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COMPARATIVE ANALYSIS OF METHODS FOR PLASTIFICATION OF SOLID WOOD

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Abstract

The study is focused on the methods of plasticizing of solid wood for the production of curved furniture parts. The ability for bending wood and the capacity of production depend on the choice of method for plasticizing wood. The comparison between the methods of plasticizing is based on the following parameters: productivity, degree of plasticity, equipment costs, universality of the method and ecology. Proposals are made for the effective implementation of the operation "plasticizing" in the manufacture of curved details from solid wood.

Key words: *plastification, steaming, bendability, degree of plasticity*

INTRODUCTION

Plasticization of wood is a major technological process in the production of curved furniture details made by bending. In its natural condition, at normal temperature and moisture, the wood has plasticity but in a quantity that is not sufficient for the bending purposes. The plasticity of wood could be increased by growth of its moisture and/or its temperature. As it is known, as a result of the changes in the plastic state of the wood, its physical and mechanical properties are also subject of variation. This increases the wood ability to change its shape and size under the influence of external pressure without being broken. According to the general opinion of experts in the branch, it is relatively ease to bend wooden details and specimen made of solid deciduous tree species – beech, walnut, elm, ash, oak, maple, cherry, etc. The keeping of the achieved curvature during bending, i.e. stabilization of the final form, is a process opposite to plasticization. Upon this process, the values of the plasticizing factors should be reduced to such levels that cause insignificant plasticizing effect.

The major problem in wood plasticization is the evaluation of wood plasticity at a certain moment. The availability of many and at the same time quite different types of factors, used for determining the wood plasticization degree, creates difficulties for the integrated evaluation of this indicator. As we know, the possibilities for wood bending are considerably increased upon usage of metal strap with end stops. In this case, it is even more difficult to evaluate the plasticity and respectively to determine the options for wood bending without failure. Practically, the most appropriate way is to determine the lowest value of the ration between the curvature radius of the bent details (R) and the size of the cross section (h) along which the detail is bent. The value of that ratio R/h is a universal indicator for assessment of the possibilities for successful production (without failure) of bent details made of solid wood. For this reason, some authors call it coefficient of bendability. Lower it is, more difficult and with higher probability for waste is the bending process. Numerous factors determine the achievement of minimum ratio between R/h. The most significant among them are: the tree species used for production of wood details; the wood plasticity degree right before its bending has started; the circumstances at which the bending process is accomplished.

The choice of the wood plasticization method is of great importance upon creating the technology for production of bent curved details. From a technological point of view this choice should provide the needed plasticity of the wood material for its bending without failure. On the other hand, the achievement of higher plasticity is related to longer duration of the plasticization and the stabilization of the already curved shape. In general, the achievement of higher degree of plasticity leads to higher production costs and lower efficiency. This means that it is not profitable to achieve high degree of wood plasticity when it is not needed. The plasticization methods are characterized mainly with their possibilities for resulting in maximum wood plasticity, the operation productivity, universality and the investment size for equipment. In this relation, the intention of the study is to evaluate and compare the methods for plasticization by the following indicators: plasticity degree, production efficiency, equipment costs, universality and ecology.

1. METHODS FOR WOOD PLASTICIZATION

There are three main groups of methods used for wood plasticization: hydro thermal, thermal and chemical plasticization of wood. It is not rare to be used in practice the combined application of methods from different groups.

1.1. Hydrothermal wood plasticization

The hydrothermal plasticization of wood is the applied mixed influence over wood with higher temperature and moisture. This condition leads to considerable decrease of the viscosity of the main connecting substance between the cellulose and the micro- and macro fibrils, such as the lignin. The methods from this group are characterized as highly environmentally and ecology friendly methods.

1.1.1. Steaming of solid wood

The steaming is expressed in the heating of wood with moisture over 15% by using a steam with temperature higher than 80ºC. The wood temperature increase is conducted via convection in the direction from the surface towards the center of the heating details. The wood specimens are placed in the steaming chamber close to each other or in rows over separating laths. Depending on the steam pressure, there are two types of steaming regimes to be used – steaming conducted at atmospheric pressure or steaming conducted at a higher pressure than it. At a steam pressure equal to the atmospheric (~0,1 MPa), the steam temperature varies in-between 95 and 100°C. At regimes with steam pressure higher than the atmospheric (for example 0,15-0,25 MPa), the steaming runs at temperatures equal to 115°C and 125°C, while the plasticization time goes down from three to five times. Nevertheless, these regimes have not been widely spread in practice due mainly to the inevitable change of wood color and the decrease in the mechanical strength of the details as a result of their treatment with higher temperatures.

