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A. Fischer · K. Richter · L. Emmenegger · T. Künniger

PM10 emissions caused by the woodworking industry in Switzerland

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Abstract PM10 emissions derived from wood processing in Switzerland's woodworking industry were estimated using two different approaches. Input data were provided by the woodworking associations and based on a written survey of selected branches of the woodworking industry. The upper extrapolation limits estimated for national PM10 wood dust emissions were 110 t/a and 318 t/a, respectively, which corresponds to a maximum of 1% or 3% of the total national industry emissions.

Feinstaubemissionen der holzverarbeitenden Industrie in der Schweiz

Zusammenfassung Die Feinstaubbelastung (PM10-Emission) aus maschinellen Bearbeitungsprozessen in der Holzindustrie der Schweiz wurde mit zwei unterschiedlichen Extrapolationsansätzen abgeschätzt. Die dafür notwendigen Daten wurden über die branchenzuständigen Verbände und über Betriebsumfragen in ausgewählten Branchen der holzverarbeitenden Industrie erhoben. Je nach Extrapolationsansatz werden für die Holzindustrie maximale PM10-Emissionswerte von 110 und 318 t/a ermittelt, was 1% bzw. 3% der gesamtschweizerisch aus Industrie und Gewerbe emittierten Feinstaubmengen entspricht.

A. Fischer · K. Richter (✉) · T. Künniger
Empa, Swiss Federal Laboratories for Materialstesting and Research, Wood Laboratory, Überlandstrasse 129, 8600 Dubendorf, Switzerland
E-mail: klaus.richter@empa.ch

L. Emmenegger
Empa, Swiss Federal Laboratories for Materialstesting and Research, Air Pollution/Environmental Technology, Überlandstrasse 129, 8600 Dubendorf, Switzerland

1 Introduction

As a potential health hazard, lung-penetrating fine dust represents a major challenge for clean air policy (Pope et al. 2002). To meet applicable limits in Switzerland a reduction of the current overall PM10 and precursor emissions by approximately 50% is required. To reach this objective a fundamental understanding of both the origin and dissemination of these fine particles is essential.

Fine dust with aerodynamic diameters of less than 10 μm (PM10) is a complex mixture of diverse chemical compounds. They partly consist of primary particles that derive from combustion or working processes and/or natural sources. By contrast, secondary particles are formed from gaseous precursor substances in the atmosphere.

Of 28,000 tons of PM10 that are annually directly emitted in Switzerland, approx. 35% originate from industry (BUWAL 2001a). An initial rough estimate suggests, that with 20% the woodworking industry accounts for a surprisingly high level of industrial PM10 emissions, making it the largest single source (BUWAL 2001b).

Woodworking processes result in the release of primary fine dust particles. Dust generation varies according to the species of wood and the wood moisture content, plus the woodworking parameters (Henkel and Jentsch 2001). The process of sanding of wood and wood-based materials is responsible for the greatest production of dust, followed by routing and circular sawing (Detering et al. 1999; Lehmann and Fröhlich 1987; Sasskortsak et al. 1986; Vinzents and Laursen 1993). Measurements of total dust levels taken in production plants and at workplaces in sawmills, plywood producers and furniture makers have demonstrated that total dust levels consist in the range of 15% and 40% percentage weight of fine dust (Kauppinen et al. 1984). Little is known of the dust concentrations beyond the filter, i.e. the emissions released to the environment, because measurements taken in woodworking operations have so far been concerned primarily with wood dust loads at the workstation (Kos et al. 2004; Poppe et al. 2002).

Therefore, the division for Air Pollution Control and Non-Ionizing Radiation of the Swiss Federal Agency for the Environment, Forests and Landscape (SAFEL/BUWAL) commissioned a study (Fischer et al. 2004) in order to assess the potential impact of wood fine dust in their strategies.The objective of this study was to provide an estimation of the PM10 emissions from woodworking processes in Switzerland.

2 Methods

2.1 Data collection

A survey conducted by the woodworking industry associations and evaluations of existing economic statistics, provided fundamental data on the structure, processed volumes, and dust reduction systems of the companies working in the industry. A significant lack of data relevant for the scope of our study was identified for joinery and wood products, carpentry and timber construction, industrial furniture production and packaging and pallets sectors. Therefore, a detailed questionnaire was sent to 30% of the member companies of the relevant industry associations to obtain specific information on production conditions (number of employees, wood volume processed [m^3/a]) and plant technology (extractor system, filter type, number and nominal power [kW] of ventilators, air volume flow of extractor system [m^3 air/h], guaranteed filter value [mg/m^3]). In addition, manufacturers and suppliers of extractor systems provided qualitative information for the formulation of the extrapolation models.

