# A European Approach to Particleboard and MDF Adhesives

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**Abstract**

In this work, the adhesives used in the European particleboard and medium density fiberboard (MDF) industry are presented. The structure of the particleboard and MDF market in Europe in relation to the adhesive type and product application is also discussed. New markets for particleboard and MDF—known as nonfurniture markets—are developing in Europe at a very fast rate. Newly developed resin systems and trends affecting the industry are also presented.

**Introduction**

In Europe, aminoplastic resins are the most important adhesives for wood-based panels, especially particleboard and medium density fiberboard (MDF). Whereas urea-formaldehyde (UF) resins are mainly used for interior-use boards, the incorporation of melamine provides resins with a lower susceptibility against hydrolysis (i.e., better water and weather resistance). Nearly all kinds of requirements can be met with these aminoplastic resins. In addition, new products such as moisture-resistant boards, fire-retardant boards, exterior-use boards, etc. have showed a rapid growth in the European particleboard and MDF market in recent years.

Aminoplastic resins with low formaldehyde content fulfill the stringent formaldehyde emission regulations that have been enforced in Europe during the last decade. In addition, boards with extremely low formaldehyde emission, similar to that of natural wood, can be produced using special melamine-urea-formaldehyde (MUF) resins. Melamine-urea-phenol-formaldehyde (MUPF), phenol-formaldehyde (PF), and polymeric methylene di-isocyanate (PMDI) resins are also used in Europe. However, the quantity of MUPF, PF, and PMDI resins consumed today by the European particleboard and MDF industry is relatively small.

**Particleboard and MDF adhesives: current status**

In Europe, most of the resins currently used in the particleboard and MDF industry are formaldehyde-based adhesives (UF, MUF, etc.) which have a formaldehyde:urea (F:U) molar ratio between 1.05 and 1.20 (1,7–9). In some cases with MDF, this F:U ratio can be smaller (0.90 to 1.00). Only 10 years ago the majority of the resins used had molar ratios as high as 1.6 (7,8). The major reason for this significant reduction over the years was the attempt of resin manufacturers to decrease formaldehyde emissions. The driving forces behind this has been consumer opinion and legal regulations.

The reduction of the molar ratio was initially achieved by introducing one or two extra steps in

The urea reacted with the residual formaldehyde, and the free formaldehyde emitted from the board was drastically reduced. However, this had many negative side effects. The plants had to tolerate longer press times, tighter moisture control, and higher glue factors in addition to the fact that the mechanical properties and water resistance of the boards were lowered. Thus, further developments to address these problems included the addition of a small quantity of melamine (usually 1 to 4%). Although this increased the production cost, it proved to be quite successful. Such MUF resins are generally more forgiving with the process variations than straight UF resins. For formaldehyde-based resins, the above approach appears to be the only way to produce particleboard or MDF with low formaldehyde emissions without the use of additives (1,7–9).

Meanwhile, the resin industry has invested much in the research of low free-formaldehyde UF resins (2,8,10). New technologies of such UF resins have recently come out in the European market by a small number of resin producers. These manufacturers claim that they combine the emission advantages of the free-formaldehyde resins with the performance advantages of the high molar ratio resins. Such resins create boards with low formaldehyde emissions with the addition of formaldehyde catchers (or scavengers) (2,8,10). It appears that the resin formulation changes capable of reducing molar ratio are at a practical limit.

Formaldehyde catchers are widely used in the European particleboard and MDF industry to reduce formaldehyde emission. There are many practical advantages to using a catcher system. One advantage is the flexibility it provides to the plant manager to vary its quantity, and therefore to control the reduction of formaldehyde emission according to the conditions and production requirements (7,9). However, the major advantage of a catcher system is that it provides a much more efficient system than that of a straight resin (8). The formaldehyde catchers can be in most cases tailor-made to meet the needs of the particular plant. They are used up to a maximum of 25 percent in the resin, achieving reductions in emission up to 60 percent (8). Experience in Europe has shown that instead of using a very low molar ratio resin, one can achieve better results by using a system of an equivalent molar ratio, which is a combination of a higher molar ratio UF resin and a formaldehyde catcher (8,9).

