Wood Industry and Engineering
ISSN: 2687-6043 e-ISSN: 2687-6035
Year: 2020 Paper Type: Research Article
Volume: 02 Number: 01 Received: 08/07/2020
Pages: 6 - 12 Accepted: 11/12/2020
https://dergipark.org.tr/en/pub/wie

MODELLING WATER INTAKE PROPERTIES OF HEAT-TREATED BEECH AND SPRUCE WOOD TREATED AT DIFFERENT TEMPERATURES USING BY ARTIFICIAL NEURAL NETWORKS

Ayşenur Gürgen[a]
aysenur.yilmaz@ktu.edu.tr
(ORC-ID: 0000-0002-2263-7323)

Sibel Yıldız
sibelyildiz@ktu.edu.tr
(ORC-ID: 0000-0001-8448-4628)

Karadeniz Technical University, Department of Forest Industry Engineering, Trabzon, Turkey

Abstract

The aim of this study is the modelling the water intake rate of heat-treated oriental beech (*Fagus orientalis* Lipsky) and oriental spruce (*Picea orientalis* (L) Link) wood samples. For this purpose, all the needed data were obtained from the beech and spruce wood samples which have been subjected to heat treatment with four different temperatures (130, 150, 180 and 200 °C) and three different periods (2, 6 and 10 hour) and then which have been subjected to the water intake process at certain periods (2, 4, 8, 24, 48, 72, 168 and 336 hour). Data were modeled using artificial neural networks (ANN) method for both tree species in terms of water intake rate characteristics, separately. Two different learning algorithms (Levenberg-Marquardt (LM) and Scaled Conjugate Gradient (SCG)) were used for the modelling process. In order to achieve the best model, all nodes between 1 and 25 were tested as hidden neuron. A total of 100 models were obtained and 2 models were chosen according to the performance of the models. For two wood species, LM learning algorithm had showed better results than SCG learning algorithm. The structures of the best models for beech and spruce were determined as 3-8-1 and 3-13-1 respectively. As a result, it has been concluded that ANN applications can be evaluated within the discipline of heat-treated wood industry.

Keywords: Heat treatment, beech, spruce, water intake, artificial neural networks

1. Introduction

Wood is a building and engineering material which has a wide usage area with its many positive properties. However, size of the wood can change according to environmental conditions, also wood can be degraded by various biotic and abiotic factors and can be easily flame at low temperatures (Kim and Singh, 2000; Grexa and Lübke, 2001). Many studies have been carried out in order to minimize the negative properties of the wood and to increase the positive properties of the wood, and the methods used in this context are called "wood modification" (Esteves and Pereira, 2009; Sandberg et al., 2017). The wood modification methods can be effective physically and chemically. In the physical methods, wood cells are filled with inorganic or organic materials (Gindl et al., 2003; Tondi et al., 2013). In the chemical methods, it was used various chemicals that change the chemical composition of the cell wall components of the wood (Kumar, 2007; Mantanis, 2017). Wood modification methods often lead to high costs. Therefore, a more environmentally friendly, more economical, and more practical alternative methods are needed. One of the applications that meet all the mentioned conditions is heat treatment (Yildiz et al., 2006; Brosse et al., 2010).

Heat treatment is a process that holding the wood between 100-250 °C in a normal atmosphere, nitrogen gas or any inert gas environment for a certain period of time. Heat treatment is applied for many purposes: to provide dimension stabilization, to increase biological resistance, to improve the performance of surface treatment so on (Esteves and Pereira; 2009; Cheng et al., 2016; Chu et al., 2016; Chung et al., 2017).

[a] *Corresponding Author*

Artificial neural networks (ANN) are an information processing technology inspired by the information processing technique of the human brain. ANN simulates the way the biological system works. The imitated nerve cells contain neurons and these neurons connect to each other in various ways to form the network. Artificial nerve cells are similar in structure to biological nerve cells. Artificial neurons connect to each other to form artificial neural networks. Just like biological neurons, artificial neurons have sections where they receive input signals, collect and process these signals, and transmit outputs.