2.2 Modelling and extrapolation of dust loads

The data collected was used to calculate the PM10 emissions on the four surveyed sectors. For this purpose, an arithmetic model, which is explained in the next section, was applied. The model is based on surveyed data and qualitative information of manufactures of extractor systems. Subsequently, the calculated emissions were extrapolated for the whole Swiss woodworking industry using the number and size of companies as indicators. Finally, two different approaches of extrapolation were selected to estimate the PM10 emissions of the non-surveyed sections. Approach I is based on the annual processed quantity of wood as basis for the extrapolation. Approach II estimates the PM10 emissions by use of the averaged volume flows per company size.

3 Results and discussion

3.1 Structure and key parameters

In regards to the response rate of approx. 30%, the results of the written survey on production and the nature of the dust reduction systems can be considered as representative. Together with the data of the economic statistics, the projected data provides an accurate reflection of the current state of the predominantly small-scale Swiss woodworking industry (Table 1).

The extractor systems used in the woodworking industry can be categorized into five different types (Table 2). The survey showed that the dominant extractor systems relative to production volumes are types A and B, and type C having some significance for carpenter's shops. Assuming that the systems are fully functional, some 70% of all filter systems used in the wood industry do not release any dust emissions to the

Table 1 Structure and key parameters of Swiss woodworking industry
Tabelle 1 Struktur und Kennzahlen der Schweizer Holzindustrie ([a] Grundlage BFS/BUWAL Statistiken, [b] Information der Industrieverbände, [c] Industriebefragung im Rahmen dieser Studie)

Sector	Reference year	Number of companies[a]	Wood volume processed (10^3 m^3/a)	State of dust extraction technique[b]
Sawmill	2002	400	2,300[a]	Good
Wood panel industry	2001	4	1,195.2[a]	Good to very good
Window manufacture	2001	380	285.7[a]	Good
Planing mill	2001	27	229.4[a]	Good
Veneer factory	2002	2	13.7[a]	Good
Pulp and paper	2001	23	585.6[a]	Good
Joinery/wood products	1998/2000	7,162	1,435.7[c]	Good
Carpentry/timber building	1998/2000	1,950	133.4[c]	Not specified
Industrial furniture production	2002	150	222.2[c]	Advanced
Transport/pallets	2002	57	602.4[c]	Not specified
Flooring/parquet	2002	6	22[a]	Good to very good

[a]Based on BFS/BUWAL statistics
[b]Information from industry associations
[c]Based on sector specific survey

environment as they return the filtered air to the work area instead. Only 2–3% of all firms do not use any kind of extractor system.

The detailed sector specific analysis of the input data of the survey based on the number of employees (representing the size of the companies) was a suitable indicator to extrapolate the data of the survey to the whole industry sector. Using this ratio of distribution, the volume flows $\dot{V}_i$ of the different extractor systems in the four sectors were calculated, as well as the wood volumes processed and produced. Table 3 provides an example of the extrapolation of the volume flow data for the joinery and wood products industry. Note that for the reason of better presentation only volume flows of extractor type A and B are listed.

According to our survey, approximately 90% of the filter systems under consideration are equipped with a fibrous filter (surface filter), which guarantees maximum dust emissions of 0.2 mg/m^3. Therefore, all further calculations were based on the characteristic values for the fibrous filter.

3.2 Dust emission of the surveyed industries

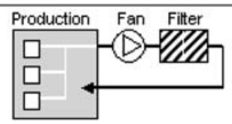
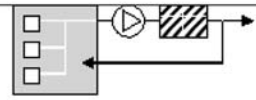
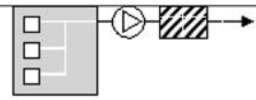
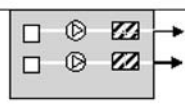
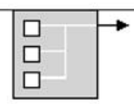
The total dust emission $\dot{m}_{\mathrm{PM}}$ into the environment was calculated according to Eq. 1. The dominant parameters are the mean concentration of particular matter $\bar{c}_{\mathrm{PM}}$ and the total nominal volume flow $\dot{V}$ of the emitting extractor types, weighted with a factor of 0.7 for the efficiency of ventilation. This was based on the assumption of an annual operation time of 2,088 h.

