Producing Panels with Formaldehyde Emission at Wood Levels

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Abstract

The acceptable levels of formaldehyde emission from composite panel products have been continuously reduced over the last decades. The driving forces have been the increased public awareness and consumer demand for non-hazardous products as well as the corresponding governmental regulations. The latest re-classification of formaldehyde by the International Agency for Research on Cancer as “carcinogenic to humans”, has triggered further concern and reactions by worker and consumer associations, “green” organisations, regulatory authorities and the industry itself. New studies on formaldehyde health effects were initiated since 2005 in both the USA and Europe and corresponding decisions on reclassification have been postponed until the results are available.

With the aim to protect people’s health and to help the industry satisfy the acceptable formaldehyde levels, CHIMAR has developed novel wood adhesive system technologies, which provide composite panels (particleboards, MDF, thin MDF, plywood and OSB) conforming to the most stringent formaldehyde standards. Even panel grades with emission at the level of natural wood (“Super E0”, the Japanese F****) are obtained, while simultaneously maintaining acceptable bonding performance and cost efficiency.

The proposed adhesive systems are the results of many years’ research and experimentation in laboratory, pilot and industrial environment. In this work, the advantages of such systems are presented. In parallel, the leading standards and regulations concerning formaldehyde emission from wood composites are reviewed and mention is made of the Occupational Exposure Limits worldwide.

Introduction

The issue of formaldehyde release from composite wood panels is mainly related to the use of urea-formaldehyde (UF) resins as bonding adhesives for their production. These high reactivity and cost effective polymers are contributing to the panel formaldehyde emission by their low resistance to hydrolysis and the presence of free non-reacted formaldehyde. Resin copolymers produced with the use of melamine either at low (urea-melamine-formaldehyde resins, UMF) or at high levels (melamine-urea-formaldehyde resins, MUF) have improved hydrolytic stability but yet questionable performance in regard to very low formaldehyde emission levels.

Urea-formaldehyde resins have traditionally been used in the production of wood-based panels (mainly particleboard, fibreboard, plywood) and related products for decades. Indoor air quality and formaldehyde emissions from composite wood products first became subject to broad public and governmental concern in the late 1970s, when the energy crisis encouraged energy saving through tight sealing of homes. This reduced the rate of outdoor air infiltration and overall ventilation rates leading to the entrapment of gaseous pollutants inside home air atmosphere. With Europe, North America and Japan as pioneers, test methods to accurately measure formaldehyde emissions from panels were developed and product emission guidelines were established. These were combined with work place exposure limits for formaldehyde. A change in the formulation of UF resins was made by the resin industries to meet the low panel emission guidelines. Moreover, competitive bonding systems such as phenol-formaldehyde resins or polymeric diphenyl methane diisocyanate (PMDI) binders were proposed.

Formaldehyde Classification

Until year 2004, formaldehyde was classified by the World Health Organization (WHO) as probably carcinogenic to humans (Group 2A). However, the International Agency for Research on Cancer (IARC) of WHO, decided to recommend the reclassification of formaldehyde as "carcinogenic to humans (Group 1)", on the basis of available scientific data (IARC 2004). This recommendation, although not legally binding, was received with concern and immediate reactions from worker and consumer associations, "green" organisations, regulatory authorities and the industry (producers and users of formaldehyde) associations (FormaCare and European Panel Federation in Europe, Formaldehyde Council and Composite Panel Association in N. America). The latter indicated that the decision of IARC had been based on studies regarding the exposure in 30-60 years ago, while the work place emission levels have declined dramatically the past three decades due to the technological progress made (Composite Panel Association 2004, Formaldehyde Council 2004). Moreover, they stressed that the IARC classification was an "hazard identification" and not a full risk assessment.

In 2005, new toxicological and cancer studies were initiated by FormaCare and the Formaldehyde Council, involving various independent research institutes in Europe and the USA. In the meantime, there were proposals to reclassify formaldehyde in Europe by the French institute for occupational risk prevention (INRS) and the German Federal Institute for Risk Assessment (BfR). However, the European Chemicals Bureau (ECB) postponed its decision on the reclassification of formaldehyde until the results of the new studies were available (FormaCare 2006). Also the U.S. Environmental Protection Agency (EPA) delayed formaldehyde reclassification until the completion of the follow-up study of the National Cancer Institute.

The IARC recommendation was finally published in December 2006 through its monograph series Volume Number 88. In this report, it is stated that "there is sufficient evidence in humans and in experimental animals for the carcinogenicity of formaldehyde" and that "formaldehyde is carcinogenic to humans (Group 1)" (IARC 2006). It is further mentioned that the highest occupational exposure to formaldehyde were measured in varnishing, production of textiles, garments, furs, in certain jobs in board mills and foundries. Lower exposure levels have been encountered in formaldehyde production (mean concentration < 1ppm). A wide range of exposure levels has been observed in the production of resins (all data were derived from the 1980s). In wood products manufacture, exposure occurs during glue mix preparation, laying of mat, hot pressing and sanding – all data were derived from the 1960s-70s-80s. The reported mean concentrations in the air were greater than 1ppm in particleboard mills and approximately 2ppm in plywood, however, recent studies reported concentrations lower than 0.4ppm in plywood and less than 0.16ppm in OSB and fibreboard plants.

