Comparative experiment on the use of a film electric heater for drying wood in vacuum conditions

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Abstract. The research was carried out at the expense of the grant of the Russian Science Foundation No. 23-76-01090, https://rscf.ru/project/23-76-01090/. The article outlines the need for woodworking enterprises to re-equip existing ones and create new technologies for deep processing. The trends of the Russian market dictate the conditions for choosing primarily domestic equipment, in this regard, the development of innovative, energy-saving, environmentally friendly wood processing technologies is relevant. Drying plants with the use of film electric heaters in vacuum conditions are a promising area of research. The proposed development will reduce the carbon footprint, with the output of high-quality lumber and reduced energy costs. The materials present the results of an experiment on the use of a film electric heater for drying wood in vacuum conditions in comparison with the traditional technology of its application. As a result, drying in vacuum conditions allowed to reduce the process by 35%, electric energy costs by 25%. The obtained result indicates the feasibility of further research in the field of low-temperature drying in vacuum conditions.

1 Introduction

Drying of wood (lumber) is the most energy-intensive process of the wood processing industry. The drying time at most wood processing enterprises in the country takes from two weeks to two months, depending on the type of lumber being dried, which leads to significant consumption of heat and electricity.

To obtain high quality of dried lumber and shorten the duration of the process is allowed by the technique, the drying process in which is carried out under low pressure (vacuum). Nevertheless, when drying in vacuum, the problem of heat energy supply arises, technologies with the use of high frequency currents, microwave, contact and convective methods have a special scientific elaboration, while the use of infrared radiation technology in vacuum conditions has not actually been considered [1].

With the advent of new low-temperature infrared radiation generators (such as film electric heater), it became possible to organize a new technology for drying wood with infrared radiation in a vacuum chamber capable of meeting, firstly, modern environmental safety requirements (because there are no combustion products and coolant, the probability

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of leakage and ingress into the soil of which cannot be excluded), secondly, the requirements of energy saving, since the drying mode is based on accurate knowledge of the optical properties of raw materials, the required exposure power and the wavelength of the generator radiation [2-4].

President of the Russian Federation V.V. Putin at a meeting on the development and decriminalization of the forest complex instructed to introduce a complete ban on the export of unprocessed softwood and valuable hardwoods from the country, and the president also instructed "to launch preferential loans for small and medium-sized businesses from 2021 for the re-equipment of production facilities and the creation of capacities for deep processing of wood," which indicates the relevance and competitive the advantage of the innovative installation we are creating, which allows to process various types of wood using green technologies [5].

2 Materials and Methods

The direct use of infrared radiation for drying lumber is protected by a patent for the invention [6]. The method is as follows: the boards are stacked in a stack consisting of packages, at least two layers of boards, with dividing elements in the form of planks. Film resistive electric heating elements are placed between the packages, covering the entire transverse area of the stack, supply voltage to the electric heaters. Drying is carried out by dry heating using electric heating elements. The drying process is carried out cyclically depending on the heating temperature of the board according to the temperature sensor installed inside the board in the stack: when the heating temperature reaches 40-45°C the power supply of electric heaters is turned off, and when reduced to 35-38°C the electric heaters turned on again, drying is carried out at a temperature of 35-45°C. The drying process is controlled by humidity and temperature sensors, ventilation is turned on at a humidity of 85-90% and turned off at a humidity of 60-65%. To exclude fog and dew accumulation on the surface of electric heaters, the latter are performed with perforation. The drying process is completed in accordance with the specified humidity readings of a certain type of wood.

Using this technology, it is important to clearly observe the ratio of the volume of the dried lumber and the volume of air in the chamber, and consider this when calculating ventilation. Ventilation should not quickly draw out moisture, which will contribute to the influx of colder air, as a result of a drop in temperature and regression of the process as a whole. Nevertheless, it is also impossible to pull out moisture slowly, since due to the constant output of water under the action of IR rays, an excess of moisture is formed, and it will precipitate as condensate on surfaces of lower temperature, and it will need to be evaporated again, respectively, to spend energy on it.

The constant search for the balance of relative humidity in the chamber, the speed of the exhaust fan, the influx of fresh cold air is a very difficult task. The solution can just be the use of this IR drying technology in a vacuum chamber, in this case there will be no need for complex control of several relative humidity parameters. When the required parameters of the temperature of the lumber and the discharge in the chamber are reached, the water will condense onto the walls and gradually drain into the drainage channels, and be removed outside. In addition, in a vacuum, the boiling point of water is lower, which will contribute to a change in the temperature regime of this technology in a smaller direction, and the absence of an environment (air, fog) of absorption of the infrared beam will allow more intensive action on the dried lumber and more selectively control the IR radiation generators. Despite the apparent complication of the design of the drying plant in the form of tightness of the chamber, vacuum installation, these measures will allow, firstly, to get rid of complex calculations and subsequent operation of the drying plant ventilation, which will constantly have disturbing factors, including the time of year and weather conditions changing during the day; secondly, reduce energy costs and reduce the drying cycle period.

