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Occupational exposure to carcinogenic wood dust in two Italian biomass power plants

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In this study we monitored exposure to airborne dust in workers performing various tasks at two biomass-fuelled thermal power plants (27 and 46 MW) over six years. The plants are mainly fuelled by forest wood chips and, to a lesser extent, by agro-food products, with annual consumption of about 300 and 450 kt. We focused on inhalable wood dust because of its potential carcinogenicity to humans. Worker exposure was assessed with personal samplers, drawing ambient air in their breathing zone to determine the real external dose of dust inhaled by the workers and the associated occupational risk. With but a few exceptions, exposure to inhalable wood dust complies to the limit of 2 mg/m³ given by the European Directives 2019/130 and 2017/2398. Further investigations will be necessary to obtain a larger number of measurements that allow for a more robust statistical investigation of the results.

KEY WORDS: air monitoring; personal samplers; occupational health; risk assessment

Biomass heating and power generation plants have recently seen a shift towards large-scale energy production (>50 MW) and are likely to increase in number even further (1). Carbon dioxide emissions per unit of energy produced by these plants are lower than those from plants on fossil fuels and are therefore believed to have lower environmental impact (2, 3).

The most common biofuel for power plants is wood chips remaining from logging operations, approximately 4–5 cm long. Operating a plant with a power exceeding 20 MW, such as those that we evaluated, involves handling and burning large quantities of wood chips, measured in tonnes per hour.

Although the fuel consists of macroscopic wood fragments, there are always fine fractions capable of becoming airborne and affecting the human respiratory system (wood inhalable dust) (4), as these particles may cause allergic respiratory symptoms, mucosal and non-allergic respiratory symptoms, and even cancer (5, 6).

Wood dust to which workers are exposed in processing are considered carcinogenic by the International Agency for Research on Cancer (IARC) (7) and by the European Union (8, 9). Strong and consistent associations with cancers of the paranasal sinuses and nasal cavity have been observed in studies of people whose occupations are associated with wood dust exposure, as well as in studies that directly estimated wood dust exposure (10). Yet, despite the recent growth in the number of biomass power plants and of workers employed in this sector, there are but a few studies of exposure to wood dust in these workplaces (4, 11–13). In particular, we know little about personal exposure of workers (to chemical agents in the air actually inhaled by workers), as environmental/ambient pollution assessments have generally been prioritised, including potential exposure of populations living in the areas near such plants (14–16).

Therefore, the aim of our study was to assess exposure to airborne wood dust in workers operating in two biomass plants with a capacity exceeding 20 MW using personal samplers to assess the actual external dose, the parameter objectively associated with health risk. We also wanted to see if this risk could be a limiting factor for the development of biomass power plants as an environmentally more acceptable alternative to fossil-fuel-based plants (3, 17).

MATERIALS AND METHODS

Our longitudinal study included two biomass power plants, monitored over approximately six years. The two plants are located in low-urbanisation areas near the sea coast and employed a total of 75 workers at the time of the study. The 27 MW plant uses a stoker boiler to burn wood chips, while the 46 MW plant uses a fluidised bed boiler. Combustion temperature inside these boilers is 500–600 °C. Wood chips used to fuel them are residues from logging operations and include both deciduous and coniferous wood from local and distant points of origin. Their calorific value is around 2000 kcal/kg. Their moisture can vary between batches and the highest tolerated is 50 % of mass. The content of the finest fuel fractions (fragments smaller than 1 mm) cannot be higher than 5 % of mass. These limits are set to reduce the amount of and therefore exposure to wood dust.

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The total annual biomass consumption of the two plants is around 700,000 t. The fuel is delivered to the plants by lorries and unloaded in large open areas called *wood parks*, where it is compacted by mechanical shovels and excavators into large heaps. Each wood park covers about 30,000 m² (Figure 1). Quality control is done on samples taken manually and subjected to thermal-physical analysis and visual inspection.

From the wood park, the fuel is transported by mechanical shovels to the loading hoppers of the combustion plant. From there it is transferred to the furnace by screw conveyors and belts, passing through a series of mechanical sieves to exclude any abnormally large chips. The power production cycle is illustrated in Figure 2.