In September 2007, an International Formaldehyde Science Conference took place in Barcelona, Spain, organized by FormaCare (the European Formaldehyde Industry Association, sector group of CEFIC, the European Chemical Industry Council). The results of newly available scientific studies on the epidemiology and toxicology of formaldehyde were presented and discussed by representatives of institutes from Europe, the USA and Brazil, European

Commission representatives and industry scientists (FormaCare 2007, Press Release). Main conclusions include the following points: a) the evidence for NasoPharyngealCancer formation is highly ambiguous, b) the leukemia formation related to formaldehyde exposure is highly improbable, c) no mutagenic effects were observed in experiments and d) in the normal living environment or at the workplace, formaldehyde exposure is not expected to lead to sensory irritation. The threshold for sensory irritation is clearly lower than that leading to cell death. Concentrations of 0.5ppm or 0.3ppm with peaks of 0.6ppm will not lead to objective signs of sensory irritation. The bottom line of the conference was that “the common use of formaldehyde in consumer products and other applications does not pose a risk to human health”. The IARC recommendation was challenged by presenting the weak points of the studies on which it was based: old data, lack of statistical robustness of data analysis, no consideration of confounding effects (also in FormaCare 2007, Scientific fact sheet). Such weak points and the newly available data suggest that there is no clear connection between formaldehyde exposure at current levels of exposure and cancer in humans.

In October 2007, a study on the “Socio-Economic Benefits of Formaldehyde to the European Union (EU 25) and Norway” was released by FormaCare, quantifying the value of formaldehyde to society and the contribution of the formaldehyde industry to the economies of these countries (Global Insight 2007). The study indicated that “consumers would have to spend an additional €29.4 billion per year if formaldehyde-based products were replaced by substitute chemicals” and that alternative products are of inferior quality and often of higher cost than the formaldehyde-based products, leading to a pronounced consumer preference for these latter products. Prior to this European study a report had been released on the “The Economic Benefits of Formaldehyde to the United States and Canadian Economies”, showing even higher economic benefits from the use of formaldehyde products (Global Insight 2005). It was found that “people use products that contain formaldehyde every day, and that formaldehyde and the products made from it provide an enormous contribution to the U.S. and Canadian economies”.

Within the EU, formaldehyde is currently classified as a Category 3-R40 substance (“limited evidence of a carcinogenic effect”), which is the lowest available EU category for suspected carcinogens. According to the findings of the Barcelona conference this category is still appropriate (Gelbke 2008). The classification of formaldehyde in the EU will be reviewed under the new regulation “Registration, evaluation, authorisation and Restriction of Chemicals” (REACH) on chemicals and their safe use. In the U.S. the current classification by Environmental Protection Agency (EPA) is that of a probable human carcinogen (B1) and EPA's Office of Research and Development is currently engaged in a re-assessment/update of the potential cancer and non-cancer risks of formaldehyde.

Occupational Exposure Limits

Ever since formaldehyde emission was identified as a potential contributor to low indoor air quality, efforts were made by both the government and industry to reduce exposure to it. One of the measures taken was the establishment of both occupational and residential exposure limits for formaldehyde.

The Occupational Exposure Limits (OELs) for formaldehyde are presented in Table 1. In countries with higher limits there are discussions to lower them following the recommendation of the International Agency for Research on Cancer (IARC).

The maximum exposure limits for formaldehyde in the living space environment of some selected countries are given in Table 2. The German value of 0.1 ppm was already established in 1977 by BGA (Anonymous 1977) and was confirmed by BfR in 2004 (Anonymous 2004).

Table 1: *Occupational Exposure Limits (OELs) for formaldehyde (IARC 2006, FormaCare 2007, Q&A on formaldehyde).*

Country	Concentration (ppm)	Type[a]
Australia	1.0	TWA
Austria	0.3	TWA
Belgium	0.3	Ceiling
Brazil	1.6	Ceiling
Canada-Alberta	0.75 / 2.0	TWA / Ceiling
Canada-British Columbia	0.3 / 1.0	TWA / Ceiling
Canada-Ontario	1.5	Ceiling
Canada-Quebec	2.0	Ceiling
Denmark	0.3	TWA & STEL
Finland	0.3	TWA
France	0.5	TWA
Germany	0.3	TWA
Greece	2.0	TWA
Hong Kong	0.3	Ceiling
Ireland	2.0	TWA
Italy	0.3	Ceiling
Japan	0.5	TWA
Malaysia	0.3	Ceiling
Mexico	2.0	Ceiling
Netherlands	1.0	TWA
New Zealand	1.0	Ceiling
Norway	0.5	TWA
South Africa	2.0	TWA
Spain	0.3	STEL
Sweden	0.5	TWA
Switzerland	0.3	TWA
United Kingdom	2.0	TWA
USA-ACGIH[b]	0.3	Ceiling
USA-NIOSH[b]	0.016	TWA
USA-OSHA[b]	0.75	TWA

