

TAMK-Department of ENVIRONMENTAL ENGINEERING

FHH-Faculty II–MECHANICAL AND BIO PROCESS ENGINEERING

BACHELOR'S THESIS

A COMPARATIVE STUDY OF PASSIVE AND ACTIVE SAMPLING METHODS FOR MEASURING INDOOR PARTICULATE MATTER

Mahnaz Soltani

Supervisors: Jarmo Lilja, PhD, Senior lecturer, Physics (TAMK)
Pasi Arvela, Lecturer/Laboratory Engineer, Physics (TAMK)
Prof. Dr.-Ing. Wilfried Stiller (FHH)
Prof. Dr.-Ing. Ulrich Lüdersen (FHH)

Commissioned by: Occupation Health Centre Tampere and TAMK
Tampere/Hannover – February 2011

Soltani, Mahnaz A Comparative Study of Passive and Active Sampling
Methods for Measuring Indoor Particulate Matter

Final Thesis 56 pages+ 21 pages Appendix

Supervisors Jarmo Lilja, PhD, Senior lecturer (TAMK)
Pasi Arvela, Lecturer / Laboratory Engineer (TAMK)
Prof. Dr.-Ing. Wilfried Stiller (FHH)
Prof. Dr.-Ing. Ulrich Lüdersen (FHH)

Commissioned by: Occupation Health Centre Tampere and TAMK

February 2011

Keywords Passive Sampler, Indoor Dust Measurement

Abstract

The presented thesis is based on evidence gathered by the *Passive Sampler* project supported by the University of Applied Sciences Tampere (TAMK) started in Mai 2010.

At the stage of the project, economic and technical reasons forced the team to choose the Passive Sampler (PS) developed by Vinzents, which is easier to implement for the laboratory experiments than the Electret Passive Sampler. In controlled circumstances the Vinzents PS is compared to conventional active dust measurement devices in order to prove the reliability of the simple and cheap passive measurement as an alternative to the more elaborate active sampling method. The measurement took place in a dust tunnel of the University of Applied Sciences in Tampere and with the same kind of fine dust sample in a size range of 1-192µm from the concrete laboratory. The results of the comparative study between passive and active sampler show a significant correlation leading to the conclusion that passive samplers offer a cheaper and easier alternative for personal dust control. Therefore, further research in this area will prove worthwhile. Due to the stage of the project a claim for completeness is impossible and further investigations are needed.

| | |
|-----------------|---|
| Soltani, Mahnaz | Eine vergleichende Studie von Passive Sampler und Active Sampler Methoden zur Messung von Feinstaub im Innenbereich |
| Bachelor Arbeit | 56 Seiten + 21 Seiten Anhang |
| Betreuer | Jarmo Lilja, PhD, Senior lecturer (TAMK) Pasi Arvela, Lecturer / Laboratory Engineer (TAMK) Prof. Dr.-Ing. Wilfried Stiller (FHH) Prof. Dr.-Ing. Ulrich Lüdersen (FHH) |
| Auftraggeber | Occupation Health Centre Tampere and TAMK |
| Februar 2011 | |
| Schlüsselwörter | Passive Sampler, Indoor Dust Measurement |

Kurzfassung

Die vorliegende Arbeit erwuchs einem Projekt zum Thema "Passive Sampler", das in Kooperation der University of Applied Sciences of Tampere (TAMK) und der finnischen Behörde für Arbeitssicherheit und Gesundheit seit Mai 2010 durchgeführt wird.

Das Ziel des Projektes besteht darin, alternative Messmethoden für eine personenbezogene Messung der Feinstaubbelastung am Arbeitsplatz zu ermitteln.

Die vorliegende Arbeit untersucht in diesem Zusammenhang die Verwendbarkeit von Passive Sampler/Passivsammlern am Beispiel des kostengünstigen und leicht handhabbaren Passive Sampler entwickelt von Vinzents. Es kann gezeigt werden, dass die mit diesem Sammler unter kontrollierten Bedingungen in einem Staubbereich gewonnenen Messergebnisse für Betonstaub der Größe 1-192 µm zuverlässig sind, dahingehend, dass Sie eine Korrelation zu den aktiv ermittelten Messwerten darstellen. Daher ist Einsatz dieses Passivsammlers zur Messung der Staubbildung am Arbeitsplatz sinnvoll und geboten.

