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Formaldehyde Emissions from Low Emitting Pressed-Wood Products and the Effectiveness of Various Remedial Measures for Reducing Formaldehyde Emissions

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Abstract

This report presents the results of chamber tests to determine the emission of formaldehyde from several low emitting US and foreign manufactured particle boards and the effectiveness of various remedial actions on the emission of formaldehyde from pressed wood products. Pressed wood products considered to represent the most recent (as of the fall of 1985) US and foreign manufacturing technology were obtained from seven US manufacturers and six European manufacturers representing four countries. Most of the pressed wood products tested were underlayment (29) and low emitting medium density fiber board (8). Two (2) industrial particle boards were tested. The technologies identified by the product's manufacturer used to reduce the emissions of formaldehyde were 1.) low fuming UF resins, 2.) low fuming UF resins with a post press scavenger (usually anhydrous ammonia) and 3.) the addition of a chemical additive. The remedial measures evaluated consisted of the application of coatings and barriers. The coatings tested for their effectiveness in reducing formaldehyde emissions were polyurethane, nitrocellulose lacquer and latex paint. The barriers evaluated were carpeting with foam padding and carpeting with waffle padding.

1 Introduction

The National Bureau of Standards (NBS) has recently [1] undertaken a series of laboratory tests for the Consumer Product Safety Commission (CPSC) to validate models used to predict formaldehyde (HCHO) emissions from pressed wood products. These tests have shown that for bare pressed wood products there is good agreement between IAQ models and measurements in a simulated house. However, a person is not often exposed directly to the emission from a pressed wood product. For example, when particle board underlayment is used as a flooring material, it is usually covered with tile or a carpet and padding. Another example could be a kitchen cabinet made with medium density fiberboard (MDF) where the MDF is usually finished with a coating or covered with another material.

Also, there have been new developments in the manufacture of pressed wood products which reportedly have lead to a reduced emission of formaldehyde. For this reason NBS with the assistance of the US Environmental Protection Agency (EPA) received from both US and foreign manufacturers samples of their lowest emitting pressed wood products. A total of 12 foreign boards and 33 recently manufactured US boards were obtained. Previously, CPSC had obtained for NBS 6 samples of low emitting medium density fiber board (MDF). These products were evaluated in specially designed medium size dynamic chambers (see ref. [1] for details on the construction, operation and test procedures used to determine HCHO emissions in dynamic chambers) to obtain their emission rates as a function of formaldehyde level at the standard conditions of 23 °C, 50% relative humidity. Several products (underlayment, industrial particle board and low emitting MDF) were coated with polyurethane, nitrocellulose lacquer and latex paint to determine the effect of these coatings on their formaldehyde emissions. The effect of padding and carpeting on the emission of formaldehyde from underlayment was also investigated.

2 Brief Summary of the Model

As discussed in reference [1], the emission rate ER (in mg/m²•h) of HCHO from a pressed wood product can be predicted from the equation:

$$ER = \alpha - \beta c \qquad (1)$$

where α and β are parameters which can be determined from laboratory measurements in the medium size dynamic chambers and c is the concentration of HCHO in the chamber (in ppb). In general α and β are functions of temperature and humidity. In this report the intercept α and the cutoff concentration at which the emission rate goes to zero:

$$cutoff = \frac{\alpha}{\beta} \qquad (2)$$

are reported for each product. The determination of these two parameters allows the prediction of HCHO levels in buildings under various loadings and air exchange rates using a mass balance model (see reference [1]).

In the tables and graphs in this report, values for α (call the intercept) and the cutoff are reported as well as ser_{100}, the emission rate at standard conditions (23°C, 50% RH and an ambient concentration $c = 100$ ppb) and the correlation coefficient R^2 and the standard error of a least squares fit of equation (1) to the chamber data for each product tested. The use of these parameters for predicting the HCHO levels in buildings due to emissions from pressed wood products is summarized in the appendix of this report.

3 Summary of Previous Data from Test for CPSC

For completeness, data from the tests performed for CPSC in the research to validate models for predicting formaldehyde levels in homes are included in this report (see references [1] and [2] for a more complete discussion of these data). Table 1 contains the results of the determination of HCHO emissions from underlayment at 23°C, 50% RH. Table 2 contains the results of similar measurements at 26°C, 60% RH. It should be noted in Table 1 that tests indicated by T1 and T2 were performed prior to subjecting the boards to the higher temperature and humidity. The boards used in the CPSC tests were manufactured at one facility in June of 1984. The tests indicated by T3 and T4 were at the higher temperature and humidity conditions. The tests indicated by T5 occurred after returning the specimens to the conditions of the test T1 and T2. The data in Table 2 show that at a temperature of 26°C and 60% RH, the emissions of formaldehyde from these products at 100 ppb (ser_{100}) occurred at rates greater than three times the rate at 23°C, 50% RH. This increase in temperature and humdity alos caused the cutoff concentrations to increase by more than 50%. It is also worthy of note that the emission rates of test T5 were all higher than those of tests T1 and T2 for all products.

4 The Effects of Carpets and Padding on Formaldehyde Emissions

Seven particle board underlayments were selected for an experiment to determine the effect of carpets and padding on the emission of HCHO from underlayment. The carpets and padding were initially tested in the medium size chambers in order to determine if they by themselves emitted any significant level of formaldehyde. It was found that they did not. Four underlayments were covered with carpet and padding in May 1986. Two boards were covered with foam padding and carpet, two with waffle padding and carpet and three were left uncovered to serve as controls. After four months, the emission rates of formaldehyde from the composite of underlayment, padding and carpet were measured in the medium size chambers. The results of these tests are summarized in Table 3. Also included in Table 3 are the results of covering underlayment U5 of the CPSC tests with a carpeting and a foam padding. As can be seen from the data of Table 3, the composite of foam padding and carpet had little effect on the emission rate of formaldehyde from the underlayment. However, the composite with carpet and waffle padding reduced the HCHO emission of the underlayment to approximately 30% of the control underlayment.

5 The Effectiveness of Coatings in Reducing Formaldehyde Emissions

In order to test the effectiveness of various paint-like coatings for reducing HCHO emissions from pressed wood products, several specimens of underlayment, industrial particle board and low emitting medium density fiber board were coated with latex paint, nitrocellulose lacquer and a polyurethane finish. Samples of the underlayment, industrial particle board and low emitting MDF were first evaluated without any coating. Some were then coated with latex paint, nitrocellulose lacquer and polyurethane and retested. The results of this test sequence are shown inf Figures 1 to 12 and summarized in Tables 6, 7, 8 and 10. Also included in Table 6 are the results of testing two underlayments received from Ball State University, one of which had an unknown coating. These results of these tests showed that nitrocellulose lacquer reduced the emission rate of formaldehyde to 69% of the precoated value for underlayment, 53% for industrial particle board and 26% for low emitting medium density fiber board. Polyurethane reduced the emission rate of underlayment to 18% of the precoated value and to 6% for the low emitting medium density fiberboard. The polyurethane and latex coated industrial particle board showed increases of 140% and 150% respectively. The latex coating had little or no effect on the emission rates of underlayment and medium density fiberboard (95% and 90% respectively).

6 The Emission Rates of Low Emitting Medium Density FiberBoard

Figure 9 and Table 5 contain the results of testing five specimens of regular MDF manufactured in the United States. From the data of Table 5 regular MDF emits formaldehyde at rates of 0.995 to 1.549 mg/m²•h. These data compare favorably with the data of reference [1] (1.36 mg/m²•h). The untreated emission rate from low emitting MDF are given in Table 8. These range from 0.429 to 0.668 mg/²•h, approximately half those of regular MDF, though still high compared with underlayment.

7 Summary of New Technology US Manufactured Particle Boards

Thirty-one (31) particle boards were received from seven US manufacturers in response to a request by EPA to provide two samples of low emitting pressed wood products. These were classified by the manufacturers as having 1.) low fuming UF resin, 2.) low fuming UF resin with a scavenger 3.) low fuming resin industrial particle board and 4.) underlayment with a chemical additive. Two boards from one manufacturer contained no information on the remedial measures used in the manufacture of the boards. The data from these products are given in Table 4 and Figures 13 and 14. The boards with low fuming resin have emissions rate ranging from 0.052 to 0.367 mg/m²•h, with five boards from two manufacturers having emission rates less then 0.1 mg/m²•h. The emission rates of products with low fuming resins and a scavenger ranged from 0.102 to 0.254 mg/m²•h.

8 Emissions from Foreign Particle Boards

Twelve particle boards were received from six manufacturers in four European countries. The results of the evaluation of these products are shown in Table 9 and Figures 15 through 20. Products of three countries, France, Sweden and Belgium, had very low emission rates (0.012 to 0.112 mg/m²•h). These boards also have very low cutoff concentrations (less than 150 ppb). The boards for Norway had relatively low cutoff concentrations (less than 317 ppb) but showed a sharp increase in emission rate as a function of ambient concentration (see Figures 14 and 15).

9 Conclusions

The data from this series of experiments have shown that various measures can be effective in reducing the emission of formaldehyde from pressed wood products

- Carpets with waffle padding can reduce HCHO emissions from underlayment by 60%
- Polyurethane coating can reduce HCHO emissions by 80% on underlayment and low emitting MDF
- Nitrocellulose lacquer can reduce HCHO emissions by 30% for underlayment, 75% for low emitting MDF and 50% for industrial particle board.
- Swedish, French and Belgium manufactured boards tested in this project can have emission rates less than 0.1 mg/m²•h and cutoff concentrations less than 125 ppb.
- Some US manufactured particle boards have characteristics approaching the best European boards.

On the negative side, there were several measures which were not effective in reducing HCHO emissions. Latex paints (as expected) do not decrease HCHO emission from pressed wood products. Coatings can have a varying effect depending on the product coated. Foam padding did not decreased HCHO emissions from underlayment. Some supposedly low emitting pressed wood products still have significant emission rates

References

[1] Grot, R.A., S. Silberstein, K. Ishiguro, "Validation of Models for Predicting Formaldehyde Concentrations in Residences Due to Pressed Wood Products, Phase I", NBSIR 85-3255, Gaithersburg, MD, 1985

[2] Silberstein, S., R.A. Grot, "Validation of Models for Predicting Formaldehyde Concentrations in Residences Due to Pressed Wood Products, Phase II", NBSIR 88-XXXX, Gaithersburg, MD, in preparation.

Appendix

A Model for Predicting HCHO Levels in a Single Zone Building Using Chamber Data

As shown and verified in references [1,2], the following model, derived using mass balance principles, can adequately predict the equilibrium level C_o of HCHO in a single zone, well mixed building:

$$C_o = \frac{\hat{\alpha}}{Ai + \beta} \tag{A1}$$

where

$$\hat{\alpha} = \frac{1}{\rho V} \sum_{\forall products} \alpha_i \cdot area_i \tag{A2}$$

$$\beta = \frac{1}{\rho V} \sum_{\forall products} \beta_i \cdot area_i \tag{A3}$$

where

Ai is the air change rate in h^{-1}

$area_i$ is the exposed area of the pressed wood product in m^2
and
α_i and β_i are the parameters of equation (1) determined from the chamber tests.

$\rho = 0.0012$ mg/cm^3 (density of formaldehyde)

V is the volume of the building in m^3

The concentration determined from equation (A1) is in ppb.

Tables A.1 and A.2 contain the predicted concentrations for a house maintained at 23°C, 50% RH completely floored with US and foreign pressed wood products. These predicted results are shown in Figures 21 to 32.

Table 1. Underlayment Obtained for CPSC Tests

23°C 50% RH

Board #	Date	intercept	cutoff	R^2	ser_{100}	Std. error
		mg/m²•h	ppb		mg/m²•h	mg/m²•h
U1-T1	10/01/84-11/16/84	0.209	205	0.912	0.107	0.020
U1-T2	02/09/85-02/14/85	0.237	241	0.914	0.138	0.029
U1-T5	04/18/86-04/28/86	0.310	393	0.994	0.231	0.009
U2-T1	11/10/84-11/13/84	0.328	268	0.994	0.205	0.014
U2-T2	02/20/85-02/26/85	0.211	270	0.789	0.133	0.025
U2-T5	04/09/86-04/18/86	0.242	313	0.989	0.165	0.008
U3-T5	03/07/86-03/19/86	0.250	324	0.895	0.173	0.029
U4-T1	09/28/84-11/14/84	0.213	261	0.371	0.131	0.062
U4-T2	03/01/85-03/05/85	0.213	277	0.866	0.136	0.026
U4-T5	04/18/86-04/28/86	0.276	359	0.969	0.199	0.018
U5-T1	10/01/84-11/12/84	0.160	260	0.724	0.099	0.025
U5-T2	02/15/85-02/20/85	0.168	283	0.883	0.109	0.018
U5-T5	03/07/86-03/19/86	0.234	337	0.901	0.164	0.019
U6-T1	11/10/84-11/12/84	0.266	222	0.993	0.146	0.012
U6-T2	02/15/85-02/20/85	0.211	262	0.985	0.130	0.009
U6-T5	04/09/86-04/18/86	0.262	345	0.974	0.186	0.015
U7-T1	11/16/84-02/08/85	0.243	274	0.813	0.154	0.027
U7-T2	03/28/85-04/02/85	0.232	266	0.813	0.145	0.039
U7-T5	03/07/86-03/19/86	0.262	308	0.913	0.177	0.026
U7-T6	10/22/86-10/30/86	0.162	212	0.975	0.085	0.012

Table 2. Underlayment Obtained for CPSC Tests

26°C 60% RH

Board #	Date	intercept	cutoff	R^2	ser_{100}	Std. error
		$mg/m^2 \cdot h$	ppb		$mg/m^2 \cdot h$	$mg/m^2 \cdot h$
U1-T3	05/09/85-07/09/85	0.377	395	0.933	0.281	0.038
U1-T4	10/30/85-11/08/85	0.663	404	0.976	0.499	0.040
U2-T3	05/09/85-07/15/85	0.432	412	0.880	0.327	0.057
U2-T4	11/08/85-11/13/85	0.418	413	0.885	0.317	0.051
U4-T3	05/04/85-07/15/85	0.457	433	0.830	0.351	0.077
U5-T3	05/04/85-07/09/85	0.365	408	0.882	0.275	0.048
U5-T4	10/30/85-11/08/85	0.428	383	0.999	0.316	0.007
U6-T3	05/09/85-07/13/85	0.489	436	0.903	0.377	0.067
U6-T4	11/08/85-11/13/85	0.431	484	0.972	0.342	0.026
U7-T3	07/22/85-08/02/85	0.386	880	0.492	0.342	0.096
U7-T4	11/13/85-11/19/85	0.319	467	1.000	0.250	0.002

