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Determination of Combustion Properties of Heat Treated Wood Materials

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Abstract

Studies on heat-treated wood are mostly focused on physical and mechanical properties. There is no sufficient study on combustion properties of heat-treated wooden material. In this study, combustion properties of heat-treated wooden material were determined. According to results of combustion, mass reduction in heat-treated wooden material less than non-heat-treated wood material. Temperature values of the heat-treated wooden material are higher than control samples. During combustion test, also, it was noticed that the amount of released gases such as carbon monoxide (CO), nitrogen oxide (NO) and oxygen (O_2) values in heat-treated wooden material are higher than control ones in general.

Keywords:, Combustion, Heat-treatment, Wood material

Isıl İşlem Görmüş Ağaç Malzemelerin Yanma Özelliklerinin Belirlenmesi

Öz

Isıl işlemle ilgili yapılan çalışmalar daha çok bu malzemenin fiziksel ve mekaniksel özellikleri üzerine yoğunlaşmıştır. Isıl işlem görmüş ağaç malzemenin yanma özellikleri üzerine yeterli çalışma yoktur. Bu çalışma da ısıl işlem görmüş ağaç malzemelerin yanma özellikleri belirlenmiştir. Yanma sonuçlarına göre, ısıl işlem görmüş ağaç malzemenin ağırlık kaybı değerleri, genel olarak kontrol ağaç malzemeden düşüktür. Isıl işlem görmüş ağaç malzemenin üst sıcaklık ve baca sıcaklık değerleri, kontrol ağaç malzemeden yüksektir. Yanma deneyi süresince, ısıl işlem görmüş ağaç malzemenin karbon monoksit (CO), azot monoksit (NO) ve oksijen (O_2) kaybı değerleri genel olarak kontrol ağaç malzemeden yüksektir.

Anahtar Kelimeler: Yanma, Isıl işlem, Ağaç malzemeler

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1. Introduction

Wooden material has a versatile usage area and it is a natural, recyclable and sustainable material. Considering its structure, which allow it to physical, chemical and mechanical modification, it is a very durable construction material. Moreover, this structure provides lots of unique properties to wood such as easy processing, color and pattern difference between species, insulation for noise and heat and makes it a high quality decorative material (Carle and Holmgren 2008, Hill 2006). Besides its positive properties, one of the negative properties of wood is the fact that it burns when suitable conditions are provided because it is an organic material. Unfavorable properties of wooden materials, except flammability, cause financial losses generally. The flammability feature can cause lethal consequences in addition to unaffordable financial losses. Not only flames, but also toxic gases released during combustion of wood threaten human life and may cause deaths (White and Dietenberger 1999, Bedranek and Kaliszuk 2007, Terzi 2008). Uysal and Kurt (2008) reported that boron-containing compounds such as borax-boric acid may prevent flammability in wooden material. According to the results, impregnation with these chemicals provides higher ignition temperatures and lower mass loss, especially in softwoods because of the higher retention ratio. In another study, Uysal and Kurt (2005) produced a 3-layer laminated wooden samples made of oak by using phenol formaldehyde and PVAc and impregnated with di-ammonium phosphate, aluminum sulfate, potassium carbonate, calcium chloride and zinc chloride. They reported that laminated samples glued with phenol formaldehyde and impregnated with zinc chloride have better values during combustion tests. One of the latest technological applications in the wood modification area is heat treatment of wood material. Heat treatment not only minimizes most of unfavorable properties of wooden materials, but also eliminates some of them. In recent times, interest in wooden products has been increasing thanks to development in the wood industry. One of the most effective factors in this trend is the heat treatment technology. Because heat treatment reduces equilibrium moisture content, it eliminates some problems which might occur in later such as molding, cracking, warping, cupping, fading, shrinking, stretching (Esteves and Pereira 2009, Boonstra 2008, Aydemir and Gündüz 2009). The aim of this study is to determine the combustion properties of heat-treated wooden materials. For this purpose, samples made of heat-treated Scotch pine, oriental beech and sessile oak woods were burnt in the developed computer-based combustion device and values such as temperature, mass loss and amount of released gas were recorded and analyzed.

