Chemical Substances and Biological Agents

# Studies and Research Projects

REPORT **R-760**


## Characterization of Dusts in Traditional Bakeries

*Brigitte Roberge*
*Simon Aubin*
*Yves Cloutier*

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## Characterization of Dusts In Traditional Bakeries



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# SUMMARY

Several studies have concluded that bakers exposed to flour dust are at risk of sensitization and of developing respiratory symptoms, and even occupational asthma (OA). Others report an increased risk of sensitization to flour at levels of 2 mg/m³, even though sensitization is prevalent in bakers exposed to 1 mg/m³ of flour dust. According to recent studies, workers in industrial or traditional bakeries could be exposed to up to 7.8 mg/m³, and mill workers up to 16 mg/m³. The majority of the studies report levels expressed as an inhalable fraction (Fi) of dust.

The present project aims to characterize the dusts in the air of traditional bakeries in terms of total dusts (Dt), inhalable fraction (Fi), and respirable fraction (Fr), and to collect data on the particle size distribution of flour dusts generated during operations using flour.

The reported results correspond to two tasks in which the bakers handle flours: 11 series of samples collected at the dough mixer/weighing, and 13 at the moulding/rounding table, where dusting with flour is done. These stationary samples covered the complete duration of the operations at each of the two workstations. The median concentration at the dough mixer workstation was 4.9 mg/m³ for Dt (range < 0.03–17 mg/m³) and 8.0 mg/m³ for Fi (0.2–19 mg/m³), and at the table workstation it was 2.4 mg/m³ for Dt (< 0.03–8.7 mg/m³) and 3.8 mg/m³ for Fi (0.2–9.2 mg/m³). The mass median aerodynamic diameter (MMAD) of the dusts collected at the dough mixer and at the table was approximately 23 µm. With the direct-reading instrument that was used, the high concentration peaks could also be linked to the different tasks performed.

The small difference between the results for the Fi duplicates complements the method's analytical validation data in terms of precision related to sampling and field manipulations. This fact shows that the sampling and analytical method using the IOM sampler is applicable in the workplace for evaluating inhalable fraction dusts.

The mean ratio of Fi/Dt is 1.6, with a standard deviation of 0.3, with the environmental measurements as well as with the impactors. It shows that the relationship is relatively constant in traditional bakeries, regardless of the workstation. Work practices differ from one baker to another: the starting speed of the dough mixer, the pouring of flour into water and vice versa, the amount of flour for dusting, etc. The median concentrations suggest that the risk of exposure to flour dust would be higher at the dough mixer workstation. A paired *t* test shows that the concentrations measured at the dough mixer differ significantly from those at the table.

The exposure values estimated for stationary sampling, expressed as Dt, seem to be lower than the reference values of 10 mg/m³ for particulates not otherwise classified (PNOC), but several are above concentrations that can cause pulmonary sensitization according to the consulted literature. The main exposure risk factors in a traditional bakery are the total amount of flour used, the type of flour, the number of dough mixers in operation, the cover of the dough mixer, and the work practices.

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# LIST OF ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| ACGIH® | American Conference of Governmental Industrial Hygienists |
| AM | Arithmetic mean |
| BEI® | Biological Exposure Indices |
| CAEQ | Classification des activités économiques du Québec (Québec Economic Activity Classification) |
| $Conc_i$ | Ambient dusts collected by an impactor |
| CSST | *Commission de la santé et de la sécurité du travail* (Québec workers' compensation board) |
| DAEV | Daily average exposure value |
| DRI | Direct-reading instrument |
| Dt | Total dusts collected on a 37-mm diameter filter placed in a closed cassette with a 4-mm orifice |
| Dti | Total dusts collected by the impactor calculated from $Conc_i$ in relation to the collection efficiency curve |
| Est | Establishment visited |
| Fi | Inhalable fraction, dust fraction corresponding to the mass of particles with aerodynamic diameter ($d_a$) between 0 and 100 µm collected by a sampler corresponding to the collection curve (ACGIH® 2010; IRSST 2005) |
| Fii | Inhalable fraction of the dusts collected by the impactor |
| Fr | Respirable fraction, dust fraction corresponding to the mass of particles collected by a sampler whose median aerodynamic diameter is 4 µm (ACGIH® 2010; IRSST 2005) |
| Fri | Respirable fraction of the dusts collected by the impactor |
| GM | Geometric mean |
| GSD | Geometric standard deviation |
| HSE | Health and Safety Executive |
| INRS | *Institut national de recherche et de sécurité* |
| IOM | Institute of Occupational Medicine |
| LCL-UCL 95% | 95% lower-upper confidence limit |
| MMAD | Mass median aerodynamic diameter |
| MRV | Minimum reported value |
| n | Number of samples |

| | |
|---|---|
| NAICS | North American Industry Classification System |
| OA | Occupational asthma |
| OSHA | Occupational Safety and Health Administration |
| PNOC | Particulates not otherwise classified, according to the ROHS |
| PVC | Polyvinyl chloride, 5 µm porosity |
| ROHS | Regulation respecting occupational health and safety |
| S | Sensitizer |
| SD | Standard deviation |
| TLV® | *Threshold Limit Values for chemical substances and physical agents* |
| TWAEV | Time-weighted average exposure value |

# 1. INTRODUCTION

During the 1920s and 1930s, several scientists identified flour as the causal agent of baker's rhinitis and asthma. Since then, this relationship has been backed up by epidemiological and environmental studies. Some studies have also identified allergenic components of flour, including alpha-amylase. In Québec, little information exists relating to environmental measurements for this food sector, traditional bakeries, which are also called artisan bakeries.

Over a 12-year period (1995–2007), the *Commission de la santé et de la sécurité du travail* (CSST) compensated 34 cases of asthma with "bakery products, grains, cereal products, etc." as causal agent for the following CAEQs (Classification des activités économiques du Québec) Québec Economic Activity Classifications): Bread and other bakery products industry (1072), and Bakery and pastry products (6014). Workers in these economic sectors can be exposed to these dusts, considered by the *Regulation respecting occupational health and safety* (ROHS) as particulates not otherwise classified (PNOC). This term comprises all inert (nuisance), mineral or organic dusts that are not regulated under a specific substance's name. The definition for PNOC found in the French regulations (INRS 2008) is "*poussières réputées sans effet spécifique*": namely that alone cannot cause any effect other than overload on the lungs or any other organ or system of the human body.

Québec regulations are based on measurement of the so-called total dust (Dt) fraction or respirable fraction (Fr). In recent years, the use of filters with an Accu-Cap® has improved the evaluation of the dust concentration. According to several scientists, Dt samples do not always seem relevant for evaluating the workers' health risk. In fact, most of the consulted current literature on flour dust exposure reports the results as the inhalable fraction (Fi) of dust.

The present project establishes a portrait of the concentrations evaluated by different methods for sampling the Fi, Fr and Dt, as well as the particle size distribution of the flour dust. It characterizes the work environment for one of the main causal agents of asthma in this Québec food industry sector on which very little research has been done.

# 2. OBJECTIVE OF THE STUDY

The project aims to characterize the airborne dusts in traditional bakeries in terms of total dusts, inhalable fractions, and respirable fractions, and to collect data on the particle size distribution of the flour dusts generated during operations using flour.

# 3. STATE OF KNOWLEDGE

The present state of knowledge was produced from scientific studies on the health effects on workers in industrial and traditional bakeries and in mills. It also includes environmental studies performed in these work environments in terms of the workers' flour dust exposure levels. Studies prior to 1990 were not considered so that only the most up-to-date knowledge possible would be reported.

## 3.1 Health effects

Occupational allergies are the result of exposure to chemical or biological agents. Occupational respiratory allergies are characterized by symptoms caused by exposure, sometimes very low, to sensitizing agents and by a symptom-free latency period, called the sensitization period (INRS 2009). Flour is documented as a causal agent that can induce a type of occupational asthma, often called *baker's asthma* (Baur 1999; Brisman *et al.* 2000; Houba *et al.* 1998b; INBP 2005; Jeffrey *et al.* 1999; Kakooei and Marioryad 2005; Karpinski 2003; McDonald *et al.* 2000; van Tongeren *et al.* 2009).

Several studies have concluded that bakers exposed to flour dust are at risk of becoming sensitized and of developing respiratory symptoms that can lead to asthma (Breton 2002; Bohadana *et al.* 1994; Brisman *et al.* 2000; Cullinam *et al.* 2001; De Zotti *et al.* 1994). In addition, Aloui Yazidi *et al.* (2001) reported that for 200 subjects in 25 Moroccan bakeries, the flour sensitization rate was 14.5%. Gautrin *et al.* (2002) reported a high incidence (16.1%) of rhinoconjunctivitis symptoms in the population of flour-handling apprentices during skin prick tests with wheat flour. The study by Harris-Robert *et al.* (2009) concluded that flour exposure increases the risk of bakers developing respiratory symptoms, regardless of the size of the bakeries. Kakooei and Marioryad (2005) concluded that flour dust affects respiratory function parameters and causes lung obstruction. Several other studies carried out on flour mill workers (Cullinam *et al.* 1994; Fakhri 1992; Kakooei and Marioryad 2005; Karpinski 2003; Laraqui *et al.* 2003; Massin *et al.* 1996; Nieuwenhuijsen *et al.* 1999, 1995a,b; Smith *et al.* 2000; Smith and Patton 1999; Zuskin *et al.* 1998) also showed respiratory symptoms and flour sensitization in the workers.

Some risk factors, including atopy, have been studied in order to assess such things as the relationship between allergen exposure and sensitization symptoms (Ameille *et al.* 2006; De Zotti and Bovenzi 2000; Droste *et al.* 2005; Houba *et al.* 1998a,b; Rosenberg 2002). These studies suggest a strong positive relationship between wheat allergen exposure and sensitization, and observe a higher prevalence in atopic workers.

Wheat flour is a complex mixture of components, several of which are allergens that could cause sensitization and induce asthma by inhalation. Several studies have dealt with the different wheat flour allergens in order to identify the agents that can cause rhinitis and induce asthma in workers (Baur and Posh 1998; Cullinam *et al.* 1994; Houba *et al.* 1996; McDonald *et al.* 2000; Merget *et al.* 2001; Smith and Smith 1998; Smith *et al.* 1997; van Tongeren *et al.* 2009; Valdiviesco *et al.* 1994). Burstyn *et al.* (1997) identified specific tasks such as flour dusting (action of throwing flour on surfaces, including the table, moulds, etc.), weighing, and ingredient mixing, that contribute the most to bakers' flour dust exposure.

Finally, some studies (Brisman *et al.* 1998; Crépy 2007; Meding *et al.* 2003; Morren *et al.* 1993) reported cases of contact urticaria or eczema in bakers, mainly related to wheat, rye and a few other flours.

## 3.2 Worker exposure

Some studies (Brisman 2002; Brisman *et al.* 2000; Heederick and Houba 2001; Nieuwenhuijsen *et al.* 1995a; van Tongeren *et al.* 2009) have reported that the risk of occurrence of rhinitis symptoms, and even asthma, increases with the flour dust exposure level.

Houba *et al.* (1998a) reported that the sensitization risk would be negligible when the exposure is reduced to 0.5 mg/m³ for the inhalable dust fraction (Fi), and to 0.2 µg/m³ for wheat allergens. These same authors, in another publication (Houba *et al.* 1998b), reported an increased risk of sensitization to wheat flour at levels of 2 mg/m³, even though sensitization was prevalent in bakers exposed to 1 mg/m³ of flour dust. Heederick and Houba (2001) recommended an exposure threshold for wheat sensitization between 0.5 and 1 mg/m³ for Fi. Nieuwenhuijsen and Burdorf (2001) stated that a reduction in exposure to 1 mg/m³ could eliminate sensitization effects. In his literature review, Baur (1999) emphasized that no study had reported cases of asthma for dust exposures below 1 mg/m³.

Finally, van Tongeren *et al.* (2009) mentioned that the establishment of an exposure value is problematic because flour dust contains several sensitizing agents that are present in varying proportions. Table 3.2-1 contains a list of different organizations' 8-hr exposure values for PNOC and flour dusts (IFA *Gestis-International Limit Values for Chemical Agents*[1]).

[1] {On line} http://www.dguv.de/ifa/en/gestis/limit_values/index.jsp (October 2010).

**Table 3.2-1: Exposure value for PNOC and flour**

| Country/organization | PNOC (mg/m³) | Flour (mg/m³) |
|---|---|---|
| Belgium (GWBB) | 3 (Fr)<br>10 (Fi) | 0.5 |
| France (INRS) | 5 (Fr)<br>10 (Fi) | |
| Germany (DFG) | 4 (Fi) | |
| Great Britain (HSE) | | 10 (Fi) (s)<br>30 (15 minutes) |
| Québec (CSST) | 10 (Dt) | |
| Spain (INSH) | 10 (Fi) | 4 (Fi) (s) |
| Sweden | | 3 |
| United States (ACGIH®) | 3 (Fr)<br>10 (Fi) | 0.5 (Fi) (s) |
| United States (OSHA) | 5 (Fr)<br>15 (Dt) | |

**Dt**: Total dusts **Fr**: Respirable fraction **Fi**: Inhalable fraction **s**: Sensitizer
DFG:*Deutsche Forschungsgemeinschaft* GWBB: Greenswaarden vooc beroepsmatige blootstelling
INSHT: *Instituto Nacional de Seguridad e Higiene en el Trabajo.*

Only a few environmental studies mention flour dust concentrations. Note that the dust fractions are reported here when they are mentioned in the consulted articles. The *Health and Safety Executive* (1999), Houba *et al.* (1998b) and Rosenberg (2002) did a literature review on the occupational exposure of workers who handle flour. The study by Baatjies *et al.* (2010) reported a geometric mean (GM) concentration of 1.33 mg/m³ for the Fi of dust with a geometric standard deviation (GSD) of 2.25 and a range from 0.25 to 7.29 mg/m³. These samples collected in the breathing zones of 112 bakers covered a complete work period in 18 industrial bakeries for different tasks. Houba *et al.* (1997a) measured the Fi of the dust collected in industrial bakeries (GM for bread production: 4.5 mg/m³). Page *et al.* (2010,2009) did a workstation study in an industrial bakery and measured a median concentration of 2.75 mg/m³ (GM: 3.01 mg/m³) in the dough preparation section. The study by van Tongeren *et al.* (2009) synthesized 1451 results of sampling carried out between 1985 and 2003 in Great Britain. It established their average concentration at 7.8 mg/m³ in industrial bakeries and 17.9 mg/m³ in mills. Bohadana *et al.* (1994) reported that the exposure to the Fi of flour dust after 5 years of employment of the population studied was 3.37 mg/m³ (range from 0.66 to 8.70 mg/m³).

Cullinam *et al.* (2001) reconsidered the data from the study published by Nieuwenhuijsen *et al.* (1995a) in relation to three concentration categories for Fi: low (GM: 0.58 mg/m³), average (GM: 1.17 mg/m³) and high exposure (GM: 4.37 mg/m³). Drost *et al.* (2005) reported that the GM for exposure to the Fi of flour dust in industrial bakeries was 2.09 mg/m³.

Kakooei and Marioryad (2005) reported, for three mills, average concentrations of Fr varying from 4.25 to 5.44 mg/m³ and Dt from 9.45 to 16.04 mg/m³. Karpinski (2003) studied the jobs in Canadian mills; depending on the task, geometric mean Fi concentrations varying from 4.83 to 12.91 mg/m³ with a GSD from 1.86 to 5.39 were measured. Smith *et al.* (2000) measured median

Fi concentrations of 6.2 mg/m³ for the production site and 18.7 mg/m³ for cleaning in a mill. Nieuwenhuijsen *et al.* (1994) reported an average concentration (GM) for three industrial bakeries of 0.4 mg/m³ and concentrations varying from 0.5 to 16.9 mg/m³ in three mills.

Jeffrey *et al.* (1999) reported a great variability in exposure for the tasks covered in their study. Category A included several tasks, namely ingredient weighing and mixing, and dough division and moulding, and category B included pastry tasks. Category A tasks produced exposures higher than those in category B. Nieuwenhuijsen *et al.* (1995c) reported a higher exposure in the ingredient and dough mixing area in bakeries as well as a great variance in exposure between workers and from one day to another.

The environmental assessment results documented in the scientific literature for traditional bakeries alone are summarized in Table 3.2-2. They refer to flour mixing tasks, and to the weighing of dry ingredients, when this information was available. A more detailed synthesis is difficult because the strategies and measuring instruments vary greatly from one study to another, and important information is missing. Also, the authors provide different types of data depending on the studies, such as geometric mean (GM), arithmetic mean (AM) or median concentrations. The results for dusts sampled in mills are not reported, nor are those for industrial bakeries.

**Table 3.2-2: Concentrations of flour dust in traditional bakeries reported in the scientific literature**

| Reference | F | Task | GM (AM) (mg/m³) | Median (mg/m³) | GSD (SD) | Range (mg/m³) |
|---|---|---|---|---|---|---|
| Bulat *et al.* (2004) | Fi | Baker | 2.1 | **1.83** | 2.42 | 0.3–13.3 |
| Burdorf *et al.* (1994) | Fi | Mixing | 5.46<br>(6.9) | | 2.09 | 1.2–16.9 |
| Burstyn *et al.* (1998) | Fi | Mixing | 4.5<br>18 | | 6.7 | 0.3–110 |
| Elms *et al.* (2006) * | Fi | Baker<br>Weighing, dough mixer | 3.3<br>4.7 | **3.6**<br>**5.2** | | |
| Elms *et al.* (2005) | Fi | Baker<br>Weighing, dough mixer | 3.3<br>4.7 | **3.6**<br>**5.2** | 3.4<br>3.4 | LQ–47.0<br>LQ–30.6 |
| Elms *et al.* (2003) | Fi | Weighing<br>Dough mixer<br>Mixing | | **11.4**<br>**7.6**<br>**6.3** | | 2.4–26.3<br>1.0–36.8<br>LQ–27.8 |
| Houba *et al.* (1997a) | Fi | Baker | 3.3<br>(3.8) | | 1.6 | |
| Houba *et al.* (1996) | Fi | Mixing | 3.0 | | 2.3 | 0.4–37.7 |
| Jeffrey *et al.* (1999) | Fi | Mixing | 4.9 | | 2.3 | 0.6–23.7 |
| Lillienberg and Brisman (1994) | Fi | Mixing<br>Baker | (7.5)<br>(2.5) | | | |
| Meijster *et al.* (2008) | Fi | Baker | (4.49) | | | |
| Meijster *et al.* (2007) | Fi | Baker | 1.5 | | 2.7 | 0.2–318 |
| Mounier-Geyssant *et al.* (2007) | Fi | Apprentice bakers | (0.63)<br>(1.10) | | (0.36)<br>(0.83) | 0.17–1.73<br>0.28–4.04 |
| Musk *et al.* (1989) | Dt | Mixing | 2.7 | | | 0.6–14.1 |
| Nieuwenhuijsen *et al.* (1995b) | Dt | Mixing | 9.0<br>(11.8) | | 2.3 | 2.2–25.0 |

F: Dust fraction reported by the authors GM: Geometric mean AM: Arithmetic mean
GSD: Geometric standard deviation SD: Standard deviation LQ: Analytical limit of quantification
*: Elms *et al.* (2006) reconsidered the data from Elms *et al.* (2005) by adding data for enzymes.

