Effects of Surface Veneering, Edge Banding, and Drilling Holes for Handles and Hinges of Wood-Based Boards on Formaldehyde Emission

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Abstract

This study determined the effects of surface veneering (V), edge banding (E), and handle and hinge holing on formaldehyde emission (FE) for standard particleboard (PB) and medium-density fiberboard (MDF). Thirty test samples were prepared from PB and MDF. Each sample was pressed by 0.6-mm beech veneer and edged with 2-mm beech veneers. In the samples, two handle holes were drilled with 18-mm depth and 5-mm diameter, and two hinge holes were drilled with 15-mm depth and 30-mm diameter. FE was measured in accordance with Turkish standards by a MultiRAE multiple gas analyzer. A significant decrease from 93 to 80 percent for PBs and from 72 to 22 percent for MDFs was detected when compared with the control samples. V and E of boards (PB/MDF + V + E) significantly reduced FE from 1.1078 to 0.0733 parts per million (ppm) (93%) for PB and from 0.2311 to 0.0667 ppm (72%) for MDF. Drilling holes for hinges and handles (H) on the surfaces of boards slightly increased FE from 0.0733 to 0.0789 ppm for PB and from 0.0644 to 0.0789 ppm for MDF. Regarding distance to E1 (0.10 ppm), unprocessed control samples and samples of PB + V and MDF + V yielded results higher than the limits of E1. In conclusion, V and E significantly reduced FE, whereas H slightly increased FE. The need for a way to reduce FE to accepted levels is of great concern for the Turkish furniture industry.

The furniture industry is one of the most significant industries that maintains the constant development of economies worldwide. The demand for the production of wood-based boards has highly increased in residential and commercial construction across the world. In 2016, the worldwide demand for particleboard (PB) was 93 million m^3, and was 99 million m^3 for medium-density fiberboard (MDF; FAOSTAT 2018). Parallel to this, consumption of wood-based boards has rapidly reached high levels in recent years. These boards are commonly used in related sectors driven mostly by demand from building and furniture industries.

Many people are aware of the growing need for more sustainable products that protect the environment. However, not as many are as enlightened about the production process of these items and why an environmentally conscious production process is necessary. As people all over the world become more aware of the importance of protecting the environment and using green products, the demand for green products will become increasingly higher. Ecodesign considers environmental values in the manufacture and design process of products. This approach requires a totally new kind of design concept and environmental impact information on the used materials. This enhanced 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.

In the wood furniture industry, efforts have been focused on the study of different environmental properties of wood-based boards and their various finishes (Burdurlu 1994; Anex et al. 1998; USEPA 1998, 2001). Others investigated the importance of material selection for furniture production in terms of ecodesign aspects (Maria and Vidal 2004, Cinar

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2005, Gonzalez-Garcia et al. 2011). A few researchers focused on gas analysis methods for formaldehyde emission (FE; Kim and Kim 2005), and formaldehyde and volatile organic compound emissions at different manufacturing stages of wood-based boards (Brockmann et al. 1998, Zhongkai et al. 2012, Aghakhani et al. 2013, Khanjanzadeh et al. 2014, Cinar and Erdogdu in press). Several life-cycle assessment case studies of the production of wood-based boards have also been performed (Raffael 2006; Rivela et al. 2006, 2007; Benotto et al. 2009; González-García et al. 2009; Wilson 2010; Saravia-Cortez et al. 2013; Silva et al. 2013, 2014; Kouchaki-Penchah et al. 2016; Cinar 2018; Nakano et al. 2018). These studies provide useful background on the fact that material selection, production, and regional characteristics should be taken into account when evaluating wood-based boards.

One of the most commonly used chemical compounds in board manufacturing is urea-formaldehyde (UF) resin because of its high performance and low cost. UF resin is the second most commonly used resin in the wood-based board industry (Park and Kim 2008, Tang et al. 2009). However, the substantial disadvantage of UF resin is FE. The hydrolysis of weak chemical bonds during board production and lifetime stage causes indoor emissions resulting in human exposure to these chemicals. At concentrations between 0.1 and 0.5 parts per million (ppm), formaldehyde is detectable by smell; some sensitive individuals experience slight irritation in the eyes, nose, and throat (Salem and Böhm 2013). At levels from 0.5 to 1.0 ppm, formaldehyde produces irritation in the skin, eyes, nose, and throat. It is often associated with breathing difficulties and nosebleeds, and it is a suspected carcinogen (Pearson 1994). At concentrations above 1.0 ppm, exposure to formaldehyde produces extreme discomfort. It can also cause dermatitis on contact, which is associated with an allergic reaction to the chemicals (Isaksson et al. 1999).

