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Chapter

Occupational Health Issue in a 2G Bioethanol Production Plant

Biancamaria Pietrangeli and Roberto Lauri

Abstract

The interest of scientists and health authorities in occupational risk related to biofuels production has recently increased due to the development of agro-industrial waste recycling processes in the framework of the European circular economy strategy and energy production from renewable sources. A common biofuel is the bioethanol, which is a leading candidate to substitute the gasoline as a transport fuel and it can be produced via biomass fermentation process. In biofuels production plants, some work activities in processing of biomass, are sources of airborne dust and the employers should demonstrate that adequate control measures have been implemented in order to prevent workers exposure. In the chapter, the production process of a 2G bioethanol plant has been analyzed in order to specify the process phases, which could generate occupational health issue related to airborne dust, and to provide technical recommendations.

Keywords: occupational health, bioethanol, biomass, airborne dust, bioaerosol

1. Introduction

In the European Union (EU), the original renewable energy directive 2009/28/EC establishes an overall policy for the production and promotion of energy from renewable sources. It requires to fulfill at least 20% of total energy needs by renewables within 2020. All EU countries must also ensure that at least 10% of their transport fuels comes from renewable sources within 2020 [1]. In December 2018, the revised renewable energy directive 2018/2001/EU came into force with a specific target for 2030: at least a 32% share of renewable energy consumption has to be achieved [2]. From an energy point of view, lignocellulosic biomass is increasingly recognized as a valuable resource, since it is an alternative to petroleum for the production of biofuels and chemicals. The first generation biofuels, such as agricultural bioethanol made from oilseed crops, have helped reduce greenhouse gases (GHG) emissions, but they also have a negative impact on water and soils, as well as competing for land used by food crops. By the year 2013, EU strategy was re-oriented towards "advanced" biofuels, made from waste or agricultural and forestry residues (second generation) or algae (third generation). In this context, bioethanol is one of the most important biofuels, which can be produced by fermentative processes of biomass, and therefore it is a leading candidate to substitute the gasoline as a transport fuel. A new approach involving the use of marginal land (i.e. land that is not suitable for food crop production or contaminated site) for the production of crops

for biofuels industry is pursued in Italy and in many other countries, where the demand for high quality water resources, arable land, food and fossil fuels is rapidly growing. *Arundo donax* was selected as a potential crop for use in these areas, since it produces more cellulosic biomass and traps more contaminants, using less land and pesticides than any other alternative crops reported in the literature [3]. The direct job creation from advanced biofuels production is expected to grow in the future. Green jobs are activities characterized by previously evaluated risks, but with a different scope and exposition in connection with newly applied technology and therefore it is strategic and important to complete the risks assessment process with respect to new or emergent risks. An inclusive sustainability assessment of bioethanol production alternatives should incorporate the occupational health and safety (OH&S) assessment and it is necessary to integrate health and safety issues at an early stages of development of the industrial process in order to define tailored mitigation measures at full scale plant [4].

2. OH&S issue of bioethanol production from biomass

OH&S risks assessment in the biorefinery industry is a systematic examination of all aspects of the work undertaken to consider what could cause injury or harm, the possible hazards elimination, and, if not, which preventive or protective measures can be adopted to decrease the risk level [5]. In the biofuels production, some work activities, such as handling, storage and processing of biomass, are sources of organic dust (bioaerosol). The interest of scientific community and health authorities in bioaerosols has recently increased due to the development of waste recycling processes in the framework of circular economy, considering the wide range of adverse health outcomes associated with exposure to bioaerosol in workplaces. These include infections, immuno-allergic, non-allergic inflammatory and toxic effects [6–10]. Bioaerosol consist of live and dead micro-organisms either as individual micro-organisms or as aggregates, fragments and micro-organisms products, such as bacterial endotoxins, β (1–3)-D glucans and mycotoxins. All these biological agents can also be carried by other particles [11]. The viability of microorganisms is less important for effects, such as chronic bronchitis, asthma, toxic pneumonitis, hypersensitivity pneumonitis and lung function decline, as these effects can also depend on the exposure to non-viable microorganisms [12]. In agriculture, similar exposures to bioaerosol containing animal, plants, microbial components, can cause severe respiratory diseases, such as organic dust toxic syndrome or allergic alveolitis (e.g., farmers lung) [13–18]. Some technical surveys and occupational hygiene measurements at different biomass power plants showed that the occupationally harmful process steps were unloading, screening, crushing, conveying of fuels and the handling of biomass in silos. Unloading produced a great amount of organic dust, which spreads to the working stations. The main occupational exposure-associated health risks for workers were bacteria and fungi, which easily spread over the air during biomass processing [19]. The measured levels of exposure to bioaerosols were especially high during the unloading of peat and wood chips. Furthermore, biomass has also a tendency to decompose, creating exposure scenarios, that should be managed to minimize both microbial growth (e.g., spore formation, endotoxin release, etc.) and off-gassing of volatile organics or other gases (e.g., carbon monoxide). Besides the mechanical irritation caused by organic dust, the workers could also be exposed to chemical irritation caused by volatile organic compounds, such as terpenes emitted into the air in the gaseous phase during the outdoor storage of agriculture residues [20]. Hexanal from fatty acids oxidation is also emitted during

