UDC 674.047

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GENERALIZED ANALYSIS OF THE RESULTS OF THEORETICAL AND EXPERIMENTAL STUDIES OF THE CONVECTIVE DRYING PROCESS OF WOOD

Convective drying is the most common method of drying lumber and blanks, veneer and chipped wood, shaped pieces and other wood products. The main equipment for drying veneer are roller dryers. For drying the chipped wood that is used for manufacturing particleboards, powerful drum dryers are mostly used where the drying agent is flue gases generated from the combustion of a mixture of natural gas and sander dust. The use of independent sources of thermal energy in the processes of drying veneer and chipped wood waste is an urgent problem, the solution of which allows recycling a variety of waste wood in woodworking industry, furniture making, sawmilling, plywood manufacturing and other industries, and also used wood which has exhausted its service life (post consumer wood). The received results of theoretical and experimental studies are recommended for use in woodworking and other industries that produce rotary-cut veneer and chipped wood, and enterprises that manufacture products from rotary-cut veneer (plywood, furniture items, musical instrument ,etc.) and also plants that manufacture products from chipped wood (particleboards, fuel briquettes and pellets and other products).

Keywords: humidity, convective drying, lumber, blanks, wood drying, speed of drying, veneer, chipped wood, heating.

Convective drying is the most common method of drying lumber and blanks, veneer and chipped wood, shaped pieces and other wood products. The basis for the characterization of scientific and practical significance of the conducted research are the obtained theoretical and experimental results which are covered in this work.

Wood drying is the most power-intensive process in woodworking industry. In due time, most boiler plants were converted to natural gas or fuel oil, the fuel which has high calorific value. But owing to the rise in prices of energy (natural gas and fuel oil), manufacturers are forced to seek for alternative, cheaper energy sources. One of these resources is a wood raw material as a dependable and renewable source of thermal energy. The scientists of some Western European countries and of Ukraine have developed a number of effective, independent sources of thermal energy, using wood raw materials as fuel , namely: Vynske energie technik NV (Belgium), Politechnik Biomass Energy (Czech Republic), “Hamech”, “Univeks” (Poland), “Krieger”, “Metallist” (Ukraine), which have high efficiency (≥90%).

The main equipment for drying veneer are roller dryers. They have a number of significant advantages over other kind of equipment. Veneer is shaped between the rollers, which prevents the veneer warping. During the movement of the veneer, the rollers further squeeze out of it some moisture without consumption of thermal energy. In a roller dryer, the thermal energy is transferred to the material (veneer) by convection from the drying agent, by conduction from heated rollers and heat radiation from the elements of the dryer.

In roller dryers, the drying agent can be steam-air mixture or flue gases. The steam-air mixture is heated by the heaters, where the heat carrier is water steam with pressure of 0.6-0.8 MPa. As a rule, water steam was produced by large boiler plants of DKVr or DE types. However, such boilers used natural gas or fuel oil as a fuel, which greatly increases the cost of generated thermal energy.

For drying the chipped wood that is used for manufacturing particleboards, powerful drum dryers are mostly used where the drying agent is flue gases generated from the combustion of a mixture of natural gas and sander dust. Besides the production of particleboards, chipped wood has been widely used recently for the manufacture of fuel briquettes and fuel granules (pellets).

When using wood waste, large boiler plants are working inefficiently. Therefore, it is reasonable to use small thermal generating units with a capacity of 1-2 MW of heat energy, which use crushed waste of wood raw material as the fuel .

There is a sufficient supply of wood raw material in Ukraine that can be used as fuel. First, a large amount of logging residues, dead and unfit for economic purposes wood. Secondly, waste from sawmill plants, furniture making, wood panel production and other industries. Thirdly, the use of wood which has exhausted its service life. Fourth, it is the woody biomass which is collected on the green plantations of fast-growing wood species: willow, poplar, aspen, and the like.

Thus, this paper deals with the energy aspects of drying chipped wood, where the drying agent are flue gases derived from the burning of wood raw material in thermal generating units. Among the thermal generating units that are to be used to provide drying plants with heat energy are modern boilers of domestic and foreign manufacturers. For drying chipped wood in the production of fuel briquettes and fuel pellets, it is advisable to use small drum or flash dryers, where the drying agent are flue gases obtained from the combustion of various waste wood.

The use of independent sources of thermal energy in the processes of drying veneer and chipped wood waste is an urgent problem, the solution of which allows recycling a variety of waste wood in woodworking industry, furniture making, sawmilling, plywood manufacturing and other industries, and also used wood which has exhausted its service life (post consumer wood). Western European countries practise cultivating fast-growing wood species (willow, aspen, poplar) which are used as fuel or for generation of synthesis gas. If dryers use flue gases as the drying agent , the gross calorific value of fuel from wood raw material is used then, which significantly increases the energy efficiency of thermal generating units and drying plants.