2. Material ve Methods

2.1. Wood Materials

Scotch pine (*Pinus sylvestris* L.), oriental beech (*Fagus orientalis* L.) and sessile oak (*Quercus petreae* Mattu Liebl.) woods were chosen randomly from timber supplier of Karabuk, Turkey. A special emphasis was put on the choice of the wood material. Accordingly, non-deficient, whole, knotless, normally grown (without reaction wood, decay, insect, or fungal infection) wood materials are selected.

2.2. Heat-Treatment Process

The specimens were heat-treated in Facilities of Nova Wooden Products company taking place in Bolu province, Turkey. This company uses industrial scale heat-treatment method which has been developed by VTT Finland and Finland Wooden Building Industry. The method has been licensed by the VTT Technical Research Centre of Finland. In this study, the Scotch pine specimens were heat treated at 212 °C±3 and the oriental beech and sessile oak samples were heat-treated at 200 °C±3 following Thermo–D class heat-treatment process. Thermo wood process is applied in three main steps. The first step is drying the woods. In this step, temperature inside the furnace is raised to 100 °C rapidly with the help of heat and water vapor. Then, heat is increased to 130 °C continuously. Wooden material is dried during this step and humidity drops to 0%. The second step is dedicated to heat-treatment process and the temperature inside wood is raised to 212 °C in softwoods and 200 °C in hardwoods in this step. The target temperature is maintained for 2 – 3 hours. The latest step includes cooling and moisturizing processes. The temperature value of wood is reduced to 50-60 °C by using sprinklers and this process is maintained until humidity of wood reaches 4–6% (Produce firm, 2017).

2.3. Performing of Combustion Tests

The combustion test was carried out according to the standard of ASTM-E –69, but some changes were made in the stand. For this purpose, a digital balance having 0.01 g precision has been used for measuring of mass reduction of materials when they are burned. Butane gas was used to make an ignition flame. The gas flow is standard as the high of flame is 25 cm and the temperature must be 1000 oC. The distance between the bottoms of the test samples which were hanged inside of the device and the top of the gas pipe was adjusted as 2.54 cm/1 inch. During the test, mass reduction, temperature and released gas (CO. NO. O_2) were determined in every 30 seconds. The test was made under a chimney where the flow of air blown was drawn with natural draft. At the beginning of

combustion test, flame source was used for 4 minutes then flame source was taken away and combustion process was continued 6 minutes. Each test lasted 10 minutes for each sample, in total. The oversized test samples were acclimatized until they have constant humidity at 20 ± 2 oC and 65 ± 3 % relative humidity in an environmental chamber. Later, they were cut with the dimensions of 9x19x1016 mm according to the procedure of related standard (ASTM E-69 2007). For use in the tests, 30 controls and 30 treatment samples were prepared for each type of wood. Thus, 180 samples were prepared in total. Multiple analysis of variance was applied to the obtained data by using a statistics package program and then, Duncan tests were applied to determine degree of significance of interaction of the factors with an error margin of 5% to reveal statistically significant differences in preference between samples.

3. Result and Discussion

The highest air-dry density (0.712 gr/cm³) was obtained in Oak control samples and the lowest air-dry density (0.494 gr/cm³) was obtained in heat-treated Scotch pine samples. The average values of density are given in Table 1.

Table 1. Average values of density (gr/cm^3)

Material	Control	Heat-treated
Scotch Pine	0.521	0.494
Oriental Beach	0.694	0.648
Oak	0.712	0.667

Figure 1 shows averages of mass reduction in % obtained during combustion tests of heat-treated and control species.