Smith and Smith (1998) studied the exposure of 394 bakers in 19 bakeries and 77 cake bakers to establish a relationship between flour dust exposure and the development of symptoms. They measured a median concentration of 10.1 mg/m³ (GSD: 13.3) at the sifter and 2.8 mg/m³ (GSD: 10.3) at weighing. Bulat *et al.* (2004) concluded that the Fi of the dust would be higher in traditional bakeries (Table 3.2-2) than in industrial bakeries (GM: 1.8 mg/m³; median: 2.3 mg/m³). Meijster *et al.* (2008) evaluated the exposure of workers in traditional and industrial bakeries as well as in mills with a direct-reading instrument (DRI) (DataRam) and an Fi sampler (PAS6). They correlated the instantaneous and maximum concentrations during different tasks. The exposure of traditional bakers consisted of an average of 26 concentration peaks per hour which could reach 371 mg/m³ for a median duration of 53 seconds. The median concentration obtained with the DRI was 0.21 mg/m³ and 1.63 mg/m³ for the Fi collected on cassette, and therefore eight times higher. From the maximum concentrations, these researchers identified that the most hazardous tasks are dough mixing (14.1 $mg/m^3$), flour dusting (6.5 $mg/m^3$), weighing (4.6 $mg/m^3$) and flour pouring (3.4 $mg/m^3$). Lillienberg and Brisman (1994) mentioned the existence of a great variability in concentration levels between bakeries, depending on production, the equipment used, the ventilation and the work methods.

The study by Nieuwenhuijsen *et al.* (1999) showed a moderate correlation between the flour dust concentration ($r = 0.42$) and wheat allergens ($r = 0.46$).

## 3.3 Particle size distribution of dusts

Sander *et al.* (2004) reported the particle size distribution of rye and wheat flours measured during asthma diagnostic tests. They noted a larger fraction between 10 and 102 µm in type-1150 rye flour than in type-550 wheat flour. In a case study, Ehrlich and Prescott (2005) concluded that rye flour dust is smaller than wheat flour dust.

Houba *et al.* (1997b) established a relationship between the flour dust particle size distribution and its α-amylase content. Their samples by cascade impactors showed that α-amylase is present as 5 µm or larger particles. For average Dt samples of 2.39 $mg/m^3$, they found 64% of the particles > 9 µm and 33% between 5.8 and 9.0 µm.

Lillienberg and Brisman (1994) reported a bimodal distribution of flour dust with maximum concentrations of fine dusts around 5 µm and larger dusts around 15–30 µm.

# 4. METHODOLOGY

## 4.1 Metrology used

Dust characterization was done with three different sampling methods using filter and cassette to collect different airborne dust fractions depending on their type: 1) total dusts (Dt), 2) inhalable dust fraction (Fi), and 3) respirable dust fraction (Fr). Also, cascade impactors were used to evaluate the particle size distribution of the airborne dust. The sampling equipment and methods used are presented in Table 4.1-1.

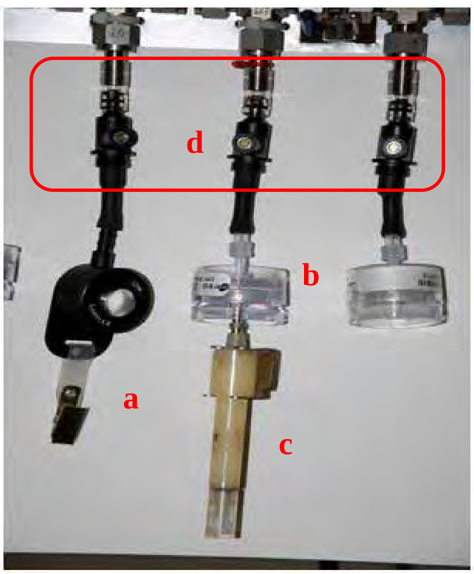
**Table 4.1-1: Sampling and analytical methods**

| | Dt | Fi | Fr | Particle size |
|---|---|---|---|---|
| Filter | Preweighed PVC, 37 mm with Accu-Cap® | Preweighed PVC, 25 mm | Preweighed PVC, 37 mm with Accu-Cap® | Silicone-coated Mylar® and preweighed PVCs, 34 mm |
| Sampler | Closed cassette, 37 mm, 4 mm orifice | IOM cassette, stainless steel, 15 mm orifice | Closed cassette, 37 mm, Dorr-Oliver cyclone | Marple 298 eight-stage impactor |
| Flow rate | 1.5 L/min | 2.0 L/min | 1.7 L/min | 2.0 L/min |
| Analytical uncertainty | 4.9% | 1.1% | 4.9% | Not available |
| MRV | 25 µg | 40 µg | 25 µg | 25 µg |
| IRSST method | 48-1 | 373 | 48-1 | 48-1 modified |

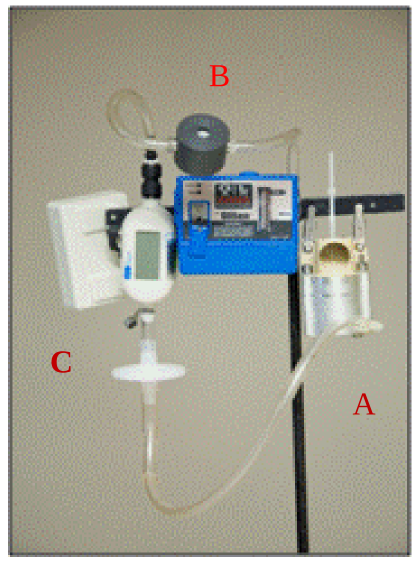
PVC: Polyvinyl chloride, porosity 5 µm MRV: Minimum reported value

The laboratories of the *Institut de recherche Robert-Sauvé en santé et en sécurité du travail* (IRSST) prepared the sampling equipment and analyzed the samples. Cassettes equipped with an Accu-cap® were used to determine the Dt and Fr to avoid the underestimation caused by losses on the inside walls of a polystyrene cassette. The use of an IOM (*Institute of Occupational Medicine)* sampler with stainless steel cassettes minimized the impact of relative humidity on the weight measurements during the laboratory analyses. Marple type impactors were used with silicone-coated Mylar® membranes as recommended by the manufacturer to prevent bounce and resuspension during impaction on the collection substrates. The cutoff diameters for these impactors are between 0.52 and 21.3 µm.

Despite the fact that all the samplers used in this project were personal samplers, the samples were stationary samples (ambient air) for reasons of comparison. The six samplers were installed on a metal plate. Each sampling train consisted of six adjustable flow sampler holders connected respectively to two closed cassettes for Dt samples, to two cassettes equipped with a Dorr-Oliver cyclone for Fr samples, and to two IOM samplers for Fi samples. The samplers were installed alternatively and adjusted to the flow rate specific to each. Figure 4.1-1a illustrates the samplers [IOM cassette (a), closed cassette (b), cassette and cyclone (c), as well as the adjustable flow sampler holders (d)]. Each of the sampling trains was connected by a Teflon® tube of variable length, depending on the location, to a 30 L/min vane pump. The flow rates were adjusted at the start and verified at the end of the sampling period by means of a DryCal model Bios flowmeter with an accuracy of 3% of the reading according to the manufacturer's specifications. A 5% variation in flow rates (before and after) is acceptable.




a




b

**Figure 4.1-1: Sampling trains**

Each sampling system was placed at a specific workstation. However, depending on the establishment evaluated, an additional sampling system could be added to this workstation to evaluate the fine structure of the ambient dust. This system consisted of a cascade impactor (A) installed in series with a Gilian brand Gilair model personal pump, an anti-pulsator device (B), and a TSi model 4146 flowmeter (C) with an accuracy of 2% of the reading according to the manufacturer's specifications. This impactor sampling train is presented in Figure 4.1-1b.

The gravimetric analyses were done using a micrometric balance with a resolution of ± 1 µg. The filters underwent treatment in a desiccator and were weighed after an acclimation period at ambient conditions in a controlled humidity chamber. The details of the analytical methods are found in IRSST methods 48-1 and 373.

A direct-reading instrument (DRI) was also used to study the evolution in concentration levels and the particle size distribution of the dusts as a function of time. A single sampling station per visited establishment was generally evaluated using the DRI, which was a GRIMM PAS model

1.108 optical particle counter (Figure 4.1-2) operating according to the scattered light principle (laser source) with an accuracy of 5%, according to the manufacturer. The optical diameters measured by this instrument are more or less proportional to the corresponding aerodynamic or geometric diameters (Ruzer and Naomi 2005). The instrument evaluates the concentration of airborne dusts every six seconds for fifteen particle size ranges (< 0.23 to > 20 µm). To simplify data interpretation, these fifteen ranges were combined to produce four ranges.

It is important to note that the data from this DRI could be biased due to the fact that it was not calibrated in the laboratory with the target contaminant.


**Figure 4.1-2: GRIMM PAS 1.108 Spectrometer**

## 4.2 Establishments visited and sampling strategy

Eleven traditional bakeries were visited. They were selected from a search on the ICRIQ.com site of the *Banque d'information industrielle* of the *Centre de recherche industrielle du Québec* (CRIQ) or proposed by members of this project's follow-up committee. A total of 24 sampling stations related to two tasks were characterized, namely dough mixing (dough production by means of a dough mixer) and rounding/dividing/moulding (on a table or mechanically). The stations were selected after preliminary visits that identified tasks more representative of the risk of worker exposure to airborne flour. The visited establishments were classified as CAEQ codes 1072 and 6014 (Québec Economic Activity Classification) or NAICS 311814 (North American Industry Classification System).

The samples were collected during periods of flour use or handling for the two above-mentioned tasks. For example, when dough mixing was finished for a work shift, sampling was suspended, even though the work shift was not completed administratively. Finally, the cleaning done during flour handling operations was of short duration and was integrated into the sampling. It was therefore not the subject of specific sampling during the intervention.

On the intervention days, information or determinants that could explain the variations in the results were collected. Some examples are the volume of the bread preparation area, the amount of flour used in the dough mixer, the number of pieces of equipment (dough mixer, moulder, dough divider, etc.) in the establishments, the number of bakers present, the presence or absence of means of control, and some work practices, if relevant.

## 4.3 Data processing

### 4.3.1 Environmental analyses

The results reported in section 5 were determined by using the mean of the duplicates obtained for each type of sampler in each sampling train. For calculation purposes, the result for all the samples whose dust concentration was below the MRV was replaced by the value obtained using equation 4.3-a. The daily average exposure value (DAEV) was calculated from the stationary sampling concentrations obtained, when flour was being handled. This calculation was done using equation 4.3-b, which corresponds to an **estimation** equivalent to an 8-hour work shift. It should also be noted that no result for Dt, Fi and Fr was corrected in relation to the weight of the blank filter, because this variation in weight of the blanks is considered as negligible.

$$Conc_{MRV} = (MRV/\sqrt{2}) / V_s \qquad \text{equation 4.3-a}$$

Where $Conc_{MRV}$: Concentration of dusts < MRV used in the calculations (mg/m³);
MRV: Minimum reported value in Table 4.1-1 (µg);
$V_s$: Sampling volume (L).

$$DAEV = \frac{C_1T_1 + C_2T_2 + \ldots + C_nT_n}{480 \text{ minutes}} \qquad \text{equation 4.3-b}$$

Where C: Concentration over a given period (mg/m³);
T: Duration of the sampling period (minutes).

### 4.3.2 Particle size distribution by impactor

The mass collected by the Marple (Sierra 298) impactors was corrected in relation to the median variation observed for a group of six blank substrates.

Two particle size distribution profiles were produced for each series of weight measurements. The first did not take into account internal losses on the surface of the first stage, visor, head, and all the other surfaces, except for the collection substrates and the filter; another did a correction based on the curves supplied by the manufacturer. This latter profile will be considered as corrected for the purposes of this study. The standard deviations (GSD) were calculated by assuming a lognormal distribution, therefore by drawing a regression line on the log probability graph of the particle size distribution. Only the most significant points were used, by giving less weight to the cumulative points below 10% and above 90%, as recommended by Lodge and Chan (1986).

The concentration evaluated by the impactor ($Conc_i$) was obtained by adding all the masses collected for each stage. The inhalable fraction (Fii) and respirable fraction (Fri), as defined by the *American Conference of Governmental Industrial Hygienists* (ACGIH®), were calculated using the results from the impactors and the respective conventional curves. The penetration percentages obtained from the ACGIH® curves and specific to a stage’s cutoff diameters were multiplied directly by the mass collected on it. The respirable or inhalable mass was obtained by summing these results for all the stages of the impactor. Simpson's rule was applied during calculation and is described in the monograph of Lodge and Chan (1986). These calculations were repeated for the uncorrected and corrected masses. To lighten the text, the uncorrected results are presented only in the appendices.

To be able to compare the samples, the histograms of the particle size distributions were normalized. The mass percentages for each particle diameter could thus be evaluated directly from the histograms.

## 4.4 Statistics

The data from this study were interpreted using statistical methods by means of computer-based tools. The results obtained from the different samplers were compared statistically using NCSS 2007 software, version 07.1.14 (Hintze J., Kaysville, Utah). The paired *t* test was used to compare the pairs of results obtained from the different samplers in relation to their type and the sampling station. A non-parametric test, the Wilcoxon signed rank test, was used when the distribution of the studied data was not recognized as normal. The null hypothesis ($H_0$) of the statistical tests was rejected when P (or Z) < 0.05 or when the value zero was not included in the 95% confidence interval of the average of the difference of the paired units.

# 5. RESULTS

The results section includes a brief description of the establishments, work practices, and various flour handling operations in bread production, as well as the Dt, Fi and Fr and particle size distribution sampling results.

## 5.1 Description of the process

To make bread using the traditional method, several steps are necessary. First, the baker weighs the flour and dry ingredients and then pours them into the dough mixer (Figure 5.1-1) with water. The gluten in the flour binds the water, and the dough traps air. Once the dough has been mixed, it is softened by incorporating small amounts of water at a given temperature. This step adds strength to the dough, which is then left to rest for up to five hours to allow the yeast or leaven to ferment. The dough then becomes more elastic and doubles in volume; this expansion is due to the release of carbon dioxide ($CO_2$) during fermentation. It is at this step that the bread's taste develops.

**Figure 5.1-1: Dough mixer**

The dough can be divided manually (Figure 5.1-2a) by the baker who cuts and weighs the pieces of dough, or automatically with a dough divider (Figure 5.1-2b) which forms regular pieces of dough of equivalent weight.

a) Manual division

b) Dough divider

**Figure 5.1-2: Dividing the dough**

Before moulding (operation that gives shape to the dough), the pieces of dough are made into balls (Figure 5.1-3) to control the strength of the dough more or less accurately. Once again, the pieces of dough are left to rest so that the dough does not tear during moulding.

**Figure 5.1-3: Rounding**

During moulding, the dough is stretched, and then rolled on itself and finally stretched again to form a baguette. This step can be done manually or mechanically using a moulder (Figure 5.1-4).

During the steps illustrated in Figures 5.1-1 to 5.1-4,[2] a rather large amount of flour is handled. The baker is therefore directly in the presence of flour dust.

**Figure 5.1-4: Moulding**

The pieces of dough are placed on a linen cloth (the couche) for the second fermentation that occurs under temperature conditions of approximately 25°C. This phase promotes a new release of $CO_2$. The dough continues to rise to approximately three times its initial volume. This step lasts from one to three hours. Before loading, the baker uses a sharp blade to make regular cuts (scarification) in each loaf to promote the release of $CO_2$ during baking. Once baking is complete, the bread cools to continue the evaporation of the water vapour and $CO_2$ that it still contains. This is the cooling step.

## 5.2 Description of the establishments and work practices

Bakers work 40 hours or more per week, depending on the work organization in the establishment. They do their work at the end of the evening, during the night, or even very early in the morning. Table 5.2-1 documents the number of bakers and the amounts of flour used at the time of our intervention, as well as the number of dough mixers and other aspects specific to the establishment.

The establishments sometimes had a dough divider and/or a moulder, as well as one or more dough mixers. Depending on the establishment, one baker would do the kneading, and another would do the moulding/rounding or even both tasks alternately or simultaneously.

[2] The photographs in this report were taken in the visited establishments with the written consent of the person in charge.

The workers wore work clothes. No one wore nitrile or other gloves. Among the visited bakeries, only one baker wore respiratory protection.

**Table 5.2-1: Characteristics of the establishments visited**

| Est | Venti-lation * | Number of bakers | Volume of the bread production area ($m^3$) | Number of dough mixers | Amount of flour (kg) | Type of flour |
|---|---|---|---|---|---|---|
| **1** | OFF | 2 | 32 | 2 | 140 | Sifted wheat, cracked rye and milled rye flour, spelt, kamut flour. |
| **2** | N | 2 | 314 | 2 | 150 | Untreated wheat, whole wheat, kamut, flax, spelt flour. |
| **3** | ON | 3 | 618 | 3 | 383 | Sifted wheat, whole wheat, rye, flax, spelt, kamut flours. |
| **4** | N | 2 | 334 | 2 | 174 | Whole wheat flour, enriched, peasant flour 4117. |
| **5** | N | 1 | 70 | 2 | 66 | Untreated wheat, whole wheat flour. |
| **6** | ON | 1 | 717 | 1 | 264 | Untreated baker’s flour enriched all-purpose flour. |
| **7** | ON | 1 | 166 | 1 | 62 | Unbleached strong, wheat flour. |
| **8** | ON | 2 | 124 | 1 | 86.5 (kneaded) 60 (weighed) | Sifted wheat, whole wheat, cracked rye and milled rye flour, spelt, kamut flour. |
| **9** | N | 2 | 60 | 2 | 202 | Unbleached enriched wheat flour, baker’s flour, kamut, flax, spelt flour. |
| **10** | N | 3 | 311 | 1 | 128 | Sifted wheat, enriched, whole wheat, multigrain flour. |
| **11** | ON | 3 | 187 | 3 | 187 | Type 65 wheat flour, whole wheat, type 170 rye, untreated baker’s, degermed wheat, kamut, soft wheat, peasant 4117 flour. |

Est: Identification of the establishment.
*: Ventilation system present and operating (ON), present and not operating (OFF), or absent (N).

The majority of the bakers started the dough mixer at medium speed instead of low speed. They added the flour to the water. This procedure, combined with a medium or higher starting speed, contributed to the dustiness of the work area. Some bakers used a large amount of flour to dust the table, moulds and other equipment. A few bakers swept the floor with a piassava type broom between operations.