The hardeners (catalysts) used in the past in Europe were mostly ammonium chloride and ammonium sulphate. During the last few years, ammonium sulphate was used instead, in most central and northern European countries, because the use of ammonium chloride had been forbidden for environmental reasons. Both of the above-mentioned hardeners react with the free formaldehyde in the resin and liberate either hydrochloric or sulfuric acid which speeds up the polymerization reaction by lowering the pH. A decade ago, the UF resins used had a molar ratio between 1.4 and 1.6 and fairly high levels of free formaldehyde. However, since the trend today is to use resins with significantly lower formaldehyde emissions, this level is insufficient to produce a significant pH drop when ammonium salts are used as catalysts. Such problems can be overcome by using new special hardeners that will not rely on the available formaldehyde in order to generate acidity (7–9). Their effectiveness therefore will not be influenced by the free formaldehyde in the resin used. The development of such special catalysts has been carried out by some resin manufacturers.

Notably, in the European particleboard industry today, the main requirement of the UF system is speed, since the modern continuous presses can run extremely fast. The speed can be as fast as 3.8 sec./mm. The UF resins applied require a modified cooking procedure and special additives. This is considered to be a major breakthrough in the field.

### The European particleboard market

The particleboard industry experienced a positive development during 1997 (3). The overall level of production in member countries of the European Federation of Associations of Particleboard Manufacturers (FESYP) amounted to 29.6 million $m^3$. Figure 1 outlines the particleboard production and capacity from 1988 to 1997 (3).

The production and consumption of particleboard throughout recent years in Europe have presented constantly increasing growth rates. In 1997, there was an increase of about 8 percent over 1996.

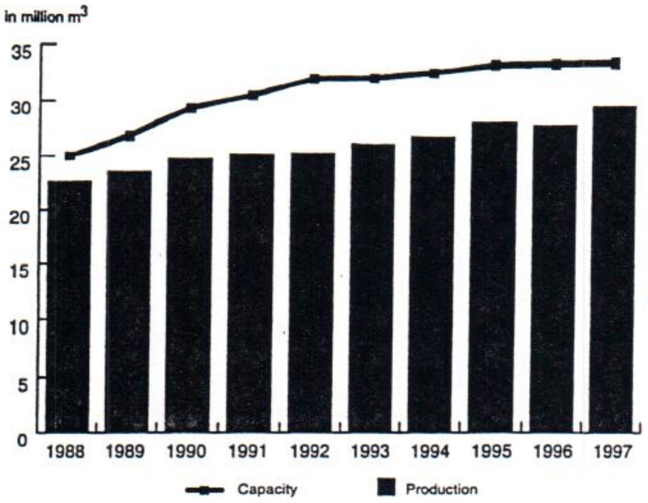


**Figure 1.**—Particleboard production and capacity 1988-1997.

There were 169 particleboard production plants in the 18 FESYP member countries (Austria, Belgium, Cyprus, Denmark, Finland, France, Germany, Greece, Italy, Latvia, Norway, Poland, Portugal, Slovenia, Spain, Sweden, Switzerland, United Kingdom, and Ireland). They provided employment for some 25,000 people. The particleboard production capacity in Europe per country is shown in Table 1 (3). Estimates of data for the particleboard industry in Central and Eastern Europe in 1996 and 1997 are presented in Table 2 (3).

The adhesives used in the European particleboard industry are mostly UF and MUF resins, but MUPF, PF, and PMDI resins are also used for special applications.

