Improvement of the design and heat supply system of a convective dehumidification chamber based on the heat engineering method

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Abstract. Long-term operation of wood-drying plants manufactured by the China in the Siberian region made it possible to establish that the basic design of chambers offered by manufacturers often does not ensure the high quality of dry sawn timber and the estimated drying cycle time, especially in winter. Among the measures aimed at improving the quality of drying, the productivity of drying plants while reducing energy consumption, we can single out the direction associated with improving the design of chambers and their heat supply systems. Thus, the relevant areas of improving the energy efficiency of drying lumber is the use of the heat engineering method to improve the functional characteristics of the heat supply systems of the chambers. The analysis of various types of heat supply schemes of chambers with water coolant was made. The advantage of using a heat supply scheme with high-quality control of the coolant flow in the chamber is substantiated. The results of the introduction of design and technological solutions of the heat engineering method are presented, which made it possible to technically re-equip existing and new drying chambers of the China. The thermal power of the calorifier installations of chambers with various types of heat supply schemes was experimentally determined. Additional requirements are formulated for fences, the technological equipment of the chambers for their operation in difficult climatic conditions of the Siberian region with the provision of high-quality drying of softwood and hardwood lumber. On the example of the existing production, the positive experience of commissioning cameras with additional technological equipment is shown. The operational parameters and dynamics of reducing the humidity of control samples in technically re-equipped chambers are given.

1. Introduction
Drying of lumber is one of the most complex and energy-intensive processes in woodworking technology. Useful yield, strength, ability to finish and, ultimately, the cost of finished products from solid wood largely depend on the quality of drying. In this regard, the current direction of scientific research in this area is to increase the energy efficiency of drying plants.

The main methods of energy saving in the drying processes of lumber are presented in [1]. The classification of thermotechnical, kinetic and combined methods of energy saving is given. An idealized scheme of the process of drying lumber from the position of minimal energy consumption is presented.

In studies [2], technical solutions and recommendations for improving the heat supply systems of chambers using the accumulation of heat energy (synergetic approach) were proposed. With the obvious advantages of this approach, for technical reasons, there is currently no active application in practice.
In studies [3–9], the issues of energy consumption and control of operational parameters during wood drying were considered. It is concluded that the reduction in energy consumption with an increase in the quality of the dried material and in general the productivity of drying plants is associated with the improvement of the design of chambers, heat supply systems and automatic control of the wood drying process.

Thermotechnical requirements for the enclosing structures of drying chambers, data on the heat consumption for drying lumber, and an analysis of the heat balance during chamber drying are given in the review [10].

Summarizing the many years of experience in the operation of convective batch chambers in the Siberian region, the following disadvantages of heat supply systems can be noted: low thermal power of the air-conditioning unit; insufficient speed of water circulation; narrowed diameters of pipes and pipe fittings; high hydraulic resistance of three-way seat valves and check valves; high power of circulation pump electric motors.

As one of the directions for solving the problems of heat supply to the chambers, the heat engineering method can be adopted. This work is devoted to the introduction of some structural and technological solutions of this method to improve the functional characteristics of heat supply systems of drying chambers made in China.

2. Methods
An analysis of patents, periodical scientific and technical publications, prospectuses, and drying plants operating in Siberia by leading companies in Finland, Germany, Italy, and China allowed us to identify four types of hot water supply to the heaters of drying chambers.

The first is a scheme with quantitative regulation of the coolant (figure 1a). It is distinguished by its simplicity of design and lower cost of the regulatory body (two-way valve), which often operates on a two-position principle. Such a scheme was mainly mounted in cameras at the end of the 20th century. The disadvantage of this scheme is the inconsistent flow rate of the coolant in the heat exchangers, which leads to unstable regulation of the parameters of the drying mode. Deviations of the mode parameters from the set ones increase the risks of the appearance of marriage and the total duration of the drying process. But according to this scheme, most cameras released during that period continue to work.

The second is a scheme with quantitative control of the coolant flow in the chamber using a three-way valve (figure 1b). Such a scheme is used when installing a single chamber with a boiler. When the water supply to the chamber is closed, water is redirected to the return pipe bypassing the chamber. This is necessary so that when the water supply to the chamber is closed, its circulation does not stop in the boiler heat exchanger. The disadvantages of such a scheme are similar to the previous one.

