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FORMALDEHYDE EMISSIONS FROM WOOD BASED PANELS AND WAYS TO REDUCE THEM

INTRODUCTION

After the energy crisis of 1972, concern for energy conservation increased. Various methods of weather proofing buildings were utilised such as less ventilation and more building sealing.

As a result, various gases which were previously dissipated outdoors were trapped indoors. One of these gases is formaldehyde. It is among the major indoor air pollutants.

One of the first steps taken to reduce pollution resulting from formaldehyde was to standardise the emission from wood based panels into three categories: E_1, E_2 and E_3.

The second step was to install guidelines to meet the standards for formaldehyde emission from boards themselves as well as the amount of formaldehyde found in ambient air.

It is important to follow the guidelines that exist in most of the industrialized countries in order to keep the air clean.

Let us not forget that we spend most of our time indoors whether it is at home, at work or in schools.

SOURCES

The main source of formaldehyde indoors is from the urea formaldehyde resins that are used for the production of particleboard, fibreboard (MDF-medium density fibreboard) or plywood. These boards are mainly used for furniture but they are also used in flooring, wall partitions and ceilings. Mobile homes use particularly high amounts of such panels.

Another source of formaldehyde is cigarette smoking and combustion gases from heating stoves and gas appliances.

Formaldehyde is also released from urea formaldehyde lacquers and foam used for insulation or for upholstery.

Other minor sources are textiles, or cosmetics. It is also used as an additive in water-based paints, as a disinfectant and as a preservative in biological laboratories and in mortuaries.

HEALTH EFFECTS

While there is sufficient evidence of carcinogenicity of formaldehyde in animals, the evidence of carcinogenicity in humans is inadequate.

Formaldehyde was classified in Group 2B by the International Agency for Research on Cancer.

The European Chemical, Industry Ecology, and Toxicology Centre (ECETOC) has recommended the classification of carcinogens into four categories[1,2]:

1. Proven human chemical carcinogen:

«A proven human chemical carcinogen is a substance for which a casual relationship has been established between previous exposure and the occurence of malignant neoplasms in man.»

2. Putative human chemical carcinogen:

«A putative human chemical carcinogen is a clearly-defined chemical substance which causes malignant neoplasms in adequate animal experimentation, under exposure conditions which correspond to those in man, or where the relevance of the exposure conditions can be deduced.»

3. Questionable human chemical carcinogen:

«A questionable human chemical carcinogen is a clearly-defined chemical substance for which there is incomplete evidence of carcinogenicity, which is based either on a) observations in man which are suggestive, but do not allow a firm conclusion of a causal relationship between previous exposure and the occurence of malignant neoplasms; or b) finding obtained in animal experiments in which the experimental model is not appropriate to conditions in man and therefore the result cannot be regarded as relevant; or c) positive findings in at least two standardized short-term tests, with unrelated end-points, which have been verified as useful for screening for carcinogenic potential.»

4. Human chemical non-carcinogen

«Ultimate proof of non-carcinogenicity is impossible. However, a clearly-defined chemical substance which has consistently shown negative results in adequate studies in man or adequate animal experimentation should be considered a "Human chemical non-carcinogen" for practical purposes.»

ECETOC is of the opinion that formaldehyde should be classified as a «Questionable Human Chemical carcinogen», because it clearly conforms to the qualifications b) and c) in definition Number 3.

On October 1984, the formaldehyde report prepared by order of the government of the Federal Republic of Germany[3] was presented to the public, its full title being «Formaldehyde -a joint report of the Federal Health Agency, the Federal Agency for Industrial Safety and the Federal Agency for Environmental Protection, with the Federal Institute of Materials Testing, the Federal Biological Agency and the chairman of the "MAK" committee of the German Society for the Advancement of Scientific Research assisting in its preparation.» Though not binding for the time being, it provides the basis for further considerations at the level of all federal ministries concerned with formaldehyde. Here are the key sentences of the report:

«The available epidemiological studies of man exposed to formaldehyde do not suggest an increase in the overall rate of cancer or in individual cancers.»

«From the point of view of test method, execution or result, none of the formaldehyde tests on animals done to date justifies the conclusion that formaldehyde is a carcinogen in man.»

