

# VOLATILE ORGANIC COMPOUND EMISSIONS DURING HOT-PRESSING OF SOUTHERN PINE PARTICLEBOARD: PANEL SIZE EFFECTS AND TRADE-OFF BETWEEN PRESS TIME AND TEMPERATURE

WENLONG WANG  
DOUGLAS J. GARDNER\*  
MELISSA G.D. BAUMANN\*

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## ABSTRACT

In previous research, it was shown that decreasing either press temperature or press time generally resulted in decreased volatile organic compound (VOC) emissions during the hot-pressing of southern pine particleboard. However, because it is impossible to reduce both pressing time and temperature while maintaining panel physical and mechanical properties, this study evaluated two sets of conditions to determine whether it might be more advantageous, from an emissions perspective, to hot-press at a lower temperature for a longer pressing time or at a higher temperature for a shorter pressing time. An enclosed caul plate was used to collect VOC emissions during the pressing of panels manufactured using each of the three major wood adhesives: urea-formaldehyde, phenol-formaldehyde (PF), and polymeric methylene diisocyanate. Each of the resins was pressed under two different temperature/time conditions that yielded panels with equivalent internal bond strengths. It was generally found that panels pressed at a high temperature for shorter press times emitted more formaldehyde, pinenes, and higher molecular weight VOCs (defined as VOCs with boiling points higher than 40°C). Increases at the higher temperature condition ranged from 10 to 204 percent. The one exception to the increases in VOCs at the higher temperature and shorter pressing times was formaldehyde emissions from panels bonded with PF resin. This may be an anomaly that results from an additive in the PF resin that serves as a formaldehyde scavenger. This study also evaluated the effects of increasing panel size on emissions from pressing of panels. Small panels (305 by 305 mm) and larger panels (610 by 610 mm) were manufactured using each resin under press conditions appropriate for the resin. In all cases, emissions from the larger panels were lower on a per weight basis compared to the smaller panels. The decreased edge area relative to panel area clearly has a significant effect on the release of the emissions from the panels during manufacture.

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Volatile organic compound (VOC) emissions arising during the manufacture of particleboard originate in the wood particles and the adhesive. The VOCs emitted from wood particles containing no adhesive resin consist of wood extractives, thermal and oxidative degradation products of wood components, and chemical reaction products of wood extractives (10-12). The VOCs emitted from wood adhesives are formaldehyde, methanol, phenol, and methylene diisocyanate (3,7,8,12). Formaldehyde emissions from particleboard production have

been investigated for over three decades. These investigations have greatly reduced the formaldehyde emissions be-

cause of the development of wood adhesives with special formulations or the addition of formaldehyde scavengers.

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The authors are, respectively, Graduate Research Assistant and Associate Professor, Univ. of Maine, Advanced Engineered Wood Composite Center, Orono, ME 04469; and Research Chemist, USDA Forest Serv., Forest prod. Lab., One Gifford Pinchot Dr., Madison, WI 53705-2398. This study was funded by USDA/CSREES/NRICGP Grant 9702592. The authors would like to acknowledge Temple-Inland Corp., Thomson, GA, Southeastern Adhesive Co., Lenoir, NC, Neste Resins, Springfield, OR, and Bayer, Pittsburgh, PA, for providing wood particles, UF resin, PF resin, and pMDI, respectively. This paper was received for publication in January 2001. Reprint No. 9261.

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However, increased research attention has turned to other VOC emissions from wood particles following the enactment of the 1990 Clean Air Act Amendments (1, 9).

In our previous work (6,7), we found that higher molecular weight VOC (HMwVOC, defined as those VOCs with boiling points greater than 40°C) emissions arising during the hot-pressing of southern pine particleboard panels are most significantly reduced by decreasing pressing time, pressing temperature, or mat moisture content. However, it is not practical to decrease both pressing temperature and pressing time simultaneously to reduce VOC hot-press emissions, because these press variables affect the mechanical and physical properties of final products. Broline et al. (2) addressed the trade-off of pressing time and temperature for emissions of methanol, formaldehyde, and ammonia from hot-pressing of pine particleboard with urea-formaldehyde (UF) resin. Further evaluation of the relative effects of pressing time and temperature while maintaining panel physical properties is needed for VOCs other than methanol and formaldehyde and for other adhesive resins.