The third is a scheme with quantitative control of the flow of coolant in the chamber using a three-way valve and an additionally installed circulation pump (figure 1c). The installed circulation pump allows faster supply of hot water to the heat exchangers, which means reducing fluctuations in the parameters of the drying mode and, therefore, reducing the risks of violating the integrity of the lumber. This method is used when installing several chambers, while the circulation pump always creates the necessary pressure and flow rate of the coolant in the heat exchangers in all installed chambers, there is no imbalance in the flow rate of the coolant both in the chambers and in the heat exchangers in the chambers.
Figure 1. Schematic diagrams of connecting the drying chamber.

a – connecting the drying chamber according to the quantitative scheme of the coolant supply;
b – scheme with quantitative control of the flow of coolant in the chamber through a three-way valve;
c – scheme with quantitative control of the flow of coolant in the chamber using a three-way valve and a circulation pump;
d – scheme with quality control of the flow of coolant in the chamber.
1 – two-way valve with electric actuator;
2 – three-way valve with electric actuator;
3 – circulation pump

The fourth is a scheme with high-quality control of the flow rate of the coolant in the chamber (figure 1d). A separate circulation pump and an electric three-way mixing valve are mounted in the heat supply circuit of each chamber. The temperature of the coolant supplied to the chamber heaters is regulated by mixing return water. It is the presence of these two elements in the circuit that allows the temperature of the drying agent to be maintained with a given accuracy (±2 °C) [12], and in chambers with a modern automatic control system, the accuracy of the temperature control of the drying agent is (±0,5 °C).

Consider the features of the heat supply schemes of some drying chambers installed at the enterprises of the Siberian forest industry, and the structural and technological solutions proposed by the authors for their optimization.

So, in 2014, 2 chambers with a capacity of 150 m³ of a standard set of SUNYO company (China) were installed at the sawmill and woodworking enterprise Green Forest (Krasnoyarsk). The heat supply system of each chamber includes a heat unit, an air heater on two farms and a pipe wiring.

Distinctive features of the heat supply system of SUNYO chambers are: narrowed nominal diameter of the supply pipe and the main pipeline fittings (Du50); a three-way seat valve (Du50) and a circulation pump (DN65) equipped with a 3 kW engine are installed as a regulating body for water flow.
After the commissioning of this unit of chambers, we measured the flow rate of the coolant (hot water) with the TDS-100H Handhold Ultrasonic Flowmetr Ver. 8.08. The measurements were carried out during the heating of a fully loaded chamber with a batch of edged pine lumber with a cross section of 35×150 mm. The ambient temperature during the measurements was 13 °C.

The experimentally established heat consumption, kW was calculated by the formula:

\[ Q_{\text{cal}} = D(h_1 - h_2), \]  

where \( D \) – is the coolant flow rate for the control time;

\( h_1, h_2 \) – coolant enthalpies at the inlet and outlet of the installation, kJ / kg.

The results of measurements and calculations of the thermal power of the camera according to the formula (1) are given in table 1.

The average values of the coolant parameters at the time of the measurements were: water consumption 41.39 m³/h, water temperature at the inlet to the chamber 90.7 °C, return temperature at the outlet of the chamber 76.9 °C. The thermal power of the air-heating unit amounted to only 713 kW, with the required 1050 kW during the period of heating the lumber. The duration of drying of sawn timber was 153 hours, and the energy consumption only for pump operation was 413 kW. With the price of electricity 3.2 rubles. for 1 kW/h at this enterprise, the cost of the pump is 1322 rubles.

**Table 1.** The results of measurements of the flow rate of the coolant and calculations of the thermal power of the air heater in the chamber manufactured by SUNYO.

| Options drying agent | Coolant parameters | Estimated heat output Qcal, kW |
|----------------------|--------------------|-----------------------------|
|                      | tₐ, °C  | Wₚ, % | V, m³/ch | tₚₐ, °C | Tₜₐₜ, °C | MGLD-150 cameras |
|----------------------|---------|------|---------|---------|----------|-----------------|
| 27,1                 | 4,1     | 41,74| 93,8    | 79,1    | 693      |
| 27,6                 | 4,4     | 41,45| 93,4    | 77,6    | 739      |
| 27,7                 | 4,6     | 41,15| 93,4    | 77,5    | 739      |

In 2015, 10 chambers with a capacity of 150 m³ were installed at a sawmill and woodworking enterprise Baikal Forest Company (Irkutsk Region) from the manufacturer of drying equipment from China, TAIFA.

The authors proposed constructive and technological solutions and formulated the basic requirements for the cameras supplied to this object, namely: the thickness of the fencing is at least 150 mm; increased thermal power of the air heater; modernized heat supply system; modern automatic control system with a base adapted to the drying regime of coniferous and deciduous species of Siberia and, of course, affordable service.

Launch of drying chambers showed that TAIFA fully complied with the requirements for chambers. Namely: 2 additional circulation fans are installed; the capacity of the air heater is increased by 50%; increased diameters of pipes (Du80) of the heat supply system; a rotary three-way valve (DN65) and a circulation pump (DN65) with a 1.7 kW engine are installed in the heating unit. As the main element of the control system, we chose the dTOUC controller (HOLZMEISTER, Italy), which allows the use of adapted drying modes of coniferous and deciduous species of Siberia.

