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EFFECTS OF TEMPERATURE AND THICKNESS OF WOOD BASED BOARDS ON FORMALDEHYDE EMISSION

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ABSTRACT

This study investigated the effects of board thicknesses and temperature on formaldehyde emission (FE) for different wood based boards, sampled from standard particleboard (PB) and medium density fiberboard (MDF). Test samples with the thicknesses of 8, 12, and 18 mm analyzed for formaldehyde emission at temperatures of 10, 20, 25, and 30°C and 65% relative moisture conent for 60, 120, and 180 minutes after production. The highest value of FE was found at 1.2922 ppm for PB and 0.3800 ppm for MDF of 18 mm, treated at the temperature of 30°C. The lowest emission was found to be 0.0611 ppm in the PB of 8 mm, and 0.0444 ppm for 18 mm MDF, treated at a temperature of 10°C. A significant increase for FE was detected in all board types at the temperatures of 20, 25, and 30°C. However, a significant decrease was also detected at 10°C for all types of boards. Accordingly, an increase from 101% to 1,192% and a decrease from 39% to 9% was observed for PBs. MDF samples yielded better results as an increase from 4% to 280% and a decrease from 55% to 31%. Regarding distance to E1 (0.10 ppm), all values were above the limits of E1 (≤ 0.10 ppm, EN 717-1), except samples treated at 10°C. In conclusion, the temperature and thickness of wood based boards significantly affect their formaldehyde emissions.

KEYWORDS: Formaldehyde emission, temperature, thickness, wood based boards

INTRODUCTION

Global industrialization and the subsequent dwindling of many natural resources have become drivers for product differentiation in wood industries. People involved in the manufacture, repair or restoration of furniture and other wood products, or in the building industry, are exposed to hazardous chemicals. Environmental pressure is directly influenced by consumers that are aware of the growing need for more sustainable products. In an effort to mitigate negative public sentiment regarding timber harvesting and management, the wood products industry has begun to differentiate products through environmental processes. Moreover, the consumption of wood materials has greatly increased due to the production of wood-based boards, which are commonly used to meet demands from the building and furniture industries. Increased awareness has caused consumers, investors, shareholders, and regulatory agencies to improve environmental sustainability requirements. This affects the forest and furniture industries regarding the production of wood based boards and their environmental aspects (Cinar and Erdogdu 2018). Both solid wood and wood-based boards such as plywood, particleboard (PB), and fiberboard (FB) are utilized because PB and FB increase the mechanical stability of wood. Consequently, the production stages of wood based boards have become a crucial issue in terms of environmentally friendly wood based products. Particularly, important amounts of urea or phenol formaldehyde are required for the manufacture of boards.

Synthetic adhesives are predominately used in the production of wood-based boards such as particleboards, high density fiberboards, medium density fiberboards, plywood, and wet-process fiberboards. One of the most commonly used chemical compounds in board manufacturing is urea-formaldehyde resin due to its high performance and low cost (Park and Kim 2008, Tang et al. 2009). However, the substantial disadvantage of urea formaldehyde resin is formaldehyde emission. The hydrolysis of weak chemical bonds during board production and lifetime stage causes indoor emissions of these chemicals, resulting in human exposure.

Formaldehyde is defined by Pearson (1994) as a colorless, distinctive, flammable, and gaseous substance found in various forms at room temperature. It has been valued in industries as a binder and preservative, used in hundreds of household products and building materials. Even though its presence in each product is small, the cumulative effect of many items together in an enclosed space is hazardous for human health. At concentrations between 0.1 ppm and 0.5 ppm, formaldehyde is detectable by smell in some sensitive individuals experiencing slight irritation in the eyes, nose, and throat (Salem and Böhm 2013). Pearson (1994) states that formaldehyde produces irritation to the skin, eyes, nose, and throat. It is often associated with breathing difficulties and nosebleeds, and it is a suspected carcinogen at levels from 0.5 to 1.0 ppm at concentrations above 1.0 ppm. It can also cause dermatitis on contact, which is associated with an allergic reaction towards the chemicals (Isaksson et al. 1999). According to Schafer and Roffael (2000), the formaldehyde in wood is a combination of mechanical and chemical degradation of wood during the preparation of flakes and depends on the quality of the wood and the pre-treatment intensity. The concentration of this formaldehyde is generally very low. However, the main release of formaldehyde comes from the adhesives which are used in wood based boards during and after manufacturing.