The moisture of the wood does not change significantly during the steaming at low pressure. The beech with initially moisture content 12 % changes it on 15% after 1 hour steaming at 95 ºC.

Figure 1. Steam chamber with atmospheric pressure of the steam



The industrial steaming of wood requires the following range of equipment: steam generator, steam chamber (Figure 1) upon regimes with atmospheric pressure of the steam or autoclave (Figure 2) with pressure controllers upon regimes with steam pressure over the atmospheric. Because of the high pressure in the autoclaves their servicing is rather complicated and dangerous process. This is another reason why it is preferred in work environment to be used atmospheric pressure of the steam. The machines for wood steaming are not expensive (average price at 1,200 €), but they are technologically necessary and required only in specialized productions (as for example in chair production factories). Generally, the autoclaves price is about two times higher than that of the steam chambers. For any production that uses at least one autoclave and one bending machine the minimum required investment is at the amount of 20,000 €.

The plasticization duration depends mostly on the width of the wood details, the tree species, the placement order in the steaming equipment (with or without separating laths) as well as depends on the steam-flow intensity. To prevent surface drying of the wood details during their steaming, they are heated with saturated

steam. The steaming with a wet steam is used for wetting the details that have lower water content than the technologically required level.

As a result of the complex mass- and heat-transfer processes in wood during its steaming, there is a disagreement on the duration time needed for wood steaming. It depends mostly on the wood specimen width and their initial water content. The most often values are 1,2 $min.mm^{-1}$ for water content over 18% and 2,4 $min.mm^{-1}$ for more dry wood. On the other hand, Lemoine and Koch (1971) recommend steaming at 0,8 $min.mm^{-1}$ for wood details that have moisture over 18%. Stevens, W. C. and Turner, N. (1970) are of the opinion that the best method for wood plasticization is its heating up till reaching the water boiling point and steaming duration of 1,8 $min.mm^{-1}$. According to Sochor, M. and Rajcan, J. C (1962) a steaming conducted for a shorter time diminishes the pressure strength and the modulus of elasticity, but requires considerably longer processing for achieving a greater effect; the total deformation depends on the wood moisture and the steaming time. It is optimal when the moisture is close to the saturation limit of the cell walls and the steaming continues till equalizing the temperature over the cross-section. The increases of the steaming time together with the high moisture decrease the total deformation asymptotically, which results in more waste upon bending. This is a serious problem for many productions since due to organization and technology reasons the time needed for bending simultaneously the wood details steamed at the same time is in the range of a few hours. Practically this means that a considerable part of the details are bent after a multiple longer steaming than necessary. In this relation, in previous study (Angelski 2010) it has been found out that the maximum plasticity of wood, steamed at 100°C, is kept for a period of time, four times longer than the time needed for reaching it.

Figure 2. Autoclave with pressure controllers for regimes with steam pressure over the atmospheric



According to Sochor, M. and Rajcan, J (1962) the availability of free steam in wood leads to more unsuccessful bending. Apart from that, by increasing the wood moisture, and in case nothing else changes, the heating of materials slows down. According to Deliiski, N (2003) the major reason for this is that the increase of moisture decreases the coefficient of temperature transfer.

The operation efficiency depends mostly on the overall dimensions of the steam chamber and on the arrangement of the details in it. The placement of the wood details over separating laths and with a space in-between the details provide evenly spread steaming. Often in practice this technology rule is violated with the main purpose for increasing the quantity of steamed details per cycle. In this case the negatives are two – the necessity of longer steaming and the uneven heating of the details.

Steaming is a universal method from the point of view of the possibility for reaching a wide range of plastic conditions for the wood. This means, that the method is suitable for plasticization of details that would be bent up to both a small and a big radius of curvature. This is the main reason this method to be most widely implemented in the production of curved wood details by bending.