Note:

U1 to U7 indicate underlayment specimens 1 through 7
T1 to T4 indicate test

Table 3. Emissions from Carpeted Underlayment

Carpet with Foam Padding

Board #	Date	intercept	cutoff	R^2	ser_{100}	Std. error
		mg/m²•h	ppb		mg/m²•h	mg/m²•h
C1	11/06/86-11/24/86	0.206	263	0.874	0.128	0.031
C2	11/06/86-11/24/86	0.188	382	0.930	0.139	0.020
U5-T2C	03/28/85-04/02/85	0.161	256	0.798	0.098	0.030

Carpet with Waffle Padding

Board #	Date	intercept	cutoff	R^2	ser_{100}	Std. error
		mg/m²•h	ppb		mg/m²•h	mg/m²•h
C3	11/06/86-11/24/86	0.112	180	0.856	0.050	0.019
C4	11/06/86-11/24/86	0.118	216	0.927	0.064	0.014

Untreated Control Underlayment for Carpets

Board #	Date	intercept	cutoff	R^2	ser_{100}	Std. error
		mg/m²•h	ppb		mg/m²•h	mg/m²•h
C5	10/22/86-10/30/86	0.310	369	0.995	0.226	0.009
C6	10/22/86-10/30/86	0.232	365	0.985	0.169	0.012
C7	10/22/86-10/30/86	0.196	347	0.971	0.140	0.015

Note:

C1 through C7 indicated underlayment boards used in carpet experiment.
U5-T2C is carpet covered underlayment U5 of Table 1

Table 4. New Technology US Manufactured Particleboards

Board #	Date	intercept	cutoff	R^2	ser_{100}	Std. error
		mg/m²•h	ppb		mg/m²•h	mg/m²•h
Unknown Classification						
USM1-1A	01/13/87-01/30/87	0.287	334	0.858	0.201	0.038
USM1-1B	01/13/87-01/30/87	0.276	350	0.913	0.197	0.030
Low Fuming UF Resin Industrial Particle Board						
USM2-1A	05/01/86-06/11/86	0.316	649	0.669	0.268	0.075
USM2-1B	05/01/86-06/11/86	0.230	582	0.675	0.191	0.053
Low Fuming UF Resin and Scavenger						
USM3-1A	04/08/86-05/13/86	0.171	973	0.224	0.153	0.061
USM3-1B	04/08/86-05/13/86	0.173	597	0.786	0.144	0.030
USM3-2A	06/15/87-06/26/87	0.254	342	0.943	0.180	0.022
USM3-2B	05/15/87-05/29/87	0.160	391	0.942	0.119	0.013
USM3-3A	04/08/86-05/13/86	0.274	347	0.969	0.195	0.016
USM3-3B	04/08/86-05/13/86	0.238	379	0.778	0.175	0.031
USM4-1A	04/08/86-05/13/86	0.187	634	0.763	0.158	0.034
USM4-1B	04/08/86-05/13/86	0.197	576	0.977	0.162	0.010
USM5-1A	06/01/87-06/15/87	0.331	431	0.989	0.254	0.014
USM5-1B	05/15/87-05/29/87	0.184	226	0.986	0.102	0.007
Low Fuming UF Resin						
USM2-2A	05/27/86-08/10/86	0.156	386	0.419	0.115	0.039
USM2-2B	05/27/86-08/10/86	0.178	403	0.524	0.134	0.049
USM2-3A	05/01/86-06/11/86	0.150	646	0.469	0.127	0.059
USM2-3B	05/01/86-06/11/86	0.270	582	0.806	0.224	0.048
USM6-1A	03/30/87-04/18/87	0.211	180	0.974	0.094	0.010
USM6-1B	03/30/87-04/18/87	0.183	185	0.978	0.084	0.008
USM6-2A	03/19/86-04/07/86	0.182	383	0.322	0.142	0.060
USM6-2B	03/19/86-04/07/86	0.200	487	0.264	0.159	0.077
USM6-3A	12/20/86-01/12/87	0.298	295	0.937	0.197	0.024
USM6-3B	01/13/86-01/30/87	0.288	365	0.946	0.209	0.024
USM7-1A	01/09/87-02/06/87	0.128	312	0.923	0.087	0.012
USM7-1B	01/09/87-02/06/87	0.116	208	0.979	0.060	0.006
USM7-1C	01/09/87-02/06/87	0.097	215	0.939	0.052	0.009
Chemical Additive						
USM6-4A	12/20/86-01/12/87	0.447	375	0.945	0.328	0.031
USM6-4B	12/20/86-01/12/87	0.425	356	0.969	0.305	0.025

Note:

USM1 through USM7 indicates US manufacturers 1 through 7
The number after the dash indicates the product sample
The final letter (A,B or C) indicates the specimen (usually two were provided for each product.

Table 5. Regular US Manufactured MDF

Board #	Date	intercept	cutoff	R^2	ser_{100}	Std. error
		mg/m²•h	ppb		mg/m²•h	mg/m²•h
MDF1	06/01/87-06/15/87	1.735	934	0.995	1.549	0.038
MDF2	06/01/87-06/15/87	1.137	796	0.984	0.994	0.045
MDF3	05/15/87-05/29/87	1.311	970	0.967	1.176	0.078
MDF4	06/01/87-06/15/87	1.293	1371	0.998	1.199	0.055
MDF5	05/15/87-05/29/87	1.435	1782	0.984	1.354	0.062

Note:

MDF1 through MDF5 indicated medium density fiber board specimens 1 through 5 all of the same US manufacturer

Table 6. Emissions from Underlayment in Coating Experiment

Board #	Date	intercept	cutoff	R^2	ser_{100}	Std. error
		mg/m²•h	ppb		mg/m²•h	mg/m²•h
		Untreated				
all untreated		0.211	400	0.420	0.158	0.036
CU1	10/04/85-10/25/85	0.241	415	0.727	0.183	0.025
CU2	07/20/85-07/25/85	0.208	329	0.913	0.145	0.020
CU3	7/20/85-7/24/85	0.201	285		0.130	
		Lacquer-treated				
all lacquer		0.152	356	0.520	0.109	0.024
CU4	10/04/85-10/25/85	0.109	463	0.781	0.085	0.010
CU2	10/07/85-10/25/85	0.212	287	0.781	0.138	0.021
		Polyurethane-treated				
CU5	10/07/85-10/9/85	0.025	1218		0.028	
		Latex-treated				
all latex		0.215	331	0.75	0.150	0.020
CU3	10/04/85-10/26/85	0.216	294	0.741	0.142	0.023
CU6	10/04/85-10/25/85	0.223	342	0.885	0.158	0.014
		Particle Boards Received from Ball State University				
		Unknown Coating				
CU7	03/30/87-04/18/87	0.035	121	0.710	0.006	0.009
		Untreated				
CU8	03/30/87-04/18/87	0.310	337	0.979	0.218	0.013

Note:

CU1 through C8 indicate underlayment boards used in coating experiment.

Table 7. Emissions from Industrial Particle Board

Board #	Date	intercept	cutoff	R^2	ser_{100}	Std. error
		mg/m²•h	ppb		mg/m²•h	mg/m²•h
Untreated						
all untreated		0.302	741	0.490	0.261	0.063
IPB1	07/18/85-07/26/85	0.370	724	0.784	0.319	0.049
IPB2	07/15/85-07/26/85	0.269	703	0.838	0.231	0.026
IPB3	07/29/85-08/12/85	0.399	506	0.934	0.320	0.030
IPB4	07/30/85-08/12/85	0.196	1312	0.491	0.181	0.039
Lacquer-treated						
IPB3	08/28/85-09/10/85	0.166	583	0.788	0.138	0.016
Polyurethane-treated						
IPB2	10/04/85-10/16/85	0.440	571	0.898	0.363	0.038
Latex-treated						
IPB4	08/29/85-09/10/85	0.471	574	0.758	0.389	0.059

Note:
IPB1 through 4 indicate industrial particle boards 1 through 4 used in coating experiment.

Table 8. Emissions from Low-Emitting Medium Density Fiberboard

Board #	Date	intercept	cutoff	R^2	ser_{100}	Std. error
		mg/m²•h	ppb		mg/m²•h	mg/m²•h
LMDF-1A	07/30/85-08/12/85	0.464	1296	0.572	0.429	0.068
LMDF-1B	07/30/85-08/12/85	0.476	1012	0.953	0.429	0.027
LMDF-1C	09/14/85-09/25/85	0.640	590	0.968	0.532	0.048
LMDF-1D	07/31/85-08/12/85	0.695	1059	0.808	0.629	0.084
LMDF-1E	08/01/85-08/12/85	0.701	1013	0.688	0.631	0.100
LMDF-1F	07/29/85-08/12/85	0.748	926	0.769	0.668	0.114
LMDF-2A	04/08/86-05/13/86	0.742	947	0.666	0.664	0.205
LMDF-2B	04/08/86-05/13/86	0.735	840	0.996	0.647	0.016
		Lacquer-treated				
LMDF-1D	08/28/85-09/10/85	0.163	723	0.600	0.141	0.021
		Polyurethane-treated				
LMDF-1B	08/26/85-09/10/85	0.100	541	0.879	0.081	0.006
LMDF-1E	08/30/85-09/10/85	0.090	1576	0.038	0.084	0.010
		Latex-treated				
LMDF-1F	09/12/85-09/22/85	0.717	644	0.994	0.605	

Note:

LMDF indicates low emitting medium density fiber board
The number after the dash indicates the US manufacturer
The final letter indicates the specimen

Table 9. Emissions from Foreign Boards

Board #	Date	intercept	cutoff	R^2	ser_{100}	Std. error
		$mg/m^2 \cdot h$	ppb		$mg/m^2 \cdot h$	$mg/m^2 \cdot h$
Sweden-1A	05/27/86-07/11/86	0.120	124	0.339	0.023	0.056
Sweden-1B	05/27/86-08/10/86	0.067	426	0.052	0.051	0.037
Norway-1A	03/19/86-04/07/86	0.406	227	0.802	0.227	0.047
Norway-1B	03/19/86-04/07/86	0.224	295	0.533	0.148	0.064
Norway-2A	03/19/86-04/07/86	0.656	317	0.907	0.449	0.066
Norway-2B	03/19/86-04/07/86	0.496	205	0.615	0.225	0.101
France-1A	03/19/86-04/07/86	0.110	240	0.363	0.064	0.024
France-1B	03/19/86-04/07/86	0.070	122	0.520	0.012	0.015
Belgium-1A	03/04/87-03/22/87	0.408	132	0.967	0.098	0.023
Belgium-1B	03/04/87-03/22/87	0.378	142	0.993	0.112	0.010
Belgium-2A	03/04/87-03/22/87	0.136	125	0.987	0.027	0.005
Belgium-2B	03/04/87-03/22/87	0.150	110	0.971	0.014	0.009

Table 10. Summary of Emission Rate Reduction from Coatings

Underlayment

	Ser_{100}	Cutoff	Percent Untreated Ser_{100}
	$mg/m^2 \cdot h$	ppb	
Untreated	0.158	400	
Lacquer	0.109	356	69%
Polyurethane	0.028		18%
Latex	0.150	400	95%

Industrial Underlayment

	Ser_{100}	Cutoff	Percent Untreated Ser_{100}
	$mg/m^2 \cdot h$	ppb	
Untreated	0.261	741	
Lacquer	0.138	583	53%
Polyurethane	0.363	571	140%
Latex	0.389	574	150%

Low Emitting Medium Density Fiber Board

	Ser_{100}	Cutoff	Percent Untreated Ser_{100}
	$mg/m^2 \cdot h$	ppb	
Untreated LMDF	0.524	981	40% (of regular)
Lacquer	0.141	981	26% (of untreated LMDF)
Polyurethane	0.085	538	6% (of untreated LMDF)
Latex	0.605	644	90% (of untreated LMDF)

Table A.1 Predicted Formaldehyde Levels at Various Air Change Rates in a House with Complete Underlayment Flooring Using New Technology US Products

	Predicted HCHO Concentrations (ppb)										
Air Change Rate	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
Board #											
USM1-1A	334	253	203	170	146	128	114	103	94	86	79
USM1-1B	350	259	206	171	146	127	113	101	92	84	78
USM2-1B	764	450	319	247	202	170	147	130	116	105	96
USM2-1B	848	388	252	186	148	122	105	91	81	73	66
USM3-1A	973	379	235	170	134	110	93	81	72	64	58
USM3-1B	597	306	205	155	124	104	89	78	69	62	57
USM3-2A	342	249	196	162	138	120	106	95	86	79	72
USM3-3A	391	234	167	129	106	89	78	68	61	55	51
USM3-3B	347	257	204	169	145	126	112	101	91	84	77
USM4-1A	634	328	221	167	134	112	96	84	75	67	61
USM4-1B	576	318	220	168	136	114	98	86	77	70	63
USM5-1A	431	317	251	207	177	154	137	123	111	102	94
USM5-1B	226	169	135	112	96	84	74	67	61	56	51
USM2-2A	386	229	163	127	103	87	76	67	60	54	49
USM2-2B	403	248	179	140	115	98	85	75	67	61	56
USM2-3A	852	544	400	316	261	222	194	172	154	140	128
USM2-3B	764	479	349	274	226	192	167	148	133	120	110
USM6-1A	180	146	122	106	93	83	75	68	63	58	54
USM6-1B	185	145	119	101	87	77	69	63	57	53	49
USM6-2A	383	243	177	140	115	98	86	76	68	62	56
USM6-2B	487	291	208	161	132	112	97	85	76	69	63
USM6-3A	295	232	191	162	141	125	112	101	93	85	79
USM6-3B	365	270	215	178	152	133	118	106	96	88	81
USM7-1A	312	187	133	103	85	72	62	55	49	44	40
USM7-1B	208	139	105	84	70	60	52	47	42	38	35
USM7-1C	215	133	97	76	62	53	46	41	36	33	30
USM6-4A	375	304	256	221	195	174	157	143	131	122	113
USM6-4b	356	289	243	210	185	165	149	136	125	116	107