Specific standards have been adopted by the European Committee for Standardization (CEN) for the different particleboard grades produced today

**Table 1.**—Particleboard production in FESYP member countries.

| Country | 1993 | 1994 | 1995 | 1996 | 1997 | Change from 1996 to 1997 |
|---|---|---|---|---|---|---|
| | (1,000 m³) | | | | | (%) |
| Austria | 1,592 | 1,598 | 1,640 | 1,650 | 1,690 | 2.4 |
| Belgium | 2,424 | 2,435 | 2,421 | 2,558 | 2,567 | 0.4 |
| Cyprus | 20 | 20 | 20 | 20 | 19 | –7.0 |
| Denmark | 232 | 265 | 285 | 295 | 303 | 2.7 |
| Finland | 439 | 477 | 484 | 498 | 475 | –4.6 |
| France[a] | 2,610 | 2,874 | 3,103 | 3,188 | 3,465 | 8.7 |
| Germany | 7,935 | 8,616 | 8,900 | 8,583 | 9,200 | 7.2 |
| Greece | 350 | 320 | 338 | 335 | 338 | 0.9 |
| Italy | 2,250 | 2,202 | 2,450 | 2,205 | 2,750 | 24.7 |
| Latvia | 101 | 148 | 130 | 140 | 150 | 7.1 |
| Norway | 313 | 372 | 389 | 384 | 393 | 2.3 |
| Poland[a] | 1,143 | 1,291 | 1,466 | 1,652 | 1,996 | 20.8 |
| Portugal | 575 | 757 | 650 | 695 | 859 | 23.6 |
| Slovenia | 216 | 195 | 294 | 246 | 250 | 1.6 |
| Spain | 1,660 | 1,730 | 1,605 | 1,690 | 1,815 | 7.4 |
| Sweden | 597 | 609 | 632 | 576 | 612 | 6.3 |
| Switzerland | 689 | 595 | 491 | 495 | 501 | 1.3 |
| United Kingdom[b] | 1,756 | 1,812 | 2,118 | 2,164 | 2,175 | 0.5 |
| **Total** | **24,902** | **26,316** | **27,416** | **27,374** | **29,558** | **8.0** |
| Total EU | 22,420 | 23,695 | 24,626 | 24,437 | 26,249 | 7.4 |
| Total EFTA | 1,002 | 967 | 880 | 879 | 894 | 1.7 |
| Total others | 1,480 | 1,654 | 1,910 | 2,058 | 2,415 | 17.3 |

[a] Including OSB.
[b] Including OSB and mineral-bonded board.

in Europe. For particleboards, specific requirements have been issued for each particleboard type depending upon the thickness range. The types of particleboards are listed in Table 3 (3).

The volumes of particleboard in each of its market sectors are not freely available in Europe. Neither FESYP nor any other official source has such data.

It is estimated that approximately 90 percent of all particleboard produced in Europe is a standard industrial grade. The majority of this falls within the 16- and 18-mm thickness grades. Straight UF resins of low molar ratio (1.05 to 1.10) are used in this category. The glue factor is at the range of 7 to 8 percent. The press times typically are between 4 to 8 sec./mm. Most of the particleboard standard grade belongs to the E1 class and is used for interior applications.

Another fast-growing market in Europe is that of moisture-resistant particleboard. Strict requirements for moisture-resistant boards have been defined according to the product application (4). The specific tests for moisture resistant boards are the following:

- V-313: Cyclic test in humid conditions (standard EN 321) which requires measurement of internal bond after a specific cyclic test; and
- V-100: Determination of moisture resistance/boil test (standard EN 1087-1) which requires measurement of internal bond after a specific boil test.

Moisture-resistant particleboard (V-313 particleboard) is at present the major special grade with volumes estimated at around 5 percent of the total market. Such a board is designed for use in humid conditions. This market has been developed substantially in recent years, mostly in France, Belgium, Holland, Italy, and Scandinavia. V-313 particleboard is produced with MUF resins with a melamine addition of 12 to 20 percent. Such resins have a molar ratio of 1.10 to 1.20. The glue factor that is usually applied is in the range of 12 to 13 percent on dry wood. The press time used ranged from 6 to 10 sec./mm.

