Attachment 3

Long-term study of formaldehyde emission decay from particleboard

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Abstract

In 1986, the National Particleboard Association and several particleboard manufacturers initiated long-term studies to determine how particleboard formaldehyde emission levels behave with the passing of time. Sixteen particleboard products manufactured in 1986 and 1987 were tested for formaldehyde emission levels repeatedly over a period of time by the FTM-2 large chamber method. Data were generated from four different large chamber locations and represented a large cross section of the U.S. particleboard industry. Data were used to generate formaldehyde emission decay curves. From these curves, the three-quarter life and half life levels of emissions were calculated. Initial measurements of formaldehyde emissions varied from a high of 0.41 ppm to a low of 0.10 ppm. The overall average initial emission level was 0.21 ppm. The overall three-quarter and half lives were 38 and 216 days, respectively. The rate at which emission levels decrease is not constant, but decreases with time. Generally, formaldehyde emission levels decreased linearly with respect to the natural log of time.

During the latter half of the 1970s and throughout this decade there has been considerable interest in the off-gassing characteristics of formaldehyde (HCHO) from wood panels bonded with urea-formaldehyde (UF) resins. Concerns about the health effects of exposure to formaldehyde emissions have been addressed by panel manufacturers through the use of new binders and secondary systems to reduce the emission potential of these products (4). These manufacturing controls, instituted largely in the early 1980s, resulted in significantly reduced formaldehyde emission levels between 1980 and 1982. Voluntary industry product standards limiting formaldehyde emission levels were instituted by the wood panel manufacturers, beginning in 1981 (11). The development of standard industry test methods has allowed manufacturers and laboratories to measure formaldehyde emissions using identical test procedures. The FTM 1 Desiccator (6) and FTM 2 Large Chamber (7) tests were key formaldehyde emission test methods developed in 1981 and 1983, respectively. Both of these methods have undergone further revisions and refinements.

One characteristic of wood panel formaldehyde emissions of particular interest is their tendency to decrease (decay) with the passing of time. This formaldehyde emission decay from wood products has been investigated by several scientists. Kazakevics (3) investigated New Zealand particleboard. The surface exposure was 0.721 m^2 with an airflow rate of 3.6 to 4.0 cm/sec. Emission rates ($mg/m^2 \cdot hr.$) rather than emission levels were determined. He concluded there was a rapid decrease in the rate of formaldehyde emission over the first year of storage.

Gammage and Matthews (2) conducted fast decay, slow decay, and research home studies. The fast decay study utilized a variable air exchange rate to maintain the formaldehyde emission level at approximately 0.1 ppm. The average ($1/e$) decay period, which represents an approximate half life, uncorrected for temperature and relative humidity (RH), was 15 months. The slow decay study utilized a very high particleboard, hardwood plywood, and medium density fiberboard mixed loading ratio (more than six times the FTM 2 loading ratio for particleboard). A ($1/e$) decay period of 26 $\pm$ 2 months was determined. Four unoccupied homes were tested for emission levels over a 2-year period. A $1/e$ decay period of 19 months was reported. Interpolation of the home data from a plot of formal-

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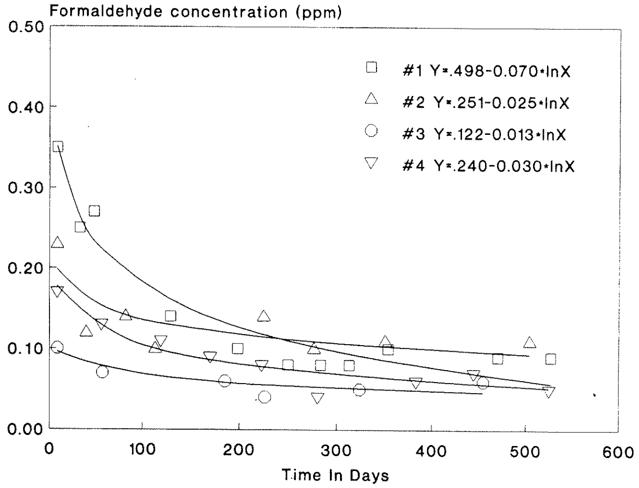

Figure 1. — Formaldehyde emission concentration data versus time for site A and the corresponding models of the emission decay relationship.

