Decay or the Decrease in Formaldehyde Concentrations or Emissions over Time and UF-bonded Wood Panel Products

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Abstract

Decay is the decrease in formaldehyde concentrations in homes or the decrease in emissions from formaldehyde containing products over time. The decrease in formaldehyde concentrations over time (decay) in home studies is typically determined by associating formaldehyde concentrations by home age. The average half life in such studies is highly variable, varying from about 1 year to more than 20 years, depending on the nature of the home population under study and other factors. Home age/concentration studies generally show that formaldehyde concentrations are higher in new homes than older homes of the same type. These types of studies have limitations as a means of assessing product emission decay profiles. The introduction of additional sources of formaldehyde as the homes age tends to cloud interpretations that seek to relate concentration change over time with emission decay of the original formaldehyde containing products in the home. Laboratory studies provide a better understanding of decay from specific products. A shorter half life, from less than a month to a little over a year, is demonstrated in laboratory experiments. Limited laboratory information indicates a 1 to 2 year half life for multiple tested UF-bonded wood products, which is longer than the half life of a UF-bonded product tested singly. Decay profiles from laboratory studies, however, are not necessarily reflective of home exposures. Controlled studies in unoccupied homes, while limited, suggest a reduction of 25 to 40% in formaldehyde concentration during the first 4 to 8 weeks, and a half life of 18 to 24 months.

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The persistence of formaldehyde has been an important question in the study of formaldehyde concentrations in buildings and the study of emissions of formaldehyde from product sources. Concurrent with the concern about formaldehyde indoor levels in North America in the late 1970s and early 1980s, questions arose about how long formaldehyde would be emitted from sources and what could be learned about the formaldehyde concentration time profile in buildings. It became the lexicon of the technical community to label this aspect of the study of formaldehyde as "decay" and to measure decay by the half life of formaldehyde concentrations. The half life is the time required for formaldehyde concentration to reach half the magnitude of the first determined or original concentration.

Decay is examined from three perspectives. First formaldehyde decay levels by home age in field studies are reviewed. These studies have included both occupied and unoccupied homes; however, the vast majority of homes were occupied. Second is the study of formaldehyde emissions over time from specific products or groups of products in laboratory tests in dynamic chambers at controlled conditions approximating conditions in living spaces. Third is a discussion of a small amount of short-term decay data from controlled studies in unoccupied homes. Decay rates of formaldehyde are very different in these three perspectives. While the technical community generally understands these differences there remains confusion among some administrators, regulators, the popular press, and the public.

Formaldehyde concentrations and home age

Home studies

Home age concentration data has only been reported in some formaldehyde studies conducted during the past 25 to 30 years. Concentration by home age was one aspect of the SRI International review report on exposures to formaldehyde inside residences prepared for the U. S. Environmental Protection Agency (EPA) (Suta 1980). Formaldehyde concentrations were plotted by home age from 5 studies, 2 of which were European. It was found, in four studies for which decay formulas were computed, that the relationship fit exponential equation models indicating that half life ranged from 1 to 5 3/4 years. Suta recognized that half life did not necessarily represent the change in formaldehyde over time from the original formaldehyde sources by stating that the "differences between the half-lives that are derived from test data and home monitoring may partly result from the particleboard being added to older homes for repair and improvement."

A later EPA sponsored review, *Formaldehyde Exposures in Residential Settings: Sources, Levels, and Effectiveness of Control Options* (Versar 1988), included summaries of 37 studies: 25 in conventional homes and 12 in manufactured homes. Nine studies referenced in the report appendix contained data on decay. Versar used decay information reported by the original authors, calculated decay from a constant, or calculated decay based on home age data in determining half life. Information on 4 studies cited by Suta (1980) and 9 by Versar (1988) are included in **Table 1**. Data in these 13 studies show that half life varied from 1 year to 21.4 years.