the storage of solid wood fuels [21]. Multiple exposures to biological and chemical agents may simultaneously have synergistic health effects on workers lower and upper respiratory tracts [22]. Some Authors reviewed the available literature on OH&S issues associated with biomass-based power generation, considering the potential exposure scenarios and providing indications of hazards, which should be considered in the context of protecting the worker health through the development of monitoring and control plans [23]. A case-study facility for the production of second generation (2G) bioethanol has been considered in order to study some workers health issues. The study has been focused on occupational hazard related to workers exposure to airborne dust occurring during storage and processing of biomass, and on the preventive and protective measures aimed at controlling the exposure levels in the examined plant.

3. The case study: the bioethanol production plant

The case study has been focused on an Italian industrial plant (**Figure 1**), that produces bioethanol via fermentation of non-food biomass, based on a mix of available agricultural waste (bagasse of sugar cane, rice or wheat straw) and energy crops, such as *Arundo donax*, *Miscanthus spp, Panicum virgatum,* available from local supply chain (within a distance, which ranges between 40 km and 70 km). According to the provisions of the Directive 2009/28/EU [1], the production of 2G bioethanol from *Arundo donax* or from the residual of the corn and rice harvest is able to decrease the GHG emissions of over 80 percentage points compared to conventional processes for the production of petrol oil. On the contrary, the first generation bioethanol allows a reduction of only 22%. Furthermore, *Arundo donax* grows on marginal soils, requires a low consumption of water, fertilizers and territory, due to the high yield per hectare [24]. The 2G bioethanol plant, examined in the case study, allows the production of low cost sugars, which can be the platform of an industrial biorefinery aimed at producing a wide range of



Figure 1.
The bioethanol production plant.

intermediate chemicals from fine to bulk chemicals. The biorefinery was built on a decommissioned industrial site of about 15 hectares located in a rural area. The main quantitative data are:

- biomass storage hall capacity = 10,000 tons;
- bioethanol production capacity = 40,000 tons/year;
- electric energy production (the installed power is equal to 13 MW);
- water recycling = 100%.

Arundo donax (wet, about 60% humidity) and wheat straw (dry, about 10% humidity) are used to produce the biofuel. Arundo is shredded on the field and fed to the plant within a few days. As the straw is dry, it can be stored for longer periods without degrading and for this reason it can be used as an emergency biomass in case of Arundo lack. Biogas and lignin are the processing waste. The biogas is used to feed three boilers for the production of technological steam, while lignin is used to feed a larger boiler, which generates steam for the electric energy production, so that the plant operates in total autonomy.

The bioethanol production process is based on the following steps:

1. Pre-treatment. The pre-treatment is aimed at breaking down the structural components of the lignocellulosic matrix, separating the main polymeric components and making them accessible to the enzymatic hydrolysis in the following step. The pre-treatment minimizes the formation of biomass degradation products, such as furfural or hydroxymethylfurfural (5-HMF), which act as inhibitors of the fermentation process.

2. Enzymatic hydrolysis. The enzymatic hydrolysis is carried out by a mixture of cellulolytic enzymes (endocellulase, exocellulase and glycosidase), which allow to obtain hexoses, such as glucose, while the fraction composed by hemicellulose is split into a mixture of pentose sugars, in which xylose and arabinose are the most abundant components.