From our observations, the bakers in eight establishments added flour to the water in the dough mixer. For 14 of the 20 dough mixers, the cover was open grillwork (Figure 5.2-1); others had a cover that could reduce the ambient dust contamination.

**Figure 5.2-1: Dough mixer covers**

## 5.3 Dust characterization – Environmental results

The characterization of the dusts in the visited traditional bakeries included the environmental results for the flour concentration as total dust (Dt), inhalable fraction (Fi) and respirable fraction (Fr) as well as the particle size distribution analyses (by means of an impactor and the DRI), an Fi/Dt ratio and various comparisons.

### *5.3.1 Dt, Fi and Fr concentrations*

The reported results correspond to two specific tasks in which the bakers handle flours: the task at the dough mixer/weighing, and the task at the moulding/rounding table. To simplify the presentation of the results, the terms *dough mixer workstation* and *table workstation* are used for the above-mentioned tasks for the remainder of this document. The sampling duration covered the flour handling period for traditional bread production without automation.

A paired *t* test was performed on all the pairs of results obtained according to the fraction (Fi or Dt), grouped by sampling station (dough mixer and table). Table 5.3-1 contains the results of these statistical tests, whose purpose was to establish whether the result of the duplicates was equivalent so that their average could be used for the calculations. The Fr was not handled in this way because the majority of the results were below the minimum reported value (MRV). Despite the fact that a significant difference was observed for the Dt duplicates at the dough mixer (Table 5.3-1), it is the authors' opinion that use of the arithmetic mean (AM) of these duplicates is acceptable for the remainder of the result analysis, considering the small average relative difference as well as the narrow 95% confidence interval. In fact, use of all the results would have increased the number of comparisons tenfold, making their analysis more complex.

**Table 5.3-1: Paired *t* test - Comparison of the duplicates of the samples**

| Compared fractions | Workstation | Number of pairs | LCL-UCL 95% /the av. diff | Average deviation (%) | Rejection of $H_0$ |
|---|---|---|---|---|---|
| Dt 1 vs Dt 2 | Dough mixer | 10 | [0.15–1.08] | 9 | Yes |
| Fi 1 vs Fi 2 | Dough mixer | 11 | [-0.23–1.67] | 3 | No |
| Dt 1 vs Dt 2 | Table | 10 | [-0.15–0.73] | 17 | No |
| Fi 1 vs Fi 2 | Table | 11 | [-0.50–1.29] | 6 | No |

The results of 11 dough mixer workstations and 13 table workstations respectively constitute a total of 66 and 78 samples per workstation for the three fractions studied (Dt, Fi and Fr), since each of them was sampled in duplicate. The AMs of the analytical results by type of sample, their duration, as well as an estimated daily average exposure value (DAEV) (see equation 4.3-b) as Dt are grouped by workstation and by establishment in Table 5.3-2.

**Table 5.3-2: Average environmental measurement concentrations**

| Est | Work-station | Duration (min) | Average concentration of the results ($mg/m^3$) | | | DAEV ($mg/m^3$ Dt) |
|---|---|---|---|---|---|---|
| | | | Dt | Fi | Fr | |
| 1 | Dough mixer | 367 | 4.6 | 5.7 | < 0.06 * | 3.5 |
| | Table | 368 | 1.5 | 2.4 | < 0.03 * | 1.2 |
| 2 | Dough mixer | 302 | 4.9 | 8.0 | < 0.5 * | 3.6 |
| | Table | 349 | 2.7 | 4.7 | < 0.4 * | 2.0 |
| | Moulder | 361 | 0.9 | 1.2 | < 0.4 * | 0.6 |
| 3 | Dough mixer | 278 | 7.5 | 14 | < 0.04 * | 4.6 |
| | Table | 334 | 2.2 | 4.1 | < 0.03 * | 1.5 |
| | Table | 331 | 3.1 | 5.9 | 0.09 | 2.2 |
| 4 | Dough mixer | 171 | 1.5 | 2.0 | < 0.06 * | 0.6 |
| | Table | 174 | 0.1 | 0.5 | < 0.06 * | |
| 5 | Dough mixer | 77 | 7.7 | 11 | < 0.13* | 3.5 ** |
| | Table | 127 | 8.7 | 9.2 | < 0.08* | |
| 6 | Dough mixer | 260 | 9.1 | 14 | < 0.03 * | 5.6 ** |
| | Table | 143 | 2.4 | 3.7 | < 0.07 * | |
| 7 | Dough mixer | 260 | < 0.03 * | 0.2 | < 0.02 * | * |
| | Table | 143 | < 0.03 * | 0.2 | < 0.03 * | |
| 8 | Dough mixer | 258 | 2.1 | 2.4 | < 0.04 * | 1.2 |
| | Table | 384 | 2.4 | 3.5 | < 0. 03 * | 1.9 |
| 9 | Dough mixer | 195 | 11 | 18 | 0.5 | 4.4 |
| | Table | 197 | 0.1 | 0.4 | < 0.05 * | |
| 10 | Dough mixer | 185 | 16 | 19 | 0.26 | 7.5 |
| | Table | 160 | 3.6 | 5.2 | < 0.07 * | |
| 11 | Dough mixer | 159 | 0.8 | 1.4 | < 0.07 * | 1.8 |
| | Table | 186 | 3.9 | 6.9 | 0.3 | |

*: Analytical results below the minimum reported value (MRV).
**: The DAEV was calculated on all the tasks, because only one baker performed them, or the tasks followed each other during the intervention.

Table 5.3-3 summarizes the main descriptive statistical data of the environmental results.

**Table 5.3-3: Descriptive statistics**

| | Dough mixer | | | Table | | |
|---|---|---|---|---|---|---|
| | **Dt** | **Fi** | **Fr** | **Dt** | **Fi** | **Fr** |
| n | 11 | 11 | 11 | 11 | 11 | 11 |
| n ≥ MRV | 10 | 11 | 2 | 8 | 11 | 2 |
| Average (mg/m³) | 6.0 | 8.6 | 0.1 | 2.5 | 3.7 | 0.1 |
| Standard deviation | 5.0 | 6.9 | 0.1 | 2.5 | 2.8 | 0.1 |
| Median (mg/m³) | 4.9 | 8.0 | 0.1 | 2.4 | 3.7 | 0.1 |
| GM (mg/m³) | 3.0 | 4.9 | 0.1 | 1.1 | 2.2 | 0.1 |
| GSD | 6.0 | 4.2 | 2.5 | 6.2 | 3.7 | 2.2 |
| Range (mg/m³) | 0.03*–16.5 | 0.2–19 | 0.03*–0.5 | 0.03*–8.7 | 0.2–9.2 | 0.03*–0.3 |
| LCL-UCL 95% | [2.6–9.3] | [4.0–12] | [0.0–0.2] | [0.9–4.2] | [1.8–5.6] | [0.02–0.1] |

n: Number of samples MRV: Minimum reported value *: Value <MRV expressed as mg/m³
GM: Geometric mean GSD: Geometric standard deviation
LCL-UCL 95%: 95% lower-upper confidence limit

The environmental results are presented in "boxplot" format in Figure 5.3-1 for the three fractions sampled per station.

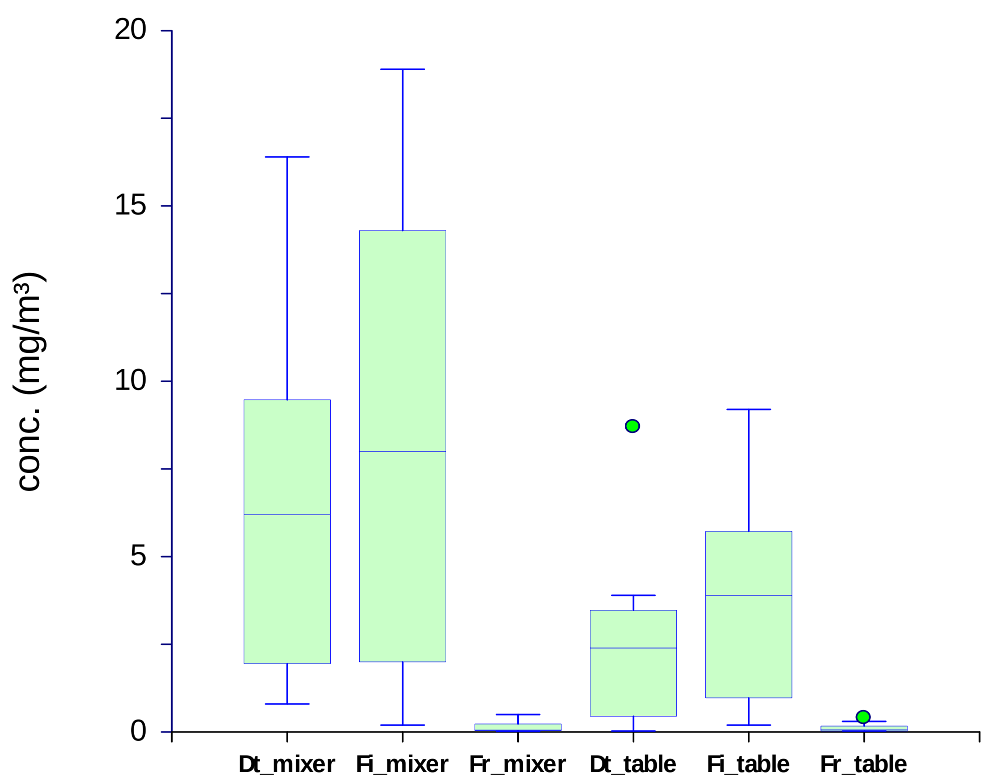



**Figure 5.3-1: Boxplots of the environmental results**

The observations collected during the interventions were related to the Dt concentrations and the total amount of flour used in the dough mixer (Table 5.3-4) by establishment. These observations mainly cover the bakers' work practices and the specific characteristics of the samples.

**Table 5.3-4: Dt and amount of flour used at the dough mixer**

| Est | Amount of flour (kg) | Dt ($mg/m^3$) | Remark |
|---|---|---|---|
| 1 | 140 | 4.6 | The flour used at the dough mixers was weighed the previous day. There were several types of flour. The dough mixers were located against a wall of the small bread production area. One had a full cover with an opening approximately 20% of the diameter; the other had no cover. The flour was added to the water. |
| 2 | 150 | 4.9 | One of the dough mixers had an open grillwork cover; the other had none. Several types of flours were used. The water was added to the flour. |
| 3 | 383 | 7.5 | The dough mixers were in a specific area. Two had a screen covering approximately 90% of their diameter; the other had a grillwork cover. Several types of flour were used. The flour was added to the water. |
| 4 | 174 | 1.5 | The dough mixer had no cover. Two types of flour were used. The flour was added to the water. |
| 5 | 66 | 7.7 | The two dough mixers were located 1.5 m in front of the table. One had no cover; the other had a grillwork cover that was never lowered. Two types of flour were used. The flour was added to the water. |
| 6 | 264 | 9.1 | The dough mixer had a grillwork cover. For each mixing operation, a large amount of flour was used, creating visible dustiness at start-up. One type of flour was used. The water was added to the flour. |
| 7 | 62 | < 0.03 * | The dough mixer was small and had a grillwork cover. Two types of flour were used. The water was added to the flour. |
| 8 | 86.5 | 2.1 | The baker placed a damp cloth on the grillwork cover before start-up. He wet his hands before cleaning the dough mixer and removing the dough, contrary to the others who put flour on their hands. Several types of flour were used. The flour was added to the water. |
| 9 | 202 | 11 | The dough mixers had grillwork covers. Several types of flour were used. The water was added to the flour. There was visible dustiness at dough mixer start-up. |
| 10 | 128 | 16 | The dough mixer had a grillwork cover and was started at low speed. Several types of flour were used. The flour was added to the water. |
| 11 | 187 | 0.8 | The amount of flour, mixed on the day of the intervention, was more than what was reported. However, the amount reported was what was mixed during sample collection. The flour was added to the water. |

*: Below the minimum reported value (MRV).

Even though the DRI was not calibrated in relation to the flour, its readings provided us with relevant information, as illustrated in Figure 5.3-2. According to our observations, the peak concentrations in this figure corresponded to the dustiness generated by the dusting of flour (technique of throwing flour on a surface to keep the dough from sticking) on the table and the use of the dough divider.

From the observations collected by the DRI, the concentration peaks could be linked to the operations being carried out at the dough mixer, as illustrated in Figure 5.3-3. The dough mixer is started after the flour to be added to it is weighed.

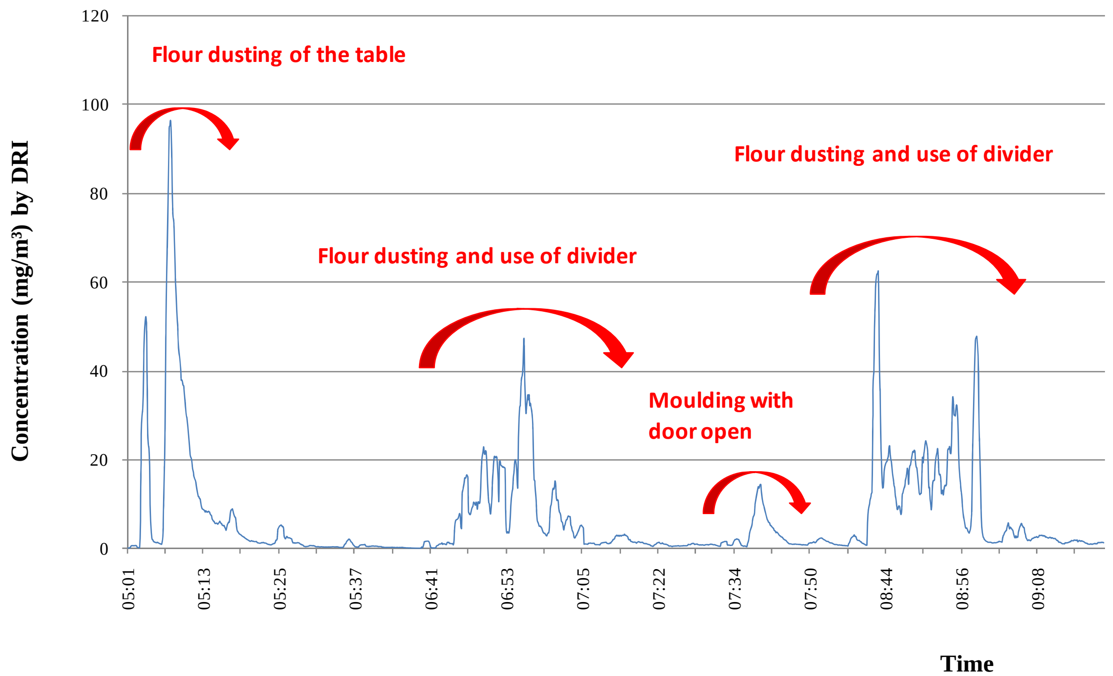



**Figure 5.3-2: Concentration read by the DRI at the table workstation in one of the establishments**

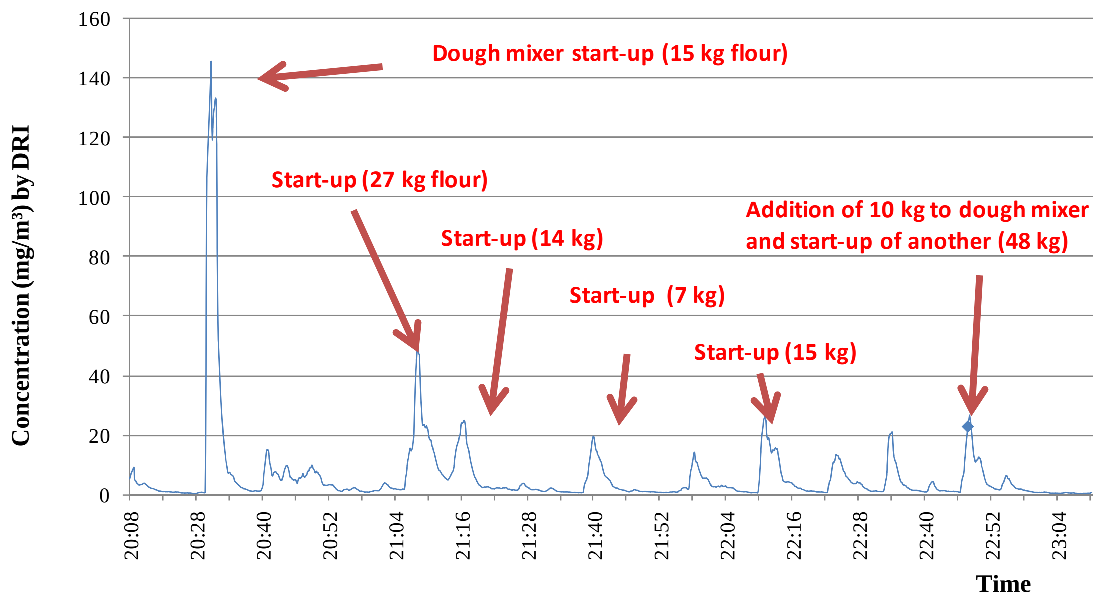



**Figure 5.3-3: Concentration read by the DRI at the dough mixer workstation in one of the establishments**

### 5.3.2 Relationship between inhalable fraction and total dust

The ratios calculated from the results for the IOM cassettes and 37-mm cassettes are listed by establishment and by workstation in Table 5.3-5. This ratio is obtained by dividing the Fi concentration by the Dt concentration. The results for establishment 7 do not appear in this table due to the Dt concentrations below the MRV. Also, the results at the table workstation in bakeries 4 and 9 were not included in the calculations of the mean and standard deviation since the Dt concentrations were below the MRV for one of the duplicates. The median ratio is 1.6 for these two workstations.

**Table 5.3-5: Fi/Dt ratio**

| Est | Fi/Dt | |
|---|---|---|
| | **Dough mixer** | **Table** |
| 1 | 1.2 | 1.6 |
| 2 | 1.6 | 1.7 |
| | | 1.3 |
| 3 | 1.8 | 1.9 |
| | | 1.9 |
| 4 | 1.3 | **5.0 *** |
| 5 | 1.5 | 1.1 |
| 6 | 1.6 | 1.5 |
| 8 | 1.1 | 1.5 |
| 9 | 1.7 | **4.0 *** |
| 10 | 1.2 | 1.4 |
| 11 | 1.8 | 1.8 |
| **Arithmetic mean** | **1.5** | **1.6** |
| **Standard deviation** | **0.3** | **0.3** |

*: The ratios at the table workstation in bakeries 4 and 9 are not part of the calculation of the average and standard deviation.

## 5.4 Dust – Particle size distribution

### 5.4.1 Impactors

Eleven (11) samples were collected by the eight-stage impactors at the dough mixer workstation and twelve (12) at the table workstation. The corrected mass median aerodynamic diameters (MMAD) are listed in Table 5.4-1 by establishment and by workstation, as well as the geometric standard deviations (GSD) by assuming the population to be lognormal. The uncorrected data are in Appendix 1.