«Moreover, the present state of knowledge gives no other substantial indications of a carcinogenic action of formaldehyde in man.»

«Since it is not possible to allay all suspicions, formaldehyde continues to be suspected of being a potential carcinogen.»[1,3]

Similar comments have been made by the responsible ministries in France[4], Italy, and the United Kingdom.

Recently, a working group of the Commission of the European Communities reviewed the literature on the relation between formaldehyde exposure and health effects.

Some points are reported in tables 1 and 2.

Table 1. - Effects of formeldehyde in humans after short-term exposure[5]

Πίνακας 1. Επίδραση φορμαλδεΰδης στον άνθρωπο μετά από έκθεση μικράς διαρκείας.

	Estimated median mg/m^3	Reported range mg/m3
Odour detection threshold	0.1	0.06-1.2
Eye irritation threshold	0.5	0.01-1.9
Throat irritation threshold	0.6	0.1-3.1
Biting sensation in nose, eye	3.1	2.5-3.7
Tolerable for 30 min- lachrymation	5.6	5-8.2
Strong lachrymation	17.8	12-25
Danger to life, oedema, pneumonia	37.5	37-60
Death	125	6-125

It is important to notice at this point that formaldehyde was generally considered a safe chemical to use because its pungent odour warned users of over-exposure. However, it is well known that a small percentage of the population is hypersensitive to formaldehyde.

Table 2. - Contributions to formaldehyde exposures[6]

Πίνακας 2. Αναλογίες φορμαλδεΰδης σε διάφορες περιπτώσεις.

	Estimated concentration mg/m^3	daily intake mg
Air	0.01	0.02
Ambient air (10% of time)		
Indoor air		
Home (65% of time)		
--- prefabricated (chipboard)	0.08-0.80	1-10
Workplace (25% of time)		
- without occupational exposure	0.04-0.16	0.2-0.8,
- with 1mg/m^3 occupational exposure	1	5
Environmental tobacco smoke (ETS)	0.02-0.20	0.1-1
Smoking (20 cigarettes/day)		1

Meanwhile, it is important to point out that exposure to formaldehyde vapours causes headaches, dermatites and asthma.

INDOOR AIR QUALITY GUIDELINES

To obtain the required low levels of exposure, there are two ways: Improve Ventilation or Decrease the Source.

The first attempt to standardization of formaldehyde emissions from wood based panels is reported in table 3.

Table 3. - Classification of practicle board according to its formaldehyde emission

Πίνακας 3 Κατάταξη μοριοσανίδων ανάλογα με την έκλυση φορμαλδεΰδης.

Class	Equilibrium concentration in a 40 m^3 test chamber*	Perforator Value (mg/100 g dry board)**
E_1	≤ 0.1ppm	≤ 10
E_2	> 0.1-1.0ppm	> 10-30
E_3	> 1.0-2.3ppm	> 30-60

* measured by the Chamber Method

** measured by the Perforator method CEN 120.

One can at present differentiate two groups of countries in relation to the low free formaldehyde issue.

In Germany, Austria, Switzerland and the Netherlands where essentially there is only one free-formaldehyde group permissible as follows:

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

In the second group of countries, we can include France, Great Britain, Belgium and the whole of Scandinavia. In these countries there are two classes of wood based panels in respect to formaldehyde emission.

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

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

In Greece unfortunately there is no standardization at all yet. Boards produced range anywhere between 15 to 100 mg free formaldehyde/100g dry board.

It is however not enough to have standards for the formaldehyde emission of boards themselves.

It is even more important to control the amount of formaldehyde gas in the ambient air itself.

Guideline values were established and are reported here below:

Table 4. - Guideline Values for Formaldehyde Emission in European Countries[7]

Πίνακας 4. Προδιαγραφές για την έκλυση φορμαλδεΰδης στις ευρωπαϊκές χώρες.