1.1.2. Boiling of solid wood

Boiling of wood in a water heated up to and over 100°C provides equivalent by quality bending compared to boiling. Nevertheless, this method of plasticization is less preferred from the furniture manufacturers. The main reason for that is the increase of the details moisture during their treatment, which inevitably leads to increase of the drying time upon stabilization of the achieved by bending shape. The technical accomplishment of the boiling requires a tank with proper dimensions and a source of energy for wood heating. Most often the boiling

is performed in an open container. The investment in equipment here is equal to those upon steaming. The major technical question upon both methods is to define properly the necessary capacity and size of the used container. It is not less responsible to choose an economically viable source of energy. Examining the plasticity of wood, Saito, Y. and team (1951) established that the bending pressures are lower for wood species plasticized by boiling rather than by steaming, and the coloring of wood is more often upon steaming. Reaching a high degree of plasticity by boiling is relatively 1.5 times quicker than by steaming.

Based on research of Nikolov and Raishev (1963), till the end of the 10th minute from the start of the plasticization the destructive force is decreased more than twice in the boiled wood specimen, and with 40% in the steamed details. The arrow of bending by the steamed specimen however is with about 17% higher than that of the boiled details. By increasing the time after the 10th minute, the arrow of bending of the steamed wood specimen registers a certain tendency of going down, whiles of the boiled details, after a minimum decrease it continuous to go up and reaches its maximum value after about 40 minutes from the process start up. This comparison between both methods of plasticization has conditional character because of the differences in the initial moisture of the specimen details. However, it comes to show significant distinctions in the dynamics of plasticization in both methods.

According to ZhiJia, L and team (2008) the optimum regime for reaching the maximum values of the destructive module upon boiling is the following: temperature of plasticization at 112°C, steam pressure of 0,16 MPa and soaking time – 3 h. Their experiment however does not make it clear to what extent changes the water content in wood and respectively, what would be the duration of the stabilization process at this boiling regime.

Based on Nikolov and Raishev (1963) upon boiling specimen details at 98,5°C with dimensions 20/20/300, the bending arrow increases up to the 10th minute of treatment, and afterwards goes down. It has been registered an increase in moisture from 39% to 43% during the 40 min operation process.

It is also in this method that the details arrangement way in the containers influences the plasticization quality and the production efficiency of the operation. Wood wetting has two major disadvantages. One of them is the discoloration, deriving when the water minerals interact with the wood. The other weakness of the wetting is the appearance of cracks along the fibers direction upon the wood drying. Besides, this method requires longer period of drying after bending, which takes time, energy and considerably decreases the operating efficiency in the production of curved details.

1.1.3. Wood heating in a currency field with high-frequency (RFH)

It is known in physics that the heating of dielectric parts (as is the wet wood) in a currency field with high frequency, is due to the на friction between the dipole water molecules. It is a result of their aim to follow the rapidly changing by sign poles of the electric field. The deriving internal friction during this rotation of the water molecules causes a temperature increase of the wood material, located in the field. Based on Misato, N. (1989) in electromagnetic field with frequency of 10GHz, 915MHz and 245MHz, the water has great energy loss.

The internal heat generation creates circumstances for occurrence of one-way movement of the water and the temperature in the material volume from the center to the surface. This is the main difference and advantage of this method over the conventional ways for heat transfer towards wood (contact, convective), where the surface temperature is higher than the one in the center and exists negative temperature gradient. This gradient slows down the water movement from its center to the surface and increases the duration of the processes of plasticization and drying.

For carrying out the method is nessesary to have a high frequency generator and a hydraulic press (fig. 3). High frequency generator applies high frequency power to the details by electrodes connected to moulds of hydraulic press. The equipment price range is in-between 14 000 € to 20 000 €. The main parameters used for control of the heating, and respectively of the plasticization duration, are: currency frequency (respectively the field power); field intension; wood wetness, the ratio between anode and grid electricity in a generator for RFH. Indirectly, the field is the bearer of the heat in the material. The increase of the frequency increases the number of the water molecules rotations at 180° for a single period of time. This increases also the temperature in the material. At different values of the frequency, the speed of the temperature increase also varies. The initial wood wetness is one of the key factors that influence the speed of temperature rising. It is very important that all details, subject of bending, are with the same wetness. Otherwise, the filed acts with all its power only upon the details with higher moisture. This is the main reason for obtaining internal rapture and cracks from hydraulic shocks. Moisture in-between 15% and 20% and frequency of electromagnetic field between 5 and 9 MHz is considered as optimal.