The process of conducting the studies involved application of the research methodology of heat-mass transfer processes of woodworking, namely, the theoretical and graphoanalytical methods of determining the duration of drying, the kinetic coefficients of the drying process and complex criteria describing the integrated process of heating and drying of wood. To process the experimental results, we used mathematical planning, classical methods of experiment conducting, and mathematical statistics evaluation of physical quantities characterizing the properties of wood (density, moisture content, anisotropy, shrinkage,...) as well as kinetic characteristics of the drying process (rate of drying, factors of moisture conduction and moisture-yielding ability, the gradient of moisture content of wood, drying coefficient). Analysed were the methods of calculating the components of heat balance of power plants in order to improve their operation and increase the effectiveness of heat energy utilization.

Obtained applied scientific results. Modernization of roller dryers SUR-4. The SUR-4 roller dryer is a steam-air dryer with a longitudinal loading of material and transverse circulation of the drying agent which is heated by steam radiators. The drying plants were reconstructed for the experimental studies. Axial fans were replaced with

more efficient centrifugal blowers which are placed on the ceiling of the dryer. In this case, the first two fans (from the charging compartment) provided heat and circulation of the gas-air mixture for the first period of drying, and the next two fans provided conditions for the second drying period. That is, it became possible to regulate the speed of circulation and thermal regime in the two equal parts of the drying plant, which is the original aspect of their modernization.

As a result of double purification of products of fuel combustion (waste wood), they are completely cleaned of soot and, at a high temperature, fed into the distribution channel and through adjustable holes to the middle of the drying chamber where they are mixed with the circulating nongaseous mixture. Consequently, all heat energy that is needed in the drying process is the heat energy of flue gases obtained from burning waste wood in the independent sources of thermal energy.

Due to the modernization of the SUR-4 dryer, new results have been obtained which differ significantly from domestic and foreign analogues, namely:

- the drying plant is converted to energy-saving heat supply – flue gases with a high calorific value of fuel;
- the drying process in the drying plant is arranged zonally – for the first period of constant drying rate and for the second period with slowing the rate of drying, with certain temperature modes and circulation rate of the drying agent, which can be changed depending on wood species and thickness of veneer sheets;
- the moisture content of wood is governed by the speed of the conveyor roller drive.

Improvement of drying plants of flash type. In drying plants of drum type (with pneumomechanical movement of material) occurs a process of continuous convective drying of chipped wood. These dryers are simple in design and are of adequate performance. The drying process is regulated by the temperature of the drying agent, its rate of circulation and the rotation speed of the drum and the angle of its slope. The temperature of the environment, usually flue gases, can range from 350 °C up to 730 °C at the inlet to the dryer. Outlet temperature of the drying agent, according to the operating requirements, should be taken from 50 °C up to 90 °C and governed by the circulation rate.

In flash-type dryers, you can create a two-step drying process due to the two-circuit design. In the two-circuit drying plant, the process of chipped wood drying can be divided into two periods: the period of constant (steady) speed of drying from the initial moisture content Wi to the critical value Wcr, and the period of slow drying from the critical value Wcr to final moisture content Wf. This division of the drying process allows to intensify heat-and-mass transfer processes. Due to this improvement of drying plants of flash type, it was possible to obtain new results which differ significantly from domestic and foreign analogues, namely:

- the drying plant uses energy-saving heat supply – flue gases with a high calorific value of fuel;
- the drying process in the dryer is divided into two periods, where the first period is of constant drying rate which occurs in the primary circuit of the dryer and the second period of the slow drying rate in the second circuit of the dryer with individual temperature regimes and circulation rate of the drying agent, depending on particle size of shredded wood, initial and final moisture content of the wood in a separate circuit.

Practical results of theoretical and experimental studies of drying processes. The following new practical results were obtained as a result of studying patterns of heat-and-mass transfer:

- solving the problems of kinetics of the drying process by experimental drying curves, the curves of drying rate and the variation of temperature in the course of time made it possible to develop a methodology for determining the intensity of heat exchange and mass transfer, which gives sufficiently accurate results for practical use;
- solving the system of equations of heat-and-mass transfer according to the corresponding initial and final boundary conditions allows determining the moisture content and temperature fields in the wood, which is of practical use in determining values for humidity and temperature deformations and corresponding stresses characterizing the quality of wood;
- the drying process for rotary-cut veneer and chipped wood is divided into two periods of constant and slow rates of drying for which experimentally were found values for the rate of drying, drying coefficients, moisture conduction, moisture-yielding ability, which allows for synthesizing the calculated dependences of the intensity and duration of drying on wood species, its moisture content and density, temperature and humidity fields of the environment in the drying plants;
- solution of differential equations of drying rate in the periods of constant and slow rates of drying allows defining a list of parameters that need to be found experimentally to transform theoretical equations into design ones in order to determine the duration of drying processes and, accordingly, to determine the performance of installations for wood drying;
- based on the law of conservation and transformation of energy, equations have been synthesized that characterize the heat balance at the interface of phases "environment-the surface of the material" during drying which determine, in one case, the amount of heat energy received from the environment that is used for heating of the material and evaporation of moisture, and, in the second case, characterize the mass flow (moisture) inside the material, that is, practically determine the values for moisture conduction and moisture-yielding ability of wood;
- the possibility has been proved for flue gases, cleared of sparks and subjected to double purification from smoke and soot, to be used in the drying processes not only of veneer and chipped wood, but lumber and blanks as well;
- based on the analysis of the results of experimental investigations on the process of drying rotary-cut veneer in the reconstructed roller-drying systems, the authors derived dependences of the temperature of the drying agent and the speed of circulation in various areas of the dryer on moisture content of the veneer, which makes it possible to divide the drying process into two periods and actually to regulate the intensity of veneer drying process;
- based on the analysis of the results of experimental investigations in the two-circuit flash drying plant, there were developed operating parameters – temperature of the drying agent at the entrance to the first and the second circuits as well as the recommended circulation rate;
- based on the results of experimental studies on rotary-cut veneer and chipped wood, a technique was developed for determining the technical- and-economic performance of reconstructed roller drying plants and pilot plants of drum and flash types, namely their productivity, duration and cost of the drying process;
- Based on the mass of moisture that evaporates during drying of rotary-cut veneer and chipped wood, the dependence of drying rate on the temperature of the drying agent was identified and mathematically described, and, in the end, the desired thermal power of the heat-generating unit was determined.

Conclusions. The above results of theoretical and experimental studies are recommended for use in woodworking and other industries that produce rotary-cut veneer and chipped wood, and enterprises that manufacture products from rotary-cut veneer (plywood, furniture items, musical instrument ,etc.) and also plants that manufacture products from chipped wood (particleboards, fuel briquettes and pellets and other products).

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УДК 674.047

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Узагальнений аналіз результатів теоретичних та експериментальних досліджень конвективного процесу сушіння деревини

Конвективне сушіння є найпоширенішим способом сушіння пиломатеріалів і заготовок, шпону та подрібненої деревини, профільних та інших виробів з деревини. Основою для характеристики наукової і практичної значимості проведених досліджень є отримані нові теоретичні та експериментальні результати. Основним обладнанням для сушіння шпону є роликові сушарки. Вони мають ряд істотних переваг в порівнянні з іншим обладнанням. Між роликами фіксується форма шпону, тобто запобігається його деформація-жолоблення. Ролики при рухові шпону додатково вичавлюють з нього частину вологи без витрат теплової енергії. В роликових сушарках теплова енергія до матеріалу (шпону) передається шляхом конвекції від агента сушіння, шляхом кондукції від нагрітих роликів та тепловим випромінюванням від елементів сушарки.

Для сушіння подрібненої деревини, що йде на виробництво деревинностружкових плит, в основному, застосовують потужні барабанні сушарки де агент сушіння – топкові гази, які утворюються від спалювання суміші природного газу та шліфувального пилу. Крім виробництва деревинностружкових плит подрібнену деревину в останній час широко використовують для виготовлення паливних брикетів і паливних гранул (пелетів).

На відходах з деревини великі котельні установки працюють неефективно. Отже, доцільним є застосування невеликих теплових агрегатів потужністю до 1-2 МВт теплової енергії, котрі, як паливо використовують подрібнені відходи з деревної сировини.

Використання автономних джерел теплової енергії в процесах сушіння шпону і подрібненої деревини є актуальною проблемою, вирішення якої дозволяє утилізувати різні відходи деревообробних, меблевих, лісопильних, фанерних та інших виробництв, а також уживану деревину, яка вичерпала свій термін експлуатації.

Якщо в сушарки подаються топкові гази, як агент сушіння, то використовується вища теплотворна здатність палива з деревної сировини, що значно підвищує енергетичний коефіцієнт корисної дії теплових агрегатів і сушильних установок.

В процесі виконання дослідження використано методологію дослідження тепломасообмінних процесів деревообробки, а саме теоретичні та графоаналітичні методи визначення тривалості сушіння, кінетичних коефіцієнтів процесу сушіння та комплексних критеріїв, що інтегровано описують процеси нагрівання та сушіння деревини.

Отримані результати теоретичних та експериментальних досліджень рекомендується використати в деревообробній та інших галузях промисловості та підприємствах, що виробляють лущений шпон та подрібнену деревину та на підприємствах, які виготовляють продукцію з лущеного шпону (фанеру, меблеві вироби, музичні інструменти тощо) і подрібненої деревини (деревинностружкові плити, паливні брикети і пелети та інші вироби).

Ключові слова: вологість, конвективне сушіння, пиломатеріали, заготовки, сушіння деревини, швидкість сушіння шпону, деревинна стружка, процеси нагрівання.