FORMALDEHYDE EMISSION A NOVEL APPROACH—STANDARDS AND LIMITATIONS IN EUROPE

ANDREW C. MARKESSINI
Bison A.C.M. Chemicals Ltd.
Fribourg, Switzerland

ABSTRACT

The formaldehyde issue is reviewed briefly in this paper. The new methods proposed in Europe at the European Community level are discussed and the situation from the industrial point of view is analyzed. The actual industrial practices for the reduction of free formaldehyde in Europe are mentioned as well as some of their advantages and disadvantages. A new approach to this issue is described. The reduction of free-formaldehyde that will be required in the near future will force the industry to adopt a global view to this matter. The accomplishment of such low free-formaldehyde levels will require a combination of a low molar ratio resin, a formaldehyde catcher, and an appropriate hardener.

INTRODUCTION

This paper reviews the free-formaldehyde emission issue. It discusses briefly the methods currently used for its determination and the regulations followed and suggests the ways practiced at the moment for its reduction with particular emphasis in the European market.

The formaldehyde issue has been "the issue" since the early 80s in Europe. The leading European country in setting up the standards as well as spreading the relative potential health hazards related to prolonged exposure at high levels of formaldehyde has been Germany. The Scandinavian press has been very damaging and has contributed significantly to spreading the so-called "evils" related to formaldehyde exposure. The present trend is to reduce formaldehyde levels to "nondetectable" levels, however, the wisdom and necessity of such restrictions remains to be justified.

The European market of wood-based panels (particleboard, fiberboard, and plywood) is more than 30 million m^3. Tables 1 and 2 show the production of wood-based panels in western Europe and the European Community in terms of volume, value, and employees.

Of the total production, more than 80% corresponds to particleboard (Figure 1) which, in 1991, within the European Federation of Associations of Particleboard Manufacturers (FESYP) member countries, registered a production level of 25.2 million m^3. There are 150 companies, in total, producing particleboard in western Europe with more than 30,000 people employed and a total turnover of about 4.6 billion ECU (US$5.4 billion).

More than 50% of the European particleboard is produced by the three larger EC member countries: Germany, Italy, and France (Figure 2). Germany itself manufactures more than 30% of

Table 1.—Production of wood-based panels in western Europe (1000m^3)*

Wood-Based Panel	1987	1988	1989	1990	1991
Particleboard	19,626	22,029	22,919	24,674	25,165
Plywood	2,192	2,272	2,280	2,528	2,654
Fiberboard Total	2,574	3,230	2,835	2,872	3,400
MDF Subtotal	741	900	1,243	1,779	2,000
Total	24,392	27,531	28,034	30,074	31,219

*Source: European Federation of Associations of Particleboard Manufacturers 1992

Table 2.—European Community wood panels industry*

Total Production	$9,575 million
Imports Extra-EC	$2,408 million
Exports Extra-EC	$554 million
Apparent Consumption	$11,215 million
Employees	66,888

*Source: European Federation of Associations of Particleboard Manufacturers 1992

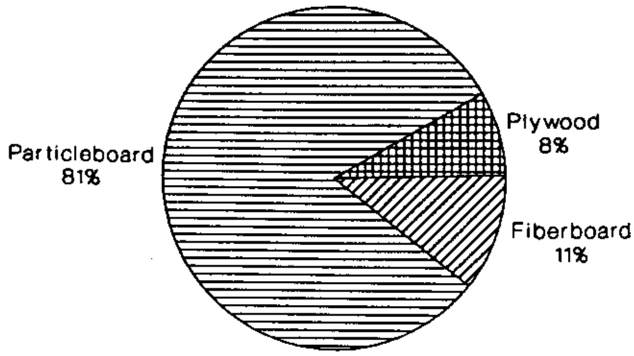

Figure 1.—*European wood-based panels production* (Source: FESYP 1992)

