Alternative energy in vegetable and crushed wood raw materials drying processes

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Abstract. The article describes an self-contained complex energy-saving plant for remote areas, that provides heat and electricity for the needs of a condenser kiln by thermochemical gasification of logging, woodworking, and agricultural waste. A special feature of the proposed plant is the condenser kiln which allows minimizing the cost of heat energy by using a compression heat pump and implementing pulse drying modes consisting of alternate stages of heating and drying. A pulse process helps avoid the use of water vapor while maintaining the quality characteristics of the materials to be dried. It was found that the use of torrefied crushed raw materials as an alternative energy source can increase the productivity of the entire self-contained drying plant.

1. Introduction

Today we see a global trend towards environmental improvement, a rational approach to resources and improving the quality of life on earth. However, at woodworking, lumber, and agricultural enterprises there is an extremely negative situation with by-products of production in the form of waste, which, in turn, entails large fines from environmental supervisory authorities. If previously storing or burning millions of tons of organic waste was acceptable, now the top priority in Russia is recycling to obtain useful products. In particular, processing of such kind of biofeedstock can produce fuel for operation of both the enterprise itself and individual equipment [1-3].

It is also worth noting that the increase in the energy tariffs growth rate renders the problem of energy saving in production activities of enterprises in various industries especially pressing. It can be solved by using alternative fuels produced from woodworking, lumber, and agricultural waste. Therefore, the introduction of energy-saving technologies based on rational environmental management is one of the important directions for improving production efficiency and skilful management of process operations.

One of the most energy-consuming processes used in many industries, can be the process of drying. In particular, in the woodworking industry, energy costs for drying lumber reach 15% of the production cost. An important role in such processes is played by the duration, which in most woodworking enterprises takes from two weeks to two months, depending on the variety of the material being dried, which also leads to significant consumption of heat and electricity. The solution of this problem is facilitated by improvement of existing methods of drying wood and search for new ones.
A literature analysis [4-6] has shown that one of the possible solutions is the development of a self-contained complex energy-saving plant for drying vegetable and wood raw materials with the production of heat and electricity for the needs of drying equipment, which is powered by an internal combustion engine that uses an alternative energy source, i.e. plant waste of agriculture and forestry, produced at woodworking enterprises. The autonomy of the plant is important if you need to deploy the drying process in remote forest and field conditions.

On-site drying raw wood using pulse technology in a condenser kiln will ensure highly efficient energy-saving drying process, reducing the transport costs.

The purpose of drying medicinal raw materials is to quickly stop intracellular biochemical processes in plants, in which active substances are destroyed affected by cell enzymes. The fastest natural way to stop biochemical processes is to dehydrate the cells, since the processes can only take place in an aqueous environment. In freshly harvested plant material, the water content is 60-80%. Removal of moisture to only 20% reduces the rate of biochemical reactions and enzyme activity, and when its content is 10-14%, the activity of enzymes is completely stopped, that is, the intracellular processes leading to the decomposition of active substances are stopped. In addition, the decrease in the vegetable mass moisture leads to retardation and arrest of the development of various fungi and microorganisms in it, which also reduce the quality of raw materials.

In this regard, we are developing a self-contained complex energy-saving vegetable and wood raw materials drying plant, which works on on-site wood and vegetable waste.

However, crushed biofeedstock used as fuel has a low energy density. The energy efficiency of such crushed waste can be improved by granulating and then torrefaction, i.e. oxygen-eliminating high-temperature exposure [7, 8].

Paper [9, 10] studies the physical and energy properties of fuel pellets subjected to various oxygen-eliminating temperature treatment. It was found that an increase in the temperature of heat treatment of wood raw materials resulted in an increase in their calorific values. The authors also determined that the volumetric heat value of the torreficate increased by 12% on average in comparison with conventional wood pellets.

A Uslu et al. [11] performed research to determine the effectiveness of pre-heat treatment of wood raw materials. It was found that this technology in combination with granulation allows obtaining fuel pellets with an energy content of up to 22.7 MJ/kg.

A research group led by Mark J Prins et al. [12] studied a wood heat-modification technology. It was found that this technology reduces the content of volatile substances and increases the calorific value of wood to 20.7 MJ/kg (at a heat treatment temperature of 270°C) compared to 17.7 MJ/kg for untreated wood.

Chen Qing et al. [13] conducted research on gasification of torrefied fuel pellets. The authors found that gasification of fuel pellets processed at a temperature of 250°C allows obtaining generator gas with a greater energy intensity and quality compared to gasification of untreated wood.

A literature analysis has shown that research in crushed plant and wood raw materials torrefaction mainly reflects the operating parameters of the process and the properties of torrefaction without further detailed analysis of practical applications.

