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# A Study on Dust Emission, Particle Size Distribution and Formaldehyde Concentration During Machining of Medium Density Fibreboard

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**A study to characterise the quantity, particle size distribution and morphology of dust created during the machining of MDF was carried out. Four different types of MDF boards were included in this study, including a 'zero-formaldehyde' board that contains isocyanate-based resin, rather than urea–formaldehyde resin. In addition, natural softwood (pine) and natural hardwood (oak) were included in the study, for comparison with MDF. The results show that in general, the dust generated by machining MDF is comparable in terms of particle size distribution and morphology with the dust generated by similarly machining hardwood or softwood. The quantity of dust generated during sanding is higher for sanding MDF compared with sanding either hardwood or softwood. However, for sawing there is no significant difference between MDF and natural woods, in terms of the quantity of dust generated. Free formaldehyde in the air was less than 0.17 mg $m^{-3}$ during machining of the Class B (higher formaldehyde potential) MDF board. There was no measurable isocyanate in the dust generated from the boards.** Crown Copyright © 2000 Published by Elsevier Science Ltd on behalf of British Occupational Hygiene Society. All rights reserved.

*Keywords*: medium density fibreboard (MDF); hardwood; softwood; formaldehyde; woodworking

## INTRODUCTION

Medium density fibreboard (MDF) is made from lingo-cellulosic fibres derived from defibrated wood chip. It is typically composed of 85–100% softwood and 0–15% hardwood. The material is often bound together with a urea–formaldehyde resin. It may leach out formaldehyde vapour in storage, and the resin can decompose when machined due to heat and gives out formaldehyde. A survey carried out by the HSE (Garrod, 1993) monitoring exposure to formaldehyde during the machining of MDF found levels to be substantially below the MEL (HSE, 1999); typical levels were 0.15 ppm (0.2 mg $m^{-3}$), time-weighed average.

Recent media reports and claims by trade unions have suggested that there is particular concern about the health effects because of the fineness of the dust produced when MDF is machined. Concerns have also been raised by the media and the trade unions about the potential health effects of exposure to formaldehyde attached to these particles which are then inhaled and penetrate to the deep lungs. A recent study in a number of woodworking factories (HSC, 1998) found that approximately 30% of MDF dust collected was respirable (i.e. below 10 μm).

This paper describes the work carried out in a controlled environment to measure the particle size distributions of a range of MDF boards and natural wood, formaldehyde release and dust emissions

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Table 1. A summary description of the test materials

| Sample | Trade name / Manufacturer | General appearance |
|---|---|---|
| A | Caberwood (standard MDF), Caberboard Ltd | Light brown (2.4 × 1.8 m × 18 mm sheet) |
| B | Medite MR (moisture resistant), Willamette Europe | Light brown surface with green coloured core (2.4 × 1.8 m × 18 mm sheet) |
| C | Medite ZF (zero added formaldehyde), Willamette Europe | Light brown with woody colour (2.4× 1.8 m × 18 mm sheet) |
| D | Medex, Medite exterior grade, Willamette Europe | Light brown surface with grey coloured core (2.4 × 1.8 m × 18 mm sheet) |
| Pine | Natural, planed | 250 × 20 mm planks |
| Oak | Natural, un-planed | 280 × 37 mm planks |

on dusts generated by two typical woodworking processes.

## TEST MATERIALS

Four types of MDF, natural oak (hardwood) and natural pine (softwood) had been purchased from local timber suppliers. These MDFs had various formaldehyde contents and were recommended for different applications by the manufacturers—they were identified as samples A–D (see Table 1).

The MDF sheets were first cut into pieces of manageable size (1.2 m × 0.9 $m^2$) so that they could be conveniently worked on. A piece of approximately 0.3 × 0.3 $m^2$ was cut out from the centre of each sheet for determination of formaldehyde content in the bulk material.

## EXTRACTABLE FORMALDEHYDE DETERMINATION

The determination of extractable formaldehyde contents was carried out in accordance with BS EN 120:1992 (BSI, 1992) by an independent laboratory (TRADA Technology Ltd, Hughenden Valley, Bucks, UK). Sheets of 0.3 × 0.3 $m^2$ MDF board were supplied to the test laboratory, coded A–D with no descriptions on the sources or suppliers.

Prior to extraction, the sample material was cut into blocks measuring 25 × 25 $mm^2$ and conditioned to constant mass in an atmosphere of 45 ± 5% relative humidity and 23 ± 1°C. Extractions were performed by the perforator method in accordance with BS EN 120:1992 on sub-samples of the cut material selected at random. Extractions were run in duplicate against a blank or control determination using toluene from the same batch as that used for the test determinations. Formaldehyde content of the extracts was assessed photometrically using the acteylacetone method with a Shimadzu UV-120-01 Spectrophotometer at an absorbance wavelength of 412 nm.

## DUST EMISSION STUDY

The work was carried out in a 2 × 2 × 2 $m^3$ (8 $m^3$) dust chamber. Before each experiment the chamber was vacuumed and the door was closed so that the dust generated would have only come from the material being worked on. Air was ventilated through an opening of 0.3 × 0.3 $m^2$ in a corner of the chamber at approximately 1 $m^3$ $min^{-1}$.