High-frequency heating is performed much faster than via steaming. Its duration is 1÷10 min depending on the power of the high-frequency generator and the cross-section of the details. Based on Laursen and Boye (1958) data, in a high-frequency field, a beech wood detail with measures 35x50x850 mm, could be bent and dried from 40% down to 10% moisture for 150 s, and from 20% moisture down to 10% only within 1 min.

Despite the relatively short heating duration, this method of plasticization is difficult for application without any waste, since it comes easily to internal cracks, surface burns of the processed details. Serious difficulties cause also the natural unequal distribution of the initial wetness along the details' transverse and longitudinal cross-section. Except that it is not suitable for wood species with big number of cellular barriers (membranes). They hinder the free access of steam from the wood, which results in internal breaks (Turner and Dean 1959). Analogical is the result from bending beech with false heartwood in a high-frequency field. Other disadvantages and limitations are the higher requirements for lack of defects in the details, the necessity for strict observation of the requirement for one and the same equally distributed moisture in all processed details, as well as the need of expensive and hardly maintained equipment.

Figure 3. High frequency generator working with two hydraulic presses



These and other reasons from technical and economical nature (as for example the high price of the generators for high-frequency, their hard maintenance, and the potential danger of radiation, electric shocks and the occurrence of accidents) create limitations for the practical implementation of the dielectric plasticization before bending of solid wood details.

Partially, those limitations are overcome by the usage of equipment for dielectric heating upon performing all phases from the process for production of curved details. This means that once the details are positioned in the equipment, they are plasticized, bent and dried. The duration of the whole cycle usually is in the range from 15 to 25 min, and simultaneously could be processed several wood specimen. Besides the single-positioned performance, another important advantage of the method is that the slower processes flow leads to a reduction of the waste, and thus to improvement of the quality of the finished bent details.

Another major technological problem upon the high-frequency plasticization of wood is that the optimum values of the plasticizing factors (wood temperature and moisture) differ in time. The heating of wood via high-frequency electricity is on behalf of the decrease of its moisture. Principally that unfavorable effect could be compensated by increase of the initial wood moisture. On the other hand, the high moisture brings to intensification of the process and the occurrence of many defects in wood. Practically it means that by this method wood cannot reach its maximum degree of plasticity.

1.2. Thermal plasticization of wood

Terminologically, the name „thermal plasticization" is not quite proper, since this group of methods could be considered as hydro-thermal. The reason for this is that the available free water in wood influences both for thermal and moisture plasticization of details. Principally, the name thermal is used to express the lack of purposely impact of water or steam. This is the reason this method to be well-known in practice as 'the dry method'. The initial wood moisture here is usually within the moisture range 8–14 %. Its heating is via conduction due to its contact with the hot metal surface. The heating is performed in a direction from the surface towards the center of the heating details. In order to achieve this heating, multi hydraulic presses with flat or

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curved metal plates are used. Another variant used in practice is the press with flat boards or attached to them heating molds. The necessity of high pressure often results in usage of specialized presses. General view of such press type is shown on figure 3. The price of such equipment is usually around 30 000 €.

Figure 3. Special hydraulic presses with curved plates for thermal plasticization



The methods from this group have two major advantages: there is no need of moistening and the inevitable afterwards drying, as well as the time for stabilization of the achieved form is shortened. The main disadvantage of the methods from this group is the lower degree of plasticity reached by the wood. Thus, these methods are very suitable for details that would be bent at relatively big curvature radiuses. In practice, the ration *R/h* does not goes below 25-30, even upon usage of metal strap with end stops. This limitation is compensated sometimes in practice by combining the thermal plasticization with the preliminary soaking of wood details with 8-12 % moisture in water heated to 60-80ºC for a period of time from 15 to 30 min.

Generally, the indirect heating via conduction has long durability. Because of the low temperature conductivity of wood, the possibility to shorten this duration is small. The limitation in this relation is also its weak resistance to large temperature and moisture gradient. Based on the above, usually in practice is used the combination between convective and conductive heating. For example steamed wood is heated additionally and at the same time is bent between the curved boards of the hydraulic press.

