Impact of a reactor design features on wood raw materials torrefaction parameters

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Abstract. We have studied the impact of a disc type reactor design features on the uniformity of different-fraction wood raw materials heat treatment before granulation. It was found that a uniform distribution of the pine chips density is provided by using plates with different hole diameters across the height of the device at the blades rotation rate of 12 rpm. These parameters ensure the efficiency of the process and contribute to production of torrefied pellets with improved calorific characteristics.

1. Introduction

Currently, the global market has an increased supply of a new type of solid biofuel, torrefied pellets [1]. Torrefaction is a process of "soft" anaerobic biomass pyrolysis at 200-320 °C and atmospheric pressure. In course of torrefaction, a part of the organic component of the biomass is thermally degraded, and the equilibrium humidity of the finished product is reduced, which makes it possible to obtain a solid hydrophobic product with improved calorific characteristics [2-4]. For torrefied pellets, depending on the process conditions, the highest calorific value can reach 22 MJ/kg, while for conventional wood pellets this does not exceed 18 MJ/kg [5, 6].

Torrefied pellets are easy to handle, store, and transport. They can even be stored outdoors without the risk of rotting, mold growth, swelling, and destruction. These advantages are particularly evident in joint combustion of torrefied pellets and coal in thermal power plants without any technical re-equipment [7, 8].

An additional reason for using torrefaction is the high environmental friendliness of biofuels, as they are CO₂-neutral [9, 10].

In solid fuel production torrefaction can be used both at the stage of preparing wood raw materials before granulation, and at the stage of processing finished pellets. The analysis of the existing pellet production schemes has revealed the prospects for using the "torrefaction-subsequent granulation" scheme. Pre-heating allows achieving fractional homogeneity of wood raw materials, increased hydrophobicity of the biomass, and reduced weathering, cracking or spontaneous combustion. This does not only significantly simplify the requirements for storage and transportation of torrefied biomass, but also has an impact on increasing the calorific value of the fuel [11].

Further research into the process of pre-heat treatment of crushed wood and the development of the
main design and process parameters of equipment for the production of torrefied pellets in order to improve the quality of the resulting products is undoubtedly relevant.

In [12], it is noted that the uniformity of heat-treated pine chips can be improved by processing the material in several successive stages of pre-treatment of the material at 180, 230, and 270 °C. Thus, the material processed at 270 °C is actually processed in three stages: first at 180 °C, and then at 230 °C and 270 °C. The research was carried out on a heat treatment plant with a continuous feed of raw materials, including a vertical reactor with stirring mechanisms. The heat was supplied using six individually controlled heating tapes located on the outside of the reactor. At each stage, the wall temperature was gradually increased and maintained for a given time until the next temperature increase, thus achieving uniform torrefaction of the entire batch.

The analysis of the literature on the technological features of various reactor designs [13-16] allowed us to design a disc type annealing reactor, in which we propose to change the disc holes size across the height of the apparatus to ensure uniformity of heat treatment of different-fraction raw materials. In this regard, the paper aims at investigation of the crushed wood heat treatment process and identification of the design features of the reactor plates that contribute to both the intensification of the process and ensuring the uniformity of torrefaction of various fractions of raw materials before granulation.

2. Methods and materials

We used shavings of various wood species sized 4-14 mm long, 0.5-3 mm wide and 0.3-1.1 mm thick as materials to study the effect of preliminary torrefaction of wood raw materials on the performance characteristics of the pellets. All the material was divided into fractions of 4, 8, 11, and 14 mm of wood raw materials.

The crushed wood material was heat treated on a laboratory unit shown in figure 1. In reactor 1 which is a cylindrical device, there are discs 2 and stirrer rotation system 3 driven by electric engine 4. The discs are mounted to a separate internal frame and are subjected to constant vibration. Depending on how high the disc is located in the reactor, the surge hole is located in the central (for odd discs) and peripheral (for even discs) zone of the disc.

The upper part of the reactor vents to the flue gas production system, which consists of flue device 5, heat exchanger 6, and gas blower 7. In the lower part the reactor is adjacent to screw feeder 8 with a cooling jacket and a gas outlet system, including gas blower 9 and afterburning and waste gas disposal device 10.

The rotation of stirrer 3, ensures chips distribution along the upper disc. The chips make a spiral movement and head to the central surge hole, where the raw material is poured onto the next disc and continues to move in the opposite direction - to the peripheral surge hole. So, the raw material is poured from the upper discs to the lower ones.

The reactor's discs have holes in them and the aggregate area of all holes is the same in all discs. In experimental studies, 9 differently designed discs were installed in the reactor: with the same hole diameter and with a variable diameter of holes in height (from large to small diameter). The hole diameter for each design is shown in table 1.

| Disc No. | 1     | 2     | 3     | 4     | 5     | 6     | 7     | 8     | 9     |
|---------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| top     |       |       |       |       |       |       |       |       |       |
| Design 1| 3     | 3     | 3     | 3     | 3     | 3     | 3     | 3     | 3     |
| Design 2| 13    | 13    | 10    | 10    | 7     | 7     | 4     | 4     | 4     |

In addition, we varied the blades rotation rate in two values: variant A - 6 rpm and variant B - 12 rpm.