The other moisture-resistant particleboard, which is used in more extreme humid and load-bearing

**Table 3.**— Types of particleboard in Europe.

| Board type | Product application | Standard |
|---|---|---|
| P2 | General purpose boards for use in dry conditions | EN 312-2 |
| P3 | Boards for interior fitments (including furniture) for use in dry conditions | EN 312-3 |
| P4 | Load-bearing boards for use in dry conditions | EN 312-4 |
| P5 | Load-bearing boards for use in humid conditions | EN 312-5 |
| P6 | Heavy duty load-bearing boards for use in dry conditions | EN 312-6 |
| P7 | Heavy duty load-bearing boards for use in humid conditions | EN 312-7 |

**Table 2.**—Data estimates for the particleboard industry in Central and Eastern Europe.

| Country | Production | | | Imports | | | Exports | | | Apparent consumption | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1996 | 1997 | Change | 1996 | 1997 | Change | 1996 | 1997 | Change | 1996 | 1997 | Change |
| | - (1,000 $m^3$) - | | (%) | - (1,000 $m^3$) - | | (%) | - (1,000 $m^3$) - | | (%) | - (1,000 $m^3$) - | | (%) |
| Bulgaria | 120 | 120 | 0.0 | - - | - - | - - | 15 | 15 | 0.0 | - - | - - | - - |
| Czech Republic | 635 | 650 | 2.4 | 68 | 65 | –4.4 | 312 | 315 | 1.0 | 391 | 400 | 2.3 |
| Estonia | 143 | 165 | 15.4 | 21 | 25 | 19.0 | 93 | 107 | 15.1 | 71 | 83 | 16.9 |
| Hungary | 386 | 429 | 11.1 | 33 | 40 | 21.2 | 132 | 150 | 13.6 | 287 | 319 | 11.1 |
| Latvia | 140 | 150 | 7.1 | 0 | 0 | 0.0 | 90 | 100 | 11.1 | 50 | 50 | 0.0 |
| Lithuania | 110 | 168 | 52.7 | 31 | 41 | 32.3 | 70 | 134 | 91.4 | 71 | 75 | 5.6 |
| Poland | 1,652 | 1,996 | 20.8 | 483 | 520 | 7.7 | 15 | 106 | 606.7 | 2,120 | 2,410 | 13.7 |
| Romania | 248 | 217 | –12.5 | 16 | 10 | –37.5 | 10 | 11 | 10.0 | 254 | 216 | –15.0 |
| Slovak Republic | 245 | 250 | 2.0 | 20 | 20 | 0.0 | 27 | 26 | –3.7 | 238 | 244 | 2.5 |
| Russian Fed. | 1,460 | 1,400 | –4.1 | 53 | 50 | –5.7 | 100 | 110 | 10.0 | 1,510 | 1,340 | –11.3 |
| Slovenia | 246 | 250 | 1.6 | 37 | 40 | 8.1 | 73 | 75 | 2.7 | 210 | 215 | 2.4 |
| **Total** | 5,385 | 5,795 | **7.6** | **762** | **811** | 6.4 | 937 | 1,149 | 22.6 | 5,202 | 5,457 | 4.9 |

conditions than V-313 particleboard, and qualified as V-100, represents one more special grade in Europe. Its market volumes are small. In general, V-100 test requirements are stricter than those of V-313. It is estimated that this market represents about 1 to 2 percent of the total market. This special market has been developed in recent years in Germany. V-100 particleboard is usually made with MUPF resins which contain about 23 percent melamine. The phenol content is approximately 5 percent. Such resins have a molar ratio of 1.05 to 1.10, and a glue factor of 13 to 14 percent. PF resins are also used in Germany for this particular particleboard grade. Their phenol content is around 9 to 10 percent. Such PF-bonded particleboards have a very low formaldehyde emission, assuming that all free formaldehyde present in the resin system has been incorporated into the PF resin by means of proper hardening conditions and hot stacking of freshly pressed boards. For V-100 particleboard, the press times are in the range of 6 to 10 sec./mm.

Fire-retardant particleboard is another special grade in Europe. Such a board is used in public buildings where fire spread must be controlled to comply with fire safety regulations. Although this particleboard grade is relatively small (<3%), a trend for further development of this market has appeared lately. The resins used for this grade are MUF resins with a melamine addition of approximately 13 to 15 percent. Such resins have a molar ratio of around 1.20. The glue factor is 13 to 15 percent. Fire retardants such as ammonium phosphates, boron-based compounds, etc., are added in amounts of 13 to 15 percent, dry wood basis. Low press times can be 9 to 11 sec./mm, while higher press times in this category are usually in the range of 12 to 13 sec./mm.

