Increase in energy efficiency of use of vegetable waste

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Abstract. Wastes of woodworking which are exposed to granulation for equalization of humidity, dispersion and also for increase in energy efficiency are the most widespread types of alternative fuel in Russia. Besides, one of the effective methods of the increase in calorific capability of granulates now is the preliminary torrefaction of wood waste - heat treatment without air oxygen access. However this technology is rather researched in detail only in relation to wood particles, while pellets from wastes of agricultural productions are also popular in the market in recent years. The possibility of the increase of the efficiency of production of pellets from sunflower pod by torrefaction is considered in this article, and the analysis of their characteristics in comparison with wood pellets is carried out. It is established that the process of heat treatment of waste of sunflower production is similar to torrefaction of wood raw materials in many respects; therefore, the equipment with similar characteristics can be used. According to the received results on pellet’s properties it is established that hygroscopicity and swelling of samples of fuel granules from sunflower pod considerably decreases with the increase in temperature of treatment that simplifies requirements for their storage and transportation. Besides, it is defined that torrefaction of the granulated fuel from sunflower pod does not yield in calorific properties to the similar fuel granules made of wood sawdust. Thus feasibility of use of heat treatment in production of fuel granules from waste of vegetable raw materials is proved.

1. Introduction
The need to develop green energy is made aware of all over the world. In the United States and the EU the share of renewable energy sources in the total production volume reaches 11% and 9.6% respectively. For example, in Denmark the share of renewable electricity in total consumption in some months is 50%, and at night can reach up to 100%. In Spain this figure reaches 30% and 50% respectively. According to forecasts from leading consulting company Branan in their study "The renewable energy Technologies", the share of green energy in the world in the total output will be close to 25% by 2020 while the production of such energy in the EU will increase 3.8 times (up to 521 GW), and in the U.S.A. - 22.5 times (up to 1260 GWh). Russia in the use of renewable energy sources is far behind. In 2008, according to the findings of the Ministry of energy of the Russian Federation, the green energy sector accounted for 0.9% of all domestically produced energy. In 2011, the share of renewables was also less than 1% of the total generation.

The use of renewable energy sources in Russia is associated with certain difficulties [1]. Thus, the distribution of wind and solar energy is limited by inconstancy of energy sources - wind and sun. There is another problem: the territory of the possible location of wind mills far removed from...
infrastructure, which complicates their connection to the power grid. Among the problems of bioenergy there is the need for land for cultivation of the crops that leads to competition with food production, as well as harmful emissions during combustion (soot, ash, CO, CO$_2$) and seasonal growth of some crops. The tidal and wave electricity has even more problems than solutions. Among the disadvantages, there are the geographical reference to the shoreline, the distance from the electricity grid, the negative impact on the environment (coastal erosion, surface discharges), the dependence on natural phenomena, the high cost and complexity of maintenance, and the rapid wear of generating equipment under the influence of water.

In this regard, the most common alternative fuel in Russia is wastes of woodworking. However, due to the different dispersion, low energy consumption, low bulk density and often high moisture content in wood waste, their direct use as a fuel is limited by the limits of the production [2, 3]. Due to these factors, the granulation of wood waste has been extended. However it is also often inefficient and economically unsustainable in Russia. So the development of methods of improving the efficiency of fuel pellets is important [4].

One of the most effective methods recognized by many researchers nowadays is provisional torrefaction – the heat treatment without access of air oxygen [5, 6]. As the process of pyrolysis at average temperatures and normal atmospheric pressure, torrefaction is able to reduce water absorption, increase the power intensity, bulk density, the oxygen content and grindability, which ultimately leads to a reduction of costs of transportation and storage [7]. At the moment, the technological process of production of torrefied pellets includes the processes of drying and direct heat treatment of wood raw materials, pelletizing and cooling. Most studies of the torrefaction process are devoted to its technology, raw materials and products [8]. At the operating temperature of 220-300 $^\circ$C the main process of torrefaction is hemicelluloses pyrolysis. Mainly woody plants are used as the raw materials [9, 10].

2. Materials and methods

In connection with the foregoing, there is a comparative experimental study of fuel pellets from classic and torrefied pellets at different temperatures of the raw materials of wood [11] and sunflower husk on hygroscopicity and swelling.

While preparing fuel pellets the wood raw material with moisture content of 8% and the sunflower husk with moisture content of 12% were pre-shredded to 2-4 mm. For the production of torrefied pellets, the raw material was subjected to preliminary heat treatment without access of air oxygen (in nitrogen) at temperatures of 473, 523 and 573 K in a laboratory setting drum-type [12, 13]. The duration of treatment was determined by the reaching of the constant mass loading, which was determined by weighing of the same bulk volume. The mass was considered to be permanent if the change in mass loading was no more than 5% in three consecutive measurements. Further heat-treated wood chips and husk were treated at room conditions until reaching the equilibrium moisture content. Granulation was carried out on a laboratory granulator KL 600.