Foreword and Background of this Work

This work is connected to the *Passive Sampler* project at the University of Applied Sciences Tampere (TAMK) in co-operation with the Finnish Institute of Occupational Health in Tampere (FIOH), which started in Mai 2010. The project involved the environmental engineering department and the chemical engineering department of the TAMK.

General Information to this Thesis:

This Bachelor thesis is created by using a German version of the Microsoft Office and therefore, the tables inside this work have decimals, where the decimal part is separated by a comma instead of a dot.

Acknowledgements

I would like to take the opportunity to thank those who made this thesis possible. In this respect I am thankful to my supervisors Jarmo Lilja and Pasi Arvela, who guided me through the whole project and the beginning of the thesis process. Furthermore I would like to thank Prof. Dr.-Ing. Stiller, whose encouragement and guidance made this thesis possible and Prof. Dr.-Ing. Lüdersen for his willingness to be the second examiner of my thesis.

Lastly I send my regards and blessings to my family and friends who always believed in me and in particular I would like to thank the one special friend who accompanied me through the whole study program.

Table of Contents

| | | |
|-----------|---|-----------|
| 1. | Introduction..... | 1 |
| 2. | Theoretical Fundamentals | 3 |
| 2.1 | Basics of Particles | 3 |
| 2.1.1 | Definition of Particles | 3 |
| 2.2 | Dust Measurement Methods..... | 10 |
| 2.2.1 | Conventional Devices for PM Measurement..... | 10 |
| 2.2.2 | Active Sampler..... | 11 |
| 2.2.3 | General Aspects of Passive Sampler | 13 |
| 2.2.4 | Passive Sampler Models | 14 |
| 2.2.5 | Passive sampling analysis | 17 |
| 3. | Comparison Study of Passive and Active Sampler | 19 |
| 3.1 | Selection of the PS Method | 19 |
| 3.1 | Basics of the Measurements..... | 20 |
| 3.2 | Preliminary Investigations for the Measurements | 21 |
| 3.2.1 | Implementation of the Preliminary Investigations..... | 21 |
| 3.2.2 | Results of the Preliminary Investigations | 22 |
| 3.2.3 | Measurement Equipment..... | 25 |
| 3.3 | Implementation of the Measurement with Vinzents | 27 |
| 3.3.1 | Preparation of the Measurement | 27 |
| 3.3.2 | Structure of the Measurement | 28 |
| 3.3.3 | Performance of the Measurement | 30 |
| 3.3.4 | Analysis of the Measurement | 31 |
| 3.4 | Results of the Measurement | 33 |
| 3.4.1 | Particle Size analysis..... | 33 |
| 3.4.2 | Active Devices | 35 |
| 3.4.3 | Passive Sampler..... | 36 |
| 3.5 | Evaluation of the Measurement | 43 |
| 3.5.1 | Calculation..... | 43 |

| | | |
|-------|--|-----------|
| 3.5.2 | Comparison of the device results | 46 |
| 3.6 | Calibration | 52 |
| 3.7 | Discussion of the Measurement | 53 |
| 4. | Conclusion..... | 56 |
| 5. | List of Literature | 58 |
| 6. | Appendix | 61 |