In this study, the water intake properties of heat-treated beech and spruce wood were investigated and the obtained data were modelled with artificial neural networks.

2. Materials and Methods

2.1. Heat Treatment

The data used in this study were obtained from doctoral thesis of Yıldız (2002).

The experimental design was consisted of a total of 12 variations. The samples were subjected to the heat treatment in an oven at four different temperatures (130, 150, 180 and 200 °C) and three different times (2, 6 and 10 hours) under the normal atmosphere condition. The heat-treated samples (3x3x1,5 cm) were dried to constant weight at 103 ± 2 ° C and their full dry dimensions and weights were measured.

The samples of the experimental and control groups were then placed in water at 20 ± 1 ° C with a weight placed on top. At the end of 2, 4, 8, 24 and 72, 168 (1 week) and 336 (2 weeks) hours, water was removed from the surface of the samples and measurements were made at the same sensitivity as before. The water intake rate was calculated as a percentage of the full dry weight, from the following Equation 1;

$$\text{Water Intake Rate (\%)} = 100 \cdot (Mi - Mo)/Mo \quad (1)$$

where Mo is the oven dry mass (g) prior to the test, and Mi is the mass of the sample removed from the water after each period (g).

2.2. Artificial Neural Network (ANN) Modelling

ANN are structures formed by the connection of artificial neural cells. ANN consist of three main layers; Input layer, hidden layers and output layer.

• Input Layer: It is the layer where the inputs to the artificial neural network are given.

• Hidden Layer (s): The data of the input layer comes to this layer. The number of hidden layers may vary from network to network. The number of neurons in the hidden layers is independent of the number of inputs and outputs. In networks with more than one hidden layer, the number of cells between the hidden layers themselves may also be different. Although the number of hidden layers and the number of neurons in these layers increases the complexity and duration of the calculation, artificial neural network can be used to solve more complex problems.

• Output Layer: It is the layer that produces the outputs of the network by processing the information coming from the hidden layers.

ANN layers of this study were presented at Figure 1.

