Formaldehyde Emission Pattern of Melamine Impregnated Paper Decorated Medium Density Fiberboard and its Furniture Products

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Melamine-impregnated paper decorated medium-density fiberboard (MIP-MDF) is the main board used for wooden furniture materials in China, and the formaldehyde released from the board and furniture products is harmful to human beings and is a wide concern. This paper aimed to pay attention to the formaldehyde emission of MIP-MDF and its furniture products. This study utilized a 1 m^3 climatic chamber to measure the formaldehyde emission of MIP-MDF and nightstand made of MIP-MDF in relation to the time and load factors. According to the results, in the 2 to 24 h stage, the emission of formaldehyde in the nightstand made of MIP-MDF materials changed significantly, and the overall trend showed a changing trend of first increasing and then declining. The formaldehyde emission of MIP-MDF stabilized after 40 h, while the formaldehyde emission of the nightstand stabilized after 60 h. As time passed, the formaldehyde emission changes of MIP-MDF and nightstand were almost the same. The formaldehyde emission of MIP-MDF and nightstand has a specific positive correlation with the carrying load. With increased carrying loads, the formaldehyde emission tends to increase, but the degree of influence gradually decreases with the addition of the carrying loads.

DOI: 10.15376/biores.18.4.8601-8613

Keywords: MIP-MDF; Nightstand; Formaldehyde; Time; Carrying load

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INTRODUCTION

Recent studies have shown that many organic pollutants are found at much higher levels indoors than outdoors. Thus, indoor organic pollutants have been widely discussed because of their harmful effects on health (He *et al*. 2019). Volatile organic compounds (VOCs) emitted by furniture seriously affect indoor air quality (Coloma-Jiménez *et al*. 2022). Studies since 2010 have found that a certain amount of formaldehyde inhalation can cause functional lesions in the nose, skin, liver, lungs, and other organs, and this can even affect the abnormal mutation of genetic material in the nucleus of mammals, resulting in hereditary diseases (Xiong *et al*. 2012). The harmful effect of the level of formaldehyde inhalation to human body in the environment is closely related to its concentration, and the threshold of formaldehyde concentration that can cause individual death in a space is 30 mg/m^3 (Xu *et al*. 2022; Khoshakhlagh *et al*. 2023). Studies show that about 87% of human time is spent indoors, so it is imperative to control indoor formaldehyde content (Kim and Kim 2005a).

Previous studies have mainly focused on emissions from building materials and vehicle cabin materials, but have seldom mentioned interior furniture, especially the use of boards for nightstands. Inside interior furniture boards such as melamine-impregnated paper decorated medium-density fiberboard (MIP-MDF), is a wood-based board with excellent performance (Wang *et al*. 2022a); it is widely used in enterprise furniture because of its excellent mechanical properties (Ümit *et al*. 2012). However, the chemical pollutants emitted by composite wood boards lead to increasingly severe indoor air pollution (Tang *et al*. 2009; Salthammer *et al*. 2010; Shalbafan *et al*. 2016; Trianoski *et al*. 2017).

The formaldehyde emission of MIP-MDF is not a direct accumulation of the material and may be affected by structural or environmental factors (Wang *et al*. 2022b). The researchers note that formaldehyde emission behavior is a complex process, and many scholars have conducted practical analysis on the formaldehyde emission process of artificial boards, including multidimensional models simulating formaldehyde emission behavior (Xu and Zhang 2003; Zhang *et al*. 2021; Zhang *et al*. 2022). The correlation between the formaldehyde content in adhesives and formaldehyde-specific emission rate from wood-based boards (He *et al*. 2012), using a small chamber method to determine the formaldehyde emission factor and the formaldehyde emission factor to find ways to reduce the impact of formaldehyde emission on using wood-based boards has been investigated (Shalbafan *et al.* 2020; Zhou *et al*. 2020). These studies provide a theoretical basis for reducing formaldehyde's harm when using wood-based boards; these studies show that the formaldehyde emission sources of wood-based boards can be mainly divided into three categories: the first type is the formaldehyde released by the lignin hydrolysis of wood itself and the adhesive used in the processing process, which belongs to the chemical combination with the board; the second type is formaldehyde adsorbed by wood cellulose and adhesives in the manufacturing process, which belongs to physical adsorption; the third type is formaldehyde free between adhesives or wood fibers, which belongs to free formaldehyde (Kim and Kim 2005b; Feng *et al*. 2022).