List of Figures

| | |
|--|----|
| Figure 1 Common Particles | 4 |
| Figure 2 Suspended Particulate Matter | 5 |
| Figure 3 Dust Measurement Methods | 10 |
| Figure 4 IOM inhalable Dust Sampler and Pump | 12 |
| Figure 5 Electret Passive Sampler | 15 |
| Figure 6 Passive Sampler developed by Vinzents..... | 17 |
| Figure 7 Dust Tunnel | 20 |
| Figure 8 Vinzents Passive Sampler Spray or Liquid..... | 23 |
| Figure 9 Vinzents Passive Sampler Test Run Results | 24 |
| Figure 10 DusTrack Laser Photometer..... | 25 |
| Figure 11 IOM inhalable Dust Sampler and Pump | 26 |
| Figure 12 Model of Vinzents Passive Sampler | 26 |
| Figure 13 Measurement Structure Position of the Sampler | 28 |
| Figure 14 Measurement Structure Positioning of Dust and DusTrack | 29 |
| Figure 15 Performance of the Measurement | 30 |
| Figure 16 Ambient Condition | 32 |
| Figure 17 Density Distribution Concrete Dust Samplej..... | 34 |
| Figure 18 Pass-Distribution Concrete Dust Sample | 34 |
| Figure 19 Forward GP Vinzents Passive Sampler T3_38 | 38 |

| | |
|--|----|
| Figure 20 Relative Frequency Distribution T3_38 | 39 |
| Figure 21 Upward GP Vinzents Passive Sampler T4_33..... | 40 |
| Figure 22 Downward GP Vinzents PS T5_46 | 41 |
| Figure 23 Relative Frequency Distribution T5_46 | 42 |
| Figure 24 Comparison of Passive Samplers | 47 |
| Figure 25 Comparison Active Devices | 48 |
| Figure 26 IOM Active and Passive Sampler..... | 49 |
| Figure 27 Mass Comparison IOM Active and Vinzents PS | 50 |
| Figure 28 Comparison DusTrack and Vinzents PS | 51 |
| Figure 29 Calibration Line Vinzents Passive Sampler..... | 52 |

List of Tables

| | |
|---|----|
| Table 1 Passive Sampler Test Run Results | 24 |
| Table 2 Experiment Procedure Details | 31 |
| Table 3 Particle Size Analysis Concrete Dust Sample | 33 |
| Table 4 Results IOM Active Dust Sampler..... | 35 |
| Table 5 Results DusTrack | 35 |
| Table 6 Results IOM Passive Sampler | 36 |
| Table 7 Results Vinzents Passive Sampler | 37 |
| Table 8 Results Particle Size Analysis T3_38 | 39 |
| Table 9 Results Particle Size Analysis T4_33 | 41 |
| Table 10 Results Particle Size Analysis T5_46 | 42 |
| Table 11 DusTrack Calculated Mass..... | 44 |
| Table 12 IOM Active Sampler Calculated Concentration..... | 45 |
| Table 13 Vinzents PS Calculated Deposition | 46 |
| Table 14 Increase of Sampled Dust PS..... | 47 |

Abbreviations and Symbols

| | |
|-----------------------------------|------------------------------------|
| AS | Active Sampler |
| Dr. | Doctor |
| FHH..... | Fachhochschule Hannover |
| LP..... | Laser Photometer |
| Ing. | Ingenieur |
| IOM | Institute of Occupational Medicine |
| PhD | Philosophiae Doctor |
| PM..... | Particulate Matter |
| Prof. | Professor |
| PS | Passive Sampler |
| TAMK..... | Tampereen ammattikorkeakoulu |
| c | Concentration |
| $\Delta t(\text{delta } t)$ | Time Frame |
| D | Deposition |
| d, \varnothing | Diameter |
| $\eta(\text{eta})$ | Viscosity of the Fluid |
| g..... | Gravitation Constant |
| $\kappa(\text{kappa})$ | Dynamic Shape Factor |

L Litre

m Mass

min..... Minute

q Volume flow

R^2 Coefficient of Determination

$\rho(\text{rho})$ Density

v..... Velocity

V Voltage

[g] Gram

[μm] Micro Meter

[mg] Milligram

[m^3] Cubic Meter

[m^2] Square Meter

[%] Percent

1. Introduction

Air is essential for all organisms on the planet not just because of supplying oxygen. Air consists of nitrogen, oxygen, water vapour and inert gases, but it may contain pollutants as well. There are many well known types of pollutants with various effects which have been widely discussed. These include smog, acid rain, the greenhouse effect and ozone holes. The consequences for human health and the environment are serious. Most of those pollutants, which cause harmful effects for humans, animals and plants are caused by human activities.