**Table 4.**—Regulations for formaldehyde emission limits.

| | |
|---|---|
| UZ 38 for finished products | Raw board (4.5 mg/100g by the perforator method) |
| UZ 76 (Blue Angel) | 3.0-3.2 mg/100g by the perforator method |
| F-zero limit | <2.0 or 2.5 mg/100g (new proposal) |

Particleboards in the E1 class using PMDI adhesives are also produced in Europe. This production process was introduced some years ago and has a few disadvantages (e.g., sticking, high cost). Today there are a couple of plants in Europe regularly producing this type of board. Isocyanate resins are used in combination with UF resin; the UF being used particularly in the surface to avoid any sticking problems. However, such resins are expensive, and although smaller quantities are used, such boards are more expensive than standard UF-bonded boards. This market is very small, possibly less than 1 percent. In addition, in the production of V-100 or V-313 boards, PMDI resins in the core layer in combination with PF or MUPF resins in the surface layer are also used in a few plants.

Another particleboard grade which is under discussion is called F0. This is a truly brand new market. Until now, it has been believed that such a particleboard grade could be only produced by using PMDI or PF resins that have zero formaldehyde emission. In fact, formaldehyde emission is not zero because of the normal emission of formaldehyde from the dried wood. In addition, many proposals of regulations have been published for the so-called "F-zero" limits (1,6,8,10). The data for formaldehyde emission is briefly summarized in Table 4.

The "Blue Angel" is a label that is awarded by the German Health and Ecology Ministry to environmentally friendly products. Today, wood-based panels, such as particleboard, used for finished house construction may be granted this Blue Angel certification. For UZ 76, a board has been developed in Germany, with desired free formaldehyde emission of less than 0.05 ppm, which corresponds to 3.0 to 3.2 mg/100 g dry board (at a moisture content of 6.5%).

F-0 particleboards are produced in Europe with MUF resins. This market is less than 1 percent of the total volume. The MUF resins used for this grade are of low molar ratio (around 0.80 to 0.90) and a melamine addition of approximately 15 to 23 percent. The press times are around 10 to 12 sec./mm. The particleboard market in Europe is summarized in Table 5.

## European MDF market

MDF was first introduced in Europe in the mid-1970s with the first sales in the United Kingdom occurring in 1976. Figure 2 outlines the rapid growth in the production of MDF from 1987 to 1997 (3).

The production and consumption of MDF in Europe in recent years has presented very rapid growth rates. There was a 20 percent increase from 1996 to 1997. The total production volume was about 5,451,000 $m^3$ (3). Industry analysts predict similar growth rates for the next 3 years as many new lines are now being established, while capacity of recently installed lines is being optimized (3).

In 1997, there were 43 MDF production plants with 52 press lines in the 18 FESYP member countries. The MDF production capacity in Europe per country is presented in Table 6 (3).

It has been shown that the applications for MDF outside the furniture industry (interior-use MDF) are more developed in Europe than elsewhere (Table 7) (4). Approximately 33 percent of the European MDF production was used in 1997 in nonfurniture applications compared to 20 percent in the United States (4).

. In Europe today, there are 18 major groups producing MDF. All produce standard industrial grade MDF, while many are producing various grades of special products (Table 8) (4).

The adhesives used in the MDF industry in Europe are mostly straight UF resins, but MUF resins are also used in many plants. Zero-added formaldehyde MDF bonded with PMDI resins comprises a very small market in Europe (<1%).