Country	Level (as available by February 1990)
Denmark	0.15 mg/m^3
Germany	0.12 mg/m^3
Finland	0.15 mg/m^3
Italy	0.12 mg/m^3 (tentative)
Netherlands	0.12 mg/m^3
Norway	0.06 mg/m^3 (recommended)
Spain	0.48 mg/m^3
Sweden	0.13 mg/m^3
Switzerland	0.24 mg/m^3
United Kingdom	no guideline values or standards
USA	0.486 Federal target ambient level
WHO	<0.1 mg/m^3

Greece: On behalf of the Ministry of Health a survey of formaldehyde was carried out in 12 new (age < 1 year) and 31 old houses (age 1-20 years) and in 7 schools, all situated in Thessaloniki. In all cases 30 minute samples were taken and analysed using the chromotropic acid technique. The measurements yielded very low concentrations of formaldehyde, all within the range of outdoor concentrations: the highest detected concentration was 22μg/m^3 and mean values of various groups of houses ranged between 8.2 and 9μg/m^3. No significant difference was found between the formaldehyde concentrations detected in the above mentioned new and old houses[8].

The reason for such low ambient air values found in Greece as compared to extremely high values for boards themselves are that Greeks ventilate their homes very well and use boards indoors mainly for furniture where they are well covered on all sides.

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

Guidelines or threshold values indicate concentrations at or below which human beings are protected for given exposure durations.

Guidelines are intended to provide background information and guidance to governments, administrations or the public in making risk management decisions or in setting standards.

On the European level standardisation is taken care of by CEN. The adoption of a standard by CEN goes through a succession of different steps. A draft is first prepared by a technical committee, which is submitted for public inquiry for 6 months. During this period all CEN member states can introduce their comments. After all the comments are discussed, a final draft is prepared, which is adopted by a plenary meeting and afterwards submitted for formal vote. After a standard is accepted in this procedure, all CEN member countries have to include it in their national standards and take back all conflicting national standards.

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

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

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

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

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

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

- the establishment and implementation of environmental protection systems by companies;
- the systematic, objective and periodic evaluation of the environmental perfomance of such systems;
- the provision of information on environmental performance to the public.

Companies operating an industrial activity may participate in the Eco-audit scheme. They have to comply with all rules and conditions and to observe all procedures set out in the regulation. The audit of a site may be conducted by the company auditors, if the company has set up an appropriate system, e.g. within the framework of the EN29000 standard, or by external auditors accredited for this purpose by a body recognised by the Member state. Companies participating in the system may use the Eco-audit logo.

This regulation has already entered into force from 1 January 1993 and shall apply with effect from 1 July 1994.

In this framework, in Germany they have already started discussing about the so-called «Blauer Engel» with desired free formaldehyde emission of less than 0.05ppm which corresponds to 3.0-3.2mg/100g dry board photometric (Moisture Content = 6.5%), an essentially formaldehyde-free board. The «Blauer Engel» is a stamp/mark awarded by the German Health and Ecology Ministry to «environmentally friendly» products. Discussions are afoot whether wood-based panels used for finished house construction should get a «Blauer Engel» certification. If yes, then what should be the safe level for formaldehyde emission? It should be noted that the value of 0.05ppm, mentioned above, is just an initial suggestion chosen as the 50% of the allowable limit of 0.1ppm. The suggestion was made by the ministry, but, needless to say, the industry, in general, is against it. As all large particleboard producers are members of the supervisory board of jury no decision is expected before 1995.

WAYS TO REDUCE THE FORMALDEHYDE EMISSIONS FROM WOOD BASED PANELS

The first attempt of resin manufacturers to decrease formaldehyde emission was by decreasing the Formaldehyde: Urea (F:U) molar ratio of the resin, i.e. by decreasing the amount of free formaldehyde in the resin. In Europe, most of the resins currently used, at least in central European countries, have a molar ratio of F:U between 1.05 and 1.2, while only 10 years ago the majority of the resins used had a molar ratio as high as 1.4 -1.6. The reduction of the molar ratio was initially achieved by introducing in the resin production process one or two extra steps of urea addition. The urea reacted with the residual formaldehyde and therefore both the free formaldehyde of the resin and the free formaldehyde emitted from the board were drastically reduced. (It should be noted that a reduction of the mole ratio from 1.5 to 1.1 can reduce the free formaldehyde emission in the final board up to ten times). However, the reduction of the free formaldehyde of the resin had many negative side-effects, which quite soon became apparent. Formaldehyde acts as a crosslinking agent during the setting of the resin. Therefore its drastic reduction resulted in a thermoplastic polymer instead of a thermosetting. This had an adverse effect on the performance of the resins. Hence the plants had to live with much longer press time, tighter moisture control, higher gluing factors and even so lower mechanical properties and water resistance, when producing E1 boards.