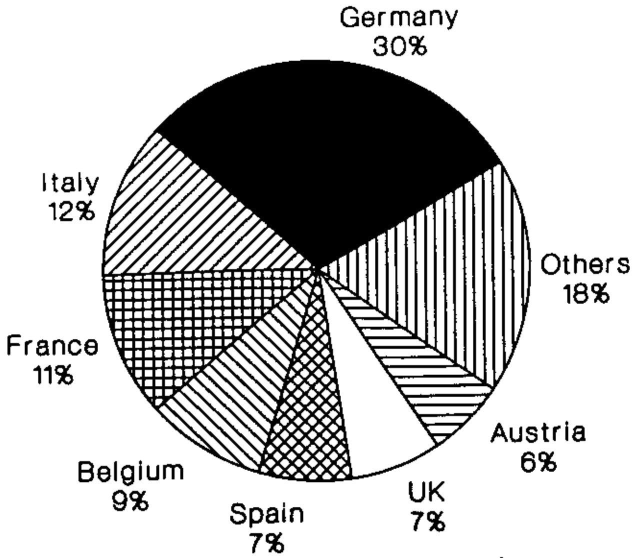

Figure 2.—*European particleboard production*

the total production. The situation is even more favorable for Europe in MDF where it produces more than 40% of the world total as shown in Table 3.

Table 3.—MDF production capacity

Country	Plants	Capacity (m^3/yr.)
Europe	34	3,399,000
Africa	3	148,000
Asia/Oceania	34	2,367,000
Latin America	4	277,000
North America	17	2,416,000
Former USSR	7	426,000
Totals	99	9,033,000

HEALTH EFFECTS

While there is sufficient evidence of carcinogenicity of formaldehyde in experimental animals, the evidence of carcinogenicity in humans is inadequate. Formaldehyde was classified in Group 2B by the International Agency for Research on Cancer (1987). Recently, a working group of the Commission of the European Communities (1990) reviewed the literature on the relation between formaldehyde exposure and health effects. The most interesting of the conclusions are quoted from this publication in the following material.

Table 4 lists the ranges of the effects of short-term exposure to formaldehyde while Table 5 gives the contribution of various atmospheric compartments to average exposure to formaldehyde.

The findings of CanTox Inc. (1988), as reported in detail in Appendix 1 note that reducing formaldehyde exposure to levels of comfort and practical necessities of the industry is important. However, it takes a tremendous amount of exposure to formaldehyde to add a tiny fraction to the human body.

METHODS FOR MEASURING FORMALDEHYDE EMISSIONS

In industrial practice, the perforator (CEN 120) is the most widespread method of measuring free formaldehyde emission for wood-based panels in Europe. The trend, however, in legislation is to take, as an ultimate basis, the chamber method, which is in the process of becoming an European standard.

On the European level, standardization is taken care of by CEN. The adoption of a standard by CEN goes through a succession of different steps. A draft is first prepared by a technical committee that is submitted to the public for inquiry for six months. During this period, all CEN member countries can introduce their comments. After all the comments are discussed, a final draft is prepared. This draft is adopted by a plenary meeting and afterwards submitted for

Table 4.—Effects of formaldehyde in humans after short-term exposure

Effect	Estimated Median (mg/m^3)	Reported Range (mg/m^3)
Odor detection	0.1	0.06 - 1.2
Eye irritation threshold	0.5	0.01 - 1.9
Throat irritation threshold	0.6	0.1 - 3.1
Biting sensation in nose, eye	3.1	2.5 - 3.7
Tolerable for 30 minutes (lachrymation)	5.6	5 - 8.2
Strong lachrymation	17.8	12 - 25
Danger to life, oedema, pnuemonia	37.5	37 - 60
Death	125	60 - 125

Table 5.—Contributions to formaldehyde exposures

Atmospheric Compartment	Formaldehyde	
	Estimated Concentration (mg/m^3)	Daily Intake (mg)
Air		
1. Ambient Air (10% of the time)	0.01	0.02
2. Indoor Air		
Home (65% of the time)		
– prefabricated chipboard	0.08 - 0.80	1 - 10
Workplace (25% of the time)		
– without occupational exposure	0.04 - 0.16	0.2 - 0.8
– with 1 mg/m^3 occupational exposure	1	5
3. Environmental tobacco smoke (ETS)	0.02 - 0.20	0.1 - 1
Smoking (20 cigarettes per day)		1

formal vote. After a standard is accepted in this procedure, all CEN member countries have to include it in their national standards and eliminate all conflicting national standards.

At the moment, there are three standards of CEN relating to formaldehyde emission that are in the process of being accepted. The Technical Committee responsible for wood-based panels in CEN is TC112, and within this committee the issue of formaldehyde was delegated to Working Group 5 (WG5). These three standards are:

1. EN717-1 — refers to the chamber method in measuring free formaldehyde emission of wood-based panels.
2. EN717-2 — refers to the gas analysis method as a tool for measuring free formaldehyde.

