Formaldehyde emission test methods for wood-based panels – evaluation and comparison for low formaldehyde resins

João Pereira*[1],Cristina Coelho[2], João Ferra[3],Paulo Cruz[4], Jorge Martins[5], Fernão Magalhães[6], Luísa Carvalho[7]

[1]Research Fellow, ARCP – Association of Competence in Polymer Network, Rua Drº Roberto Frias, 4200-465, Porto, PORTUGAL
[2]Assistant Professor, DEMad-Dept. of Wood Engineering, Polytechnic Institute of Viseu, Campus Politécnico de Repeses, 3504-510 Viseu, PORTUGAL
[3]Research & Development, EuroResinas – Industrias Químicas, 7520-195 Sines, Portugal.
[4]Product & Business Development, EuroResinas – Industrias Químicas, 7520-195 Sines, Portugal.
[5]Coordinator Professor, DEMad-Dept of Wood Engineering, Polytechnic Institute of Viseu, Campus Politécnico de Repeses, 3504-510 Viseu, PORTUGAL
[6]Assistant Professor, LEPAE, Dept. of Chemical Engineering, University of Porto- Faculty of Engineering, Rua Drº Roberto Frias, 4200-465, Porto, PORTUGAL
[7]Coordinator Professor, DEMad-Dept of Wood Engineering, Polytechnic Institute of Viseu, Campus Politécnico de Repeses, 3504-510 Viseu, PORTUGAL
**Email:* jamp@fe.up.pt

ABSTRACT

Formaldehyde is a common organic compound very used as raw-material in several industrial applications, namely in urea-formaldehyde (UF), melamine-urea-formaldehyde (MUF) and phenol-formaldehyde resins (PF) production. These resins are used in the manufacture of wood-based panels for decades, playing a central role within their production and properties. In 2004, the IARC has classified formaldehyde as "carcinogenic to humans", which forced regulation authorities from several countries and the market itself, to increase the restrictions on formaldehyde emission from wood-based panels.

The evaluation and classification of formaldehyde emissions from wood-based panels is not uniform in all producing countries. Europe, USA and Japan were pioneers in the development of test methods and defined their own standards and methods to determine the formaldehyde release using different principles and equipments. The chambers and cells methods determine the formaldehyde emission, but are very time consuming. Other derived methods, as the perforator developed for pretesting and production control, evaluate the formaldehyde content (emittable potential). There is doubt of which is more appropriate and the validity of the correlations between the different methods.

In this paper, we present a review on several formaldehyde test methods and release classes, as well as a comparison of results obtained at our laboratory (chamber, gas analysis, desiccator and perforator methods) for particleboard produced with low formaldehyde emission (UF and MUF) resins. A commercial particleboard was also tested with those formaldehyde emission methods an also with chamber method.

1. Introduction

Urea-formaldehyde resins (UF) are the most widely used in the production of wood-based panels, mostly due to its reactivity, high performance, excellent adhesion to wood and low cost. The great disadvantage is formaldehyde emission during the production of wood-based panels and the subsequent emission during the service life of boards (Dunky, 1998).
Formaldehyde is an organic compound produced worldwide on a large scale and it is used as a chemical feedstock in several industrial applications, namely for the production of formaldehyde-based adhesives for wood and wood composites, as UF, melamine-formaldehyde (MF), phenol-formaldehyde (PF), phenol-resorcinol-formaldehyde (PRF).
Adverse health effects from exposure to formaldehyde in pre-fabricated houses, especially irritation of eyes and upper airways, were the first reported in the mid-1960 (Salthammer et al., 2010). In 2004, the *International Agency for Research on Cancer* (IARC) from WHO recommended the reclassification of formaldehyde "carcinogenic to humans (group 1)" and in 2006 this recommendation was finally published (IARC 2006). As a consequence, various authorities and institutions have been concerned about formaldehyde as an indoor priority pollutant and new regulations have emerged considering exposure limits increasingly lower.
Within European Union, formaldehyde is currently classified as 3-R40 substance ("limited evidence of carcinogenic effect"), but the classification is been reviewed under the new regulation for chemicals "Registration, evaluation, authorization and restrictions of Chemicals" (REACH). For this purpose, FormaCare (2010) (formaldehyde sector group of the European Chemical Industry Council) established a REACH taskforce to facilitate the creation of a consortium allowing European formaldehyde manufacturers to work together as a unified group for their REACH compliance activities.
Apart of formaldehyde classification, resins producers have been in the development of new resins and formaldehyde scavengers in order to reduce formaldehyde emission at levels close or even lower than natural wood (Schafer and Roffael 2000). On the other hand, due to the shortage of wood raw material, wood-based panels producers have been forced to the use of an increasing percentage of recycled wood, which seems to lead to an increase of formaldehyde emissions (Martins et al., 2007).
Facing the new guidelines and emission standards, a considerable effort have been made by wood panel manufactures to provide products with low formaldehyde emissions. In fact, the release of formaldehyde from building products has been decreased in the last decades (FormaCare, 2010)
For the determination of formaldehyde emission in wood-based products, several methods and standards have been emerged in Europe, United States and Japan. Each method measures a slightly different emission characteristic and frequently produces results in different and non-interchangeable units (Athanassiadou and Ohlmeyer 2009). This proliferation of test methods and incomparable results often create confusion among government regulators, consumers and industry personnel (Athanassiadou and Ohlmeyer 2009). Furthermore, the formaldehyde emission values in 70s and 80s were substantially higher, and though the test methods developed need to be adapted and improved to the current emission ranges. New