The panel size of the particleboard is expected to affect the rate of VOC emissions during hot-pressing by increasing the internal vapor pressure and changing the temperature distribution within the board. Similar to vapor movement in the porous materials (4,5), the migration of VOC press emissions in the particle furnish is a combination of diffusion and convection. The driving forces of VOC emissions are the VOC concentration gradient and vapor pressure gradient. An understanding of increased board dimensions on VOC hot-pressing emissions can provide useful information for particleboard manufacturers attempting to estimate VOC emissions from hot-pressing on an industrial scale.

#### OBJECTIVES

The goals of this study were to evaluate the effects of pressing time, pressing temperature, and panel size on the emissions of VOCs emitted during the hot-pressing of southern pine particleboard. Specifically, as a follow-up to previous work, this research was intended to:

I provide information on the relative effects of pressing time and temperature on the emissions of VOCs during hot-

pressing while maintaining panel physical properties;

- determine whether panel size affects emission rates from particleboard during pressing.

#### MATERIALS AND METHODS

##### MATERIALS

Particles composed of about 95 percent southern pine and 5 percent other species were commercially prepared by Temple-Inland Corp., Thomson, GA. The particles used for comparing emissions under different pressing time and temperature conditions were from the same batch as those used for the previous study (7). The particles used for investigating the panel size effect on VOC emissions were different batches from those used for the previous study (7). UF resin, phenol-formaldehyde (PF) resin, and polymeric methylene diisocyanate (pMDI) resin were provided by Southeastern Adhesive Company, Neste Resin Corp, and Bayer Corp., respectively.

Chemicals used for GC/MS calibration (1-pentanal, hexanal, 2-heptanone, octanal,  $\alpha$ -pinene, camphor, (-)-borneol, hexadecane, heptadecane, and octadecane) were Sigma research reagents. Methylene chloride is the American Chemical Society certified product of Fisher Scientific.

##### VOC COLLECTION SYSTEM

The VOC hot-pressing collection system was composed of a closed caul plate and a VOC emission-collecting system. There were two caul plates used for this study: one with an inner caul plate frame size of 500 by 500 mm (18 by 18 in.), which was used at Michigan Technological University (6); the other with inner caul plate frame size was 915 by 915 mm (36 by 36 in.) and this was used at the USDA Forest Products Laboratory, Madison, Wisconsin. The closed caul plates were designed to prevent the loss of VOCs and to construct 19-mm (3/4-in.) panels.

*Experiments performed at Michigan Technological University.* — Experiments to evaluate press emissions for panels with similar physical properties were conducted at Michigan Tech. A 400- by 400-mm caul plate was used, and the VOC collecting method was described in a previous publication (7).

*Experiments performed at the USDA Forest Products Laboratory.* — Experiments conducted at the Forest Products Laboratory were aimed at evaluating the

effect of increased panel size on VOC press emissions. A 915- by 915-mm caul plate was used. Ambient air was pulled through the caul plate and the collection system at a rate of 5.0 L per minute by a vacuum oil pump. An extra Allihn condenser was installed between the caul plate and the collection system to cool the VOC and vapor stream prior to entering the scrubbers. The vacuum rate remained at 5.0 L per minute during the collection. VOC emissions trapped by the enclosed caul plate were pulled through two 500-mL scrubbers chilled in an ice bath to about 0°C. The first scrubber contained 140 mL of distilled water and the second contained 140 mL of methylene chloride. Both scrubbers also had fritted glass spargers on their inlets to assure dispersion of the vapors.

##### PANEL MANUFACTURE

*Panel manufacture for the mechanical property tests.* — The wood adhesive was sprayed onto the particle furnish in a drum blender by using a compressed air spray head. After blending, the furnish was hand felted into a 400- by 400-mm (16- by 16-in.) deckle box. The mat was then pressed in the hot-press maintained at the desired temperature. The press cycle was as follows: 1) increase the press hydraulic pressure from 0 to 6.7 MPa (0 to 900 psi) in the first 30 seconds and maintain the press hydraulic pressure for 15 seconds; 2) decrease the press hydraulic pressure to 4.5 MPa (600 psi); 3) in the last 30 seconds, decrease the press hydraulic pressure from 4.5 to 0 MPa (600 to 0 psi) gradually. Four thickness stops with a thickness of 20 mm (3/4 in.) were placed on each corner of the lower platen. For each press condition, four particleboard replicates were made.