After entering the lower part of the column, the wood particles are removed from the device with Screw Feeder 8, where they are gradually cooled by heat transfer to the jacket refrigerant. Lowering
the temperature of the material is necessary to prevent possible spontaneous combustion in contact with air oxygen. After cooling, the processed material is unloaded for further studies.

For subsequent tests, pellets were made from heat-treated crushed wood of various fractions. The wood chips were briquetted using a press in special molds. The of torrefied solid fuel were analyzed for calorific value on the IKA C200 calorimeter.

3. Results

Based on the study results, we made graphs of variance in the average densities of various fractions of crushed wood raw materials for discs with equal hole diameter and with varying hole diameter across the height of the reactor (figure 2).

Analyzing the variants of using discs (1, 2), it is seen that the most uniform distribution of the multi-fraction chips density is provided by using discs with different hole diameters (design 2). In this regard, we proposed a layout of discs with large holes in the upper part of the reactor with a reduction to smaller holes in the central and lower parts. Note that the aggregate hole area for all discs is the same. Such a layout allows smaller fractions of raw materials to reach, without delaying on the upper discs, the lower ones through large holes of the upper discs. This way, the time of the small fractions stay in the reactor is reduced to provide the uniformity of heat treatment of the entire batch of wood particles.

The analysis of changes in the curve shapes at different blades rotation rates (A, B) indicates that a greater uniformity of treatment is also provided by using different disc hole diameters.
Figure 2. Changes in the average density of various fractions of crushed wood raw materials: 1 - when using discs with equal hole diameters; 2 - when using discs with different hole diameters; A - at blade rotation rate of 6 rpm; B - at blade rotation rate of 12 rpm.

However, at lower blade rotation rates (variant A), there is a decrease in productivity, since even small particles are forced to stay in the reactor for the maximum amount of time. Increasing the blade rotation rates (variant B) results in a slight increase in the unevenness of chips treatment on the discs, both with equal and different diameter of the holes. But the use of discs with different hole diameters at a rotation rate of 12 rpm (2-B) allows smaller fractions of raw materials to reach, without delaying on the upper discs, the lower ones through large holes of the upper discs. As a result, the time of the small fractions stay in the reactor is reduced with uniform treatment of large fractions of raw materials. Such mode of chips movement provides not only the uniformity of different-fraction raw materials treatment, but also helps improve the reactor performance.

Further, the paper dwells upon the calorific characteristics of the pellets produced by torrefying the wood chips with subsequent granulation (figure 3). Two granule types were analyzed. In the first case, the pellets were produced from wood materials torrefied on discs with equal hole diameters, in the second case – on discs with different hole diameters. The blade rotation rate in both cases was 12 rpm.

It was found that for all pellet types, an increase in the treatment temperature resulted in a noticeable increase in the calorific value. However, as can be seen from the graph, pellets from wood raw materials heat-treated using discs with different hole diameters have a higher calorific value. This is due to a more uniform distribution of the wood materials density during heat treatment.

A lower calorific value is typical for pellets made from wood chips heat-treated on discs with equal hole diameters. As can be seen from figure 2, in case of high-speed rotation on these discs, part of the large fractions of raw material has a low degree of heat treatment, which ultimately results in reduction of the calorific value of the final product. Given that large fraction material has a greater proportion in weight equivalent, the uniformity of heat treatment has a significant impact on the energy characteristics of torrefied pellets.
Figure 3. The highest pellets calorific value depending on the treatment temperature.

The above studies have shown the feasibility of the design of a disc-type reactor with variable hole diameters and an average blade rotation rate of 12 rpm. To provide heat treatment uniformity of different-fraction raw materials, we propose the following variation in the size of disc hole diameters across the height of the device: from large ones on the top discs to smaller ones in the central and lower parts of the column.

4. Conclusions
The analysis of the existing designs of equipment for production of torrefied pellets by torrefaction and subsequent granulation of wood raw materials allowed us to design a disc-type annealing reactor, the main feature of which is the nature of the raw materials movement.

The studies have shown that the uniformity of different-fraction wood raw materials heat treatment is provided by using reactor discs with different hole diameters. In addition, the hole diameter gradually changes across the height of the device: from large ones on the top discs to smaller ones in the central and lower parts of the column. The increase in the productivity and economic efficiency of the process is also contributed to by the blade rotation rate since the time of the small fractions stay in the reactor is reduced ensuring the uniformity of thermal modification of the different-fraction chips.

Experimental studies of the effect of treatment modes on the energy characteristics of solid fuels have shown that an increase in the treatment temperature results in a noticeable increase in the calorific value of wooden pellets. At the same time, the efficiency of using discs with different hole diameters was confirmed, since uniform heat treatment of wood raw materials further helps produce pellets with increased calorific characteristics.

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