Ready-made solutions are presented on the market in the form of press vacuum drying chambers of the PVSK type or the production company TPC "Vysota", etc. [7,8]. Liquid heating panels, usually aluminum, are used as heaters in them. Heating of the circulating liquid comes from an electric boiler with heating elements. The laying of lumber takes place manually, after each stacked row of lumber, a liquid heating panel is placed, as a result, a fully stacked stack for drying is obtained, which is a rather complex structure consisting of many tubes and quick-release connectors. In the heating system, it is important to provide: control of uninterrupted circulation of the coolant; a system of emergency automatic shutdown of heating elements in case of overheating; an emergency system in case of leakage of the coolant, etc. A large number of aluminum heating panels, a circulation and heating system of the coolant, a heating control system, indicates a rather complex design of the heating unit, as a consequence of its high cost and complexity in operation. In addition to this unit, there is an equally complex discharge unit in the chamber, that is, creating and maintaining a vacuum in the required range. Heating of lumber is carried out in such installations by contact method.

We propose to completely change the approach of using electric energy in the vacuum lumber drying system. At the same time, the rarefaction unit should be left the same, and in the lumber heating unit, the use of a system with a coolant should be completely abandoned. Instead, it is proposed to use not contact heating of lumber, but heating under the effect of infrared radiation. The use of low-temperature film resistive electric heating elements is proposed as an IR radiation generator [9, 10]. That is, the film electric heaters will be stacked with lumber according to the technology described in the patent above, power will be supplied directly to the film electric heaters inside the chamber, which will eliminate the "heat carrier intermediary". The use of infrared radiation technology will reduce the metal consumption by reducing the number of heating panels and the possibility of their manufacture from non-metallic polymer materials, as well as due to the absence of a pipeline system and the need for coolant circulation.

To date, there is a backlog on this topic, namely, a number of experiments on the patented technology have been conducted [6] in the laboratory of the Department of "Energy Supply and Automation of Technological Processes" of the South Ural State Agrarian University (Fig. 1).

Fig. 1. Appearance of a pilot sample of a lumber drying plant using film electric heaters.

According to the results of the experiments, patterns and relationships were obtained, which made it possible to obtain a methodology for writing a program for drying various kinds of lumber. According to this method, the drying process regulations for birch and pine have been worked out. It was revealed that the set of lumber temperatures should be increased stepwise, the ratio of the volume of the dried lumber to the volume of the chamber should be at least 1:5, and the total thickness of the laid boards, excluding gaskets between film electric heaters, should not exceed 150 mm. The average electricity consumption, considering these parameters, is in the range of 300-450 kWh per 1 m^3. Such a difference in the values of electricity consumption is due to non-compliance with the recommended parameters, besides, external factors constantly affect the process.

To consider this technology in vacuum conditions, an experiment was conducted in an operating vacuum drying plant, at the company "Maidas" (Russian Federation, Chelyabinsk, Chicherena Str., 42A, office 13), engaged in woodworking. The drying plant of the enterprise is a vacuum chamber with aluminum radiators, which are stacked between the lumber. A coolant heated by a solid fuel boiler flows through the radiators by means of a circulation pump (Fig. 2).

Fig. 2. The appearance of the vacuum drying plant of the production enterprise "Maidas".

For the experiment, the system with aluminum radiators was completely removed from the chamber and film electric heaters were installed (Fig. 3). The experiment was carried out in comparison with the proven patented technology (1), and in vacuum conditions (2), namely the same volume of 2.3 cubic meters stacked 125 mm without considering the gaskets between the film electric heaters.

Fig. 3. Loading lumber into a vacuum chamber with installed film electric heaters.

3 Results and Discussions

The results of the experiment comparing the proven patented technology (1) and in vacuum conditions (2) are shown in the table and in Figures 4 and 5, respectively, recorded using the Owen Process Manager (OPM) software. This software is intended for PC communication with OVEN devices via AC-4 interface converters [11,12].

Table 1. The result of an experiment comparing the proven patented technology (1) and in vacuum conditions (2).

No.	Parameter	Conditions of use of film electric heaters	
		According to the patented technology (1)	Under vacuum conditions (2)
1	Drying process duration, number of days	8	5
2	Final moisture content of lumber, %	6	12
3	Electric energy costs, kWh per 1 m^3	390	290