Solid combustion residues (bottom ash) accumulate in the boiler sub-grid and are discharged directly into two pits, from which they are removed by mechanical shovel to be loaded onto trucks and sent for disposal. The combustion gases are treated with cyclone scrubbers and dry filters to eliminate fine unburned particulate matter (fly ash) from the gaseous flow leaving the plant. The fly ash is collected in special silos and periodically loaded onto trucks for disposal.

All tasks that may involve workers' exposure to wood dust are carried out in the open (outdoor environment). Mechanical shovels and trucks used for handling wood chips are equipped with a pressurised operator cabin with forced entry of filtered and conditioned air. In addition, special mobile water spray cannons are used to settle the dust released from the wood chips stored in the wood parks. The loading hoppers, in turn, are equipped with a water spray system that is automatically activated as the wood chips are being loaded. Where technically feasible, outdoor areas are cleaned by suction.

All workers entering the wood park or areas with potential airborne wood dust must wear respirator masks compliant with the European norm 149:2001+A1:2009 (18). Workers involved in cleaning operations and fuel sampling are required to wear half-face dust masks.

Sampling and analysis

To measure the airborne wood dust, ambient air was sampled using battery-powered personal air sampling pumps (GilAir Plus

Figure 1 Biomass power plant and wood chips stored at the wood park

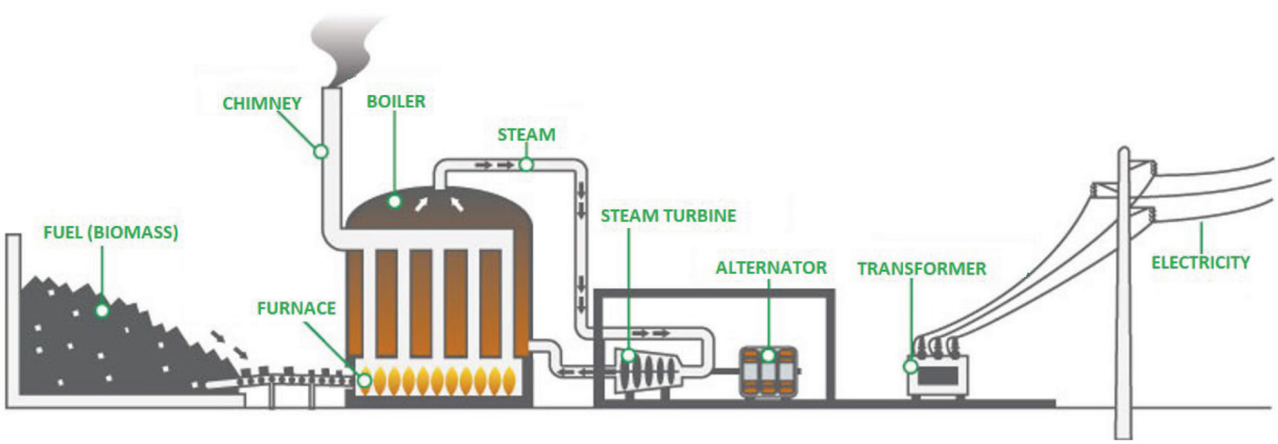

Figure 2 Biomass power plant: production cycle diagram

and Gilian 5000, Sensidyne, St. Petersburg, FL, USA) following the European norm 13137:2022 (19).

Each pump was equipped with a sampling head consisting of a 37 mm Teflon filter membrane with a pore size of 5 μm, housed in a steel filter holder with a protective cone.

Samples were collected at a flow rate of 3 L/min to ensure that only the inhalable fraction of airborne dust is captured, as defined by the European norm 481:1993 (20). The flow rate of each pump was checked at the beginning and the end of each sampling using an optical bubble flow meter (DryCal® DC-Lite, Bios International, Butler, NJ, USA). After sampling, the filter membranes were kept at 50 % relative humidity and 20 °C and weighed on a precision scale (Sartorius ME5 Micro Balance, Sartorius AG, Gottingen, Germany), as was done before the sampling. The sampling and analysis method followed the standard procedure issued by the Italian Certification Committee UNICHIM (21).