test methods have been proposed in order to comply with the new requirements: higher accuracy, lower detection limits, quicker and reliability.

2. Materials and methods

In the scope of the projects E0-Formaldehyde and ECOUF, different formulations of UF and MUF have been synthesized using different parameters in order to complain with the formaldehyde emission limits of different standards. For each resin, particleboard panels were produced at laboratory scale and then characterized in order to quantify the physical and mechanical performance as well as the formaldehyde emission or content. A commercial particleboard was also tested for formaldehyde analysis.
The production of particleboards is essentially divided into three stages: blending, mat formation and pressing. Wood particles for the face layer and core layer were provided by Sonae Indústria, Oliveira do Hospital plant) and were composed of different proportions of pine, eucalyptus, pine sawdust and recycled wood. The moisture content of the standard mixtures was checked before blending, using an infrared balance. The average of the moisture content of the face and core layers particles was 2.5 % and 3.5% respectively. Wood particles were then blended with the resin, catalyst and paraffin in a laboratory glue blender. The gluing factor was 6.3 % resin solids in the face and 6.9 % in the core, based on the oven-dry weight of wood particles. The resin was more catalyzed in the core layer (3% solids based on oven-dry weight of resin) than in the face layer (1 % solids based on oven-dry weight of resin). The paraffin level was 0.15 % solids (based on oven-dry weight of wood). Three-layer particleboard was hand formed in an aluminium container with 220x220x80 mm and then pressed in a laboratory scale hot-press, controlled by a computer. The glued particles were pressed at 190 ºC for 150 s to produce panels with a target density of 650 kg/m^3 and thickness of 17 mm.
After pressing, boards were stored in a conditioned room (20 ºC, 65 % relative humidity) and then tested accordingly to the European standards. The boards were tested according to the European standards for density (D) (EN 323), internal bond (IB) (EN 319), moisture content (MC) (EN 322) and thickness swelling (TS) (EN 317). For each series, one board was randomly selected for formaldehyde content (FC) analysis according to EN 120 (perforator method), three boards were used for desiccator method (JIS A 1460), one panel of each series was submitted to gas analysis method (EN 717-2) for determination of formaldehyde emission. A commercial particleboard were also used and submitted to those methods and also to EN 717-1. In the next section we describe the test methods for formaldehyde analysis.

3. Test methods for formaldehyde emission determination

The formaldehyde emission from panels in service is caused, not only by residual formaldehyde trapped as gas in the structure of substract, as well as dissolved in water present in the interior of board (moisture), but essentially due the reversibility of reactions

causing the hydrolysis of weakly bound formaldehyde from N-methyols groups, acetals and hemiacetals and methylene ether bridges (Dunky 1998).
Formaldehyde release depends on internal and external factors. The internal factors include the type of wood and resin employed, parameters and operating conditions in panel production and panel age. External factors are the temperature, air exchange rate, the total panel area in relation to the total volume of the space in which the panels are placed (Athanassiadou and Ohlmeyer 2009).
Test methods for the determination of formaldehyde emission should take into account the factors listed above, in order to be reliable and reproducible.
The existing methods can be divided by two main principles: measurable emission (the really emitted amount of formaldehyde under the test conditions) and the emittable potential of formaldehyde in the panel (the emitted (free) formaldehyde is determined without considering if that quantity may be released or not, and in how much time) (Dunky 2004).
Table 1 resumes the most important test methods and related standards for the determination of formaldehyde from wood-based panels.