3. Fermentation. This step is performed by a selected strain of *Saccharomyces cerevisiae*, which is able to utilize all the monomeric sugars in order to achieve high yields of bioethanol.

4. Distillation. Bioethanol is separated from the residue of the fermentation broth in the distillation columns. The ethanol stream is successively subjected to a dehydration phase, which allows to obtain a 99% pure product.

4. Biomass storage and processing in the bioethanol facility

In the case study facility, biomass is stored in a covered shed with side movable gates. The storage area is about 20,000 square meters and is composed by two distinct areas:

1. zone for storage of the fresh biomass (e.g., *Arundo donax*, wood chips);

2. zone for storage of the dry biomass (straw).

In the storage hall, there are belt-conveyors, which move the biomass to the thermoelectric power plant and to the pre-treatment area. During biomass unloading, the gates are opened in order to limit the worker exposure to dust. In this working area, the cleaning practices are planned by the use of industrial sweepers (**Figure 2**) provided with dust control, which are suitable for use in areas, where explosive atmospheres could occur. Cleaning practices by compressed air are strictly forbidden. The cleaning operations are daily for the storage area floor and weekly for the equipment.

In the biomass hall, the daily work activities are the reception of the biomass (straw, arundo, wood chip) and its storage. The straw bales are unloaded and placed in a specifically signed area in one step by a forklift provided with the closed cabin (**Figure 3**). This procedure minimizes the bales moving and therefore the workers exposure to dust is strongly reduced. For the other biomasses, after unloading,



Figure 2.
Cleaning operation of the straw storage hall.



Figure 3.
Forklift used to transfer the straw bales.

the storage operations take place in automatic way. The worker operates, in remote control, cochleas and belt-conveyors, which transfer the biomass to three storage vessels and to the pre-treatment area.

In case of straw utilization, the straw bales are taken from the storage area and placed on the belt-conveyor of the grinding plant. The worker monitors the straw plant operation from the control room and therefore no manual operation is carried out by the employees. The specific worker task consists in ensuring the correct transport of the biomass from storage vessels and/or from straw plant to the boiler or to pre-treatment step. Inspections are planned along the walkways adjacent to the belt-conveyor. Considering that some areas of the storage hall are classified as Atex

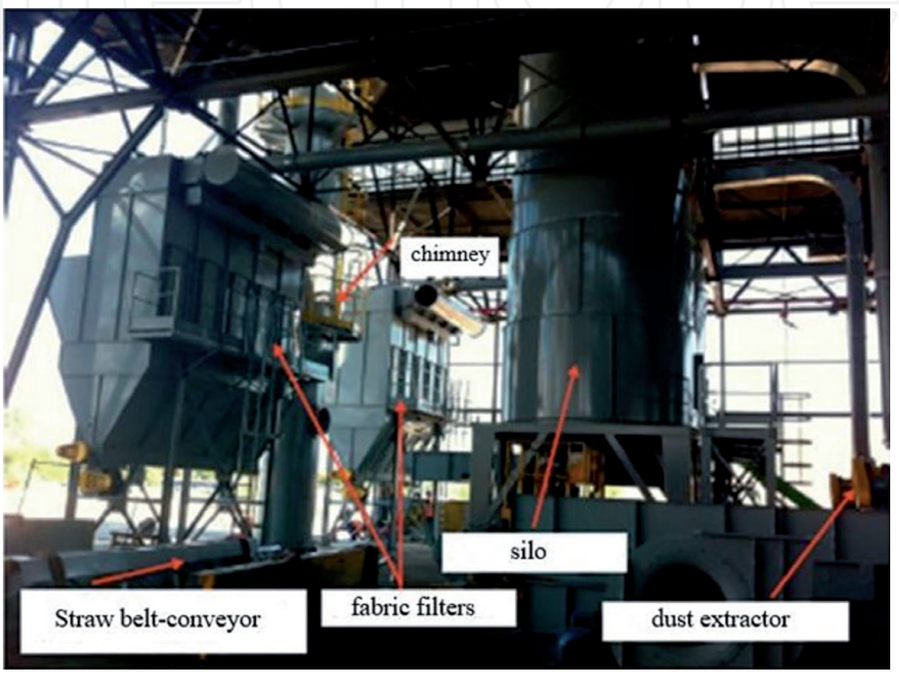


Figure 4.
Straw feeding plant.