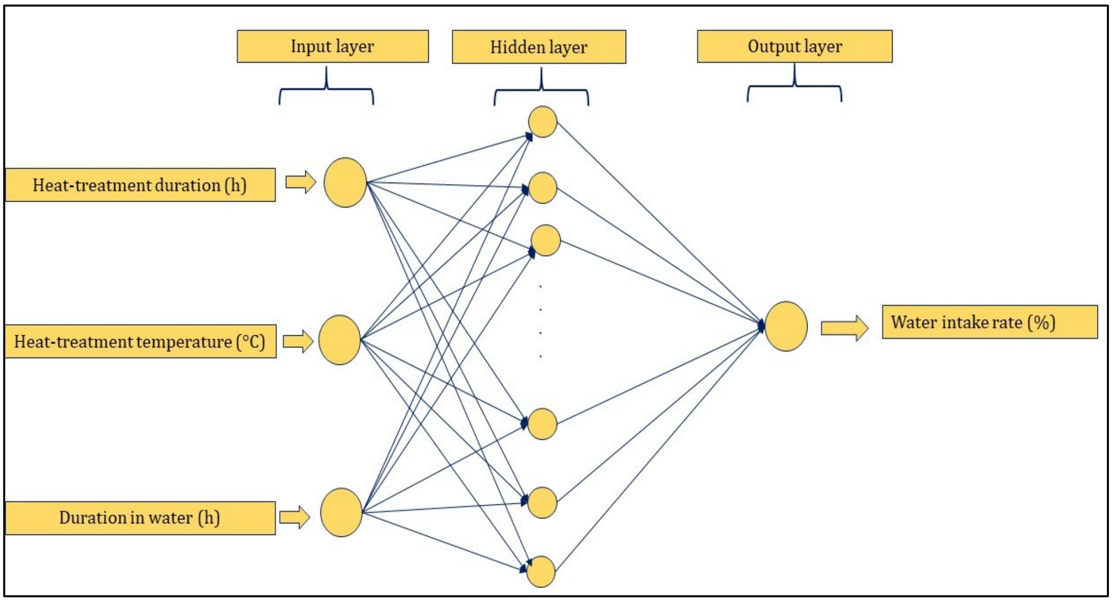

Figure 1: ANN layers of this study

The data were modeled by using ANN method, which is separate for both tree species in terms of water intake rate characteristics. 70 % of the data were used for training, 15 % for verification and 15 % for testing. Two different learning algorithms (Levenberg-Marquardt (LM) and Scaled Conjugate Gradient (SCG) were used in the modelling process. In order to achieve the best model, all numbers between 1 and 25 were tested as hidden neurons. A total of 100 models were obtained and the two best models were selected according to the performance of the models.

To determine network performance, mean square error (MSE), mean absolute percentage error (MAPE) coefficient of determination (R^2) were used. MSE and MAPE values were determined according to following Equations 2 and 3;

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(e_i - p_i)^2 \tag{2}$$

$$MAPE = \frac{1}{n}\sum\left|\frac{e_i - p_i}{e_i}\right| * 100 \tag{3}$$

where, e is the experimental result, p is the prediction result and n is the number of samples.

3. Results and Discussion

3.1. Heat Treatment

The highest and the lowest water intake rate (%) of samples were presented at Table 1.

Generally, it was observed that the water intake rate decreased as the heat treatment time and temperature increased. The changes in the sorption capacities of heat-treated wood are explained by cellulose, wood polyoses, lignin and their different thermal stability as well as their chemical structure ratios (Kollmann and Schneider, 1963).

Wood is less hygroscopic when exposed to high temperatures. The reduction in hygroscopicity depends on the combination of heat treatment time and temperature. The ratio of highly hygroscopic hemicelluloses of wood decreases at heat treated with high temperature. The explanation of the increase in dimension stabilization is based on the amount of hemicellulose in wood, which is greatly affected by the high temperature (Edvardsen and Sandland, 1999).

In theory, wood is stabilized by thermally degrading hemicelluloses containing the most hygroscopic polymers in the cell wall and reducing the amount of free polar adsorption groups that can react with water (Inoue et al., 2007; Feist and Sell, 2007).

Table 1: The highest and the lowest water intake rate (%) of samples

Heat treatment temperature (°C)	Heat treatment duration (h)	Duration in water	Wood sample	
			Beech	Spruce
130	2	2 hour	18,93±1,30	73,45±3,61
		2 week	82,77±2,72	155,38±5,30
	6	2 hour	13,56±2,72	71,17±6,20
		2 week	80,38±2,95	158,99±5,56
	10	2 hour	20,43±1,42	68,17±3,53
		2 week	71,32±2,34	165,65±8,42
150	2	2 hour	14,61±2,88	66,73±4,29
		2 week	82,80±2,17	135,25±2,88
	6	2 hour	20,33±1,69	60,67±9,40
		2 week	77,46±3,73	154,18±8,18
	10	2 hour	10,28±1,68	48,88±13,10
		2 week	82,51±4,79	154,63±5,38
180	2	2 hour	14,79±0,85	31,85±3,30
		2 week	73,75±2,77	162,26±3,53
	6	2 hour	12,77±1,59	67,67±7,69
		2 week	68,71±3,05	160,28±5,27
	10	2 hour	12,43±0,46	71,62±4,58
		2 week	63,08±3,10	154,50±5,32
200	2	2 hour	15,12±2,74	59,87±4,43
		2 week	61,02±3,86	143,00±6,42
	6	2 hour	10,91±5,49	71,19±4,95
		2 week	68,53±5,09	150,92±5,19
	10	2 hour	17,66±3,87	51,48±7,80
		2 week	74,22±4,53	154,15±9,62

In many studies, changes in dimensional stability of wood samples such as beech, alder, oak, eucalyptus, poplar, scotch pine, birch, spruce, fir, such as has been investigated specially in temperatures between 100-230 degrees and 2-48 hours of heat treatment applications. In these studies, dimension stabilization up to 55-90% has been achieved, usually depending on the technique used with increasing temperature and time (Bekhta and Niemz, 2003; Rowell et al., 2009; Srinivas and Pandey, 2012).