Several case studies of the production of wood-based boards have been performed on environmental properties of wood based boards and their various finishes (Raffael 2006, Rivela et al. 2006, 2007, Benotto et al. 2009, González-García et al. 2009, Wilson 2010 Saravia-Cortez et al. 2013, Silvia et al. 2013, 2014, Kouchaki-Penchah et al. 2016, Nakano et al. 2018). Some efforts have been also focused on the study of environmental properties of wood based boards and their various finishes. Brockmann et al. 1998, USEPA 1998, 2001, Cinar 2005, Kim and Kim 2005, Gonzalez et al. 2011, Chuck and Jeong 2012, Zhongkai et al. 2012, Aghakhani et al. 2013, Khanjanzadeh et al. 2014). Others investigated the effects of temperature and humidity on formaldehyde emissions (Luo et al. 2005, H'ng et al. 2012, Oliveira et al. 2017). These studies provide useful background on the fact that board production, material selection and regional characteristics should be taken into account when evaluating wood-based boards. Wood based boards for furniture production are widely used. Among them, the largest shares are particleboards and medium density fiber boards. They are used in refined form, usually laminated or veneered with artificial and natural foils, in addition coated lacquers. In the Turkish wood based-board production, urea-formaldehyde resins are commonly used for the production of most wood based products. These resins contain formaldehyde in free and bound form. Free formaldehyde penetrates directly into the environment and its emission quickly disappears, while the bond is released in a stay manner as a result of degradation of the resin, which intensifies due to high humidity and temperature.

Knowledge of the environmental impact of wood based boards is a key factor in enabling producers to improve their products from an environmentally friendly perspective and thus expedite their introduction into the growing market for "green" products. Environmental factors should be taken into account at the earliest possible stage of product development and design (Cinar 2005). Significantly, it is possible to indicate that wood-based boards made into furniture before entering houses, could be safer against formaldehyde emission after its manufacture.

This paper analyses the effects of wood based board types, board thicknesses, and temperatures on formaldehyde emissions for standard particleboards and fiber density boards, which are typically used in the wood based furniture manufacturing sector in Turkey.

MATERIAL AND METHODS

Methods

This study determined the effects of board type, temperature, and thickness on formaldehyde emissions for particleboards and medium density fiberboards as well as analyzed and compared the obtained emissions with the accepted limit values as ppm (per million particular part). Eco-Indicator 99 (Goedkoop and Spriensma 2000) was used to check the quantitative data representing formaldehyde emission, which was measured in accordance with TS EN 717-1 (2006) by a MultiRAE multiple gas analyzer (RAE Systems, Inc., Sunnyvale, CA, USA.

Materials

Wood based boards and adhesive

Two types of wood-based boards with three different thicknesses were analyzed:

1) standard particleboards (PB), produced according to TS EN 312 (2005) and 2) medium density fiberboards (MDF), produced according to TS EN 622-5 (2008). Urea-formaldehyde (UF) adhesive, W-Leim Plus 3000, code 230026592, Lillestrom, Norway was used for boards production. These materials and standards are commonly used in the Turkish furniture industry. Particleboards and fiberboards were supplied from the main factories of Turkey. The samples were obtained from boards of 210 x 280 x 0.8/0.12/0.18 cm according to TS EN 326-1 (1999). The characteristics of boards and adhesive are given in Tab. 1.

Tab. 1: The Characteristics of adhesive (UF) and boards .