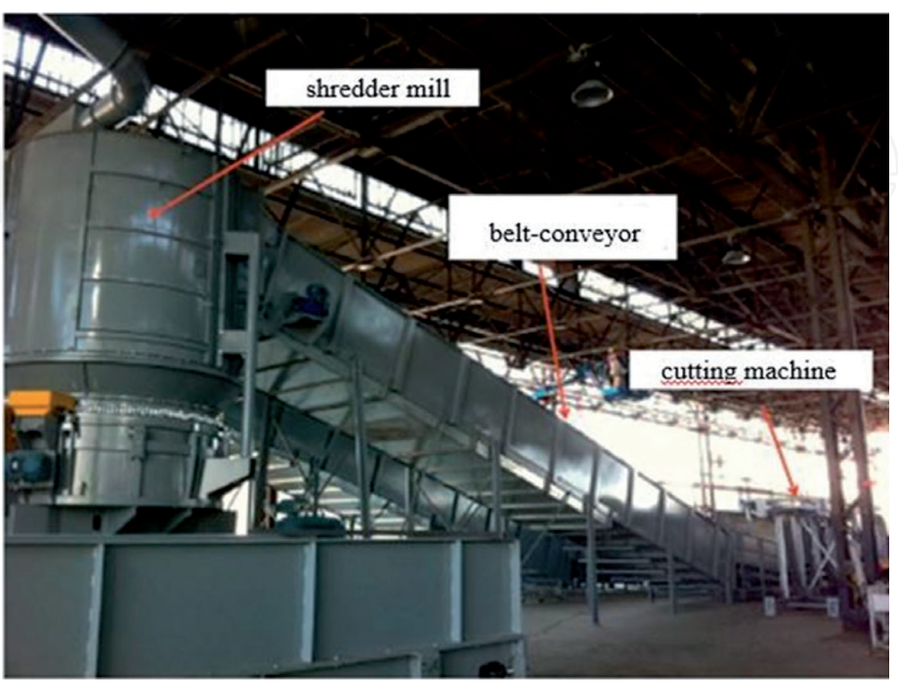


Figure 5.
Straw feeding plant: Shredder mill.

zones, the entire surface is protected by an automatic fire-fighting system, which is activated by temperature-sensitive strips placed on the ceiling and there are also wheeled fire extinguishers (their mass is equal to 30 kg) and an adequate number of portable fire extinguishers (their mass is equal to 6 kg). The biomass is successively transferred, through a second belt-conveyor, to a completely enclosed shredder mill aimed at suppressing the dust release. The mill cuts the biomass into small fragments, which are more suitable for the next fermentation step. The shredded biomass is successively moved to a silo by pneumatic transport system. Two magnets remove any small metal fragment, while a trap collects the heavy solid parts, such as stones, etc. The air is moved to a fabric filter, which traps the dust, before ejecting the air into the atmosphere through the chimney. The process activities are continuous and fully automated without the operator performing manual operations (**Figures 4** and **5**).

5. Dust control strategy in the bioethanol production plant

In the bioethanol production plant, some process steps, such as unloading, storage and processing of the biomass, represent sources of risks for workers health, because they generate releases of airborne dusts in the work environment. In particular, the workers exposure to organic dust is associated with a wide range of health effects. Indeed, respiratory symptoms and lung function impairment are the most important health outcomes. In the facility, the plant design, the equipment and working methods have been implemented for limiting the workers exposure to airborne dust by containment/isolation principle. In addition, as part of dust control strategies, a dust monitoring program has been performed by the company in different working areas of the plant in order to assess the effectiveness of the adopted containment and control measures, but no specific measurement of the components of the organic dust has been carried out. The airborne dust sampling (twenty-two monitoring points) was conducted twice year (2016) in nine plant working areas, where the occupational exposure could be relevant:

1. the biomass storage areas (six monitoring points);

2. the biomass pre-treatment area (one point);

3. the power plant area (four points);

4. the lignin centrifugation area (two points);

5. the fermentation area (one point);

6. wood chipping process (two points);

7. the production control room (one point);

8. lab (one point).

9. offices areas (four points).