3. EN 717-3 — refers to the determination of formaldehyde emission by the flask method.

FORMALDEHYDE EMISSION REGULATIONS

The guideline values for formaldehyde emissions established or suggested in several European countries are summarized in Table 6.

Table 6.—Guideline values for formaldehyde emission in European countries

Countries	Formaldehyde Emission (mg/m^3)
Denmark	0.15
Germany	0.12
Finland	0.15
Italy	0.12 (tentative)
Netherlands	0.12
Norway	0.06 (recommended)
Spain	0.48
Sweden	0.13
Switzerland	0.24
WHO	<0.1

It is fair to say that Germany pioneered the reduction of free formaldehyde both in terms of legislation as well as in actual practice. It seems that Europe will follow Germany in respect to the formaldehyde emission restrictions in the very near future.

The situation in Germany was reviewed two years ago by Mr. Oliver Jann of the BAM Institute in an excellent presentation during the 25th International Particleboard/Composite Materials Symposium (1991). An extensive review on European legislation was presented in this auditorium last year by Dr. Lehmann and Dr. Roffael (1992). Hence, I will not try to review in depth, but will rather, update you by referring to any recent advances.

In 1991, the German government notified the Commission of the European Communities about its "Prüfvefahren fur Holzwerkstoffe" (test methods for wood-based panels). Detailed opinions/observations against this notification were introduced by six member countries and the EFTA Secretariat, as well as by the Commission itself.

In spite of these objections, a final decision was made concerning the implementing orders of the "Gefahrstoffverordnung," when, at the end of October 1991, the German government published the test methods for wood-based panels in the "Bundesgesundsheitblatt." Compared to the initial proposals of the German authorities, some beneficial changes were introduced in the final publication. The main request made of industry was that the results of the "derived test methods" (such as perforator and gas analysis values) should be considered as equivalent to the tests in "large chambers."

In principle, however, industry remains opposed to this publication that requires a lot more clarification. The European Communities have been asked to take Germany to the European Court of Justice for establishing barriers to trade. To this aim, an official complaint was introduced with the CEC in November 1991.

Another action that will have a probable impact on the promotion of low free-formaldehyde boards in the market is the so-called Eco-label award scheme. A regulation was published exactly one year ago (March 1992) in the Official Journal of the European Communities. The regulation establishes a Community award scheme for an Eco-label, with a view to promote the development, manufacture, marketing, and use of environmentally friendly products.

Criteria used to determine the level of environmental impact are: the use of natural resources and energy resources; the use of raw materials; emissions into air, water, and soil; generation of waste and noise. Furthermore, clean and sustainable technologies should be used to ensure a high level of environmental protection and to prevent destruction of the ecosystem.

The Eco-label may be awarded to products that satisfy community health, safety, and environment requirements. It may also be awarded to products containing a substance of preparation that has been classified as dangerous. This is true if the products have a reduced environmental impact during their entire life cycle without compromising product or workers' safety or significantly affecting the properties that make a product fit for use. To establish requirements for the award of the label, product groups will be established. Before deciding upon a group and its specific criteria, the main interest groups will be consulted in a "forum." The forum will consist of representatives from industry, retailers, consumer organizations, environmental organizations, and independent scientists. "Construction products" were chosen as a product group under the Ecolabeling directive.

On 27 March 1992, the "proposal of a Council regulation (EEC) allowing voluntary participation by companies in the industrial sector in a Community Eco-audit scheme" was published in the Official Journal of the European Communities.

The regulation establishes an "Eco-audit scheme" for the evaluation and improvement of the environmental performance of industrial activities and the provision of the relevant information to the public. The objective of the "Eco-audit" is to promote improvements in the environmental performance of industrial activities by:

1. The establishment and implementation of environmental protection systems by companies.
2. The systematic, objective, and periodic evaluation of the environmental performance of such systems.
3. The provision of information on environmental performance to the public.

Companies operating an industrial activity may participate in the Eco-audit scheme. They have to comply with all rules and conditions and observe all procedures set out in the regulation. The audit of a site may be conducted by the company auditors, if the company has set up an appropriate system, e.g., within the framework of the EN29000 standard, or by external auditors accredited for this purpose by a body recognized by the member country. Companies participating in the system may use the Eco-audit logo. This regulation has been in force since 1 January 1993 and will remain in effect from 1 July 1994.