*Panel manufacture for VOC collection.* — The wood adhesive was sprayed onto the particle furnish in a drum blender by using a compressed air spray head. After blending, the furnish was hand felted into a 305- by 305-mm (12- by 12-in.) or a 610- by 610-mm (24- by 24-in.) deckle box. The mat was then pressed in the hot-press maintained at the desired temperature. The time and VOC emission collection system were started when the caul plate was closed. For each panel size with each resin, three particleboard replicates were made.

TABLE 1. — Comparison of internal bond strength of particleboard manufactured as a function of hot-pressing temperature and time. <sup>a</sup>

	IB of UF-bonded board <sup>b</sup>		IB of PF-bonded board <sup>c</sup>		IB of pMDI-bonded board <sup>d</sup>	
	Pressing time (min.)					
	3.5	3	6	4.5	3.5	3
	166	188	166	188	160	182
1	0.751	0.735	N/A	0.806	1.308	1.314
	0.711	0.796	0.853	0.889	1.314	1.268
	0.702	0.778	0.870	0.787	1.200	1.246
2	0.800	0.812	0.848	0.967	1.086	1.009
	0.781	0.864	0.774	0.961	1.184	1.067
	0.802	0.752	0.817	0.860	1.206	0.976
3	0.900	0.694	0.840	0.964	0.695	0.983
	0.809	0.734	0.879	1.005	1.034	1.039
	0.874	0.703	0.868	0.952	0.768	0.895
4	0.724	0.781	0.952	1.082	N/A	0.890
	0.740	0.764	0.929	0.970	N/A	1.044
	0.765	0.711	0.900	0.835	N/A	1.182
Average	0.780	0.760	0.866	0.923	1.088	1.076
Ratio of medians	1.02		0.94		1.00	
Lower bound of 95% confidence interval on ratio of median	0.87		0.80		0.65	
Upper bound of 95% confidence interval on ratio of median	1.21		1.10		1.55	

<sup>a</sup> Internal bond data included the four panels as full replicates and three subsamples from each panel.

<sup>b</sup> Press conditions for UF resin were: resin content, 7 percent, mat moisture content, 10 percent, board density, 769 kg/m<sup>3</sup> (48 pcf).

<sup>c</sup> Press conditions for PF resin were: resin content, 7 percent, mat moisture content, 10 percent, board density, 769 kg/m<sup>3</sup> (48 pcf).

<sup>d</sup> Press conditions for pMDI resin were: resin content, 5 percent, mat moisture content, 10.2 percent, board density, 769 kg/m<sup>3</sup> (48 pcf).

#### ANALYSIS OF VOC EMISSIONS

The detailed procedures used for the analysis of VOC emissions were described in a previous article (6). The contents of the two scrubbers were combined and twice extracted with methylene chloride. The methylene chloride extraction solution was analyzed by gas chromatography/mass spectrometry (GC/MS). The VOCs were quantified using external standards. The HMwVOC emissions in the methylene chloride extraction solution (excluding formaldehyde, methanol, and the other lower molecular compounds, which elute earlier than methylene chloride) can be calculated by combining the estimated amount of the 70 largest peaks. Formaldehyde was analyzed by using the chromotropic acid technique described by Carlson et al. (3).

#### PANEL MECHANICAL PROPERTY TESTS

The internal bond (IB) strength of the particleboard was evaluated according to the methods outlined in ASTM D 1037. Three replicates were used for each test. Before the mechanical tests, the samples were conditioned in an environmental chamber at 20 ± 3°C and 65 ± 1 percent relative humidity to attain their equilibrium conditions.

TABLE 2. — Emissions from panels hot-pressed with three different resins under high temperature, short pressing time conditions and low temperature, long pressing time conditions.

