of the volatile compound; mixing of combustible gases with an oxidizing medium; ignition and combustion of the gas mixture; thermal decomposition of the carbon residue in flameless combustion mode (this stage is not presented in Fig. 2). Due to the uniform heating of the sample, the rate of thermal decomposition of combustible components was the same over the entire surface of the granule, which can be explained by homogeneous gas-phase ignition of volatile compounds in the vicinity of the sample (Fig. 2). The sample under consideration was characterized by a gas-phase ignition mechanism upon reaching threshold concentrations and temperature of a mixture of combustible gases released during thermal decomposition of the material. After the ignition of the fuel, the process of gas-phase combustion of volatile compounds follows, proceeding mainly over the granule, where the stoichiometric concentration ratio of combustible gas components was established. The formation of flame on the surface of the sample can be explained by the relatively low and intense thermal decomposition of volatile components.
Figure 2. Ignition and consequent combustion of fuel granule of brewing industry wastes at different temperatures of heating medium ranged from 500 to 700°C.

Figure 3 illustrates the change in the gas-phase product quantitative composition (CO, CO₂, NOₓ, and SO₂, in particular) generated during the combustion of a brewing industry waste sample. Figure 3 shows that with the increasing temperature of the heating medium, a decrease in the concentration of CO in the composition of gas-phase combustion products was observed. It is also important to note that for heating medium temperatures T_g=500-600 °C, the profile of CO emission had a bimodal form. This could be explained by the staged character of volatile compounds evolution during intense heating. So, the first stage of the process was characterized by the release of volatile compounds from the surface of the fuel pellet, while the second refers to their outlet from the sample volume. In this case, the extremum of CO concentration under the low-temperature heating mode (T_g=500 °C) was observed at the early stage of sample combustion, where volatile substances were intensively released. With an increase in the T_g temperature (700 °C), the profile acquires a monomodal form with a characteristic extremum shift to the left part of the time scale, which was associated with an increase in the emission rate of volatile compounds. It’s also worth noting that the observed narrowing of the curves, which occurred as a result of a reduction in the total time spent on the brewing industry waste sample combustion. It should be emphasized that an increase in the heating medium temperature contributes to a significant decrease in the CO concentration in emitted gases from 2500 to 500 ppm (Fig. 3a).
Figure 3. Profile of the main components (CO, CO\textsubscript{2}, NO\textsubscript{x}, and SO\textsubscript{2}) concentration in gas-phase products released during the combustion of brewery industry waste samples.

In turn, with an increase in T\textsubscript{g}, an increase in the CO\textsubscript{2} concentration in gas-phase products of combustion was noted from 80000 to 112000 ppm. It is important to note that the dependence of the maximum CO\textsubscript{2} concentration on the heating medium temperature T\textsubscript{g} was exponential. An increase in the concentration of CO\textsubscript{2} was obviously associated with more intense oxidation of the produced CO and a decrease in the total time of the combustion. The nature of the oxides emission depends on the temperature of the heating medium. With its growth, an increase in the concentration of nitrogen oxides was observed due to the involvement of molecular N\textsubscript{2} from the air in the combustion process, which also agrees with the results obtained by other authors [9]. In this case, the SO\textsubscript{2} emission for all considered modes has a similar dependence. The only difference between obtained profiles was their position in the time scale, which was associated with the stages of the volatile compounds release and the beginning of the fuel pellet combustion.

**Conclusions**

The results of the study illustrated that the brewing industry wastes were characterized by a high content of volatile substances and an acceptably low ash value, and low calorific value allowing using this type of wastes as the main fuel for energy facilities. The brewing industry wastes combustion process was studied using the high-frequency video imaging method. It was found that with increasing heating medium temperature (from 500 to 700 °C), the ignition delay time of the sample increases exponentially. In this case, the sample combustion was accompanied by the formation of an intense flame near the pellet surface, whose volume was 2-3 times the size of the fuel granule under consideration. It was also found that the sample minimal ignition temperature was 337 °C. Using an in-line gas analyzer, the emission profiles of the main components (CO, CO\textsubscript{2}, NO\textsubscript{x}, and SO\textsubscript{2}) in gas-phase combustion products were determined. With the increasing temperature of the heating medium, the modality of the profile characterizing the release of CO changes, and its concentrations in the released gases decrease. Thus, the intense oxidation of the resulting CO and a reduction in the total
time of the combustion process (with an increase in the heating medium temperature) causes the observed increase in the concentration of CO2 emission.

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References
[1] Berkhout B, Bertling L, Bleeker Y, de Wit W, Kruis G, Stokkel R and Theuws R The Brewers of Europe: The Contribution made by Beer to the European Economy (Amsterdam) 270
[2] Ortiz I, Torreiro Y, Molina G, Maroño M, Sánchez J 2019 Waste Biomass Valori. 10 3809
[3] Mejores técnicas disponibles en el sector cerveceria. (AINIAInstituto Tecnológico Agroalimentario) 119
[4] Tabakaev R, Kanipa I, Astafev A, Dubinin Y, Yazykov N, Zavorin A, Yakovlev V 2019 Fuel 245 29
[5] Kuznetsov G, Yankovsky S 2019 Therm. Eng. 66 133
[6] Larionov K, Mishakov I, Slyusarsky K 2019 J. Phys. Conf. Ser1359(1) 012058
[7] Kuznetsov G, Yankovsky S, Tolokolnikov A, Zenkov A, Cherednik I 2020 Energy 194 116896
[8] Glushkov D, Kuznetsov G, Nigay A, Yashutina O 2019 J. Energy. Inst. 92 1944
[9] Nyashina G, Vershinina K, Strizhak P 2020 Fuel Process. Technol. 201 106334