In all the experiments, two people were inside the chamber, the machinist and his assistant, both wearing respiratory and hearing protection. Personal samplers (IOM inhalable dust samplers) were attached to them (one on each lapel), and five IOM samplers were placed around the process to

measure the background dust concentrations in the chamber. Two of the five samplers were equipped with 2,4-dinitrophenylhydrazine (DNPH) impregnated filters to measure the free formaldehyde released in the process. In addition, two sorbent tubes (Kitagawa 710) were used to give a direct reading of free formaldehyde concentrations in the chamber. A further sampler was used to collect airborne samples for scanning electron microscopy (SEM) examination. Therefore, a total of 12 samples were taken in each experiment. Figure 1 shows a schematic diagram of the experimental set-up.

Dust that settled on table tops was gathered carefully for formaldehyde-in-the-dust and particle-size analyses.

*Electric saw*

A Bosch (model PKS 46, 620 W, 4600 rpm) circular saw was used in the sawing experiment. The blade was 150 mm diameter and 2 mm width. The exhaust from the saw was open to the dust chamber.

Cuts were made along the shorter length of the MDF sheets (0.9 m): between 24 and 26 cuts were made in the 30 min of each experiment. Pine and oak were cut along the width of the planks: 48 cuts were made in the same duration of time.

The quantity of material cut in each experiment was, therefore, approximately equal, so that comparisons of dust liberated could be made.

*Electric sanding*

A Bosch (model PEX 125) circular handheld sander was used. It operates at 11 000 rpm at 250 W and uses 125 mm diameter sanding paper. Two grades of sanding paper were used, i.e. 80 and 180 grit (grain per inch). Normal pressure was exerted on the work pieces during sanding, both on the surfaces and along the edges to simulate industrial processes. The exhaust was not filtered so the dust was expelled into the work chamber.

For the MDF sheets an area of $1 \times 0.9\ m^2$ and two edges on each sheet were sanded for an episode of 4 min with a break of 1 min. This operation was repeated twice, and a further 15 min of dust sampling was carried out. Similarly in the case of pine and oak, areas of $0.9\ m^2$ were sanded for the same time in the 30 min experimental run. A circular sanding pattern was used.

## PARTICLE SIZE AND DUST MORPHOLOGY ANALYSIS

The particle size distributions of the dust were measured by three methods: a 10-stage Micro-Orifice Uniform Deposit Impactor (MOUDI) for dust in the airborne state; Scanning Electron Microscopy (SEM) on the settled dust, dust col-

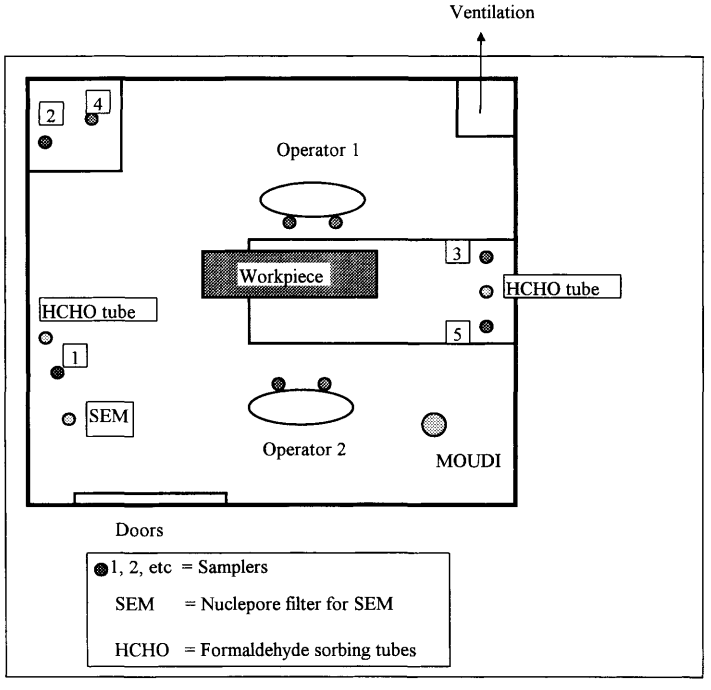



Fig. 1. A schematic diagram of the experimental set-up in the $8\ m^3$ chamber.

lected on impactor stages and filters; and size distribution—by a time-of-flight instrument (Aerosizer)— of the settled dust.

*MOUDI*

The MOUDI (Marple *et al.*, 1991) is a 10-stage impactor with rotating stages to minimise the effect of overloading in the impaction stages. By operating the instrument at selected flow rate and pressure drop across the stages, good-sized cuts can be obtained. It has an entry cut-off at 18 μm, and the subsequent cut-points are: 10, 5.6, 3.2, 1.8, 1, 0.56, 0.32, 0.18, 0.1 and 0.056 μm, and a backing filter. By weighing the impaction stages before and after sampling, the particle size distribution of the airborne dust can be constructed.

*SEM*

Dust collected from the table tops, on Nuclepore filters and on selected stages of the MOUDI were examined under the SEM for particle morphology. Micrographs were taken to provide some information on the particle morphology of the dust particles.

*Aerosizer*

The API (Amherst Process Instrument) Aerosizer measures particle size by expanding the air-particle suspension through a nozzle into a partial vacuum. The air leaves the nozzle at a near-sonic velocity and continues to accelerate through the measurement zone. Particles are accelerated by the drag forces generated by the airstream: small particles are accelerated to nearly the air velocity by the drag force between the air and the particles and larger particles experience lower acceleration because of their greater inertia.