Considering that both plants have clearly separated operation areas, it was possible to limit the assessment of ambient exposure to wood dust to the pre-combustion areas of operation. Five operations (types of workers) with potential exposure to inhalable wood dust were identified: 1) heap forming (moving wood chips unloaded from trucks in the wood park using a mechanical shovel); 2) feeding the combustion plant (transporting the fuel from the wood park to the loading hoppers using a truck or mechanical shovel); 3) fuel sampling (manually collecting random samples from each batch in the wood park for quality control in the lab); 4) supervision by general services officer (supervising fuel handling and management of the wood park, alternating between outdoor and office tasks); and 5) cleaning and sweeping (cleaning the wood park and outdoor premises using both vacuum and manual equipment).

There are 15–20 workers assigned to these tasks in each of the two plants, making up slightly less than half of all workforce. About 75 % of these workers perform tasks 1 (heap forming) and 2 (feeding the combustion plant).

All workers wore personal samplers described above, drawing ambient air in the workers' breathing zone (near the face). Samples were collected for at least 50 % of the work shift to average out all potential variations in exposure.

Based on the analysis of tasks and duties carried out before the investigations and on the observation of actual working conditions carried out during the investigations, it is possible to state that the employee's exposure over the period not sampled is equivalent to that over the period sampled. Measurements obtained in this way accurately represent average exposure over the entire work shift (reference period) for comparison with regulatory limits (22, 23).

In addition, environmental wood dust concentrations were measured with static sampling stations positioned at several points of the pre-combustion areas. The same sampling and analysis method was adopted for static sampling, including the instrumentation and materials used, positioning the samplers on special supports (290 Xtra Aluminium 3-Section Tripod, Manfrotto Spa, Vicenza, Italy) at a height of approximately 1.5 m above ground, corresponding to the height of the nose/mouth of workers in upright position. Samples were collected on the same days as personal sampling. Sampling time was approximately 6 h.

Comparison with the EU OEL reference limit for occupational exposure to wood dust

The European Union has recently lowered the occupational exposure limit (OEL) for hardwood (deciduous wood) dust from 3 mg/m³ to 2 mg/m³ (4). This limit applies to the inhalable fraction of airborne dust and includes all wood dust in the mixture, even if it contains softwood (coniferous wood). As defined by the European Committee for Standardization (CEN) (20), inhalable dust refers to particles "that can be breathed into the nose or mouth". This classification is determined by particle size of up to 100 μm in diameter (about the width of a human hair). The limit of 2 mg/m³ refers to the entire work shift, that is, to the average exposure of each worker weighted over the entire eight-hour work shift.

Data processing and statistical analysis

Considering the spatial and temporal variability of ambient wood dust concentrations between workplaces (areas of operation), static sampling is generally not representative of worker exposure, which is why we evaluated personal sampler measurements separately from those obtained with static samplers. The first were used to compare them with regulatory limits and to assess the risk of worker exposure, while the latter were used to evaluate environmental pollution in the pre-combustion areas and dust dispersion (distribution) during various fuel handling operations.

To compare our results with regulatory limits, personal sampler data were processed using the statistical procedure recommended by the Institut National de Recherche et de Sécurité (INRS) (22) and adopted by the European norm 689:2018 (23). This procedure requires the calculation of geometric distribution parameters, geometric mean (GM), and geometric standard deviation (GSD), which, together with the logarithm of the exposure limit (OEL), allow for the calculation of the U_R variable using the following formula:

$$U_R = \frac{\ln(OEL) - \ln(GM)}{\ln(GSD)}$$

where U_R is the probability of exceeding the exposure limit, accounting for uncertainties within a 70 % confidence interval. U_R is compared to the threshold value of the variable U, named U_T, which depends on the number of measurements (22, 23). If U_R is greater than U_T, then the exposure limit is respected with a 95 % probability.