[a]*TWA:8h time-weighted average, STEL: short-term exposure limit.*

Table 2: *Formaldehyde maximum exposure limits (MEL) in the living space in various countries (as in 1999).*

Country	HCHO MEL, living space (ppm)
USA	0.10
Denmark	0.12
Finland	0.12
Norway	0.10
Sweden	0.20
Austria	0.10
Germany	0.10
Switzerland	0.10
UK	--
Belgium	--
France	--
Greece	--
Australia	0.10
Canada	0.10

Determination of formaldehyde release from wood-based panels

Key element for the efforts to evaluate or control the contribution of wood products on the quality of indoor air is the means of measuring the actual formaldehyde emissions of a product. Measurement of a product's potential to emit formaldehyde is the basis for determining indoor air quality through modelling. A variety of test methods for measuring product emission levels are applied worldwide, producing a corresponding variety of test results. Each method measures a slightly different emission characteristic and frequently produces results in different and non-interchangeable units. This proliferation of test methods and incomparable results often creates confusion among government regulators, consumers and industry personnel. One of the most common misunderstandings is that citing a formaldehyde level of a wood product is meaningless unless the test method and conditions are also cited. Over the past several years there has been an increasing effort to bridge these differences in testing methods between Europe and North America mainly.

Formaldehyde emissions from pressed wood products come from two sources within the product: free formaldehyde (formaldehyde molecules left non-reacted) and the long-term relatively steady-state breakdown of the urea-formaldehyde bond (resin hydrolysis). Furthermore, there are two types of factors influencing the level of formaldehyde emissions from panel products: internal and external factors. Internal factors comprise of the type of wood and resin employed, the parameters and conditions of panel production, and the panel age as well. External factors represent the temperature, relative humidity, air exchange rate, and total panel area in relation to the total volume of the space in which the panels are placed. All these factors are taken into consideration when measuring formaldehyde emission.

Formaldehyde test methods were developed along two tracks: large test chambers designed to imitate a room in a home, and smaller, quicker tests suitable for lab bench and plant quality control. The large chambers, due to their perceived accuracy with which they simulate human environments, became known as “reference” tests and were frequently cited in government regulations and standards. The smaller tests became known in Europe as “derived” test methods (Marutzky and Margosian 1995).

In industrial practice, the perforator method is the most widespread test procedure for measuring formaldehyde content from particleboards and MDF in Europe, and is also employed worldwide with the exception of North America. It is accurate, reproducible, and its application cost as compared to the gas analysis and large chamber methods has been calculated to rate at 0.5 : 8 : 100 respectively. In the case of very low formaldehyde emissions, however, the perforator method is not considered as a reliable method. Small chambers are also widely utilised in Europe and North America and can be very accurate, relatively easy to adapt at both laboratory and plant environments, and correlate well to large chambers.

An overview of selected test methods and related standards in use is presented in Table 3.

Table 3: *Formaldehyde test methods (Athanassiadou 2000, Marutzky 2008).*

Test method	Standard, standard draft or method name
Chamber	EN 717-1, ASTM E 1333, ASTM D 6007, JIS A 1901, JIS A 1911, ISO 12460-1, ISO 12460-2
Gas analysis	EN 717-2, ISO 12460-3
Flask method	EN 717-3, AWPA method
Desiccator	ASTM D 5582, JIS A 1460, JAS 235, JAS 233, AS/NZS 4266.16, ISO 12460-4
Perforator	EN 120, ISO 12460-5
Other	Field and Laboratory Emission Cell “FLEC”, Dynamic Microchamber “DMC”

Formaldehyde emission standards for wood-based panels

Apart from regulations governing formaldehyde concentration in workplace and living environments, guidelines for panel formaldehyde emission levels have been established.

Germany pioneered in this field as well as in reducing panel formaldehyde emissions in actual industrial practice. In 1980, the world's first formaldehyde regulation for wood products was published in Germany (ETB-Richtlinie). That guideline combined the formaldehyde steady state concentration, determined by a large chamber test, and the formaldehyde content, determined by the perforator method, classifying particleboards according to their formaldehyde release into three different emission classes, E1, E2 and E3 (Table 4).