Both MIP-MDF and the adhesives used in its production contain a certain amount of formaldehyde. Various countries have successively issued several testing programs for formaldehyde detection of wood-based boards (Yang *et al*. 2009). Among them, the climate box method has become a widely used measurement method because of its advantages of high accuracy and low risk (Hemmilä *et al*. 2019). Domestic and international studies have shown that it is necessary to study the relationship between MIP-MDF and the formaldehyde emission of furniture (Seyedeh *et al*. 2021). According to the research, under the theoretical state, when the formaldehyde release quantity tends to be stable, different carrying loads are one of the critical factors affecting the formaldehyde release quantity (Kim and Tanabe 2014). Due to the different release surface areas or carrying load, the amount of formaldehyde released by the furniture of the same material will change (Wang *et al*. 2020; Khorramabadi *et al*. 2023).

This research used a 1 m^3 climate box to simulate the real use environment, and the main research of this paper was the formaldehyde emission of MIP-MDF, and nightstand made of MIP-MDF in relation to the time and load factors. To avoid experimental errors caused by material uncertainties or material uncertainties in the furniture, a nightstand made from the same batch of the same board was selected; thus, the MIP-MDF and nightstand made of MIP-MDF were used.

EXPERIMENTAL

Test Materials and Equipment

The test material selected was melamine-impregnated paper decorated medium-density fiberboards (MIP-MDFs) with 18 mm thickness, moisture content (7.4%), specific gravity measurement on all test pieces (mean of 710 kg/m^3), and the glue used for MIP-MDF was melamine resin adhesive. Melamine-urea-formaldehyde impregnated Bond Paper used by MIP-MDF has a gluing content of 142%, a volatilization content of 6.5%, and a recurring degree of 63.7%. The sample dimensions were 500 mm × 500 mm for MIP-MDFs (Fig. 1) and 550 mm × 390 mm × 570 mm for the nightstands (Fig. 2) made of MIP-MDFs. The samples were provided by the Guangdong Xinhongyang Science and Technology Co., Ltd. (Heshan, Guangdong, China). The experiments were started as soon as the samples arrived. Experimental operation requirements according to national standards GB/T 17657 (2022) and GB/T 15516 (1995), the specific experimental apparatus and equipment are shown in Table 1, and the reagents used are shown in Table 2.

Table 1. Experimental Facilities

Instrument	Product Model	Manufacturer (of a product)
1.0 m³ VOC environment experiment box	HD-F803-4	Dongguan Haida Instrument Co.
Spectrophotometer	723PC Visible Spectrophotometer	
Programmable constant Temperature and humidity testing machine	HD-E702-1000B40	
Digital display constant temperature water bath	HH-2	Changzhou Yuexin Instrument Manufacturing Co.
Gas flow meter	/	Yangzhou Sell Lauter Experimental Instrument Co.
Volumetric cylinder	/	
Glue-tipped burette	/	
Volumetric flask	/	
Electronic balance	/	
Sampling tube	/	
Vial	/	
Cuvette	/	
Conical flask	/	
Triangle Beaker with Stopper	/	
Jars	/	

Fig. 1. MIP-MD

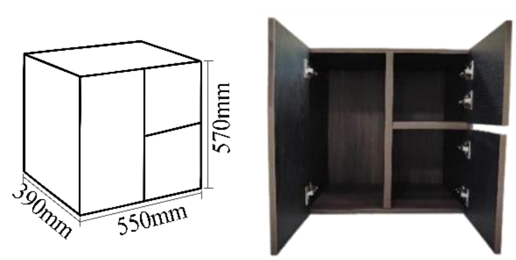

Fig. 2. MIP-MDF nightstand

Table 2. Experimental Reagents

Reagent	Chemical Formula	Purity Standard
Formaldehyde (HCHO)	CH_2O	Analytical purity
Acetylacetone	$C_5H_8O_2$	Analytical purity
Ammonium acetate	CH_3COONH_4	Analytical purity
Iodine (chemistry)	I_2	Analytical purity
Caustic soda	NaOH	Analytical purity
Sulfuric acid	H_2SO_4	Analytical purity
Sodium hyposulfide	Na_2SO_4	Analytical purity

Experimental Design

In this paper, the experimental study refers to the formaldehyde emission determination. A 1.0 m^3 climatic chamber method for testing the formaldehyde emission pattern of MIP-MDF and its nightstand was used to study the relationship between the formaldehyde emission time and carrying loads of MIP-MDF and its nightstand. Three sets of experiments were designed following the national standard GB/T 17657 (2022).