However, the application of this procedure to verify compliance with the exposure limit requires a preliminary check on the homogeneity of work exposures used for the test. To this end, we employed qualitative analysis of the homogeneity of the operational tasks performed by the workers, verification that the measured exposures follow a log-normal distribution using the Shapiro-Wilk test, and verification of the linearity of the probability curve of the measured exposures. The verification of compliance with the exposure limit was carried out separately for each of the tasks. The probability curve was constructed and evaluated according to CEN standard EN 689:2018+AC:2019 Annex E (23).

Comparisons between measurements for different tasks and survey years were carried out using one-way ANOVA (multi-group comparison) analysis applied to log-transformed data, while the measurements from the two monitored plants were compared with the Student's *t*-test applied to log-transformed data. Additionally, multiple linear regression was performed to evaluate differences between tasks, monitoring years, or plants while controlling for the other two factors.

All statistical analyses were run on SigmaStat software version 4.0 (Grafiti LLC, Palo Alto, CA, USA).

RESULTS AND DISCUSSION

A total of 56 samples were collected with personal samplers worn by workers of both plants over the six-year monitoring. Table 1 and Figure 3 show the results obtained with personal samplers worn by workers operating at the pre-combustion sections of the two plants, grouped by tasks. In addition, Table 1 provides comparison with the EU OEL reference limit for occupational exposure to wood dust for each task.

With the exception of task 4 (supervisor), the results show a high GSD, especially those related to task 1 (heap forming). Although GSD greater than 3 may indicate excessive heterogeneity among the workers in the group (22), the CEN EN 689 standard (23) indicates that a group of workers is homogeneous if the analysis of the jobs does not show significant differences between them and the distribution of the results is log-normal. We considered the statistical procedure for comparison with the limit applicable to tasks 1, 2, 3, and 5 but not to task 4, whose measurements do not follow log-normal distribution.

High GSD values within different tasks are probably related to outdoor work, where air movement is not controlled, and to the variability in dust concentrations between batches as a function of humidity. High GSD values within different tasks can also be a consequence of long monitoring. However, long-term monitoring should provide more reliable results.

Two tasks exceeded the limit of 2 mg/m^3, fuel sampling and sweeping/cleaning, and failed to comply with the EN 689 limit. However, the average exposure was below the limit for both of these tasks. The reason for higher exposure with these tasks may be that they are performed out in the open, unlike heap forming and combustion plant feeding, which are performed inside the pressurised cabins of the fuel handling machines. Therefore, the protection of workers working in the open relies on the use of personal protective equipment (dust masks).

Even though the compliance test could not be applied to supervision (performed by the general services officer) where the number of collected samples was low and log-normal data distribution was rejected, the results for workers performing this task are well below the 2 mg/m^3 limit, most likely because it involves outdoor and indoor activities.

The differences in exposure levels between fuel sampling or cleaning/sweeping and the other tasks are statistically significant, based on the results of the one-way ANOVA ($p<0.001$) of log-transformed data.

Table 1 Occupational exposure to wood dust in mg/m^3 measured with personal samplers and grouped by work task

	Task 1	Task 2	Task 3	Task 4	Task 5
	Heap forming	**Combustion plant feeding**	**Fuel sampling**	**Supervision**	**Cleaning / sweeping**
Samples (N)	19	9	11	7	10
Geometric mean (GM)	0.171	0.130	0.604	0.192	0.904
Geometric standard deviation (GSD)	3.64	2.97	2.64	1.51	2.63
Arithmetic mean (M)	0.368	0.204	1.051	0.207	1.421
Standard deviation (SD)	0.467	0.183	1.588	0.086	1.734
Maximum	1.536	0.557	5.707	0.319	6.133
Minimum	0.018	0.024	0.207	0.128	0.172
Interquartile range (Q3–Q1)	0.309	0.299	0.694	0.162	1.132
Normality test**	0.197 passed	0.600 passed	0.201 passed	0.047 failed	0.856 passed
Probability (U_R)	1.90	2.51	1.23	(*)	0.81
Compliance test ($U_R>U_T$)	Passed	Passed	Failed	(*)	Failed