Within this framework, Germany has already started discussing the so-called "Blauer Engel" (Blue Angel) which would have a desired free formaldehyde emission of less than 0.05 ppm. This would correspond to 3.0 - 3.2 mg/100 g dry board photometric (MC=6.5%), an essentially formaldehyde-free board. The "Blauer Engel" is a stamp/mark awarded by the German Health and Ecology Ministry to "environmentally friendly" products. Discussions are afoot as to whether wood-based panels used for finished house construction should get a "Blauer Engel" certification. If yes, then the question is what should be the safe level for formaldehyde emission? It needs to be noted that the value of 0.05 ppm (mentioned earlier) is just an initial suggestion chosen as 50% of the allowable limit of 0.1 ppm. The suggestion was made by the ministry, but, needless to say, the industry (apart from one sole exception—a regular isocyanate producer) is against it. As all large particleboard producers are members of the supervisory board or jury, no decision is expected before 1995.

I will not go into details about the legal situation in different European countries. There have been many reviews presented at the International Particleboard/Composite Materials Symposium about this subject, the most recent one being that of Dr. Lehmann and Dr. Roffael (1992), and there have not been any major changes since then. I will refer instead to the actual industrial practice of the moment.

The concept of E1 and E2 boards has become generally accepted in Europe. During the last few years, the E1 and E2 board concept, originally born in Germany, has made an effective contribution towards the reduction of the content of releasable formaldehyde in the boards by other particleboard manufacturing countries. Inevitably, the results and decisions from Germany form the basis for the actions of most of the industry in central and northern Europe. Currently, these areas are adopting a wait-and-see attitude to the formaldehyde reduction problem.

In order to have a clearer view of the current market situation in Europe, the author differentiates two groups of countries in relation to the low free formaldehyde issue. The first group of countries, Germany, Austria, Switzerland, and the Netherlands, there is, essentially, only one free formaldehyde group permissible as follows:

1. FF < 6.5 mg/100 g photometric as average per 1/2 year, 95% of the values.
2. 8 mg/100 g photometric as maximum (5% of values) related to 6.5% moisture content of the samples.
3. 8 < FF < 10 mg photometric are to be sold but they must be labeled "only for lamination."

The second group of countries includes France, Great Britain, Belgium, and the whole of Scandinavia. In these countries, there are two classes of wood-based panels with respect to formaldehyde emission. The two classes are:

1. E1 < 10 mg/100 g dry board
2. E2 between 10-30 mg/100 g dry board

It should be emphasized that the above division is by no means a formal one. It just reflects the current industrial practice that in many cases does not correspond to the legal requirements in each country. For example, in Belgium, which by the way is the biggest European particleboard exporter, the law refers to the B1 and B2 classes (<14 mg/100 g and 14 < FF < 28 mg/100 g), respectively. However, many companies think in terms of E1 and E2 instead.

DIFFERENT PROCESSES TO ACHIEVE E1 EMISSION LEVEL

There are three ways of achieving E1 production:

1. Resin formulations
2. Separate additions to furnish or veneer
3. Postmanufacture panel treatments

I would say that the latter two are only occasionally practiced in Europe, although I believe they might be more widespread in the United States. This is due to the fact that both of them need a considerable investment and add an extra production step that increases production cost to a nonaffordable level. The most successful of the many different processes tried is the addition of urea either in a solid or a solution form. Basically, there are two different ways the industry applies this:

1. By the addition of solid urea before the drier (0.4% by weight on the wood) and an extra cost of about 1.2 DM/m^3 (US $ 0.73/m^3) of final board
2. By the addition of urea solution (45%) before the drier (2.2 - 8.0% urea on resin solids)

Of the many postmanufacture panel treatments tried, two will be mentioned.

1. The Casco system (addition of urea in the paraffin emulsion), which was practiced with limited success mainly in Denmark and Sweden.
2. The ammonia gas aftertreatment.

Most of the approaches adopted by the industry in order to reduce formaldehyde emissions involved changes in the resin mixture formulations. There are two explanations for this. First, changing the formulation in a plant is, most of the time, very easy and it does not need any extra investment. Second, traditional particleboard manufacturers do not understand much of the resin chemistry involved and prefer to have ready-made solutions supplied by their resin suppliers or other experts.