In **Figure 6**, the working areas of the airborne dust monitoring plan are reported. The dust sampling performed by the company in different working areas has been both static and personal. The area sampling provides a concentration, that reflects the general dust concentration in a defined area, while personal

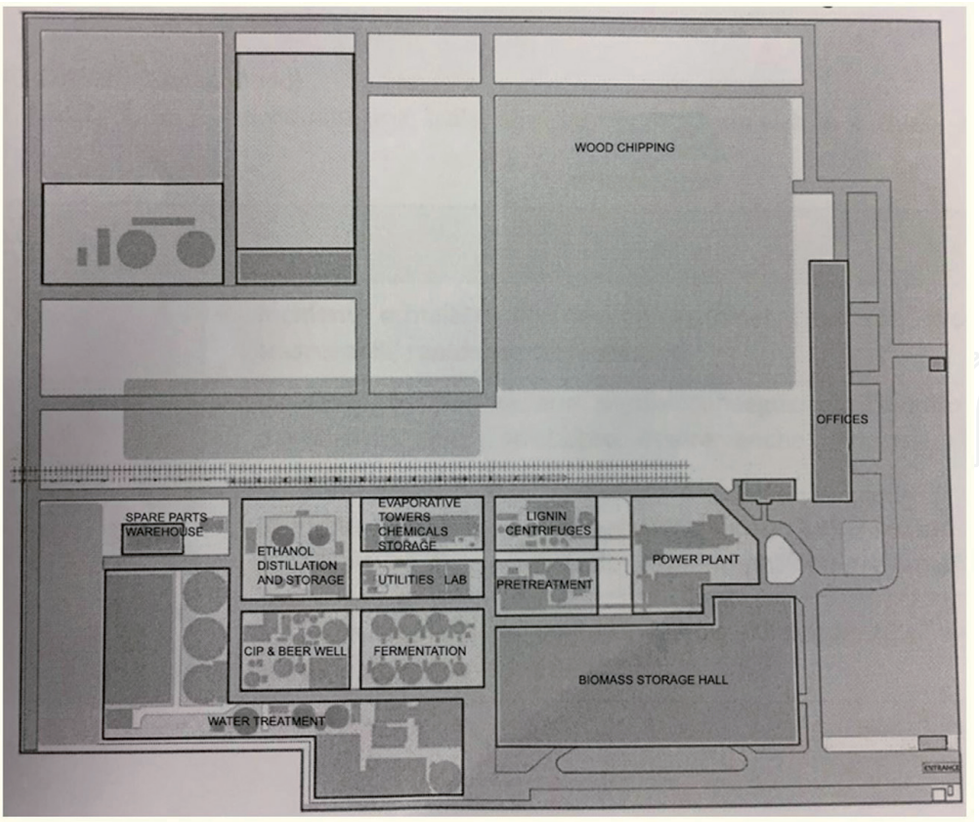


Figure 6.
The working areas of the airborne dust monitoring plan.

sampling provides a concentration measurement of airborne dust to which an individual is exposed. The airborne dust has been measured as the inhalable (or total dust) and respirable dust fraction, where the inhalable aerosol is the mass fraction of particles, which can be inhaled into the nose or mouth, and the respirable aerosol is the mass fraction of particles that may reach the alveoli in case of inhalation. Today, the American Conference of Governmental Industrial Hygienists (ACGIH) recommends TLVs guidance values equal to 10 mg/m^3 inhalable and 3 mg/m^3 respirable for insoluble or poorly soluble particles not otherwise specified (PNOS). The dust limits are based on personal exposure for a standard shift of eight consecutive hours and calculated as a time-weighted (TLV-TWA) average [25]. The inhalable and respirable dust fractions were determined by gravimetric methods of sampling and analysis, which are commonly used to measure quantities of airborne particulate matter collected from workplace atmospheres. The gravimetric dust sampler provides the time-weighted average concentration of dust. As the samplers determine the respirable dust, they are provided with a Dorr-Oliver cyclone, which separates respirable and oversize dust. The filters have been pre and post-weighted to determine the dust mass and to calculate the mean of dust concentration over sampling period [26, 27].