3.2. Modelling

For both tree species, better results were obtained from LM learning algorithm rather than SCG learning algorithm. The structures of the best networks for beech and spruce were determined as 3-8-1 and 3-13-1, respectively. Performance of optimum model for beech and spruce were presented at Table 2 and 3, respectively.

Table 2: Performance of optimum model for beech

	Training	Validation	Test	All
MSE	1,256958	4,672605	4,299709	2,198807
MAPE	2,173973	4,925614	4,814419	2,960319
R^2	0,998647	0,99291	0,992862	0,997489

Table 3: Performance of optimum model for spruce

	Training	Validation	Test	All
MSE	0,67048	11,51173	5,156684	2,26709
MAPE	0,794216	2,277427	2,030294	1,077476
R^2	0,999659	0,996869	0,989868	0,998865

Real value and ANN results for beech and spruce were presented at Figure 2 and 4, respectively. Also, coefficient of determination (R^2) for beech and spruce were presented at Figure 3 and 5, respectively.

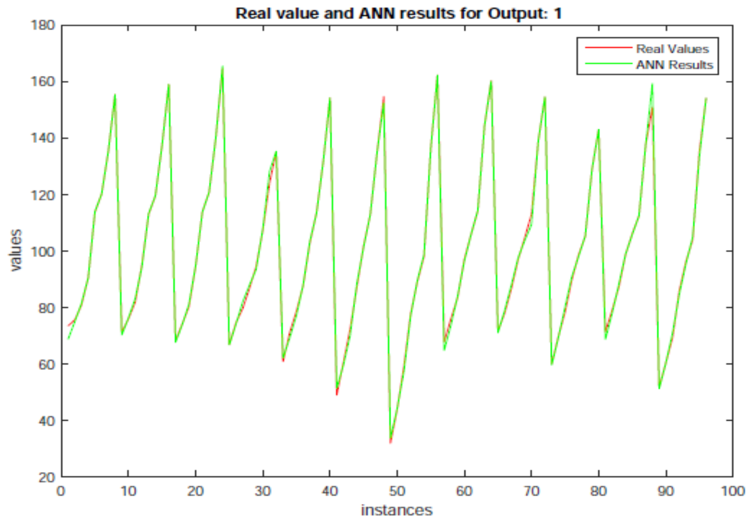

Figure 2: Real value and ANN results for beech

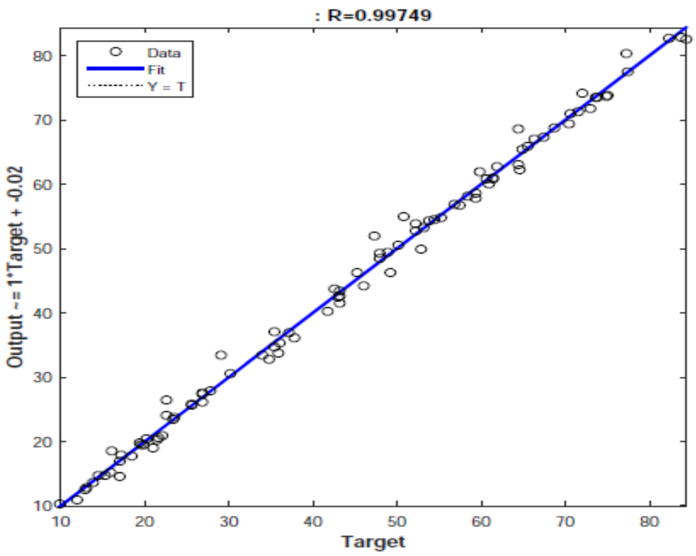

Figure 3: Coefficient of determination for beech

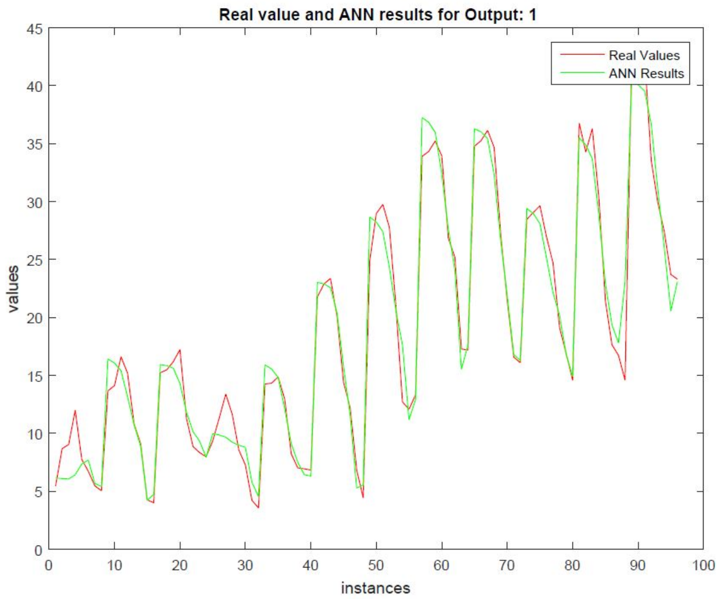

Figure 4: Real value and ANN results for spruce

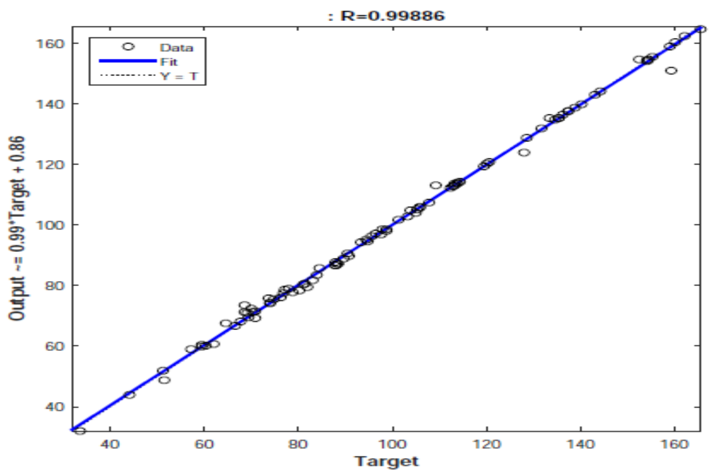

Figure 5: Coefficient of determination for spruce