Table 1: Standards and test methods for the determination of formaldehyde from wood-based panels (Athanassiadou, 2000, Marutzy, 2008)

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

3.1 Real emission

3.1.1 Chamber method

The evaluation of the real emission of formaldehyde of a product under typical indoor conditions in real-life and over defined time scales requires the use of a climate-controlled chamber. The formaldehyde concentration in the air inside the chamber is measured. The American standard ASTM E 1333 presents a large test chamber that aims to imitate the conditions of a living room with 22 m^2. The standard ASTM D 6007 presents a smaller chamber (0.02 a 1 m^3) and the specimens remain in the operating chamber until a steady state formaldehyde concentration is reached (the interval when the formaldehyde concentration is not changing with time). The CARB (Californian Air Resources Boards) approved recently regulations that require the use of these chambers for the qualifying tests, which increased the importance of these methods. The *International Organization for*

Standardization (ISO) presents as reference method the standard ISO /FDIS 12460-1 (1 m^3) and a derived method (ISO/DIS 12460-2).
The European standard EN 717-1 (chamber method) presents three volume options: > 12 m^3, 1 m^3 and 225 L. The operating conditions are slightly different from the American standard: temperature of (23 ± 0,5) °C and relative humidity of (45 ± 3) %. The air exchange rate is the double of the American standard, i.e 1/hr. The analysis time is at least ten days. The principle advantage of the chamber method is that simulates more accurately the indoor environment and the uses a great volume of sample, which minimizes the influence of material variability. Small chambers are widely used in Europe and North America and can be very accurate, relatively easy to adapt at both laboratory and plant and correlate well with the large chambers.
In this study, a chamber of 1 m^3 was used. Two test pieces of 500 mm x 500 mm x board thickness were placed in the chamber. Formaldehyde emitted from the test pieces mixes with the air in the chamber, which is sampled at least twice a day. The formaldehyde concentration is determined by drawing air from the outlet of chamber through two gas washing bottles containing water, which absorbs the formaldehyde. The concentration of formaldehyde in the chamber atmosphere is calculated from the concentration in the water in the gas washing bottles and the volume of the sampled air. It is expressed in [mg/m^3]. Sampling is periodically continued until the formaldehyde concentration in the chamber reaches the steady-state, which requires at least 11 days (EN 717-1). Each of the standards specifies a different method for determining when a steady-state condition is achieved. All, however, accept a change in formaldehyde emission of less than 5% over a given period as representing a quasi steady-state condition. In addition, all the standards propose that the test is stopped after 28 days, even if the steady-state condition is not reached (Irle, 2011).

3.1.2 Gas analysis method

The gas analysis (EN 717-2) is a derived test that determines formaldehyde release at accelerated conditions: a temperature of 60 ºC and within a period of 4 hours. In this method, a test piece with dimensions of 400 mm x 50 mm x board thickness and edges sealed is placed in a closed chamber at (60 ± 0.5) ºC with a relative humidity lower than 3 %, an airflow of (60 ± 3) L/h and under an overpressure of 1000 to 1200 Pa. Formaldehyde released from test piece is continually drawn from the chamber and passes though gas wash bottles containing water, that absorbs formaldehyde (EN 717-1). The formaldehyde is determined at hourly intervals, up to 4 hours. Every hour, the air is automatically led into one of a series of pairs of wash bottles. At the end of test, the formaldehyde release is calculated from the formaldehyde concentration, the sampling time and exposed area of the test piece expressed in [$mg.m^{-2}.h$]. Despite from the time of analysis, this test involves a high investment in equipment. The standard EN13986 indicates this method for faced and coated, overlaid or veneered wood-based panels.
In this method, as well as the other European methods, the concentration of formaldehyde is determined photometrically (UV/Vis spectrometer) using the acetylacetone method. This method is based in the Handtzsch reaction which envolves the cyclization of 2,4-pentadione, ammonium acetate and formaldehyde to form DDL (dihydropyridine 3,5 diacetyl-1,4-

dihydrolutidine), which presents a maximum absorvance at 412 nm. The molecule also exhibits fluorescence and though it can be determined, using a fluorimetric spectrophotometer, at a wavelength of emission of 510 nm.