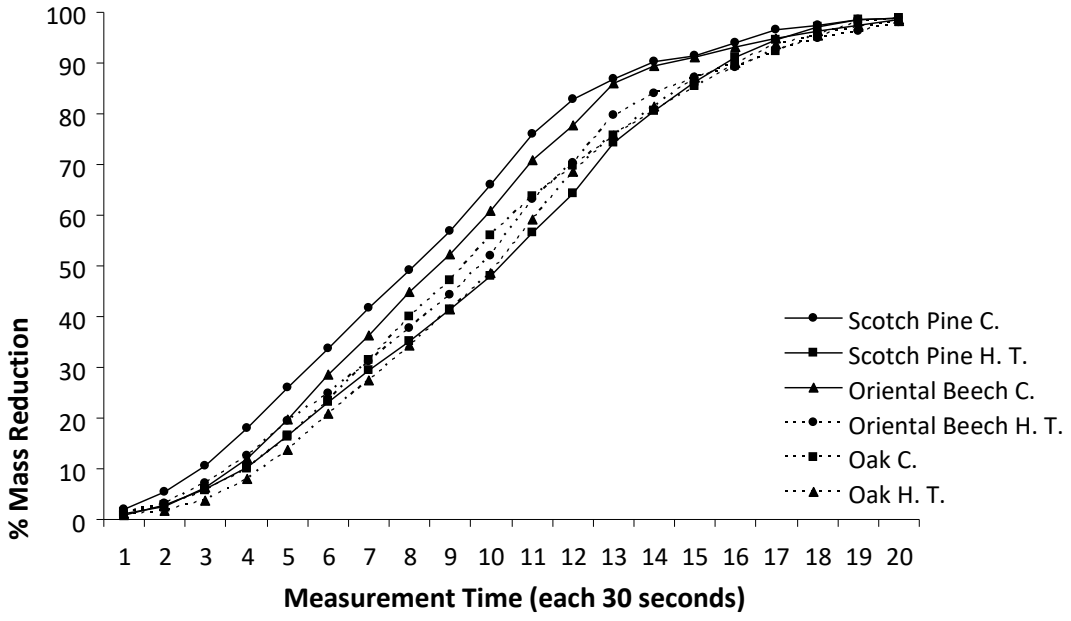

Figure 1. Mass Reduction Values (%).

According to the results seen in the figure showing mass reduction in % obtained during combustion tests of heat-treated and control species. highest mass reduction occurred in Scotch pine control species with 49.17% (8th measurement) as a result of flame source while the lowest one occurred in heat-treated oak species with 34.28%.

Close values were found at the end of combustion for the control and heat-treated wooden material species in case of all three woods. Figure 2 shows average values related to temperature measurements conducted in the control and heat-treated wooden material species at the end of the combustion test.

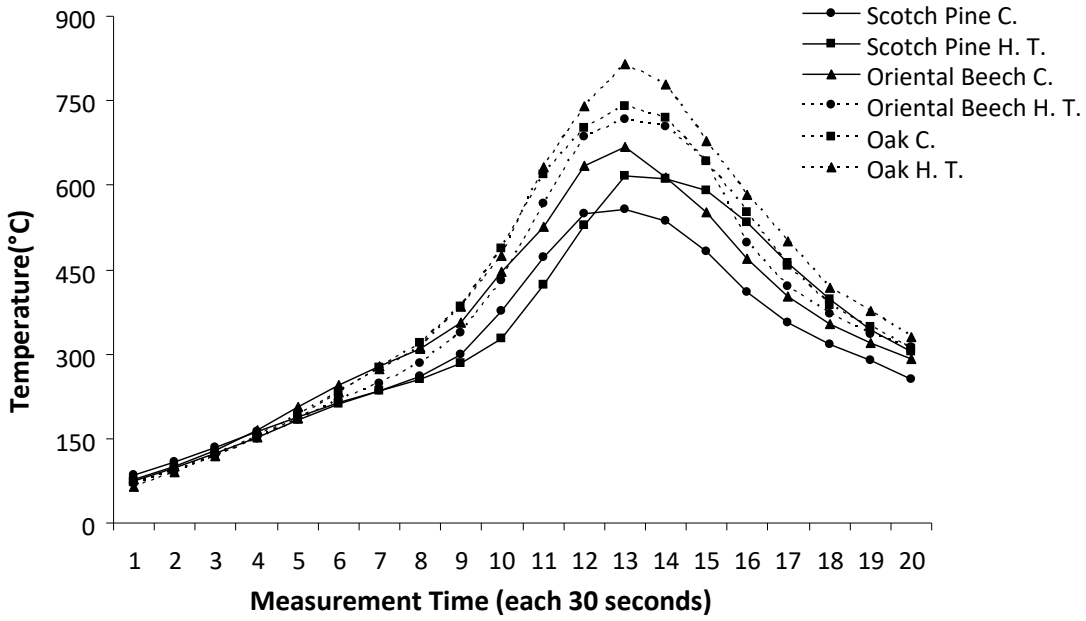

Figure 2. Temperature Values (ºC).