In addition to the home studies in the decay analyses of Suda (1980) and Versar (1988), Syrotynski (1985) provided a table of formaldehyde concentration by home age data cells (1 to 12 months, 13 to 24 months, etc) in 148 complaint manufactured homes (study number 14 in **Table 1**). The data for 102 homes less than 84 months in age were plotted with the average concentration value for each age cell considered at the cell mid-points: 6 months, 18 months, etc. The 46 homes older than 84 months were placed in a single age cell category and were not included in this analysis. The exponential model provided the best fit of the averages in each data cell among linear, power and logarithmic models and predicted a half life of approximate 3.5 years.

The exponential has been the typical mathematical model used in relating formaldehyde concentration to home age. Where reported, data correlation R^2s varied from 0.07 to 0.99[1] with more than 50% of the R^2 values below 0.50 as noted in **Table 1**. Versar (1986) selected an aggregate of the Clayton and Wisconsin non-complaint manufactured home data as the best representation for decay for wood panel products in homes. The exponential model described by Equation **[1]** was the best fit of the combined data and resulted in a half life of 2.92 years. This decay value was used by Versar (1986) as an input in their formaldehyde exposure model for predicting formaldehyde concentration profiles in homes.

$$y = 0.504\, e^{-0.00065x} \qquad \textbf{[1]}$$

where:
y is formaldehyde concentration (C) in ppm, and
x is home age in days.

Versar (1986) reported that the correlation coefficient (R) for the equation is 0.59 and the R^2 value is 0.35, implying that home age determines approximately 35% of the home formaldehyde level, while all other factors determine the other 65% of variability.

Half life in home studies is influenced by the nature of the home population under study

Three home studies identified in **Table 1** had average or median concentrations under 0.10 ppm, yet the half life of formaldehyde in homes in these studies varied between 3.8 and 21.4 years: Reiland et al. (1985) at 3.8 years, Sexton et al. (1986) at 15.5 years, and Stock and Mendez (1985) at 21.4 years. The following suggests that the large disparity in observed half life is influenced by the differences in experimental design and the nature of the homes in the study.

Manufactured homes in the early to mid 1980s typically contained large quantities of particleboard decking and hardwood plywood paneling interior finish on most of the walls. In the California manufactured home study reported by Sexton et al. (1986), formaldehyde was collected for 1 week using Lawrence Berkeley Laboratory (LBL) designed passive monitors, available from Air Quality Research, with analysis by the chromotropic acid method. Versar (1988) provided a more detailed breakout of the number of home age cells than described by Sexton et al. (1986). Only 0.64% of the homes cited in Versar were less than one year old. The half life of formaldehyde concentration was 15.5 years. The weighted average concentration for the summer and winter measurements in the homes, at 0.075 ppm, was relatively low compared to other studies in manufactured homes during the period. This study was primarily a study of older homes containing high loading rates of UF-bonded wood panel building products.

[1] The 0.99 R^2 was only for homes 3 years or less in age in the Reiland et al. (1985) study. Homes over the full spectrum of age had much lower R^2 correlations.

The 0.07 ppm average formaldehyde concentration in the Texas study of 78 homes (Stock and Mendez 1985) was determined from data by collecting formaldehyde in a sampling train of two impingers, each containing 15 ml of deonized water, with analysis by chromotropic acid. No manufactured homes were included in a study that contained five categories of dwellings: conventional houses, energy efficient houses, apartments, condominiums, and energy efficient condominiums. There was no breakdown on the number of homes less than 1 year old, however, 14% of the homes were less than 2 years old. While there was a definite relationship between average formaldehyde concentration and home age, there were only small differences after homes reached 5 years in age. The reported formaldehyde half life was 21.4 years. No information was provided concerning the presence of formaldehyde containing building materials or components in furnishings or the loading rates of these possible sources. In the analysis of questionnaire responses only one significant factor was noted: residences with good kitchen ventilation, characterized as homes having an exhaust fan to the outside. Formaldehyde levels in homes with these fans were significantly lower than dwellings with lesser ventilation capacity. It is almost certain that the homes, in general, contained much lower loading rates of UF-bonded building products than the mobile homes evaluated by Sexton et al. (1986). Based on the type of dwellings in the study, it is anticipated that few homes contained hardwood plywood paneling.