* The test cannot be applied because the data does not follow log-normal distribution. It needs to be verified with a larger sample size. ** Shapiro-Wilk test on log-transformed data

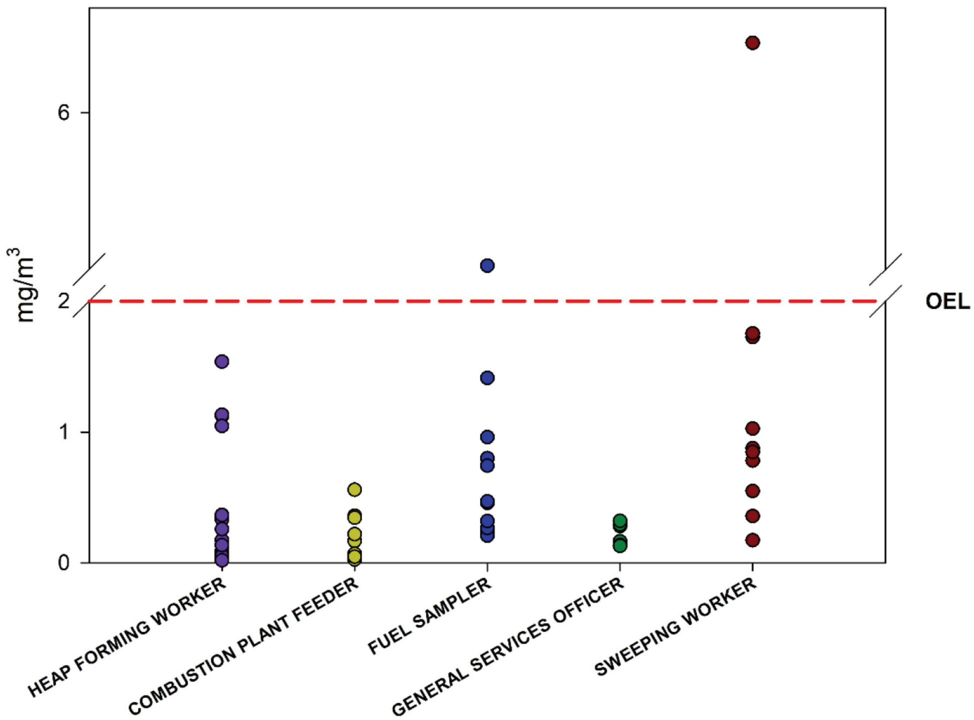

Figure 3 Occupational exposure to wood dust measured with personal samplers and grouped by specific work tasks