As with particleboard, the exact volumes of the various MDF grades are not freely available. An es-

**Table 5.**—Volume of particleboard products in Europe.

| Product type | Percent of total volume |
|---|---|
| | (%) |
| Standard industrial grade | ≈90 |
| Moisture resistant grade (V313, V100) | ≈6 to 7 |
| Fire retardant grades | <3 |
| Zero-added formaldehyde | <1 |
| F-zero grade | <1 |

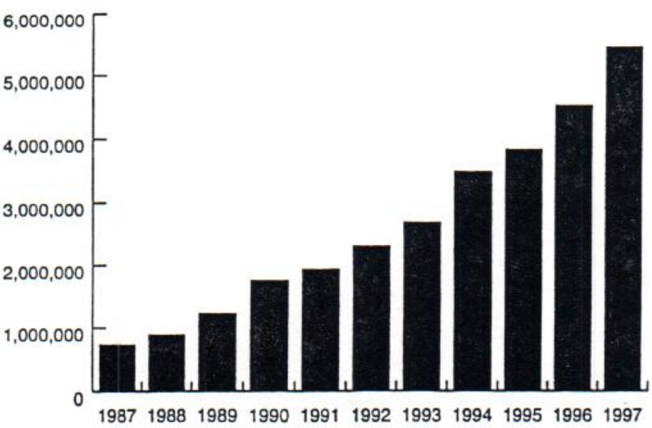


**Figure 2.**—European production of MDF in $m^3$.

**Table 6.**—MDF production capacity in Europe per country.

| Country | Production capacity January 1995 | Production capacity December 1997 |
|---|---|---|
| | (1,000 $m^3$) | (1,000 $m^3$) |
| Germany | 967 | 1,780 |
| Italy | 910 | 1,240 |
| Poland | 154 | 480 |
| Spain | 580 | 472 |
| France | 430 | 463 |
| Great Britain | 370 | 430 |
| Portugal | 89 | 424 |
| Ireland | 300 | 310 |
| Luxemburg | - - | 250 |
| Belgium | - - | 200 |
| Denmark | 100 | 100 |
| Sweden | - - | 90 |
| Austria | 80 | 80 |
| Greece | 65 | 65 |
| Czech Republic | 60 | 62 |
| Slovenia | 55 | 55 |
| **Total** | **4,160** | **6,501** |

**Table 7.**—Percentage of furniture and nonfurniture MDF produced by region.

| Region | Furniture | Nonfurniture |
|---|---|---|
| | (%) | (%) |
| Europe | 67 | 33 |
| North America | 80 | 20 |
| Asia | 68 | 32 |

timation of the current MDF market structure in Europe is outlined in Table 9 (4).

It is estimated that approximately 60 to 65 percent of all MDF produced is standard industrial MDF with the majority being 18 mm thick. UF and MUF resins of low molar ratio (0.95 to 1.00) are mostly used in this category. The press times vary between 9 and 11 sec./mm.

Moisture-resistant MDF and MDF for laminated flooring are the two main special grades at present with volumes estimated for each at about 10 percent of the total market. Moisture-resistant MDF is a product designed for use in humid conditions. It is successfully used for kitchen furniture, bathroom furniture, window boards, etc. This market has been developed substantially in recent years in the United Kingdom and Ireland. Such MDF (known as MDF-H) is produced with MUF resins which contain 12 to 15 percent melamine. The press times are around 9 to 11 sec./mm. For this grade, much scope exists for the continued growth of moisture-resistant MDF as a substitute for conventional products in joinery applications (4).

Wood constitutes about 6 percent of the total flooring market in Europe. MDF itself represents about 80 percent of the total laminated flooring market in Europe. Laminated flooring MDF has achieved spectacular growth over the past few years. Introduced in Sweden in the 1980s, this MDF grade has been successfully used as a substrate for a wide variety of overlay materials such as wood veneers, high pressure laminates, and melamine-impregnated papers. MDF used for this application is made with 3 to 5 percent melamine-fortified UF resins, since higher moisture resistance is necessary. Press times vary between 9 and 12 sec./mm.

Exterior grade MDF (known as MDF-H2) is designed for use in exterior conditions. It is used in a wide range of applications including external signs, shop fronts, door parts, garden furniture, etc. MUF (12 to 17% melamine) resins are usually used for this special grade. Such boards must pass the V-313 test to be classified as exterior grade MDF. The press times used in this case are 9 to 11 sec./mm. PF resins for MDF products are not currently used in Europe as far as it is known.