**Table 5.4-1: Particle size distribution by establishment and by workstation**

| Est | Workstation | MMAD (µm) | GSD (µm) |
|---|---|---|---|
| 1 | Dough mixer | 23.9 * | 1.6 |
| | Table | 22.0 | 2.4 |
| 2 | Dough mixer | 19.9 * | 1.9 |
| | Table | 22.6 * | 2.0 |
| | | 14.1 | 2.0 |
| 3 | Dough mixer | 25.2 | 1.7 |
| | Table | 17.8 * | 1.9 |
| 4 | Dough mixer | 23.2 | 1.7 |
| 5 | Dough mixer | 23.1 | 1.6 |
| 6 | Dough mixer | 22.4 | 1.8 |
| | Table | 20.7 | 1.8 |
| 7 | Dough mixer | 12.7 ** | 2.5 |
| | Table | 1.6 | 4.0 |
| 8 | Dough mixer | 24.2 | 1.8 |
| | Table | | |
| 9 | Dough mixer | 22.4 | 1.9 |
| | Table | 2.7 ** | 14.5 |
| 10 | Dough mixer | 24.4 | 1.9 |
| | Table | 23.2 | 1.9 |
| 11 | Dough mixer | 14.5 ** | 3.8 |
| | Table | 27.7 | 2.4 |

MMAD: Mass median aerodynamic diameter
GSD: Geometric standard deviation
*: Two possible modes of distribution
**: Less than or equal to the MRV

The main descriptive statistical data for the particle size distribution results obtained by the impactors are summarized in Table 5.4-2.

**Table 5.4-2: Descriptive statistics of the corrected particle size distribution results**

| | Mass median aerodynamic diameter (MMAD) | | | |
|---|---|---|---|---|
| | Dough mixer | | Table | |
| | <MRV included | <MRV not included | <MRV included | <MRV not included |
| n | 11 | 9 | 9 | 8 |
| n ≥ MRV | 9 | 9 | 8 | 8 |
| Average (µm) | 21.4 | 23.2 | 17.2 | 18.7 |
| Standard deviation | 4.1 | 1.6 | 8.7 | 8.0 |
| Median (µm) | 23.1 | 23.2 | 20.7 | 21.4 |
| GM (µm) | 21.0 | 23.1 | 13.4 | 15.1 |
| GSD | 1.3 | 1.07 | 2.56 | 2.5 |
| Range (µm) | 12.7–25.2 | 19.9–25.2 | 1.6–27.7 | 1.6–27.7 |
| LCL-UCL 95% (µm) | [18.7–24.2] | [22.0–24.4] | [10.5–23.9] | [12.0–25.9] |

n: Number of samples
MRV: Minimum reported value
GM: Geometric mean
GSD: Geometric standard deviation
LCL-UCL 95%: 95% lower-upper confidence limit

Figure 5.4-1 contains the corrected aerodynamic diameters (MMAD) in boxplot format by workstation.

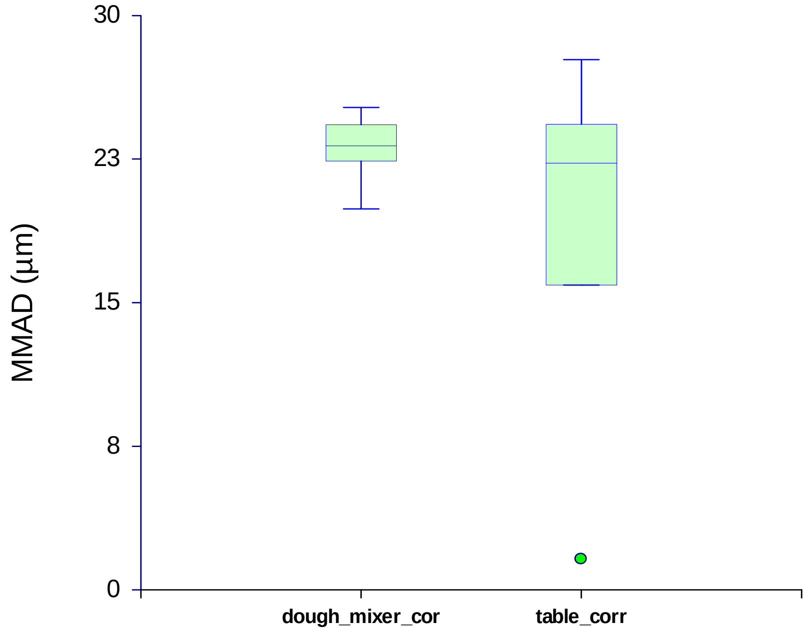



**Figure 5.4-1: Boxplots of the corrected particle size distribution results**

The normalized histograms of the mass fractions for each of the sampling stations are presented in Appendix 2. The number indicates the establishment, and the letter, the workstation. For example, 1T corresponds to establishment 1 at the table workstation.

The concentrations calculated from the masses collected by the impactor are grouped by impactor concentration ($Conc_i$), Fii and Fri of the dusts and presented in Table 5.4-3. They are illustrated in boxplot format in Figure 5.4-2. The uncorrected concentrations are in Appendix 3.

**Table 5.4-3: Concentration calculated from the masses collected by the impactor**

| Est | Work-station | Corrected concentration (mg/m³) | | |
|---|---|---|---|---|
| | | $Conc_i$ | **Fii** | **Fri** |
| 1 | Dough mixer | 5.8 | 3.7 | 0.1 |
| | Table | 1.4 | 0.9 | 0.1 |
| 2 | Dough mixer | 8.4 | 5.5 | 0.2 |
| | Table | 7.1 | 4.6 | 0.2 |
| | Moulder | 1.6 | 1.2 | 0.1 |
| 3 | Dough mixer | 21 | 13 | 0.1 |
| | Table | 7.2 | 5.0 | 0.7 |
| 4 | Dough mixer | 5.1 | 3.2 | 0.0 |
| 5 | Dough mixer | 9.0 | 5.7 | 0.0 |
| 6 | Dough mixer | 13 | 8.4 | 0.2 |
| | Table | 5.3 | 3.4 | 0.1 |
| 7 | Dough mixer | < **0.1 *** | * | * |
| | Table | 0.5 | 0.4 | 0.4 |
| 8 | Dough mixer | 4.7 | 3.0 | 0.1 |
| 9 | Dough mixer | 21 | 13 | 0.5 |
| | Table | < **0.5 *** | < **0.4 *** | < **0.3 *** |
| 10 | Dough mixer | 19 | 12 | 0.6 |
| | Table | 5.1 | 3.3 | 0.1 |
| 11 | Dough mixer | < **0.7 *** | < **0.5 *** | < 0.1 * |
| | Table | 6.6 | 4.2 | 0.3 |

***: Less than or equal to the MRV.**

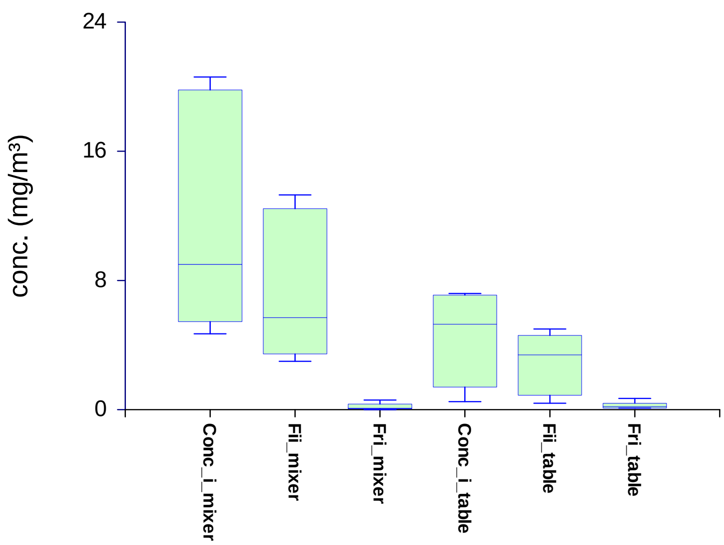
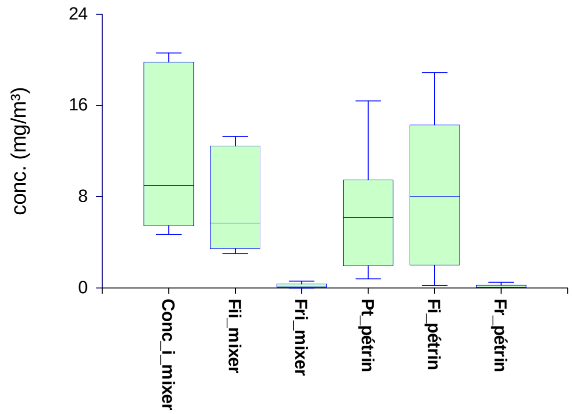
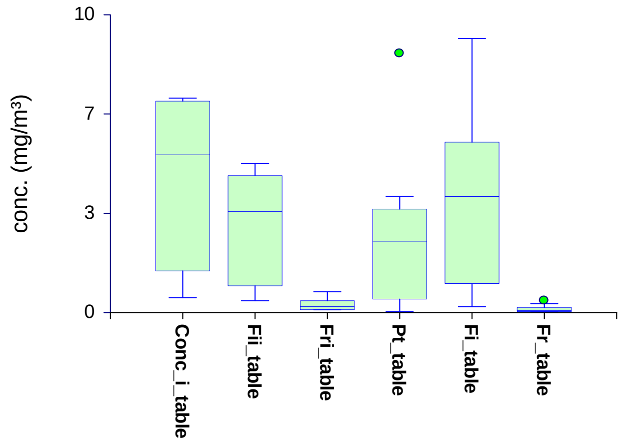



**Figure 5.4-2: Boxplot of the corrected concentrations by fraction**

The concentrations obtained with the impactors (Table 5.4-3) and those for the environmental measurements (Table 5.3-2) by workstation are illustrated in boxplot format in Figures 5.4-3a (dough mixer) and 5.4-3b (table workstation). A paired *t* test was also performed on the data obtained with the IOM cassettes (Fi) and impactors (Fii) (Table 5.4-4) to verify whether the Fi results were significantly greater than the Fii results.




**a: dough mixer workstation** **b: table workstation**

**Figure 5.4-3: Boxplot of the corrected concentrations by workstation**

**Table 5.4-4: Paired *t* test - Comparison of the inhalable fraction concentrations**

| Compared fractions | Workstation | P (α = 0.05) | T | Type of test | Rejection of $H_0$ |
|---|---|---|---|---|---|
| $H_0$ hypothesis: difference between the values = 0 | | | | | |
| Fi vs Fii | Dough mixer | 0.019 | 2.92 | Parametric | Yes |
| Fi vs Fii | Table | 0.169 | 1.56 | Parametric | No |

Fi: Inhalable fraction obtained by IOM cassette.
Fii: Inhalable fraction calculated from the dusts collected by the impactors.

## 5.4.2 Direct-reading instrument

The mass percentage read by the DRI by particle size fraction is summarized in Table 5.4-5 and illustrated in Figure 5.4-4.

**Table 5.4-5: Mass percentage read by the GRIMM PAS 1.108 by particle size fraction**

| | | Mass percentage (%) read by the DRI | | | |
|---|---|---|---|---|---|
| **Est** | **Workstation** | **0.23–4.0 µm** | **4.0–10.0 µm** | **10.0–20 µm** | **> 20 µm** |
| 1 | Table | 4.5 | 25.7 | 52.1 | 17.7 |
| 2 | Dough mixer | 3.6 | 45.8 | 45.6 | 5.0 |
| | Table | 1.4 | 26.3 | 57.2 | 15.1 |
| 3 | Dough mixer | 1.4 | 21.8 | 57.8 | 19.0 |
| | Table | 6.8 | 14.6 | 49.4 | 29.2 |
| 4 | Table | 20.1 | 15.9 | 42.8 | 21.1 |
| 5 | Dough mixer | 2.0 | 17.2 | 58.0 | 22.7 |
| 6 | Dough mixer | 1.2 | 18.6 | 54.5 | 24.0 |
| 7 | Dough mixer | 24.5 | 34.8 | 31.6 | 9.1 |
| 8 | Dough mixer | 7.3 | 24.4 | 47.0 | 21.3 |
| | Table | 2.7 | 23.0 | 54.4 | 19.9 |
| 9 | Dough mixer | 13.9 | 26.0 | 49.1 | 6.0 |
| 10 | Dough mixer | 6.1 | 42.7 | 46.4 | 4.7 |
| 11 | Dough mixer | 35.7 | 25.1 | 30.2 | 9.0 |

**Dough mixer workstation**

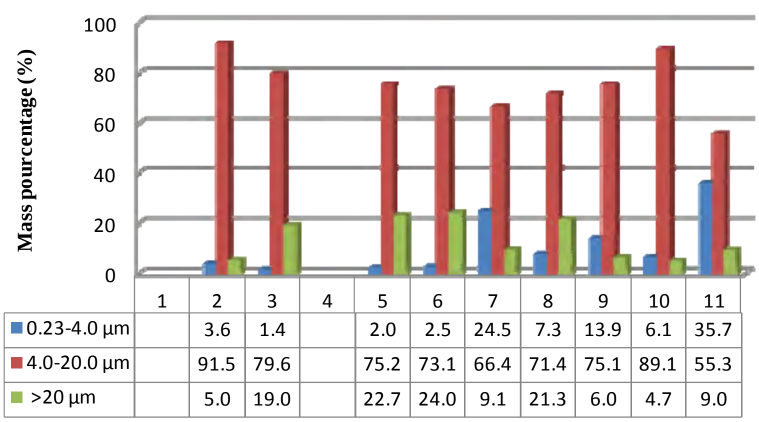



**Table workstation**

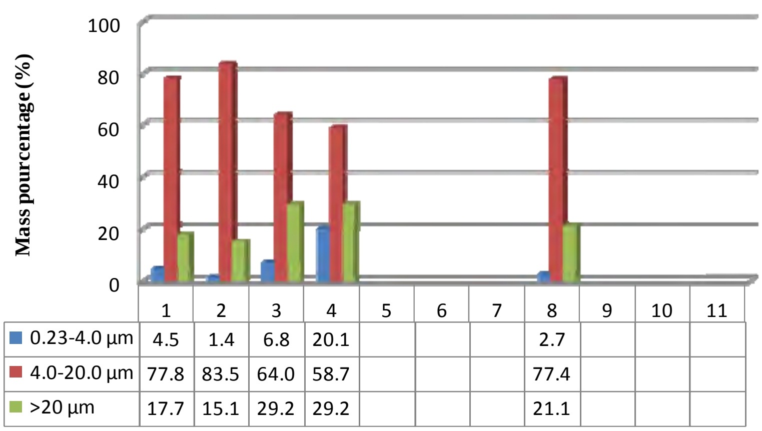



**Figure 5.4-4: Mass percentages read by the GRIMM PAS 1.108 by particle size fraction**

# 6. DISCUSSION

This section covers the analysis of the environmental and particle size distribution results, the limitations of the study, and the recommendations

## 6.1 Dust – Environmental results

This section of the discussion deals with the concentrations measured by the different samplers, comparison of the Dt and Fi concentrations, as well as an estimate of the risk of flour exposure at the studied workstations for a traditional bakery.

### *6.1.1 Dt, Fi and Fr concentrations*

The environmental results (Table 5.3-2) correspond to the arithmetic mean of the sample duplicates, as described in the methodology section (section 4.1). The small bias observed (Table 5.3-1) between the Dt duplicates at the dough mixer workstation does not call into question the use of their arithmetic mean for the reasons explained in section 5.3.1. However, this bias could be explained by the positioning of the Dt cassettes, one at the edge of the plate and the other in the centre (Figure 4.1-1), such that the aspiration zone for cassette Dt1 is different from that of cassette Dt2. The authors explain the lack of significant difference in the Dt duplicates at the table workstations by the low concentrations measured (Table 5.3-1 and Meijster *et al.* (2008)).

In this study, the new method using the IOM sampler for sampling and analyzing the inhalable dust fraction was applied. The small difference obtained between the results of the Fi duplicates (4.5%), at the dough mixer and at the table, complements the method's analytical validation data for IRSST method 373 in terms of precision, including the variability due to sampling and field manipulations.

### *6.1.2 Relationship between the inhalable fraction and total dusts*

The median concentrations of Dt (Table 5.3-3) are less than those of Fi. Furthermore, examination of the results of a paired *t* test on these results (Table 6.1-1) leads to the conclusion that Fi is significantly greater than Dt. This situation is also observed in Table 5.3-5 where the value of the ratio (AM: 1.6, SD: 0.3) shows that the relationship is relatively constant in this type of work environment, regardless of the workstation. This can be explained by the samplers' efficiency curves. In fact, as discussed in section 6.2, the IOM sampler is more effective for sampling larger sized particles and therefore heavier ones, while the 37-mm closed cassette is known for underestimating exposure to particles with an aerodynamic diameter greater than 20 µm (Vincent 2007).

**Table 6.1-1: Paired *t* test - Comparison of the concentrations of the Fi and Dt fractions**

| Compared fractions | Work-station | P ($\alpha$ = 0.05) | T | Type of test | Rejection of $H_0$ |
|---|---|---|---|---|---|
| $H_0$ hypothesis: difference between the values = 0 | | | | | |
| Fi vs Dt | Dough mixer | 0.005 | 3.56 | Parametric | Yes |
| Fi vs Dt | Table | 0.001 | 4.48 | Parametric | Yes |

The study by Perrault *et al.* (1999) reported that the Fi concentrations were approximately 2.1 times greater than the Dt concentrations, in the workers' breathing zones as well as for stationary sampling for the establishments visited in their study. These establishments are listed in four different sectors, one being a Québec mill in which the researchers reported an Fi/Dt ratio of 2.35 (n=16). Finally, based on the concentrations reported by Karpinski (2003), who studied 17 Canadian flour mills, this ratio would be 2.64.

These ratios differ from the ratio obtained from the concentrations measured in traditional bakeries. Even though flour is involved in these two environments (traditional bakeries and flour mills), they use distinct processes. The difference in the factors could be due to the different particle size distributions, as mentioned by Perrault *et al.* (1999).

### 6.1.3 Estimation of dust exposure

Work methods differ from one baker to another; some use more flour than others when dusting with flour and in moulding/rounding. During the use of a dough divider (Figure 5.1-2b) and flour dusting, the authors observed projections of flour, as illustrated in Figure 5.3-2 (table workstation). Also, visible dustiness was observed when the dough mixer was started, which translated into relatively high concentration peaks, presented in Figure 5.3-3 (dough mixer workstation). Appendix 4 presents all of the DRI results in graphical form; concentration peaks caused by the different tasks at the dough mixers (bag emptying and dough mixer start-up) and at the table (moulding/rounding) were observed.

In establishment 9, moulding was mainly done outside of the sampling period. In fact, the sampling period corresponded to approximately half the duration of the moulding/rounding tasks. In this establishment, as in some others (namely establishments 1, 8, 9 and 10), the dough was mixed on one day, and then placed in a temperate zone until the next day when it was rounded and moulded.