It can be concluded that the closer coefficient of determination (R^2) value to 1 means that the higher the predictive success of the model. In this study, R^2 values were determined as 0.997 and 0.998 for beech and spruce samples, respectively. It can be deduced that, under the same extraction conditions, when ANN is used to estimate the experiments studied, the model predicts the values of spruce somewhat more accurately than the values of beech samples.

4. Conclusion

In this study, water intake rate of heat-treated beech and spruce were modelled using ANN.

Important findings can be sorted as below;

• Generally; it was observed that the water intake rate decreased as the heat treatment time and temperature increased.

• Wood is less hygroscopic when exposed to high temperatures.

• Heat-treated spruce wood samples were more hygroscopic than the heat-treated beech wood.

• The structures of the best networks for beech and spruce were determined as 3-8-1 and 3-13-1, respectively.

• The predictability of model for spruce were better than model for beech.

5. Acknowledgments

This study was presented as oral presentation at International Gap Conference on Mathematics-Engineering- Science and Medical Studies (21-23 June 2019) in Adıyaman, Turkey.

References

Bekhta P. and Niemz P. (2003). Effect of High Temperature on the Change in Color, Dimensional Stability and Mechanical Properties of Spruce Wood. Holzforschung, 57(5), 539-546.

Brosse N., El Hage R., Chaouch M., Pétrissans M., Dumarçay S. and Gérardin, P. (2010). Investigation of The Chemical Modifications of Beech Wood Lignin During Heat Treatment. Polymer Degradation and Stability, 95(9), 1721-1726.