Resin type	Compound(s), emissions	Average emissions from low temp/long press time <sup>a</sup>	Average emissions from high temp/short press time <sup>b</sup>	Percent change in average emissions
		----- (mg/kg OD Board) -----		
UF	Formaldehyde	34	34	0.0
	HMwVOC	12	15	25
	Pinene	3.8	5.5	44.7
PF	Formaldehyde	12	9.8	-18.3
	HMwVOC	96	108	12.5
	Pinene	28	31	10.7
pMDI	Formaldehyde	0.69	2.1	204
	HMwVOC	20	42	110

<sup>a</sup> Low temperature, long press time was 166°C, 3.5 minutes for UF, 166°C, 6 minutes for PF, and 160°C, 3.5 minutes for pMDI.

<sup>b</sup> High temperature, short press time was 188°C, 3.0 minutes for UF, 188°C, 4.5 minutes for PF, and 182°C, 3 minutes for pMDI.

#### RESULTS AND DISCUSSION

##### RELATIONSHIP BETWEEN PRESSING TEMPERATURE AND PRESSING TIME

The investigation of VOC hot-press emissions for the trade-off between pressing temperature and time was performed at such conditions that the mechanical properties of the particleboard produced were the same. Broline et al.

(2) have shown that pressing panels at higher temperatures for shorter times yields equivalent IB strengths as when pressing at lower press temperatures for longer times. For this study, the conditions that were used were 166°C (330°F) at 3.5 minutes press time and 188°C (370°F) at 3 minutes press time for UF resin; 166°C (330°F) at 6 minutes and 188°C (370°F) at 4.5 minutes for PF resin; and 160°C (320°F) at 3.5 minutes

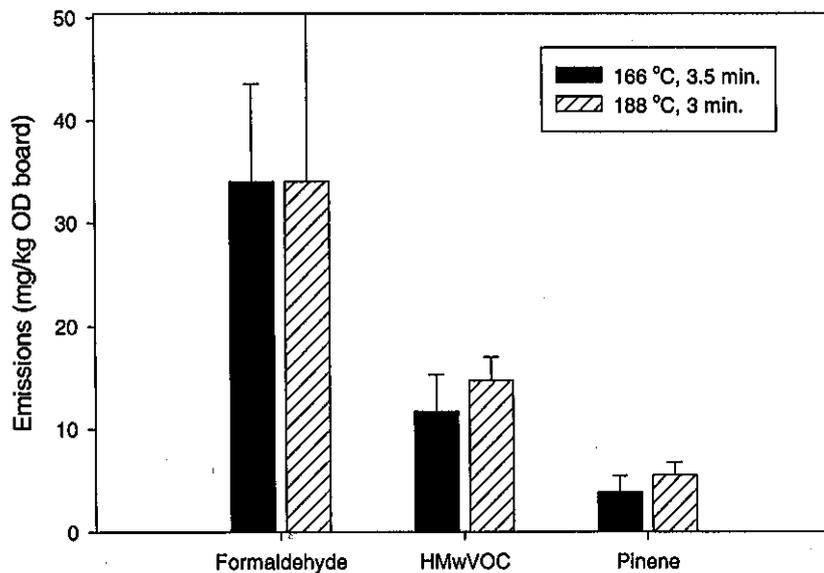


Figure 1. — Comparison of VOC emissions using different pairings of hot-pressing temperature and time for UF resin. Pressing conditions: resin content 7 percent, mat moisture content 9.8 percent, board density 769 kg/m<sup>3</sup>.