6. Airborne dust monitoring: results and discussion

Analysis of the results of airborne dust monitoring in twenty-two different working areas of the bioethanol production plant, shows that dust concentration, with regard to inhalable and respirable fractions, in all monitored stations is below the ACGIH guidance values. **Figures 7–9** show the results of airborne dust

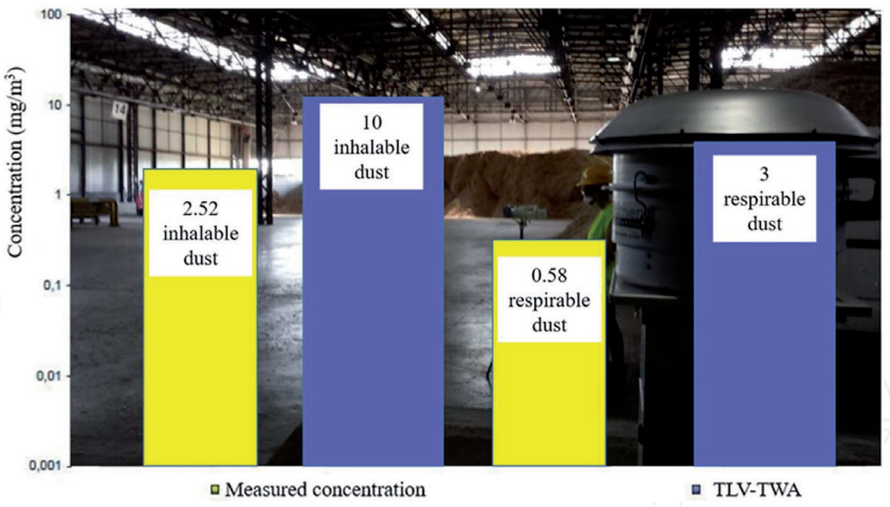


Figure 7.
Biomass storage hall: airborne dust monitoring results (static sampling).

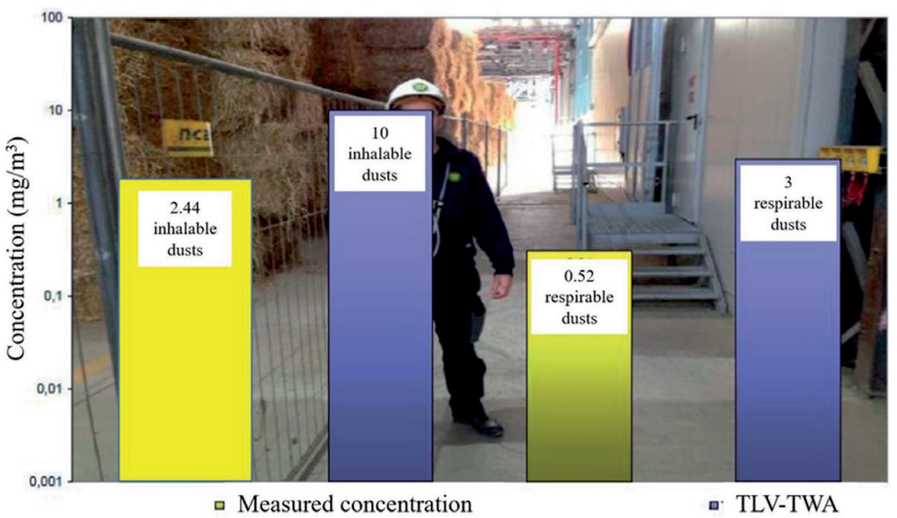


Figure 8.
Straw bales storage area: airborne dust monitoring results.

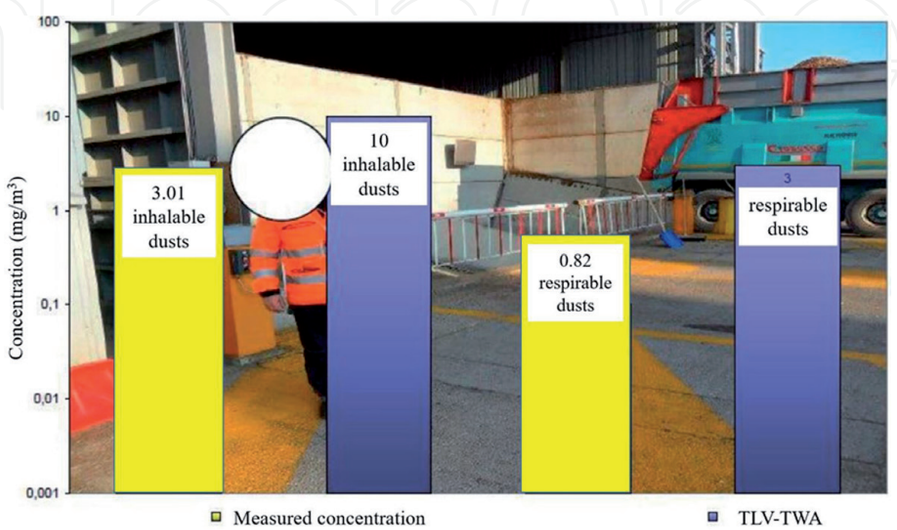


Figure 9.
Wood chips unloading area: airborne dust monitoring results (personal sampling).