3.1.3 Desiccator method

The more relevant desiccator method is defined in the Japanese standard JIS A 1460. It is one of the most economical methods, but it has a drawback. The test pieces shall be conditioned under standard conditions at temperature of (20 ± 2) ºC and a relative humidity of (65 ± 5) % until they have reach constant mass, which can take one week. Test-pieces are cut into rectangles of 150 mm by 50 mm. A number of test-pieces, corresponding to as close as possible to 1800 cm^2 total surface area (ends, sides and faces), are attached to a supporting metal and placed on a stainless steel wire net above a crystallizing dish containing water inside the desiccator with a nominal dimension of 240 mm. The lid is placed on the desiccator and the samples are sealed inside for 24 hours at (20±1)°C. The emitted formaldehyde is absorbed by the water in the crystallizing dish. The concentration of formaldehyde in the water is determined by a photometric method using acetylacetone method, but the reaction conditions and reagents quantities are different from the European standards EN 717-1 and EN 120. The emission of formaldehyde is expressed [mg/L].
There are several variations of the desiccator method as defined in ASTM D 5582, with some differences: the desiccator diameter (250 mm) and the procedure duration (2 hours). Other standards that are based on the same principle are JAS 233 and JAS 235. A recent harmonized standard was adopted by the International Standardization Organization, as ISO/CD 12460-4.

3.2 Emission potential

3.2.1 Perforator method

The perforator method (EN 120) measures the formaldehyde content of wood-based panels. While a test by the chamber method may take several days until the samples attain the equilibrium stage, the perforator method is quicker and expeditious, being much more indicated to daily factory production control. This test is the most popular for measuring formaldehyde content in particleboard and MDF in Europe. The EN 13986, indicates this method for unfaced particleboard, OSB, MDF and flaxboards. It is also employed worldwide with exception to North America. The formaldehyde is extracted from test pieces (110 g of 25 × 25 mm specimens) by means of boiling toluene for 2 hours and then transferred into distilled or demineralized water. The formaldehyde content of this aqueous solution is determined photometrically by the acetylacetone method. The disadvantage of this method is the environmental impact of the toluene emission and residues. The results are expressed in [mg/100 g oven dry board]. The perforator values for particleboards, OSB and MDF shall be applied to wood-based panels conditioned to a reference moisture content (6.5 %.). For different moisture contents, correction factors, calculated by an equation stated in the specifications standards for each type of wood-based panel, are used. This correction factor is contestable as it depends on other factors rather than the moisture content of boards (Roffael

and Johnsson, 2011). The accuracy of this method has been very discussed for values below 4 mg/100 g oven dry board). A similar method established by ISO 12460-5.

3.3 Formaldehyde methods survey

Considering the different existing methods, and taking into account that seems difficult to find a worldwide agreement on establishing a reference method, it is important to know the different methods and their main features. Table 2 presents the testing parameters used in this study.

Table 2: Testing parameters for the methods used in this study

	Methods			
	Chamber EN 717-1	**Gas analysis EN 717-2**	**Desiccator JIS 1460**	**Perforator EN 120**
Pre-conditioning	no	No	7 days	no
Volume	1 m^3	4 L	6 L	-
Temperature	(23 ± 0.5) ºC	(60 ± 0.5) ºC	(20 ± 0.5) ºC	-
Relative humidity	(45 ± 3) %	< 3 %	-	-
Air exchange rate	1 h^{-1}	-	-	-
Loading ratio	1 m^2/m^3	10 m^2/m^3	≈ 30 m^2/m^3	-
Total surface area	1 m^2 (2 boards)	0.040 m^2 (2 boards)	≈ 0.18 m^2	110 g
Unsealed Edges	1.5 m/m^2	No	yes	yes
Testing time	10 to 28 days	4 hours	24 hours	3 hours
Analysis method	acetylacetone	Acetylacetone	acetylacetone	acetylacetone
Units	mg/m^3 (air)	mg/m^2h	mg/L	mg/100 g oven dry board

In fact, there is no method that stands out, presenting all of them advantages and drawbacks. Their application costs has been calculated to rate at 0.5:8:100 for perforator, gas analysis and large chamber, respectively (Athanassiadou and Ohlmeyer 2009). Formaldehyde testing in chambers are usually time consuming and uses sophisticated equipment.
However, due to the need of wood-based panels producers to operate on the global market, they have to certificate their products according to the different countries or regions's regulations that consider different reference methods, as Japan (desiccator), U.S.A. (chamber method) and Europe (perforator method). A new approach of a closer co-operation of the different regions of the world with regard to formaldehyde release test methods was taken between CEN/TC 112 and ISO/TC 89. A resolution was taken in Sydney, 2011-2: "ISO/TC 89 unanimously supports a further development of the standards series ISO 12460 "Determination of formaldehyde release" under the Vienna Agreement in cooperation with CEN/TC 112 to become EN ISO standards.