Table A.2 Predicted Formaldehyde Levels at Various Air Change Rates in a House with Complete Underlayment Flooring Using Foreign Products

Air Change Rate	Predicted HCHO Concentrations (ppb)										
	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
Sweden-1A	124	97	79	67	58	51	46	41	38	35	32
Sweden-1B	426	155	95	68	53	44	37	32	28	25	23
Norway-1B	227	197	174	155	140	128	118	109	102	95	89
Norway-1B	295	216	171	141	120	105	93	83	76	69	64
Norway-2A	317	280	250	226	207	190	176	164	153	144	136
Norway-2B	205	184	167	153	141	131	122	114	107	101	96
France-1A	240	150	109	86	70	60	52	46	41	37	34
France-2B	122	82	62	50	42	36	31	28	25	23	21
Belgium-1A	132	121	112	104	97	91	86	81	77	73	70
Belgium-1B	142	129	118	108	100	94	88	82	78	73	70
Belgium-2A	125	100	83	71	62	55	49	45	41	38	35
Belgium-2B	110	91	78	68	61	55	50	46	42	39	36

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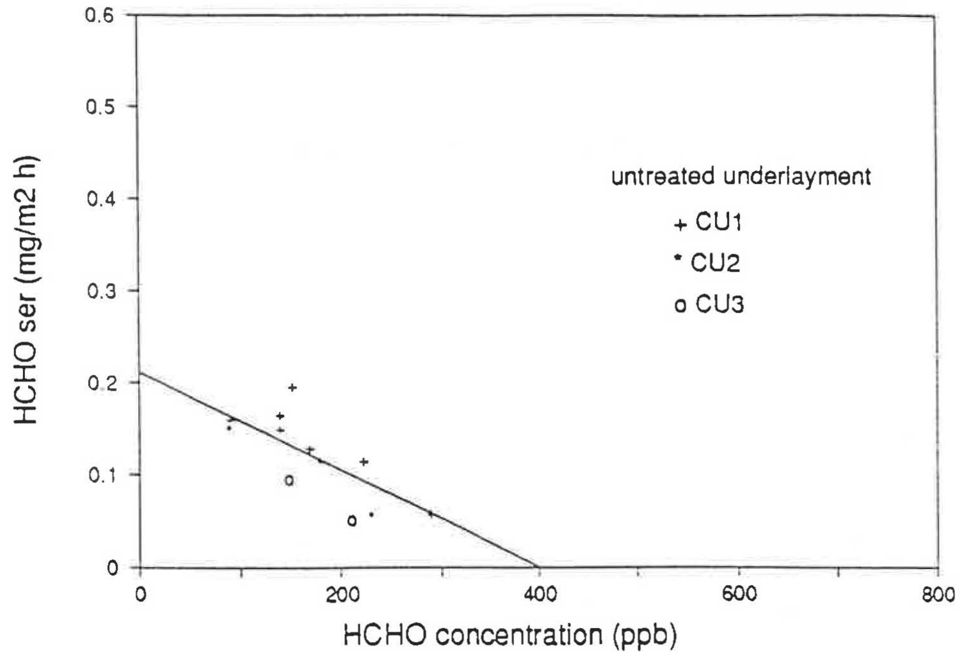