The time-of-flight (tof) of a particle is measured when it passes through two laser beams in the measurement zone. The instrument is calibrated with known-size particles to generate a look-up table. By mapping the tof of a dust cloud to this look-up table the size distribution is obtained. The Aerosizer is capable of measuring dust particles between 0.2 and 700 μm when the sample is presented to the instrument using the dust dispenser or directly through the sampling probe.

In this work a small amount of dust sample (approximately 1 g) of the settled dust was presented for measurement by the Aerosizer. Both numeric and volume (mass) size distributions were measured, using densities of the woods obtained by Thorpe and Brown (1995).

## FORMALDEHYDE CONCENTRATION DETERMINATION

*Formaldehyde in the air*

Formaldehyde in the air was measured by sorbent tubes and by filters impregnated with 2,4-dinitrophenylhydrazine (DNPH) in pumped samplers. Kitagawa 710 tubes were used to give direct reading measurements. Two tubes were used during processing of MDF boards. They were set to sample at 300 ml $min^{-1}$ for 30 min (duration of the experiment). The coloration in the tubes at the end of the experiment gave the formaldehyde concentrations in parts per million (ppm) of air sampled. These were converted to mg $m^{-3}$ for ease of comparison.

DNPH-impregnated filters were used to sample (at 2 l. $min^{-1}$) in-line at sampler positions 1 and 5. The filters were desorbed into acetonitrile and aliquot portions of the desorbate were analysed by HPLC with UV detection at 360 nm. Analytical limits of detection are typically below 100 ng per sample.

*Formaldehyde in the dust*

Dust samples of MDF boards collected from the floor were analysed in accordance with NIOSH *Manual of Analytical Methods 5700* (NIOSH, 1994). The concentration of formaldehyde was measured by extracting the dust sample in warm water (37°C) for 4 h, then derivatising the resultant wash in a solution of 2,4-dinitrophenylhydrazone and using an HPLC-UV technique.

It was suggested, however, that isocyanates present in MDF as resins might decompose and either release into the air in storage or breakdown in the heat generated by cutting or sanding. Some samples were analysed for isocyanates, accordingly.

## RESULTS AND DISCUSSION

*Extractable formaldehyde determination*

Table 2 shows the total extractable formaldehyde content in the MDF samples A–D. The standard controlling formaldehyde content in fibreboards in the UK is the Fibreboard Specification Standard EN 622-1:1997 (BSI, 1997). Two classes of specification are cited in the Standard:

Table 2. Perforator values (mg formaldehyde per 100 g sample) of the MDF samples

| Sample | Test 1 | Test 2 | Average |
|---|---|---|---|
| A (Caberwood) | 7.6 | 7.3 | 7.5 |
| B (Medite MR) | 16.6 | 16.2 | 16.4 |
| C (Medite ZF) | 0.7 | 0.6 | 0.7 |
| D (Medex) | 5.4 | 5.6 | 5.5 |

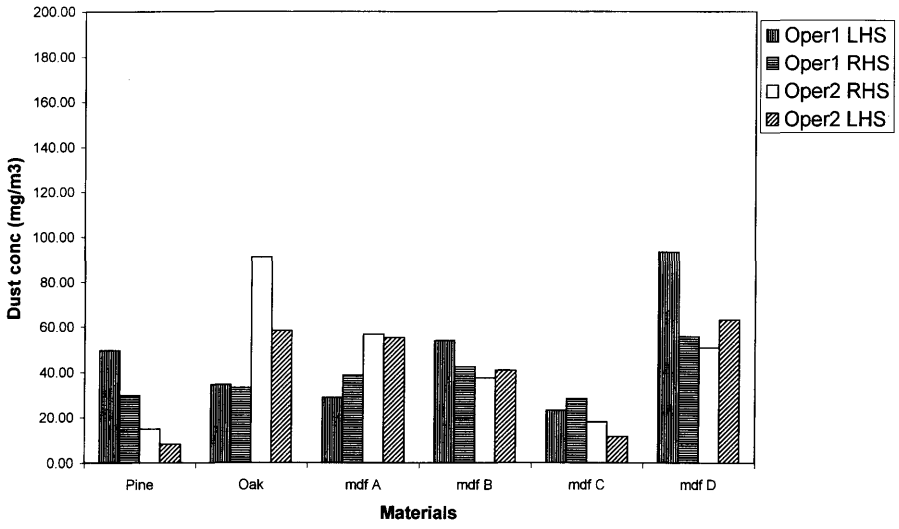



Fig. 2. Personal exposures during sawing.

- Class A boards: < 9 mg per 100 g;
- Class B boards: < 40 mg per 100 g.

The results indicate that samples A, C and D comply with Class A limits set by the current standard, while sample B is a Class B board. The samples also comply with information provided in the material safety data sheet supplied by the manufacturers.

*Dust emission results*

The dust concentrations during the three processes were measured and the results are presented graphically in Fig. 2–4. Only the personal dust concentrations are shown.

*Sawing*. The positioning of the background samplers had resulted in some very high dust concentrations (more than 400 mg $m^{-3}$) being measured during sawing. The exhaust, at the back of the saw where large projectiles were expelled, directed dust particles towards the background samplers 2 and 4, positioned just behind the operator. These were large particles and they settled to the floor or surfaces quickly. Smaller particles with much less mass would float in the air for longer periods of time.