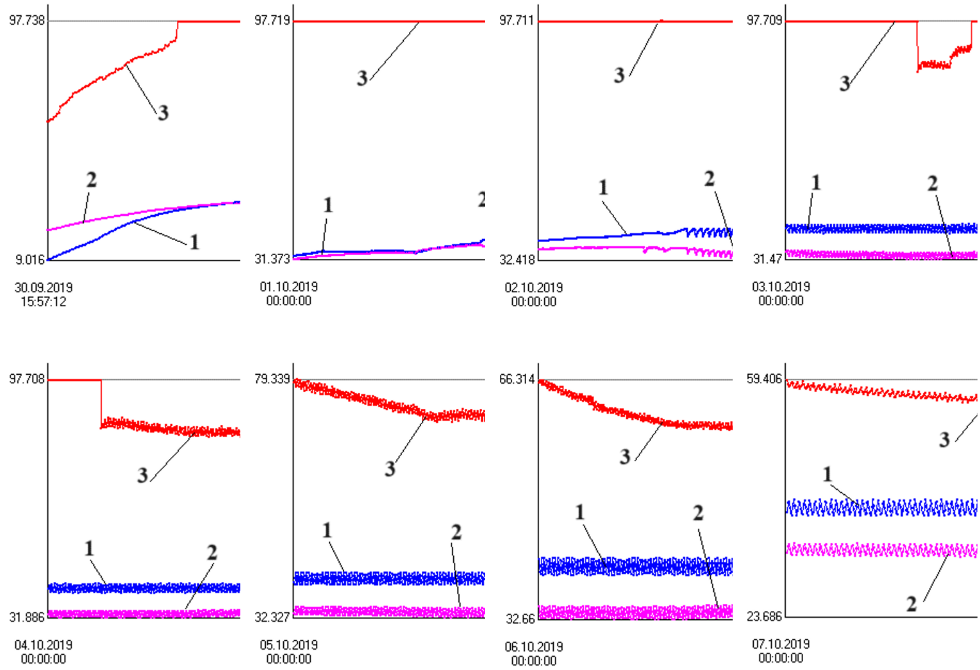

Fig. 4. The process of IR drying of wood using a patented technology (1): 1 - board temperature; 2 – air temperature in the chamber; 3 – air humidity.

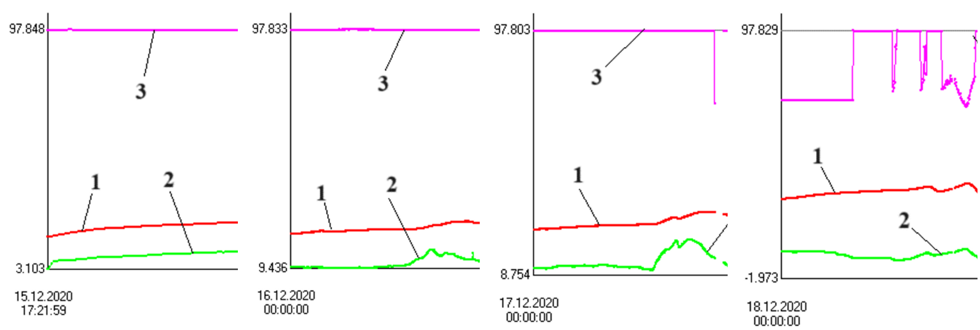

Fig. 5. The process of IR drying (film electric heaters) of wood under vacuum conditions (2): 1 - board temperature; 2 – air temperature in the chamber; 3 – air humidity.

It follows from the graphs in Figure 4 that at the beginning of the process, curve (2) was higher than (1), this is due to the fact that the board was loaded into the chamber from the street (the temperature at this time of year is an order of magnitude lower than the temperature in the chamber). Then curves (1) and (2) equalized and had the same values in the range of 29-31°C, which indicates the heating of the lumber. Then came the phase of active release of free moisture, at which point the curve (1) became higher (2) and a gradual increase to the set value of the upper setpoint of the board temperature (40°C) by the automatic control system began. After reaching the set temperature values of the board, the curves characterize the drying process as oscillating. The humidity of the air inside the chamber gradually decreases, which indicates a less intensive moisture output from the wood and the closer the end of the process, the greater the difference between the curves (1) and (2).

It follows from the graphs of Figure 5 that the humidity of the air environment throughout the process was at the limit values (≈98%), this is explained by the fact that in the vacuum chamber all moisture condenses on colder surfaces and since the sensor was installed directly above the stacked stack of boards, it was one of such surfaces, respectively, the readings its not correct and it is virtually useless for an automatic control system. The air temperature in the chamber after heating the boards and starting the vacuum pump ranged from 9 to 16°C, the maximum value of 21°C was registered in the active phase of a sunny day. It should be noted that the chamber is installed outdoors, the experiment was carried out in winter, the ambient temperature varied in the range from -10 to -24°C. The automatic control system set the value of the upper setpoint of the board temperature, as in the patented 40°C technology, but this temperature was not reached during the entire drying period (the maximum reached 36°C).

4 Conclusion

The drying curves show completely different patterns of the drying process using film electric heaters in vacuum conditions in comparison with the proven patented technology [6]. Nevertheless, with the constant operation of film electric heaters in vacuum conditions, the cost of electrical energy and drying time are lower, which indicates the expediency of continuing research on infrared drying of lumber using film electric heaters in a vacuum chamber.

The primary task will be to study the optical properties of the IR radiation generator and the spectral characteristics of wood of various breeds, followed by their coordination into a single "emitter-receiver" system, which will complement the existing knowledge outlined in this paper and will form the basis for the formation of an algorithm for the automatic control of the drying process.

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