Figure 1. Emission Rates of Untreated Underlayment for Coating Experiment

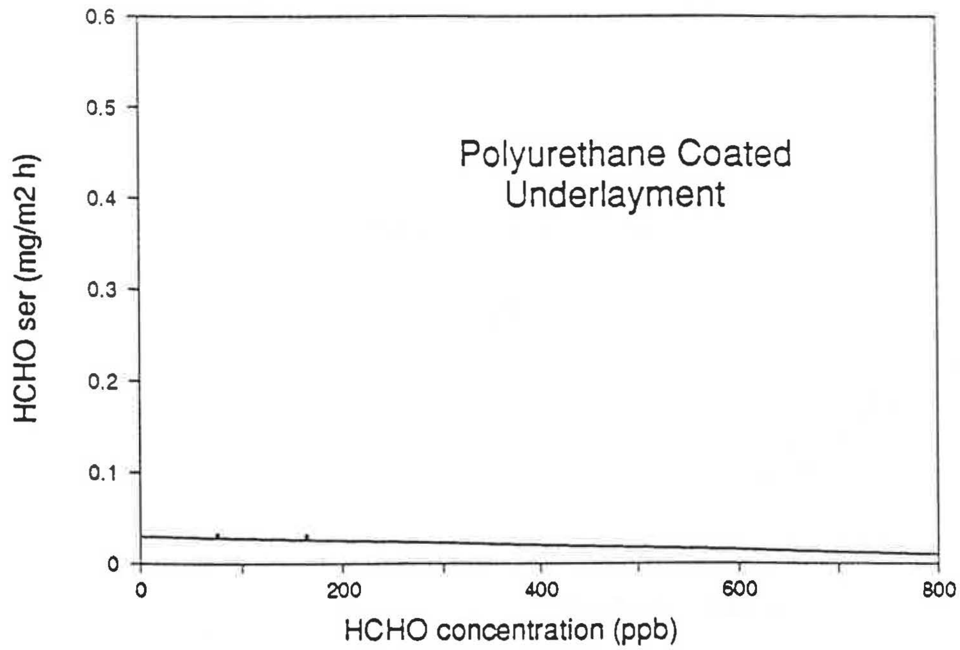


Figure 2. Emission Rates of Polyurethane Coated Underlayment

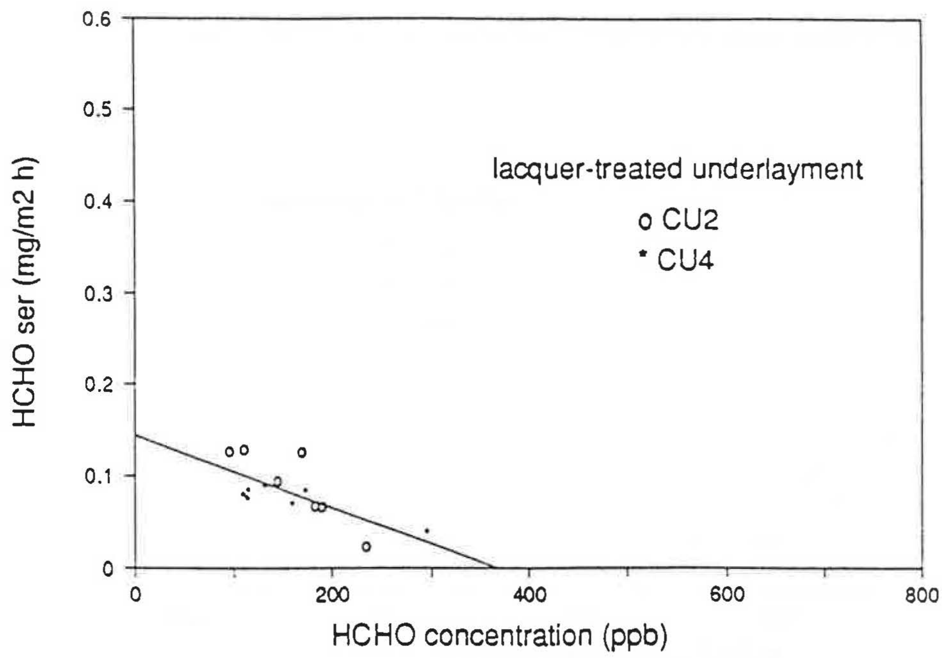


Figure 3. Emission Rates of Lacquer Treated Underlayment

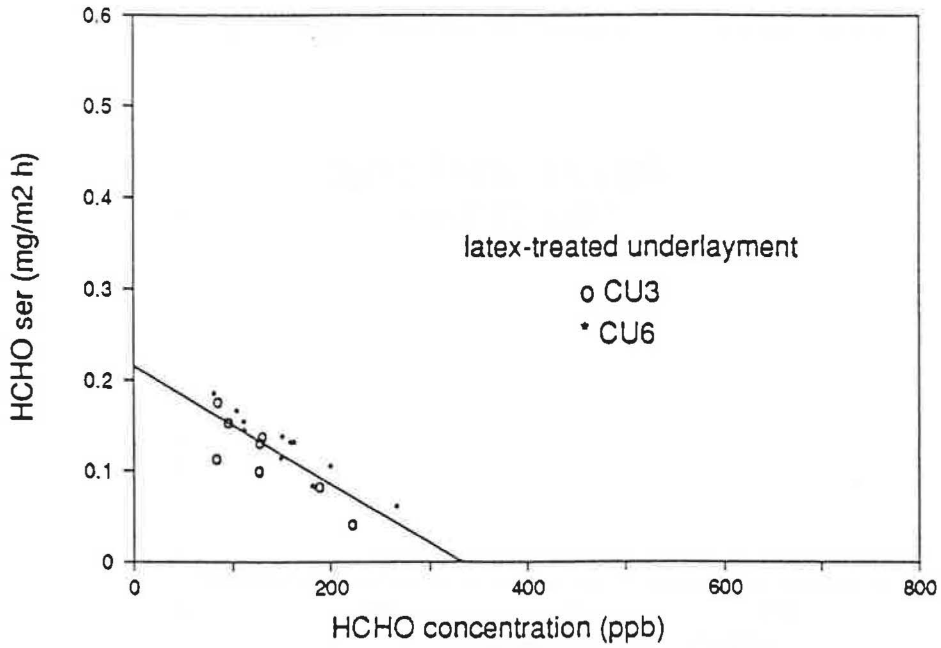


Figure 4. Emission Rates of Latex Treated Underlayment

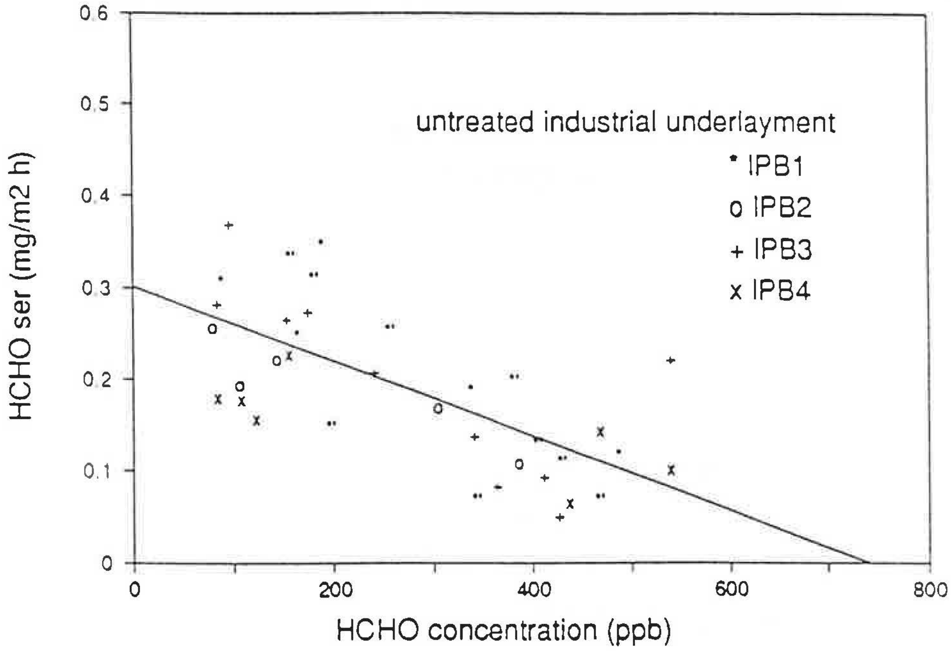


Figure 5. Emission Rates of Untreated Industrial Particle Board

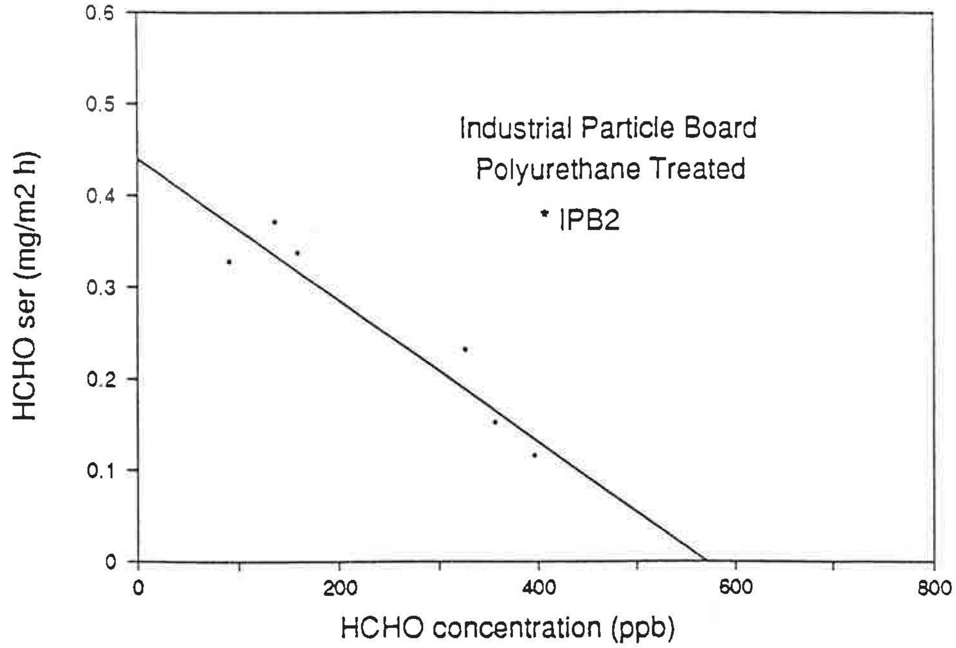


Figure 6. Emission Rates of Polyurethane Treated Industrial Underlayment

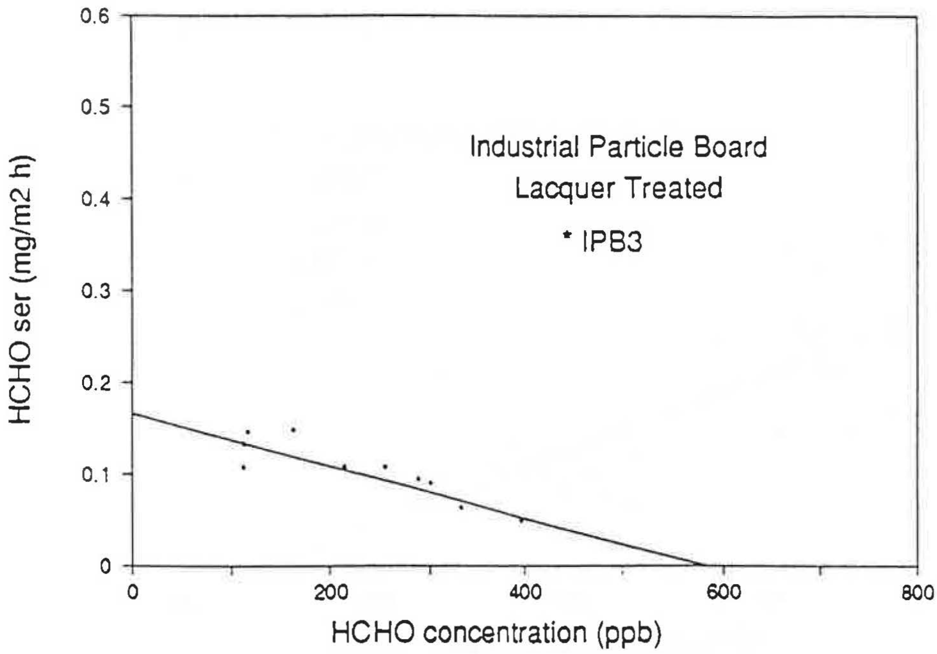


Figure 7. Emission Rates of Lacquer Treated Industrial Underlayment

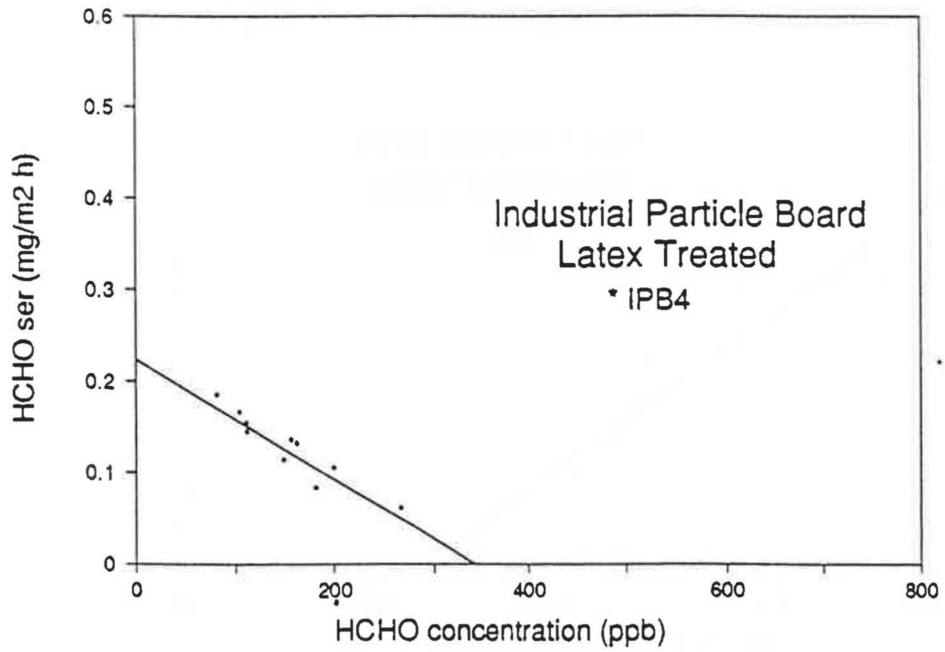


Figure 8. Emission Rates of Latex Treated Industrial Underlayment

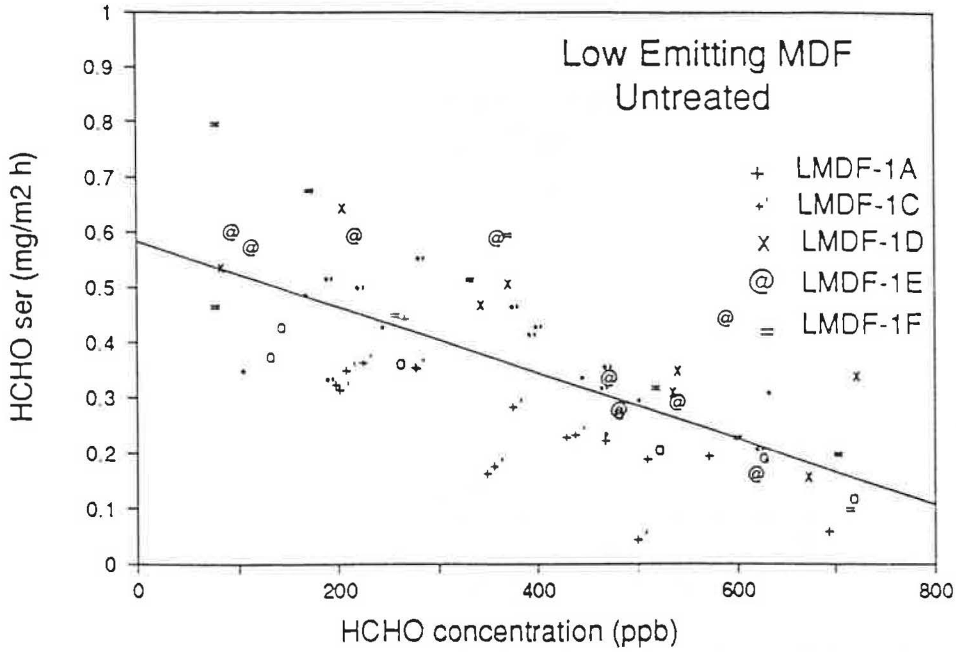


Figure 9. Emission Rates of Untreated Low Emitting MDF

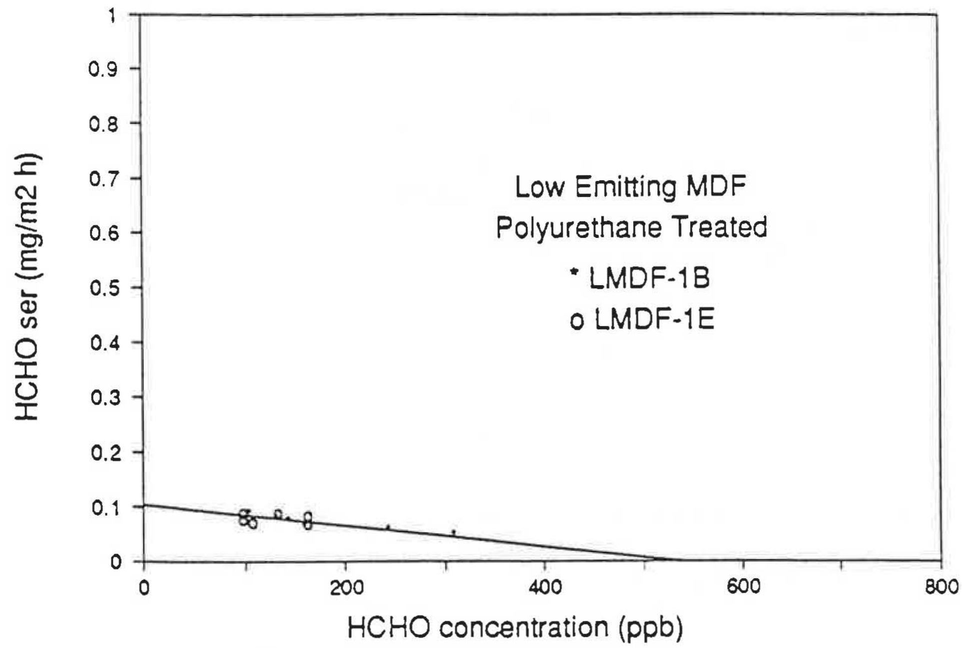


Figure 10. Emission Rates of Untreated Low Emitting MDF

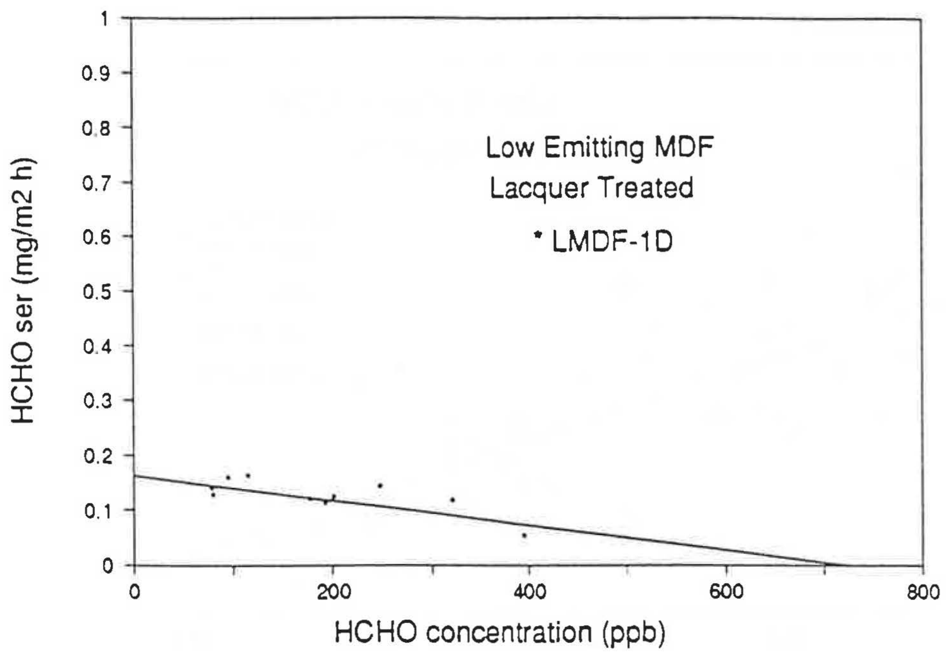


Figure 11. Emission Rates of Lacquer Treated Low Emitting MDF

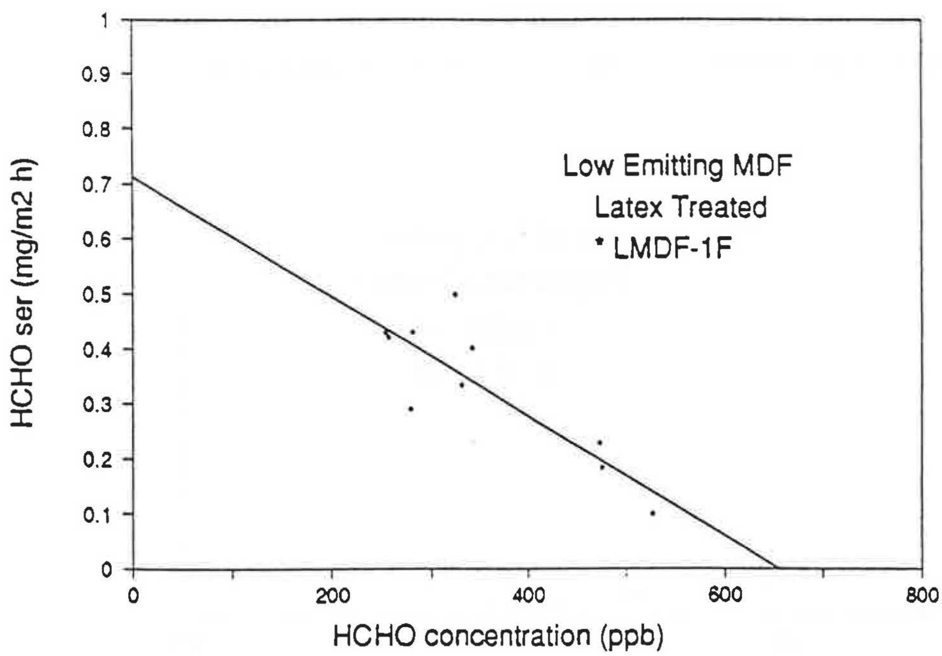
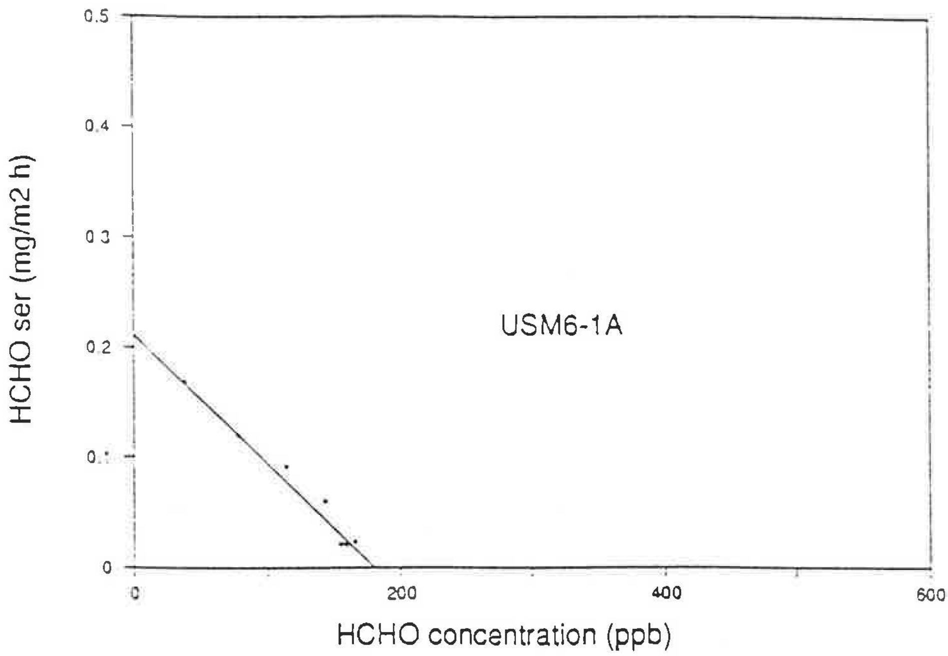