(a) The MIP-MDFs with the size of 500 mm × 500 mm were used to investigate the time pattern of the formaldehyde emission pattern. Two boards were set up in each group, and five replicated experiments were conducted.

(b) The cumulative size of the MIP-MDFs was 500 mm × 500 mm. The boards were composed of three different carrying loads: 1.393 m^2, 2.283 m^2, and 3.340 m^2 to investigate the effect of different carrying loads on the formaldehyde emission pattern of the boards. A total of five repetitions of the experiment were conducted.

(c) Three states (closed, half-opened, and fully opened) were evaluated for the MIP-MDF nightstands made of the same batch of materials in the actual use process. The carrying loads of the three states were calculated as 3.340 m^2/m^3, 2.283 m^2/m^3, and 1.393 m^2/m^3, respectively, to explore the influence of different carrying loads on the formaldehyde emission pattern of nightstand. Each group was set up with two nightstands and three different carrying loads, and the experiment was repeated three times.

Experimental Methods

(1) Group-a experiment used samples of dimensions 500 mm × 500 mm MIP-MDFs; Group-b experiments were conducted with 500 mm × 500 mm MIP-MDFs cumulative treatment to achieve three different carrying loads: 1.393 m^2, 2.283 m^2, and 3.340 m^2; Group-c experiments took the same batch of materials of size 550 mm × 390 mm × 570 mm MIP-MDF nightstands, divided into three different states (closed, half-open, and full-open), after measurement, the carrying loads of the three different states is respectively 1.393 m^2/m^3, 2.283 m^2/m^3, and 3.340 m^2/m^3. Concerning the provisions of GB/T17657 (2022), the constant temperature and humidity box was set to temperature (23±1)°C, relative humidity (50±5)%, air exchange rate 1.0 times/h, and the specimens underwent equilibrium treatment (15±2) d.

(2) After the equilibrium treatment, to control the surface area where MIP-MDF releases formaldehyde, aluminum tape without formaldehyde was used to seal the edge of the boards. The control surface area of each board was 0.5 m^2, vertically placed in the center of the climate chamber. The distance between the boards was 200 mm at maximum. The climate chamber’s conditions were set to 23 °C, 50% RH, and air exchange rate of 1.0 times/h, and the process is shown in Fig. 3.

(3) The sample data were recorded at 2 h, 4 h, 6 h, 8 h, 10 h, 12 h, 24 h, 36 h, 48 h, 60 h, 72 h, 84 h, 96 h, 108 h, 120 h, and 132 h.

(4) The formaldehyde emission test was conducted on the samples according to acetylacetone spectrophotometry. The experimental design process and experimental steps refer to the standard GB/T17657 (2013) (extraction valve pumping capacity was 2 L/min, extraction experiment time was 60 min (Fig. 4). Approximately 10 mL of distilled water and 10 mL of absorption solution from each of the two absorbers were used. A mixture of 10 mL acetyl acetone solution and 10 mL ammonium acetate solution were taken in each container, and labelled as mixed samples as A_0, A_1, and A_2, respectively. The samples were placed in a constant temperature tank at (60 ± 1) °C for 10 min and cooled to room temperature away from light. The above solution was inverted into a 10-mL colorimetric dish, the spectrophotometer's wavelength was adjusted to 412 nm for comparison experiment, and the absorptions were recorded as A_0, A_1, and A_2, successively. The experiment was repeated twice in each group.