Among the four MDF sheets, sample D generated the most dust. Oak produced about the same amount of dust as the MDF, and pine appeared to be less dusty when sawn. More grinding against the saw blade was experienced for the harder material (oak), whereas pine was a softer material and was easier to cut from the bulk. The pine dust particles

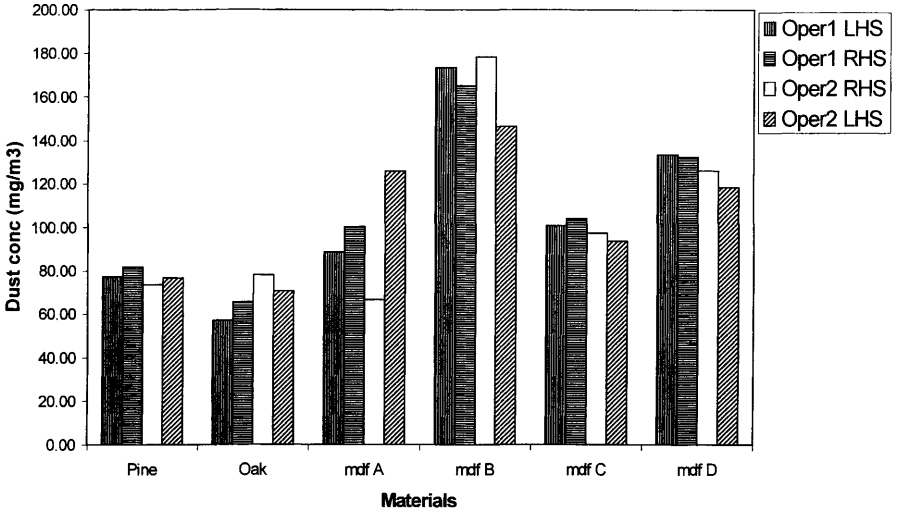



Fig. 3. Personal exposures during sanding with 180 grit sanding paper.

would be larger because larger 'chunks' were ripped out by the sawing teeth.

*Sanding.* A very much finer dust was produced by sanding. For the finer grade paper (180 grit) less dust was generated. It also appeared that the dust would float in the air for longer and was dispersed in the chamber more uniformly as demonstrated by the fact that all samplers measured about the same dust concentrations (Fig. 3). Fine dust in the exhaust from the sander was not easily visible under normal ambient light. However, using a dust lamp at suitable angles the dust cloud could be seen clearly.

MDF produced more dust in sanding than the natural wood—pine gave the least dust in both sanding scenarios and oak generated about 30% less dust than the MDFs.

The very high concentrations measured in this study were in controlled conditions for short periods in order to investigate the dust emission during machining of wood products when no control was in place. They cannot, therefore, be directly compared with 8 h TWA MEL (HSE, 1999) for wood dust (5 mg $m^{-3}$).

*Particle size analysis*

*MOUDI.* In all the experiments no measurable amount of dust particles was impacted on stages below 1 μm (stage 6 in the MOUDI). Heavy deposits were found on the top three impaction stages (10, 5.6, and 3.2 μm cut stages), indicating that the airborne size distribution (by mass) of the dust was large and, most probably, the majority of the dust was outside the respirable size fraction (CEN, 1993). No quantitative measurement was made with this instrument due to overloading of dust particles on the top impaction stages.

*SEM examination.* Dust samples collected from the table top or floor, on filters and on selected stages from the MOUDI, were examined by SEM.

Fibrous particles of more than 400 μm in length and 40 μm wide were found, but very few small particles (< 10 μm) were observed despite a laborious search through the samples. For example, Fig. 5 shows a highly magnified image of an MDF A saw dust sample collected on the Nuclepore filter. The micrograph shows a typical fibrous wood chip about 50 μm long and 15 μm thick.

Figure 6 shows a typical micrograph of MDF A dust from sanding a sample with 80 grit paper. Particles smaller than 10 μm were found and have similar morphology as the larger particles resulting from sawing.

These micrographs are typical for all test materials. Very few small particles, less than 10% by mass, were generated from any of the test materials by sawing and sanding. These results are comparable to the Aerosizer measurements, described below.

*Aerosizer.* Tables 3–5 show the results using the Aerosizer to measure the particle size distributions of the samples. Some of the more interesting size distributions are shown in the graphs.

In sawing (Table 3), pine produced the size distribution with the largest particles, with a mass median diameter (mmd) value of 72.2 μm. Oak, in contrast, had the smallest size distribution, with an mmd of 32.9 μm. The bi-modal number distribution in oak probably resulted from the two size fractions of dust generated in sawing hardwood: grinding of the blade with the wood and ripping of the material by the saw teeth. The long tail in the number distribution in oak (Fig. 7) was interesting, but time did not permit further investigation. It was also noted

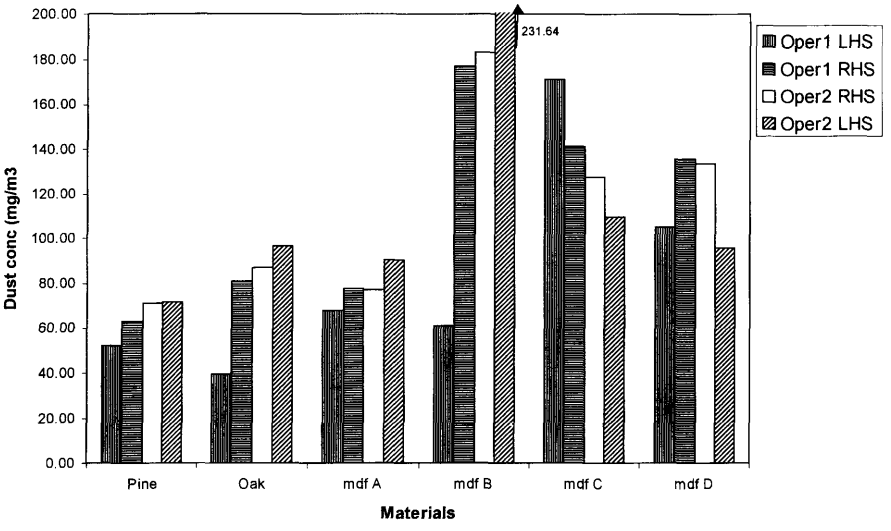



Fig. 4. Personal exposures during sanding with 80 grit sanding paper.

