Advances in reducing formaldehyde emission from wood-based panels

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Abstract Formaldehyde emission is one of important issues in the wood-based panel industry. Recently, many countries tighten regulations on formaldehyde emissions emitted from wood-based panels due to harmful effect of formaldehyde on the humans. Urea-formaldehyde (UF) resin is the most used synthetic resin as binder in the production of wood-based panels for indoor applications. Disadvantages of UF resin are the formaldehyde emission and low water resistance. UF resin is classified according to the formaldehyde releases, Super E0, E0, E1, and E2, which are from lowest to highest, respectively. Many researchers have focused on the synthetic and natural formaldehyde scavengers for decreasing the formaldehyde emission from the wood-based panels. In this study, recent studies for reducing formaldehyde emission from wood-based boards were reviewed.
KEYWORDS: FORMALDEHYDE EMISSION, WOOD-BASED PANEL, UREA-FORMALDEHYDE, SCAVENGERS

1. *Introduction*

Formaldehyde is considered a health hazard, hence wood-based panels must be within the limits imposed by the strictest regulations in terms of formaldehyde release. Formaldehyde is the first member in the homologous series of aldehyde. It is the colorless gas with sharp scent that irritates the mucous membrane of the nose and throat. Wood industry has already reduced formaldehyde emission of raw panels (uncoated) by more than 80% over the past twenty years to minimize indoor air contaminants [1]. Urea-formaldehyde (UF) is the most used synthetic resin in the production of wood-based panels used indoor applications due to its significant advantages such as low-cost, easy supply, transparent color, lower hot pressing temperature, and duration, good mechanical properties of the board in dry conditions. Despite of the mentioned significant advantages, UF resin has two main drawbacks, formaldehyde emission from the wood-based panel, and low water resistance in humid environment. UF resin is mainly responsible for the formaldehyde emission from wood-based panels [2]. For indoor and furniture applications, a lower formaldehyde content is required, if classified under the E1 emission class.

According to International Composite Board Emission Standards (ICBES), there are 3 European formaldehyde classes, namely, E0, E1 and E2. This classification is based on the measurement of formaldehyde emission levels. For instance, E0 is classified as having less than 3 milligrams of formaldehyde emission of every 100 grams of wood based panel. E1 and E2, conversely, are classified as having 9 and 30 grams of formaldehyde per 100 grams of the panel, respectively. All around the world variable certification and labeling schemes are there for such products that can be explicit to formaldehyde release, like that of Californian Air Resources Board (CARB).

Table 1. *CARB phase 2 formaldehyde limits [3].*

Product	Allowable Formaldehyde Concentrations
Hardwood plywood	0.05 ppm
Medium density fiberboard	0.11 ppm
Thin medium density fiberboard	0.13 ppm
Particleboard	0.09 ppm

Parameters affecting formaldehyde emission from particleboard produced using UF resin [4] :

1. Tree species and wood acidity
2. F/U molar ratio of UF resin
3. The amount of resin used
4. Density and thickness of particleboard
5. Hardener type and content
6. Free-formaldehyde content in the UF resin
7. Moisture content of mattress
8. Moisture content of finished panel
9. Hot pressing parameters (temperature, time, and pressure)
10. Environmental conditions (humidity and temperature) for finished particleboard
11. Overlaying of particleboard

The proposed formaldehyde emission reduction solution is summarized below [5].
• To change the molar ratio of U/F in glue production,
• Chemical formaldehyde bonding materials (urea, tannic acid, âmine, ammonia, melamine and cyanoguinidin)
• Development of new glue formulations,
• The usage of alternative adhesives (phenol formaldehyde, isocyanate) to urea formaldehyde adhesives,
• The usage of plant and animal-based glues,
• Nanotechnology and plasma applications,
• Changing production conditions (such as press temperature and pressure)

The materials relasing formaldehyde in a room are shown in Figure 1. Especially, furniture is one of the most important materials on the formaldehyde release because it is produced using UF resin.