The Bonneville Power Administration study (Reiland et al. 1985) was in electrically heated homes: 182 homes with energy efficient designs were compared with 348 homes with conventional designs. Formaldehyde concentrations were determined using LBL developed passive monitors with analysis by chromotropic acid. The median formaldehyde concentration was 0.092 ppm with energy efficient homes having slightly higher concentrations (11%) than control homes. This was attributed primarily to home age: the median age of energy efficient homes was 1 year while the median age of control homes was 3 years. About 5% of the homes were described as 0 years old and 40% were 1 year old. The average half life of formaldehyde concentrations as reported by Versar (1988) was 3.8 years. The shorter half life observed was, no doubt, influenced by the high percentage of newer homes included in the study as compared with the age profile of homes in the Sexton et al. (1986) and Stock and Mendez (1985) studies.

An example of the likelihood of a multi-phase process in the formaldehyde concentration decay profile is illustrated by the incompleteness of Versar's characterization of the Bonneville study (# 11 on **Table 1**) as having a correlation R^2 of 0.99 using the exponential model and comments by the authors of the Bonneville study (Reiland et al. 1985):

> "The fit was poor when all years were considered, and when just years four to ten were considered separately (R^2 = 0.54 and 0.14, respectively). The fit was much closer (R^2 =0.99) when the first 3 years were considered separately, yielding a time constant of 5.5 years . . . The first 3 years could represent decay of a strong, short-time constant source (such as cabinets or furniture) as observed in other studies . . . and the later years the decay of other slower sources (such as subflooring)."

The description of possible decay stages appears to be an over simplification of what occurs in homes. The effects of interactions of formaldehyde sources and sinks such as gypsum wall board and details on possible formaldehyde release mechanisms are not addressed in the Bonneville characterization.

Controlled laboratory and field studies

Dynamic chamber decay studies on UF-bonded wood products

There have been few designed laboratory decay studies on UF-bonded wood products. Several practical considerations act to prevent performing such projects. The ideal way of conducting these experiments is to keep formaldehyde source samples in dynamic chambers at some established conditions similar to what would occur in the field, and periodically extracting air for formaldehyde determinations during the life of the study. It is not practical in intermediate and long-term experiments to dedicate the use of a dynamic chamber, particularly a large chamber, for a study of decay that could take months, if not years. Moreover, the results could become irrelevant when there are advances in UF resin, or other technologies during the course of a long-term experiment that could affect decay. What generally has occurred is a potpourri of single or a few data points described by a relatively small number of authors. These data points are available where decay information was not the primary study objective. Notable exceptions are the decay studies described by Zinn, Cline, and Lehmann (1990); Baumann (2000); and the slow and fast decay project by Oak Ridge National Laboratory.

A project sponsored by the Composite Panel Association (CPA) consisted of large chamber tests performed at four laboratory sites: the CPA laboratory and at three particleboard manufacturer's laboratories (Zinn, Cline, and Lehmann 1990). The initial and subsequent formaldehyde emissions from the products were determined by testing particleboard at standard conditions of loading at 0.43 m^2/m^3 (0.13 $ft.^2/ft.^3$), 25° C (77° F), 50% RH and 0.5 air changes per hour (ASTM 1996, ANSI 1999) from formaldehyde collected in an aqueous solution of 1% sodium bisulfite in impingers with analysis by chromotropic acid. The average initial concentration of the 16 products in the study was 0.21 ppm, somewhat higher than the 0.15 to 0.16 ppm reported for particleboard as an average by CPA for the 1998-2000 period (CPA 2001). Data analysis consisted of comparing the fit of formaldehyde emissions over time with logarithmic, power, and exponential models. It was found that the logarithmic, Equation **[2],** provided the best fit. The correlation of the data to the logarithmic model is good with an overall average R^2 of 0.88 and a range of R^2s from 0.65 to 0.98 for the 16 products as shown on **Table 2**.

$$y = m \cdot (\ln t) + b \qquad \textbf{[2]}$$

where
y is the formaldehyde concentration in ppm,
t is the natural log (ln) function of time, and
b is a natural log function (ln) constant.

The average half life of the 16 products was 0.59 years (216 days) with a range of 0.225 to 1.02 years (82 to 371 days). Decay was more rapid during the earlier part of the experiment as half the reduction in average emissions between the initial concentration and the half life concentration occurred in only 0.104 years (38 days). This time period was referred to as the 3/4 life.