Indoor and Outdoor Pollutants

Airborne particles are called aerosols. They can derive from many sources, especially from any kind of combustion and the mechanical treatment of solid material by crushing, surface treatment or rubbing.

Pollution is not only caused by outdoor activities, but also by indoor processes. Depending on the kind of household or place of work, there is a substantial number of pollutants created indoors to which other pollutants coming from outside have to be added. Sometimes there is no big difference between the types of pollutants inside and outside of a house or place of work, but as most people spend more time indoors, those pollutants inside buildings pose a much greater threat to human health due to the extended exposure.

Health Problems

Particulate matter can cause many health problems for humans as these particles are respirable. The harmful effects vary with the different types of dust and can cause diseases such as "pneumoconiosis" simply meaning "dusty lung", scar tissues, or the loss of lung elasticity. Particles can dissolve into the bloodstream and may affect the brain, kidneys and other organs depending on the size of the particle, which means, the smaller a particle is, the deeper it can penetrate into the human body. Therefore, health care – either at home or at the place of work – must focus on easier and cheaper methods of preventing an intensive contact with these airborne particles.

Particulate Matter Measurement

There are various methods of measuring the exposure to airborne particles, but the measurement methods are mostly based on active control either by measuring just the total amount of particles in a room or by actively working personal sampling. Mostly devices for active measurements, especially those for personal monitoring are expensive, difficult to use and maintenance-intensive.

The Present Work

One of the tasks of the following thesis is the examination of alternative control devices in terms of easier and cheaper measurement possibilities. The idea is to investigate a possible substitution of the active sampling control with passive samplers.

The usefulness of passive samplers will be shown by using these devices in controlled circumstances of a laboratory and by comparing the results of active devices and passive sampling methods. The possible results of this examination may have extensive consequences for the use of passive samplers in field experiments and later in measuring the amount of fine dust particles at workplaces.

Passive Samplers have the advantage of working without continuous power source or electricity. So passive sampling is based on natural forces like diffusion, sorption, gravitational forces or van-der-Waals forces.

As the following thesis deals with the measurement of airborne pollutants or aerosols in the form of particles in a given environment as a comparative study of passive and active samplers, it is important to present the theoretical fundamentals in chapter 2. Among these fundamentals are the specific properties of these particles, the categorization of the existing devices and the presentation of the passive sampler theories and individual models. In the 3rd chapter an examination of particulate matter in an individual environment is presented in a comparative study and put into perspective.

2. Theoretical Fundamentals

2.1 Basics of Particles

There are various kinds of air-borne particles, which are summed up under the term of aerosols. The focus of this thesis will be on fine dust a sub-category of aerosols.

2.1.1 Definition of Particles

Aerosol is a generic term for a mixture of solid and liquid particles in the air, which can consist of organic and nonorganic materials. It includes mist, dust, smoke, fibres, and bioaerosols such as viruses, bacteria, fungi and pollen.

The duration of the stable state of an aerosol amounts to at least a few seconds and can last up to a year or more. The long stable particles include a size range from 0,001- 10 μm and the particles, which can be separated from the air within minutes can be up to 100 μm . The connection between the size of the particle and the possibility of separating it from the surrounding shows the importance of the particle size for the behaviour of the aerosol. All the aerosols properties depend on the particle size. Moreover aerosols have a wide size range and the regularity of the properties may change with the particle size. The aerodynamic diameter is the decisive factor for the behaviour of an aerosol. This physical parameter defines if a particle can be removed by a certain technique. *(Spengler/Samet/ McCarthy 2001, 9.2), (Hinds 1999, 8 ff)*

Figure 1 shows the size ranges for commonly found particles.

PARTICLE SIZE REMOVAL RANGE BY FILTRATION

These sizes of well known objects and particulates illustrate the size of the micrometer (or micron).