Despite the external similarity of the chambers of SUNYO and TAIFA companies, their operation revealed a significant difference in the functioning of heat supply systems, which affected the drying of sawn timber and, in general, the profitability of these enterprises.

To compare the efficiency of the heat supply systems of the SUNYO and TAIFA chambers, during the launch of the latter, we measured the consumption of hot water using a flow meter and calculated the thermal power of the chambers. The experiment was carried out during the heating of pine lumber.
with a section of 38-150 mm. The results of measurements and calculations by the formula (1) are shown in table 2.

Table 2. The results of measurements of the flow of coolant and calculations of the thermal power of the air-heating unit in the chamber of the production of TAIFA.

| Options drying agent | Coolant parameters | Estimated heat output Qcal, kW MGLD-150 cameras |
|-----------------------|--------------------|-----------------------------------------------|
|                       | t\text{c}, °C     | W\text{p}, % | V, m³/ch | t\text{pr}, °C | T\text{обр}, °C |
| 28,2                  | 4,3                | 47,14      | 94,8 | 68,1 | 1421 |
| 28,7                  | 4,5                | 47,47      | 94,4 | 67,6 | 1436 |
| 28,8                  | 4,8                | 46,89      | 91,2 | 65,9 | 1339 |

The average values of the measured and calculated parameters were: water flow rate 47.07 m³/h, water temperature at the inlet to the chamber 92.4 °C, return water temperature at the outlet of the chamber 66.5 °C, respectively, the coolant temperature difference is 25.9 °C at the calculated thermal power of the air-heating unit 1380 kW. The drying time of lumber was 135 hours, and the energy consumption for pump operation, respectively, 207 kW. With the price of electricity 2.95 rubles. for 1 kWh, the cost of operating the pump amounted to 609 rubles, which is 2 times less than in the chamber of the SUNYO company.

Performance parameters and curves of experimental drying of birch lumber 25 mm thick in the TAIFA chamber are presented in figure 2.

Drying was carried out by soft mode. The drying time was 210 hours at a calculated value of 197 hours. The average deviation of the actual temperature of the drying agent (t\text{fact}) in the chamber from the set temperature (t\text{set}), at steady state, was 0.3 °C with a standard value of ±2 °C. The average deviation of the actual equilibrium humidity (EMC\text{fact}) from the set (EMC\text{set}) was ±0.8% with an acceptable value of ±1% [11]. However, at the end of drying with steady-state thermal conditions in the chamber, an increase in the temperature of moist air is observed with the mixing valve closed. The reason for this violation of the drying regime is related to the throughput (K\text{v}) of the three-way valves in closed mode.

3. Conclusions
Forestry enterprises should choose dehumidifying chambers considering not only the price, but also with a detailed analysis of their technical characteristics, features of the complete set of heat supply systems.
and, in general, the chambers’ ability to work effectively at negative ambient temperatures. Companies from China may well be manufacturers of such equipment.

Long-term operation of convection drying chambers made in China in the Siberian region allows us to draw the following conclusions:

- In chambers with limited thermal power, especially in the winter season, the duration of heating of wood, the consumption of electric energy and, consequently, the cost of drying lumber are increased. Also, during the operation of the chambers in the winter, when the supply and exhaust ventilation dampers are opened, the temperature will decrease by a measure, which may lead to a violation of operating parameters and the appearance of drying defects (fungal infections). The costs of additional equipment (increasing the number of heat transfer tubes, increasing the diameter of the main pipes in the chamber, as well as the diameter of the pipe fittings) will undoubtedly lead to a 5-7% increase in the cost of the chambers.
- A significant difference was found in the cost and efficiency of the thermal unit of the cameras. So, the price of a seat valve with an electric actuator is almost 3 times higher than the price of a rotary (mixing) valve. Structurally, the seat valve in comparison with the check valve has a greater hydraulic resistance. Therefore, camera manufacturers are forced to install a high-power circulation pump when mounting a seat valve. Hence, the cost of electricity for the operation of such pumps is growing, which negatively affects the cost of drying lumber.
- The typical configuration of drying chambers from China is not enough to work effectively in the difficult climatic conditions of Siberia. It is imperative to increase the thickness of the camera enclosures to 150 mm, install additional sections of air heaters, recount and increase the diameters of the pipelines of the heat supply system. It is necessary to equip the heating unit with rotary (mixing) valves and circulate hot water with quality control (figure 1d).

To increase the efficiency of the heat supply systems of the drying chambers in the future, design and technological developments will be aimed at solving the problem of excess thermal power of air-heating units with the lowest throughput (Kv) of three-way valves.

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