1.3. Chemical methods for plasticization of wood

The chemical plasticization lies in the creation of conditions for transformations in the wood cell walls, which result in partial changes in the connecting matrix and in loosening the ties between the cell walls. The plasticity degree is so that the irreversible plastic deformations are prevailing. This facilitates sustainably not only the bending process but also the stabilization of the achieved shape. The chemical plasticization uses water solutions of ammonia, urea, dicyandiamide, ethylenediamine, thermoplastic phenol-formaldehyde resins from the novolacs type.

The main advantage of the chemical plasticization over the hydro-thermal is that in the chemical process we can bend easily and without waste, up to reaching the maximum possibilities for wood bending.

The tree species from the solid deciduous types are plasticized most strongly under the ammonia interaction (NH_3), especially when it is liquid and under pressure. In this case, the needed time for plasticization of detail with 10 mm width is one hour. In order to utilize the maximum plasticity, the detail should be bent up to 15 min after treatment. Compared to the natural wood, the wood treated with ammonia increases its overall deformation 1,4 times, the elasticity is decreased 5 times, the reversible deformation increased 5 пъти, while the residual deformation -19 times. The necessary bending force for wood details treated with ammonia is considerably lower than that needed for steamed details. In practice they could even be bent manually. Apart from these advantages, the plasticization with ammonia has also serious negatives. The result is inevitably brown volume coloring of wood; the soaking duration is in the range of few hours; the ammonia is dangerous and highly inflammable, as well as makes the production process quite expensive, health-harmful for the workers and

pollutes the environment. Based on the above-mentioned reasons, the plasticization with ammonia is not any more implemented in the production.

2. INDICATORS FOR COMPARISON OF THE PLASTICIZATION METHODS

Table 1 presents the data for technical-economical indicators, which are used for comparison of the plasticization methods. They are determined upon usage of beech wood details with cross-section dimensions of 25/30/250mm. The needed time for plasticization by steaming is calculated through a software product. It has been developed by Deliyski (2003) for solving mathematical models of the process of heat-treatment of prismatic wood details. The data for the other plasticization methods are taken from some previous experiments (Angelski 2010) or from production experience.

From a technology point of view the most important issue is the chosen plasticization method to provide the necessary plasticity of wood so thus to assure its bending without problems. The necessary wood plasticity for bending up to the minimum ratio *R/h* (1,5/1), could be provided by steaming, boiling, and chemical plasticization. The steaming at a steam pressure over the atmospheric is characterized with short duration of the operation. Nevertheless, due to the high temperature heating of wood, these types of regimes have two major disadvantages: the wood color changes and the possibility for defects occurring during bending increases. The main reason for the defects is that the high temperature decreases the moisture and respectively the wood plasticity. The steaming at atmospheric pressure of the steam and the boiling are the methods that plasticize wood more slowly, but the possibility for defects in bending in those cases is considerably lower. The chemical plasticization with ammonia is applicable only in the cases when wood would be colored darker. The low production efficiency and the harmful effect of the ammonia on people and environment have limited significantly the application of this method. From economical point of view, the most appropriate for wood plasticization is the usage of its high-frequency heating. The major disadvantage of that method is that by its usage we cannot achieve the maximum values of the *R/h* ratio. From the other hand, the investment in equipment is only economically viable for serried production. The thermal plasticization between hot press plates has limited application in practice. Because of the low values of the *R/h* ratio it is used for bending of thin wood details.

Table 1. Data for some technical-economical indicators of the plasticization methods, при обработване на букова дървесина с габаритни размери 25/30/250 mm.

Method for plastification	Initially moisture of beech wood	Minimum reachable ratio R/h	Necessary time for plastification, min	Necessary time for stabilization , h	Necessary equipment	Main Advantages	Main Disadvantages
Steaming at low pressure 95ºC	20	1,5/1	14	241	Steam generator, Steam chamber	high degree of plasticity, environment-tally friendly	Extensive drying
Steaming at high pressure 135 ºC	20	1,5/1	6	240	Steam generator, Autoclave	high degree of plasticity, high productivity	Reduce strength, discoloration, more failures in bending
Boiling at 98,5 ºC	20	1,5/1	22	260	Water Tank, Heating source	high degree of plasticity, environment-tally friendly	extensive drying, discoloration