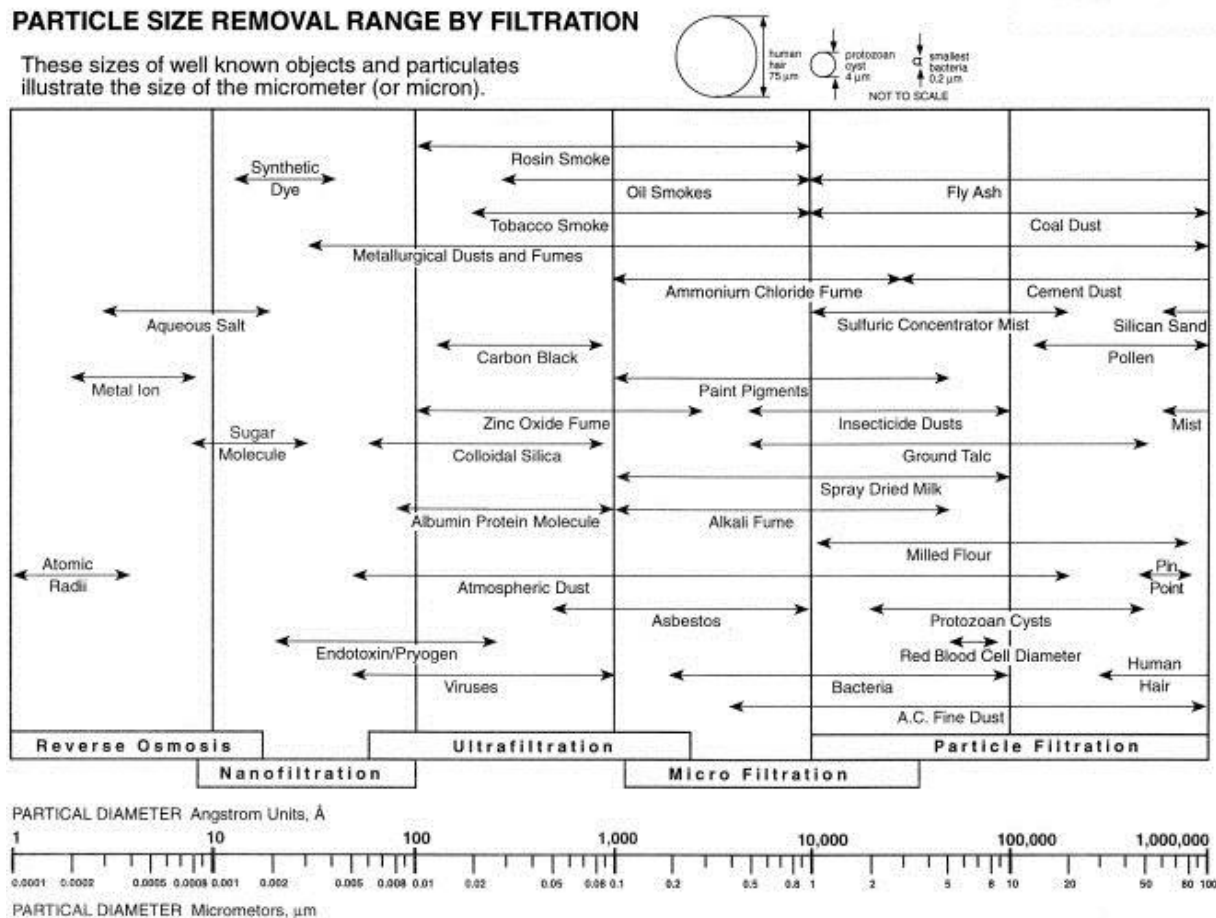


Figure 1 Common Particles¹

Dust

Dust is the generic term for all occurring solid particles in ambient air from different kind of sources. Dust describes usually a solid-particle aerosol, which develops by natural causes or any kind of combustion.

