The Technology of Thermochemical Processing of Wastes
Enterprises of the Woodworking Industry in the Regulation of
Environmental Pressure

R R Khasanshin¹, R R Safin², I A Valeev³

¹Associate Professor, Kazan National Research Technological University, Russia, Karl Marx Street, 68, 420015, Kazan, Russia
²Professor, Kazan National Research Technological University, Russia, Karl Marx Street, 68, 420015, Kazan, Russia
³Associate Professor, Kazan National Research Technological University, Russia, Karl Marx Street, 68, 420015, Kazan, Russia

E-mail: rusl2881@mail.ru

Abstract. The development of industry is always accompanied by an increase in the negative impact on nature. A variety of waste generated at the production stage for a long time is stored and accumulated. This is especially true for organic waste, the amount of which is steadily increasing as the industry develops. In this regard, the issue of their processing is becoming increasingly important. Currently, one of the optimal types of organic mass processing is pyrolysis. However, in most cases, thermochemical processing technologies, used at enterprises, are not capable of meeting modern requirements for energy consumption and environmental friendliness. The article investigates the high pressure effect on the process of thermochemical treatment of wood waste. As a result of processing the obtained data, the dependences of the duration of the process of thermal decomposition of wood and the output of charcoal on the pressure in the chamber, ambient temperature, size and humidity of the pyrolized wood raw material were determined. It has been established that with an increase in the process pressure, the duration of the process of thermochemical processing of wood waste decreases, and the output of coal increases.

1. Introduction
Currently, the renewable natural plant resources are increasingly involved in the production of socially important products [1-3]. The greatest interest for science and production is woody biomass due to its wide availability and the huge potential for its technological processing into commercial products. In addition to industrial wood, the wood waste generated in the woodworking enterprises is used in production [4-6]. The amount of generated wood waste at various stages of technological processes is very impressive, but the proportion of waste processed in the production is low. The problem of utilization and recycling of wood waste is one of the urgent ones, since the currently available technologies in Russia and in the world allow rational using of this type of raw material only by half [7-11].
One of the best types of wood waste processing is pyrolysis. The simplicity of the hardware design, the variety of the obtained products, and the ease of adjusting the system parameters make this method the most promising [12-14].

Currently, various technologies of wood pyrolysis are used in the world. It is especially developed in the USA and in Europe. In general, thermal processing can be divided into high-speed and low-temperature pyrolysis [15-19]. The methods of high-speed pyrogenetic decomposition include the thermochemical processing of wood waste by the methods of ultra-pyrolysis, oxidative pyrolysis, high-frequency pyrolysis, electro-thermal pyrolysis, and pyrolysis in low-temperature plasma. The methods of low-temperature pyrolysis include the pyrolysis of wood waste according to the traditional technology [17-20].

The authors [20] presented the work in which the process and the device of biomass ultra-pyrolysis was developed, where fast (less than 100 ms) heating of the raw material in the fluidized bed to a temperature of 700–1000 °C with the minimum contact time (less than 500 ms) was provided.

Maa and Bailey [21] studied the influence of various factors on the kinetics of high-temperature pyrolysis of cellulose-containing materials. It is established that the particle size has a decisive influence on the speed of the process.

Various products can be obtained during the processing of raw wood by the pyrolysis method: charcoal, pyroligneous distillate, furnace (non-condensable) gases. Charcoal is a valuable raw material for various industries and is in steady demand, both in Russia and abroad. It finds application in life, chemical, metallurgical, medical, and other industries. Pyroligneous distillate is a condensation product of a vapor-gas mixture, which, upon further processing, produces veterinary and smoking preparations, wood saponified resin, and wood-resin creosote oils, which have antiseptic properties and are used for processing of special leather on tanneries to replace toxic oxide-phenyl. Furnace (non-condensable) gases can be used both for carrying out the pyrolysis process itself and for obtaining cheap energy when it is burned. However, pyroligneous distillate and non-condensable gases are not trapped in most existing devices and are simply released into the atmosphere that leads to the loss of valuable products [19-23].

The conducted literature review has shown that the demand for efficient small-sized mobile pyrolysis chambers has recently increased with the development of small and medium-sized woodworking enterprises. However, in most cases, the pyrolysis technologies used in industry are not capable of meeting modern requirements for energy consumption, environmental friendliness, and efficiency. Therefore, the creation of modern equipment with the ability to control the resulting decomposition products and reduce the duration of the process is relevant.

2. Materials and methods

In this regard, studies have been conducted to improve the process of wood pyrolysis by regulating the pressure of the medium.

The setup for thermochemical processing of wood waste was created for experimental studies. The functional diagram and the appearance of the experimental unit are presented in figure 1.

The experimental unit consists of a pyrolysis chamber 1, which is connected through a pipe with a valve 2 to an apparatus pressure control system consisting of a coil condenser 3, a heat exchanger 4 with condensate collectors, a vacuum receiver 5 with a vacuum pump 6, and liquid ejectors 7. Pyrolysis chamber 1 is maintained at a predetermined value with the help of temperature controller 8, electric heaters 9, thermocouple 10 and control panel 11. The pressure in the pyrolysis chamber 1 is recorded using a differential manometer 12. The change in mass of the sample 13 during pyrolysis is recorded using a strain gage transducer 14. The signal passes through the digital converter 15 and enters the computer 16. The change in mass of the sample recorded by the sensor is stored in the database and processed in real time. As a result of data processing, the duration of pyrolysis is determined.