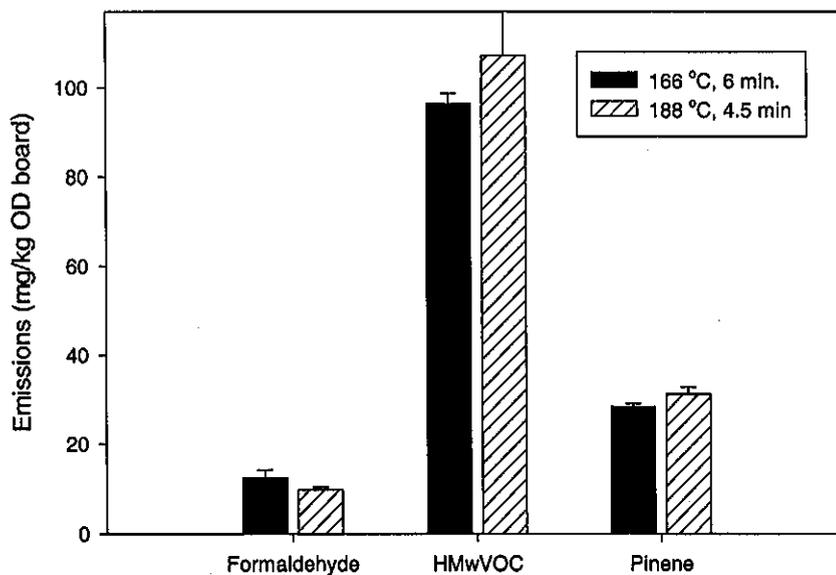


Figure 2.—Comparison of VOC emissions using different pairings of hot-pressing temperature and time for PF resin. Pressing conditions: resin content 7 percent, mat moisture content 9.3 percent, board density 769 kg/m<sup>3</sup>.

and 182°C (360°F) at 3 minutes for pMDI resin. The IB strengths for all the panels along with confidence intervals are given in **Table 1**. The two pressing conditions for each resin yielded similar IB strengths.

The average formaldehyde, HMwVOC, and pinene emissions from panels pressed under a low temperature, long

pressing time condition and high temperature, short pressing time condition are summarized in **Table 2** and **Figures 1** through **3**. **Figure 1** shows the VOC press emissions as a function of the two pressing conditions for UF resin. While formaldehyde emissions were nearly identical for the two conditions, the HMwVOC and pinenes were higher at the higher temperature/longer press time

condition. However, a t-test showed that the changes observed were insignificant at the 95 percent confidence level.

The VOC hot-pressing emissions from PF-bonded particleboard as a function of the two press conditions are shown in **Figure 2**. The HMwVOC and pinene emissions were lower with the lower temperature and longer pressing time, although the change in the HMwVOC emissions was not statistically significant due to variation in the data. In contrast, formaldehyde emissions were reduced by 18.3 percent at the higher temperature and shorter pressing time as compared to the lower temperature, longer pressing time conditions. It is probable that this reduction in formaldehyde emissions is due to a proprietary chemical additive in the resin. This observation is consistent with previous work (7) in which the effects of the additive were also observed. The decrease in formaldehyde emissions is likely because of the additive reacting with the formaldehyde more quickly at the higher temperature, so the reaction rate is the dominating factor in determining the release rate of formaldehyde. Overall for this system, lowering pressing temperature and increasing pressing time results in lowering pinene and HMwVOC emissions while increasing formaldehyde emissions.

For pMDI-bonded particleboard, the formaldehyde, HMwVOC, and pinene emissions were greater at a higher pressing temperature and lower pressing time compared to a lower pressing temperature and longer pressing time (**Fig. 3**). The formaldehyde, HMwVOC, and pinene emissions were significantly decreased by 67.1, 52.4, and 50 percent, respectively, if a lower pressing temperature and longer pressing time were chosen. Therefore, a lower pressing temperature and longer pressing time can be used to minimize VOC emissions without compromising the IB strength of the resulting pMDI-bonded particleboard.

#### VOC PRESS EMISSIONS AS A FUNCTION OF PARTICLEBOARD PANEL SIZE

To determine whether panel size affects the amount of VOCs emitted during hot-pressing, two different sized panels (305 by 305 mm and 610 by 610 mm) were made using each of the resin types. The average emissions from each panel type are given in **Table 3** and shown graphically in **Figures 4** through **6**. Emissions of formaldehyde, HMw-

VOC, and pinenes on a per unit panel weight basis were lower for the larger panels than the smaller panels for all resin types. For the UF-bonded panels, doubling the panel edge length resulted in a decrease in emissions of HMwVOC and pinene by 34.6 percent (from 107 to 70 mg/kg OD board) and by 38.5 percent (from 39 to 24 mg/kg OD board), respectively. Formaldehyde emissions from the UF-bonded panels decreased from 250 to 211 mg/kg OD board, although there was enough variation in the data that this reduction was not considered statistically significant.