Adhesive	Density ($g \cdot cm^{-3}$)	pH	Viscosity (mPas)	Amount of solid material (%)
Urea-formaldehyde	1.220	8.0	16.000 ± 3.000	55 ± 1
Boards	Dimension	Density ($g \cdot cm^{-3}$)	Weight (g)	Amount of Adhesive ($g \cdot m^3$)
MDF	500 x 500 x 18	0.7433	3620.58	180 - 200
	500 x 500 x 12	0.7800	2348.86	120 - 135
	500 x 500 x 8	0.7900	1715.42	80 - 100

PB	500 x 500 x 18	0.6433	2867.15	180 - 200
	500 x 500 x 12	0.6667	2129.77	120 - 135
	500 x 500 x 8	0.7500	1447.28	80 - 100

Note: Adhesive properties given as measured at 20°C

Preparation of samples

Test samples were prepared from a combination of particleboards and medium density fiberboards with thicknesses of 8, 12, and 18 mm. Samples were cut into 500 × 500 mm dimensions for 8, 12, and 18 mm size thickness and weighed with a sensitive scale (Precia Gravimetrics AG 312-6200C, Dietikon, Switzerland) in compliance with TS EN 326-1 (1999), packed with transparent nylon for avoiding emission, and stored at room temperature of 20 ± 2 °C and 60 ± 5% relative moisture content in order to obtain a moisture value equal to the internal environmental conditions according to TS 2471 (2005). A total of 30 test samples were prepared for the experiment, 15 particleboards and 15 medium density fiberboards with a thickness of 18, 12 and 8 mm. Test pattern consisted of 5 samples for 18 mm, 5 for 12 mm, 5 for 8 mm for particleboards and 5 samples for 18 mm, 5 for 12 mm, 5 for 8 mm for medium density fiber boards.

Implementation of experiment

The climatic test cabinet, physical description

Chamber tests were used to measure the formaldehyde emission from wood-based products under specific temperature and humidity conditions appropriate to end-use (Que and Furuno 2007). The dimensions of the Climatic Test Cabinet were externally 90 x 90 x 200 cm and internally 75 x 75 x 132 cm. The Climatic Test Cabinet contained a slotted angle iron frame used to support particleboards and fiberboards in a horizontal position parallel to the floor. A very small non-sparking circulating fan located 1.20 m above the floor was attached to the angle iron frame near the fresh air inlet. Additionally, an air conditioner (split unit) and an atomizing humidifier were situated on a shelf set about 1.72 m above the floor and centered along the wall and a MultiRAE Multiple Gas Analyzer was integrated to the Climatic Test Cabinet (Fig. 1).

Fig. 1: Climatic test cabinet and multi-RAE multiple gas analyzer.

Board loading and measurement of formaldehyde emission

Samples of particleboards and fiberboards were inserted into the Climatic Test Cabinet with no board-preconditioning period observed. The Turkish Standard TS EN 717-1, which is adapted from EN 717-1, provides reliable methods of testing to characterize low formaldehyde emitting products and provides data that can reassure consumers about the impact of wood-based panel products on indoor air quality. The boards were placed in the support rack in a horizontal position parallel to the floor. The measurements were taken from the newly manufactured particleboards and medium density fiberboards, which were stored less than three days in the board factory for sale. The samples were placed one by one into the Climatic Test Cabinet TK 600 NUVE (2012) with 65% relative moisture and temperatures of 10, 20, 25, and 30°C for 60, 120, and 180 min intervals. Subsequently, the concentrations of formaldehyde were measured by the Multi-RAE multiple gas analyzer over the test specimens prepared from boards supplied immediately from the factory in accordance with TS EN 717-1 (2006). For each measurement, the Climatic Test Cabinet TK 600 NUVE was ventilated for 5 minutes and the Multi-RAE multiple gas analyzer was calibrated.