In this regard, this paper aimed at studying the effect of the torrefaction temperature of crushed biofeedstock in the form of vegetable and wood waste on operating parameters of the self-contained vegetable and wood materials drying plant.

2. Methods and Materials
The self-contained complex energy-saving vegetable and wood raw materials drying plant (figure 1) works as follows: crushed wood and/or vegetable waste is fed to the Gasifier 17 for thermochemical conversion followed by generator gas production [14]. The resulting generator gas, after purification in Cyclone 18, enters Water-Air Heat Exchanger 16, where it is cooled by transferring heat energy to a liquid heat carrier, which is sent to Main Heater 11 using Circulation Pump 15 to heat the air in Drying Chamber 1. The generator gas, after cooling and additional purification in Filter 19, enters Internal
Combustion Engine 14, which produces thermal and mechanical energy when burned. Heat energy in the form of spent flue gases enters Water-Air Heat Exchanger 16. After cooling, the flue gases are released into the atmosphere. Mechanical energy is used to implement pulsed drying in the form of alternate heating stages and drying stages in Drying Chamber 1. For the heating stage, Electric Generator 13 is put into operation by belt transmission from Internal Combustion Engine 14. Electric Generator 13 generates electricity for Fan 6 that circulates the air in Drying Chamber 1 at the drying stage, and for Circulation Pump 15 which supplies the heated liquid coolant to Main Heater 11 at the heating stage. For the drying stage, Compressor 12 the heat pump is put into operation by belt transmission from Internal Combustion Engine 14 for dehumidification of the air in Dehumidifier 3 and natural circulation of air due to operation of heat exchangers represented by Dehumidifier 3 and Heater 2. Condensed moisture in the heat exchangers represented by Dehumidifier 3 during drying accumulates in Condensate Collector 4 and is removed through Condensate Trap 5.

Condenser kiln of the self-contained complex energy-saving vegetable and wood raw materials drying plant (figure 1) includes Drying Chamber 1 equipped with a circulation and air conditioning system and a heat pump with heat exchangers represented by Heater 2 and Dehumidifier 3, under the Dehumidifier there is Condensate Collector 4 and Condensate Trap 5, the circulation and air conditioning system contains Fan 6 and Perforated False Ceiling 7. The circulation and air conditioning system additionally has False Walls 8, behind which heat exchangers represented by Dehumidifier 3 are located on both sides of the drying chamber, and False Floor 9 equipped with Nozzles 10 for pumping air, above the false floor is Main Heater 11 in which the heated liquid coolant circulates. Above False Floor 9, in the side parts of Drying Chamber 1, there are heat exchangers represented by Heater 2. As a heat pump, the complex contains a compression heat pump. The compression heat pump includes Compressor 12, which together with Generator 13 is connected to Internal Combustion Engine 14. Generator 13 is connected to Fan 6 of the circulation and condensing system and to Circulation Pump 15 for supplying the liquid heat carrier by tubes from Water-Air Heat Exchanger 16 to Main Heater 11. The condenser kiln is equipped with Gasifier 17 which produces generator gas for operation of Internal Combustion Engine 14. Gasifier 17 contains Cyclone 18 and Filter 19. Internal Combustion Engine 14 and Gasifier 17 are equipped with Water-Air Heat Exchanger 16 for heating the liquid coolant. It contains water as a liquid coolant. The compression heat pump contains freon as a refrigerant.

Drying proceeds as follows: the material to be dried 20 is stacked in Drying Chamber 1 of the condenser kiln for lumber or placed on perforated sheets for vegetable feedstock. After loading the material and closing the chamber, the material is heated by heating the air environment of Drying Chamber 1. To do this, Fan 6 of the circulation and condensation system is activated according to the scheme of the aerodynamic path for forced air circulation, as well as Main Heater 11. After the heating
stage, drying is carried out with Fan 6 switched off, for this, heat pump is activated, that contains Compressor 12, heat exchangers represented by Dehumidifier 3 and Heater 2. At the drying stage, air naturally circulates due to the operation of heat exchangers represented by Dehumidifier 3 of the compression heat pump located behind the Side False Walls 8, and heat exchangers represented by Heater 2 of the compression heat pump, located in the side part above the False Floor 9, due to the temperature difference. The heating stage is continued until the material reaches 70°C, the drying stage is continued until the material is cooled to 40°C. Drying includes alternate stages of heating and drying (pulse drying), which allows doing without intermediate and final moisture heat treatment, and continues until the moisture content of the material reaches 6-8%.