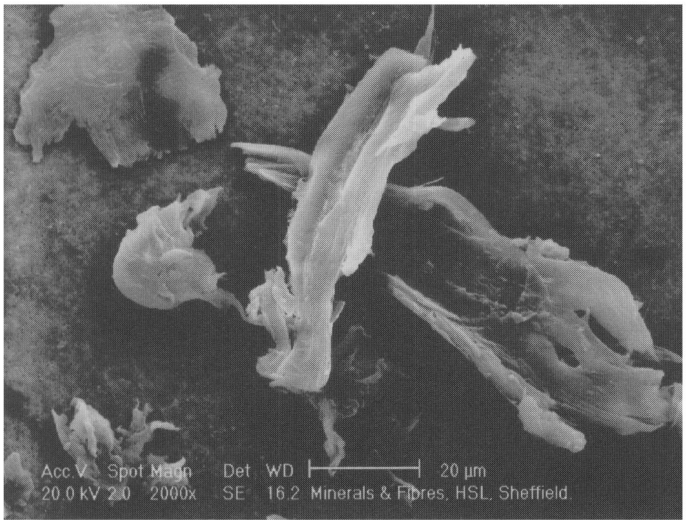



Fig. 5. A typical SEM micrograph of saw dust from MDF A.

Table 3. Particle size distributions of the dusts generated by sawing

| | Number distribution (µm) | | | | | | Volume (mass) distribution (µm) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| % under | Pine | Oak | MDF A | MDF B | MDF C | MDF D | Pine | Oak | MDF A | MDF B | MDF C | MDF D |
| 10 | 6.2 | 1.1 | 5.6 | 6.4 | 5.7 | 4.4 | 33.2 | 15.1 | 22.6 | 25.8 | 20.0 | 21.5 |
| 25 | 11.9 | 1.9 | 9.0 | 9.9 | 9.1 | 8.0 | 47.3 | 22.7 | 31.8 | 36.4 | 27.1 | 30.3 |
| 50 | 20.0 | 5.7 | 15.0 | 16.4 | 14.7 | 13.9 | 72.2 | 32.9 | 43.8 | 54.0 | 36.9 | 42.9 |
| 75 | 30.0 | 11.3 | 24.5 | 26.6 | 23.1 | 22.7 | 103.7 | 43.4 | 54.7 | 76.7 | 47.9 | 55.1 |
| 90 | 48.3 | 19.3 | 36.2 | 38.6 | 32.5 | 33.7 | 128.7 | 52.2 | 69.1 | 94.3 | 57.2 | 71.2 |
| Mean | 18.6 | 4.9 | 14.5 | 16.0 | 14.0 | 12.9 | 68.0 | 30.3 | 41.2 | 51.0 | 34.9 | 40.6 |
| Mode | 30.0 | 8.9 | 15.0 | 16.7 | 16.2 | 16.0 | 80.0 | 37.7 | 48.2 | 91.9 | 41.4 | 45.4 |

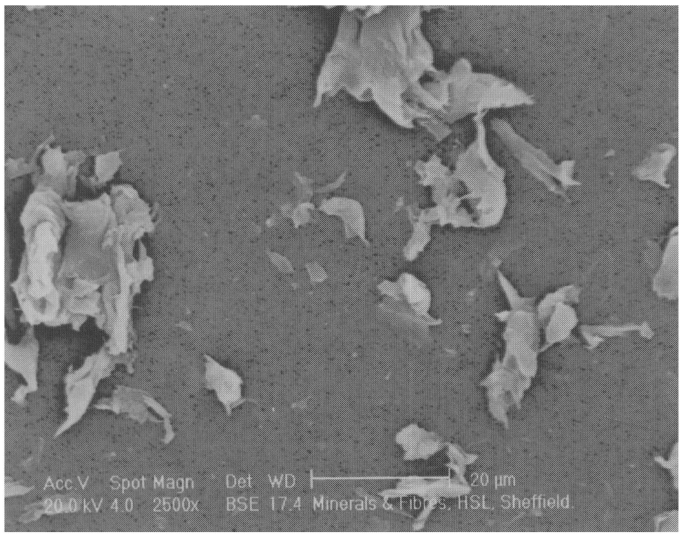



Fig. 6. An SEM micrograph of MDF dust from sanding (180 grit).