Table 4: *Classification of particleboards according to their formaldehyde emission (ETB-Richtlinie, Roffael 1993).*

Emission class	Equilibrium concentration in a 40 m^3 test chamber (ppm)	Iodometric Perforator value (mg/100g dry board)
E1	≤ 0.1	≤ 10
E2	0.1 - 1.0	10 - 30
E3	1.0 - 2.3	30 - 60

In 1989, there was a new regulation determining a more stringent E1 level (photometric average perforator value= 6.5mg/100g dry board). This E1 level is valid till today and has been adopted, more by trade than by regulation, by a lot of other European countries. Currently the European formaldehyde limits for wood-based panels are summarized in the harmonized standard EN 13986 (Wood-based panels for use in constructions-Characteristics, evaluation of conformity and marking). This includes two emission classes E1 and E2 (Table 5), the upper value of class E1 being 8mg/100g dry board (according to EN 120, perforator method) with rolling average of the values found from the internal factory control over a period of half year not higher than 6.5mg/100g for particleboards and OSB or 7mg/100g for MDF. In countries like Germany, Austria, Denmark and Sweden, the regulation requires compliance with emission limits of 6.5mg/100g dry board. However, many European countries still have legislation allowing the production and distribution of E2 boards (according to EN 13986).

Table 5 summarizes the current classification of wood-based panels in respect to formaldehyde emission according to the European, Australian, U.S.A. and Japanese standards.

Table 5: *Current formaldehyde emission standards for wood-based panels in Europe, Australia, the U.S.A. and Japan.*

Country	Standard	Test method	Board class[a]	Limit value
Europe	EN 13986	EN 717-1 EN 120	E1-PB, MDF, OSB	≤ 0.1 ppm ≤ 8 mg/100g
		EN 717-1 EN 717-2	E1-PW	≤ 0.1 ppm ≤ 3.5 mg/(h m^2)
		EN 717-1 EN 120	E2-PB, MDF, OSB	> 0.1 ppm > 8 - ≤ 30 mg/100g
		EN 717-1 EN 717-2	E2-PW	> 0.1 ppm > 3.5 - ≤ 8.0 mg/(h m^2)
Australia & New Zealand	AS/NZS 1859-1 & 2	AS/NZS 4266.16 (Desiccator)	E0-PB, MDF	≤ 0.5 mg/L
			E1-PB	≤ 1.5 mg/L
			E1-MDF	≤ 1.0 mg/L
			E2-PB, MDF	≤ 4.5 mg/L
USA	ANSI A208.1 & 2	ASTM E1333 (large chamber)	PB	≤ 0.18 or 0.09 ppm
			MDF	≤ 0.21 or 0.11 ppm
Japan	JIS A 5908 & 5905	JIS A 1460 (Desiccator)	F**	≤ 1.5 mg/L
			F***/"E0"	≤ 0.5 mg/L
			F****/"SE0"	≤ 0.3 mg/L

[a]PB: particleboard, MDF: medium density fibreboard, OSB: oriented strand board, PW: plywood

Acting proactively, the European panel producers through its EPF body agreed to only produce E1 boards and that compliance should be monitored through a system of internal and external checks (EUWID 2007). At the same time, the EPF members firmed up the E1 limit values for ongoing production monitoring. However, the discussions on a new emission class in Europe still continued favouring limits similar to that of the Blue Angel certification for environmentally-friendly products and services = wood-based panels with formaldehyde emission at least 50 % below the value of 0.1ppm set out in class E1, thus emissions of less than 0.05ppm.

In 2008, EPF decided to draw up its own formaldehyde standard, called EPF-S, specifying limits of 4mg/100g for PB and 5mg/100g for MDF with thickness > 8mm according to EN 120 (EUWID 2008). This decision came after IKEA had announced that it will introduce its new equivalent to half E1 formaldehyde emission limits for a number of types of wood-based panels from September 2008 (IOS-MAT-0003). The EPF-S has the status of an industry standard and specifies the requirements for a new class of low formaldehyde emitting panels. Further versions of EPF-S will include equivalent limit values expressed in ppm according to EN 717-1 (chamber test method).

In Japan, strict formaldehyde emission limits for wood-based panels were enforced from the beginning of the 21st century (Table 5). The emission limit of the Japanese F** class is more or less equivalent to European E1-class, while the F*** and F**** emission limits are much lower than the E1-class. Correlations usually reported are perforator values of approximately 2.5-3.0mg/100g for F*** ("E0") and approximately 1.5-2.0mg/100g for F**** ("Super E0"), (Dunky 2005). The emission of F**** boards is close to the emission of solid untreated wood (e.g. between 0.008 - 0.01 ppm or 0.5-2.0mg/100g for spruce wood flakes, Marutzky *et al.* 2004).

In USA, the formaldehyde emission limits for particleboard and MDF were in the level of 0.3ppm (test method ASTM E1333) according to national voluntary standards ANSI A208.1 & 2 respectively, till beginning of 2009. The limit for industrial plywood was the same while for plywood wall panels the limit was 0.2ppm. Such limits were also valid in Canada.