Initial formaldehyde concentration plotted by half life of formaldehyde for the products in the Zinn, Cline and Lehmann survey are shown in **Figure 1**. The logarithmic model provided a better fit of the data than either of the linear, power or exponential models with a correlation R^2 of 0.7099. The data clearly shows that there is a moderately strong influence of initial formaldehyde emissions on half life: generally, the higher the initial concentration the more rapid the half life. The data suggests that the half life of particleboard with an initial concentration of 0.15 ppm, typical of current product (CPA 2001), is about 9 months.

Baumann (2000) described formaldehyde decay for 12 particleboard and MDF products in a study of VOCs. Formaldehyde air samples were collected in an aqueous solution of 1% sodium bisulfite in impingers with analysis by chromotropic acid. Extrapolation between the data points was required for an estimate of half life. Information on these findings is shown in **Table 3.** Except for four tests (4B, 5B, 9B, and 11B), the half life was less than 1 month. Some of the conditions of test may have contributed to the shorter half life than that reported by other observers. Testing was performed in small 0.053 m^3 (1.87 ft^3) stainless steel dynamic chambers. A desirable experimental feature was that samples were housed in the test chambers for the course of the testing: ~ 6 weeks or less. The surface area of the samples was 0.021 m^2 (0.226 ft^2) providing for a loading rate of 0.40 m^2/m^3 (0.12 $ft.^2/ft.^3$), only slightly lower than the standard 0.43 m^2/m^3 (0.13 $ft.^2/ft.^3$) for particleboard (ANSI 1999), but higher than the standard 0.26 m^2/m^3 (0.08 $ft.^2/ft.^3$) loading rate for MDF (ANSI 2002). Temperature at 23^o C (73.4^o F) and relative humidity at 45 ± 5% are consistent with typical indoor conditions. The edges of the samples were sealed with two coats of a saturated solution of sodium silicate, minimizing the likelihood of increased emissions from the edges and ends of samples that could accelerate decay. The 1.13 air change per hour rate used in these experiments is greater than the more common 0.50 AC/hour standard large chamber rate (ASTM 1996).

Information on other laboratory experiments describing formaldehyde concentrations over time is shown in **Table 4**. Some data that appeared in the Versar (1988) review included preliminary information (Zinn 2005) from Zinn, Cline, and Lehmann (1990). To avoid duplication none of the data that could have appeared in the 1990 paper are shown in the table. Experiments that contained less than three concentration/time points are also not included in **Table 4**. Experiments were performed under a variety of loading rates and conditions as described in the footnotes to the table. Except for data on multiple product tests (number 11 and 15), the average half life of the 7 particleboard products was about 1 year, slightly longer than the findings of Zinn, Cline, and Lehmann (1990). The average half life of the 5 MDF products was also about 1 year.

In an experiment performed after the Versar (1988) review was published, Sundin and Roffael (1989) found in a dynamic chamber experiment that formaldehyde emissions of UF-bonded particleboard decreased by 50% in 1 year with testing at three-month intervals. The particleboard tested contained a formaldehyde-capturing agent or scavenger, Kenosize FR 4514. Since the samples were wrapped in polyethylene foil between tests during the course of the study, the reported 1 year half life was likely longer than would have been observed if the samples had been exposed to air during the study period.

Two test series in **Table 4** involved multiple products tested over time. Test number 11 combined particleboard, hardwood plywood paneling and MDF with an observed half life of 1.52 years, much greater than the half life of any of the three products tested singly, with a range 0.62 to 1.08 years (Matthews et al. reported by Versar 1988). The air change rate of the tests on the single products was different than that of the three products tested together making the single product and multiple product comparison problematic. A separate study by other observers (Groah and Gramp 1988) indicates a half life of 2.10 years for three products tested together (test number 15). The half life for these products tested singly– particleboard, hardwood plywood paneling and MDF– ranged from 1.07 to 1.40 years. The half life values in this series are conservative: samples of each product were dead stacked ~8 weeks between the initial and second chamber test, thus, the half life would likely be less than that stated.