3.4 Emission limits for wood based-panels

In recent years, national regulations for formaldehyde were established and/or reformulated in some countries limiting the formaldehyde emission from wood-based panels. The standards for formaldehyde test methods do not refer a classification of wood-based panels according to the results of formaldehyde emission or release. This classification is established in the specification standards of each product. The harmonized European standard EN 13986 (Wood-based panels for use in construction) classifies formaldehyde emission into two classes: E1 or E2 (see table 3).

Table 3: Overview on actual upper limits of formaldehyde emission (PB – Particleboard, MDF – Medium Density Fibreboard, PW – Plywood, OSB – Oriented Strand Board, LVL – Laminated Veneer Lumber) (Athanassiadou and Ohlmeyer, 2009)

Region	Standard	Test method	Board class	Board type	Limit value
Europe	EN 13986	ENV 717-1	E2	PB, OSB and MDF (unfaced)	> 0.124 mg/m^3 air
		EN 120			8 < mg/100 g oven dry board ≤ 30
		ENV 717-1		PW, SWP and LVL (unfaced)	> 0.124 mg/m^3 air
		EN 717-2		PW, PB, OSB, MDF, LVL (and others) overlaid	3.5 < mg/m^2.h ≤ 8
		ENV 717-1	E1	PB, OSB and MDF (unfaced)	≤ 0.124 mg/m^3 air
		EN 120			≤ 8 mg/100 g oven dry board
		ENV 717-1		PW, SWP e LVL (unfaced)	≤ 0.124 mg/m^3 air
		EN 717-2		PW, PB, OSB, MDF, LVL (and others) overlaid	≤ 3.5 mg/m^2.h
Japão	JIS A 5908 & 5905	JIS A 1460	F**		≤ 1.5 mg/L
			F***		≤ 0.5 mg/L
			F****		≤ 0.3 mg/L
USA	ANSI A208.1 & 2	ASTM E1333 (large chamber)		PB, MDF	≤ 0.3 ppm
				PW	≤ 0.2 ppm
	CARB	ASTM E1333	Phase 1	PB	0.18 ppm
				MDF	0.21 ppm
			Phase 2	PB	0.09 ppm
				MDF	0.11 ppm

Internal discussions within the European wood-based panel Associations, lead EPF (European Panel Federation) to launch its own formaldehyde standard EPF-S, that corresponds to a perforator value below 4 mg/100 g oven dry wood for PB and 5 mg/100 g oven dry wood for MDF (thickness > 8 mm). Driven by IKEA (IOSMAT 0003), an equivalent class with half E1 formaldehyde emission limits was also introduced: the so-called E0 (or E0.5) (not yet recognized officially by CEN). Recently, the members of EPF agree to only produce E1 class.
In Japan, more strict limits are defined in standards JIS A 5908 e 5905 as, by descending order F**, F*** e F****. The F** is more or less equivalent to European E1 class, while the F*** e F**** are much lower. The emission of F**** is close to the emission of solid untreated wood, between 0.5-2 mg/100 g (Athanassiadou and Ohlmeyer, 2009).
In the United States, ANSI A208.1 & 2 refer the limits for formaldehyde emission presented in table 4. More recently, CARB (*California Air Resources Board*) established more stringent formaldehyde limits for wood-based panels, being nowadays as reference for wood-based panels market. Phase 1 limits are roughly equivalent to E1 (and F**) class while Phase 2 limits are similar to F***. These regulations state that, beyond the compliance of those emission limits, wood-based panels and finishing goods for sale or used in California must also be certified by a CARB approved third party certification laboratory, unless they are approved Ultra Low Emission Formaldehyde (ULEF) or No Added Formaldehyde (NAF) products. NAF and ULEF products must demonstrate a 90% or better compliance with a 0.04 ppm (ASTM E1333) limit.
Different authors have attempted to establish correlations between formaldehyde testing methods (desiccator, perforator and chamber). Due to the different operating conditions used in each method, it is not possible a direct relation, although it can be found approximate correlations in literature (Risholm-Sundman, Larsen et al. 2006; Que and Furuno 2007; Park et al. 2010). In the very low region of emission, there is poor correlation between corrected perforator values and the emission of boards (Roffael and Johnsson, 2011). According to these authors, in the perforator value, the mass transfer coefficient, finds no consideration. So, boards with the same perforator value but of different densities may have different emission characteristics. Table 4 presents a relationship between the limits of the different methods, some of them based on correlations.