Another special market is that of fire and flame retardant MDF (FR-MDF). Such a product is used in public buildings where fire spread must be controlled to comply with fire safety regulations. Unfortunately in Europe today, the MDF panel requirements for such uses tend to vary considerably. A common European standard is mandatory in this case. Although this MDF grade is relatively small (<3%), there are signs of further development. The resins used for this grade are mostly UF. The glue factor is higher (≈15%), and a large proportion (6 to 10%) of the fire-retardant agents (ammonium sulfates, phosphates, boron-based compounds, etc.) are usually applied (3).

Panel requirements tend to vary considerably for each country and achieving certification takes considerable time and resources. It appears today that the development of a "Single Burning Item" test as a common European standard for fire-retardant-

**Table 8.**—Various MDF products by industry group.

| Product type | No. of groups | Percent of groups |
|---|---|---|
| | | (%) |
| Standard MDF | 18 | 100 |
| Cut-to-size MDF | 12 | 67 |
| Faced MDF (melamine, foil, etc.) | 12 | 67 |
| Thin MDF (<6 mm) | 10 | 56 |
| Moisture-resistant MDF | 9 | 50 |
| Light and super-light MDF | 9 | 50 |
| Lacquered/printed MDF | 9 | 50 |
| Flooring quality MDF | 6 | 33 |
| Fire-retardant MDF | 5 | 28 |
| Zero-added formaldehyde MDF | 5 | 28 |
| High-density MDF | 5 | 28 |
| Exterior-grade MDF | 4 | 22 |

**Table 9.**—Estimate of the volume (% of total) of special MDF products in Europe.

| Product type | Percent of total volume |
|---|---|
| | (%) |
| Standard industrial grade | ≈60 to 65 |
| Moisture resistant grade | <10 |
| Flooring quality | <10 |
| Fire & flame retardant grades | <3 |
| Zero-added formaldehyde | <1 |
| High density | <5 |
| Exterior grade | <3 |

treated particleboard and MDF will remove the current obstacles.

## Formaldehyde emission from particleboard and MDF

Formaldehyde is among the major indoor air pollutants. The main source of formaldehyde emission indoors comes from particleboard and MDF products. One of the first steps in reducing pollution from formaldehyde was to standardize the emissions from particleboard into three classes: E1, E2, and E3 (Table 10) (5,6). However, acceptable levels of formaldehyde emission have been continuously reduced in Europe over the last few years. The corresponding lower limit for MDF (for E1 class) is 7.0 mg/100 g. For both particleboard and MDF formaldehyde emission, a correction of the perforator value to 6.5 percent board moisture content should be made.

The formaldehyde emission indoors has been extensively researched since the early 1970s. Occupational exposure limits for formaldehyde concentration were first issued in several European countries in an attempt to handle possible problems. Residential standards were also determined in the United States and other countries (6,7,9).

The basis of all regulations had been the recommendation of the German Federal Health Agency in 1977 for a maximum formaldehyde concentration in the air of 0.1 ppm (= 0.12 mg/m$^3$). As a consequence, there is now a clear status concerning the subsequent formaldehyde emission from all wood-based panels given with the German Regulation of Hazardous Substances (now German Regulation of Prohibition of Chemicals) and the German Federal Health Code (2,6). It was the big effort in research and development in the chemical industry, and the harmonic cooperation with the wood-based panels industry, which made it possible to overcome the problem of formaldehyde emission.

Table 10.–Classification of particleboards according to their formaldehyde emission.

| Class | Chamber method, prEN 717-1: concentration in 40 m$^3$ chamber | Perforator method, EN 120: perforator value |
|---|---|---|
| | (ppm) | (mg/100 g) |
| E1 | 0.015 to 0.1 | 6.5 to 10 |
| E2 | 0.1 to 1.0 | 10 to 30 |
| E3 | 1.0 to 2.3 | 30 to 60 |

It is apparent from Table 11 (7) that the formaldehyde concentration limits in most of the industrialized countries have been dramatically reduced over the last 20 years to keep the air clean and protect the health of humans. The formaldehyde contents of the wood-based panels today are 10 to 15 times lower than those 15 years ago (8,9). Therefore, it appears that the problem of formaldehyde emission from wood-based panels has been limited to a very significant degree.