With increased awareness of the human impact on the environment and the integration of environmental considerations into the furniture industry, sustainability is a crucial issue for wood-based board manufacturers and furniture designers. Consequently, the production stages of furniture have become a crucial issue in terms of being an environmentally friendly process using wood-based boards.

The Turkish wood-based board production industry is the third largest manufacturer, with a volume of 5.1 million m^3 for PBs and 6.8 million m^3 for MDF per year (TUIK 2017) and is the 13th biggest exporter of furniture in the world (TOBB 2017). It is possible that wood-based boards made into furniture before entering houses could have lower FE after the manufacturing process. Most environmental impacts can be effectively reduced by addressing them at the design stage.

However, no research has been carried out regarding the environmental aspect of Turkish furniture. This paper analyzed the effects of surface veneering (V), edge banding (E), and handle and hinge holing (H) on FEs for standard PBs and fiber density boards, which are typically used in the production of board furniture in Turkey.

Experimental

Methods

This study determined the effects of V, E, and H on FE for PBs and MDFs, as well as analyzed and compared the obtained emissions with the accepted limit values. Eco-Indicator 99 (Goedkoop and Spriensma 2000) was used to check the quantitative data representing FE, 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 adhesives.—Two types of wood-based boards with 18-mm thicknesses were analyzed: (1) standard PBs, produced according to TS EN 312 (2005), and (2) MDFs, produced according to TS EN 622-5 (2008). PBs and fiberboards were supplied by the main factories in Turkey. UF adhesive (W-Leim Plus 3000, code 230026592; Lillestrom, Norway) was used to press the surfaces with beech veneer with a thickness of 0.6 mm, and poly(vinyl) acetate (SAFRAN; code SD450, CE71; Kocaeli, Turkey), which is a nontoxic water-based glue, was used to cover the edges with 2-mm beech veneers, commonly used in the production of furniture in Turkey. The characteristics of boards and adhesives are given in Tables 1 and 2.

Preparation of samples.—Test samples were prepared from PBs and MDFs with a dimension of 210 by 280 by 0.18 cm in compliance with TS EN 326-1 (1999). Samples were cut into dimensions of 500 by 500 by 18 mm and weighed with a sensitive scale (Precia Gravimetrics AG 312-6200C; Dietikon, Switzerland), packed with transparent nylon for avoiding emission, and stored at a room temperature of 20°C ± 2°C and 60 ± 5 percent relative humidity to obtain a moisture value equal to the internal environmental conditions according to TS 2471 (2005).

A total of 30 test samples was prepared for the experiment, 15 PBs and 15 MDFs with a thickness of 18 mm. Five unprocessed control samples were also prepared. Test pattern consisted of five samples for PB + V, five for PB + V + E, five for PB + V + E + H, five for MDF + V, five for MDF + V + E, and five for MDF + V + E + H. With respect to the process, each sample was pressed by 0.6-mm beech veneer, edged with 2-mm beech veneers, and drilled for two handle holes with 18-mm depth and 5-mm diameter and two hinge holes with 15-mm depth and 30-mm diameter.

Implementation of the experiment

Climatic test cabinet, physical description.—Chamber tests were used to measure the FE 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 200 by 90 by 90 cm and internally 132 by 75 by 75 cm. The climatic test cabinet contained a slotted angle iron frame used to support PBs and fiberboards in a horizontal position parallel to the floor. A very small, nonsparking circulating fan located 1.20 m above the floor was attached to the angle

Table 1.—Characteristics of wood-based boards (medium-density fiberboard [MDF] and particleboard (PB).

Boards	Dimensions (mm) Thickness	Width	Depth	Density (g/cm^3)	Weight (g)
MDF	18	500	500	0.7433	3,620.58
PB	18	500	500	0.6433	2,867.15

Table 2.—Characteristics of adhesives.