Figure 12. Emission Rates of Latex Treated Low Emitting MDF



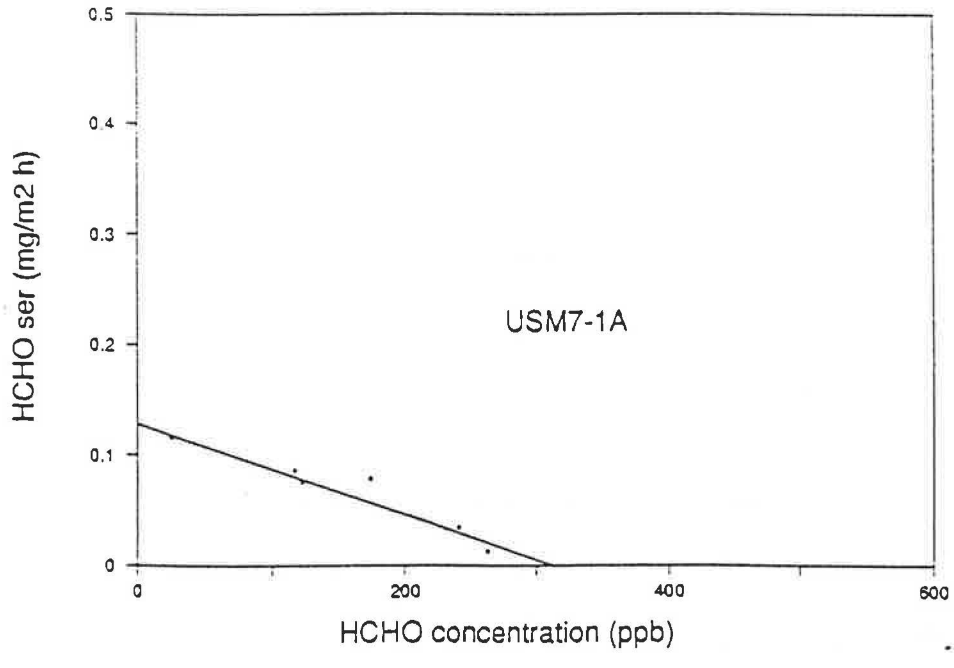


Figure 13. Examples of US Particle Boards Using Low Fuming UF Resins and a Scavenger

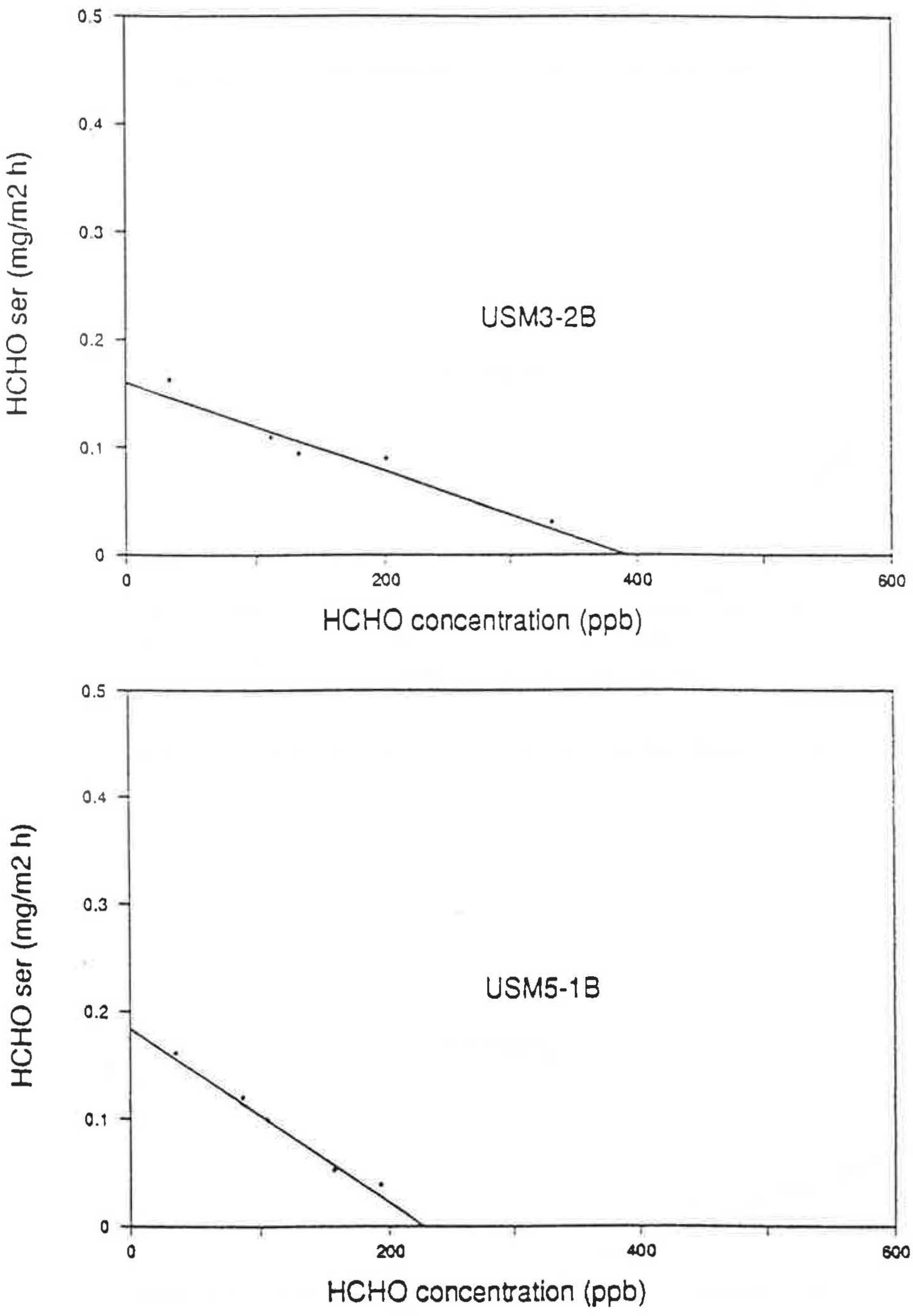
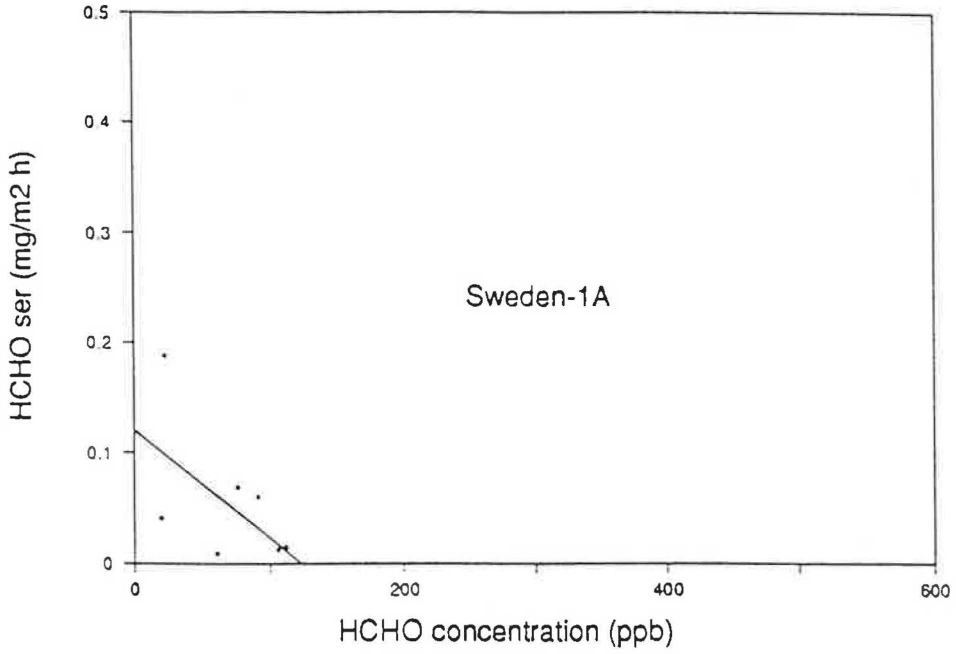


Figure 14. Examples of US Particle Boards Using Low Fuming UF Resins



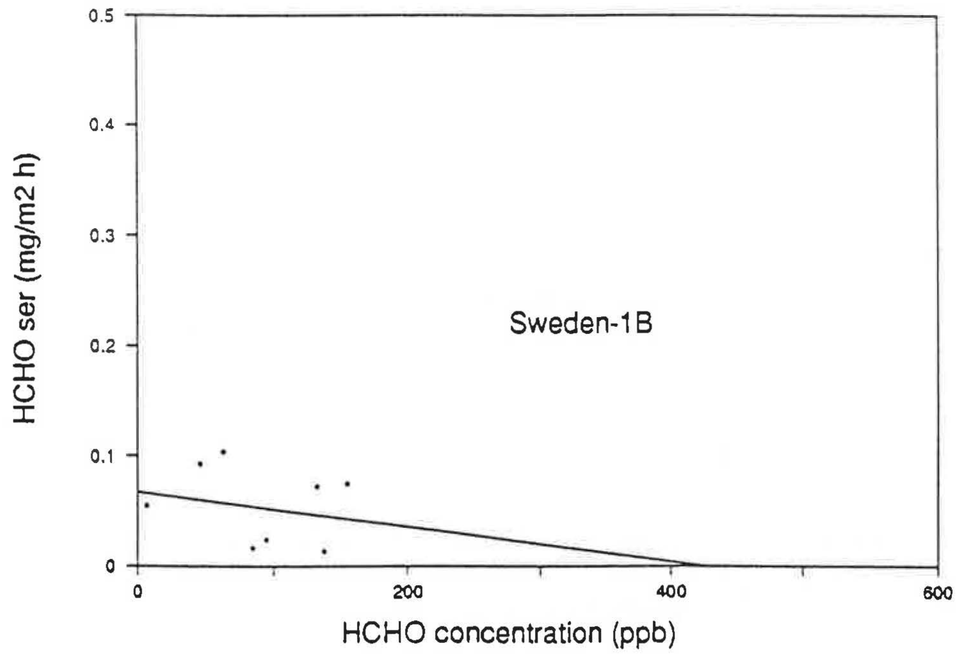
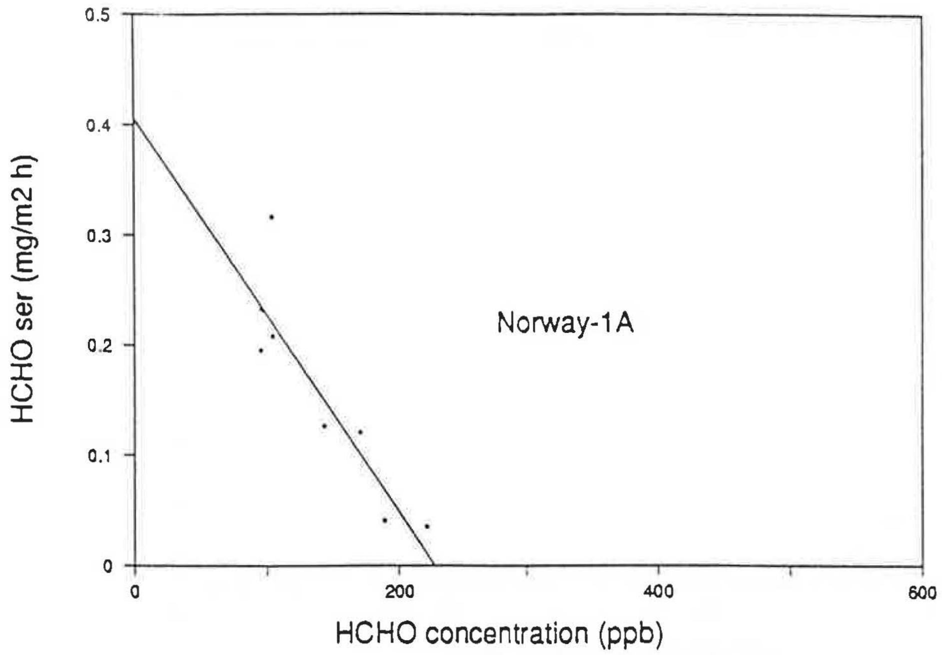