According to the figure showing average values related to temperature measurements in the control and heat-treated wooden material species at the end of the combustion test. highest temperature occurred in heat-treated oak sample with 814 °C while the lowest one occurred in the control of Scotch pine with 557.2 °C. Figure 3 shows average values related to O_2 measurements in % conducted in the control and heat-treated wooden material species at the end of the combustion test.

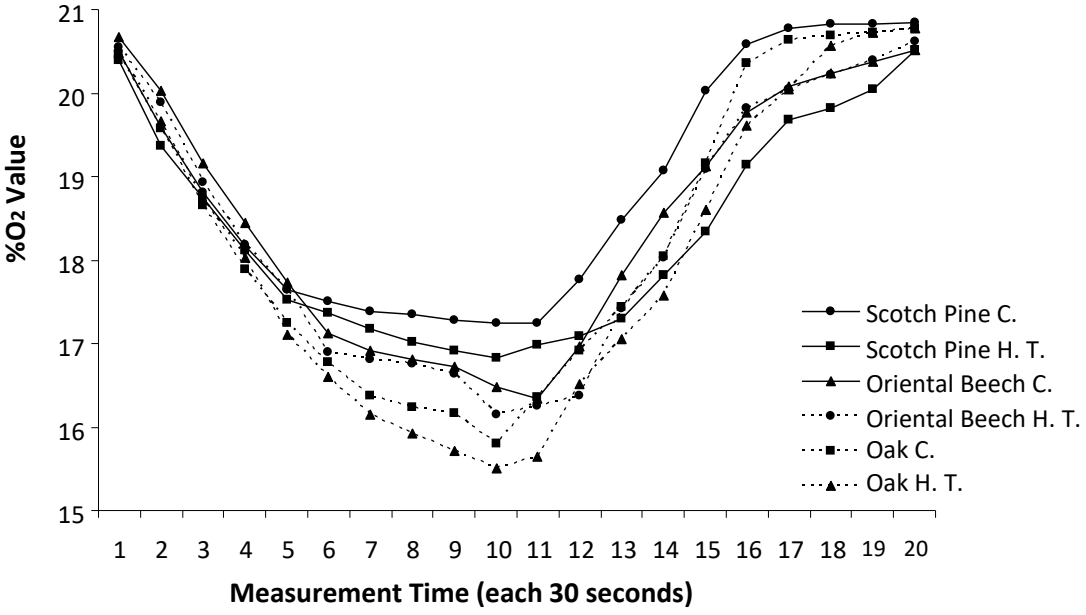

Figure 3. O_2 Values (%).

According to the figure showing average values related to O_2 measurements in % conducted in the control and heat-treated wooden material species at the end of the combustion test. highest O_2 amount was found as 17.24% in the control of Scotch pine while the lowest one was found as 15.51% in the heat-treated oak species. Figure 4 shows average values related to CO measurements conducted in the control and heat-treated wooden material species at the end of the combustion test.

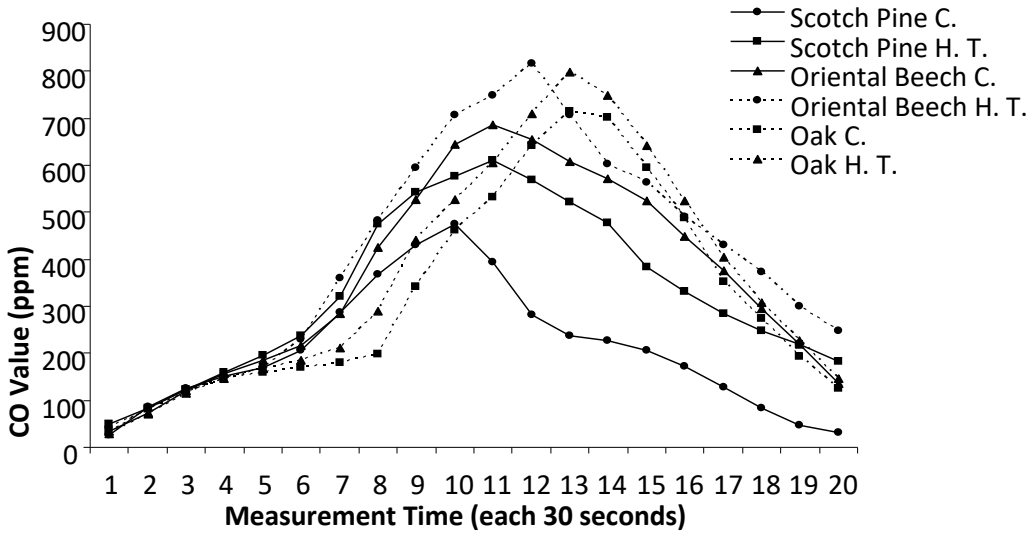

Figure 4. CO Values (ppm).