The first attempt to address this problem was the addition of a small quantity of melamine (1-4%). Although this increases the cost by about 10%, it proved quite successful. These resins are much more forgiving with process variations than straight urea formaldehyde (UF) resins and their use gives the industry some confidence that they will meet the formaldehyde emission regulations without much worry about meeting the rest of their standards. This approach to producing low free formaldehyde boards is the only way to produce boards meeting the German standard (6.5mg/100g dry board) without the use of any additives. However, they are obviously more expensive than straight UF resins.

In the meantime, the resin industry has invested much in research for low Free Formaldehyde (FF) straight Urea Formaldehyde (UF) resins and has partially solved the problems related to the introduction of the extra steps of urea addition, by modifying the process parameters and changing the overall structure of the prepolymers produced. New technology straight UF resins have recently come out in the European market by a small number of resin producers. The producers claim that they combine the emission advantages of the low FF resins with the performance advantages of the high FF resins. It is too early to evaluate these resins. These resins will give E1 boards (mg/100g dry board) without any additives, but in order to meet the 6.5mg/100g limit the addition of formaldehyde catchers is still needed. It appears that the resin formulation changes to the direction of reducing the molar ratio are at a practical limit.

Another way to produce E1 boards is by using isocyanate adhesives. This process was introduced some years ago and although it has several disadvantages (e.g. sticking, high cost, toxicity problems), there are a couple of plants in Europe producing regularly this type of board. Isocyanate resins are used in combination with UF resin, the UF being used particularly in the surface in order to avoid any sticking problems. Needless to say, isocyanate resins are terribly expensive and although smaller quantities are used the boards are still much more expensive than normal UF boards.

Last but not least, formaldehyde catchers are used along with resins for formaldehyde reduction. There are many practical advantages in using a catcher. One advantage is the flexibility it gives the plant manager to vary its quantity and hence the reduction of formaldehyde emission according to the conditions and the production requirements. The main advantage is however the fact that it is a much more efficient system rather than using a straight resin.

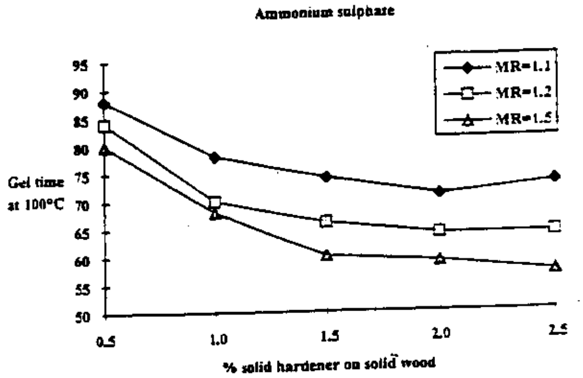
The formaldehyde catchers can be tailor-made in most cases to meet the particular requirements of the plants where they are going to be used. They can be used at a maximum of 25% on the resin used and can achieve reductions in free formaldehyde emissions of up to 60%. Experience worldwide shows that instead of using a very low molar ratio resin one can achieve better results in terms of both formaldehyde emission reduction and mechanical properties by using a system of an equivalent molar ratio which is a combination of a higher molar ratio UF resin and a formaldehyde catcher.

Finally it is important to point out that it is not possible anymore to use the standard catalysts now that such low molar ratio urea formaldehyde resins are used. The hardener commonly used earlier was ammonium chloride, while the last few years ammonium sulphate is used instead, at least in most central and northern European countries as the use of ammonium chloride was forbidden for environmental reasons. Both of these hardeners react with the free formaldehyde in the resin and liberate either hydrochloric or sulphuric acid, which speed up the polymerisation reaction by lowering the pH. A few years ago, the UF resins used had molar ratios between 1.3.-1.6 and fairly high levels of free formaldehyde. However, since the trend nowadays is to use resins with significantly lower levels of free formaldehyde, this level is insufficient to produce a significant pH drop when ammonium salts are used as catalysts. Therefore the effect of the reduction of the molar ratio on the gel time* is much more obvious nowadays. In general, higher levels of hardener result in a lower gel time as you can see in Figure 1, but this response is much less at lower resin mole ratios. In fact, in some cases gel times can even become longer when increasing the hardener level. This is true, because there is a competition for the available formaldehyde between the hardener and the curing reaction itself.