Table 4. Particle size distributions of dusts generated by sanding using 180 grit paper

| | Number distribution (μm) | | | | | | Volume (mass) distribution (μm) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| % under | Pine | Oak | MDF A | MDF B | MDF C | MDF D | Pine | Oak | MDF A | MDF B | MDF C | MDF D |
| 10 | – | – | 1.8 | 2.5 | 2.0 | 1.7 | – | – | 12.6 | 12.0 | 12.3 | 10.9 |
| 25 | – | – | 3.6 | 6.2 | 4.5 | 4.0 | – | – | 16.7 | 15.8 | 16.5 | 14.5 |
| 50 | – | – | 9.2 | 10.2 | 9.1 | 8.4 | – | – | 22.5 | 20.7 | 22.2 | 19.7 |
| 75 | – | – | 14.4 | 15.0 | 14.2 | 12.8 | – | – | 29.3 | 26.5 | 29.3 | 26.1 |
| 90 | – | – | 19.9 | 19.8 | 19.6 | 17.6 | – | – | 35.4 | 31.7 | 36.2 | 32.5 |
| Mean | | | 7.3 | 8.8 | 7.6 | 6.82 | | | 21.6 | 20.0 | 21.5 | 19.1 |
| Mode | | | 12.7 | 12.1 | 12.1 | 10.6 | | | 25.7 | 22.4 | 22.7 | 21.4 |

Table 5. Particle size distributions of dusts generated by sanding using 80 grit paper

| | Number distribution (μm) | | | | | | Volume (mass) distribution (μm) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| % under | Pine | Oak | MDF A | MDF B | MDF C | MDF D | Pine | Oak | MDF A | MDF B | MDF C | MDF D |
| 10 | 2.6 | 1.7 | 2.6 | 4.3 | 3.1 | 1.9 | 23.8 | 13.8 | 17.2 | 15.5 | 14.8 | 16.0 |
| 25 | 3.3 | 5.3 | 6.8 | 7.8 | 6.8 | 4.8 | 32.6 | 18.9 | 23.5 | 20.9 | 20.3 | 22.2 |
| 50 | 4.7 | 9.5 | 12.2 | 12.5 | 11.2 | 9.9 | 44.4 | 25.6 | 32.2 | 28.0 | 27.8 | 31.0 |
| 75 | 13.9 | 15.5 | 19.3 | 18.4 | 17.4 | 16.6 | 52.1 | 33.2 | 41.3 | 35.6 | 35.7 | 40.6 |
| 90 | 27.9 | 22.1 | 27.8 | 26.0 | 24.8 | 24.6 | 70.0 | 39.8 | 49.4 | 42.1 | 42.3 | 49.2 |
| Mean | 6.6 | 8.0 | 10.5 | 11.4 | 10.0 | 8.4 | 41.9 | 24.3 | 30.3 | 26.5 | 26.1 | 29.1 |
| Mode | 3.8 | 11.6 | 14.8 | 14.3 | 13.1 | 12.5 | 53.7 | 30.0 | 37.2 | 32.4 | 31.9 | 34.9 |

that very large dust particles were generated from pine.

As expected, finer grade sanding paper generated finer dust (Tables 4 and 5). Bi-modal numeric size distributions were observed in all test materials, indicating either both ripping and grinding actions in sanding or disintegration of the sanding paper.

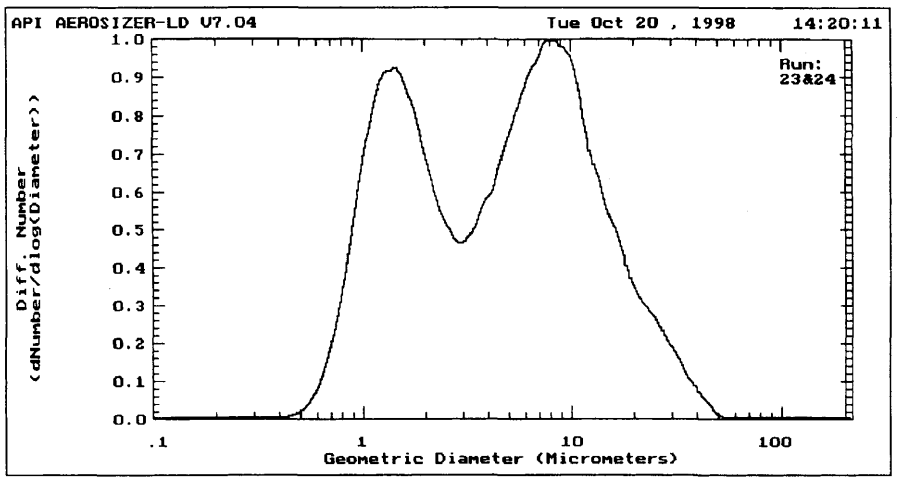
Relating to the dust emission results, MDF B always produced the most dust in sanding. It did not, however, produce the coarsest dust, the mmd being 20.7 and 28 μm, when using 180 and 80 grit sanding paper, respectively.

Interesting results were obtained for pine: although the number distribution indicated that small dust particles were generated (mode equal to 3.8 μm), a second peak at 20 μm shifted the mass size distribution when the sample was sanded with 80 grit paper (Fig. 8). This appeared to imply that the bi-modal distribution is real and sanding produces two size distributions due to grinding and ripping of the material.