According to the figure showing average values related to CO measurements conducted in the control and heat-treated wooden material species at the end of the combustion test. highest CO value was found in the heat-treated oak species as 799 ppm while the lowest value was found as 475 ppm in the control of Scotch pine.

Figure 5 shows average values related to NO measurements conducted in the control and heat-treated wooden material species at the end of the combustion test.

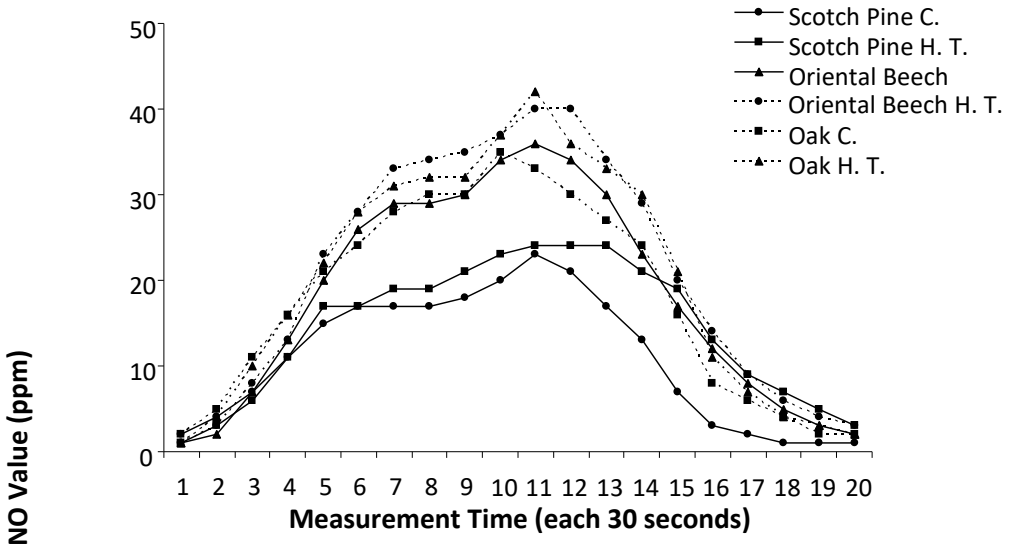

Figure 5. NO Values (ppm).

According to the figure showing average values related to NO measurements conducted in the control and heat-treated wooden material species at the end of the combustion test. highest NO value was found in the heat-treated oak species as 42 ppm while the lowest value was found as 23 ppm in the control of Scotch pine.

Table 2. The multi-variance analyses connected with wood materials and process types mass reduction (a), temperature (b), O_2 (c), CO (d), and NO (e) values.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
(a)					
Corrected Model	34680,025(a)	5	6936,005	5,637	,000
Intercept	11081273,392	1	11081273,392	9005,780	,000
A	9199,401	2	4599,700	3,738	,024
B	18649,544	1	18649,544	15,157	,000
A * B	6831,080	2	3415,540	2,776	,062
(b)					
Corrected Model	3436701,985(a)	5	687340,397	16,265	,000
Intercept	473628371,033	1	473628371,033	11207,833	,000
A	3143371,890	2	1571685,945	37,192	,000
B	274180,908	1	274180,908	6,488	,011
A * B	19149,187	2	9574,593	,227	,797
(c)					
Corrected Model	238,968(a)	5	47,794	16,916	,000
Intercept	1219241,601	1	1219241,601	431530,145	,000
A	107,192	2	53,596	18,969	,000
B	101,217	1	101,217	35,824	,000
A * B	30,559	2	15,280	5,408	,005
(d)					
Corrected Model	14234711,034(a)	5	2846942,207	54,018	,000
Intercept	399694838,225	1	399694838,225	7583,886	,000
A	8436238,129	2	4218119,064	80,035	,000
B	4561078,518	1	4561078,518	86,543	,000
A * B	1237394,387	2	618697,193	11,739	,000
(e)					
Corrected Model	42203,008(a)	5	8440,602	50,618	,000
Intercept	1095496,109	1	1095496,109	6569,662	,000
A	34589,633	2	17294,817	103,717	,000
B	7458,712	1	7458,712	44,730	,000
A * B	154,663	2	77,332	,464	,629

A: Wooden materials B: Proceeding type

Table 3 shows results of the Duncan test performed to decide the significance of the differences between the test groups.