The first attempt of resin manufacturers to decrease formaldehyde emission was by decreasing the F:U molar ratio of the resin, i.e., by decreasing the amount of free formaldehyde in the resin. In Europe, most of the resins currently used, at least in central European countries, have a molar ratio of F:U between 1.05 and 1.2, while only 10 years ago the majority of the resins used had a molar ratio as high as 1.4 - 1.6. Initially, the reduction of the molar ratio was achieved by introducing in the resin production process one or two extra steps of urea addition. The urea reacted with the residual formaldehyde and therefore, both the free formaldehyde of the resin and the free formaldehyde emitted from the board were reduced drastically. (It should be noted that a reduction of the mole ratio from 1.5 to 1.1 can reduce the free formaldehyde emission in the final board up to ten times.)

However, the reduction of the free formaldehyde of the resin had many negative side-effects that quite soon became apparent. Formaldehyde acts as a crosslinking agent during the setting of the resin and therefore, its drastic reduction had an adverse effect on the performance of the resins. Hence, the plants had to live with much longer press times, tighter mat moisture control, and higher gluing factors. The process yielded boards with lower mechanical properties and water resistance.

The first attempt to address this problem was in the addition of a small quantity of melamine (up to 7%) to the resin. Although this increased the resin cost by about 10%, it proved quite successful. At present, five companies in Europe produce these so called "melamine-fortified" resins. The amount of melamine used mostly is either 1% or 4%, on a liquid basis. These resins are much more forgiving with process variations than straight UF resins and their use gives the industry some confidence that they will meet the formaldehyde emission regulations without too much worry about meeting the rest of their standards. This approach to producing low free formaldehyde boards is the only way to produce boards meeting the German standard (6.5 mg/100 g dry board) without the use of any additives. However, the resin system is obviously more expensive than straight UF resin.

In the meantime, the resin industry has invested much in research for low free formaldehyde (FF) straight UF resins and has partially solved the problems related to the introduction of the extra steps of urea addition, by modifying the process parameters and changing the overall structure of the prepolymers produced.

Recently, new technology-straight UF resins have recently come out in the European market by three resin producers. The producers claim that they combine the emission advantages of the low FF resins with the performance advantages of the high FF resins. Their cost is in the range of 360-370DM/t, DM20/t higher, on an average, than other UF resins still on the market. It is too early to evaluate these resins. They have been tried in a few plants, but in general, plant managers still feel more comfortable by using melamine-fortified resins. There is only one plant using such a resin on a continuous basis. These resins will give E1 boards (<10 mg/100 g dry board) without any additives, but in order to meet the 6.5 mg/100 g limit, the addition of urea or other formaldehyde scavengers is still needed. It appears that the resin formulation changes in the direction of reducing the molar ratio are at a practical limit.

Most plants have tried to compensate for the inferior performance of the new resins by replacing the traditional hardeners such as ammonium sulphate by special hardeners (e.g., ammonium nitrate—52% solution, or solutions of ammonium nitrate and urea at a total solids content of up to 70%) or by increasing the quantity of the hardener used (up to 5 - 6% solid hardner to solid resin).

Although it is not clear if it falls in this category, I will briefly refer to the E1 boards produced by using MDI as an adhesive. This process was introduced some years ago and although it has several disadvantages (e.g., sticking, high cost, toxicity problems), there are a couple of plants in Europe regularly producing this type of board. MDI is used in combination with UF resin, the UF being used particularly on the surface in order to avoid any sticking problems. Needless to say, isocyanate resins are terribly expensive (about 2300 DM/t) and although smaller quantities are used, the boards are still, by at least 40%, more expensive than normal UF boards.

Last but not least, a variety of formaldehyde scavengers are used for formaldehyde reduction. There are at least six commercial products available on the European market at the moment. They are the simpler to use—i.e., by adding to the resin mixture. There are many practical advantages in using a scavenger, the main one being the flexibility it gives the plant manager to vary its quantity and hence, the reduction of formaldehyde emission according to the conditions and the production requirements.

The simplest scavenger is 45% plain urea solution. The formaldehyde scavengers used mostly in Europe are urea-formaldehyde based, but they can be tailor-made to meet the particular requirements of the plants that will be using them. They can be used at a maximum level of 25% of the resin used and can achieve reductions in free formaldehyde emissions of up to 60%. Our experience shows that instead of using a very low molar ratio resin, one can achieve better results in terms of both formaldehyde emission reduction and mechanical properties by using a system of an equivalent molar ratio that is a combination of a higher molar ratio UF resin and a formaldehyde catcher.