$$\dot{m}_{\mathrm{PM}} = ((\bar{c}_{\mathrm{PM}}\dot{V}\eta) + \dot{m}_F)T \quad (1)$$

where,

- $\dot{m}_{\mathrm{PM}}$: total mass flow of particular matter [t/a]
- $\bar{c}_{\mathrm{PM}}$: mean concentration of particular matter [mg/m^3]
- $\dot{V}$: total nominal volume flow [m^3 /h]
- η: ventilation efficiency (effective/nominal flow)
- $\dot{m}_{\mathrm{F}}$: mass flow of particular matter of extractor type F systems [mg/h]
- T: operation time [h/a]

Table 2 Classification of extractor systems used in woodworking industry
Tabelle 2 Klassifikation der verschiedenen Ablufterfassungssysteme in der Schweizer Holzwirtschaft

Extractor systems in woodworking industry	Principle	Share of installation in survey [%]	Share of volume flow into environment [1)] f_i
A 	Central extraction Complete return of filtered air to the work area	57	0
B 	Central extraction Filtered air is returned to the work area (usually in winter) or released to the environment (usually in summer)	18	0.5
C 	Central extraction Release of filtered air to the environment	10	1
D 	Decentral extraction Filtered air is returned in majority to the work area	9	0
E 	Decentral extraction Filtered air is released in majority to the environment	3	1
F 	No extraction / filtering	3	not applicable.

[1)] $f_i = \frac{\dot{V}_{out}}{\dot{V}_{ret} + \dot{V}_{out}}$ where $\dot{V}$ = total nominal volume flow; out: air released to the environment; ret: air returned to the work area

[a] $f_{\mathrm{i}} = \frac{\dot{V}_{\mathrm{out}}}{\dot{V}_{\mathrm{ret}}+\dot{V}_{\mathrm{out}}}$ where $\dot{V}$ = total nominal volume flow; out: air released to the environment; ret: air returned to the work area

Table 3 Projection of total volume flows of extractor types A and B of the Swiss joinery and wood products industry based on the response of the survey
Tabelle 3 Hochrechnung der Volumenströme der Absaugsysteme A und B der Schreinerindustrie auf der Basis der Umfrageergebnisse

Extractor type	Result of survey				Projection to Swiss industry			
	A		B		A		B	
	Volume flow (m^3/h)	No of companies responded	Volume flow (m^3/h)	No of companies responded	Volume flow (m^3/h)	No of companies CH	Volume flow (m^3/h)	No of companies CH
Company size (no of employees)								
Up to 5	661,421	136	152,396	25	10,197,232	2,097	2,085,378	342
6–9	752,715	91	229,237	23	10,040,873	1,214	2,969,684	298
10–19	649,132	56	214,711	23	9,210,159	795	2,884,524	309
20–49	671,302	24	678,150	24	8,951,469	320	7,483,683	265
50–99	202,860	4	456,416	9	2,798,311	55	4,477,112	88
100–299			122,882	2			1,356,057	22
300–499								
More than 500			150,000	1			150,000	1
Total	2,937,430		2,003,792		41,198,044		21,406,438	

The estimate of the mean concentration of particular matter ($\bar{c}_{PM}$) considered the extraction efficiencies of the guided extractor systems based on the assumptions:

– 70% (*f* = *0.7*) of all dust extraction systems are fully functional and achieve guaranteed filter values (*c* = *0.2* mg/m^3)
– 20% (*f* = *0.2*) of all dust extraction systems are older and exceed the guaranteed filter values (*c* = *10* mg/m^3)
– 10% (*f* = *0.1*) of all dust extraction systems are defect and considerably exceed the guaranteed filter values (*c* = *50* mg/m^3).

It follows:

$$\bar{c}_{PM} = 0.7 \times 0.2\,\mathrm{mg\,m^{-3}} + 0.2 \times 10\,\mathrm{mg\,m^{-3}} + 0.1 \times 50\,\mathrm{mg\,m^{-3}} \quad (2)$$

The total nominal volume flow of the guided extractor systems in the four sectors is calculated as follows:

$$\dot{V} = \sum_{i=\mathrm{A}}^{\mathrm{E}} f_i \dot{V}_i \quad (3)$$

Where,
$\dot{V}$: total nominal volume flow (m^3/h)
$\dot{V}_i$: total nominal volume flow of installations with extraction system i ($i = A$ to E, see Table 2)
f_i $\frac{\dot{V}_{out}}{(\dot{V}_{ret}+\dot{V}_{out})}$ (share of volume flow into environment of extraction system i; Table 2)