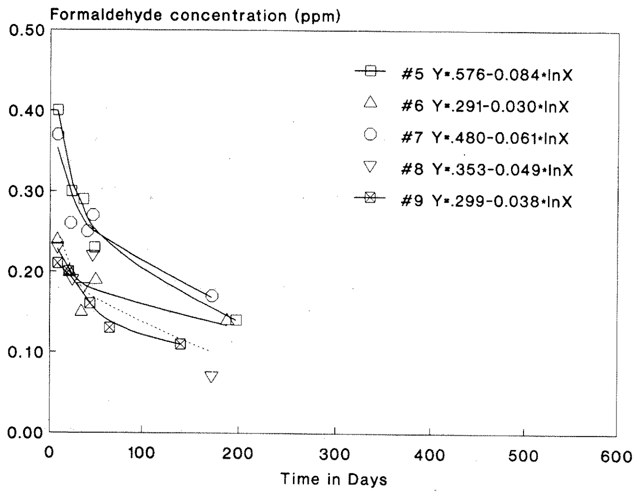

Figure 2. — Formaldehyde emission concentration data versus time for site B and the corresponding models of the emission decay relationship.

dehyde concentration versus time results in an estimated decay half life of 13 months.

Singh (8) and Anderson (1) conducted measurements of formaldehyde in manufactured homes according to home age for the U.S. Department of Housing and Urban Development (HUD) and the State of Wisconsin. Versar (10) combined these data to generate the most widely used information for exposure assessment. Their decay model, $y = 0.504e^{-.00065x}$ predicted an emission decay half life of 2.92 years. However, this model was not based on product decay but on formaldehyde data measurements plotted against home age. In addition, there were very few measurements made in any new homes when the initial formaldehyde concentrations and decay rates would likely be the greatest.

In 1986, the National Particleboard Association (NPA) and several particleboard manufacturers initiated long-term studies to determine how particleboard formaldehyde

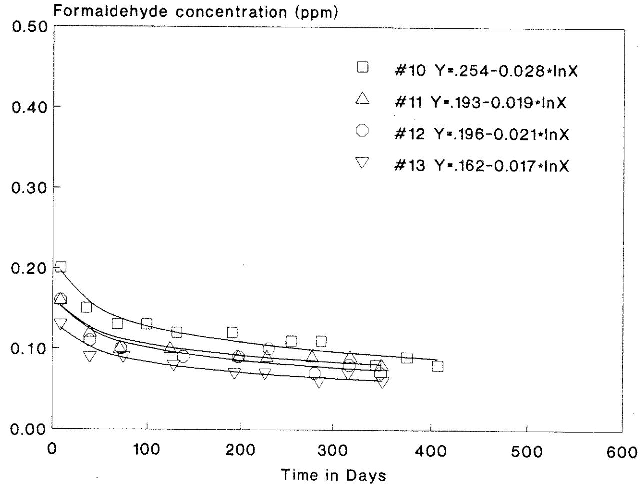

Figure 3. — Formaldehyde emission concentration data versus time for site C and the corresponding models of the emission decay relationship.

emission levels behave with the passing of time. This paper evaluates data from four of these studies with the objective of characterizing these emission levels with respect to time.

Procedure

Formaldehyde emission testing was performed by three particleboard manufacturers and the NPA. These participants are defined as sites A through D. Sixteen medium density particleboard panel products, representing all particleboard manufacturing regions of the United States, were included in this review study.

All formaldehyde emission tests were performed using the large chamber test method as set forth in FTM 2-1985 (7). The initial large chamber test was performed between 10 and 32 days from the date of board manufacture. Prior to initial testing, all panel samples were either stacked within product bundles (dead stacked) or wrapped in plastic film.