For PF-bonded panels, only the formaldehyde exhibited a statistically significant reduction upon increasing panel size, although the emission of formaldehyde from these panels was very low for both sizes. The 305-mm panels emitted 1.8 mg/kg OD board while the 610-mm panels emitted 0.84 mg/kg OD board. The large panels also emitted less HMwVOC and pinene than the smaller panels, although the change was not statistically significant.

During the hot-pressing of pMDI-bonded particleboard, the emissions of formaldehyde, HMwVOC, and pinene pMDI-bonded particleboard were significantly decreased by 20, 29.5, and 32.6 percent, respectively, when the panel edge size was doubled.

Overall, increasing the panel size decreases the VOC hot-pressing emissions on a per unit weight basis. This decrease is likely due to a balancing of several processes that affect the emission rates from the panels during hot-pressing. The first factor is the increase in vapor pressure, which is likely to occur in a larger panel. The flux of vapors, including VOCs, increases with increasing vapor pressure due to an increasing pressure gradient between the panel and the outside air. The particle mat during hot-pressing can be treated as what Luikov (45) described as a capillary-porous body with the wood particles and fibers forming capillaries through which the water and VOC vapors may move. During hot-pressing, the mat temperature rapidly rises above 100°C and convection filtration of both water vapor and VOCs occurs in the mat. Relaxation of the total pressure gradient occurs at the edge of the mat, and Darcy's Law describes the flux of the vapor through the mat as in Equation [1]:

$$j_a = -k_a \bar{\nabla} p \quad [1]$$

where:  $j_a$  = the filtration flux of vapor or VOCs ( $\text{kg}/\text{m}^2 \cdot \text{h}$ );  $k_a$  = the molar transfer coefficient, which is related to the penetration factor of humid air and the relative concentration of vapor or VOCs in humid air stream;  $\bar{\nabla} p$  = the total pressure gradient.

However, the increase in panel size decreases the edge area relative to panel volume from which the emissions may escape. The emission rate is proportional to the edge area of the particleboard, as shown in Equation [2].

$$Q_a = A j_a \quad [2]$$

where:  $Q_a$  = the total flow rate of vapor or VOCs ( $\text{kg}/\text{h}$ );  $A$  = the edge area of the board during hot-pressing ( $\text{m}^2$ );  $j_a$  = the total flux of vapor or VOCs at edge of the board ( $\text{kg}/\text{m}^2 \cdot \text{h}$ ).

This relationship indicates that all panel dimensions, including thickness, will affect the flow rate of VOCs emitted from a panel during hot-pressing. In our research, we used a fixed board thickness (19 mm), the edge area per unit board weight is decreased to one half when the panel edge size is doubled. This will decrease VOC emissions per unit board weight if the flux of VOC emissions remains the same. However, the total pressure gradient will increase when the panel size is increased, which