Fast decay and slow decay

A series of Oak Ridge National Laboratory (ORNL) laboratory and field experiments investigated the persistence of formaldehyde (Gammage and Matthews 1988). The "fast" decay procedure, performed at 23^o C (73.4^o F) and 50% RH, was designed to modify the air change rate to maintain formaldehyde levels in a laboratory test room at ~0.1 ppm (0.05 - 0.11 ppm). This procedure was designed to determine the assumed inherent decay characteristics of the product. Formaldehyde surface emission monitors (FSEM) were used to sample emissions from 5 MDF, 7 particleboard, and 4 hardwood plywood products. A half-life of 21 months for MDF, 15 months for particleboard, and 11 months for hardwood plywood were determined.

The "slow" decay concept was designed to "simulate a potential indoor compartment with large quantities of pressed-wood products and moderate exchange with outdoor air." Testing was in a large 117 m^3 (4132 ft^3) chamber at 0.40 ± 0.03 air changes per hour and at a total loading rate of 2.7 m^2/m^3 (0.82 $ft.^2/ft.^3$) with formaldehyde collected on a molecular sieve with pararosaniline analysis. Initially the weaker emitters among various MDF, particleboard, and hardwood plywood products were anticipated to suppress emissions from the stronger emitters resulting in a prolonged decay period. A half life for the three combined products of 28 ± 2 months was observed after correcting concentrations for 23^o C (73.4^o F), 50% RH, and 0.4 air changes per hour.

These studies were augmented by experiments in four unoccupied research homes in Karns, Tennessee (Gammage and Matthews 1988). Formaldehyde concentration data in these homes were normalized to 23° C (73.4° F), 50% RH, and 0.2 air changes per hour. An exponential decay model indicated a half life of 19 ± 4 months, which was less than that observed in the "slow" decay laboratory study. Primary formaldehyde sources in the homes were carpet covered particleboard underlayment and kitchen cabinets containing industrial particleboard components. The experimental homes were not otherwise furnished. The total loading rate of the formaldehyde sources was 0.29 m^2/m^3 (0.09 $ft.^2/ft.^3$), much lower than the very high loading of 2.7 m^2/m^3 (0.82 $ft.^2/ft.^3$) in the "slow" decay study.

Discussion - concentration/home age and controlled laboratory studies

Formaldehyde concentration by home age studies clearly demonstrates that newer homes with new building products and other new formaldehyde sources have higher formaldehyde levels than older homes within the same home type. There are, however, limitations on valid extensions that can be made from this data, and to what extent mathematical models derived from such data can be used to predict decay profiles over time for products, or for general populations of homes. Findings from formaldehyde concentration by home age studies reveal little if anything about the decay characteristics of a single product because most homes have multiple sources. Moreover, newer sources of formaldehyde are continually being brought into homes as they age. This distorts the shape of concentration/home age decay curves, sometimes presumed to represent decay characteristics of the original formaldehyde sources. Thus, points on the decay curve can be elevated in older homes and artificially low in newer homes because the introduced products are not present.

In a study for the Formaldehyde Institute, Whippie (1986) describes some interpretational difficulties of using home age/formaldehyde data as a means of approximating formaldehyde emission decay from wood products:

- Most home age studies have little or no information about product loading rates, source strength of formaldehyde emitters, air change rates, and other information important in making product decay rate assessments.

- Most home age studies contain data generated weeks or months after homes are completed and thus bypass the first phase, or most of the first phase in the decay process.

- In home age studies conducted during the 1980s, formaldehyde concentrations in older homes were likely higher because higher emitting wood based panels were used. This tends to flatten the formaldehyde decay curve when older homes are compared to newer homes.

- Home age/concentration studies generally make no allowance for the introduction of new formaldehyde emitters in the home, such as could occur with the purchase of furniture after the homes are finished. During the life of the home, sources from projects such as remodeling kitchens or adding a paneled room can also be important as the home ages.