Panel time records were initiated upon removal of the test panels from dead stack or plastic wrap. At this time, the panels were put into the conditioning chamber for 7 days followed immediately by the first large chamber emission test. Between repeat tests, the panel samples were stored in a laboratory or work area in such a way as to allow ambient air to circulate around all sides of the panels. This laboratory air was heated or cooled to maintain comfortable indoor conditions. Temperature, RH, and ventilation rates were not recorded.

Formaldehyde emission data for each of the 16 test panels, as well as the combined data from all panels were regressed against the natural log of time, ($\ln(t)$) using the linear model:

$$HCHO = F + G \times \ln(t) \qquad [1]$$

where:

$HCHO$ = formaldehyde emission level (ppm)
$\ln(t)$ = natural log of time in days

Estimates of the time (t), to three-quarters and one-half of the initial formaldehyde emission levels were made from the regression equations on a sample-by-sample basis and for the combined data set. These points are classified as the "three-quarter" and "half" lives, respectively. Sample data were plotted against time in days utilizing a computer graphics package and natural log power fit techniques to show decay curves for each sample as well as for the combined data set from all samples.

Results and discussion

Formaldehyde emission results are plotted by test site in Figures 1 through 4. Initial measurements of formaldehyde emissions varied from a high of 0.41 ppm for sample number 5 to a low of 0.10 ppm for sample numbers 3 and 14. The overall average initial emission level was 0.21 ppm.

Table 1 summarizes the results of the regression fit of the emission levels to the natural log of time. Coefficients of determination (r^2 values) were equal to or greater than 0.80 for 13 of the 16 samples. The lowest r^2 value was 0.65 for sample no. 2. Using these regression equations to estimate decay life for the individual samples resulted in an average three-quarter life of 38 days and half life of 216 days. Three-quarter life values varied from a low of 23 days to a high of 48 days. Half life values for the samples varied between 82 and 371 days.

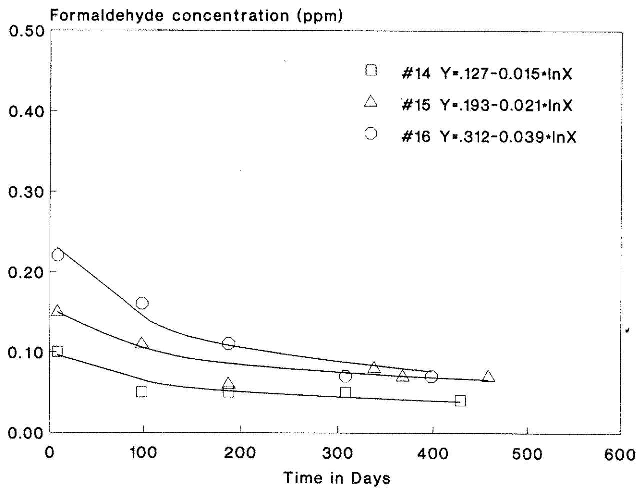

Figure 4. — Formaldehyde emission concentration data versus time for site D and the corresponding models of the emission decay relationship.

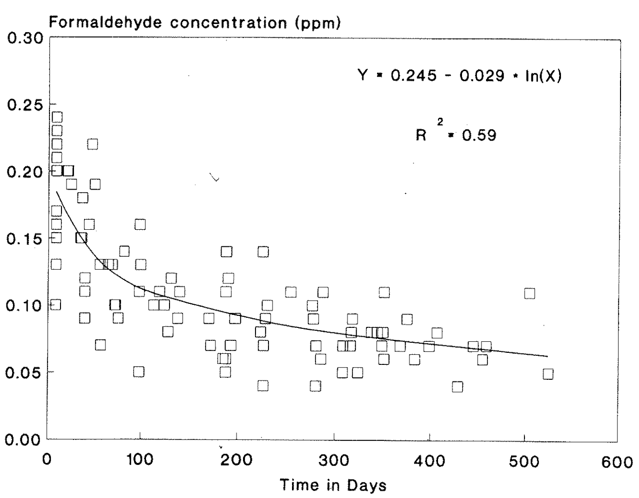

Figure 5. — Formaldehyde emission concentration data versus time for test panels that were at or below HUD limitations and the corresponding model.