Table 4: Relationship between different methods and standard limits ([a]Values obtained by correlation) (Harmon, 2008)

Method	Japan		Europe	IKEA	USA	
	F***	F****	E1	E0.5	CARB F1	CARB F2
EN 120 [mg / 100 g odb]	≤ 4.5[a]	≤ 2.7[a]	≤ 8.0	≤ 4.0	≤ 11.3[a]	≤ 5.6[a]
EN 717-1 [mg / m^3 air]	≤ 0.054[a]	≤ 0.034[a]	≤ 0.124	≤ 0.050	≤ 0.176[a]	≤ 0.088[a]
ASTM E1333 [ppm]	≤ 0.055[a]	≤ 0.035[a]	≤ 0.127[a]	≤ 0.051[a]	≤ 0.180	≤ 0.090
JIS A 1460 [mg / L]	≤ 0.5	≤ 0.3	≤ 0.9[a]	≤ 0.4[a]	≤ 1.3[a]	≤ 0.6[a]

Results and discussion

Several panels produced in our laboratory bonded with different resins (UF and MUF) and doped with different formaldehyde scavengers were tested with three different methods, the perforator method (EN120), the gas analysis method (EN717-2) and the desiccator method (JIS A1460). Due to the reduced size of the samples, the chamber method could not be applied. A commercial particleboard was also tested using the former three methods and also using the chamber method (EN717-1).
Due to the different behavior of the bonding systems, mainly bonding strength and mechanical spring-back, only the panels having a thickness of 17 ± 0.2 mm, a density of 650 ± 20 kg/m^3 and an internal bond higher than 0.40 MPa (EN319) were evaluated for formaldehyde emissions/content.

Figure 1 shows the results for the panels, which were evaluated both with EN 120 and JIS A1460. It can be observed that there is a very weak correlation for the values of the two methods. They can easily have differences of 40% for values around 1 mg/L (JIS A1460). The results for very low formaldehyde emissions and very low formaldehyde contents, seems to be completely independents. These results can be easily justified by the presence of scavengers, which has a very different behavior during both tests, mainly due to the temperature and environmental humidity: the JIS A1460 test is carried out at near ambient temperature and relative humidity, while the EN 120 is carried out at a much higher temperature (over 110ºC) and in the presence of toluene.

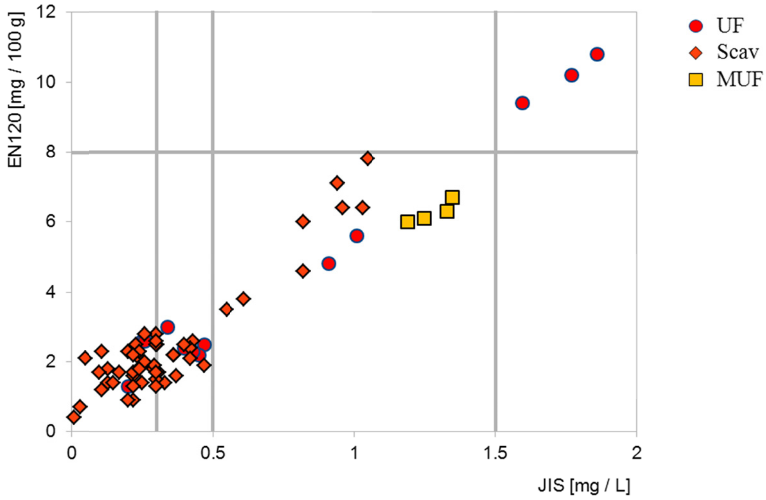

Figure 1: Formaldehyde content (EN 120) and formaldehyde emission (JIS A1460) for the same samples

In figure 2, they are presented the results for the panels, which were evaluated both with EN 120 and EN 717-2. As expected, globally the results are very similar of those presented in figure 1. In this case, we have also a formaldehyde content test and a formaldehyde emission test. As both methods are used for the same classification standard, the fact that some of the samples have different classification (E1 or E2) is a very important finding.