Factors such as the use of unvented gas fuel appliances and cigarette smoking result in the episodic release of formaldehyde. Formaldehyde from these types of sources does not change in a consistent way with time, but can influence the shape of the formaldehyde concentration decay curve. Homes in certain urban areas can be subject to higher levels of outside ambient formaldehyde than homes in rural areas. Outside ambient levels can also be influenced by seasonal changes in meteorological patterns and are typically higher in the winter than summer and higher in the daytime than at night (CARB 1992). Thus, the times during the day and year when air samples are taken can influence the observed formaldehyde concentration profile during the study.

In a critique of relating formaldehyde concentrations to home age and the interpretation of such data, Groah and Zinn (1991) stated "the low correlation coefficients of fitted equations derived from examining home age/formaldehyde concentration data are accompanied by tortuous efforts to fit simple exponential and power curve models to a complex process." Information in **Table** 1 is used to illustrate the possible aberrations in fitting simple mathematical model curves to average concentration and half life data by using the ten studies in the table containing sufficient half life information (studies #1, 2, 3, 5, 6, 7, 9, 11, 13, and 14). **A**mong linear, logarithmic, exponential and power models, the two models exhibiting the best correlation to this 10 study data set were the exponential and power models. The data was slightly better correlated with the power model with a R^2 of 0.6112 as compared to the R^2 of 0.5561 for the exponential model as demonstrated in **Figure 2**. As a predictor, the power model suggests a half life of about 5 years from year 2.5, whereas the exponential model indicates a half life of about 10 years from year 2.5[2].

Groah and Zinn (1991) suggested a three-phase formaldehyde decay process. A rapid flash-off during the first weeks after construction or installation of the formaldehyde products represents the first phase. Test procedures and emission guidelines sometimes anticipated this early emission rate phase as being uncharacteristic of concentrations to which occupants of spaces are exposed. For example, conditioning periods of 7 days for samples were established for North American test methods for determining formaldehyde concentrations from wood products (ASTM 1994, ASTM 1996).

The first decay phase is followed by a less steep decline that occurs from a few months to perhaps a year or more and includes release of some free formaldehyde but is probably dominated by weak-bonded formaldehyde to constituents in wood, including additional mechanisms related to the cured glue bond. The last and probably final phase or continuum of phases is more gradual and is probably influenced by complex interactions related to the cured urea-formaldehyde glue bond, the wood itself, and wood moisture all related to home seasonal humidity factors, loading rates, and background levels in the home.

[2] Year 2.5 is near the shortest average half life of 2.33 years of any study appearing in Table 1.

Laboratory studies have sometimes been characterized as unrealistic because they establish decay profiles within a pristine environment and do not reflect the home where other emitters may be present. As previously stated, it is generally not practical to retain UF-bonded wood product samples in large chambers for the duration of intermediate to long term decay experiments in laboratories. Samples, however, are typically stored in indoor locations where there are background levels of formaldehyde. Zinn, Cline, and Lehmann (1990) reported that the average background formaldehyde levels in two of the four laboratory testing sites were 0.08 ppm (site A) and 0.06 ppm (site C) where samples were stored between large chambers tests. It is likely that formaldehyde levels at all four storage sites were higher than would be anticipated at many home construction sites. Formaldehyde concentrations during storage were all probably greater than home background levels when only minor formaldehyde sources are present. The Consumer Products Safety Commission (1997) has suggested that "formaldehyde is normally present at low levels, usually less than 0.03 ppm, in both outdoor and indoor air."

Short-term control studies in unoccupied homes

Two experiments in manufactured homes were conducted in the early 1980s, each over an approximate two-month period as described by Groah, Gramp, Garrison, and Walcott (1985). A joint HPVA/CPA team tested two homes in 1980 with air sampling using impingers containing an aqueous solution of 1% sodium bisulfite. Formaldehyde was determined using the chromotropic acid procedure. The four 1981 homes were also described in the U. S. Department of Housing and Urban Development sponsored study (Singh et al. 1982). Both chromotropic acid and pararosaniline were used in analyzing air samples in these 4 homes. Formaldehyde levels in the six homes were somewhat erratic over the first several weeks as emissions from formaldehyde sources became in equilibrium with the sinks and weaker emitters that tended to initially suppress emissions from the stronger sources. The average of the first three-week sampling period was used as the initial concentration period to allow for some equilibrium adjustment. The average formaldehyde concentrations during weeks 6, 7 and 8 (homes 1 and 2) and weeks 7, 8, and 9 (homes 3 - 6) represented the comparison period as shown in **Table 5**. All concentrations were adjusted for a temperature of 25^{o} C (77^{o} F) using the technique described by Berge et al. (1980). The average decrease in formaldehyde concentration over this period– effectively about 5 - 6 weeks– was 40% with a range of 35 to 48%. All of the homes contained particleboard decking and hardwood plywood wall paneling on most of the interior walls.