Figure 15. Emission Rates from Swedish Boards



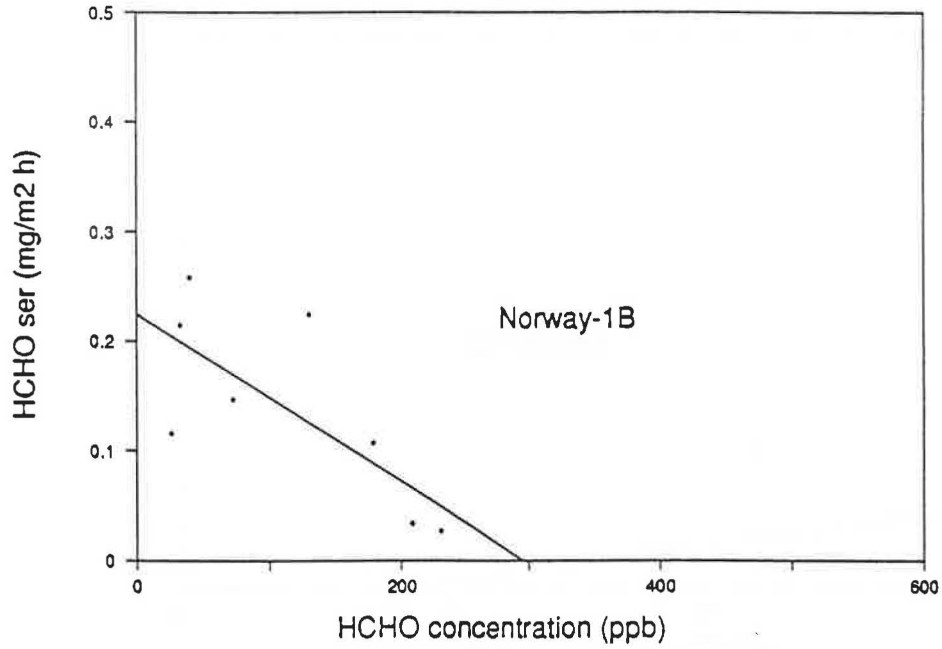


Figure 16. Emissioh Rates from Norwegian Manufacture #1

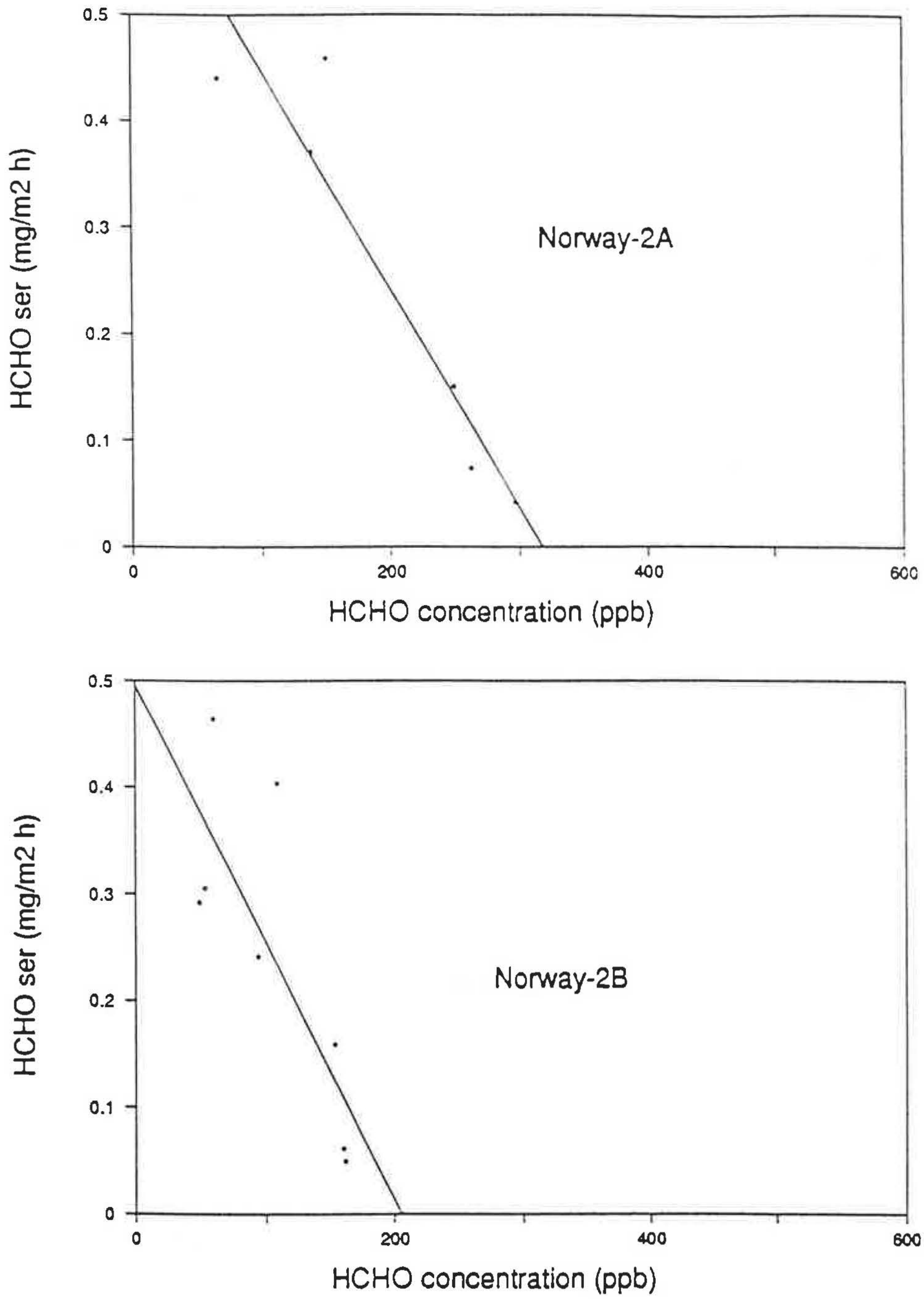
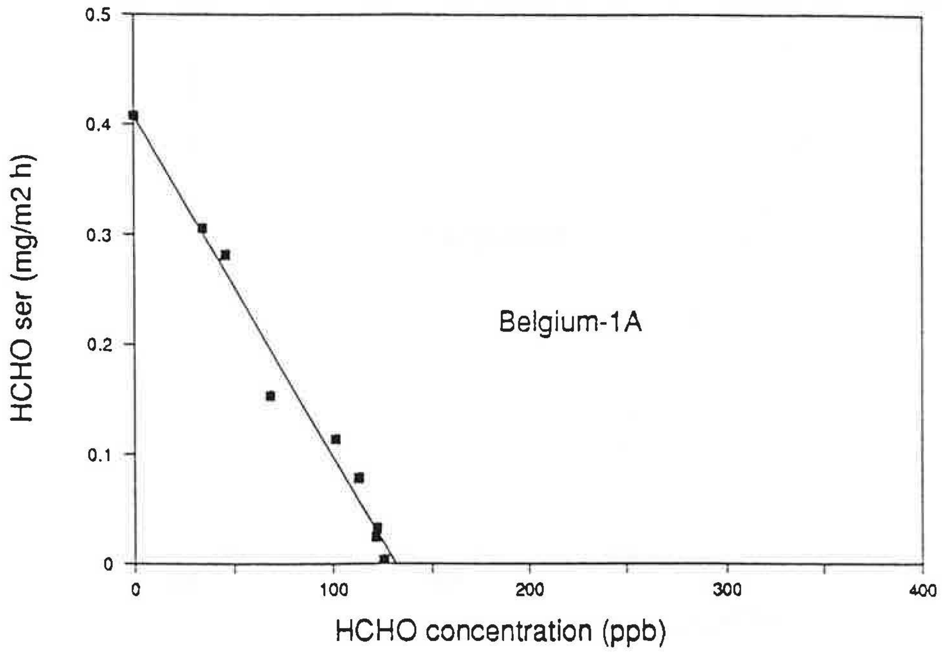


Figure 17. Emission Rates from Norwegian Manufacture #2



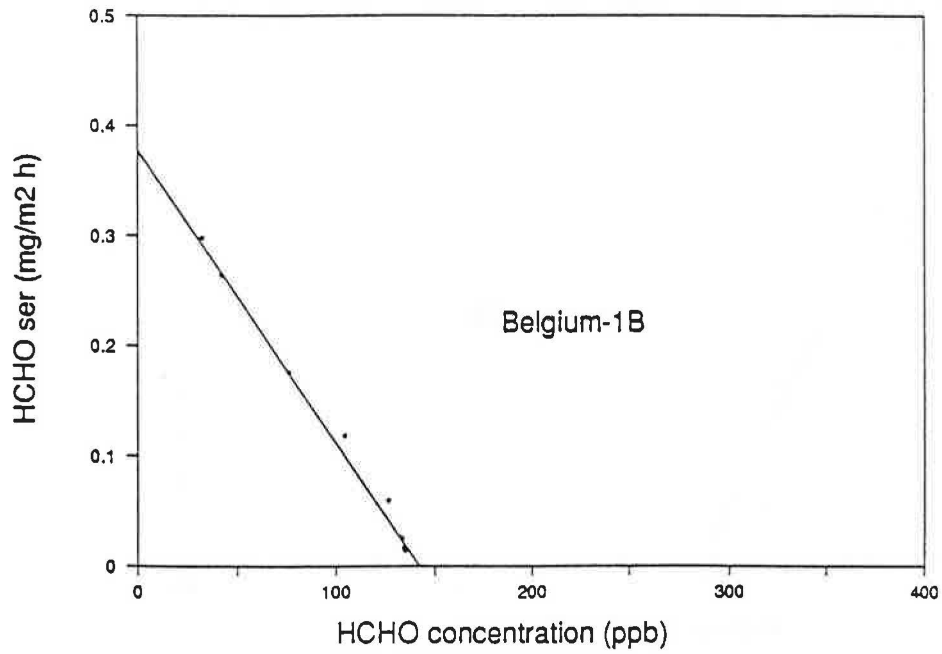
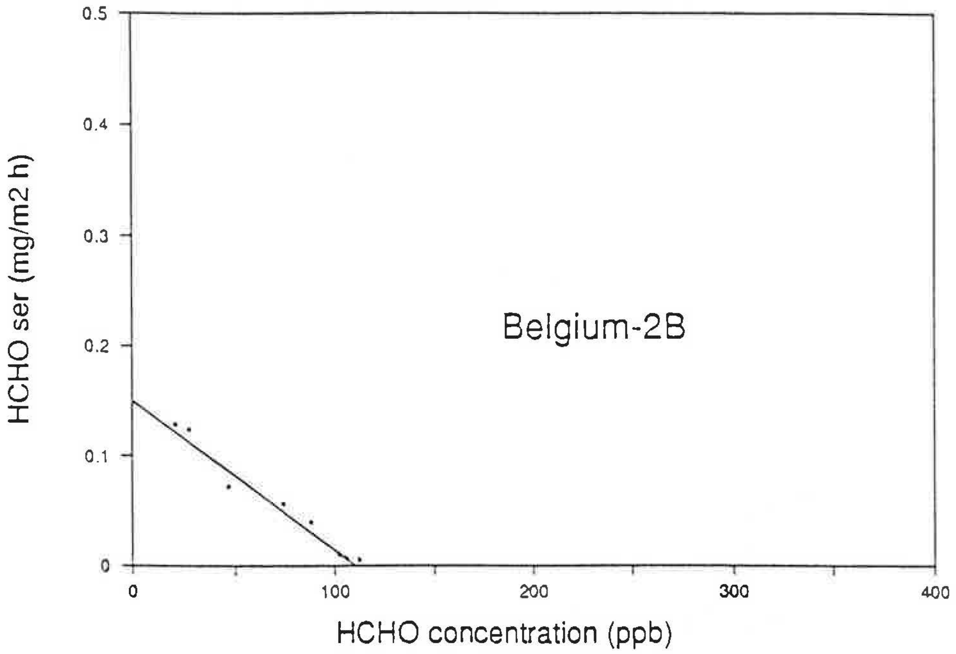