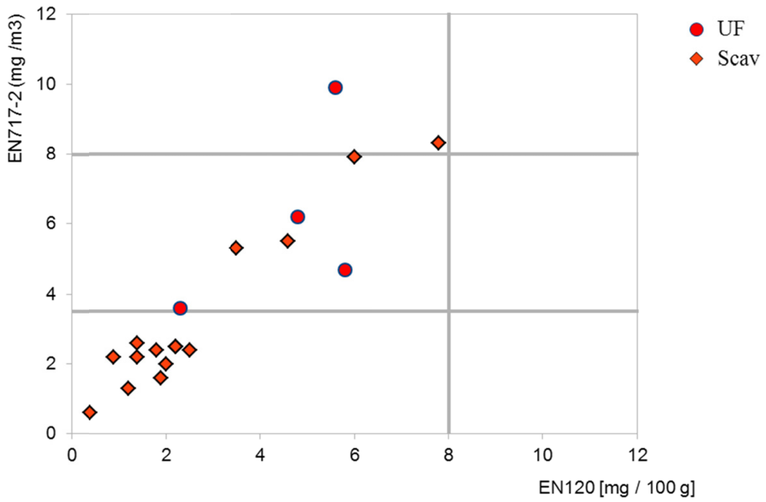

Figure 2: Formaldehyde content (EN120) and formaldehyde emission (EN717-2) for the same samples

These results cannot be easily justified as before due to the presence of scavengers, which still have very different behaviour during on both test mainly due to the air temperature and humidity. The EN 717-2 test is performed at a temperature of 60ºC and in the presence of dry air, while EN 120 is carried out at a much higher temperature (over 110ºC) and in the presence of toluene. The different permeability of the panels and the fact that EN 120 is supported on a phase-equilibrium (toluene-water), while EN 717-2 is a dynamic "desorption" test, could possibly explain the results.
Figure 3 shows the results for panels, which were evaluated both with EN 717-2 and JIS A1460. As expected, these results gave better correlations that the ones of both figures 2 and 3, since we are in the presence of two emission evaluation tests. Nevertheless, there are still some major differences that can also be justified by the dynamic nature of both methods. In fact, JIS A1450 is supported on a phase-equilibrium (air-water) while EN 717-2 is a dynamic "desorption" test.

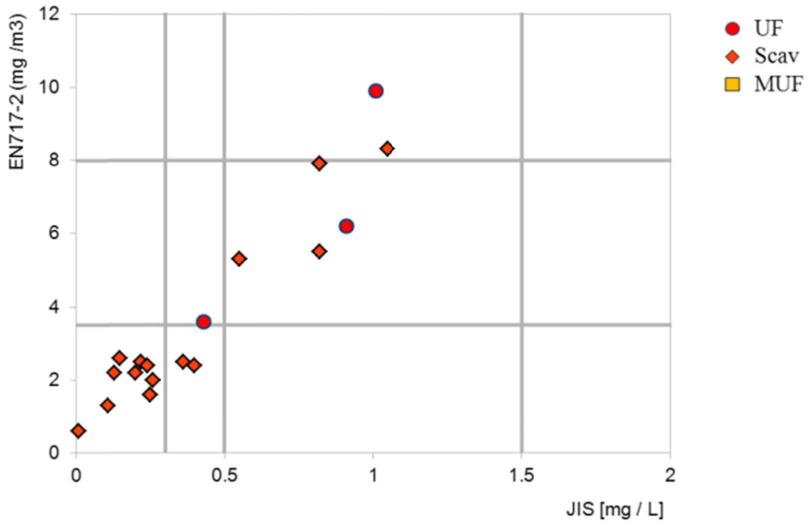

Figure 3: Formaldehyde emission values (JIS A1460 and EN717-2) for the same samples

In table 5, they are presented the results for both the formaldehyde emissions / contents values and the products classification for a commercial panel, which were evaluated with the EN717-1, EN 717-2 and JIS A1460 methods. These results show that this board can be classified either as E1 or E2 according to the method that was selected.

Table 5: Results for the four tests performed on an commercial panel

Method	Value	Japan	Europe
EN 120 [mg / 100 g oven dry board]	5.3		E1
EN 717-1 [mg / m^3 air]	0.166		E2
EN 717-2 [mg / m^3 air h]	5.6		E2
JIS A 1460 [mg / L]	1.60	F*	

These results were expected and could be justified by the conditions of the tests, as mentioned before (JIS A1460 and EN 717-1 tests are carried out at near ambient temperature and humidity; the perforator method is conducted in the presence of boiling toluene at around 110ºC and the gas analysis test is conducted at a temperature of 60º, in the presence of dry air).