We used this plant to conduct a number of studies on the effect of the properties of generator gas obtained by gasification of the pre-torrefied crushed raw materials in the form of vegetable and wood waste on the processes in the self-contained drying plant. Preliminary torrefaction of vegetable feedstock was carried out at 200 – 280°C in the pilot plant described in [15, 16].

3. Results and Discussion

We determined the composition of the generator gas from the gasifier depending on the temperature of pre-torrefaction of the crushed raw material (figure 2). In case of the crushed feedstock torrefaction, there was an increase in the content of hydrogen and carbon monoxide in the generator gas with a decrease in carbon dioxide, which indicated an increase in the torrefaction temperature of the crushed feedstock, that is, the energy intensity of the generator gas increased. The graph in figure 2 shows that the crushed feedstock torrefaction temperature above 240°C provides the greatest energy intensity of the generator gas.

![Figure 2. The composition of generator gas resulting from gasification of torrefied crushed raw materials in the form of vegetable and wood waste.](image)

We identified the effect of the resulting generator gas on the power of the internal combustion engine (figure 3). As can be seen from the graph, the engine power is directly proportional to the temperature of the wood fuel heat treatment. Thus, the engine power can be increased by 10-15%. 

Figure 3. The dependence of the engine power on the temperature of torrefied wood fuel.

In order to confirm the energy efficiency of using torrefied crushed raw materials as fuel, we studied the dependence of the temperature and relative humidity of the drying agent on the temperature of the wood fuel heat treatment (figure 4).

Figure 4. Dependence of the temperature and relative humidity of the drying agent on the wood and vegetable fuels torrefication temperature.

The graph shows that an increase in the crushed feedstock torrefaction temperature gives an increase in the temperature of the liquid agent in the heat exchanger (water) due to an increase in the temperature of the generator gas supplied to Heat Exchanger 16. Besides, there is a decrease in the relative humidity of the drying agent in the condensation dryer due to an increase in the power of the heat pump. In total, the drying rate of the material increases by more than 20%.

In addition, a special feature of the proposed drying plant is the condenser kiln which helps minimize the cost of heat energy due to the compressor heat pump and pulse drying modes (figure 5). Pulse drying consists of alternate heating and drying stages [17, 18].

At the first stage, we studied pulse drying of wood materials of three species: pine, birch, and oak. Figure 5 shows the heating and drying stage indicators of temperature, medium relative humidity, and sample humidity, revealing the nature of wood samples drying (100x100x20).
Figure 5. Indicators of the "heating-drying" stage in pulsed drying of wood raw materials: a) Tenv. is the temperature of the environment, Tm.surf is the material surface temperature, °C; Tm.c. is the temperature in the center of the material, °C; b) relative humidity; c) Wm.surf. is the material surface humidity, %; Wm.c. - the humidity in the center of the material, %; d) pine, birch, oak drying curves.

Data analysis revealed a gradual increase in temperature at the heating stage (figure 5a), and a more rapid increase in the medium temperature due to heated air circulation results in an increase in the
relative humidity in the chamber (figure 5b). The material humidity changes slightly, since the increase in the temperature of the material is exponential (figure 5c), equalizing with the temperature of the medium only at the end of the stage. When the temperature of the material reaches the set temperature of the medium, the heating stage moves to the drying stage [19-21].

At the drying stage, the moisture from the surface layers of the heated material is intensively evaporated (figure 5c) and the material is cooled (figure 5a) due to moisture condensation (figure 5b). A pulsed drying process helps avoid the use of water vapor to relieve internal stresses, since there are no large differences in humidity in the thickness of the material (figure 5d).

Summing up what has been said, the proposed self-contained complex energy-saving plant allows for highly efficient energy-saving drying of wood raw materials in remote areas by generating its own electricity and heat from wood and vegetable waste.

4. Conclusion

The study of the generator gas properties allowed us to establish that increasing the torrefaction temperature of the pre-crushed plant and wood materials as fuel leads to an increase in engine power, a significant reduction in the relative humidity of the environment in the condenser kiln due to an increased performance of the heat pump.

Thus, the use of torrefied crushed raw materials as an alternative energy source can increase the productivity of the entire self-contained drying plant for remote terrain conditions.

In addition, we obtained data on pulse drying of wood materials for pine, birch, and oak samples, which showed the effectiveness of using the self-contained drying plant that works on the on-site vegetable and wood waste. The use of the pulse drying technology in a condenser kiln allows adjusting and controlling a wide range of parameters, thereby achieving high drying efficiency for the material being dried, in particular wood materials and vegetable stock.

The next stage will involve research on this technology for drying medicinal plant raw materials including leaves, roots, trunks, extracts, crushed biomass, that require immediate drying with specified parameters to preserve valuable components.

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