Adhesives	Density (20°C; g/cm^3)	pH (20°C)	Viscosity (20°C; mPa)	Amount of adhesive application (g m^{-2})
Urea-formaldehyde	1.220	8.0	16.000 ± 3.000	180−200
Poly(vinyl) acetate	1.1	5.0	16.000 ± 3.000	80−100

iron frame near the fresh-air inlet. Additionally, an air conditioner (split unit) and an atomizing humidifier were situated on a shelf 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).

Board loading.—Samples of PBs and fiberboards were put inside the climatic test cabinet and were placed in the support rack in a horizontal position parallel to the floor. The samples were placed one by one in the climatic test cabinet TK 600 NUVE (2012) with 60 ± 5 percent relative humidity and at a temperature of 20°C ± 2°C for 60-, 120-, and 180-minute intervals. Subsequently, the concentrations of formaldehyde were measured by the Multi-RAE multiple gas analyzer over the test specimens prepared from boards in accordance with TS EN 717-1 (2006).

Measurement of FE.—Four types of measurements for FE were made; the first one was to measure the FE from the unprocessed samples as controls. The second measurement was carried out from the veneered samples without edge banding and handle and hinge holes, the third one from the veneered and edge covered samples, and the last one was obtained from the samples that were veneered, edged, and had drilled handle and hinge holes on the surfaces. For each process, the values were measured at 60-, 120-, and 180-minute intervals. The climatic test cabinet TK 600 NUVE was ventilated for 5 minutes, and the MultiRAE multiple gas analyzer was calibrated after each measurement.

Data evaluation.—To determine the effects of V, E, and H on FE, the results were compared with the results of the unprocessed samples (control) and the internationally accepted limit of 0.10 ppm of E1 (UNE EN 717-1 2006). 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. Analysis of variance (ANOVA) was used to determine whether the differences between the variables at the $P < 0.05$ level were statistically significant or not. Statistics and Microsoft Office Excel (SPSS) programs were used to evaluate the data.

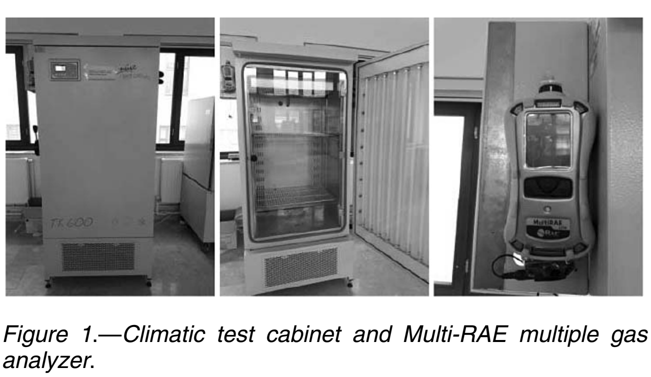


Figure 1.—Climatic test cabinet and Multi-RAE multiple gas analyzer.

Statistical evaluation.—The measurements of FE in the unprocessed and processed wood-based boards were accepted as the dependent variables, whereas the time and the types of processes were accepted as the independent variables. Afterward, to examine the effect of different processes (unprocessed PB/MDF + V, V + E, V + E + H) and time (60, 120, and 180 min) on the release of FE in the wood-based boards (PB and MDF), the techniques of one-way vANOVA were used. To compare the significant means of the variance in the analysis, the data are presented in graphic form.

Reliability test.—The reliability of the dependent variables, including evaluations about measurement values of the FE in the wood-based boards, was tested using Cronbach's alpha test.

Results and Discussion

Cronbach's coefficient estimates of internal consistency for the two scales were as follows: PB: 0.974; MDF: 0.997 (Table 3). Previously conducted studies (Cronbach 1951, McKinley et al. 1997, Kaplan and Saccuzzo 2009, Panayides 2013) have stated that the alpha reliability coefficients for all items (60-, 120-, and 180-min measurements) can be accepted as reliable when they are above 0.70. Therefore, this scale is considered to be highly reliable. The results of reliability analysis of the dependent variables are shown in Table 3.

The results of FE for wood-based boards as control samples (unprocessed), the processes of V, E, and H, and time for 60-, 120-, and 180-minute periods, including the distance of average values to E1 (0, 10 ppm), are given in Table 4. According to these results, the average values were found to be 1.1078 ppm for unprocessed PB and 0.2311 ppm for unprocessed MDF samples.