5. Conclusions

The aim of this work was to present a review on several formaldehyde test methods and release classes, as well as a comparison of results obtained at our laboratory (chamber, gas analysis, desiccator and perforator methods) for particleboard produced with low formaldehyde emission (UF and MUF) resins.
Different particleboards produced at the laboratory, bonded with different UF and MUF resins and doped with several different formaldehyde scavengers were tested using the EN 120, the EN 717-2 and JIS-A1460 testing methods. Several tests were conducted on a commercial particleboard panel using the former three methods, plus the chamber method (EN 717-1).
The main conclusions of this study were:
-No correlations where found between the different methods; the deviations are more significant on the lower range of the formaldehyde emissions / content.
-A commercial panel can be classified differently as E1 and E2 depending on the select method.
This work emphasis the need to establish a worldwide system for evaluating and classify wood-based panels, regarding the formaldehyde emission. The present situation with many standard for classification and testing not only increases costs, by increasing complexity of the quality control procedures, but, more important, can mislead the market.

Acknowledgments

This work is co-founded by FEDER (Fundo Europeu de Desenvolvimento Regional) / QREN (E0_formaldehyde project with reference FCOMP010202FEDER005347) and national funds through FCT (project PTDC/EQU-EQU/111571/2009 with the reference FCOMP-01-0124-FEDER-015239) under the framework of COMPETE-Programa Operacional Factor de Competitividade (POFC).The authors wish to thank Euroresinas and Sonae Indústria PCDM for providing the equipment and some of the raw materials needed for this work.

References

Athanassiadou, E. and M. Ohlmeyer (2009). "Emissions of Formaldehyde and VOC from Wood-based Panels". In COST Action WG3 (E49)-Performance in use and new products of wood based composites. M. Fan, M. Ohlmeyer, M. Irle (eds.), pp.219-240,London, Brunel University Press

Blair, A., P. Stewart, et al. (1986) "Mortality among Industrial-Workers Exposed to Formaldehyde" Journal of the National Cancer Institute 76(6): 1071-1084

CARB (2009) "A Quick Reference Guide to the California Air Resources Board's Airborne Toxic Control Measure (ATCM) for Formaldehyde Emissions from Composite Wood Products"

Dunky, M. (1998) "Urea-formaldehyde (UF) adhesive resins for wood" International Journal of Adhesion and Adhesives 18(2): 95-107

Dunky, M. (2004) “Challenges with formaldehyde based. In COST E34 Conference”. M. Properzi, F. Pichelin and M. Lehmann (eds). Biel, Switzerland.

FormaCare. (2010). "Wood panels & formaldehyde." from http://www.formaldehyde-europe.org/fileadmin/formaldehyde/PDF/BS.Wood.pdf.

Harmon, D. M. (2008). “CHANGE - Its Challenges and Opportunities”. Technical Formaldehyde Conference. Hannover, Germany.

IARC (2006) “Monographs on the Evaluation of Cancinogenic Risck to Humans”, World Health Organization - International Agency For Research On Cancer. 88.

Irle, M. (2011) “Analysing formaldehyde and how it can be done”, Wood-based panels International, May 2011

Martins, J., J. Pereira, et al. (2007). “Effect of recycled wood on formaldehyde release of particleboard”. COST Action E49 Conference "Measurement and Control of VOC Emission from Wood-Based Panels. F. WKI. Braunschweig, Germany.

Maruztky (2008). “Global formaldehyde regulations and requirements: Current situation and developments”, 6th European Wood-based Panel Symposium, Hanover, October 10th, 2008

Que, Z. and T. Furuno (2007) "Formaldehyde emission from wood products: relationship between the values by the chamber method and those by the desiccator test." Wood Science and Technology 41(3): 267-279.

Risholm-Sundman, M., A. Larsen, E. Vestin, A. Weibull (2006) "Formaldehyde emission - Comparison of Different standard methods", Atmosferic Environment 41: 3193-3202.

Roffael, E. and B. Johnsson (2011). “The perforator value in balance”. Proceedings of the International Panel Products Symposium, Llandudno, Wales, U.K.

Salthammer, T., S. Mentese, and R. Marutzky (2010). “Formaldehyde in the Indoor Environment”, Chem. Rev. 2010, 110, 2536–2572

Schafer, M. and E. Roffael (2000). "On the formaldehyde release of wood." Holz Als Roh-Und Werkstoff 58(4): 259-264