Three of the samples, numbers 1, 5, and 7, were boards whose initial emission characteristics were above the HUD limit of 0.3 ppm for particleboard (9). These samples were not included in the combined data pool. The average initial formaldehyde level for the remaining 13 samples was 0.18 ppm. This compares with the annual certified formaldehyde emission average of 0.18 ppm for the years of 1987 and 1988 as reported by the NPA (5). The predicted regression curve for the combined data from the 13 samples is illustrated in Figure 5. This 216-day average half life is less than the 13 months interpolated from Gammage (2) and much less than the 2.92 years used by Versar (10). However, all three results were derived using different test methods.

The decay coefficient (G) is a measure of the rate of change in the emission levels with respect to time. These coefficients (Table 1) can be shown to be highly correlated ($r^2 = 0.90$) to the initial emission levels. Furthermore, as initial emission levels decreased, the rate of decay also decreased.

Periodic ambient formaldehyde concentrations were determined for the storage areas at two of the test sites. Average levels at sites A and C were 0.08 and 0.06 ppm, respectively. There was no attempt to gather background data to match specific sample tests. A few individual sample test results were below these background levels. This anomaly could be a result of the procedures outlined in the FTM 2-1985 test for conditioning prior to each large chamber evaluation. Samples are to be conditioned for 7 days at a maximum permissible formaldehyde background level of 0.1 ppm. In order to assure conformance to these re-

TABLE 1. — *Summary of particleboard decay parameters.*

Site	Sample	r^2	Linear model variables[a] (*F*)	(*G*)	Initial *HCHO*	¾ life[b]	½ life[b]
					(ppm)	----- (days)	-----
A	1	0.93	0.498	−0.070	0.35	29	99
A	2	0.65	0.251	−0.025	0.23	23	219
A	3	0.80	0.122	−0.013	0.10	46	350
A	4	0.89	0.240	−0.030	0.17	43	176
B	5	0.98	0.576	−0.084	0.41	24	82
B	6	0.75	0.291	−0.030	0.24	40	--[c]
B	7	0.91	0.480	−0.061	0.37	28	130
B	8	0.73	0.353	−0.049	0.23	39	128
B	9	0.94	0.299	−0.038	0.21	41	--[c]
C	10	0.94	0.254	−0.028	0.20	44	268
C	11	0.94	0.193	−0.019	0.16	46	371
C	12	0.90	0.196	−0.021	0.16	38	262
C	13	0.95	0.162	−0.017	0.13	42	280
D	14	0.93	0.127	−0.015	0.10	35	198
D	15	0.86	0.193	−0.021	0.15	48	293
D	16	0.92	0.312	−0.039	0.22	42	169
Average					0.21	38	216
Standard deviation					0.09	8	91
Maximum					0.41	48	371
Minimum					0.10	23	82

[a] $HCHO = F + G \times \ln(t)$.
[b] Times are referenced from time zero when the panels were removed from dead stacking or plastic wrap.
[c] Sample not tested long enough to determine half life.

quirements, some facilities conduct this 7-day conditioning in a closed recirculating air system where formaldehyde background levels can be below those recorded for other locations at those test sites.

The data presented are assumed to be representative of medium density particleboard made with current manufacturing practices and technologies. This study does not attempt to specifically identify the sources of variability in emission levels and decay rates. However, in this sample of 16 particleboard products, differences in these characteristics were observed. Manufacturing variables that might contribute to this variability include raw material, resin formulation, board porosity, and board density, among others.

Conclusions

1. Formaldehyde emission levels from particleboard can be expected to decrease over time.

2. The rate at which emission levels decrease is not constant, but diminishes with time. On average, the 16 samples in this study decreased from their initial emission levels by 25 percent in just 38 days. Fourteen samples, tested long enough to reach a half life, took an average of 216 days to reach the 50 percent emission level.

3. Generally, formaldehyde emission levels decreased linearly with respect to the natural log of time.

4. Decay of panel emission levels with respect to time of these medium density particleboards was strongly related to the initial emission level. The higher the initial emission level the greater the initial rate of decay.

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