(5) The values were substituted into Eq. 1 to calculate the formaldehyde emission of MIP-MDF and its nightstand, where A_0 is A_b, and the mean values of A_1 and A_2 are substituted into A_S,

$$C = \frac{f \times (A_s - A_b) \times V_{sol}}{1000 V_{air}} \quad (1)$$

where C is the formaldehyde emission, mg/m^3; f stands for slope of the standard curve, and its unit is mg/L; A_s stands for absorbance of the absorbent solution; A_b stands for absorbance in distilled water; V_{sol} stands for absorbent volume (mL); V_{air} stands for volume of air extracted, and its unit is m^3.

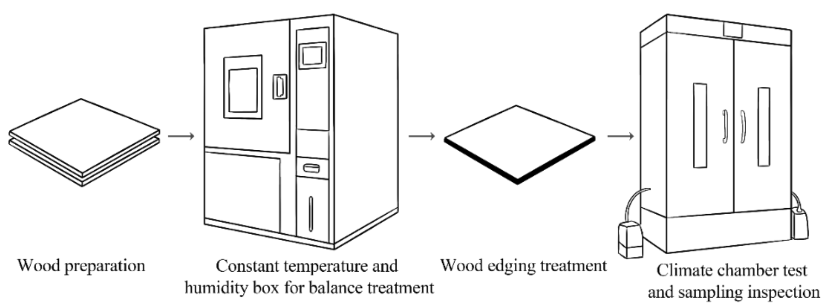

Fig. 3. Simple flow chart of sample testing with 1 m^3 climatic chamber method

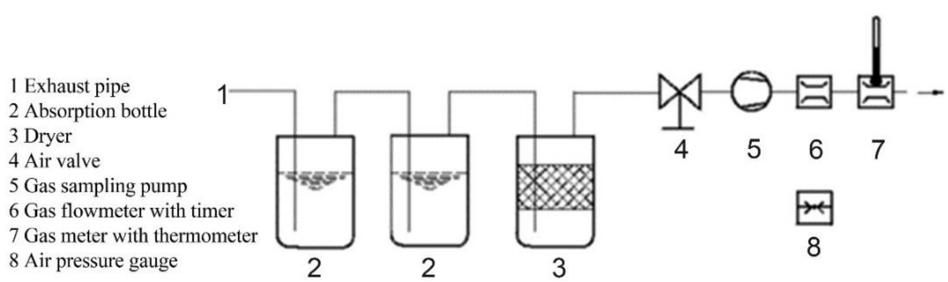

Fig. 4. Formaldehyde test experimental diagram with acetylacetone spectrophotometry

RESULTS AND ANALYSIS

Formaldehyde Emission Pattern of the MIP-MDF

The formaldehyde emission of MIP-MDF showed a general trend of first rising and then falling and reached the highest point in 20 h. The formaldehyde emission was 0.116 mg/m^3 when it got to the highest point, which was 113.46% higher than the initial concentration of 0.054 mg/m^3. It gradually declined after 8 h, and it stabilized after 40 h. The stabilized formaldehyde emission was 0.039 mg/m^3, which met the requirements of formaldehyde emission standards for the wood-based board, and it decreased by 29.4% relative to the initial concentration 0.0385mg/m^3, which meets the formaldehyde emission standard requirements for wood-based boards, close to the initial concentration decreased by 29.4%. The experimental data are shown in Table 3, and the trend chart of the formaldehyde emission process is shown in Fig. 5.

Table 3. MIP-MDF Formaldehyde Emission Data at Each Time Node

Time(h)	2	4	6	8	10	12	24	36
Group1 (mg/m^3)	0.056	0.086	0.099	0.110	0.099	0.070	0.052	0.043
Group2 (mg/m^3)	0.052	0.085	0.093	0.119	0.103	0.068	0.053	0.039
Group3 (mg/m^3)	0.057	0.084	0.100	0.118	0.096	0.071	0.054	0.045
Group4 (mg/m^3)	0.053	0.078	0.099	0.120	0.099	0.070	0.051	0.043
Group5 (mg/m^3)	0.057	0.079	0.094	0.113	0.098	0.066	0.050	0.040
AVG (mg/m^3)	0.055	0.082	0.097	0.116	0.099	0.069	0.052	0.042
SD	0.002	0.003	0.003	0.004	0.002	0.002	0.001	0.002