Figure 18. Emission Rates from Belgium Manufacture #1



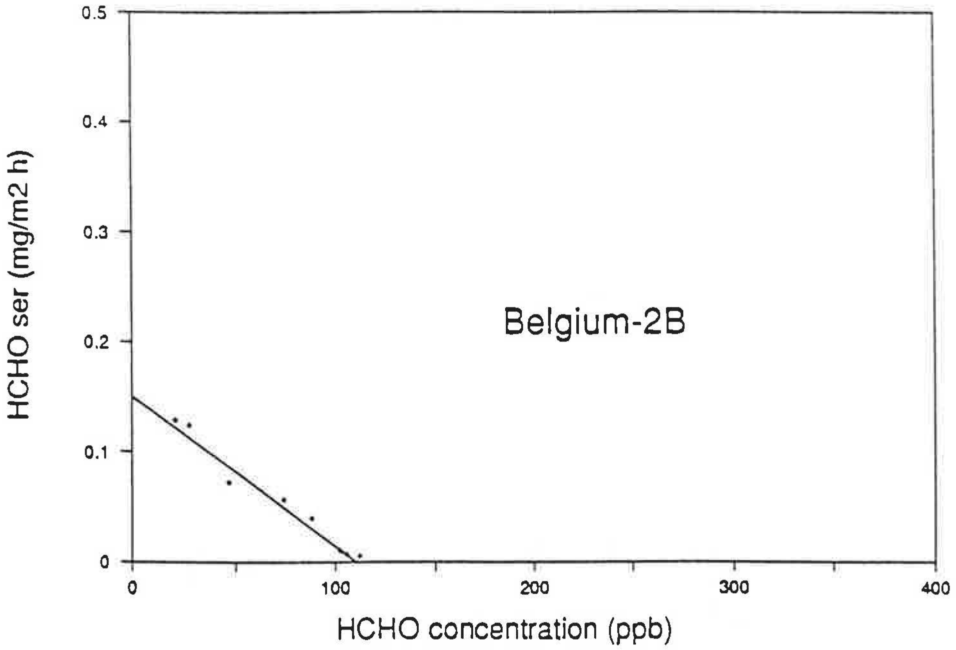


Figure 19. Emission Rates from Belgium Manufacture #2

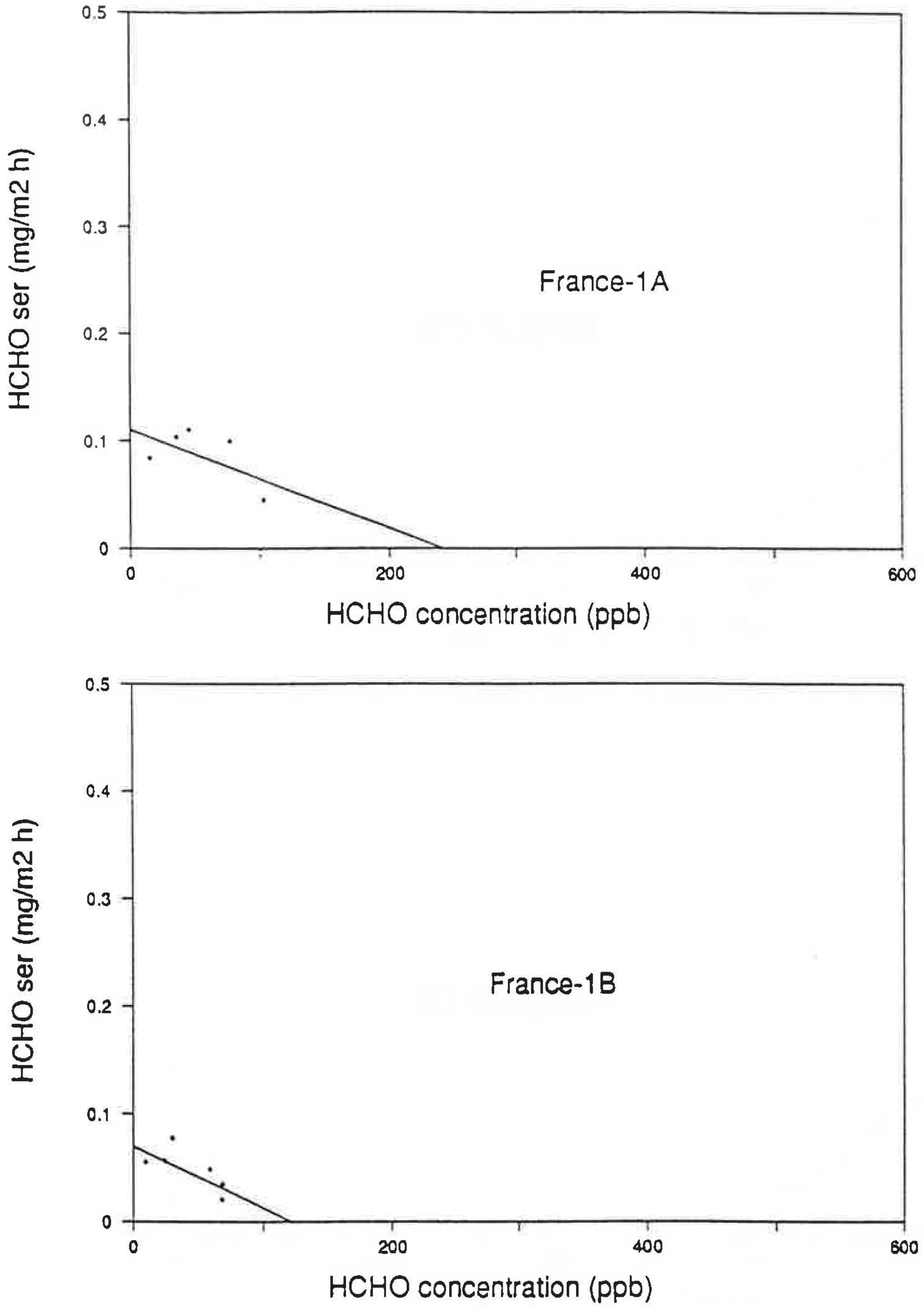


Figure 20. Emission Rates from France Manufactured Boards

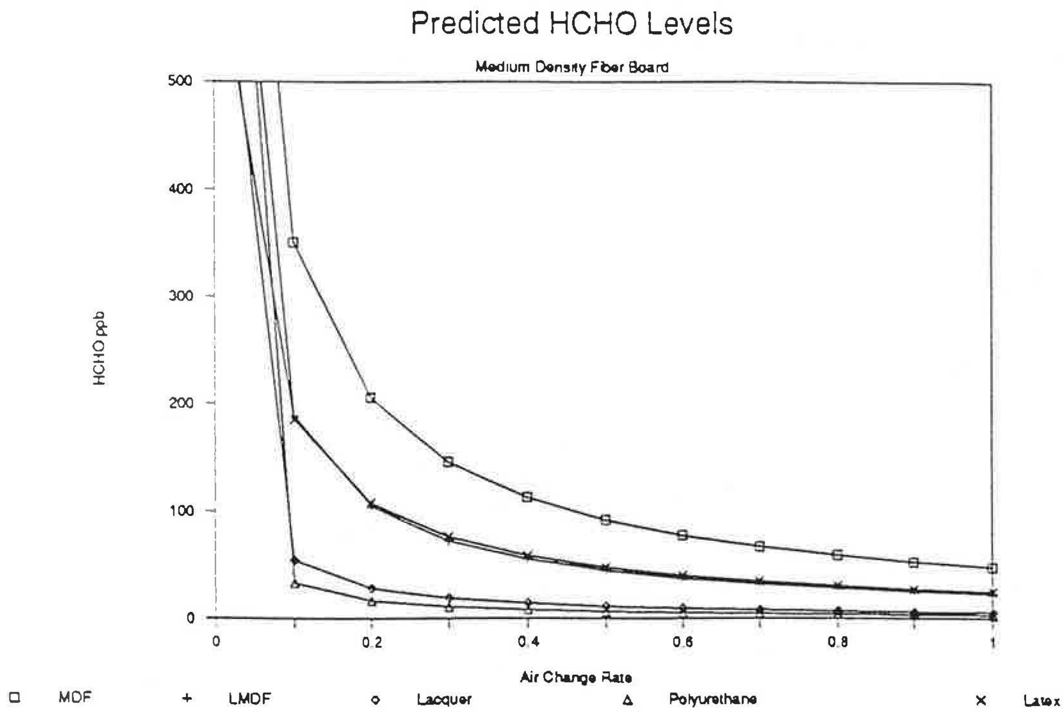


Figure 21. Predicted HCHO Levels from Medium Density Fiber Boards

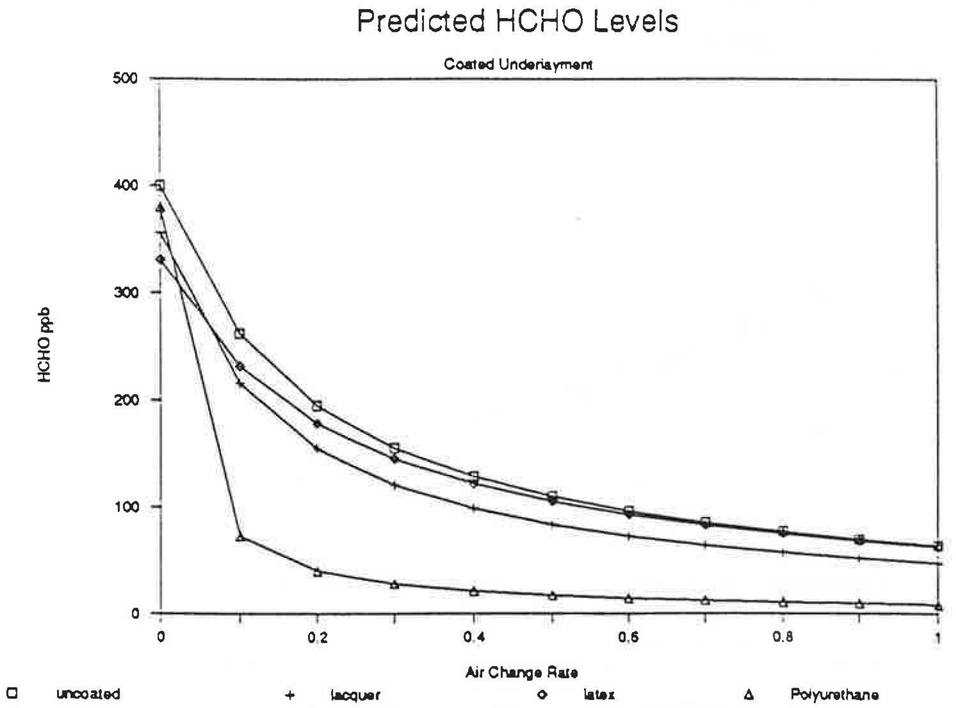


Figure 22. Predicted HCHO Levels from Coated Underlayment

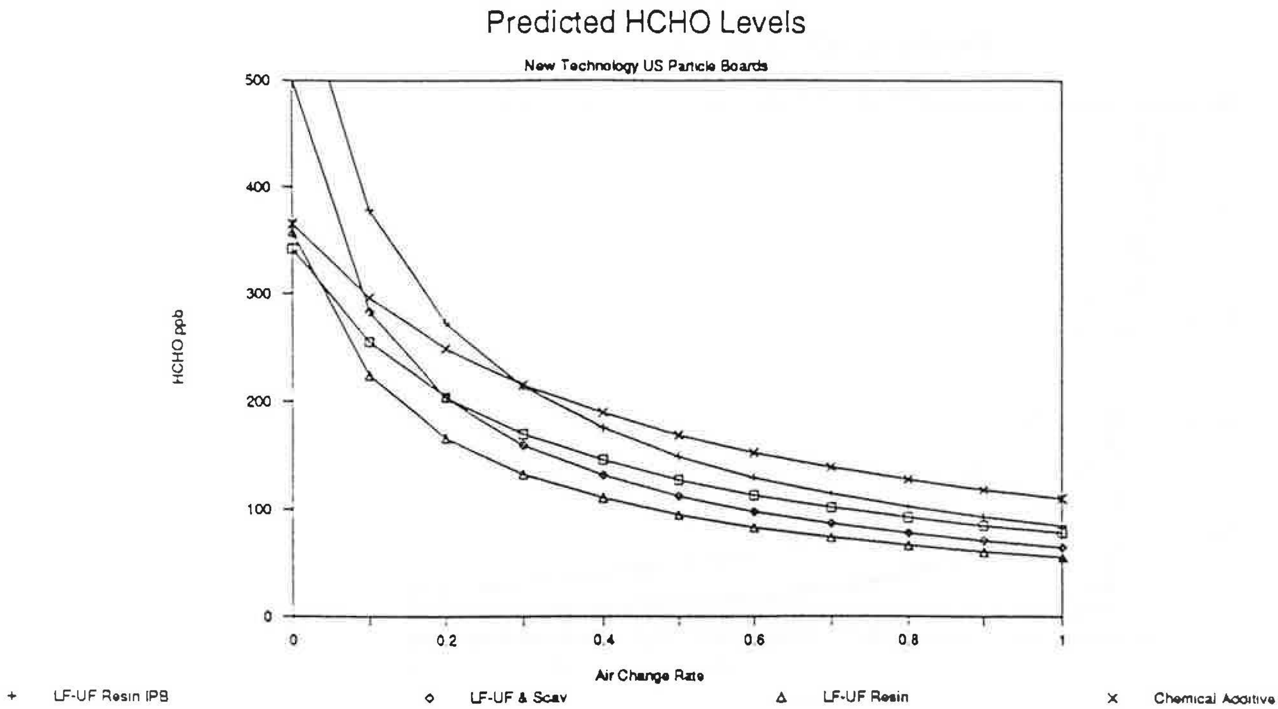


Figure 23. Predicted HCHO Levels from New US Technology Boards

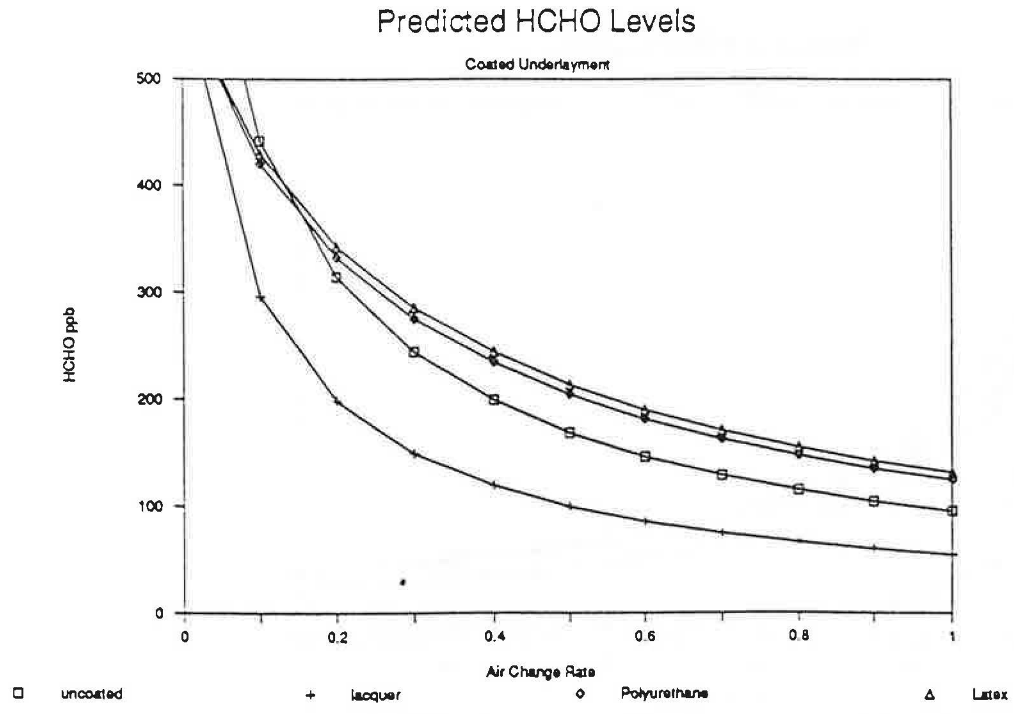


Figure 24. Predicted HCHO Levels from Industrial Particle Boards

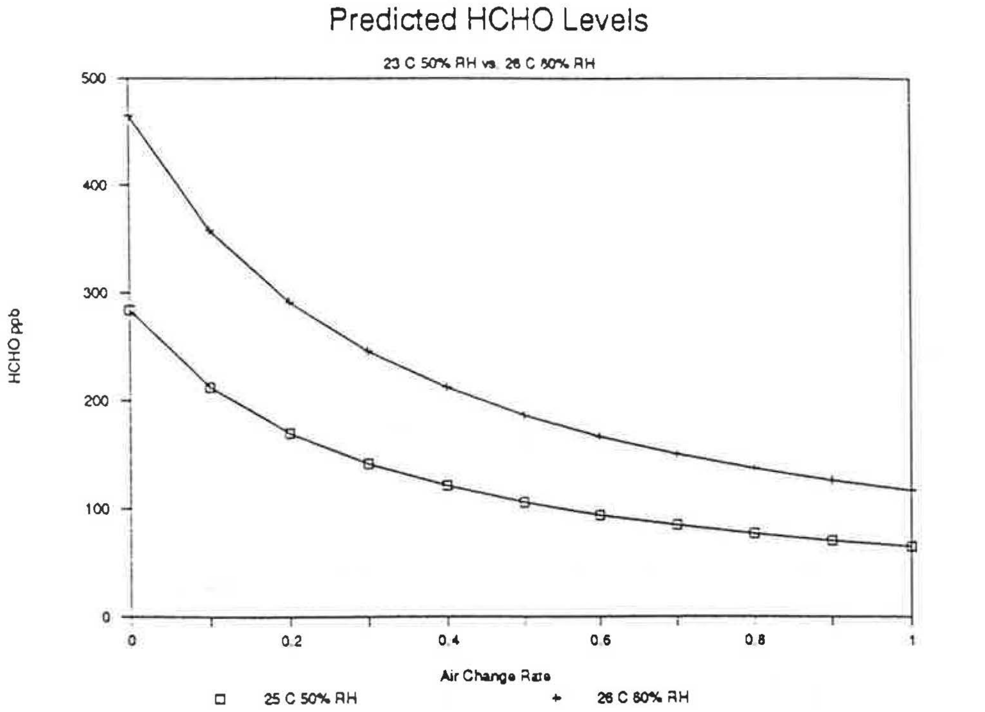


Figure 25. Predicted Effect of Temperature and Humidity on HCHO Levels