Finally, there is the importance of the catalyst system. This system is used by spreading low molar ratio urea-formaldehyde resins. It may not be like that in the United States because of the acidity of the wood available, but the use of a hardener, usually by introducing it in the resin mixture, has been normal practice in Europe for many years. Commonly, the hardener used earlier was ammonium chloride. In the last few years, however, ammonium sulphate is used instead, at least in most central and northern European countries. This is because the use of ammonium chloride was forbidden for environmental reasons. Both of these hardeners react with the free formaldehyde in the resin and liberate either hydrochloric or sulphuric acid, that speeds up the polymerization reaction by lowering the pH.

A few years ago, the UF resins used had molar ratios between 1.3 - 1.6 and fairly high levels of free formaldehyde. However, the trend nowadays as already mentioned, is to use resins with significantly lower levels of free formaldehyde, insufficient in any case to produce a significant pH drop when ammonium salts are used as catalysts. Therefore, the effect of the reduction of the molar ratio on the gel time is much more obvious nowadays. In general, higher levels of hardener result in a shorter gel time (Figure 3). But this response is much less at lower resin mole ratios. In fact, in some cases, gel times can become even longer when increasing the hardener level. This is true, because there is a competition for the available formaldehyde between the hardener and the curing reaction itself.

The use of a special hardener can solve this problem. The difference is very simple. Special hardeners do not rely on the available formaldehyde in order to generate acidity. Their effectiveness is, therefore, not influenced by the availability of free formaldehyde in the resin. The influence of the molar ratio on the reactivity curve of a resin when using a special hardener is shown in Figure 4.

As you can easily see, the reactivity curves are similar for all different molar ratios. This means that the molar ratio does not significantly influence the way the hardener speeds up the polymerization.

THE LATEST DEVELOPMENT

By now you may have started wondering what is really the novel element the title of this paper promises. The traditional way of solving the free formaldehyde problem was to ask the

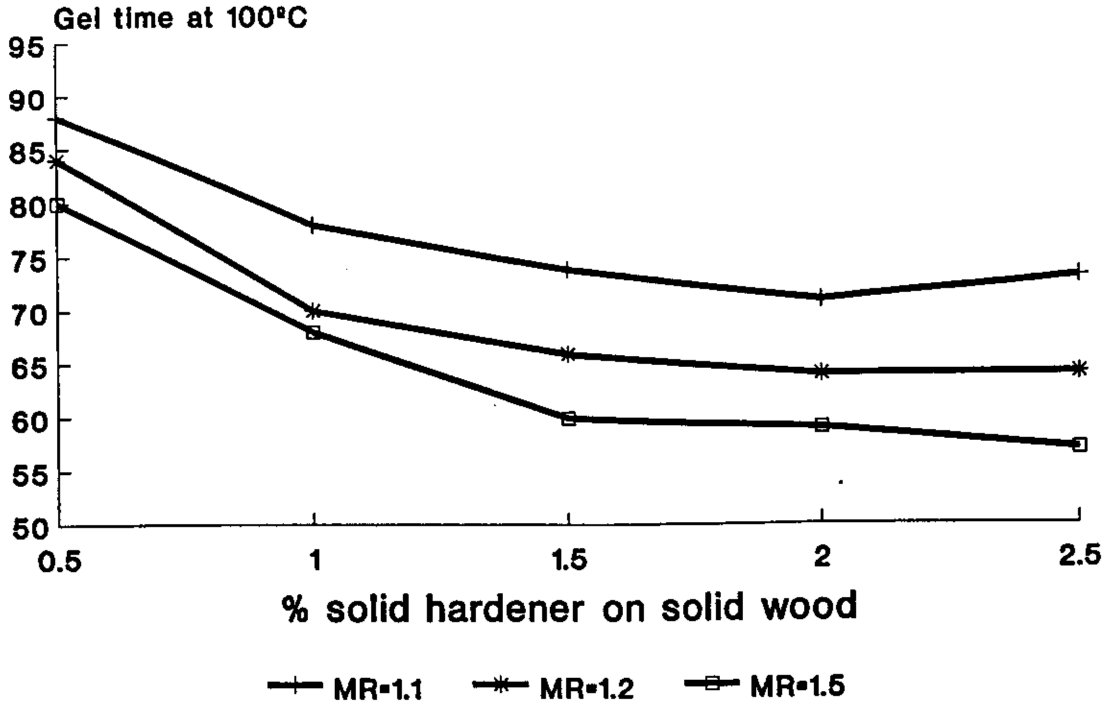

Figure 3.—*Influence of hardener level on reactivity (normal hardener [ammonium sulphate]) (MR = mole ratio) (gel time = seconds)*