The Air Resources Board of California (CARB) adopted a new regulation in April 2007 to reduce the formaldehyde emissions from composite wood products, including particleboard, MDF and hardwood plywood (Airborne Toxic Control measure, ATCM, CARB 2007). The modified version of this regulation was finally approved in April 2008. This regulation proposed the reduction of formaldehyde emission standards in two phases (Table 6). Phase 1 limits (effective from January 2009) are roughly equivalent to the European E1 emission class that is the Japanese F** class (Table 7). Phase 2 limits (effective from January 2010 and January 2011) are comparable to the Japanese F*** limits, the so-called E0 levels in Europe. This new regulation established the most stringent formaldehyde emission limits on wood products in the United States and required that wood panels and products manufactured from wood panels be certified by a "third party" laboratory (Third Party Certifier, TPC) approved by the CARB. The CARB new emission standards apply to panels (also to panels used in finished goods) sold, supplied, offered for sale, or manufactured for sale in California. There are special provisions for manufacturers using NAF (No-Added Formaldehyde) & ULEF (Ultra-Low-Emitting Formaldehyde) resins (e.g. reduced testing frequency, exemption from third party certification).

Although the CARB regulation is only valid in California many particleboard, MDF and plywood plants around the world have already been certified to satisfy the CARB requirements and the number of application for certification is continuously rising. In February 2009, the American National Standards Institute (ANSI) has approved revised national voluntary standards for ANSI A208.1-2009 Particleboard and ANSI A208.2-2009 MDF for Interior Applications. Sponsored by the Composite Panel Association (CPA), the standards include new grades as well as harmonization with the formaldehyde emission ceilings and other requirements enacted by CARB.

Table 6: *The California Air Resources Board new standards, Phase 1 and Phase 2 Formaldehyde Emission Standards for Hardwood Plywood (HWPW), Particleboard (PB), and Medium Density Fibreboard (MDF), (CARB 2008)[a].*

Effective Date	Phase 1 (P1) and Phase 2 (P2) Emission Standards (ppm)				
	HWPW-VC	HWPW-CC	PB	MDF	Thin MDF
01.01.2009	P1: 0.08	-	P1: 0.18	P1: 0.21	P1: 0.21
01.07.2009	-	P1: 0.08	-	-	-
01.01.2010	P2: 0.05	-	-	-	-
01.01.2011	-	-	P2: 0.09	P2: 0.11	-
01.01.2012	-	-	-	-	P2: 0.13
01.07.2012	-	P2: 0.05	-	-	-

[a] Based on the primary test method [ASTM E 1333-96 (2002)] in ppm. HWPW-VC = veneer core; HWPW-CC = composite core.

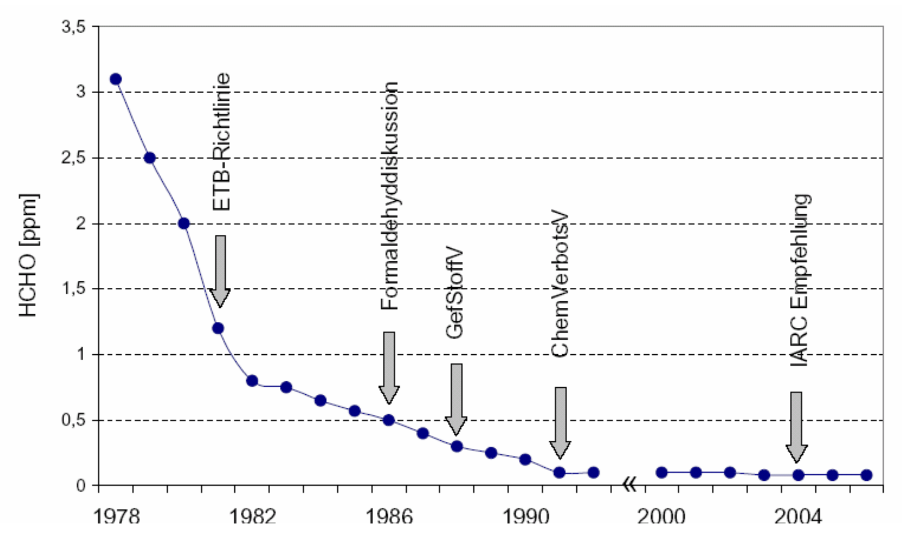
Table 7: *CARB versus European and Japanese standards (CARB 2008, h)[a].*

P1 (ppm)	**E1**	**F*****	**F******
HWPW (0.08)	more	comparable	less
PB (0.18)	less	less	less
MDF (0.21)	less	less	less
P2 (ppm)	**E1**	**F*****	**F******
HWPW (0.05)	more	more	comparable
PB (0.09)	more	comparable	less
MDF (0.11)	comparable	less	less

[a]Values in parentheses are the Phase 1 or Phase 2 standards in ppm. “More” means the proposed standard is “more stringent” than applicable E1, F***, or F**** standards.

Reduction of panel formaldehyde emissions - the industry response

Facing the developments in formaldehyde re-classification and new emission standards, the wood panel manufacturers provided products with reduced formaldehyde release (Figure 1).