Time(h)	48	60	72	84	96	108	120	132
Group1 (mg/m^3)	0.050	0.045	0.044	0.049	0.044	0.039	0.039	0.038
Group2 (mg/m^3)	0.051	0.048	0.041	0.045	0.046	0.039	0.040	0.037
Group3 (mg/m^3)	0.048	0.044	0.045	0.047	0.044	0.041	0.041	0.035
Group4 (mg/m^3)	0.050	0.046	0.043	0.048	0.048	0.042	0.037	0.039
Group5 (mg/m^3)	0.046	0.047	0.042	0.046	0.043	0.039	0.038	0.063
AVG (mg/m^3)	0.049	0.046	0.043	0.047	0.045	0.040	0.039	0.037
SD	0.002	0.001	0.001	0.001	0.002	0.001	0.001	0.001

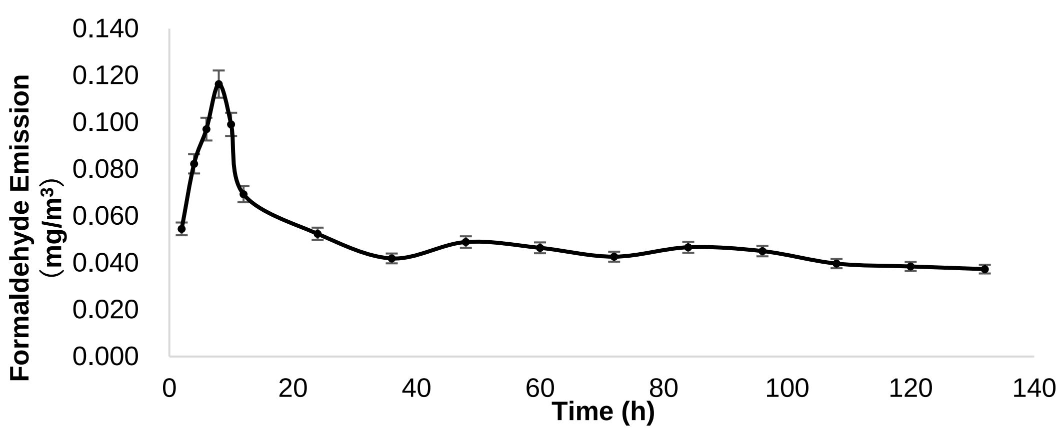

Fig. 5. MIP-MDF formaldehyde emission process trend diagram

Formaldehyde Emission Pattern of the MIP-MDF Nightstands

The results showed that the formaldehyde emission of MIP-MDF nightstands initially increased and then gradually decreased. The initial emission value was 0.096

mg/m^3. The time node of 8 h reached the highest, and the formaldehyde emission rate was 0.163 mg/m^3. It gradually decreased after 8 h and stabilized after 60 h, and the average formaldehyde emission after stabilization was 0.088 mg/m^3. Through the data collection of 132 h, the formaldehyde emission in the stage of 2 to 20 h, the formaldehyde emission varied a lot, and the overall trend was first increasing and then declining. At the 60 to 132 h stage, the formaldehyde emission was stable. The experimental data are shown in Table 4, and the trend chart of the formaldehyde emission process is shown in Fig. 6.

Table 4. MIP-MDF Nightstands Formaldehyde Emission Data at Each Time

Time(h)	2	4	6	8	10	12	24	36
Group1 (mg/m^3)	0.099	0.120	0.125	0.169	0.109	0.073	0.081	0.089
Group2 (mg/m^3)	0.094	0.116	0.132	0.163	0.109	0.070	0.082	0.090
Group3 (mg/m^3)	0.095	0.114	0.135	0.157	0.103	0.070	0.079	0.091
AVG (mg/m^3)	0.096	0.117	0.130	0.0163	0.107	0.071	0.080	0.090
SD	0.002	0.003	0.004	0.005	0.003	0.001	0.002	0.001

Time(h)	48	60	72	84	96	108	120	132
Group1 (mg/m^3)	0.072	0.082	0.085	0.085	0.090	0.087	0.085	0.086
Group2 (mg/m^3)	0.070	0.078	0.091	0.085	0.091	0.088	0.085	0.087
Group3 (mg/m^3)	0.070	0.081	0.087	0.088	0.089	0.089	0.088	0.091
AVG (mg/m^3)	0.071	0.080	0.088	0.086	0.090	0.088	0.086	0.088
SD	0.001	0.002	0.003	0.001	0.001	0.002	0.001	0.002