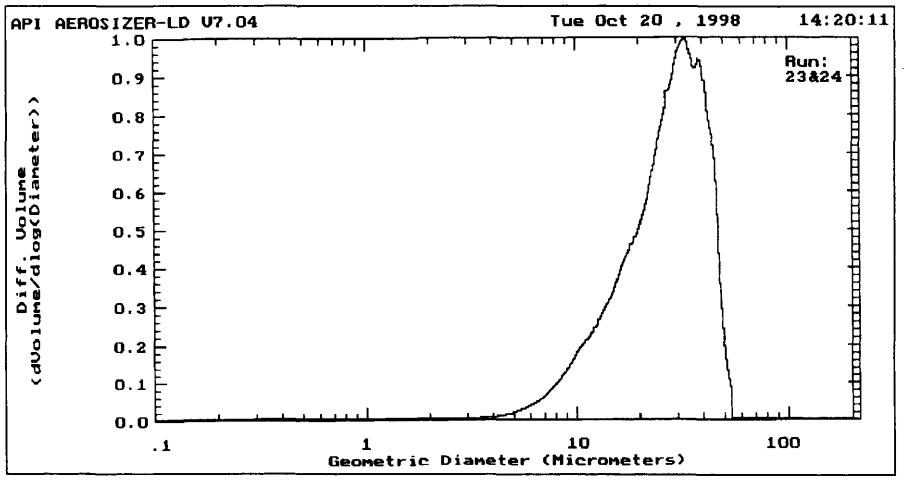
The results are consistent with field measurements (e.g. HSC, 1998), which indicate that less than 30% by weight of the airborne dust in the workplace is smaller than 10 μm. It should be noted that there are other sources of particulates in the workplace air, whereas in this work the atmosphere is predominately MDF dust generated from the processes.

Table 6. Free formaldehyde concentrations in the air during woodworking processes

| MDF sample | Machine process | Formaldehyde concentration (mg $m^{-3}$) | | | |
|---|---|---|---|---|---|
| | | Detector tube 1 | Detector tube 2 | Filter 1 | Filter 2 |
| A (Caberwood) | Sawing | 0.09 | 0.09 | 0.08 | 0.08 |
| | Sanding 180 grit | n/a | 0.07 | 0.09 | 0.07 |
| | Sanding 80 grit | 0.05 | 0.05 | 0.13 | 0.12 |
| B (Medite MR) | Sawing | 0.03 | n/a | 0.05 | 0.11 |
| | Sanding 180 grit | 0.01 | 0.09 | 0.11 | 0.16 |
| | Sanding 80 grit | 0.03 | 0.12 | 0.17 | 0.17 |
| C (Medite ZF) | Sawing | 0.03 | 0.03 | 0.03 | 0.03 |
| | Sanding 180 grit | 0.03 | 0.07 | 0.03 | 0.03 |
| | Sanding 80 grit | 0.03 | 0.07 | 0.07 | 0.04 |
| D (Medex) | Sawing | 0.01 | 0.07 | 0.05 | 0.05 |
| | Sanding 180 grit | 0.01 | 0.08 | 0.05 | 0.07 |
| | Sanding 80 grit | 0.01 | 0.07 | 0.05 | 0.05 |




(a) Number distribution




(b) Volume distribution

Fig. 7. Typical size distribution of oak (hardwood) dust generated by sawing.

Table 7. Formaldehyde in dust contents, measured by the NIOSH 5700 method

| MDF sample | Machine processes | Formaldehyde in dust (NIOSH 5700 method) | Formaldehyde in bulk (BS 120 method) |
|---|---|---|---|
| | | mg per 100 g of dust | mg per 100 g of board |
| A (Caberwood) | Sawing | 87.7 | |
| | Sanding 180 grit | 103.6 | 7.5 |
| | Sanding 80 grit | 106 | |
| B (Medite MR) | Sawing | 55.5 | |
| | Sanding 180 grit | 31.6 | 16.4 |
| | Sanding 80 grit | 125.4 | |
| C (Medite ZF) | Sawing | 0.4 | |
| | Sanding 180 grit | 6.3 | 0.7 |
| | Sanding 80 grit | 14.5 | |
| D (Medex) | Sawing | 48.3 | |
| | Sanding 180 grit | 54.5 | 5.5 |
| | Sanding 80 grit | 51.3 | |

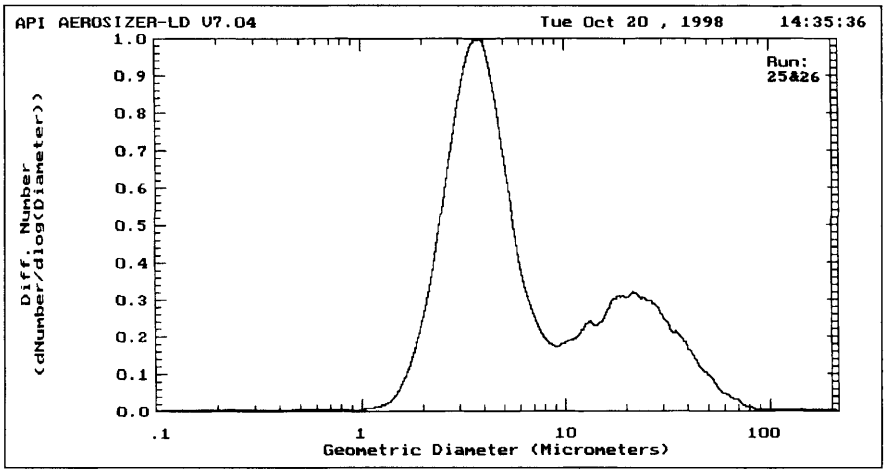
*Formaldehyde in the air*

The results of free formaldehyde released during machining are given in Table 6. Both the detector tubes and DNPH-impregnated filters gave very low concentrations. These are in good agreement with previous results measured in industry.