Regarding the different processes of boards used, a significant decrease from 93 to 80 percent for PBs and 72 to 22 percent for MDFs was detected in both board types in comparison with the control samples. According to Table 4, veneering and edge banding of boards (PB/MDF + V + E) significantly reduced the FE from 1.1078 ppm to 0.0733 ppm (93%) for PB and from 0.2311 ppm to 0.0667 ppm (72%) for MDF. Board veneering also decreased the FE from 1.1078 to 0.2267 (79%) for PB and from 0.2311 ppm to 0.1789 ppm (22%) for MDF. However, drilling holes for hinges and handles on the surfaces of boards, which were veneered and edge banded with beech veneers, slightly increased FE from 0.0733 ppm to 0.0789 ppm for PB and from 0.0644 ppm to 0.0789 ppm for MDF.

Table 3.—Results of reliability analysis of the dependent variables.

Boards	Time (min)	Item reliability	Scale reliability
Particleboard	60	0.985	0.974
	120	0.922	
	180	0.974	
Medium-density fiberboard	60	0.998	0.997
	120	0.993	
	180	0.997	

Table 4.—Formaldehyde emissions and distance to E1 (0.10 ppm).[a]

	Minutes				Reduction		Distance to E1 of μ	
Wood-based boards	60	120	180	Mean (μ)	ppm	%	ppm	%
PB (unprocessed)	0.9167	1.1167	1.2900	1.1078	1.1078	—	1.0078	1.0078
PB + V	0.2100	0.2267	0.2433	0.2267	−0.8811	−79.5386	0.1267	126.67
PB + V + E	0.0700	0.0700	0.0800	0.0733	−1.0344	−93.3801	−0.0267	−26.67
PB + V + E + H	0.0667	0.0800	0.0900	0.0789	−1.0289	−92.8786	−0.0211	−21.11
MDF (unprocessed)	0.2167	0.2333	0.2433	0.2311	0.2311	—	0.1311	131.11
MDF + V	0.1633	0.1800	0.1933	0.1789	−0.0522	−22.5962	0.0789	78.89
MDF + V + E	0.0600	0.0667	0.0667	0.0644	−0.1667	−72.1154	−0.0356	−35.56
MDF + V + E + H	0.0733	0.0800	0.0833	0.0789	−0.1522	−65.8654	−0.0211	−21.11

[a] ppm = parts per million; PB = particleboard; MDF = medium-density fiberboard; V = veneered; E = edge banding; H = hole (8-mm diameter for handles and 30-mm diameter for hinges. Two holes were made for each process).

Regarding distance to E1 (0.10 ppm), unprocessed control samples and samples of PB + V and MDF + V yielded results higher than the limits of E1. However, the veneered and edged samples and veneered, edged, and drilled samples of PB and MDF had less FE: almost 27 percent for PB + V + E, 21 percent for PB + V + E + H, 36 percent for MDF + V + E, and 21 percent for MDF + V + E + H. Figures 2 and 3 show FE for the different processes.

The differences between values of FE in the wood-based boards (PB and MDF) were tested with one-way ANOVA. According to the ANOVA results given in Table 5, the differences between the dependent variables (including the measurement values of the FE in the boards) were found to be statistically significant (at a level of $P < 0.001$) in terms of all the items related to the scale.

Figure 4 illustrates the differences in FE depending on the wood-based boards. For each dependent variable, according to each time interval, the PB board released more FEs than the MDF board. Consequently, the differences between the wood-based boards have a significant influence (at a level of $P < 0.001$) on the values of FE. This result may be due to the fact that the cellular structure of the fibers used in MDF is more degraded than the fibers used in PB. Thus, the FE bound to the cellulosic molecule chain forming the PB cell wall may be released more rapidly than MDF. Another aspect could be that the compaction of the mat of fiberboards to an average density higher than PBs allows for 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 FE than MDF. Additionally, several factors interfere with FE , as argued by Meyer and Boehme (1997), He and Zhang (2010), Pirayesh et al. (2012), Zhongkai et al. (2012), Costa et al. (2013), Cinar (2018), and Cinar and Erdogdu (in press). According to them, assuming the same parameters have been used for the board production, pressure, amount of adhesive, pressing time, raw materials, chips for PB, fibers for MDF, temperature, thickness, and time in service all play a significant role in FE. In addition to all of this, this study adds that the processes of V, E, and H on the surfaces of PBs or fiberboards for furniture production significantly affect FE, too.