The result for establishment 5 is explained by the small bread production area (area in a bakery where the ovens are found and where the dough is worked), the proximity of the table, and the dough mixers. The dough mixers were also operated while work was being done at the table for 36% of the sampling period. These observations may explain why this establishment's results differed from those of the other establishments. Its bread production area was not equipped with a ventilation system.

In establishment 7, the measured concentrations were low, even below the MRV. This can be explained by the low production of bread on the day of the intervention, the baker's work practices, and the efficiency of the ventilation system.

The median concentrations (Table 5.3-3) and the boxplots (Figure 5.3-1) suggest that the highest risk of flour dust exposure would be at the dough mixer workstation. A paired *t* test (Table 6.1-2) shows that the concentrations measured at the dough mixer were significantly higher than those at the table.

**Table 6.1-2: Paired *t* test - Comparison of concentrations by workstation**

| Fractions | Compared workstations | P ($\alpha$ = 0.05) | T | Type of test | Rejection of $H_0$ |
|---|---|---|---|---|---|
| $H_0$ Hypothesis: difference between the values = 0 | | | | | |
| Fi | Dough mixer vs table | 0.039 | 2.37 | Parametric | Yes |
| Dt | Dough mixer vs table | 0.046 | 2.28 | Parametric | Yes |

The more flour there is in the dough mixer, the greater the dust contamination when the dough mixer is started. As an example, consider the qualitative readings obtained (rounded off) with the DRI in two bakeries (Figure 6.1-1):

a maximum concentration of 1,780 mg/m³ obtained when mixing 80 kg of flour
compared to
a maximum concentration of 6.1 mg/m³ when mixing 10 kg of flour.

There is a greater than 280-fold estimated difference between their dust contamination levels at start-up, as read by the DRI. Each of these two bakeries had only one dough mixer with a grillwork cover, and the DRI was positioned at an equal distance from it.

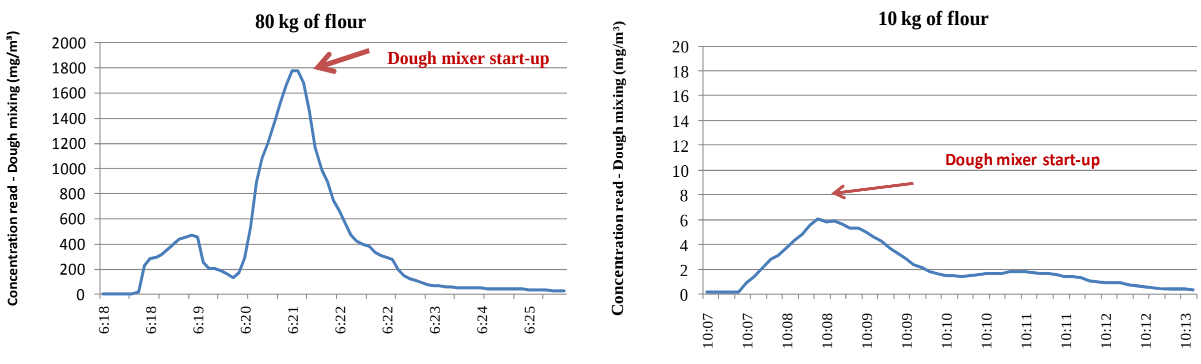



**Figure 6.1-1: Estimation of the dust generated during start-up of the dough mixer**

A baker's tasks are varied and some do not involve flour handling or are administrative in nature. According to the calculation of the DAEV, carried out using equation 4.3-b, the bakers' exposure for the visited establishments seems to be below the time-weighted average exposure value

(TWAEV) recommended in Schedule I of the ROHS (PNOC: 10 mg/m³) if the personal exposure measured during the work shift were identical to the concentrations measured with stationary sampling. Normally, the concentrations measured in the baker's breathing zone would be different from the stationary sampling concentrations. However, Houba *et al.* (1998a,b) reported that the risk of flour dust sensitization increases if the Fi levels are above 2 mg/m³, even though this sensitization is prevalent in bakers exposed to levels of 1 mg/m³. The DAEVs calculated for stationary sampling are mostly above this latter level. Only the DAEVs obtained in establishment 4 (where the bakers do not dust with flour to any great extent and due to the distance of the table workstation), and in establishment 2 at the table workstation at the moulder (equipment not extensively used) are below this level.

## 6.2 Dust – Particle size distribution

The histograms presented in Appendix 2 illustrate the particle size distributions for all of the sampling stations. The particle size distributions, corrected or not, show the possible presence of two modes: one consisting of larger dusts (between 20 and 50 µm) and another of finer dusts (smaller than 1 µm). Some particle size distributions may therefore result from the overlapping of two distinct populations of particles. The mode smaller than 1 µm, linked to an additional population of finer dusts, does not seem to be present in all the establishments. It was observed in those establishments using enriched flour or all-purpose flour, based on information from the bakers (see Table 5.2-1). This is explained by the fact that the establishments use various brands of different flours.

Despite the fact that the inhalable fraction (Fii) concentrations varied between the MRV and 14 mg/m³ and that the impactor concentrations ($Conc_i$) varied between the MRV and 21 mg/m³, the particle size distributions are similar, without being identical, for particles larger than 10 µm. The existence of a practically similar particle size distribution for the largest particles is useful for occupational hygienists doing assessments in traditional bakeries.

### *6.2.1 Particle size distribution at the dough mixer workstations*

The median MMAD calculated for the dough mixer workstations, except for those where the collected masses were below the MRVs, was 23.2 µm for the corrected profiles. The corrected particle size distributions for these workstations are presented in Figure 6.2-1. The uncorrected profiles are in Appendix 5. The particle size distributions for the different dough mixer workstations are similar, with a mode around an aerodynamic diameter of 20 µm.

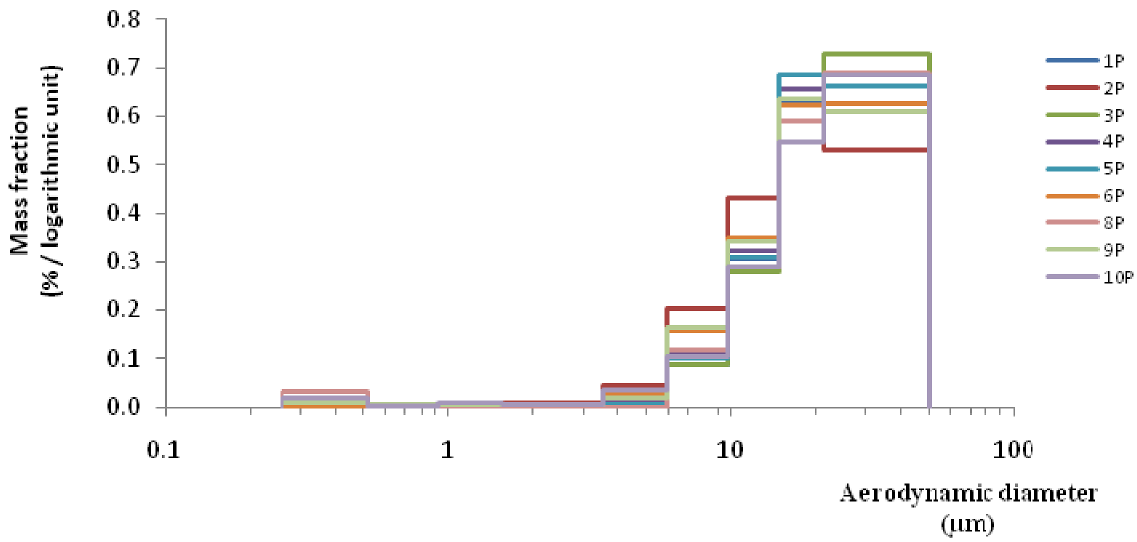



**Figure 6.2-1: Particle size distribution at the dough mixer workstation by establishment**

## 6.2.2 Particle size distribution at the table workstations

The corrected particle size distributions for the table workstations, whose collected masses were significant, are presented in Figure 6.2-2. One notes a higher proportion of smaller dusts compared to the histograms for the dough mixer workstations. Sampling station 2T2 was eliminated for the reasons given below. The uncorrected profiles are in Appendix 5.

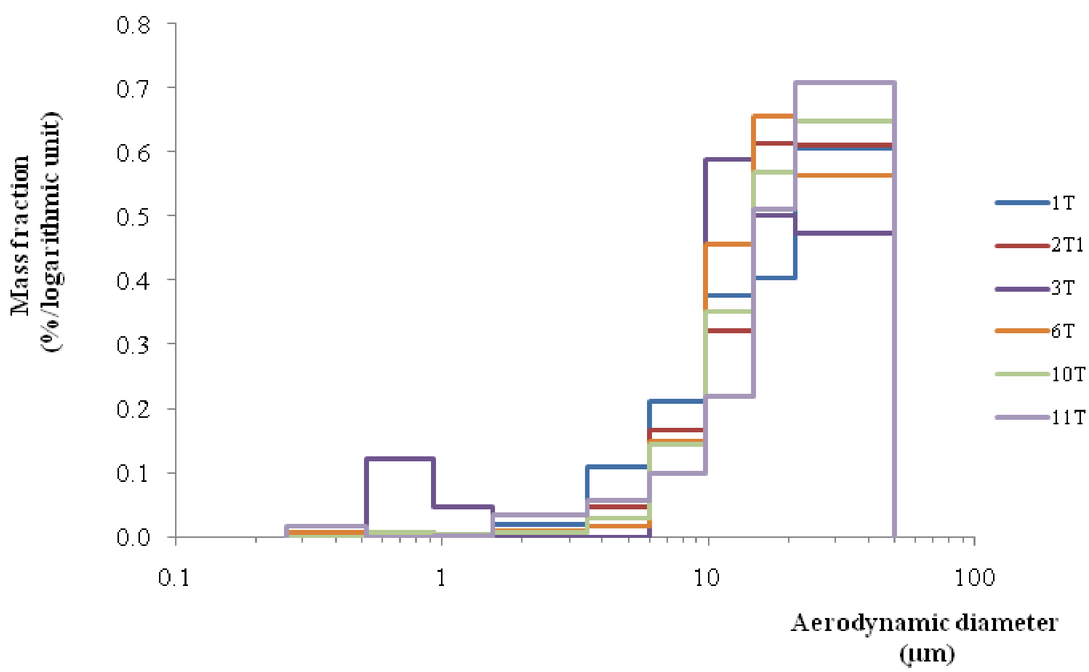



**Figure 6.2-2: Particle size distribution at the table workstation by establishment**

The particle size distributions obtained for the table workstations had rather variable profiles, except for establishment 3. This establishment's different profile seems to be related to the bakers' work practices. By eliminating this establishment's particle size distribution histogram (Figure 6.2-3), more similar distributions are found for the establishments.

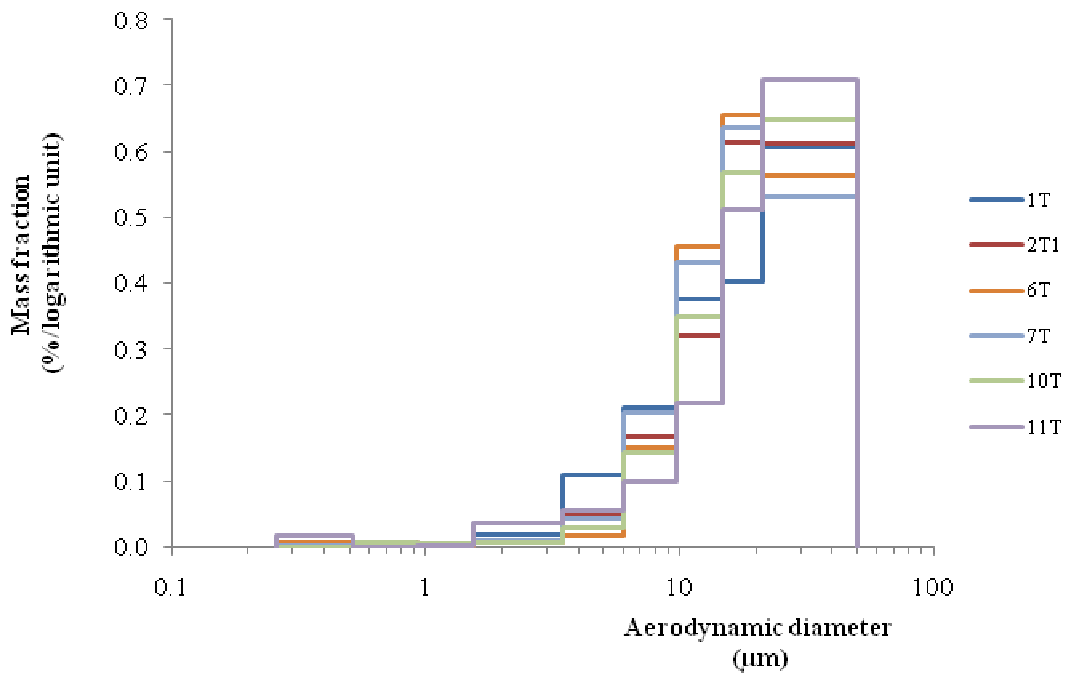



**Figure 6.2-3: Particle size distribution at the table workstation without establishment 3**

The median of the MMADs is 22.3 µm for the corrected profiles for the table workstations without the less significant results. A larger variability is noted in the masses collected on each stage for these workstations than for the dough mixer workstations. Figure 5.4-1 shows this variability in the results for the table workstations. This figure also shows that the MMADs for these workstations are slightly smaller than those for the dough mixer workstations. This is normal due to the larger proportion of fine particles, which can be seen on the histograms.

One effect of the distance between two sampling stations (2T1 and 2T2), located approximately 1.5 m apart (see Table 5.4-3), was identified for establishment 2. In this establishment, the baker works mainly near sampling station 2T1, while sampling station 2T2 is located close to the mechanical moulder, which is rather infrequently used. The particle size distributions for these two sampling stations were isolated in Figure 6.2-4. Sampling station 2T2 has higher proportions of finer particles. This is explained by a reduction in the number of larger particles due to sedimentation and therefore by an enrichment of the ambient aerosol by small particles. This reduction increases with the distance from the emission point located near sampling station 2T1.

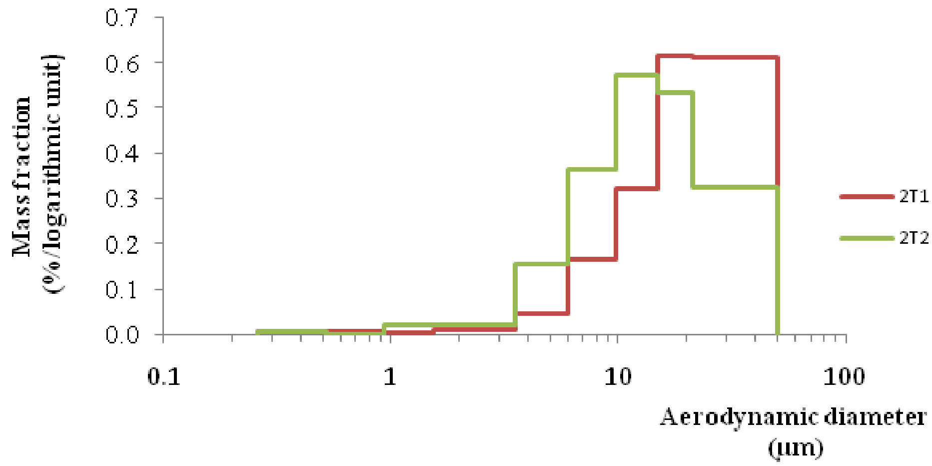



**Figure 6.2-4: Particle size distribution at two table workstations in establishment 2**

### 6.2.3 Direct-reading instrument

The particle size distribution results obtained by DRI are similar to the particle size distribution profiles obtained by the Marple impactors. In fact, Table 5.4-5 shows the presence of one mode in the interval between the 10 and 20 µm diameters while taking into account the instrument limitations (section 4.1). It is normal to observe a difference between the optical diameter measured by an optical counter (GRIMM PAS 1.108) and the aerodynamic diameter obtained using an impactor (see section 4.1). Also, by assuming that the optical diameter is close to the geometric diameter and that the density of the particles is greater than 1.0, it is normal for the geometric diameter to correspond to a larger aerodynamic diameter.

## 6.3 Relationship between Fi, Fii and the dusts collected by the impactor

The inhalable fractions (Fii) obtained by multiplying the IOM sampler's theoretical efficiency curve by the impactor data for the table workstations do not differ significantly from the measured Fi, whereas for the dough mixer workstations, they are significantly different (see Table 5.4-4). However, the Fii gave results whose median is slightly less than that obtained with the IOM samplers (Table 5.4-4 and Figure 5.4-3). This can be attributed to the correction process, which would not completely correct for the losses.

In fact, the impactors' correction curves show greater losses for large particles than for small particles. They are limited to diameters smaller than 30 µm. The particle size distributions obtained in the traditional bakeries studied show that a large proportion of the mass lies in this zone. However, the fact that there is no significant difference for the table workstations, where there is a larger proportion of small particles, may indicate that the correction process is more efficient for small particles and less efficient when there are larger proportions of larger particles. The difference may also be due to an overevaluation of the inhalable fraction by the IOM samplers.

The impactor concentration ($Conc_i$) is an evaluation of the actual concentration of particles present in the ambient air. Closed cassettes also sample this actual concentration with more or less efficiency, and by convention, the fraction is called “total dusts (Dt).” The median of the results obtained for $Conc_i$ is substantially larger than the median of the Dt obtained by the cassettes (Figure 5.4-3).

The total dust (Dti) that would theoretically be sampled by closed cassettes can be evaluated by multiplying the impactor data by the efficiency curve for the closed cassettes, as was done for the inhalable fraction (Fi). An approximate curve for a cassette’s efficiency, illustrated in Figure 6.3-1,[3] was estimated for this study by combining the data of the efficiencies obtained by different researchers under different conditions (represented by the points in the figure).

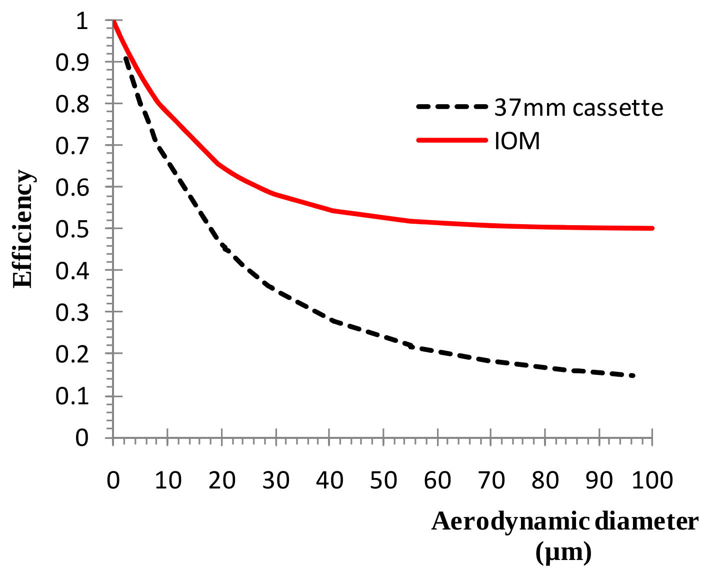



**Figure 6.3-1: Best-fit trend curve for Dt compared to that for the IOM**

The results obtained using this theoretical curve appear in Appendix 6 in Tables A.6-1 (for the uncorrected concentrations) and A.6-2 (for the corrected concentrations).