Table 3. Duncan Test Results of Wood Materials ($p \leq 0,05$)*

Source of variance	Mass redection (%)	HG	Temp. (°C)	HG	O_2 %	HG	CO (ppm)	HG	NO (ppm)	HG
Oak- HT	52,37	a	406,8	e	18,05	a	365,3	c	20,6	c
Scotch Pine-HT	52,81	a	337,9	b	18,31	b	330,3	b	14,8	b
Oak-Control	54,16	ab	390,3	de	18,32	b	326,0	b	18,1	b

Oriental Beech-HT	54,44	ab	369,6	cd	18,34	b	410,8	d	21,2	c
Oriental Beech-Control	58,00	bc	357,3	bc	18,49	b	360,7	c	18,4	b
Scotch Pine-Control	61,12	c	314,4	a	18,90	c	207,1	a	11,4	a

HG homogeneity group * The mean values marked with the same letters are statiscally identical.

Table 3 shows results of the Duncan test conducted to determine that variances depending on wooden material and type of the treatment in mass reduction in %. temperature. O_2. CO. NO values are significant. Figures in the table evaluate duration of the measurement in general while they show variances in mass reduction in %. temperature. O_2. CO. NO values depending on wooden material and type of the treatment.

As a result of statistical comparison of wooden materials and types of treatment. a statistical variance is seen in mass reduction in % in heat-treated and control species of Scotch pine. beech and oak woods. Any variance was not seen between heat-treated Scotch pine species groups and oak species groups in the interactions. Any variance was not seen between the oak control species groups and heat-treated beech species groups in the interactions.

4. Conclusion

It was found in the study according to results of air-dry specific weight values that heat-treated wooden material had lower specific weight than those of the controls. Specific weight was found 5.8% in the wooden material made of Scotch pine. 7.2% in the wooden material made of beech and 7% in the wooden material made of oak, respectively of these the reason may be mass reduction caused by heat treatment. loss of water kept in wood due to reduction of existing hydroxyl groups. loss of matters in compounds of wood's cell wall and destruction of hemicelluloses (Viitanen et al.. 1994; Fengel and Wegener. 1989; Feist and Sell. 1987; Jamsa and Viitaniemi 2001).

It was found that specific weight values of the heat-treated wooden material species decreased compared with the control samples.

Schneider and Ruscher reported that the higher mass reduction occurs in woods of leaved trees compared with woods of needle-leaved trees if they are heated under certain conditions (Schneider and Ruscher. 1973)

Considering mass reduction values in % occurred at the end of combustion tests against heat-treated species and the controls. heat-treated wooden species were found lower at the end of flame source combustion (8th measurement or 4th minute) compared with the controls. It was observed that mass reduction value in % decreased to 29% Scotch pine wood. to 16% in beech and to 14% in oak.

It is believed that presence of resin in Scotch pine accelerates combustion and this causes more mass reduction at earlier measurement times.

Scotch pine material gained resistance to after heat treatment compared with beech and oak materials. Thermal conductivity value in heat-treated wooden material decreases. Thermal conductivity of heat-treated wooden material made of needle-leaved tree decreases by 20-25% compared with the control. Therefore. ThermoWood is ideal if fire resistance is essential (Boonstra et al.. 2006; Mayes and Oksanen. 2002).

Note that the mass reduction values in % occurred at the end of combustion tests against the controls. highest value was found in the wooden species made of Scotch pine at the end of flame source combustion (8th measurement or 4th minute). It was observed that mass reduction values in % occurred in the beech species 9% lower and in the oak species 19% lower compared with the Scotch pine species.