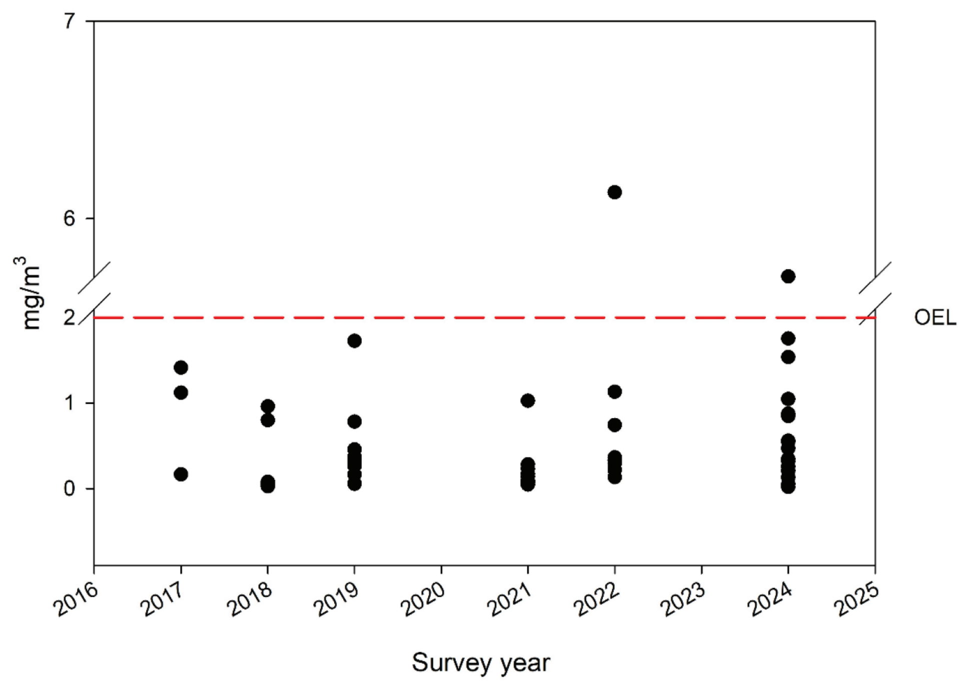

Figure 4 Occupational exposure to wood dust measured with personal samplers by survey year

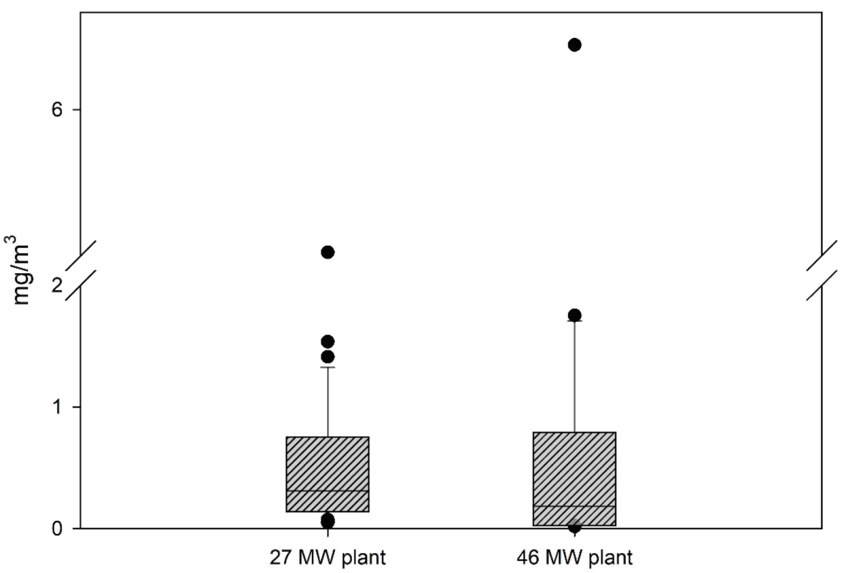

Figure 5 Occupational exposure to wood dust measured with personal samplers by plant

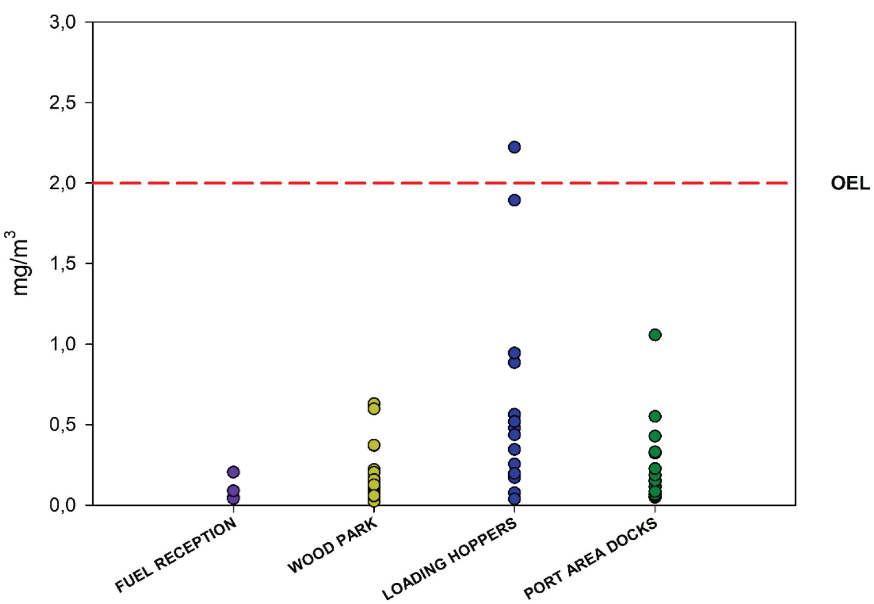

Figure 6 Wood dust dispersion in ambient air (mg/m^3) at different operational areas of the biomass power plants measured with static samplers