concentrations in the working stations characterized by higher dust production. These areas respectively are the biomass storage hall, the straw bales storage area and wood chips unloading area. The concentrations have been compared with the ACGIH guidance values (TLV-TWA). The highest dust concentrations were found during the personal sampling (September 2016) carried out at the wood chips unloading area and were equal to 3.01 mg/m^3 for inhalable dust and 0.82 mg/m^3 for the respirable fraction (**Figure 9**). At the straw storage area, the personal sampling dust concentrations were equal to 2.44 mg/m^3 for inhalable dust and 0.52 mg/m^3 for the respirable fraction (**Figure 8**). In comparison, in the adjacent control room of the storage area, the exposure values were equal to 0.49 mg/m^3 for the inhalable fraction and 0.12 mg/m^3 for the respirable fraction. Another area exposed to dust production risk is that of the wood chipping process, which was characterized by measured exposure values equal to 2.59 mg/m^3 for inhalable dust and 1.98 mg/m^3 for respirable dust.

In order to provide a better assessment of workers exposure, the composition of the organic dust (bioaerosol) and its content of specific biological agents and/or their part or products, should be evaluated. In the examined plant, no specific measurement of the components of the organic dust has been carried out. The bioaerosol characterization is extremely complex and the prior knowledge of likely agents and their risk levels are required. Indeed, the bioaerosol may consists of live and dead microorganisms, either as individual microorganisms or as aggregates, fragments and microorganisms products, such as bacterial endotoxins, β (1–3)-D glucans and mycotoxins [28]. It follows that the measurement and interpretation of bioaerosol concentrations data are difficult. For example, the grain dust may contain fragments from grain, husk and straw, soil particles, pollen, bacterial spores and cells, fungal spores and hyphae, fragments and feces of mites and insects, microbial components such as endotoxins, glucans, peptidoglycans, mycotoxins, antigens, and allergens [29]. In agriculture, similar exposures to bioaerosol represent a major risk associated with severe respiratory diseases, such as organic dust toxic syndrome or allergic alveolitis (e.g., farmers lung) [13–18], but actually it is not clear which specific bioaerosol components primarily account for the observed health effects. In addition to these adverse health effects, some protective role of microbial exposure on atopy and atopic diseases has been suggested [6]. Certain microorganism-associated molecular patterns have been identified as agents, that might influence the development of the immune system, which in turn leads to protective effects for asthma and atopy [30].

A basic problem in quantitative assessment of exposure to bioaerosol is the variability of microbial agents, which can be substantially greater than that commonly found for chemical agents, because microorganisms may rapidly proliferate in case of favorable conditions. Rohr et al. [23] have shown that the tests results (by culture based-methods) of fungal and bacterial levels in the bioaerosol of biomass-based power stations indicated extremely variable concentrations. The workers exposure to inhalable airborne fungi, bacteria, endotoxin at five biofuel heating or power plants showed that the exposure levels differed among the plants. This was due to the different process equipment, tasks and the handled biofuels [31]. In particular, it should be noted that bioaerosol analysis by culture based-methods could underestimate the real contamination of the workplace. Furthermore, the viability of microorganisms is less important for health effects, which can be also caused by exposure to non-viable microorganisms [12]. Nowadays, there are several gaps in knowledge concerning each step of the biological risk assessment, with regard to hazard identification, exposure assessment, and, above all, relationship between exposure and health risk. A systematic review of the studies on health effects of bioaerosol concluded that none of the analyzed studies provided suitable dose–response relationships for derivation of exposure limits [32]. The main reasons were:

1. lack of studies with valid dose–response data;

2. diversity of employed measurement methods for microorganisms and bioaerosol emitted by facilities;

3. heterogeneity of health effects;

4. insufficient exposure assessment.