Mass reduction values related to the controls correlate with densities of the wooden materials. Materials having lower densities are ignited more rapidly and easily. higher densities make ignition harder and slow combustion rate down (Kantay. 1987).

Considering mass reduction values in % occurred at the end of combustion tests against the heat-treated wooden material species. highest value was found in the wooden species made of beech at the end of flame source combustion (8th measurement or 4th minute). It was observed that mass reduction values in % occurred in the Scotch pine species 7% lower and in the oak species 9% lower compared with the beech species.

Take into account the temperature values occurred at the end of combustion tests. highest values were found in the heat-treated oak species while the lowest one was observed in the controls of Scotch pine. Heat-treated wooden material species were found higher compared with the controls. It was observed that the temperature values increased in the heat-treated species by 7% in the Scotch pine species. by 3% in the beech species and by 4% in the oak species compared with the controls. Notice that the temperature values occurred at the end of combustion tests against the controls. highest values were found in the oak species. It was observed that the temperature values are lower in the Scotch pine species by 19% and by 8% in the beech species compared with the oak species.

Considering temperature values occurred at the end of combustion tests against the heat-treated species. highest values were found in the oak species. It was observed that the temperature values are lower in the Scotch pine species by 17% and by 9% in the beech species compared with the oak species.

Considering O_2 values occurred at the end of combustion tests. highest O_2 values were found in the controls of Scotch pine while the lowest one was observed in the heat-treated oak species. Heat-treated wooden material species were found lower compared with the controls. It was observed that O_2 values decreased in the heat-treated species by 3% in the Scotch pine species. by 1% in the beech species and by 2% in the oak species compared with the controls. Take into account O_2 values occurred at the end of combustion tests against the controls. highest values were found in the Scotch pine species. It was observed that the O_2 values are lower in the beech species by 2% and by 3% in the oak species compared with the Scotch pine species. O_2 amount measured after combustion in the controls of Scotch pine group. which completes combustion rapidly. increases and makes the average O_2 higher.

Notice that the O_2 values occurred at the end of combustion tests against the heat-treated species. highest values were found in the Scotch pine and beech species. It was observed that the O_2 values are lower in the oak species by 2% compared with the Scotch pine and beech species. Considering CO values occurred at the end of combustion tests. highest CO values were found in the heat-treated beech species while the lowest one was observed in the controls of Scotch pine species.

It may be said that the reason for lower CO amount in the controls of Scotch pine is its faster combustion (Goldstein. 1973). CO values in the heat-treated wooden material species were found higher compared with the controls. It was observed that CO values increased by 59% in the Scotch pine wooden material. by 14% in the beech species and by 12% in the oak species. According to the study conducted by Goldstein. gases like CO and methane are produced in rapid pyrolysis. The reason for the fact that CO amount is higher in the heat-treated Scotch pine species may be that it burns slowly. The reason for the fact that CO amount is lower in the controls of Scotch pine species may be that it burns rapidly (Goldstein. 1973).

Take into account CO values occurred at the end of combustion tests against the controls. highest values were found in the beech species. It was observed that the CO values are lower in the Scotch pine species by 43% and by 10% in the oak species compared with the beech species. Considering CO values occurred at the end of combustion tests against the heat-treated species. highest values were found in the beech species. It was observed that the CO values are lower in the Scotch pine species by 20% and by 11% in the oak species compared with the beech species.

Considering NO values occurred at the end of combustion tests. highest NO values were found in the heat-treated beech species while the lowest one was observed in the controls of Scotch pine. Heat-treated wooden material species were found higher compared with the controls. It was observed that NO values increased in the heat-treated species by 36% in the Scotch pine species and by 17% in the beech species and the oak species compared with the controls. Take into account NO values occurred at the end of combustion tests against the controls. highest values were found in the beech and oak species. It was observed that the NO values are lower in the Scotch pine species by 39% compared with the beech and oak species. Considering NO values occurred at the end of combustion tests against the heat treated species. highest values were found in the beech and oak species. It was observed that the NO values are lower in the Scotch pine species by 29% compared with the beech and oak species.

Note that the results of the combustion tests in general. it was found that the heat treated wooden material have lower mass reduction. higher temperature values. and higher O_2 loss and CO and NO release compared with the non-treated wooden material. However. it was found that ignition time is longer in the heat treated wooden material compared with the non-treated wooden materials.

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