Table 2 Wood dust levels in ambient air (mg/m^3) measured at different operational areas with static samplers

	Fuel reception	Wood park	Loading hoppers of the combustion plant	Port area (loading and unloading dock)
Samples (N)	7	20	17	22
Geometric mean (GM)	0.061	0.126	0.362	0.131
Geometric standard deviation (SD)	1.81	2.45	2.89	2.38
Arithmetic mean (M)	0.073	0.185	0.585	0.201
Standard deviation (SD)	0.060	0.175	0.614	0.234
Maximum	0.204	0.629	2.222	1.056
Minimum	0.040	0.023	0.037	0.047
Interquartile range (Q3–Q1)	0.044	0.153	0.543	0.186

Figure 4 shows the 56 readings of personal samplers by year of monitoring. Our one-way ANOVA test on log-transformed data found no statistically significant differences between the years (p=0.102), which suggests that exposure conditions were quite uniform and that variations in climatic conditions and plant operations did not significantly affect exposure levels over the years.

Figure 5 compares the results obtained by personal samplers between the two plants. Using the two-tailed Student's *t*-test on log-transformed data, we found no statistically significant difference between them (p=0.182), which indicates comparable exposure.

A multiple linear regression analysis considering all the three factors studied (tasks, monitoring years, plants) also shows that the differences between plants and monitoring years are insignificant (p=0.526 for monitoring years and p=0.129 for plants).

As for static measurements in different operational areas of the two monitored plants, Table 2 shows that the area with the highest airborne dust levels was the fuel loading hopper of the combustion plant. Fortunately, workers are not directly exposed there, as the loading operation is carried out by mechanical devices operated from inside a pressurised cabin.

CONCLUSIONS

Our findings show that, in general, the exposure of workers handling wood chips at the two biomass plants kept within the EU limit of 2 mg/m^3 and was therefore within the acceptable health risk. For fuel sampling and cleaning/sweeping, however, we could not establish compliance with sufficient reliability, but those that are compliant involve about 75 % of the workforce handling wood chips.

Workers engaged in the two outdoor tasks with higher exposure risk (fuel sampling and cleaning/sweeping), where wood dust levels may exceed the limit, can be adequately protected by personal protective equipment (dust masks).

Considering that wood dust is potentially carcinogenic, we recommend to keep exposure regularly monitored with personal samplers. It is also desirable to introduce changes to operating procedures for fuel sampling and cleaning/sweeping in order to achieve full compliance with the 2 mg/m^3.

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Profesionalna izloženost kancerogenoj drvnoj prašini u dvjema talijanskim termoelektranama na biomasu

U ovom smo istraživanju šest godina pratili izloženost lebdećim česticama drvne prašine u radnika na različitim poslovima u dvjema termoelektranama na biomasu snage 27 odnosno 46 MW. U objema se termoelektranama mahom za gorivo rabi mljeveno drvo te u manjoj mjeri otpadni poljoprivredno-prehrambeni proizvodi, a godišnja potrošnja doseže oko 300 odnosno 450 kt. Istraživanje se ograničilo na lebdeće drvne čestice koje mogu biti kancerogene za ljude. Izloženost radnika mjerena je osobnim skupljačima zraka u razini disanja ne bi li se utvrdila stvarna doza udahnute prašine i s njom povezani profesionalni rizik. Uz tek nekoliko iznimaka, izloženost drvnoj prašini bila je u skladu s graničnom vrijednosti od 2 mg/m³ propisanom europskim direktivama 2019/130 i 2017/2398. Potrebna su daljnja istraživanja s većim brojem mjerenja, koja bi omogućila robusniju statističku analizu.

KLJUČNE RIJEČI: higijena rada; osobni skupljači uzoraka; praćenje kakvoće zraka; procjena rizika