ETB-Richtlinie: ETB-Guideline
Formaldehydediskussion: Formaldehyde discussion
IARC Empfehlung: IARC recommendation
GefStoffV: German Regulation on hazardous substances
ChemVerbV: German Regulation on prohibition of chemicals

Figure 1: *Formaldehyde reduction for particleboards between 1978-2006 (Marutzky 2008.)*

For the production of low emission boards, the following means are employed:

i. aminoplastic resins with low molar ratios F/U or $F/(NH_2)_2$, respectively;
ii. introduction of formaldehyde scavengers in the resin mix;
iii. addition of formaldehyde scavengers during the production of the boards, e.g. to the wet or to the dried wood furnish;
iv. post manufacture treatment of the boards;
v. application of a diffusion barrier by coating or laminating or veneering of the board;
vi. alternative gluing systems (PF, PMDI, resins based on biomass products or by-products e.g. soy, tannin, lignin).

Such efforts and products aimed to meet the new demands for very low formaldehyde emission from composite panel products without any deterioration in panel performance or significant modification of manufacturing plant operating conditions and above all with due respect to production costs. Lately, formaldehyde-based resin products providing panels with formaldehyde emission values at the level of natural wood were offered (Athanassiadou *et al* 2007, Kantner 2008).

The CHIMAR HELLAS Approach to the Formaldehyde Emission Reduction

CHIMAR HELLAS S.A. is an innovating **technology provider** for the resin and wood-based panel industries. It is also a pioneer in the field of formaldehyde emission reduction through its industrial research and development work. Following a process of continuously experimenting at laboratory, pilot and industrial scale, CHIMAR has developed forefront resins and gluing systems, which provide panels with the desirable properties (acceptable mechanical strength and water resistance properties) and low formaldehyde emission, even at the level of the Japanese F**** class ("Super E0"), i.e. emission at the level of natural wood. This innovative technology of CHIMAR has been applied in several plants around the world reducing formaldehyde emissions both during panel production and the subsequent emissions from finished panels.

As per CHIMAR technology, the formaldehyde emission problem can be solved by the use of:

- **Innovative gluing systems** of resins and chemical additives, consisting of high performance aminoplastic resins in combination with special additives (formaldehyde scavengers, hardeners, cross-linking agents) the synergistic action thereby provides panels with the desirable properties and formaldehyde emission as low as required.
- **Advanced technologies for resin synthesis,** by better exploiting the active ingredients during resin synthesis and efficient monitoring and control of the synthesis parameters to provide resins for boards with very low formaldehyde emission (emission at the level of natural wood) and acceptable mechanical strength and water resistance properties.
- **Resins based on biomass products or by-products** (e.g. soy, tannin, starch, lignin, pyrolysis oil) that combine the utilisation of renewable raw materials with high bonding performance and reduced formaldehyde emission at the same time.

All of the above-mentioned technologies have been optimised to offer cost savings to the resin and wood-based panels industries as well as to their end users-the consumers of such products.

The present work aims to report findings from recent tests at the industrial scale, to produce low formaldehyde emission panels by applying the above first two approaches. Yet, CHIMAR already in 1993 reported results from industrial particleboard production using a system of **UF** resin and formaldehyde scavenger (formaldehyde catcher), that provided panels with formaldehyde emission at the level of natural wood (1.8mg/100g of board, Markessini 1993).

It is noteworthy, that all the UMF resins mentioned below have melamine content up to 4.5% w/w, resulting in an increase of the cost of the adhesive up to 25% according to current raw material pricing.

Materials, Methods and Results

"E0" MDF

Industrial production was performed by applying the CHIMAR resin technology in an MDF mill with the aim to produce panels of "E0" emission quality (formaldehyde content as measured by the perforator method EN 120). A urea-melamine-formaldehyde, UMF, resin was applied in MDF with target density and thickness of 720kg/m^3 and 14mm respectively. Formaldehyde scavenger (FS) was used as well. The wood fibre species consisted of 50% beech and 50% softwood. The results from the boards' analysis that was carried on-site are shown in Table 8.

Table 8: *Data from industrial "E0" MDF*

Press factor, s/mm	Same as in E1
Resin factor, %	20% higher than in E1
Board density, kg/m^3	690-710
Board thickness, mm	14.0-14.3
IB, N/mm^2	0.6-0.7
Formaldehyde content, EN 120, mg/100g dry board	2.5-3.0

F/E0 MDF***

Industrial production was run to produce MDF with formaldehyde release lower than 0.5mg/L (E0 grade according to AS/NZS 4266.16 which is equivalent to F*** according to JIS A 1460). A **UF** resin of CHIMAR technology was applied. The target board thickness was either 6 or 16mm. The analysis of the boards' properties was performed on-site and the results are shown in Table 9, representing average values of series of samples.