A mean ratio situated around 1.5 between the Fii and the Dti collected by a closed cassette was established by using the curve in Figure 6.3-1. It corresponds approximately to the mean ratio of 1.6 established from the environmental samples in the bakeries (Table 5.3-5). Note that it was established from the particle size distributions obtained for the flour samples in traditional bakeries.

## 6.4 Limitations of the study

The conclusions of this report relate to traditional bakeries. Extrapolations to other workplaces that use or produce flour must be done with care. The types of flours were not taken into account in result interpretation. As shown in this report, they can affect the particle size distributions of

[3] This curve is adapted from the curve obtained by Vincent, James (2007). It was adapted using mathematical formulas by the authors of this report.

the airborne dust. Also, the results correspond to stationary sampling concentration levels and not personal sampling. The DAEVs were calculated for stationary sampling and are not representative of personal sampling exposures; the samples at these two stations may differ greatly due to distance. Also, the DAEVs were calculated by assuming that the exposures were zero outside the sampling periods, which is rather unlikely.

Several bakeries in the study used different flours and in variable quantities, depending on the day and the demand. The data in our study do not specifically take these factors (type of flour and the amount used) into account because the sampling durations were likely not long enough for estimating dust concentration levels for each flour used.

Despite the fact that the impactor data were corrected according to the manufacturer's specifications, the impactor concentration ($Conc_i$) is an evaluation of the concentration present in the air. Closed cassettes (Dt) sample this fraction rather efficiently.

## 6.5 Recommendations

Characterization of the flours, at the emission points and in relation to the distance, would provide knowledge about changes in the particle size distribution. Calculation techniques involving the impactor data require more research on the evaluation of losses, particularly for diameters larger than 21 µm.

By studying these workstations at the same time as personal exposures are evaluated, the exposure of bakers in traditional bakeries could be documented. Also, the concept of work practice could be specifically documented for the purpose of demonstrating the link between certain practices and increased risk. Note that some studies report a higher risk of respiratory problems, including baker's asthma, in relation to the concentration level and the duration of exposure.

Finally, studies on flour dusts show a potential for sensitization when the exposure is above 2 mg/m³ for the inhalable fraction. According to some studies, the inhalable fraction correlates better with the toxicological effects than do the total dusts. In a context of consultation with the CSST, it would be interesting to establish a new and lower reference value for flour dusts expressed as an inhalable fraction.

# 7. CONCLUSION

The small difference between the results for the Fi duplicates, at the dough mixer and at the table, complements the method's analytical validation data for the method using the IOM sampler in terms of precision, including the variability due to sampling and field manipulations. This shows that the new sampling and analytical method is routinely applicable in the workplace for evaluating inhalable fraction dusts. The DAEVs calculated for stationary sampling seem to be below the reference values, but were all above the concentrations that can cause lung sensitization, a level reported in the consulted literature. However, these DAEVs cannot be considered as representative of personal exposures.

A mean ratio around 1.6 was determined between the inhalable fraction and total dust. This ratio, which showed that the IOM sampler could collect higher concentrations, was theoretically confirmed by the impactors' particle size distribution data. The small structures measured using Marple type impactors showed practically similar profiles for the dough mixer workstations, with one mode situated between 20 and 50 µm, and another at the sub-micron level (< 1 µm), which would be present only when certain flours are used. Profiles much more variable than those for the dough mixer workstations were observed for the table workstations with larger proportions of small particles. These particle size distribution profiles also sometimes show the possible presence of a sub-micron mode. Some of the deviations observed in several establishments can be explained by the effect of distance, the forces involved, and the work practices. The ambient particle size distribution was shown to be enriched by smaller particles over a distance of 1.5 m and was attributed to sedimentation.

From our observations, the main exposure risk factors in a traditional bakery are:

- the total amount of flour used;
- the type of flour;
- the amount of flour per dough mixing operation;
- the number of dough mixers in operation;
- the cover of the dough mixer;
- the work practices:
    - adding flour to water,
    - emptying flour bags,
    - the dough mixer's start-up speed,
    - dusting with flour,
    - using a broom and not a vacuum to clean up the flour on the floor.

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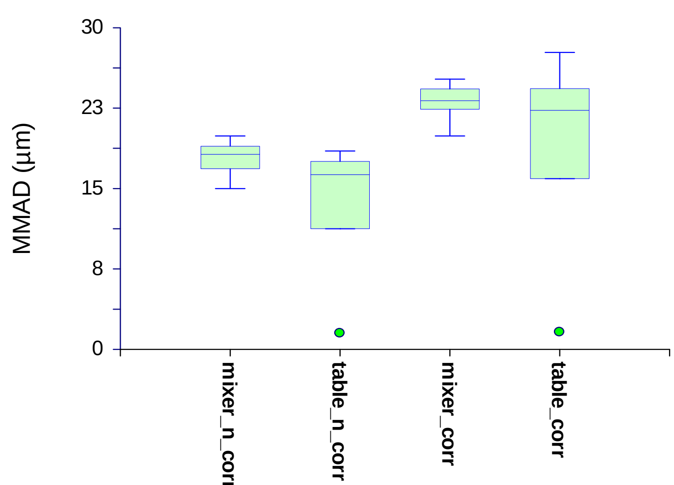
# APPENDIX 1: PARTICLE SIZE DISTRIBUTION BY ESTABLISHMENT AND BY WORKSTATION

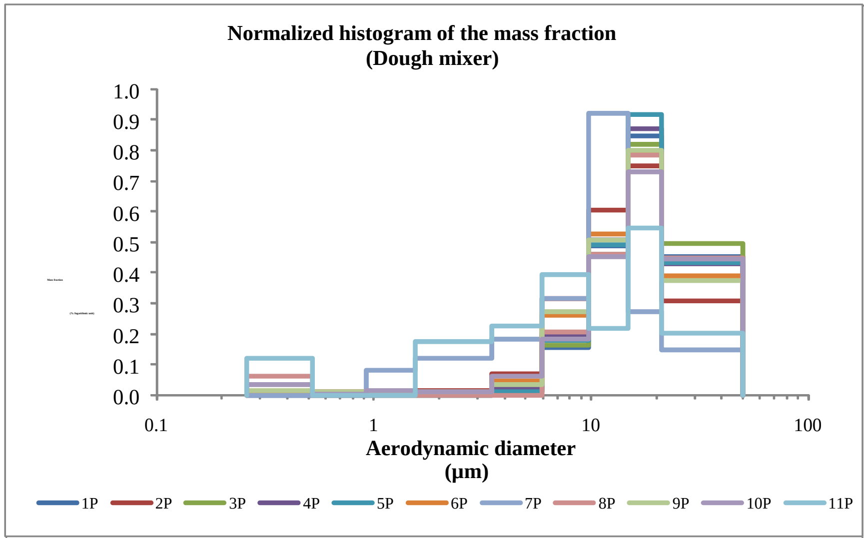
| | | Uncorrected | | Corrected | |
|---|---|---|---|---|---|
| Est | Workstation | MMAD (µm) | GSD | MMAD (µm) | GSD |
| 1 | Dough mixer | 19.9 * | 1.7 | 23.9 * | 1.6 |
| | Table | 14.5 | 2.1 | 22.0 | 2.4 |
| 2 | Dough mixer | 15.0 * | 1.7 | 19.9 * | 1.9 |
| | Table | 16.4 * | 1.8 | 22.6 * | 2.0 |
| | | 11.2 | 1.8 | 14.1 | 2.0 |
| 3 | Dough mixer | 19.4 | 1.6 | 25.2 | 1.7 |
| | Table | 14.4 * | 6.4 | 17.8 * | 1.9 |
| 4 | Dough mixer | 18.2 | 1.6 | 23.2 | 1.7 |
| | Table | ** | | ** | |
| 5 | Dough mixer | 18.5 | 1.5 | 23.1 | 1.6 |
| | Table | | | | |
| 6 | Dough mixer | 17.0 | 1.7 | 22.4 | 1.8 |
| | Table | 16.2 | 1.6 | 20.7 | 1.8 |
| 7 | Dough mixer | 9.4 ** | 2.2 | 12.7 ** | 2.5 |
| | Table | 1.5 | 3.9 | 1.6 | 4.0 |
| 8 | Dough mixer | 18.3 | 1.8 | 24.2 | 1.8 |
| | Table | | | | |
| 9 | Dough mixer | 16.7 * | 1.8 | 22.4 | 1.9 |
| | Table | 1.4 ** | 8.4 | 2.7 ** | 14.5 |
| 10 | Dough mixer | 17.9 * | 1.8 | 24.4 | 1.9 |
| | Table | 17.2 | 1.8 | 23.2 | 1.9 |
| 11 | Dough mixer | 8.8 ** | 3.0 | 14.5 ** | 3.8 |
| | Table | 18.5 * | 2.5 | 27.7 | 2.4 |

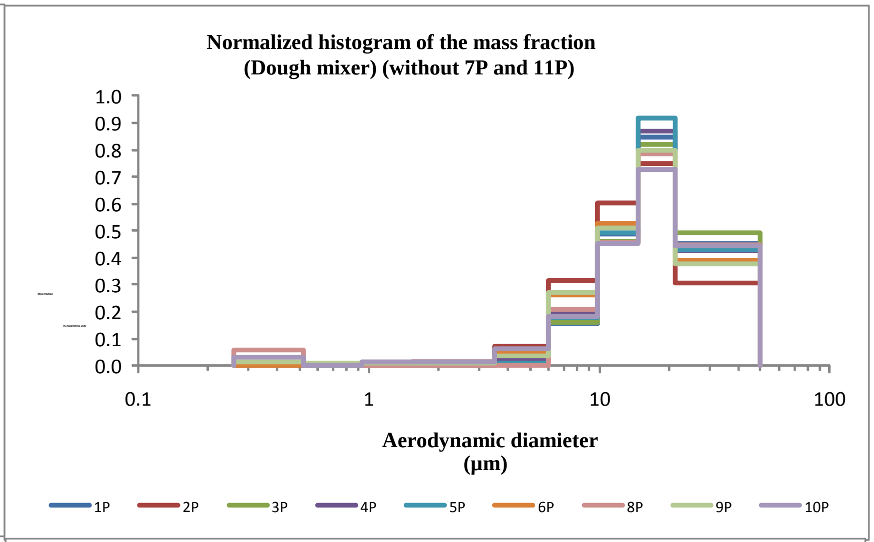
MMAD: Mass median aerodynamic diameter GSD: Geometric standard deviation
*: Two possible modes of distribution **: Less than or equal to the MRV

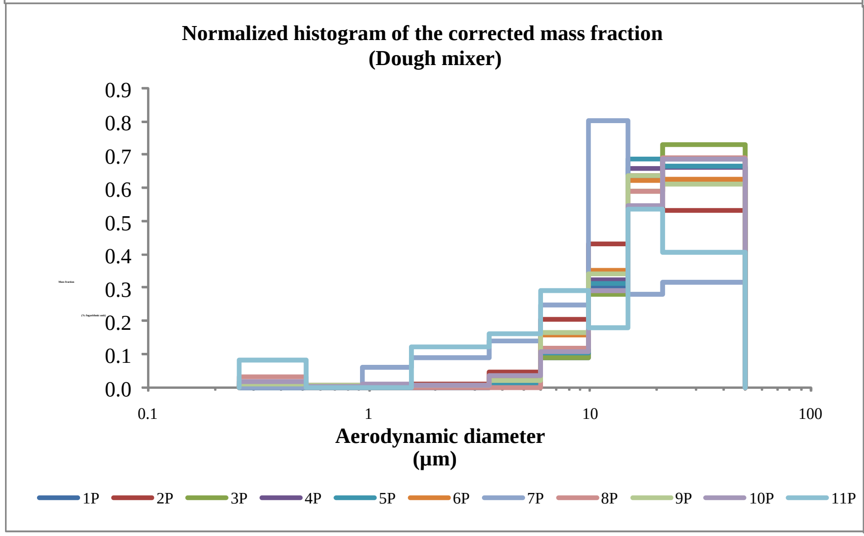


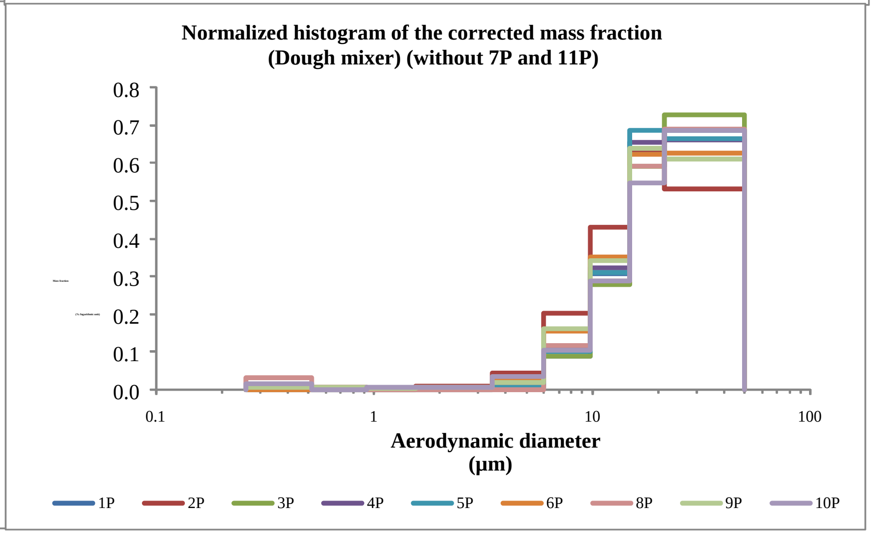

**Boxplots of the corrected and uncorrected particle size distribution results**

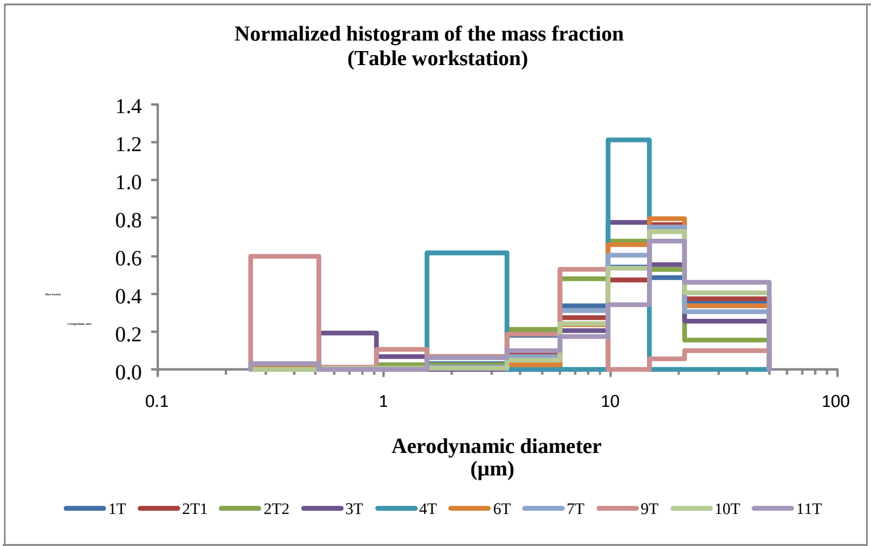
# APPENDIX 2: HISTOGRAMS OF THE PARTICLE SIZE DISTRIBUTION PROFILES BY SAMPLING STATION

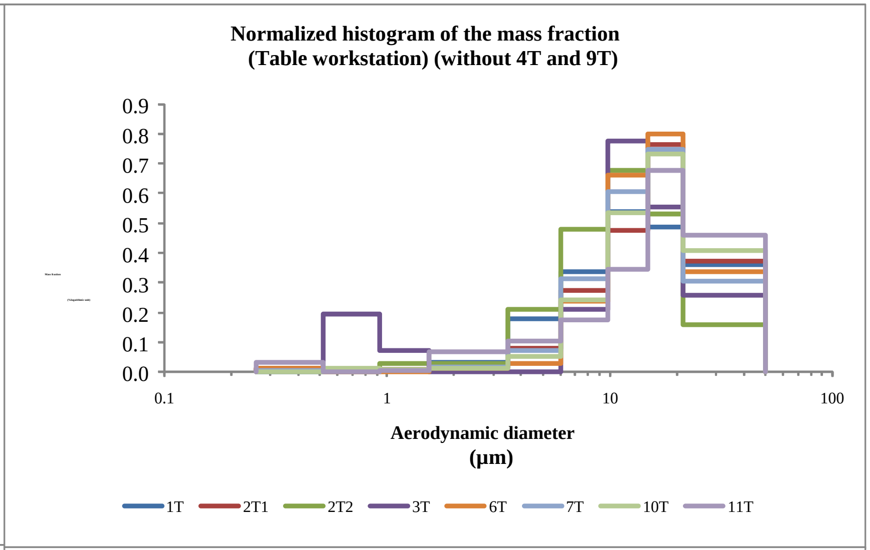


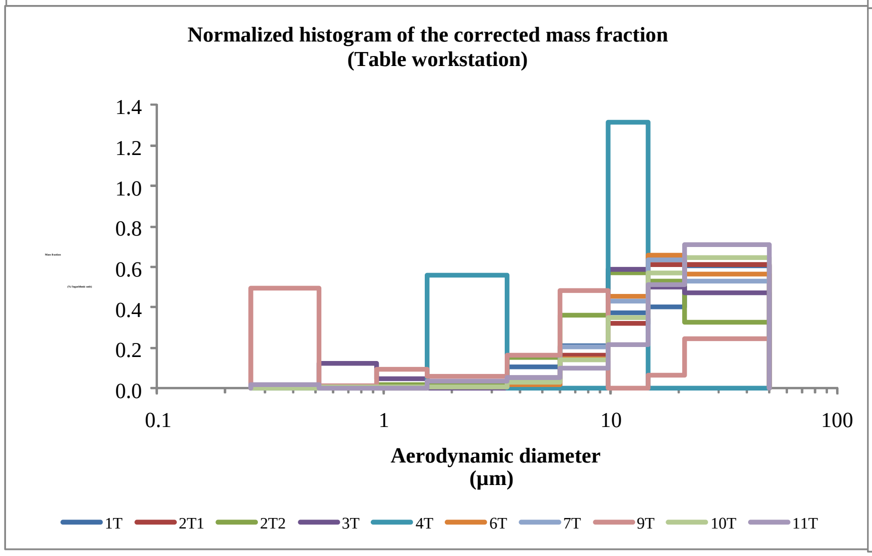



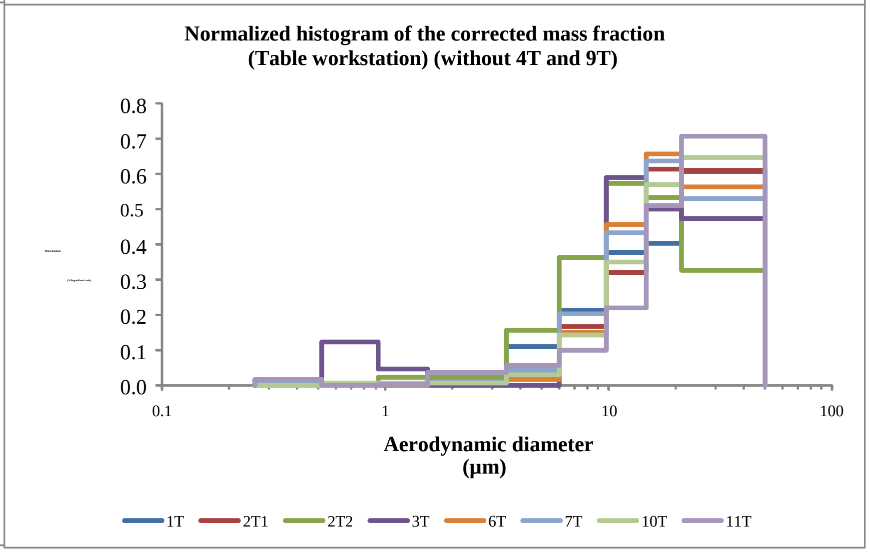




Normalized histogram of the mass fraction
(Table workstation)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.1
1
10
100
Aerodynamic diameter
(µm)
1T
2T1
2T2
3T
4T
6T
7T
9T
10T
11T