* Measurement that depicts the reactivity of the resin.

Plate 1. Influence of hardener level on reactivity (normal hardener)

Σχήμα 1. Επίδραση του σκληρυντικού στην αντίδραση (κανονικό σκληρυντικό).

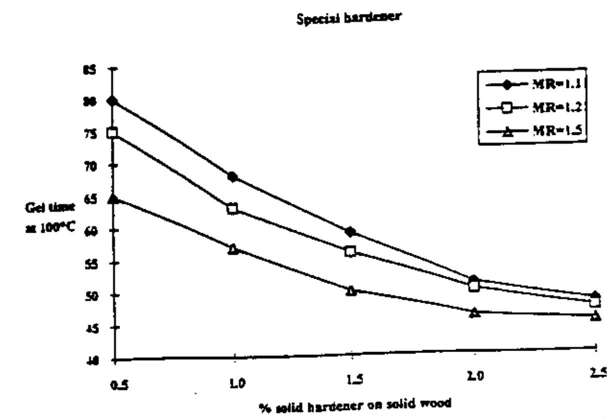


In figure 1, one may notice that as the amount of hardener is increased, gel time is reduced for resins having higher molar ratios. This is not so for resins having low molar ratios.

The use of a special hardener can solve this problem. The difference is very simple. Special hardeners do not rely on the available formaldehyde in order to generate acidity. Their effectiveness is therefore not influenced by the availability of free formaldehyde in the resin. The influence of the molar ratio on the reactivity curve of a resin when using a special hardener is shown in Figure 2.

Plate 2. Influence of hardener level on reactivity (special hardener)

Σχήμα 2. Επίδραση του σκληρυντικού στην αντίδραση (ειδικό σκληρυντικό).



The reactivity curves are similar for all different molar ratios. This means that the molar ratio does not significantly influence the way the hardener speeds up the polymerisation.

The traditional way of solving the free formaldehyde problem was to ask the resin manufacturer to supply a lower molar ratio resin. It seems particleboard producers have started realising the fact, that reducing the free formaldehyde, especially at the levels which are anticipated to come in force in the near future, is not a matter of changing the resin alone. The modern approach is to achieve the target by changing the resin system itself: i.e. using a different resin, mixing in a formaldehyde catcher and using a special hardener as well.

By following the above mentioned approach the lowest free formaldehyde emission values ever reported for boards based on urea-formaldehyde resins were obtained, lower than 2.0mg/100g dry board. The final results are summarized in Table 5, whereby in Column I figures reported are of boards produced without any formaldehyde catcher and without any special hardener, while in Column II figures reported are of boards produced with both a formaldehyde catcher and a special hardener. All the figures are averages over a 12h period.

From table 5 one may find out that it is possible to obtain the more stringent free formaldehyde values, 1.9 mg/100g dry board, in this case without deterioration in the properties nor changing of parameters such as press time or amount of resin used.

This is considered to be a significant breakthrough in the technology of making boards.

It is important to point out here that such low free formaldehyde values may be emitted from the wood itself.

At such low levels of free formaldehyde emission the boards are considered to be formaldehyde free.

Table 5. Industrial Trial for the production of extremely low free formaldehyde boards -Figures are averages over a 12h period

Πίνακας 5. Βιομηχανικές δοκιμές για την παραγωγή μοριοσανίδων με εξαιρετικά χαμηλή ελεύθερη φορμαλδεΰδη - οι τιμές είναι ο μέσος όρος για διαστήματα 12 ωρών.