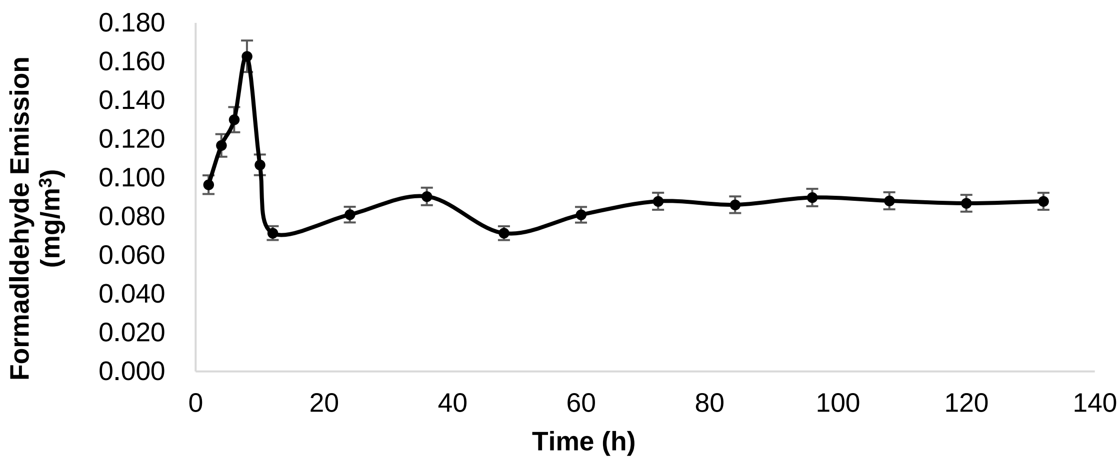

Fig. 6. MIP-MDF nightstands formaldehyde emission process trend diagram

Influence of Carrying Load on Formaldehyde Emission Per Unit of MIP-MDF and Nightstands

To explore the effect of the carrying load on the formaldehyde emission per unit of the MIP-MDF and nightstand, the stable value of formaldehyde emission from 40 to 132 h was taken for the MIP-MDF, and the stable value of formaldehyde emission from 60 to 132 h was taken for the nightstand. The formaldehyde emission of MIP-MDF and nightstand with different carrying load and its unit formaldehyde emission comparison of specific data are shown in Table 5, with the increase of carrying load in the climate chamber, the formaldehyde emission of MIP-MDF and nightstand samples in the steady state generally showed an increasing trend. However, the formaldehyde emission per unit area showed a decreasing trend. With the increase of MIP-MDF and nightstand carrying load, formaldehyde emission tends to grow, but with the increase of the carrying load, its growth tends to slow down.

The relationship between the formaldehyde emission from the MIP-MDF and the formaldehyde emission from the nightstand is shown in Fig. 7. It can be seen from the figure that there is a specific linear relationship between the carrying load and the formaldehyde emission from the MIP-MDF and before the carrying load and the formaldehyde emission from the nightstand. The linear relationship between the carrying load and the formaldehyde emission from the MIP-MDF is fitted with the equation $y = 0.029x - 0.004$; where $R^2 = 0.997$; the linear relationship between the carrying load and the formaldehyde emission from the nightstand is fitted with the equation is $y = 0.024x - 0.008$, where $R^2 = 0.999$, as observed in the graph and the fitting equation of the linear relationship, the slope of the linear equation between the carrying load and the formaldehyde emission of the board is high.

The relationship between formaldehyde emission per unit of MIP-MDF and formaldehyde emission per unit of nightstand is shown in Fig. 7. The figure shows that there was a particular linear relationship between carrying load and formaldehyde emission per unit of MIP-MDF, carrying load, and formaldehyde emission per unit of nightstand. The linear relationship between carrying load and formaldehyde emission per unit of MIP-MDF was fitted as $y = -0.003x + 0.0443$; $R^2 = 0.871$; the linear relationship between carrying load and formaldehyde emission per unit of nightstand was fitted as $y = -0.003x + 0.0358$; $R^2 = 0.987$. It can be seen from the graph and the linear relationship fitting formula that with the increase of the carrying load, the formaldehyde emission per unit of the board and the formaldehyde emission per unit of the nightstand decreased by a similar magnitude. The MIP-MDF board was fully exposed during the experiment, but the nightstands made of the board had an internal space, and the air convection was not smooth in the internal space, resulting in different formaldehyde release of the same carrying capacity.