Normalized histogram of the mass fraction
(Table workstation) (without 4T and 9T)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.1
1
10
100
Aerodynamic diameter
(µm)
1T
2T1
2T2
3T
6T
7T
10T
11T


Normalized histogram of the corrected mass fraction
(Table workstation)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.1
1
10
100
Aerodynamic diameter
(µm)
1T
2T1
2T2
3T
4T
6T
7T
9T
10T
11T

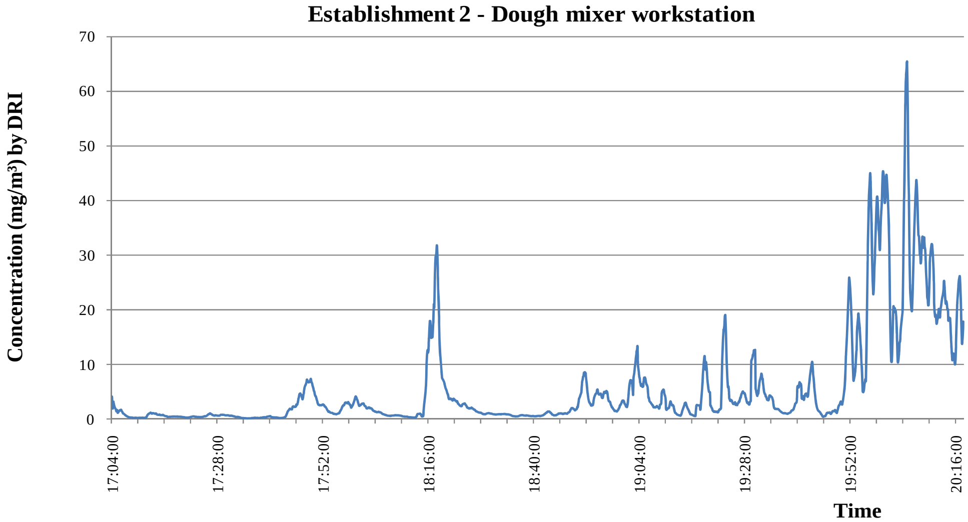

Normalized histogram of the corrected mass fraction
(Table workstation) (without 4T and 9T)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.1
1
10
100
Aerodynamic diameter
(µm)
1T
2T1
2T2
3T
6T
7T
10T
11T

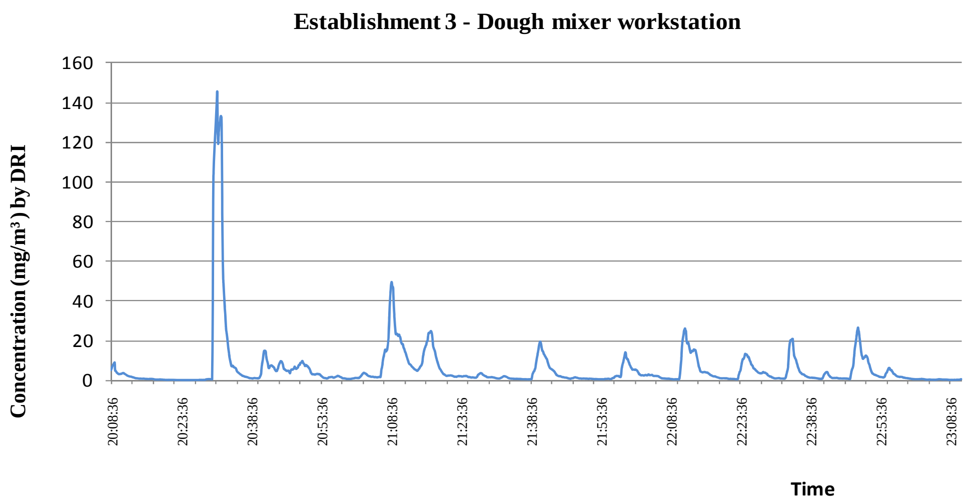
# APPENDIX 3: CONCENTRATION CALCULATED FROM THE MASSES COLLECTED BY THE IMPACTOR

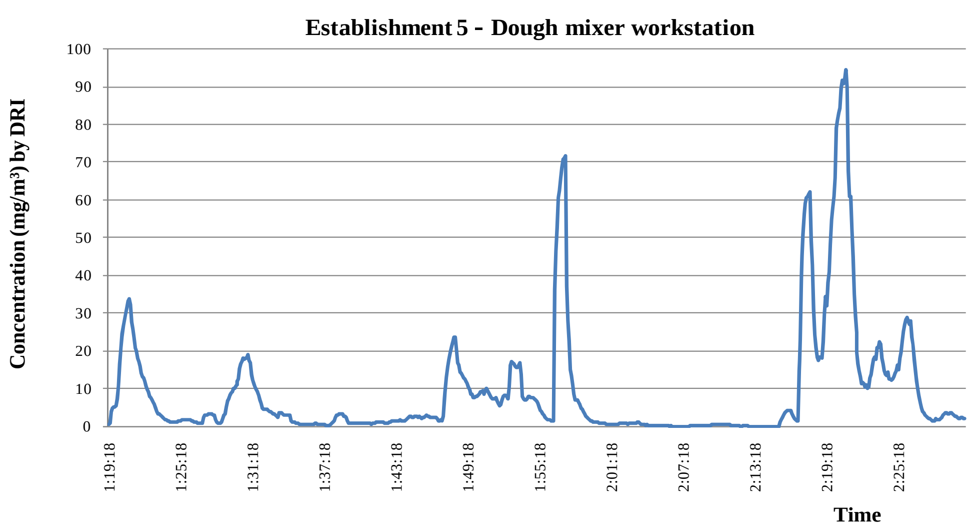
| Est | Work-station | Uncorrected concentration ($mg/m^3$) | | | Corrected concentration ($mg/m^3$) | | |
|---|---|---|---|---|---|---|---|
| | | $Conc_i$ | Fii | Fri | $Conc_i$ | Fii | Fri |
| 1 | Dough mixer | 3.0 | 2.0 | 0.1 | 5.8 | 3.7 | 0.1 |
| | Table | 0.8 | 0.6 | 0.1 | 1.4 | 0.9 | 0.1 |
| 2 | Dough mixer | 4.9 | 3.4 | 0.2 | 8.4 | 5.5 | 0.2 |
| | Table | 3.9 | 2.7 | 0.2 | 7.1 | 4.6 | 0.2 |
| | Moulder | 1.1 | 0.8 | 0.1 | 1.6 | 1.2 | 0.1 |
| 3 | Dough mixer | 10.2 | 6.7 | 0.1 | 20.6 | 12.8 | 0.1 |
| | Table | 4.5 | 3.3 | 0.7 | 7.2 | 5.0 | 0.7 |
| 4 | Dough mixer | 2.7 | 1.8 | 0.0 | 5.1 | 3.2 | 0.0 |
| | Table | * | * | | * | | |
| 5 | Dough mixer | 4.7 | 3.1 | 0.0 | 9.0 | 5.7 | 0.0 |
| 6 | Dough mixer | 7.1 | 4.8 | 0.2 | 13.1 | 8.4 | 0.2 |
| | Table | 3.0 | 2.0 | 0.1 | 5.3 | 3.4 | 0.1 |
| 7 | Dough mixer | **< 0.04 *** | * | * | **< 0.1 *** | * | * |
| | Table | 0.5 | 0.4 | 0.3 | 0.5 | 0.4 | 0.4 |
| 8 | Dough mixer | 2.5 | 1.6 | 0.1 | 4.7 | 3.0 | 0.1 |
| 9 | Dough mixer | 11.3 | 7.7 | 0.5 | 20.6 | 13.3 | 0.5 |
| | Table | **< 0.4 *** | **< 0.4 *** | **< 0.3 *** | **< 0.5 *** | **< 0.4 *** | **< 0.3 *** |
| 10 | Dough mixer | 9.9 | 6.7 | 0.6 | 19.0 | 12.1 | 0.6 |
| | Table | 2.7 | 6.7 | 0.1 | 5.1 | 3.3 | 0.1 |
| 11 | Dough mixer | **< 0.5*** | **< 0.4 *** | **< 0.1 *** | **< 0.7 *** | **< 0.5 *** | < 0.1 * |
| | Table | 3.4 | 2.3 | 0.3 | 6.6 | 4.2 | 0.3 |

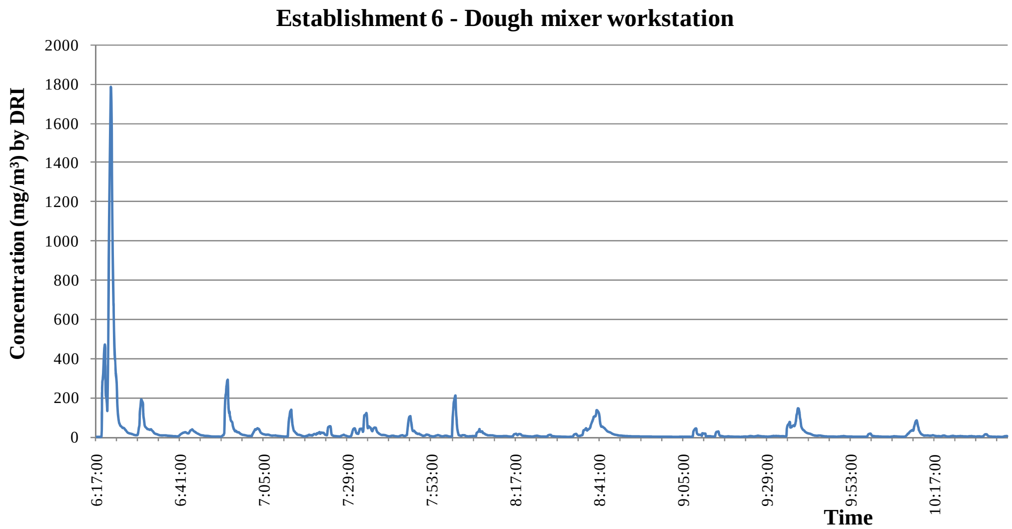
***: Less than or equal to the MRV.**

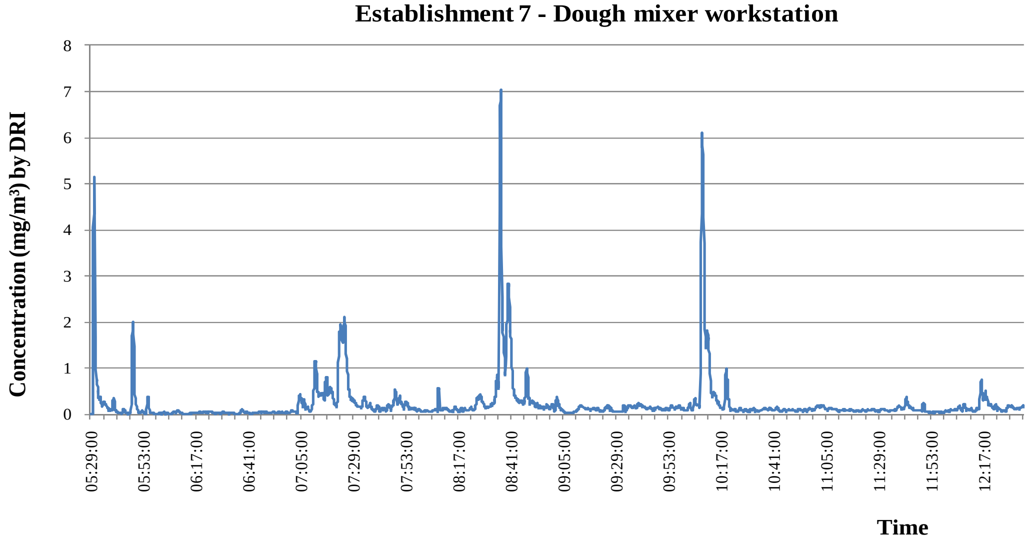
# APPENDIX 4: CONCENTRATION READ BY THE DRI BY ESTABLISHMENT

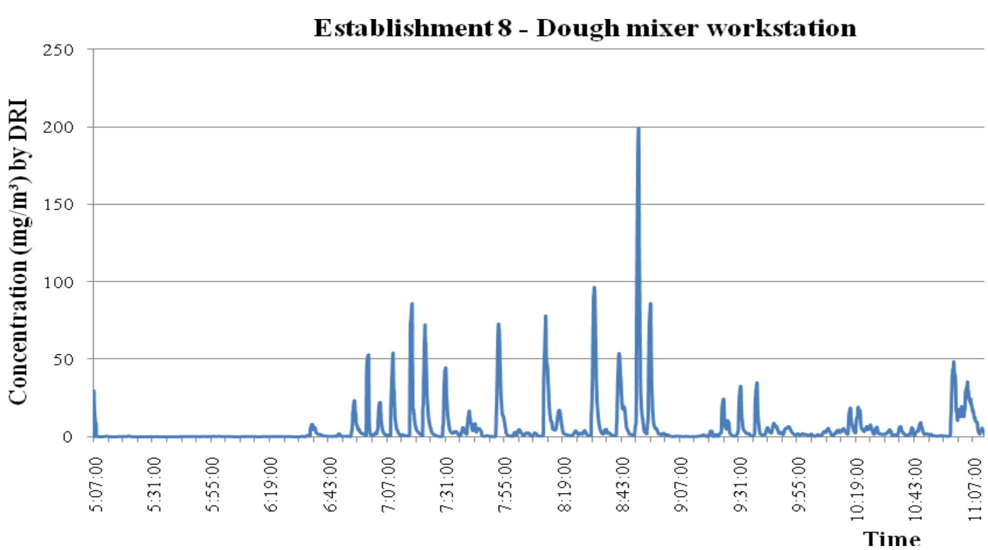


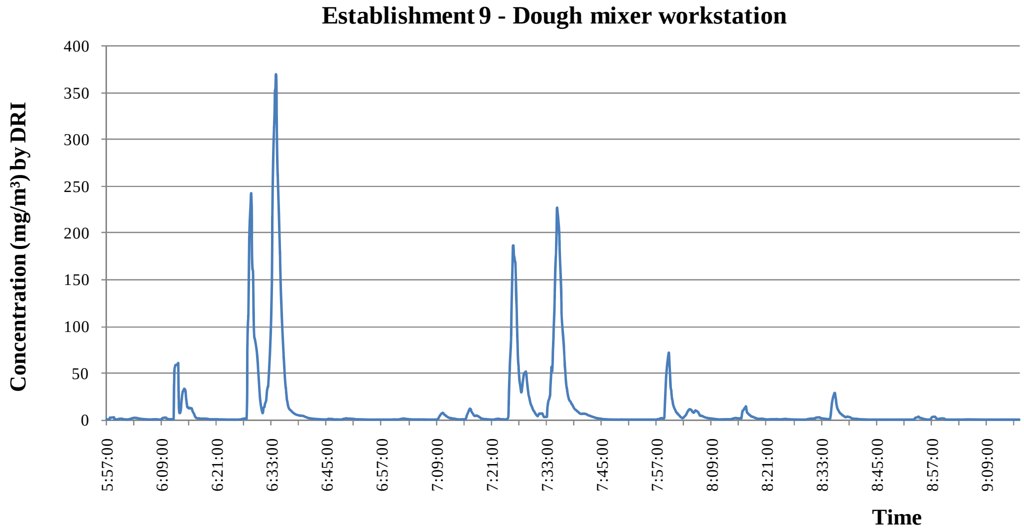



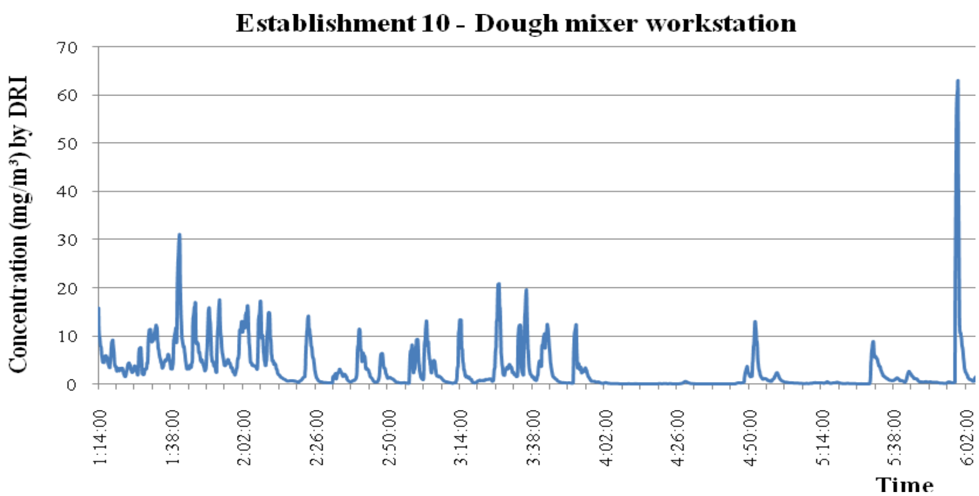



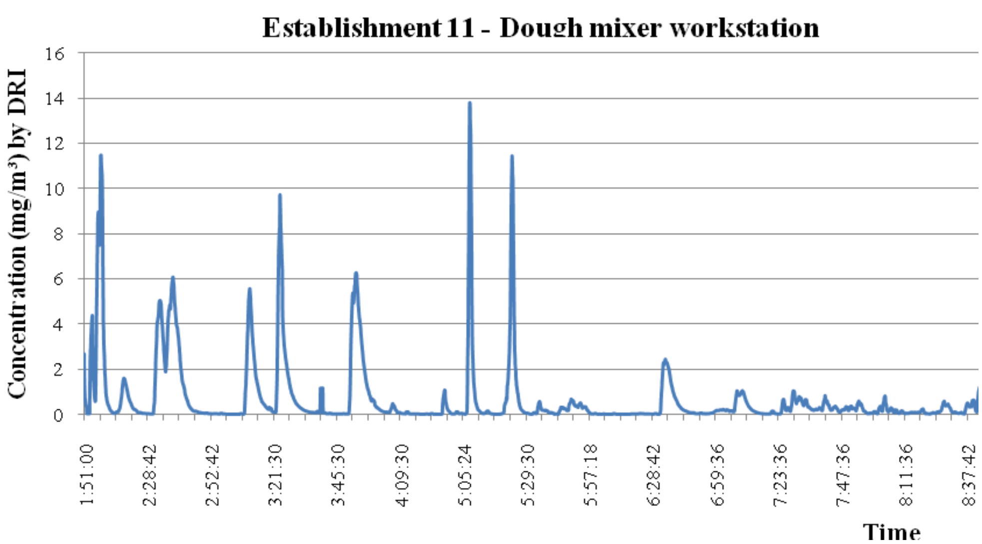

Establishment 6 - Dough mixer workstation
Concentration (mg/m³) by DRI
2000
1800
1600
1400
1200
1000
800
600
400
200
0
6:17:00
6:41:00
7:05:00
7:29:00
7:53:00
8:17:00
8:41:00
9:05:00
9:29:00
9:53:00
10:17:00
Time