To determine the water absorption of pellets a standardized method carried out in desiccators containing a saturated solution of soda (Na$_2$CO$_3$ • 10H$_2$O) was used. The pellets were kept out for 30 days in air at a degree of saturation of 0,75. Simultaneously with the detection of the current moisture content of the samples, their basic dimensions for the study of the process of swelling were measured. The moisture content of samples was determined by the gravimetric method by measuring the current mass, followed by final drying to an absolutely dried state at a temperature of 105 $^\circ$C [14].

Table 1 shows some parameters of fuel pellets from classic and torrefied pellets at different temperatures of the raw materials of wood and sunflower husk [15].

| Fuel type. Settings | Fuel pellet from wood sawdust | Fuel pellet from sunflower husk | Fuel pellet from thermally modified wood | Fuel pellet from thermally modified |
|---------------------|-------------------------------|--------------------------------|----------------------------------------|-----------------------------------|

Table 1. Comparative characteristics of the pellets
The efficiency of the combustion process of fuel pellets was determined using calorimeter IKAC 5003 and the experimental stand for the firing tests, consisting of a vertical ceramic tube, inside which a gas burner and measuring devices are mounted, and the investigated sample is set during the experiments.

3. Results and discussion

Sunflower husks and pellets were used as experimental samples at different temperatures in the drum-type installation without access of air oxygen in this work [16, 17]. Figure 1 shows the kinetic curves of the change in the relative masses of sunflower husks at different temperatures of heat treatment. As the result of these studies, the change curve of a stream of volatile during the torrefaction of sunflower husks presented in Figure 2 has been obtained.

![Figure 1](image1.png)

**Figure 1.** Kinetics of relative masses of sunflower husks at different temperatures processing.

Analysis of the formation of volatile products in the torrefaction process is characterized by active gas-making in the range of 10-25 minutes for each temperatures of treatment. It should be noted that at elevated temperatures above 250 °C, there is a sharp increase in the flow of volatile products of decomposition due to the beginning of decomposition of more heat-resistant components of sunflower husk at these temperatures.

![Figure 2](image2.png)

**Figure 2.** Changing the flow of volatiles during the torrefaction of sunflower husks.

The results of experimental studies of the water absorption and swelling of the samples are presented as the kinetic dependencies of humidity and the relative volume of fuel pellets in the process of treating in humid conditions (Figure 3). As it can be seen from the graphs, with increasing treatment
temperature hygroscopicity and, as a result, swelling of samples of fuel, pellets are significantly reduced, which not only greatly simplifies the requirements for the storage and transportation of torrefied pellets, but also retains its energy value. The identity of the behavior of wood pellets and sunflower husk should be noted.

![Figure 3. Kinetics of moisture (a) and the relative volume of pellets (b) created from wood with different degrees of thermal treatment.](image)

The analysis of the obtained values characterizes a significant increase in the mass of the heat of combustion of fuel pellets with the increase of the torrefaction temperature. However, in the case of bringing the heat released to volume values, the symmetry of the pattern is broken: a significant reduction in the density of torrefied pellets with increasing extent of heat treatment of wood raw material largely compensates the increase in the mass of the heat of combustion, that, ultimately, not only does not give the desired efficiency in relation to the issues of logistics, but also prevents significantly increasing of thermal efficiency of boiler.

In order to assert, what kind of fuel is highly competitive due to the above qualities, studies have been conducted to determine their thermal properties (table.2). Samples of biomass fuel from classic wood and sunflower husk used in this study were compared with the biomass of these same fuels after thermal modification [18, 19, 20].

**Table 2. Thermophysical properties of pellets**

| Fuel pellets made from wood sawdust | Fuel pellets made from sunflower husks | Fuel pellet based on thermally modified raw materials | Fuel pellet made from thermally modified sunflower husk |
|-----------------------------------|---------------------------------------|------------------------------------------------------|------------------------------------------------------|
|                                   |                                       |                                                      |                                                      |
According to the obtained results of the thermo physical properties of fuel pellets, one can see that granulated fuel made from sunflower husks does not yield to fuel pellets made from wood sawdust, but on the contrary, surpass them according to the higher heat of combustion. One can also see that the fuel pellets from sunflower husks burn much faster and as a consequence have less ash content. Along with these properties one can conclude that the thermal treatment of granulated biofuel significantly improves the rates of their thermophysical properties.

4. Conclusion
On the basis of experimental studies it was found that granulated biofuel has many advantages compared with traditional fuels. The authors see that granulated biofuel made from sunflower husks comparable with the fuel pellets made from wood raw material, is ergonomic and its burning in the boiler furnace is more effective. In addition, pellets made from sunflower husks are a more economical way of heating, as there is no other ways to use this material, while the wood raw material is widely used in various composite materials. Thanks to these qualities, pellets made from sunflower husks have high competitiveness in comparison with common types of granulated fuel and can be widely used.

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