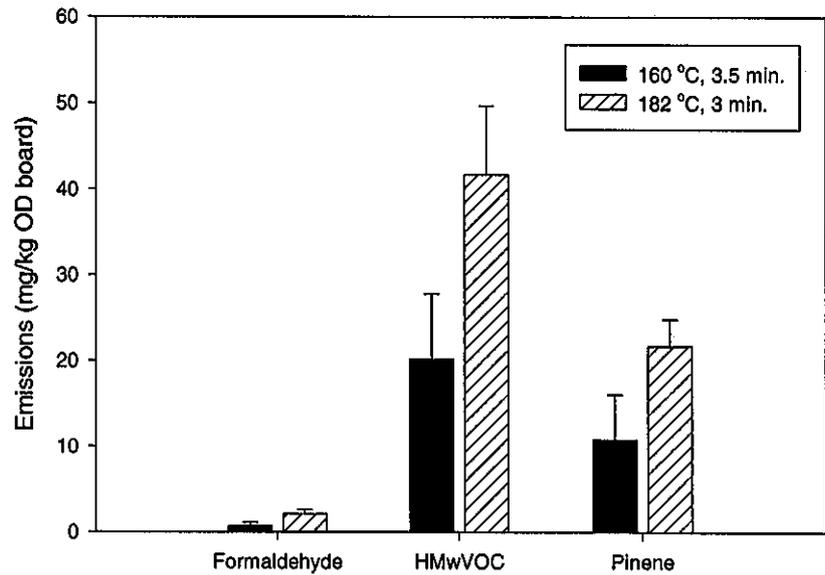


Figure 3.—Comparison of VOC emissions using different pairings of hot-pressing temperature and time for pMDI resin. Pressing conditions: resin content 5 percent, mat moisture content 10.3 percent, board density 769  $\text{kg}/\text{m}^3$ .

TABLE 3. — Emissions from small (305 mm) and large (610 mm) panels hot-pressed with three different resin types.

Resin type	Compound(s), emissions	Average emissions from small panels	Average emissions from large panels	Percent change in average emissions
		----- (mg/kg OD Board) -----		
UF	Formaldehyde	250	211	-15.6
	HMwVOC	107	70	-34.6
	Pinene	39	24	-38.5
PF	Formaldehyde	1.8	0.8	-55.6
	HMwVOC	161	128	-20.5
	Pinene	57	40	-29.8
pMDI	Formaldehyde	3.0	2.4	-20
	HMwVOC	95	67	-29.5
	Pinene	43	29	-32.6

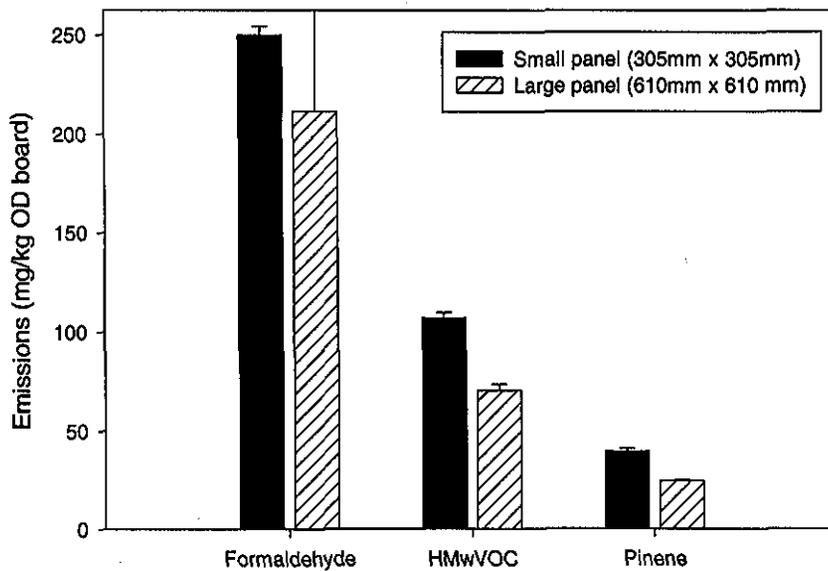


Figure 4. — VOC hot-pressing emissions as a function of panel size for UF resin. Press conditions: press temperature 182°C (360°F), press time 6 minutes, resin content 7 percent, mat moisture content 12 percent, board density 769 kg/m<sup>3</sup>.