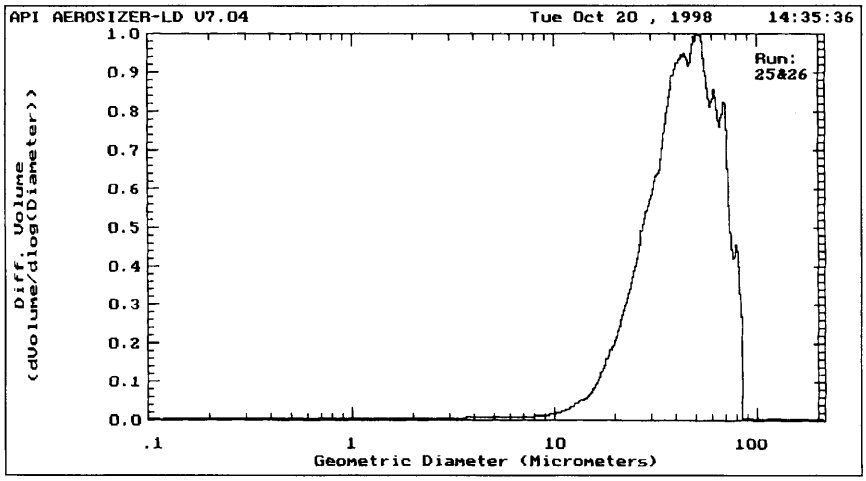
*Formaldehyde in dust*

Formaldehyde in dust was extracted and measured. Table 7 gives the results of dust collected from the worktable top and surfaces. Approximately 0.5 g of dust was used in the extraction, using the NIOSH 5700 method. This method is believed to give a good estimation of formaldehyde availability in the body since the extraction is at body temperature (in warm water at 37°C) for 4 h. The washings are then aggressively derivatised in a strong acidic condition so that all dissolved urea–formaldehyde is degraded to formaldehyde.

The formaldehyde content in the bulk materials is also given alongside for comparison. It can be seen that there is approximately 10 times more formaldehyde in the dust than in the sheets. In an evaluation of methods to determine formaldehyde content in resin-containing wood-board dusts, Priha (1996) found comparable results: the DNPH (NIOSH 5700) method recovers between 8 and 10




(a) Number distribution




(b) Volume distribution

Fig. 8. Typical size distribution of pine (softwood) dust generated by sanding using 80 grit sanding paper.

times more formaldehyde from MDF than the acetylacetone (BS 120) method. Priha concluded that acidity of the solutions plays an important role in the hydrolysis of the reagents.

It was decided to use the NIOSH 5700 method in this work, because it was thought that some particles may be small enough (respirable particles) to penetrate into the deep lungs in which a more aggressive environment may exist in breaking down the resin to release formaldehyde, so that all available formaldehyde should be determined.

*Isocyanates in dust*

Initially, the wood dusts were desorbed in a toluene solution containing an excess of 2-methoxy piperazine and a proportion of the solution qualitatively analysed by HPLC according to MDHS 25/2 (HSE, 1994). The woods contained many compounds, some of which overloaded the detector, but no isocyanate derivatives of methylene bis-(4-phenylisocyanate) (MDI), toluene diisocyanate (TDI) or 1,6-hexamethylene diisocyante (HDI) were identified when examining their UV spectra. This result was not unexpected as wood contains many compounds which would be expected to derivatise any isocyanates present in the glues.

Samples of wood dust were then heated in order to vaporise any free isocyanate and analysed by GC-MS (gas chromatography-mass spectroscopy) using an Automatic Thermal Desorptor (ATD 400) (split 2%, desorb temperature 200°C, desorb time 10 min, trap high 300°C, trap desorb time 10 min) in order to obtain a reproducible, known amount onto the GC column. The injection temperature was restricted to 200°C as it was felt unlikely that wood would reach this temperature during processing. A known weight of sample was placed inside an ATD tube and desorbed which had the advantage that a known quantity of isocyanate monomer can be spiked onto a filter paper, analysed under the same conditions and a detection limit estimated.

The total ion chromatograms were extracted with typical ions for HDI, MDI, TDI and phenyl isocyanate (chosen by examination of the mass spectra of standards) and the molecular weight for methyl isocyanate (57). From the detection limit of spikes of isocyanates on a filter it was calculated that less than 0.02% (1.2 μg) of the wood was either HDI or TDI (2,4 or 2,6) for a sample of approximately 6 mg. On examination of the chromatograms no isocyanate monomers were found.

## CONCLUSIONS

The following conclusions can be made from the results of the study.

There is no significant difference in the quantity of dust generated from sawing the different types of MDF boards or from hardwood (oak) and softwood (pine). MDF produced more dust in sanding than the natural wood—pine gave the least dust in both sanding operations and oak generated about 30% less dust than the MDFs. In terms of particle morphology there is no significant difference between MDF dusts and natural wood dusts: both contain very large fibrous-type particles.

The size distributions are similar. However, hardwood dust is the smallest and softwood dust the largest while the size of the MDF dusts lies between from either sawing or sanding. There are fewer than 10% (by mass) particles smaller than 10 μm, either in dust collected from table tops and surfaces, or from airborne measurements.

Free formaldehyde in the air arising from machining all four types of MDF was less than 0.17 mg $m^{-3}$ under the test conditions, namely the work being carried out in a semi-enclosed chamber with ventilation at approximately 1 $m^3$ $min^{-1}$; but there is no measurable isocyanates from the dusts of any of the samples.

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