For the companies without any guided extractor system (category F), representing only approx. 3% of the woodworking industry, a dust emission value of 10 mg/m^3 was assumed. A reduction factor of 0.2 was introduced; estimating that the natural ventilation is roughly 20% of the forced ventilation in companies with comparable size.

$$\dot{m}_F = V_F \times 10\,\mathrm{mg\,m^{-3}} \times 0.2 \quad (4)$$

Finally, PM10 emission was calculated by weighting the total dust emission with the minimum (15%) and maximum (40%) fine dust concentration value according to (Kauppinen et al. 1984):

$$\dot{m}_{PM10} = \dot{m}_{PM} 0.15 \quad (resp.\ 0.40) \quad (5)$$

The results for the four surveyed sectors are shown in Table 4. The range of PM10 emissions varies considerably between the single sectors. As expected, the highest emissions are released by the joinery and wood products industries, where the dust extraction systems are permanently activated and wood is processed intensively, compared to e.g. the packaging industries.

3.2.1 Projection of the dust loads of the other woodworking sectors

In the extrapolation approach I, the dust loads were extrapolated from the processed volume of wood in each sector of the industry. To achieve this objective, the total yearly dust loads $\dot{m}_{PM}$ in "t/a" previously established for the four surveyed sectors (see Table 4) were converted into "t/m^3 of wood" by means of the processed volumes of wood

$$E_{PM} = \frac{\dot{m}_{PM}}{V_{wood}} \quad (6)$$

where,
E_{PM}: sector specific emission factor [mg/m^3]
$\dot{m}_{PM}$: total mass flow of particular matter [t/a]
V_{wood}: volume of processed wood in each sector [m^3/a] (see Table 1)

Weighted with the fine dust ratio already used in Eq. 5, this resulted in emission factors of 1 g/m^3 of wood (15% PM10) in the packaging industry to 47 g/m^3 of

Table 4 Total ($\dot{m}_{PM}$) and PM10 emission ($\dot{m}_{PM10}$) of the four sectors surveyed
Tabelle 4 Gesamte ($\dot{m}_{PM}$) und PM10 Emissionen ($\dot{m}_{PM10}$) der vier befragten Industriesektoren

Sector	Wood volume processed (10^3 m^3/a)	$\dot{V}$ (10^3 m^3/h)	$\dot{V}_{out_{A-E}}$ (10^3 m^3/h)	$\dot{m}_{PM}$ (t/a)	$\dot{m}_{PM10}$ [t/a]
Carpentry/timber products	1,334.3	15,670	5,305	57	15
Industrial furniture production	222.2	4,242	1,509	16	2
Joinery/wood products	1,435.7	72,000	15,900	170	46
Transport/pallets)	602	1,489.3	388	14.2	1.13

wood (40% PM10) in joineries. These maximum and minimum factors of emission and the annual processed volume of wood was used to calculate the PM10 emissions of the industry sectors not addressed in the survey. The results of the extrapolation approach I are presented in Table 5. It is important to note that the wide range of data as approximated by approach I reflects an uncertainty which is founded in the model itself. The application of emission factors determined in dust intensive sectors to industry branches that are obviously less dust intensive, but high in processed volume (e.g., sawmill) results in an overestimation of the fine dust loads. Therefore, results of approach I should be considered as best-case and worst-case emission.

In extrapolation approach II, the dust emissions of the sectors not surveyed were estimated on the basis of the mean volume flows determined for each company size category from the questionnaires returned by the surveyed sectors (Table 3). This approach presupposes that volume flow of the extractor systems correlates with company size, a fact that is confirmed by the available data. Within the four sectors surveyed a reasonable correlation of the mean volume flows and the size of the companies was found (Fig. 1). Assuming that this relation reflects the situation in the other sectors of the woodworking industry, the total volume flow of each sector was split based on the relative share of the extractor systems. Subsequently, $\dot{m}_{PM}$ and $\dot{m}_{PM10}$ (see Table 5) were calculated for each sector using Eqs. 1 and 5. Extrapolation approach II takes account of the company size and the filter technology used in the surveyed sectors and permits a rather more refined analysis as a result.