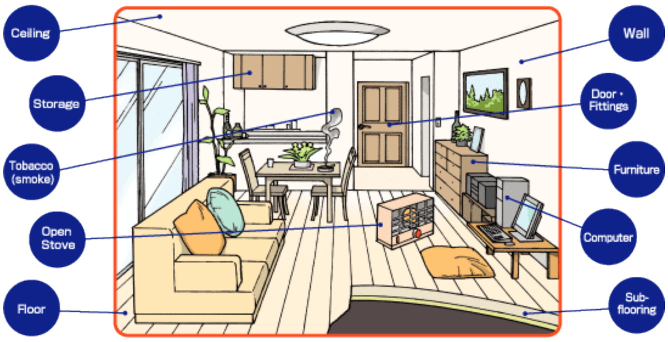

Fig. 1. *Materials relasing formaldehyde in a room [6].*

The formaldehyde emission standards for different countries are given in Table 2

Table 2. *Current formaldehyde emission standards for wood-based panels in Europe, Australia, the USA, and Japan [32].*

Country	Standard	Test method	Board class	Limit value
Europe	EN 13986	EN 717–1 EN 120	E1–PB, MDF, OSB	≤ 0.1 ppm ≤ 8 mg/100 g o.d. boar
		EN 717–1 EN 717–2	E1–PLW	≤ 0.1 ppm ≤ 3.5 mg/(h.m^2)
		EN 717–1 EN 120	E2–PB, MDF, OSB	> 0.1 ppm > 8 ≤ 30 mg/100 g o. board
		EN 717–1 EN 717–2	E2–PLW	> 0.1 ppm > 3.5 ≤ 8.0 mg/(h.m^2)
Australia & New Zealand	AS/NZS 1859–1 & 2	AS/NZS 4266.16 (Desiccator)	E0–PB, MDF	≤ 0.5 mg/L
			E1–PB	≤ 1.5 mg/L
			E1–MDF	≤ 1.0 mg/L
			E2–PB, MDF	≤ 4.5 mg/L
USA	ANSI A 208.1 & 2	ASTM E1333 (large chamber)	PB	≤ 0.18 or 0.09 ppm
			MDF	≤ 0.21 or 0.11 ppm
Japan	JIS A 5908 & 5905	JIS A 1460 (Desiccator)	*F***	≤ 1.5 mg/L
			*F****/"E0"	≤ 0.5 mg/L
			*F*****/"SE0"	≤ 0.3 mg/L

PB: particleboard; MDF: medium density fiberboard; OSB: oriented strand board
*F*** class in Japan more or less equivalent to European E1-class
*F**** and *F***** are of much lower emission than the E1
*F***** emission is close to the emission of solid untreated wood

There is a direct relationship between the formaldehyde emission and the formaldehyde content of the resin. The resin producers have focused on the reduction in the F/U molar ratio in the last decades to decrease formaldehyde emission from wood-based panels. Nevertheless, the reduction in the formaldehyde content in the UF resin decreases the reactivity of UF resin, which adversely affects the mechanical properties and dimensional stability of the panels. Another strategy is the use of scavengers. Natural or bio-based substancessuch as pozzolan, tannins, charcoal, starch, chitosan, and chemical compoundssuch as as primary and secondary amines, sodium sulfites, borax, and ammoniumphosphates have been tested [7].

2. Applications for decreasing the formaldehyde emission from wood-based panels

Hot press parameters, press temperature, time, and pressure, affects the formaldehyde and VOC emissions from the wood-based panels and they decrease with increasing severity of the pressing parameters. Furthermore, the panel manufacturers use powder urea as formadehyde scavenger, which is added into the UF resin solution. It is one of the most commonly used formaldehyde scavenger is urea, mainly as aqueous solution, due to its low cost and good performance [8]. Wood based panels with low-formaldehyde emission can be produced using methyl-diphenoldiisocyanate (PMDI) adhesive.