The differences among the FEs according to the different processes (unprocessed, V, V + E, V + E + H) for PB were tested with one-way ANOVA. According to the ANOVA results given in Table 6, the differences among the dependent variables including the FE in different processes were found to be statistically significant (at a level of $P < 0.001$) in terms of all the items related to the scale.

Figure 5 illustrates the values of FE as the dependent variables that depend on the different processes used. For each dependent variable according to the time intervals, the unprocessed PB releases more FEs than the PB + V, PB + V + E, and PB + V + E + H boards. On the other hand, the results of PB + V + E and PB + V + E + H boards show a decrease in FE. Figure 5 shows the differences between the release of FEs from processed and unprocessed PBs.

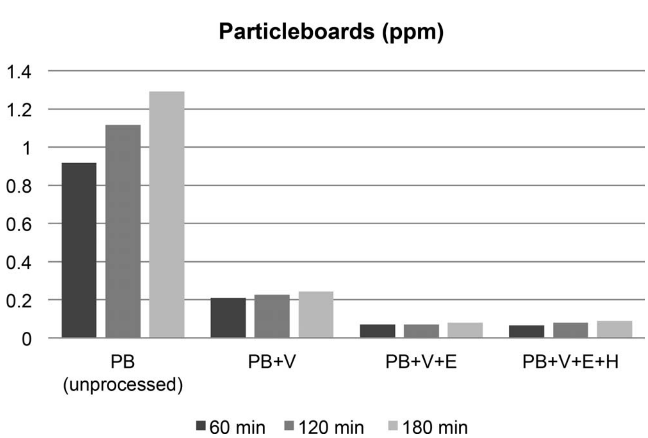


Figure 2.—Formaldehyde emission for different processes when using particleboard.

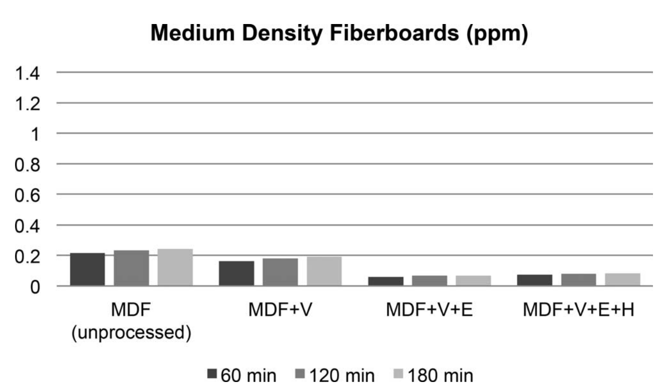


Figure 3.—Formaldehyde emission for different processes when using medium-density fiberboard.

Table 5.—Analysis of variance of the dependent variables (particleboard and medium-density fiberboard).

Board types	Sum of squares	df	Mean square	F	Significance[a]	Results
60-min						
Between groups	1.745	7	0.249	70.563	0.000*	$P < 0.001$
Within groups	0.057	16	0.004			
Total	1.802	23				
120-min						
Between groups	2.641	7	0.377	24.158	0.000*	$P < 0.001$
Within groups	0.250	16	0.016			
Total	2.891	23				
180-min						
Between groups	3.571	7	0.510	11.468	0.000*	$P < 0.001$
Within groups	0.712	16	0.044			
Total	4.283	23				

[a] * = Significant at $\alpha = 0.001$.

Table 6.—Analysis of variance of the dependent variables regarding the different processes.

Particleboard	Sum of squares	df	Mean square	F	Significance[a]	Results
60-min						
Between groups	1.484	3	0.495	73.931	0.000*	$P < 0.001$
Within groups	0.054	8	0.007			
Total	1.538	11				
120-min						
Between groups	2.256	3	0.752	24.525	0.000*	$P < 0.001$
Within groups	0.245	8	0.031			
Total	2.502	11				
180-min						
Between groups	3.037	3	1.012	11.449	0.000*	$P < 0.001$
Within groups	0.707	8	0.088			
Total	3.745	11				

[a] * = Significant at $\alpha = 0.001$.