Table 9: *Data from industrial F***/E0 MDF*

	6mm	16mm
Press temperature, ^{o}C	180-190	180-190
Press factor, s/mm	Same as in E1	Same as in E1
Resin factor, %	8.3	10.5
Board density, kg/m^3	790-810	680-700
IB, N/mm^2	1.3-1.5	0.90-0.95
MOR, N/mm^2	40-42	30-35
Thickness swell, %	18-20	7-8
Formaldehyde emission, AS/NZS 4266.16, mg/L	0.3-0.5	0.3-0.5

F/E0 moisture resistant MDF***

Industrial production was performed aiming at producing moisture resistant (MR) MDF with formaldehyde release lower than 0.5mg/L (E0 grade according to AS/NZS 4266.16 which is equivalent to F*** according to JIS A 1460). A UMF resin of CHIMAR technology was applied. The target board thickness was 18mm. The analysis of the boards' properties was performed on-site and the results are shown in Table 10.

Table 10: *Data from industrial F***/E0 MR MDF*

Press temperature, ^oC	180-190
Press factor, s/mm	Same as in E1
Resin factor, %	13 and 16
Board density, kg/m^3	700-720
IB, N/mm^2	1.0-1.2
Thickness swell (TS), %	5.1-5.8
MOR, N/mm^2	37-40
MOR-A, N/mm^2 (2h 70^oC)	4.9-5.3
IB after cycling test, N/mm^2	0.2-0.4
TS after cycling test, %	5-7
Formaldehyde emission, AS/NZS 4266.16, mg/L	0.27-0.39

F/E0 moisture resistant thin MDF***

Industrial production was run to produce moisture resistant (MR) thin MDF with formaldehyde release lower than 0.5mg/L (E0 grade according to AS/NZS 4266.16 which is equivalent to F*** according to JIS A 1460). An MUF resin of CHIMAR technology was applied in combination with a CHIMAR formaldehyde scavenger (FS). The scavenger was used in substitution of the resin solids at various levels. The target board thickness was 4mm. The analysis of the boards' properties was performed on-site and the results are shown in Table 11, representing average values of series of samples.

Table 11: *Data from industrial F***/E0 MR thin MDF*

Press factor, s/mm	Same as in E1
Resin factor, %	18
Scavenger level, %	10, 15, 20
Board density, kg/m^3	795-832
IB, N/mm^2	1.30-1.89
Thickness swell, %	4.2-9.1
Formaldehyde emission, AS/NZS 4266.16, mg/L	0.31-0.45

F*/"SE0" MDF***

Furthermore, industrial production was performed aiming at producing MDF with emission lower than 0.3mg/L (according to JIS A 1460, "Super E0" grade). A CHIMAR system of UMF resin and formaldehyde scavenger was applied. The scavenger was used in substitution of the resin solids at two different levels. The target board thickness was 16mm. The analysis of the boards' properties was performed on-site and the results are shown in Table 12, representing average values of series of samples.

Table 12: *Data from industrial F****/"SE0" MDF*

Press factor, s/mm	Same as in E1
Resin factor, %	16 and 18
Scavenger level, %	15, 20
IB, N/mm^2	0.9-1.1
Thickness swell, %	7.0-7.4
Formaldehyde emission, JIS A 1460, mg/L	0.27-0.29

F*/"SE0" thin MDF***

Industrial production aiming at producing "SE0" MDF (emission lower than 0.3mg/L according to JIS A 1460) of a target thickness of 3mm was performed too. A CHIMAR system of UMF resin was applied. The analysis of the boards' properties was performed on-site and the results are shown in Table 13, representing average values of series of samples.

Table 13: *Data from industrial F****/"SE0" thin MDF*	
Press temperature, °C	180-190
Press factor, s/mm	12 and 14
Resin factor, %	14 and 16
Hardener level, %	0-1.5
Board density, kg/m^3	840-860
IB, N/mm^2	1.6-1.8
MOR, N/mm^2	50-60
Thickness swell, %	16-21
Formaldehyde emission, JIS A 1460, mg/L	0.26-0.28

ULEF thin MDF

Industrial production was run aiming at producing thin MDF with formaldehyde emission satisfying the ULEF (Ultra-Low-Emitting-Formaldehyde) values foreseen by the new CARB regulation (for thin MDF a ULEF-target value of 0.04ppm and ULEF-cap value of 0.06ppm according to ASTM E 1333 to qualify for an exemption from third party certification or a ULEF-target value of 0.08ppm and ULEF-cap value of 0.11ppm according to ASTM E 1333 to qualify for less frequent testing). A CHIMAR system of UMF resin and formaldehyde scavenger was applied. The analysis of the boards' properties was performed on-site and the results are shown in Table 14, representing average values of series of samples.

Table 14: *Data from industrial ULEF thin MDF*	
Press factor, s/mm	Same as in E1
Resin factor, %	12 and 17
Scavenger level, %	4-12
Board density, kg/m^3	880-930
IB, N/mm^2	1.4-2.1
MOR, N/mm^2	42-50
Formaldehyde emission, ASTM E 1333, ppm	0.04-0.08

F/E0 particleboard***

Industrial production was carried out to produce particleboards with formaldehyde release lower than 0.5mg/L (E0 grade according to AS/NZS 4266.16 which is equivalent to F*** according to JIS A 1460). A UMF resin of CHIMAR technology was applied without adding formaldehyde scavenger. The target board thickness was 16mm. The analysis of the boards' properties was performed on-site and the results are shown in Table 15, representing average values of series of samples.