Establishment 7 - Dough mixer workstation
Concentration (mg/m³) by DRI
8
7
6
5
4
3
2
1
0
05:29:00
05:53:00
06:17:00
06:41:00
07:05:00
07:29:00
07:53:00
08:17:00
08:41:00
09:05:00
09:29:00
09:53:00
10:17:00
10:41:00
11:05:00
11:29:00
11:53:00
12:17:00
Time

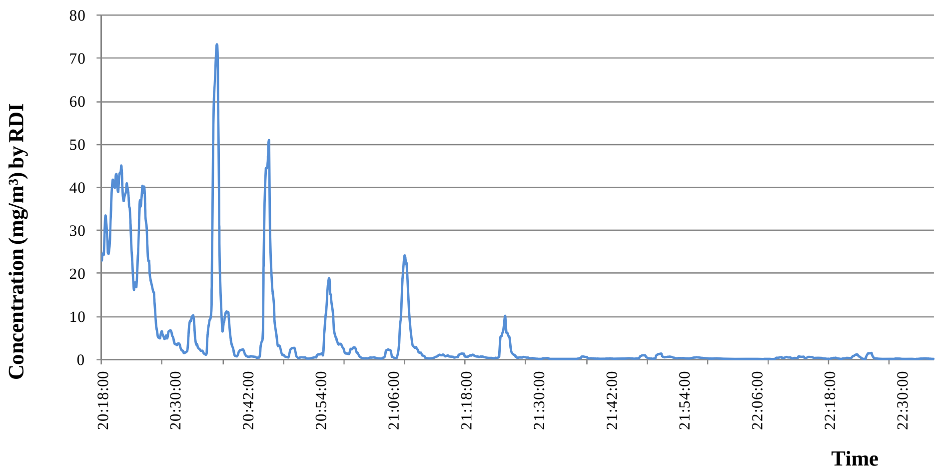

Establishment 8 - Dough mixer workstation
Concentration (mg/m³) by DRI
250
200
150
100
50
0
5:07:00
5:31:00
5:55:00
6:19:00
6:43:00
7:07:00
7:31:00
7:55:00
8:19:00
8:43:00
9:07:00
9:31:00
9:55:00
10:19:00
10:43:00
11:07:00
Time


Establishment 9 - Dough mixer workstation
Concentration (mg/m³) by DRI
400
350
300
250
200
150
100
50
0
5:57:00
6:09:00
6:21:00
6:33:00
6:45:00
6:57:00
7:09:00
7:21:00
7:33:00
7:45:00
7:57:00
8:09:00
8:21:00
8:33:00
8:45:00
8:57:00
9:09:00
Time

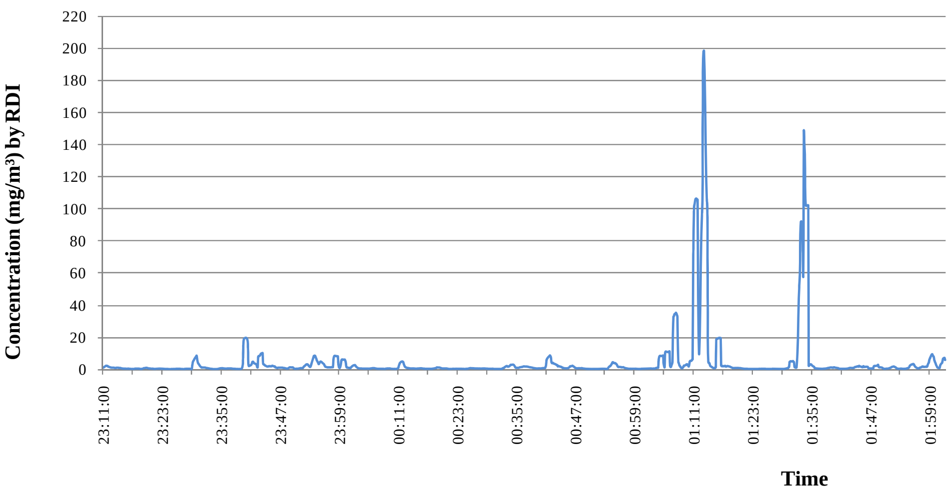

Establishment 10 - Dough mixer workstation
Concentration (mg/m³) by DRI
70
60
50
40
30
20
10
0
1:14:00
1:38:00
2:02:00
2:26:00
2:50:00
3:14:00
3:38:00
4:02:00
4:26:00
4:50:00
5:14:00
5:38:00
6:02:00
Time


Establishment 11 - Dough mixer workstation
Concentration (mg/m³) by DRI
16
14
12
10
8
6
4
2
0
1:51:00
2:28:42
2:52:42
3:21:30
3:45:30
4:09:30
5:05:24
5:29:30
5:57:18
6:28:42
6:59:36
7:23:36
7:47:36
8:11:36
8:37:42
Time

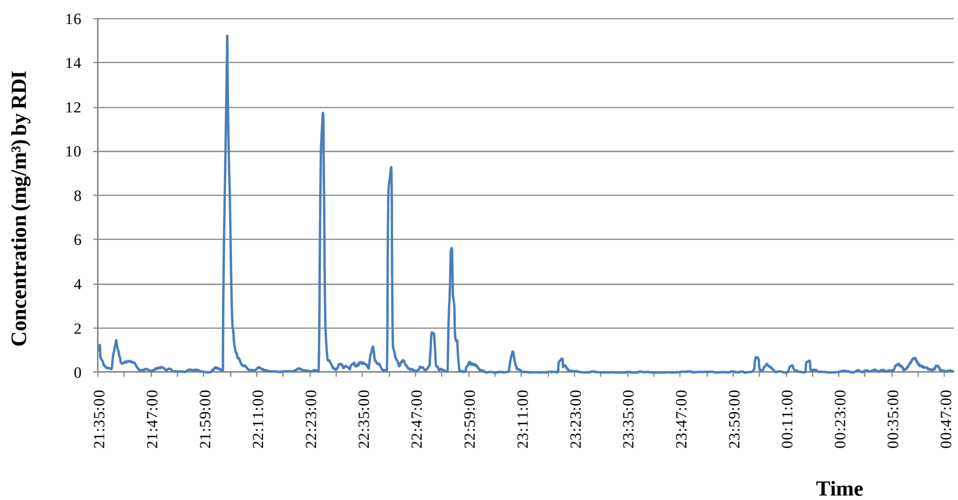
**Establishment 2 - Table workstation**

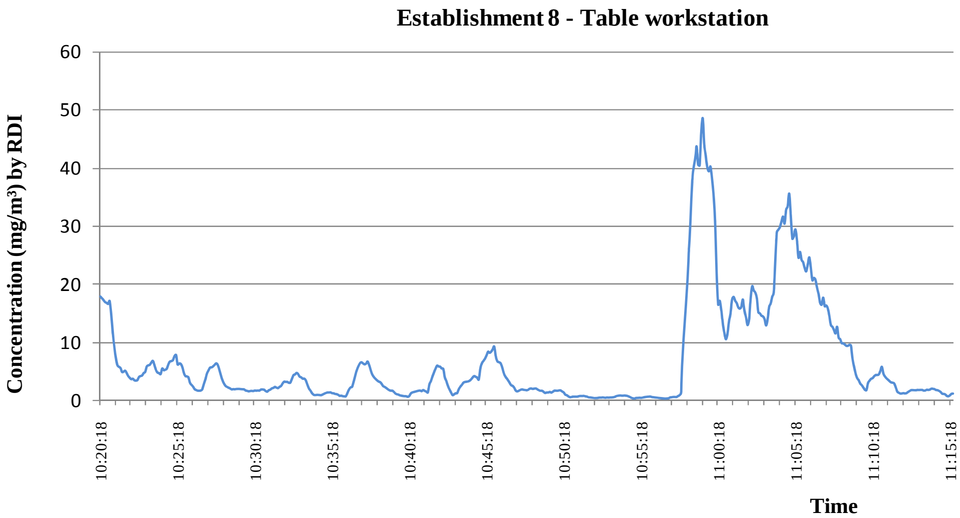



**Establishment 3 - Table workstation**

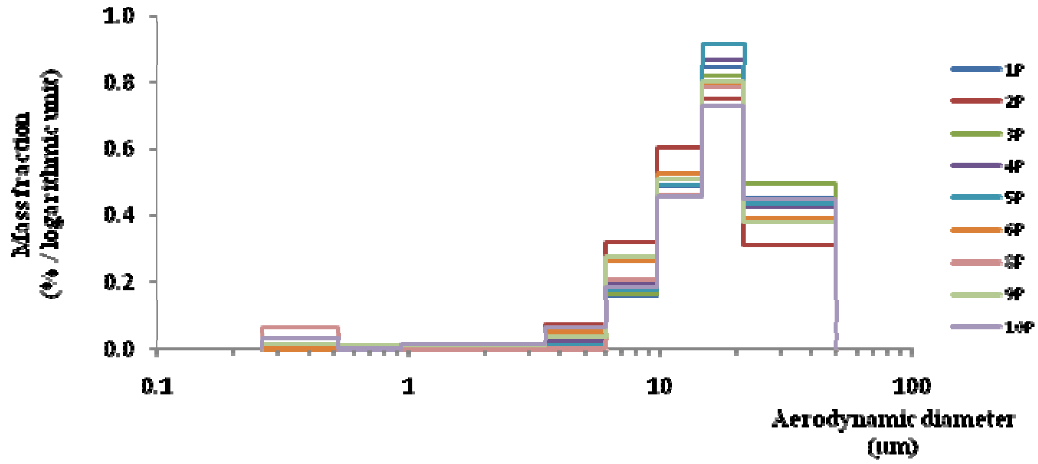



**Establishment 4 - Table workstation**

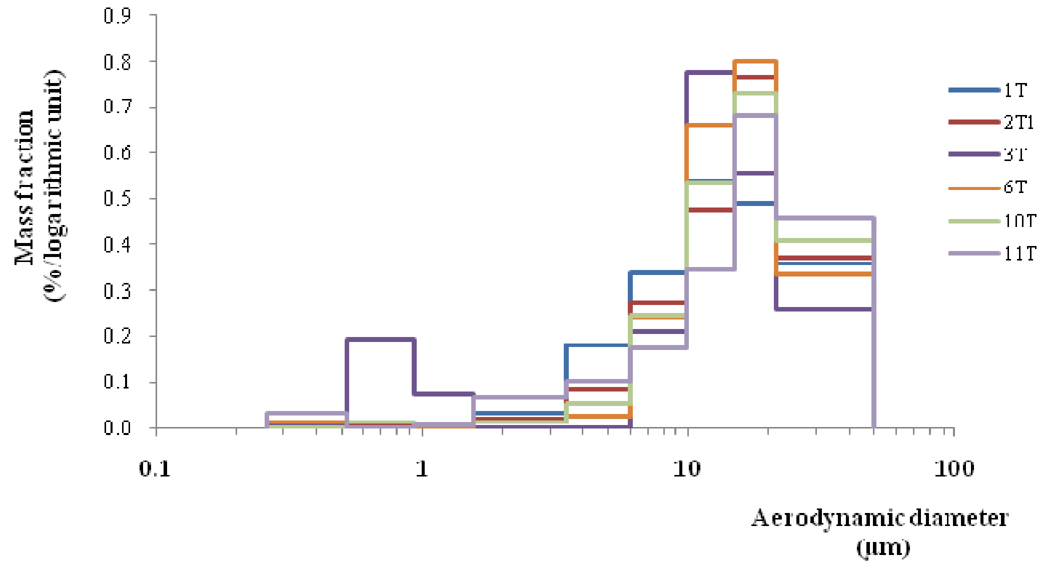



Establishment 8 - Table workstation
Concentration (mg/m³) by RDI
60
50
40
30
20
10
0
10:20:18
10:25:18
10:30:18
10:35:18
10:40:18
10:45:18
10:50:18
10:55:18
11:00:18
11:05:18
11:10:18
11:15:18
Time

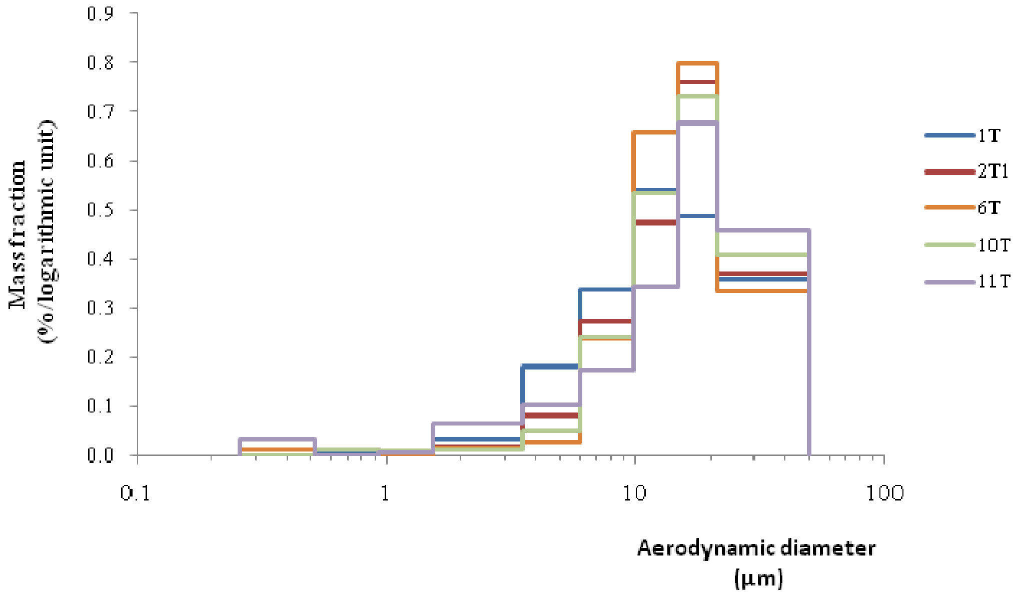
# APPENDIX 5: UNCORRECTED PARTICLE SIZE DISTRIBUTION PROFILES




**Uncorrected particle size distribution at the dough mixer workstation by establishment**




**Uncorrected particle size distribution at the table workstation by establishment**




**Uncorrected particle size distribution without establishment 3**

# APPENDIX 6: IMPACTOR CONCENTRATIONS CALCULATED FROM THE UNCORRECTED AND CORRECTED CONCENTRATIONS AND THE INHALABLE FRACTION/TOTAL DUST RATIO

**Table A.6-1: Uncorrected concentration (mg/m³)**

| Workstation | Dough mixer | | | Table | | |
|---|---|---|---|---|---|---|
| Est | Fii | Dti | Fii/Dti | Fii | Dti | Fii/Dti |
| 1 | 2.0 | 1.4 | **1.4** | 0.6 | 0.4 | **1.5** |
| 2 | 3.4 | 2.6 | **1.3** | 2.7 | 2 | **1.4** |
| | | | | 0.8 | 0.7 | **1.1** |
| 3 | 6.7 | 4.7 | **1.4** | 3.3 | 2.6 | **1.3** |
| 4 | 1.8 | 1.3 | **1.4** | | | |
| 5 | 3.1 | 2.2 | **1.4** | | | |
| 6 | 4.8 | 3.5 | **1.4** | 2 | 1.5 | **1.3** |
| 8 | 1.6 | 1.2 | **1.3** | | | |
| 9 | 7.7 | 5.7 | **1.4** | | | |
| 10 | 6.7 | 4.9 | **1.4** | 1.9 | 1.4 | **1.4** |
| 11 | | | | 2.3 | 1.7 | **1.4** |
| | | Median: | 1.4 | | Median: | 1.3 |

Dti: Impactor concentration calculated in relation to the efficiency curve from the uncorrected concentrations.

**Table A.6-2: Corrected concentration (mg/m³)**

| | Dough mixer | | | Table | | |
|---|---|---|---|---|---|---|
| Est | Fii | Dti | Fii/Pti$_i$ | Fii | Dti | Fii/Dti |
| 1 | 3.7 | 2.4 | **1.5** | 0.9 | 0.7 | **1.3** |
| 2 | 5.5 | 3.9 | **1.4** | 4.6 | 3.2 | **1.4** |
| | | | | 1.2 | 0.9 | **1.3** |
| 3 | 13 | 8.4 | **1.5** | 5 | 3.7 | **1.4** |
| 4 | 3.2 | 2.2 | **1.5** | | | |
| 5 | 5.7 | 3.8 | **1.5** | | | |
| 6 | 8.4 | 5.8 | **1.4** | 3.4 | 2.4 | **1.4** |
| 8 | 3.0 | 2.0 | **1.5** | | | |
| 9 | 13 | 9.2 | **1.4** | | | |
| 10 | 12 | 8.2 | **1.5** | 3.3 | 2.2 | **1.5** |
| 11 | | | | 4.2 | 2.9 | **1.4** |
| | | Median: | 1.5 | | Median: | 1.4 |

Dti: Impactor concentration calculated in relation to the efficiency curve from the corrected concentrations.