The EPA sponsored pilot home study (Hare et al. 1996, Koontz et al. 1996) consisted of one "medium" (run 7 in **Table 5**) and two "high" (runs 8 and 9) loading configurations in a single conventional home. Four products– particleboard underlayment, hardwood plywood wall paneling, kitchen and vanity cabinets, and partition doors– were the primary formaldehyde sources. Loading rates of the UF-bonded wood panel building products and components in cabinets and doors in this study are probably typical of products found in homes in 2005 when the aggregate of the four wood based sources are present. Formaldehyde concentrations at day 7 and day 33 are displayed and compared in **Table 5** as a measure of short-term decay. The decrease in formaldehyde concentration for runs 8 and 9 were fairly consistent with a 25% and 33% decline, respectively. There was an increase in formaldehyde concentration in run 7 at 29%; however, this was likely a data aberration. The surface area of the gypsum board on the walls and ceiling in this experimental home was greater than the total surface areas of the formaldehyde sources combined and was identified as an important sink (Hare et al. 1996, Koontz et al. 1996). During the first loading (run 7 on **Table 5**) the gypsum wall and ceiling finish was a net absorber of formaldehyde over the initial period of the test thus depressing apparent emissions from the combined emitters during the first weeks of the study. During the latter days of experiment # 7, the gypsum board likely became bulked or partially bulked with absorbed formaldehyde, and perhaps also became an emitter. These interactions probably skewed the concentration over the short one-month time period within which data was collected, thus inverting the decay curve. The gypsum wallboard was not replaced between the three runs (7, 8, and 9). In runs 8 and 9 gypsum wallboard already had been bulked with formaldehyde from previous runs. Results from runs 8 and 9 were likely more reflective of decay from the original sources of formaldehyde.

Conclusions

Analysis of formaldehyde by home age confirms that newer homes generally have higher levels of formaldehyde. In such studies, decay is more rapid when the home population contains homes in all age classes, including a reasonable number of new homes.

In general, the higher the average formaldehyde concentration in home age studies the more rapid the decay. In controlled laboratory studies the higher the initial emission the more rapid the decay.

Concentration by home age studies provides useful information about exposures to occupants in homes. Inherent limitations of such studies generally make them unsuitable for interpreting changes in formaldehyde emissions over time from the original UF-bonded wood products and other product sources.

The Karns, Tennessee experimental homes project indicated a half life of about 19 months at moderate loading rates of formaldehyde sources. This study in unoccupied homes was not confounded by the introduction of additional formaldehyde sources during the study period.

In controlled laboratory studies the half life of formaldehyde concentration varies from less than 1 month to about 1 year for particleboard. A large chamber laboratory study performed at four test sites on 16 particleboard products suggest that the half life of current typical particleboard with ~0.15 ppm formaldehyde concentration at standard test conditions is about 0.75 years (9 months).

There is limited data on formaldehyde decay rates from hardwood plywood and MDF. The data available suggests the half life in hardwood plywood is probably slightly more rapid than particleboard. Data for MDF indicates that the half life is probably slightly less rapid than particleboard.

Very limited laboratory data on decay profiles of multiple UF-bonded wood products show half life periods of about 18 to 24 months for the decay of particleboard, hardwood plywood, and MDF tested together.

Short-term decay information is available from a few controlled studies in unoccupied homes. These studies generally indicate a reduction of formaldehyde concentration of about 25 to 40% over the first several months. Caution is advised in interpretational extensions from these studies: most available data is from earlier manufactured homes containing uncharacteristically high loading rates of UF-bonded formaldehyde sources, compared with current loading rates in both manufactured and conventional homes.

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