	I	II
% dry resin/dry wood (core)	8.0	8.0
% dry resin/dry wood (face)	9.5	9.5
% dry hardener/dry resin	2.5	2.5
% formaldehyde cather on liquid resin	---	25.0
% special hardener on normal hardener	---	25.0
Press time (s/mm)	7.0	7.0
Press temperature °C	200	200
Thickness (mm)	16.1	16.1
Density (kg/m^3)	651.0	658.0
Internal Bond (N/mm^2)	0.50	0.48
MOR (N/mm^2)	17.2	17.3
2h thickness swelling (%)	5.1	5.5
24h thickness swelling (%)	13.9	13.7
Free formaldehyde (mg/100g dry board)	7.6	1.9
Moisture content (%)	6.7	6.5

CONCLUSIONS

The major source of formaldehyde indoors is the wood-based panels due to the formaldehyde based resins used.

Research and development the last fifteen years has led to solutions that are acceptable to the industry which produces the boards and meet even the most stringent ecological demands.

Such low formaldehyde emissions are required by the so-called «Blue-Angel» i.e. 0.05 ppm which corresponds to 3.0-3.2 mg/100g dry board (measured photometrically and moisture content of 6.5%).

These values may be reached by using a combination of resin, formaldehyde catcher and a special hardener.

Actually, industrial production with free formaldehyde values below 2.0 mg/100 g dry board was obtained without any deterioration of board properties, without increasing press times and without even increasing the amount of resin used.

This is considered a major breakthrough in the field.

It is important to inform the reader at this point that such values of free formaldehyde are reached by smoking only a couple of cigarettes.

Actually, smoking 20 cigarettes a day corresponds to 1mg daily intake assuming a respiratory volume of 20 m3/day, not considering the other disadvantages caused by smoking.

The lack of standardization in some countries does not give an incentive to the industry to reduce the free formaldehyde emission. In spite of that several companies do reduce the levels emitted of their own free will.

It is therefore imperative that standardization is enforced by the official services to be followed by a law which will allow only the use of El boards.

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ΕΦΗ ΜΑΡΚΕΣΙΝΗ

Χημικός

ARI Ltd

ΕΚΛΥΣΗ ΦΟΡΜΑΛΔΕΫΔΗΣ ΑΠΟ ΕΠΕΝΔΥΣΕΙΣ ΜΟΡΙΟΣΑΝΙΔΩΝ ΚΑΙ ΤΡΟΠΟΙ ΜΕΙΩΣΗΣ ΤΗΣ

ΠΕΡΙΛΗΨΗ

Στις αρχές της δεκαετίας του ογδόντα, η Φορμαλδεΰδη αναγνωρίσθηκε σαν μια ουσία σημαντικής μολύνσεως των εσωτερικών χώρων.

Μελετήθηκε η επίδρασή της στην υγεία και τα μέσα ενημερώσεως έκαναν γνωστά τα αποτελέσματα παγκοσμίως.

Το αποτέλεσμα ήταν ο καθορισμός ορίων για την έκλυση φορμαλδεΰδης από τις μοριοσανίδες.

Αργότερα, ορίστηκαν οι προδιαγραφές για την περιεκτικότητα του αέρος σε φορμαλδεΰδη, στις περισσότερες βιομηχανικές χώρες.

Οι τιμές αυτές γίνονται όλο και πιο μικρές, έτσι ώστε να συζητείται ήδη στη Γερμανία η κατασκευή μοριοσανίδων χωρίς φορμαλδεΰδη.

Στα εργοστάσια όπου παράγονται ρητίνες με βάση τη φορμαλδεΰδη οι οποίες χρησιμοποιούνται για την παραγωγή μοριοσανίδων με βάση το ξύλο και οι οποίες είναι η κύρια πηγή εκλύσεως της φορμαλδεΰδης, έχει γίνει τα τελευταία χρόνια σημαντική έρευνα και πρόοδος σε συνεργασία με τις βιομηχανίες παραγωγής μοριοσανίδων. Το αποτέλεσμα είναι πως μπορούμε ήδη να αντιμετωπίσουμε τις πιο αυστηρές προδιαγραφές.

Τελευταία, πρωτότυπη έρευνα οδήγησε στη παραγωγή μοριοσανίδων με ρητίνες φορμαλδεΰδης, οι οποίες όμως είναι εντελώς απαλλαγμένες από έκλυση φορμαλδεΰδης.