Table 5. Formaldehyde Emission Corresponding to MIP-MDF and Nightstand Samples

Carrying Load (m^2/m^3)	Formaldehyde Emission (mg/m^3)		Formaldehyde Emission per unit (mg/m^3-m^2)	
	MIP-MDF	Nightstand	MIP-MDF	Nightstand
1.394	0.054 (0.33)	0.040(0.35)	0.039	0.031
2.283	0.080 (0.40)	0.063(0.23)	0.034	0.028
3.340	0.111 (0.48)	0.088 (0.28)	0.033	0.026

Note: Value in parentheses are coefficients of standard variation in percentage.

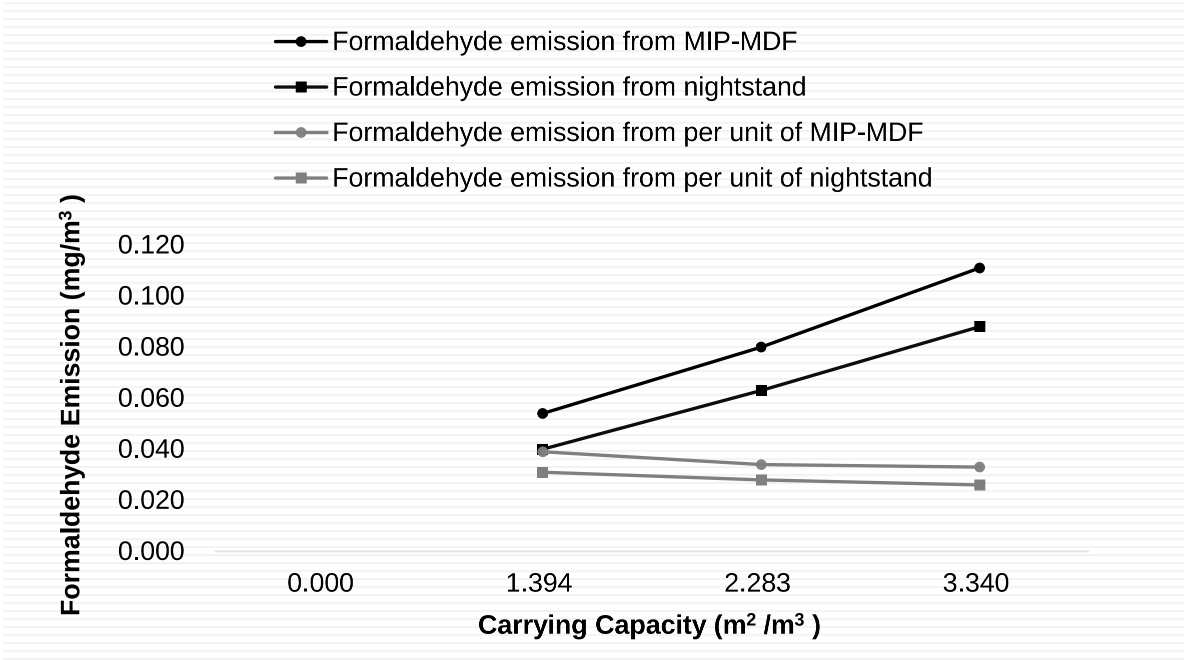

Fig. 7. Relationship between formaldehyde emission from MIP-MDF and nightstand, and relationship between formaldehyde emission from per unit of MIP-MDF and formaldehyde emission per unit of nightstand

The Relationship Between Formaldehyde Emission of MIP-MDF and Nightstand

Through the above analysis, it can be seen that the formaldehyde emission of MIP-MDF and its nightstand had a more apparent positive correlation with its carrying load, and the trend of change was similar. The three sets of data could be fitted to produce a more apparent linear relationship, which can be used to indicate the relationship between formaldehyde emission of the MIP-MDF and the nightstand in the same measurement conditions. The specific data are shown in Table 6, and the specific formaldehyde emission relationship is shown in Fig. 8.