Data evaluation

To determine the effects of temperature and thickness on formaldehyde emission, the results were compared to calculate the distance to limit 0.10 ppm of E1 (EN 717-1) and were represented in the form of tables. The obtained results were also analyzed for correlation. The dependent and independent variables, which comprised the research hypothesis, were tested with suitable statistical methods. The arithmetic means and standard deviation values of the research data were calculated accordingly. The Analysis of Variance (ANOVA) test was used to determine whether the differences between the variables at $p < 0.05$ level were statistically significant or not. Statistics and 'Microsoft Office Excel (SPSS) programs were used to evaluate the data.

Statistical evaluation

The measurements of the formaldehyde emission in the wood based boards were accepted as the dependent variable, and the temperature with board type and thickness were as the independent variables. The model of the research was formed in a 2 x 3 x 4 factorial design (board type * thickness * temperature). To examine the effect of differences in board thicknesses (8, 12, and 18 mm) and temperature (10, 20, 25, and 30 °C) on the release of the formaldehyde emission in the wood based boards (PB and MDF), the techniques of one-way variance analysis (ANOVA) and multivariate analysis of variance (MANOVA) were used. To compare the significant means of the variance in the analysis, the data is presented in graphic form.

Reliability test

The reliability of the dependent variables, including evaluations about measurement values of the formaldehyde emission in the wood based boards, was tested using the Cronbach's Alpha test.

RESULTS AND DISCUSSION

The Cronbach's Alpha "a" coefficient estimates of internal consistency for the three dependent variables scale, including the formaldehyde emission measurement values are given in Tab. 2.

Tab. 2: Results of reliability analysis of the dependent variables.

Scale items	Time (min)	Item reliability	Scale reliability
Treatment 1	60	0.997	0.995
Treatment 2	120	0.998	
Treatment 3	180	0.995	

Accordingly, the reliability coefficient for the scale of three dependent variables was 0.995. Previous studies have stated that the alpha reliability coefficients for all items can be accepted as 'reliable' when they are above 0.70 (Cronbach 1951, Bagozzi and Yi 1988, McKinley et al. 1997, Grewal et al. 1998, Kim and Jin 2001, Kaplan and Saccuzzo 2009, Panayides 2013). Therefore, this scale was highly reliable.

The results of formaldehyde emission for wood based boards at 20, 25, and 30°C temperatures for different thicknesses and time for 60, 120, and 180 min periods including with the distance of mean to the limit value (0.10 ppm) are shown in Tab. 3.

Tab. 3: Formaldehyde emissions at different thickness, time and temperature.

Board types	Temperature °C	Thickness (mm)	Time minute			Mean	Distance to limit 0.1 ppm	
			60	120	180	μ	ppm	%
PB	10	8*	0.0600	0.0600	0.0633	**0.0611**	-0.0389	-38.89
		12	0.0700	0.0767	0.0833	0.08	-0.0233	-23.33
		18	0.0833	0.0933	0.0967	0.0911	-0.0089	-8.89
	20	8	0.1767	0.2067	0.2200	0.2011	0.1011	101.11
		12	0.2767	0.2867	0.3067	0.2900	0.1900	190.00
		18	0.4400	0.5067	0.5800	0.5089	0.4089	408.89
	25	8	0.2900	0.3167	0.3367	0.3144	0.2144	214.44
		12	0.4233	0.4633	0.5200	0.4689	0.3689	368.89
		18	0.7867	0.8667	0.9633	0.8722	0.7722	772.22
	30	8	0.3867	0.4367	0.4933	0.4389	0.3389	338.89
		12	0.5667	0.7400	0.7500	0.6856	0.5856	585.56
		18	1.1967	1.2933	1.3867	**1.2922**	1.1922	1,192.22
MDF	10	8	0.0667	0.0700	0.0700	0.0689	- 0.031	-31.11
		12	0.0600	0.0633	0.0667	0.0633	-0.037	-36.67
		18	0.0400	0.0467	0.0467	**0.0444**	-0.056	-55.56
	20	8	0.0967	0.1033	0.1133	0.1044	0.004	4.44
		12	0.1133	0.1400	0.1600	0.1378	0.038	37.78
		18	0.1800	0.2100	0.2533	0.2144	0.114	114.44
	25	8	0.1700	0.1833	0.2067	0.1867	0.087	86.67
		12	0.2033	0.2500	0.2867	0.2467	0.147	146.67
		18	0.3000	0.3133	0.3367	0.3167	0.217	216.67
	30	8	0.2467	0.2733	0.3233	0.2811	0.181	181.11
		12	0.3367	0.3700	0.4033	0.3700	0.270	270.00
		18	0.3700	0.3767	0.3933	**0.3800**	0.280	280.00