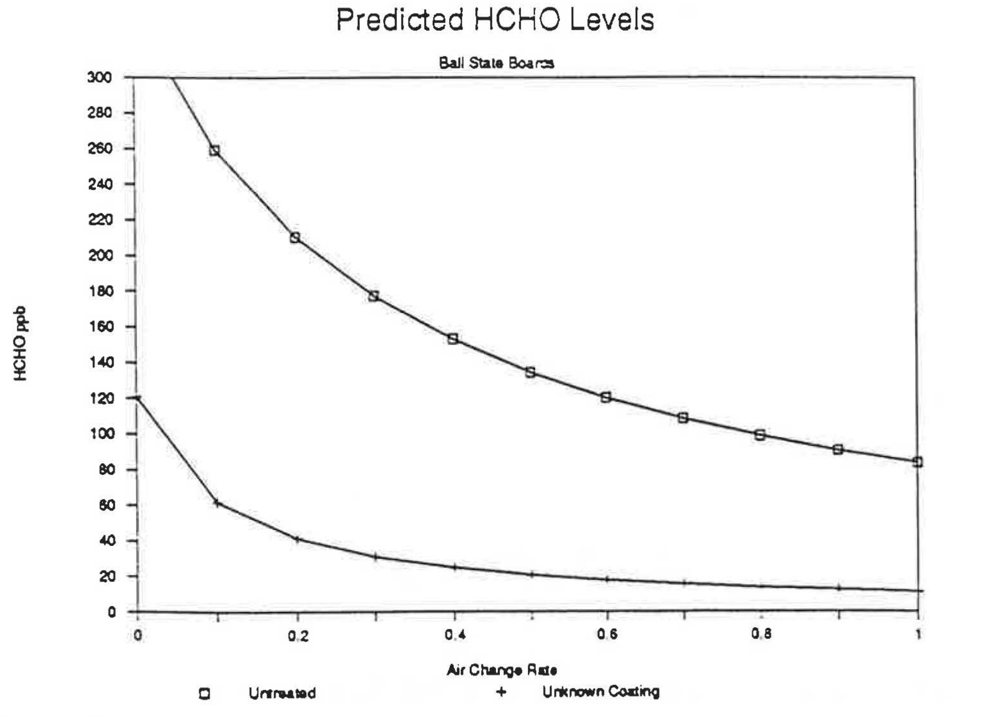


Figure 26. Predicted HCHO Levels From Coated and Uncoated Ball State Boards

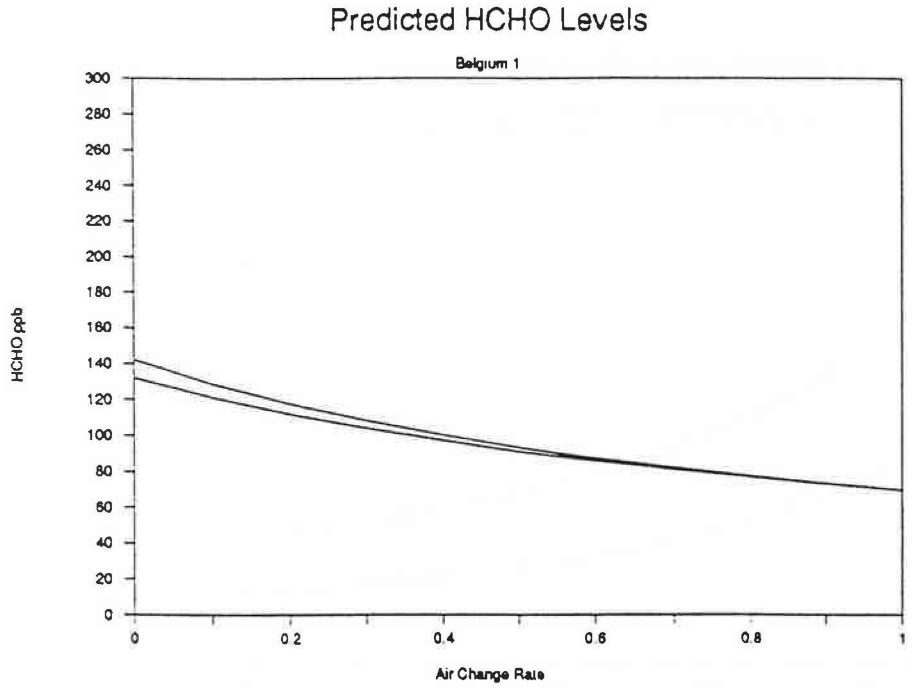


Figure 27. Predicted HCHO Levels From Belgium Manufacturer # 1.

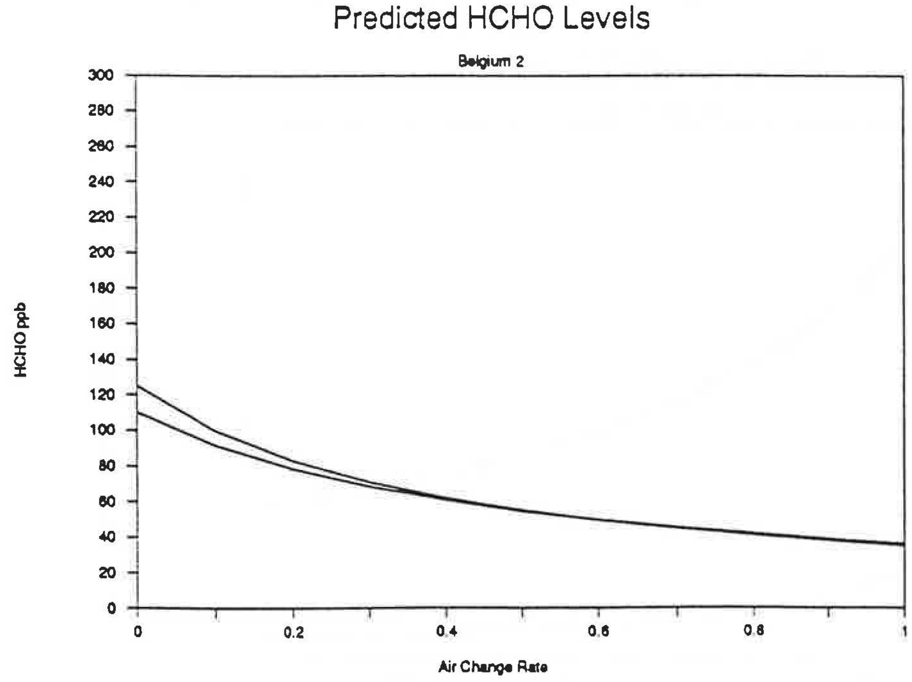


Figure 28. Predicted HCHO Levels From Belgium Manufacturer # 2.

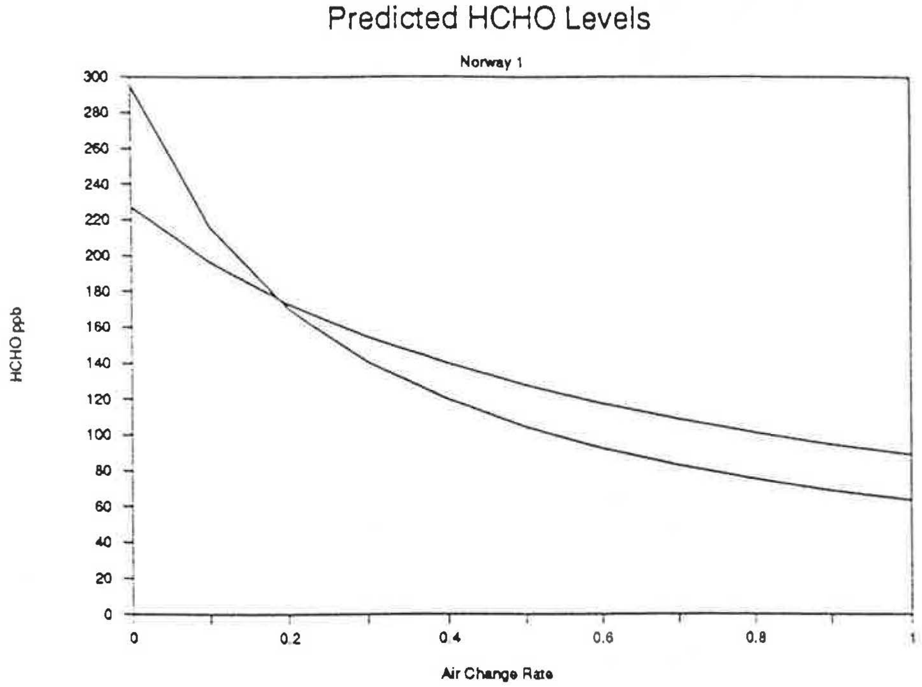


Figure 29. Predicted HCHO Levels from Norweign Manufacturer # 1

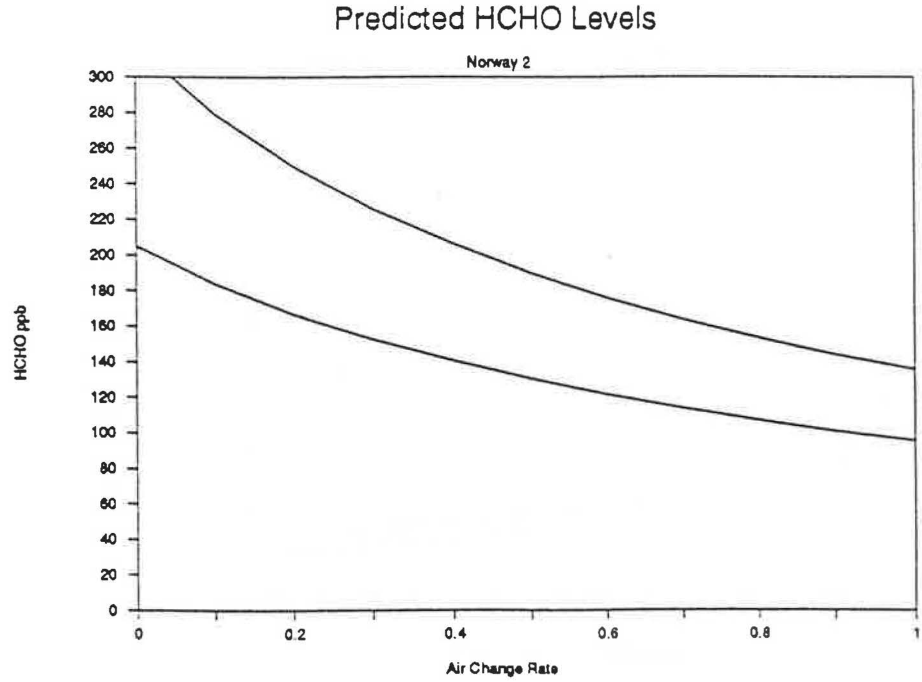


Figure 30. Predicted HCHO Levels from Norweign Manufacturer # 2

Predicted HCHO Levels

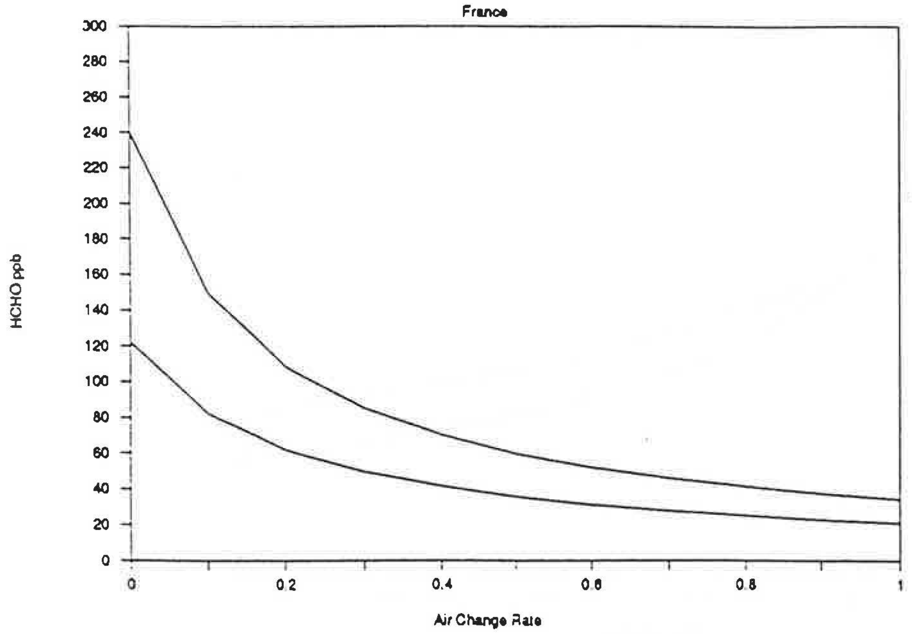


Figure 31. Predicted HCHO Levels from French Boards

Predicted HCHO Levels

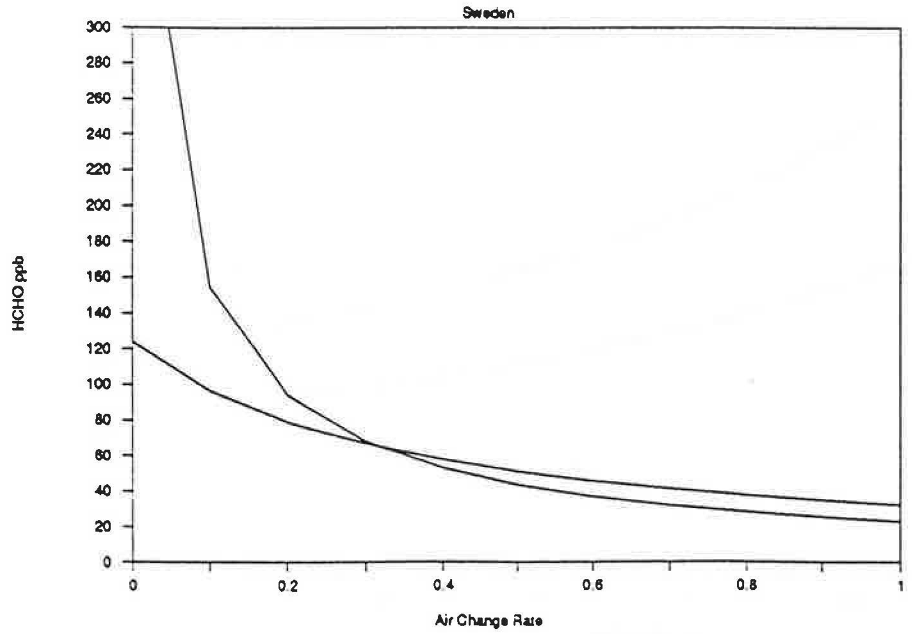


Figure 32. Predicted HCHO Levels from Swedish Boards