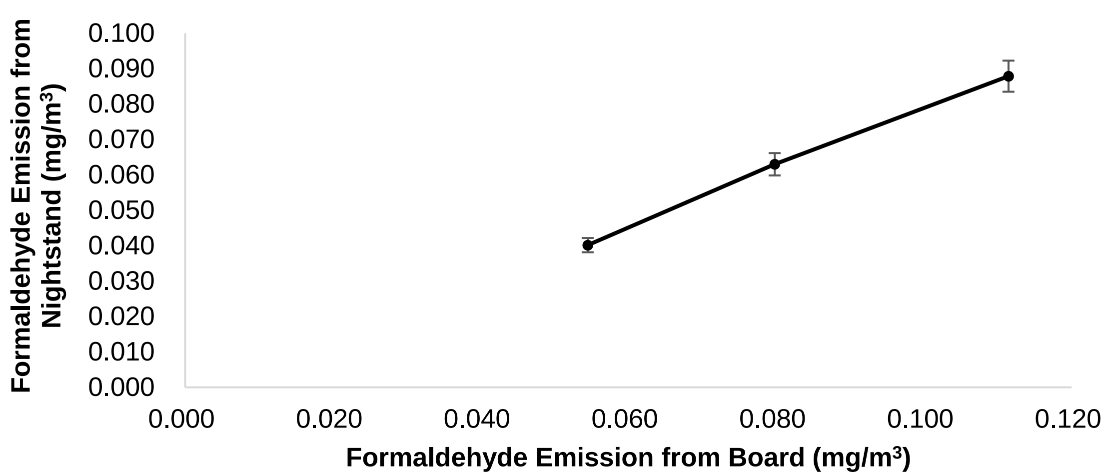

Fig. 8. Relationship between formaldehyde emission per unit of MIP-MDF and its nightstand

Table 6. Formaldehyde Emission of MIP-MDF and Furniture

Group No.	Carrying Load (m^2/m^3)	Formaldehyde Emission of Board (mg/m^3)	Formaldehyde Emission from Nightstand (mg/m^3)
1	1.394	0.054	0.040
2	2.283	0.080	0.063
3	3.340	0.111	0.088

Note: Retain three valid decimal places

From Fig. 8, there was a particular linear relationship between the two, and the fitting equation was $y = 0.836x-0.005$; $R^2 = 0.998$, where the independent variable x is the formaldehyde emission from MIP-MDF, and y is the formaldehyde emission from MIP-MDF furniture, and the relationship coefficient $K = 0.8356$.

CONCLUSIONS

The experiments carried out in this work showed that with the same kind of nightstand, formaldehyde emissions will be affected by different carrying loads and changes. For the manufacture of decorated furniture with different carrying loads, the following conclusions can be drawn. These are based on the formaldehyde emission relationship, as well as the tabulated results:

1. The formaldehyde emission rule as a function of time when making predictions for medium density fiberboard with decorated paper lamination and its corresponding nightstand is almost identical. However, the stabilization time of the nightstand is more delayed, which may be related to the nightstand having a particular spatial structure and incomplete formaldehyde emission in the early stage.
2. For the nightstand using the same amount of board, the MIP-MDF nightstand formaldehyde emissions, and exposed surface area, there is a specific positive correlation. With the increase in carrying loads, the formaldehyde emission of furniture tends to increase, but with the rise in the release area, the degree of influence decreases gradually.
3. The final content reached after formaldehyde emission stabilization of the wood-based board materials selected in this paper was more significantly affected by the carrying load. A specific linear relationship exists between formaldehyde emission from MIP-MDF and its nightstand in the control experiments set up with different carrying loads, with a fitting formula of $y = 0.8356x - 0.0048$ and $R^2 = 0.998$.

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Article submitted: September 11, 2023; Peer review completed: October 7, 2023; Revised version received and accepted: October 18, 2023; Published: October 30, 2023.
DOI: 10.15376/biores.18.4.8601-8613