PB: Particleboard, MDF: Medium Density Fiberboard, μ: Measurement mean

With respect to the means of formaldehyde emission of wood based boards after three days of production, the effect of board type on the emission values was found to be significant. Regarding to emission concentrations, the highest emission value (1.2922 ppm) was found in the samples of 18 mm PBs, treated at the temperature of 30°C, while the lowest emission (0.0444 ppm) was observed in the samples of 18 mm MDFs, treated at the temperature of 10°C.

Regarding temperature, a significant increase was detected in all board types which were treated at 20, 25, and 30°C. However, at the treatment of 10°C, a significant decrease was also detected in all samples. Accordingly, an increase from 101% to 1.192 % and a decrease from 39% to 9% was observed for PBs. The MDF samples yielded better results as an increase from 4% to 280%, a decrease from 55% to 31% were observed respectively. Regarding distance to limit values (0.10 ppm), except the results of the samples which were treated at 10˚C, all values were above the limits of E1 (≤ 0.10 ppm, EN 717-1).

The results of formaldehyde concentrations were obtained from thirty samples of PB and MDF. Each sample was tested and good reliability of results were obtained with a maximum relative standard deviation. It should be noted that these results did not indicate that a certain type of wood-based board is environmentally friendly. The results of one-way variance analysis (ANOVA) for formaldehyde emission for the PB and MDF, board thickness, and temperature are given in Tab. 4.

Tab. 4: ANOVA for the dependent variables, PB and MDF, Board thickness, temperature.

Treatments		Combinations	Sum of squares	df	Mean squares	F	Sig.	Results
PB and MDF	**Treatment 1**	Between groups	0.828	1	0.828	13.201	0.001*	P < 0.001
		Within groups	4.389	70	0.063			
		Total	5.217	71				
	Treatment 2	Between groups	1.085	1	1.085	14.483	0.000*	P < 0.001
		Within groups	5.246	70	0.075			
		Total	6.331	71				
	Treatment 3	Between groups	1.232	1	1.232	14.335	0.000*	P < 0.001
		Within groups	6.018	70	0.086			
		Total	7.251	71				
Board Thickness	**Treatment 1**	Between groups	0.718	2	0.359	5.508	0.006*	P < 0.01
		Within groups	4.499	69	0.065			
		Total	5.217	71				
	Treatment 2	Between groups	0.814	2	0.407	5.089	0.009*	P < 0.01
		Within groups	5.517	69	0.080			
		Total	6.331	71				
	Treatment 3	Between groups	0.966	2	0.483	5.301	0.007*	P < 0.01
		Within groups	6.285	69	0.091			
		Total	7.251	71				
Temperature	**Treatment 1**	Between groups	2.052	3	0.684	14.699	0.000*	P < 0.001
		Within groups	3.165	68	0.047			
		Total	5.217	71				
	Treatment 2	Between groups	2.593	3	0.864	15.722	0.000*	P < 0.001
		Within groups	3.738	68	0.055			
		Total	6.331	71				
	Treatment 3	Between groups	3.021	3	1.007	16.190	0.000*	P < 0.001
		Within groups	4.230	68	0.062			
		Total	7.251	71				

Notes: * a: 0.001 is the level of significance.

According to the one-way variance analysis (ANOVA) results given in Tab. 4, the differences among the dependent variables for PB and MDF types, board thicknesses (8, 12 and 18 mm) and temperatures (10, 20, 25, and 30 ˚C) were found to be statistically significant (at a level of $p < 0.001$) in terms of all the items related to the scale.