Table 15: *Data from industrial F***/E0 PB*	
Press temperature, °C	210
Press factor, s/mm	Same as in E1
Resin factor, % core/surface	8.5 / 9.5
Board density, kg/m^3	630
IB, N/mm^2	0.42
MOR, N/mm^2	16.3
Thickness swell (TS), %	12.1
Formaldehyde emission, AS/NZS 4266.16, mg/L	0.29

F/E0 moisture resistant particleboard***

Furthermore, industrial moisture resistant particleboards of E0 emission grade (according to AS/NZS 4266.16 which is equivalent to F*** according to JIS A 1460) were produced using an MUF resin of CHIMAR technology. The on-site analysis of the boards' properties provided the results shown in Table 16, which actually represent the average values from series of samples.

Table 16: *Data from industrial F***/E0 MR PB*

Press temperature, ^{o}C	210
Press factor, s/mm	6.0
Resin factor, % core/surface	8.5 / 9.5
Board density, kg/m^3	642
IB, N/mm^2	0.61
Thickness swell (TS), %	4.3
MOR, N/mm^2	18.2
MOR-A, N/mm^2 (2h 70^{o}C)	6.4
Formaldehyde emission, AS/NZS 4266.16, mg/L	0.27

EPF-S particleboard

Particleboards of the EPF-S emission class (formaldehyde content less than 4mg/100g dry board as measured by the perforator method EN 120) were produced industrially. A UMF resin of CHIMAR technology was applied. The target board thickness was 16mm. The analysis of the boards' properties was performed on-site and the results are shown in Table 17, representing average values of series of samples.

Table 17: *Data from industrial EPF-S PB*

Press temperature, ^{o}C	205
Press factor, s/mm	Same as in E1
Resin factor, % core/surface	8.3 / 8.5
Board density, kg/m^3	650-680
IB, N/mm^2	0.40-0.50
MOR, N/mm^2	13-14
Thickness swell (TS), %	14-16
Formaldehyde content , EN 120, mg/100g dry board	3.0-3.5

ULEF particleboard

Industrial production was performed aiming at producing particleboards with formaldehyde emission satisfying the ULEF (Ultra-Low-Emitting-Formaldehyde) values foreseen by the new CARB regulation (for particleboard a ULEF-target value of 0.04ppm and ULEF-cap value of 0.06ppm according to ASTM E 1333 to qualify for an exemption from third party certification or a ULEF-target value of 0.05ppm and ULEF-cap value of 0.08ppm according to ASTM E 1333 to qualify for less frequent testing). A CHIMAR system of UMF resin and formaldehyde scavenger (surface only) was applied. The analysis of the boards' properties was performed on-site and the results are shown in Table 18, representing average values of series of samples.

Table 18: *Data from industrial ULEF PB*

Press factor, s/mm	6.5
Resin factor, % core/surface	8 / 10
Scavenger level, %	1.8-2.5
Board density, kg/m^3	670-690
IB, N/mm^2	0.52-0.58
MOR, N/mm^2	15-18
Formaldehyde emission, ASTM E 1333, ppm	0.02-0.04

Discussion and Conclusions

The following points can be made in relation to the industrial production of MDF and particleboard:

- The desired quality of MDF and PB panels in regard to low formaldehyde emission (F***/E0, F****/"SE0", EPF-S, ULEF level) can be achieved by using either an advanced aminoplastic resin or an innovative system of aminoplastic resin plus scavenger.
- There was no need to change the production parameters or plant settings.
- There was no loss in productivity or significant increase of production cost.
- The board properties were not adversely affected by the introduction of low emission resin system. In many cases there was even an improvement of the board properties.
- The low emission quality can be achieved even in very specific cases such as the thin or moisture resistant panel products.

These developments have shown that it is possible to meet the new demands for very low formaldehyde emission from composite panel products with the use of properly formulated aminoplastic resins systems, without any deterioration in panel performance or significant modification of plant operating conditions or need to employ other types of binders. The formaldehyde emission values that can be obtained are **at the level of natural wood.**

CHIMAR HELLAS has succeeded in reducing the panel formaldehyde emissions by developing innovative resin systems, using advanced resin synthesis technologies and components that are well studied and controlled. Through its worldwide experience, network of customers and collaborating research institutes, CHIMAR HELLAS develops and implements integrated solutions to the formaldehyde emission problem. CHIMAR research and development is ongoing and the publication of further positive data on low emission panels will follow.

As in the case of all chemicals, the wise use of formaldehyde together with the respect of formaldehyde emission standards and exposure limits are the means for safeguarding the worker and consumer health and quality of life levels.

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