The allowable formaldehyde concentration (Occupation Exposure Limit) for workplace exposures in 13 countries ranges from 0.3 ppm to 2.0 ppm, with the majority of them between 0.5 and 1.0 ppm (5,6,8). These exposure limits in most industrialized countries are reasonably very strict. Also, the lowest occupational exposure limit for the living space in most countries is around 0.1 ppm. It is obvious from Table 12 that the acceptable exposure level in ambient air is usually 5 to 10 times lower than the exposure limit in workplace, except in three countries. There are also three other countries with no limits for the living space.

Another problem—which has not yet been solved—is how to measure the formaldehyde emission

Table 11.–Maximum exposure limits for formaldehyde in the workplace environment in various countries.

| Country | Formaldehyde concentration | | |
|---|---|---|---|
| | 1976 | 1985 | 1998 |
| | - - - - - - - (ppm) - - - - - - - | | |
| United States | 5.0 | 3.0 | 1.0 |
| Denmark | 5.0 | 1.0 | 0.3 |
| Finland | 5.0 | 1.0 | 0.5 |
| Norway | - - | 1.0 | 0.5 |
| Sweden | - - | 1.0 | 0.5 |
| Austria | - - | - - | 0.5 |
| Germany | 5.0 | 1.0 | 0.5 |
| Switzerland | - - | 1.0 | 0.5 |
| United Kingdom | 10.0 | 2.0 | 2.0 |
| Belgium | - - | 2.0 | 1.0 |
| France | - - | - - | 2.0 |
| Australia | - - | - - | 1.0 |
| Canada | - - | - - | 1.0 |

from particleboard and MDF products. In Europe there are three different methods for determination of formaldehyde emission issued by CEN:

- extraction method called the perforator method (EN 120);
- formaldehyde release by the gas analysis method (EN 717-2); and
- formaldehyde release by the flask method (EN 717-3).

One more standard for determination of formaldehyde emission (prEN 717-1: "Determination of formaldehyde release—Formaldehyde emission by the chamber method") is currently being translated and should be officially issued next year. However, exact correlations should be defined between the steady-state concentration test in a small or big climate chamber and the laboratory test methods such as perforator, gas analysis, and flask method, or even the desiccator method. It is apparent that the particleboard and MDF industry needs quick and reliable test methods for supervising production and for assuring compliance with the regulations.

## Current developments: a new resin system

A unique free-formaldehyde process with a conventional formaldehyde-based resin has been developed by A.C.M. Wood Chemicals. This new F-0 system is based on a combination of MUF resin, a formaldehyde catcher, and a special hardener. The resin has a low molar ratio of about 0.75 to 0.90 and a melamine addition of 10 to 18 percent. It can achieve industrial production of particleboards with free-formaldehyde emission values below 2.0 mg/100 g dry board (perforator value) without any deterioration in the board properties, and without increasing press times or amount of resin. The press times used in this innovative process are in the range of 10 to 12 sec./mm.

**Table 12.**—Maximum exposure limits for formaldehyde in the living space and the workplace environment in various countries

| Country | Living space | Workplace |
|---|---|---|
| | - - - - - - - (ppm) - - - - - - - | |
| United States | 0.10 | 1.0 |
| Denmark | 0.12 | 0.3 |
| Finland | 0.12 | 0.5 |
| Norway | 0.10 | 0.5 |
| Sweden | 0.20 | 0.5 |
| Austria | 0.10 | 0.5 |
| Germany | 0.10 | 0.5 |
| Switzerland | 0.10 | 0.5 |
| United Kingdom | - - | 2.0 |
| Belgium | - - | 1.0 |
| France | - - | 2.0 |
| Australia | 0.10 | 1.0 |
| Canada | 0.10 | 1.0 |

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