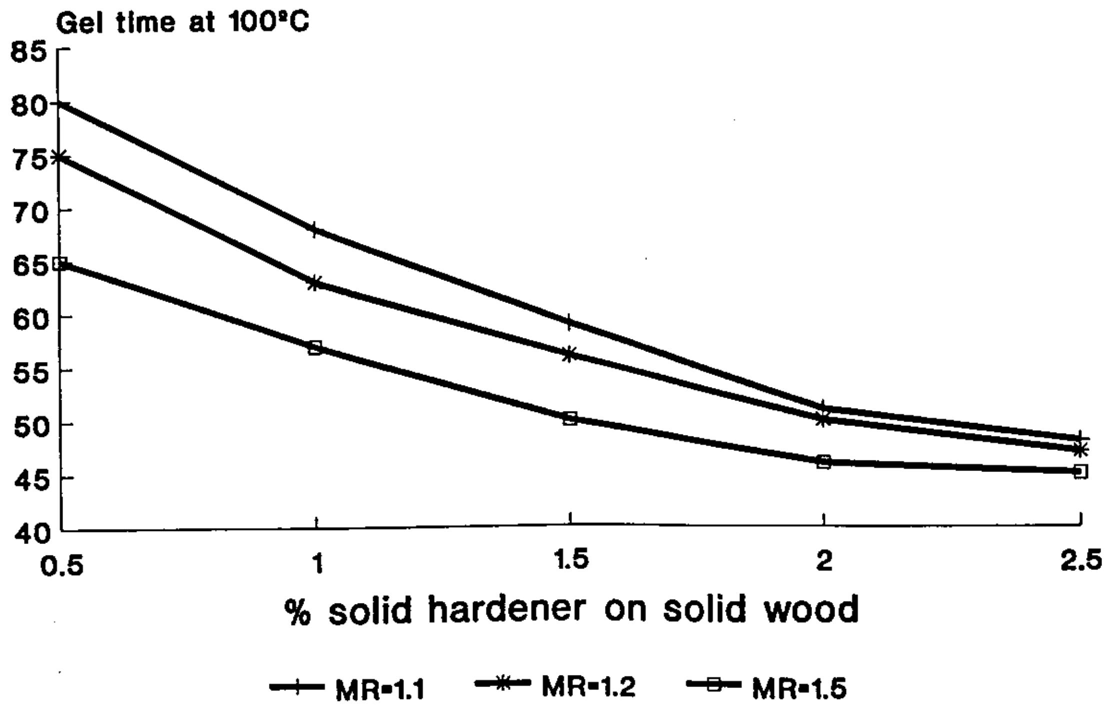

Figure 4.—*Influence of hardener level on reactivity (special hardener) (MR = mole ratio) (gel time = seconds)*

Table 7.—Industrial trial for the production of extremely low free formaldehyde boards (figures are averages over a 12-hour period)

Production Specifications	I	II
% dry resin/dry wood (core)	8.0	8.9
% dry resin/dry wood (face)	9.5	10.2
% dry hardener/dry resin	2.5	3.9
% formaldehyde catcher on liquid resin	--	25.0
% special hardener on normal hardener	--	25.0
Press time (s/mm)	7.0	7.8
Press temperature (°C)	200	200
Thickness (mm)	16.1	16.2
Density (kg/m^3)	653.0	662.0
Board Properties		
Internal Bond (N/mm^2)	0.52	0.49
MOR (N/mm^2)	17.0	16.4
2 hour thickness swelling (%)	5.4	5.9
24 hour thickness swelling (%)	14.3	15.3
Free formaldehyde (mg/100 g dry board)	8.2	1.8
Moisture content (%)	6.5	6.3

resin manufacturer to supply a lower molar ratio resin. It seems to me, and most particleboard producers have started realizing the fact, that reducing the free formaldehyde, especially at the levels that are anticipated, in the near future, is not a matter of changing the resin alone. The modern approach is to achieve the target by changing the resin system itself: i.e., using a different resin, mixing in a formaldehyde catcher, and using a special hardener as well and doing this in an optimum way. This is not an easy task at all.