Experimental studies were carried out as follows. The pre-weighed sample 13 is placed on a special bowl 17, the pressure of which is transferred to the strain gage transducer 14 by means of the rod 18.
After that, the pyrolysis chamber 1 is sealed by means of the cover 19 and the unit is turned on. According to the plan of the experiment the pyrolysis temperature is set using the temperature controller 8. The pressure in chamber 1 is maintained manually at the set point by means of valve 2 and the pressure control system.

![Figure 1. The scheme of the experimental unit.](image)

In the case of the experiment in a rarefied medium, the ejectors 7 and the vacuum receiver 5 enter into operation. When conducting experiments under overpressure, the valve 2 is closed until the required pressure due to the release of volatile components and the temperature effect, after which the pressure is gradually released through the valves 2 and 20. The experiment ends when the sample mass stabilizes, that indicates the end of the release of volatile substances.

The parameters of the wood pyrolysis process varied within the following limits: the medium temperature during the thermochemical treatment period was set within 600 °C; the duration of exposure at a given processing temperature was 5-40 minutes; medium pressure was set in the range of 0.1-2 atm. The wastes of the processing of coniferous and hardwood wood (aspen, birch, pine) with maximum sizes up to 60 mm were used as a model material for experimental studies of pyrolysis kinetics.

3. Results and discussion
The kinetic curves of changes in the temperature and mass of the pyrolyzed sample were obtained as a result of thermochemical processing of wood (Figure 2).

The kinetic curves of changes in temperature and mass at various pressures of the medium are presented in figure 2. According to the diagram, the duration of the pyrolysis process decreases with increasing pressure of the medium, and the output of coal increases. The process increases and the output of coal decreases with decreasing pressure. The decrease in the duration of the pyrolysis process with increasing pressure is explained by an increase in the rate of thermochemical reaction and temperature. The residence time of the reaction products also increases that contributes to a more complete carbonization of wood. With decreasing pressure, the temperature of the sample is significantly reduced due to the intense heat removal of the reaction products that leads to a slower thermochemical reaction.
Figure 2. The kinetic curves of temperature and mass at different values of pressure.

The dependence of the duration of the pyrolysis process on the pressure of the medium is presented in figure 3.

Figure 3 shows that with increasing pressure in the apparatus, the process of wood pyrolysis proceeds more intensively that is explained by the formation of more stable compounds of decomposition products, accompanied by the release of a large amount of heat, which, in turn, accelerates the decomposition process.

Figure 3. The dependence of the duration of the pyrolysis process on the pressure of the medium.

At the same time, studies have shown that the reduced pressure in the chamber contributes to an increase in the yield of liquid products due to their rapid removal from the reaction zone, without interacting with charcoal (a strong catalyst for chemical reactions). To study the effect of the pressure of the vapor-gas mixture in the chamber at different periods of the charring process of wood, the kinetic curves of change in the mass of the samples were obtained during the process at different values of the total pressure (Figure 4).

From the presented dependences it is seen that in the initial period a more intensive decrease in the mass of the samples occurs at increased pressures. The final period of thermal decomposition corresponds to the release of the heaviest fractions of chemical products. Therefore, the removal of the latter occurs more intensively at lower pressures in the apparatus.

Thus, in order to intensify the deep pyrolysis of wood, it is advisable to control the pressure in the apparatus during the process itself.
In addition, the influence of the moisture content of treated wood on the duration of the pyrolysis process was established. With an increase in moisture content, the change in the duration of the process increases (Figure 5).

**Figure 5.** The dependence of the duration of the pyrolysis process on the initial moisture content of the sample.

4. Conclusions

The research on the thermochemical processing of wood waste has been conducted in this work. An experimental facility has been developed that allows intensifying and reducing the fire hazard of the process of wood pyrolysis.

It has been established that with an increase in the pressure of the medium, the duration of the process of thermochemical processing of wood waste decreases, and the output of coal increases. In order to intensify the process of thermochemical processing of wood, it is advisable to control the pressure in the apparatus during the process itself. It is also advisable to carry out the pyrolysis of wood at high pressures of the medium in the initial period of thermal decomposition, and to reduce the pressure further to remove heavy fractions.

It should also be noted that humidity has a special effect on the kinetics of the thermal decomposition site: with an increase in the initial moisture of the samples the duration of the process increases. At the same time, the coal obtained from the wet material is superior in its operational and thermal characteristics to the coal obtained from the dry material.

The developed experimental setup and the series of experiments show the possibility of using the proposed method of wood pyrolysis at regulation of environmental pressure in industrial conditions. The introduction of new wood pyrolysis apparatus capable of operating at different pressures will allow obtaining the necessary products with a significant intensification of the process.

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