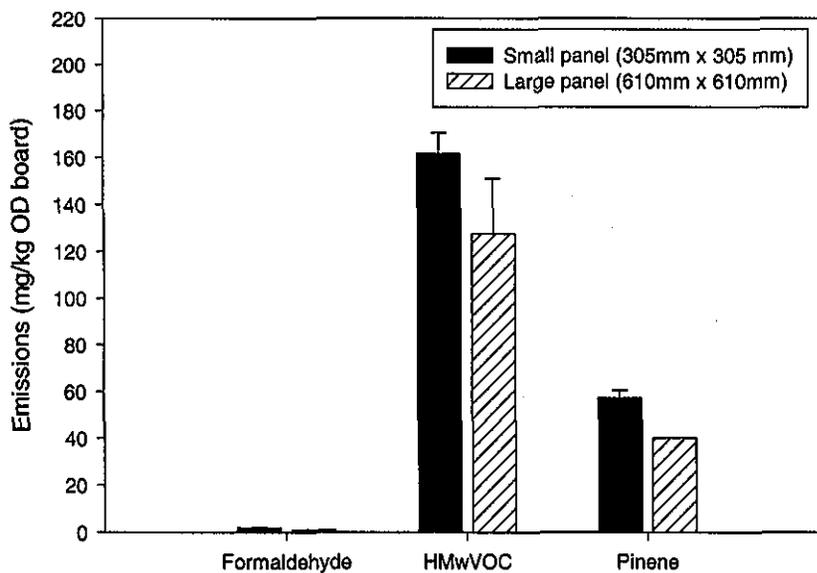


Figure 5. — VOC hot-pressing emissions as a function of panel size for PF resin. Press conditions: press temperature 182°C (360°F), press time 8 minutes, resin content 6 percent, mat moisture content 13 percent, board density 769 kg/m<sup>3</sup>.

will increase the flux of VOC emissions. Thus the two factors work in opposition. The results of our study indicate that the effect of the reduced panel edge area per unit of hoard weight had a greater effect on the emission rate than the change in pressure gradient from the inside of the panel. This effect must be taken into consideration when comparing small-scale laboratory research to

emissions from industrial-scale manufacturing operations.

### CONCLUSIONS

The trade-off between pressing temperature and time for VOC press emissions was investigated by producing particleboard panels with similar IB strengths under different pressing time and temperature conditions. In most

cases, within panels hot-pressed using the same resin, panels pressed at the lower temperature, longer pressing time condition emitted less formaldehyde, pinenes, and HMwVOCs than panels hot-pressed at the higher temperature for shorter times. One notable exception to the decreasing emissions with lower temperature, higher pressing time conditions were the emissions of formaldehyde from PF-bonded particleboard, which were lowered under the higher temperature, shorter pressing time conditions. It is expected that this may be somewhat of an anomaly due to additives in the resin that was used. This result is consistent with our previous research with this resin (7).

Evaluation of the effect of increasing panel size showed that the primary influence on the emissions was related to the decrease in edge area through which VOCs could escape. For all three resins, the emissions of formaldehyde, HMwVOC, and pinenes decreased when the panel edge size was doubled.

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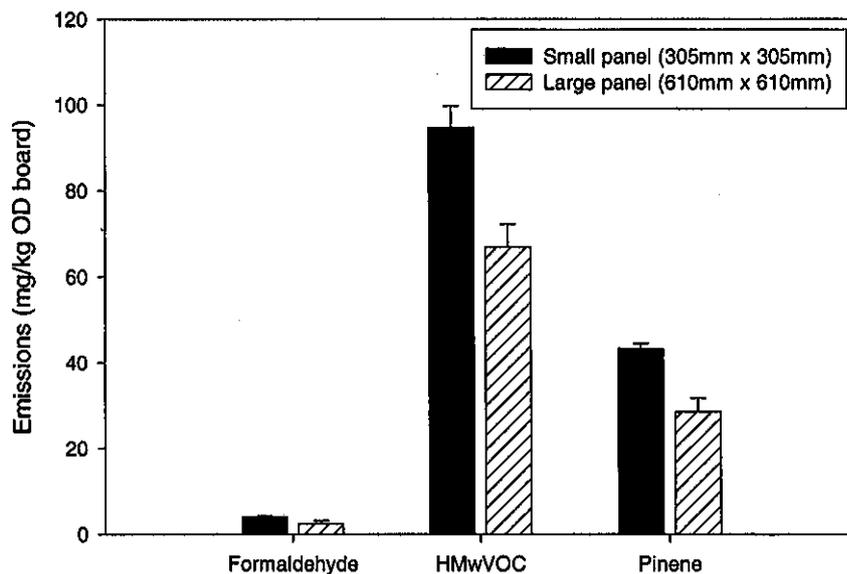


Figure 6.—VOC hot-pressing emissions as a function of panel size for pMDI resin. Press conditions: press temperature 182°C (360°F), press time 6 minutes, resin content 4.5 percent, mat moisture content 10 percent, board density 769 kg/m<sup>3</sup>.