Fig. 2 illustrates the differences for the values of formaldehyde emission for the dependent variables depending on time, thickness and temperature for PB and MDF.

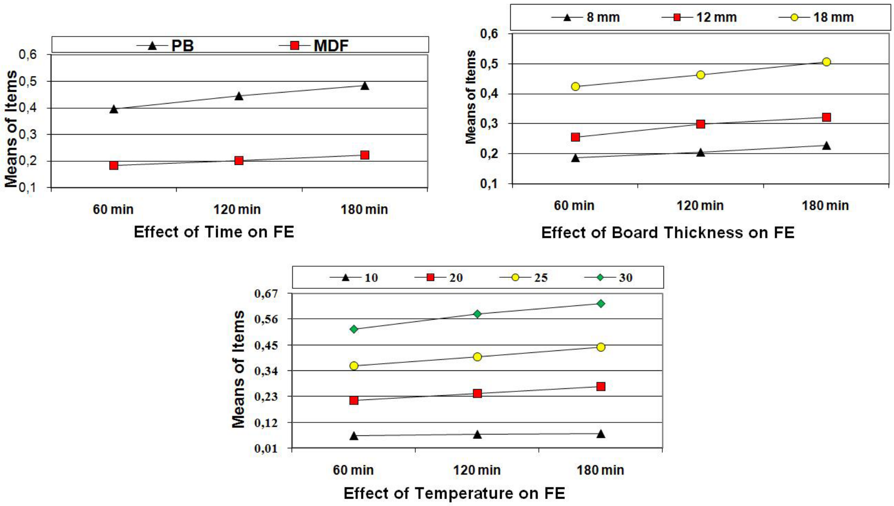

Fig. 2: Effects of time, thickness and temperature on FE for wood based board types.

For each dependent variable depending on the time, the PB released more formaldehyde emissions than the MDF. Consequently, the differences between the wood based boards have a significant level of $P < 0.001$ influence on the measurement values of the formaldehyde emission.

For each dependent variable depending on the thickness, the 18 mm thickness of boards releases more formaldehyde emissions than the 8 and 12 mm thicknesses. Consequently, the differences between the various board thicknesses have a significant influence (0.006 for T1, 0.009 for T2, and 0.007 for T3) on the measurement values of the formaldehyde emission.

As shown in Fig. 2, for each dependent variable depending on the temperature, the 30°C temperature released more formaldehyde emissions than wood based boards at 10, 20, and 25°C. Consequently, the differences between the various ambient temperatures have a significant level of $P < 0.001$ on the measurement values of the formaldehyde emission.

Tab. 5 gives the effects of interactions between independent variables (board type * board thickness * temperature) and formaldehyde emission values of for dependent variables (treatments for 60, 120, and 180 min).

Tab. 5: MANOVA of the independent variables.

Independent variables	F	df	Sig.	Results
Board	86.453	3	0.000*	P < 0.001
Thickness	20.845	6	0.000*	P < 0.001
Temperature	9.823	9	0.000*	P < 0.001
Board *Thickness	9.805	6	0.000*	P < 0.001
Board *Temperature	7.870	9	0.000*	P < 0.001
Thickness*Temperature	6.840	18	0.000*	P < 0.001
Board *Thickness*Temperature	5.112	18	0.000*	P < 0.001

Note: * a: 0.001 is the level of significance.

The main effects (board type, material thickness, and temperature), the two-way interactions for (board * thickness), (board * temperature), and (thickness * temperature) as well as the triple interaction for (board * thickness * temperature) were to be found significant at a level of $p < 0.001$.