I am very happy to bring you some good news. Only a couple of months ago by following the approach just described, we achieved the lowest free formaldehyde emission value ever reported for a UF, 1.8 mg/100 g dry board. I cannot give many details of the trials, I will just give you the final results as summarized in Table 7. Under I in the table, the figures reported are of boards produced without any formaldehyde catcher and without any special hardener. Under II, the figures reported are of boards produced with both a formaldehyde catcher and a special hardener. All the figures are averages over a 12 hour period.

SUMMARY AND CONCLUSIONS

The current trend in the European wood-panels industry, initiated in Germany, is the further reduction (practically elimination) of free formaldehyde emissions to very low (nearly undetectable) levels. The industry will have to follow the regulations and this requires intensive research. The plants and the adhesive manufacturers will have to seek the solution in changing not the resin itself, but their whole resin system (resin, formaldehyde catcher, hardener, other additives) as well as monitoring very closely their production parameters and even customizing the specific resin formulations for the individual plants. Provided that product innovation continues and the current quality and production rates can be maintained, in spite of the need to comply with very low free formaldehyde regulations, I strongly believe that there are tremendous opportunities for growth in a market becoming competitive at an ever increasing rate.

REFERENCES

CanTox, Inc. 1988. Biological Risk Assessment of the Potential Carcinogenesis from Exposure to Airborne Formaldehyde, Version 2. Unpublished report prepared for the Formaldehyde Institute.

Commission of the European Communities. 1990. EUR 13216-European concerted action "Indoor Air Pollution and its Impact on Man." COST Project 613: Report No. 7: "Indoor Air Pollution by Formaldehyde in European Countries." Office for Official Publications of the European Communities. Luxembourg.

DIN EN120. 1984. Particleboard, determination of formaldehyde content, extraction method called Perforator. *DIN Pocket book 60.* Beuth-Verlag. Berlin.

European Federation of Associations of Particleboard Manufacturers. 1992. Annual Report 1991/92. European Federation of Associations of Particleboard Manufacturers. Brussels.

Gefarstoffverordnung. 1986. Regulation on dangerous materials. *Federal Law Gazette* 47, Teil 1:1470.

International Agency for Research on Cancer (IARC). 1987. IARC Monographs on the evaluation of the carcinogenic risk of chemicals of humans. *Overall Evaluations on Carcinogenicity: An Update of IARC Monographs.* Volumes 1-42, Supplement 7. Lyon, France.

Jann, O. 1991. Present state and developments in formaldehyde regulations and testing methods in Germany. *Proceedings, Twenty-Fifth International Particleboard/Composite Materials Symposium,* T. M. Maloney, Ed. Washington State University. Pullman, WA. pp. 273-283.

Lehmann, W. and Roffael, E. 1992. International guidelines and regulations for formaldehyde emissions. *Proceedings, Twenty-Sixth International Particleboard/Composite Materials Symposium,* T. M. Maloney, Ed. Washington State University. Pullman, WA. pp. 124-150.

U.E.A. 1991. The Furniture Industry in the EC Countries. European Furniture Manufacturers Federation. Brussels.

APPENDIX 1

DAILY FORMALDEHYDE TURNOVER IN THE BODY*

Formaldehyde is a normal metabolite produced and used by the body in large amounts. Assuming a half-life of 1.5 minutes in the blood and an endogenous blood concentration of 2.5 mg/l, the amount of formaldehyde turned over per day in the body (assuming the body pool volume is 43l for a 60 kg person) can be calculated as follows:

1. Ambient concentration of blood = 2.5 mg/l
2. In the absence of production, this level would decrease by 50% in 1.5 minutes to 1.25 mg/l
3. In order to maintain an ambient level of 2.5 mg/l, 1.25 mg/l must be produced each 1.5 minutes

Therefore:

1. Production rate = 1.25 mg/1.5 minutes = 0.83 mg/l/minute
2. Total daily production = 0.83 mg/l/minutes × 43l × 1440 minutes/day = 51.4 g/day

*Source: CanTox, Inc. 1988.

This estimate is based on the assumption that blood formaldehyde is in equilibrium with formaldehyde in total blood fluid and is evenly distributed throughout the body fluids.

A person continuously exposed to the 24 hour exposure limit of 1 ppm (1.23 mg/m^3) formaldehyde and who inhales 20 m^3 per day would take in 24.6 mg or 0.0246 g formaldehyde per day. This is 2000 times less formaldehyde than that turned over in the body during the course of normal metabolism. The addition of such a tiny fraction to the body pool would not be expected to add significantly to the risk of developing formaldehyde-induced systemic effects.