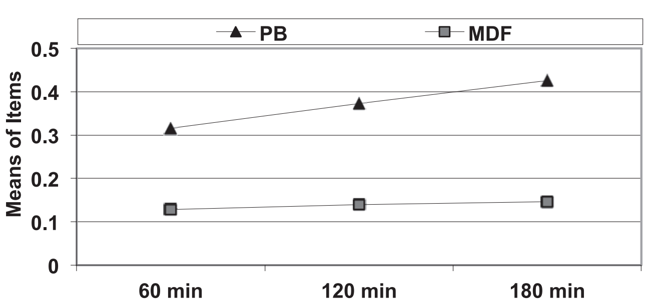
The differences in FE depending on the different processes used (unprocessed, V, V + E, V + E + H) for MDF were tested with one-way ANOVA. According to the ANOVA results given in Table 7, the differences between the FEs were found to be statistically significant (at a level of $P < 0.001$) in terms of all the items (with 60-, 120-, and 180-minute intervals) related to the scale.

Figure 6 illustrates the differences among the FEs depending on each process used. For each dependent variable, the unprocessed MDF releases more formaldehyde than the MDF + V, MDF + V + E, and MDF + V + E + H boards. On the other hand, the results of MDF + V + E and MDF + V + E + H boards are very close to each other. Consequently, the differences among the processes have a significant influence on the FE values.

According to the main results, the formaldehyde concentration of unprocessed PB and MDF were found to be higher than the limit of E1. On the contrary, V and E significantly reduced the formaldehyde concentration. However, H on the surfaces of boards that were veneered and edge banded with beech veneers slightly increased FE from 0.0733 ppm to 0.0789 ppm in PB and from 0.0644 ppm to 0.0789 ppm in MDF. This indicates that the processes of wood-based boards and the materials used for furniture production have significance before furniture enters interiors in terms of environmental aspects. With respect to the results of this study, the unprocessed samples of PB with the dimensions of 500 by 500 by 18 mm with a density of 0.7433 g/cm^3 release formaldehyde concentrations of 1.1078 ppm, and the MDF samples release 0.2311 ppm. However, after V and E, the formaldehyde concentrations crucially decrease. This suggests that surface-laminated and edge-banded wood boards could be another solution to reduce or control FE while producing furniture.

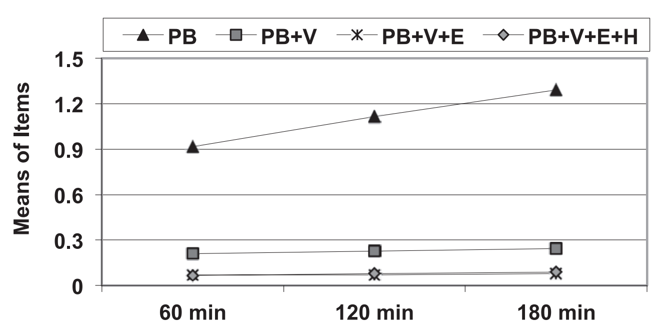
Parallel to these research findings, the total sum of FE can be calculated as 8.7 million ppm for Turkish PB production in reference to 1.1078 ppm that was obtained from the unprocessed samples of PB for the study. For Turkish MDF production, 2.4 million ppm FE was calculated in reference to 0.2311 ppm from the samples of unprocessed MDF.

According to the findings in this research, after V and E of PB and MDF, the reduction was 93 percent for PB and 72 percent for MDF. The total sum of formaldehyde concentration for the Turkish wood-based board production could be reduced from 8.7 million ppm to 0.609 million ppm for PB and from 2.4 million ppm to 0.672 million ppm for MDF in the case of surface and edge covering. According to the results of the study, the formaldehyde concentrations of PBs and fiberboards were found to be significantly higher than the internationally accepted levels. The need for ways to reduce FE to



Note: PB: Particleboard, MDF: Medium Density Fiberboard

Figure 4.—Effect of wood-based board types (particleboard and medium-density fiberboard) on formaldehyde emission.