In literature, of some natural scavengers such as paper sludge [9], chestnut shell flour [10], condensates obtained from kiln-drying of wood [11], phenolated kraft lignins [12], tannins extractives [13], soy flour [14], Chitosan [15], pine cone flour [16]. Zhang et al. [17] reported that formaldehyde emission of coated medium density fiberboard panels could be reduced by cold air and ammonia plasma treatment by 21% and 31%, respectively. Cold plasma treatment as an efficient and environmentally friendly method, which was completely different from the convenrional formaldehyde scavengers, can significantly reduce the formaldehyde emission without decreasing bond performance of wood particles or fibers. In addition, the charcoal has a considerable impact on the amount of formaldehyde released by the manufactured boards. Kowaluk et al. [18] reported that the 50 wt% content of charcoal caused about 80% reduction of formaldehyde emission. Ayrilmis et al investigated the potential utilization of such condensates from oak, beech and walnut, which were obtained in a 7.8 MHz vacuum dryer. The condensate was replaced with the deionized water (5%) in the production of urea-formaldehyde (UF) and melamine-urea-formaldehyde (MUF) resins in the reactor. The formaldehyde emission from particleboard and medium density fibreboard decreased significantly with addition of the condensate into the UF and MUF resins. Previous studies reported that some synthetic scavengers such as propylamine [19], ammonium pentaborate [20] and ammonium bicarbonate [21], aluminium oxide [22], melamine, polyvinyl alcohol, and adipic acid dihydrazide [23] were effective to decreased the formaldehyde emission from the wood-based panels. Furthermore, Réh et al. [24] reported that beech bark flour decreased the formaldehyde emission from plywood by up to 74% without decreasing the mechanical properties of thewood-based panels. Bark of some wood species such as walnut and chestnut contains the high amount of phenolics, which may decrease the formaldehyde emission from the wood-based panels when the bark flour was added into the UF resin mixture [25,26].

Effect of nanofillers (titanium dioxide) as scavenger on the formaldehyde emission of E0 grade UF using at 0.5%, 1%, and 3 wt% based on the oven dry weight of UF resin was investigated by Park and Lee [27]. Costa et al. [28] investigated the effects of sodium metabisulfite, ammonium bisulfite, and urea on the technological properties and formaldehyde emission of particleboard. Among the scavengers, the sodium metabisulfite was the best additive giving the particleboards with zero formaldehyde emission. Dudkin et al. [29] added aluminum oxide nanoparticles in the UF resin to decrease the free-formaldehyde. Chotikhun et al. [18] determined the formaldehyde emission and mechanical properties of the particleboards produced from Eastern redcedar using silicone dioxide (SiO_2) nanoparticles added modified starch as a binder [31]. Nine different particleboards were produced with nanoparticle contents of 0%, 1%, and 3% at three density levels of 600, 700, and 800 kg/m^3. The results showed that the nanoparticle content above 1% adversely affected the mechanical properties of the particleboard. Very low formaldehyde emission value of 0.07 ppm was determined for the particleboards.

Effect of nanocellulose on the formaldehyde emission wood-based panels was also investigated by Ayrilmis et al. Three grades of liquid urea-formaldehyde (UF) resins such as super E0 (SE0), E0 and E1 were modified by adding different amounts of microfibrillated cellulose (MFC, 5 wt%). The incorporation of the MFC into the SE0 up to 30 wt% significantly decreased the formaldehyde emission from of the UF resin while this riot observed for El) and El grade resins. The total volatile organic compounds (TVOCs) of the LVLs considerably decreased with increasing MFC content at 25 °C and 35 °C.

3. Conclusions

Formaldehyde emission is one of the important characteristics of wood-based panels which limits their use in indoor application. There are different ways to reduce the formaldehyde emission from the wood-based panels. The most widely used teo methods are to decrease formaldehyde/urea ratio and add the formaldehyde scavengers. Recently, use of environmentally friendly and sustainable formaldehyde scavengers in the production of wood-based panels has increased. Although only E1 grade wood-based panels are accepted by the many countries, it is expected that the use of E0 panels will increase in near future in the market.

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