Concerning wood based board types and thicknesses, particleboards have a higher formaldehyde concentration than medium density fiberboards. Additionally, as the thicknesses of boards increase in both PB and MDF, formaldehyde emission also increases significantly. Several factors could interfere with the formaldehyde emission. Assuming the same parameters have been used, pressure, amount of adhesive, pressing time, the raw materials; chips for PB, and fibers for MDF, play a significant role on formaldehyde emission. The compaction of the mat of fiberboards to an average density higher than particleboards may allow better surface contact and a compact structure. This results in better adhesive utilization because more adhesive-coated fibers might be in intimate contact instead of with voids. This could be the reason PBs have higher formaldehyde emission than MDF. Chamber studies have shown that the formaldehyde concentration levels emitted from different wood species ranged from 2 to 9 ppb, which were much lower than the emission limit value of 100 ppb for wood-based boards (Meyer and Boehme 1997). Therefore, as argued by He and Zhang (2010) and Zhongkai et al. (2012), during the drying and hot pressing processes, the formaldehyde content in wood fibers after resin application dramatically decreases. This is probably due to the formaldehyde being abundantly emitted when drying the wood fibers after the resin application.

In regards to temperature, samples did not show formaldehyde emission at the temperature of 10°C. A very low emission (0.06 to 0.09 ppm for PB and 0.04 to 0.06 for MDF) was observed. The increase of the temperature to 20, 25, and 30°C induced the emission of formaldehyde for both PB and MDF. When the temperature is raised, all the processes with a potential to contribute to the emission of FE increased. Myers (1985) showed an exponential formaldehyde emission from wood-based products. The emission from particleboard increased between the temperatures of 23 and 40 °C. The increase of the temperature to 50°C affected the emission of formaldehyde mainly in Type A laminate flooring (Marutzky 1997). Temperature, one of the environmental parameters that influence formaldehyde emissions, is also argued by a number of authors (Bremer et al. 1993, Wolkoff, 1998, Yang, 1999, Cox et al. 2005 and Zhang et al. 2007). These authors reported on emission variations with changes in temperature and concluded that the emitted substances were temperature dependent.

According to the results of the study in reference to the Turkish wood-based board production industry, the formaldehyde concentration of particleboards and fiberboards were significantly higher than the accepted international levels. The need to look for ways to reduce the formaldehyde emission to accepted levels is a great concern for the Turkish furniture industry. Salem et al. (2012) state that governments of many countries have already imposed or are about to impose regulations limiting the formaldehyde emission from building materials as well as from materials used for the manufacture of furniture, engineered flooring, housing, and other industrial products. The emission of formaldehyde in wood products can be minimized during the manufacturing process, or by post treatment and surface treatment of the boards. Reduction in F/U molar ratio has been a strategy adopted in the last decades to decrease formaldehyde emission. However, this reduction decreases the reactivity of UF resins. Currently, reactivity of industrial UF adhesives is near the minimum limit accepted for industrial board production (Myers 1984, Dongbin et al. 2006).

CONCLUSIONS

The main results of this study indicate that temperature, thickness and type of wood based boards significantly affect the formaldehyde emission. Standard particleboards have a higher environmental impact than medium density fiberboards.

- The highest value of FE was found (1.2922 ppm) in the samples of 18 mm, treated at a temperature of 30°C while the lowest emission was found (0.0611 ppm) in the samples of 8 mm, treated at a temperature of 10°C for particleboards.
- The highest value of FE was observed to be as 0.3800 ppm in the samples of 18 mm, treated at a temperature of 30°C while the lowest emission was 0.0444 ppm, treated at a temperature of 10°C with the thickness of 18 mm for Medium Density Fiber boards.
- Regarding to temperature, a significant increase was detected in all board types, at temperatures of 20, 25, and 30°C. However, a significant decrease was also detected at 10°C for all types of boards. Accordingly, an increase from 101% to 1,192% and a decrease from 39% to 9% was observed for PBs. The MDF samples yielded better results as an increase from 4% to 280%, and a decrease from 55% to 31% were observed respectively.
- Regarding to distance to limit values (0.10 ppm), except the results of the samples which were treated at 10°C, all values were above the limits of E1 (≤ 0.10 ppm, EN 717-1).

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