Thermal heating between curve hotplate press 100 ºC	12	25/1	10	114	Hot Plate Hydraulic Press, molds	high productivity	less degree of plasticity, more failures in bending
High frequency	18	16/1	4	2	Hydraulic Press, molds, HF-generator	high productivity	Requirement for uniformly distributed moisture
Gaseous Ammonia	20	1,5/1	180	290	Ammonia storage tank, autoclave	high degree of plasticity	Reduce strength, discoloration of wood, low productive, noxious

3. CONCLUSION

Based on all the above analysis and the comparison of the solid wood plasticization methods before its bending, the following major conclusions could be made:

- The high degree of wood plasticity is achieved by steaming, boiling and treatment with ammonia;
- From technological point of view, the steaming is the most appropriate method for solid wood plasticization before its bending. By its usage, the wood can achieve high degree of plasticity without changing much its color and strength characteristics. Although boiling is much rarely applied in practice, this plasticization method is equivalent to steaming. Wood is fastly plasticized and the increase of its moisture during this time is not sufficient. Main problem is the change in wood color, but it is not sustainable in case that the detail would be colored.
- Steaming and boiling are universal and ecology-friendly methods for wood plasticization.
- The highest productivity from all the methods of plasticization is the high-frequency heating of wood. Nevertheless, its usage has economical efficiency only in serial production. Major technical advantage is that all the phases in the production of curved details through bending are accomplished in the same equipment.
- Main problem in the thermal plasticization is that this method has slight palsticizing effect upon wood. Often, during the subsequent bending the result is high percentage of waste. this is the maion reason this method to be rarely applied in practice.
- Mostly because of the low productivity and the harmful effects on environment the methods for chemical plasticization have lost their industrial significance and application.
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REFERENCES

Gaff, M & Prokein, L 2011, 'The influence of selected factors on coefficient of bendability', *Annals of Warsaw University of Life Sciences, Forestry and Wood Technology*. No. 74 (2011), p. 78-81

Laursen S, & Boye, C 1958, 'Orientering om omkostningerne ved anvendelse af hojfrekvens til opvarmning og samtidig bojning af massive, mindre traeemner", *Troeindustrien*, Vol. 8, No. 3, pp. 47-9

Lemoine, T & Koch, P 1971 'Steam-bending properties of Southern Pine', *Forest Products Journal*, Vol. 21, No. 4, pp. 34-42.

Misato, N 1989 'Wood bending by Microwaves', *Wood machine*, No.104

Peck, E 1957 'Bending Solid Wood to Form', *Agriculture handbook*, Forest service. U.S.D.A., no. 125

Saito, Y, Kitahara, K & Ishu, K 1951 'An experimental study in wood bending' *Wood Industry*, Japan, Vol. 6, pp. 12-17.

Stevens, W & Turner, N. 1970 '*Wood Bending Handbook*', Woburn, Massachusetts, Woodcraft Supply Corp.

Turner, N & Dean, A 1959 'The reaction of some well-known bending timbers when heated in a radio frequency field', *Wood*, Vol. 24, No. 3, pp. 97-100.

Wangaard, F. 1952 'The steam-bending of Beech' Beech *Utiliz. Ser. Ntheast. For. Exp. Stn.*, No. 3, pp. 26.

ZhiJia, L, Li, L, FuCheng, B & RuiJuan, W 2008, 'Study on wood bending technology', *Chinese Forestry Science and Technology*, Vol. 7, No. 2, pp. 15-22.

Ангелски, Д 2010 'Изследвания върху процесите на пластифициране и огъване на детайл от масивна дървесина', Канд.дис., София, ЛТУ, с 155

Делийски, Н 2003 'Моделиране и технологии за пропарване на дървени материали в автоклави. Дисерт. за д.т.н., София, ЛТУ, с. 358

Кавалов, А. 1970 'Пластифициране на дървесина с амоняк' *Дървообработваща промишленост*, No 2, с 11-14.

Манкевич Л, '*Основы гнутья древесины*', Минск, 1961

Николов, Св & Райчев, А 1963 'Сравнителни изучавания върху влиянието на различните методи за пластифициране на буковата дървесина в бъчварското производство' *Научни трудове на ВЛТИ*, т.11