Table 5 compares the results yielded by both extrapolation approaches I and II for each sector. Under worst-case conditions, a maximum fine dust load of approx. 318 t/a can be expected for the wood industry as a whole (extrapolation approach I). For the non-surveyed sectors, the dust emissions clearly correlate with the total volume of processed wood. If company size and the sector-specific evaluation of the survey is taken into consideration, a mean maximum PM10-emission of 110 t/a appears to be more realistic (extrapolation approach II). The minimum value of 42 t/a is identical in both models.

4 Conclusions

The evaluation of the extensive data material collected for this extrapolation demonstrated that plants in the Swiss woodworking industry release annually a maximum of 318 t/a fine dust (PM10) to the environment. More realistic assumptions reduce this emission figure to a maximum of 110 t/a. The higher estimation represents a worst-case approach and equate to approximately 3% of total primary PM10 emissions from industry in Switzerland, whereas the lower value corresponds to

Table 5 Range of PM10 emissions extrapolated by approach I and II
Tabelle 5 Wertebereiche der Staubemissionen aus Berechnung I und II

Wood industry sector	Approach I		Approach II	
	$\dot{m}_{PM10_{15\%}}$ [a] (t/a)	$\dot{m}_{PM10_{40\%}}$ [b] (t/a)	$\dot{m}_{PM10_{15\%}}$ (t/a)	$\dot{m}_{PM10_{40\%}}$ (t/a)
Veneer factory	0.02	0.70	0.03	0.07
Flooring/parquet	0.02	1.04	0.05	0.13
Planing mill	0.24	10.87	0.10	0.27
Wood panel industry	1.25	56.61	0.15	0.25
Pulp and paper	0.61	27.74	0.39	1.03
Sawmill	2.41	108.94	1.21	3.22
Window manufacture	0.30	13.53	2.00	6.00
Transport/pallets	0.63	1.67	0.63	1.67
Industrial furniture production	2.00	6.00	2.00	6.00
Carpentry/timber products	9.00	23.00	9.00	23.00
Joinery/wood products	26.00	68.00	26.00	68.00
Total	42	318	42	110

[a]Calculated with 15% fine dust percentage weight and dust concentration of 1 g/m^3
[b]Calculated with 40% fine dust percentage weight and dust concentration of 47 g/m^3

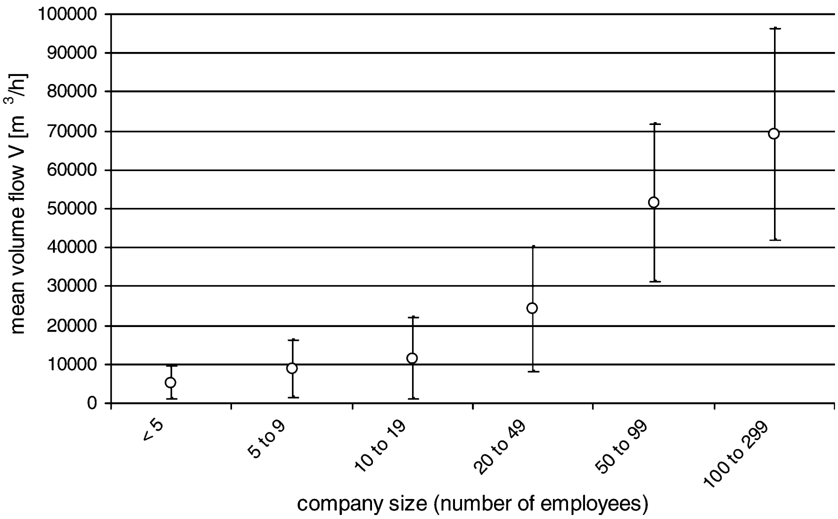


Fig. 1 Relation of mean volume flow and company size
Abb. 1 Zusammenhang zwischen der Betriebsgrösse und dem durchschnittlichen Volumenstrom der Absauganlagen

only 1% of the national industrial emission. Both figures are distinctly lower than the values obtained in previous assessments of the fine dust sources caused by the woodworking industry of 20% (BUWAL 2001b).

Thanks to vast improvements in dust reduction technology over recent decades, emissions of fine dust to the environment have been drastically reduced in all sectors of the woodworking industry. Emissions can presently be considered as low in respect to total annual levels of primary PM10 emissions in Switzerland. There is potential for further improvement in filter systems with old technology or which are no longer fully functional. Moreover, greater effort is required in regards to workplace hygiene, where dust concentrations should be reduced to a minimum.

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