Cheng S., Huang A., Wang S. and Zhang, Q. (2016). Effect of Different Heat Treatment Temperatures on The Chemical Composition and Structure of Chinese Fir Wood. BioResources, 11(2), 4006-4016.

Chu D., Xue L., Zhang Y., Kang L. and Mu J. (2016). Surface Characteristics of Poplar Wood with High-Temperature Heat Treatment: Wettability and Surface Brittleness. BioResources, 11(3), 6948-6967.

Chung H., Park Y., Yang S.Y., Kim H., Han Y., Chang Y.S. and Yeo H. (2017). Effect of Heat Treatment Temperature and Time on Sound Absorption Coefficient of *Larix kaempferi* Wood. Journal of Wood Science, 63(6), 575-579.

Edvardsen K. and Sandland K.M. (1999). Increased Drying Temperature–Its Influence on the Dimensional Stability of Wood. European Journal of Wood and Wood Products, 57(3), 207-209.

Esteves B. and Pereira H. (2009). Wood Modification by Heat Treatment: A Review. BioResources, 4(1), 370-404.

Feist W.C. and Sell J. (2007). Weathering Behavior of Dimensionally Stabilized Wood Treated by Heating Under Pressure of Nitrogen Gas. Wood and Fiber Science, 19(2), 183-195.

Gindl W., Zargar-Yaghubi F. and Wimmer, R. (2003). Impregnation of Softwood Cell Walls with Melamine-Formaldehyde Resin. Bioresource Technology, 87(3), 325-330.

Grexa O. and Lübke H. (2001). Flammability Parameters of Wood Tested on a Cone Calorimeter. Polymer Degradation and Stability, 74(3), 427-432.

Inoue M., Norimoto M., Tanahashi, M. and Rowell R.M. (2007). Steam or Heat Fixation of Compressed Wood. Wood and Fiber Science, 25(3), 224-235.

Kim Y.S. and Singh A.P. (2000). Micromorphological Characteristics of Wood Biodegradation in Wet Environments: A Review. IAWA journal, 21(2), 135-155.

Kollmann F. and Schneider A. (1963). Über Das Sorptionsverhalten Wärmebehandelter Hölzer. Holz als Roh-und Werkstoff, 21(3), 77-85.

Kumar S. (2007). Chemical Modification of Wood. Wood and Fiber Science, 26(2), 270-280.

Mantanis G.I. (2017). Chemical Modification of Wood by Acetylation or Furfurylation: A Review of The Present Scaled-Up Technologies. BioResources, 12(2), 4478-4489.

Rowell R.M., Ibach, R. E., McSweeny, J. and Nilsson, T. (2009). Understanding Decay Resistance, Dimensional Stability and Strength Changes in Heat-Treated and Acetylated Wood. Wood Material Science and Engineering, 4(1-2), 14-22.

Sandberg, D. Kutnar A. and Mantanis, G. (2017). Wood modification technologies-a review. iForest-Biogeosciences and Forestry, 10(6), 895.

Srinivas K. and Pandey, K.K. (2012). Effect of Heat Treatment on Color Changes, Dimensional Stability, And Mechanical Properties of Wood. Journal of Wood Chemistry and Technology, 32(4), 304-316.

Tondi G., Thévenon M.F., Mies B., Standfest G., Petutschnigg A. and Wieland S. (2013). Impregnation of Scots Pine and Beech with Tannin Solutions: Effect of Viscosity and Wood Anatomy in Wood Infiltration. Wood Science and Technology, 47(3), 615-626.

Yıldız S. (2002). Isıl Işlem Uygulanan Doğu Kayını Ve Doğu Ladini Odunlarının Fiziksel, Mekanik, Teknolojik ve Kimyasal Özellikleri. KTÜ Fen Bilimleri Enstitüsü Orman End. Müh. Anabilim Dalı Doktora Tezi, Trabzon, pp.265.

Yildiz S., Gezer E.D. and Yildiz U.C. (2006). Mechanical and Chemical Behavior of Spruce Wood Modified by Heat. Building and Environment, 41(12), 1762-1766.