Indeed, it is important to highlight that health effects of exposure to bioaerosol can substantially vary from person to person, because the human response to exposure to biological agents depends on individual susceptibility to infections and allergies [33]. A variable human response has been described for workers exposure to organic dust in different workplace areas and it was shown that the dust composition may play an important role in determining its health effects [34]. Because of lack of health-related exposure limits for bioaerosol components based on toxicological or epidemiological studies from the workplaces or environmental health [32, 35], few occupational exposure standards (not OELs) have been set by regulatory organizations, such as the ACGIH or the AIHA [10, 28, 36]. Although the research in this field is going on, setting OELs requires more exposure–response data derived from a greater number of animal models and, in particular, epidemiological studies of human exposure. Standardized and reproducible measurement methods are also required to compare studies in different environments [10, 35]. Considering that, it is not very likely that OELs for biological agents in bioaerosol will be developed in short times [35], the TLV referred to "particulates not otherwise regulated" [25] is used in lack of more specific values. Besides the availability of health-related exposure limits (OELs) for biological agents and additional studies on the respiratory health of biofuels plant workers, the identification of exposure indicators, easy to monitor, such as airborne dusts, can be useful tools for the routine assessment of workers exposure. Furthermore, some authors indicated that inhalable dust, at least in some workplaces, showed a good correlation with total bacterial counts and bacterial endotoxins and therefore it could be proposed as a valid indicator of human exposure to bioaerosol in workplaces with similar exposures [37, 38]. Considering that the scientific evidence on health effects of bioaerosol emissions related to biomass processing in bioethanol production plants is still limited, all valuable preventive technical measures, in accordance with the controls hierarchy [39, 40], should be taken into account for decreasing the exposure to airborne dust.

The case study facility has adequate plant layout and control measures aimed at limiting the workers exposure to organic dust. The preventive technical measures include:

- Separating the dusty operations from non-dusty activities;

- Reducing the speed of all vehicles near the plant;

- Using enclosed dusty machines (e.g., mill, which shreds the biomass) in order to reduce the spreading of bioaerosol in the work environment;

- Automated production and remotely controlled operations without the presence of workers;

- Reducing the discharge points and amount of materials, which have to be transferred;

- Employing frequent cleaning operations in the biomass storage area by good practices (industrial sweepers provided with dust control or mobile vacuum cleaners used to clean up possible spillages along the belt-conveyers).

Within the dust control strategy, the monitoring program ensures a reasonable representation of exposure to airborne dust for specific work activities (personal workers sampling) and for the working areas (stationary sampling) in the bioethanol production plant. In addition, the dust monitoring is a valid tool in order to assess the effectiveness of airborne dust containment measures. With regard to the experimental evidence that the inhalable dust could be a suitable tool for assessing the workers exposure to bioaerosol, by simple and not expensive methods [37, 38], it would be advisable planning specific studies in order to verify these observations in biofuels production plants. Furthermore, tailored workers health surveillance studies should be performed in order to link the bioaerosol exposure to the respiratory health of biofuels plant workers.

7. Conclusions

In bioethanol production plants, some work activities in the processing of biomass are sources of airborne organic dust. In the case study facility, the plant design, the equipment and working methods have been implemented for limiting the workers exposure to airborne dust by containment/isolation principle. In addition, a dust monitoring program has been performed in order to assess the effectiveness of the adopted containment and control measures, but no specific measurement of the components of the bioaerosol has been carried out. In order to overcome the current knowledge gaps in establishing agreed bioaerosol monitoring protocols and developing reliable dose–response data, the potential risk should be managed by a precautionary approach, such as in other comparable industries [41]. Every worker, even if only potentially exposed, must be protected using the best practices based on the most up-to-date scientific knowledge and on the current level of technological development. In order to prevent respiratory impairment among workers of bioethanol production plants, the employers should demonstrate that adequate control measures have been developed in order to keep the exposure to dust as low as possible. In the examined plant, the preventive technical measures, the work equipment and working methods of biomass processing ensure the observation of the ACGIH guidance values for inhalable and respirable dusts in the workplace. Limited information is available on workers health surveillance programs in the biofuels production plants and therefore there is the real need of data collection on workers symptoms and diseases associated with the exposure to airborne dust in order to improve the knowledge on health outcomes of highest concern, such as respiratory impairment, airways irritation and sensitization.

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