Notes: PB: Particleboard, V:Veneered., E: Edge banding, H: Hole

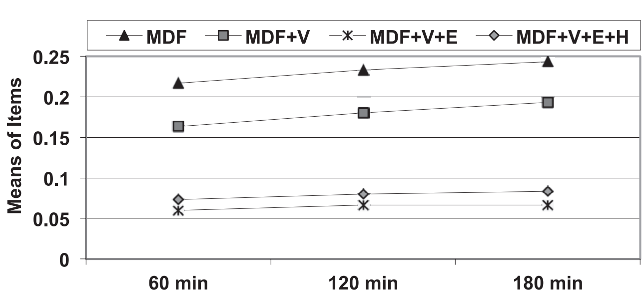
Figure 5.—Effect of the different processes on formaldehyde emission (particleboard).

Table 7.—Analysis of variance of the dependent variables regarding the different process (medium-density fiberboard).

Medium-density fiberboard	Sum of squares	df	Mean square	F	Significance[a]	Results
60-min						
Between groups	0.050	3	0.017	44.593	0.000*	$P < 0.001$
Within groups	0.003	8	0.000			
Total	0.053	11				
120-min						
Between groups	0.058	3	0.019	34.039	0.000*	$P < 0.001$
Within groups	0.005	8	0.001			
Total	0.062	11				
180-min						
Between groups	0.066	3	0.022	41.125	0.000*	$P < 0.001$
Within groups	0.004	8	0.001			
Total	0.070	11				

[a] * = Significant at $\alpha = 0.001$.

accepted levels is a great concern for the Turkish furniture industry. The emission of formaldehyde in wood-based products can be minimized during the manufacturing process or by posttreatment and surface treatment of the boards. Several arguments could be made on the results of this research. The main argument could be for the reduction of FE while boards are produced. For example, a significant reduction of FE could be formaldehyde scavengers: sodium metabisulfite and ammonium bisulfate. The tested scavengers showed distinct performances under the different emissions testing conditions, which were interpreted in terms of the stability of the chemical compounds formed upon formaldehyde capture (Nemli and Colakoglu 2005, Buyuksari et al. 2009, Pirayesh et al. 2012, Costa et al. 2013). Another argument might be that panels could be produced according to commonly accepted dimensions for furniture panels that are veneered or laminated and edge banded before introducing them to the furniture industry, instead of producing boards with the dimensions of 210 by 280 or 180 by 366 cm. Parallel to the development and demand increase in Europe, surface-covered and edge-banded wood panel production becomes an industry within the Turkish forest products industry by being open to development and investment (Dilik et al. 2010). This might have a positive impact on Turkish furniture trade in the global market.



Notes: MDF: Medium Density Fiberboard, V: Veneered., E: Edge banding, H: Hole

Figure 6.—Effect of the different processes on measurements (medium-density fiberboard).

Conclusions

The main results in this study indicate that V, E, and H for standard PBs and fiber density boards significantly affect FE:

1. Regarding the different processes of boards, a significant decrease from 93 to 80 percent for PBs and 72 to 22 percent for MDFs was detected in both board types in comparison with the control samples.
2. Veneering and edge banding of boards (PB/MDF + V + E) significantly reduced the FE from 1.1078 ppm to 0.0733 ppm (93%) for PB and from 0.2311 ppm to 0.0667 ppm (72%) for MDF.
3. Board veneering also decreased FE from 1.1078 to 0.2267 (79%) for PB and from 0.2311 ppm to 0.1789 ppm (22%) for MDF.
4. Drilling holes for hinges and handles on the surfaces of boards that were veneered and edge banded with beech veneers slightly increased FE from 0.0733 to 0.0789 ppm for PB and from 0.0644 to 0.0789 ppm for MDF.
5. Regarding distance to E1 (0.10 ppm), unprocessed control samples and samples of PB + V and MDF + V yielded results higher than the limits of E1. However, the V + E samples and V + E + H samples of PB and MDF had less FE, respectively: almost 27 percent for PB + V + E, 21 percent for PB + V + E + H, 36 percent for MDF + V + E, and 21 percent for MDF + V + E + H.

In light of these conclusions, formaldehyde concentration of PBs and fiberboards were found to be significantly higher than the internationally accepted levels. The need for ways to reduce the FE to accepted levels is a great concern for the Turkish furniture industry. The reduction of formaldehyde concentration and processes of wood-based boards and furniture production are significantly important in terms of environmental aspects. Considering the number of wood-based boards and complementary elements that go into the present furniture industry design projects, designers should be aware of the consequences of their work and must begin to consider their impact on the environment.

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