¹ http://www.h2odistributors.com/global/productpics/misc/chart_particle-size_xl.gif

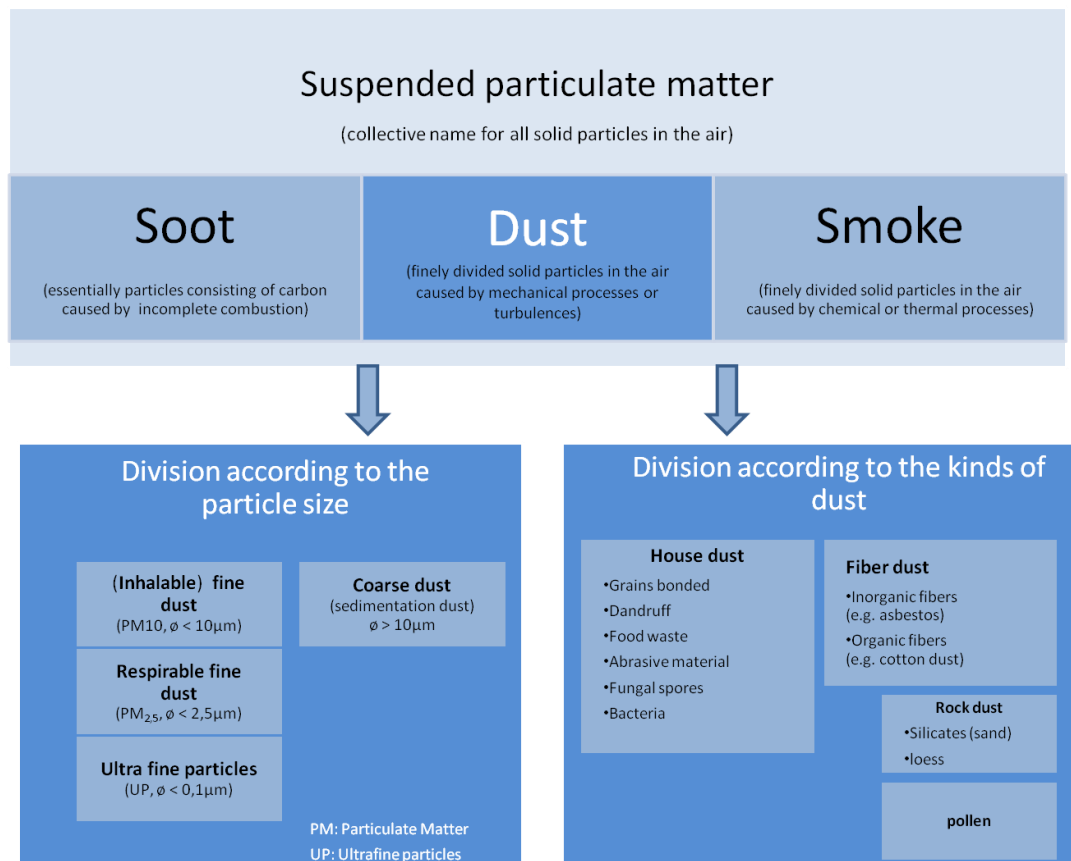


Figure 2 Suspended Particulate Matter²

Particulate Matter

Fine dust or particulate matter is a term that is only applied to dust whose components are smaller than $10\mu\text{m}$, regard of its chemical composition. Among those components of fine dust there are for example soot, heavy metals, organic substances and many more.

The examination of pollution caused by fine dust has become more important over the last ten years because fine dust can penetrate into the lungs and cause serious harm there. This is the reason why the standard values are related to the inhalable dust particles. The notation **PM₁₀** stands for particulate

²<http://upload.wikimedia.org/wikipedia/commons/2/24/Staub-Definitionen.png>

matters with an aerodynamic diameter of 10 μ m or less and **PM_{2,5}** for particulate matters with an aerodynamic diameter of 2,5 μ m or less.³

Properties of Particles

The size of the aerosol particle is the most important physical parameter, when it comes to analyzing and explaining their individual behaviour. As will be shown in this paper, the relationship between particle size and the individual properties of each particle is essential for the measurement of individual particles. The size of a particle is defined by its diameter measured in [μ m].

Particles have in general an irregular shape with a different actual diameter, which is difficult to measure. Therefore, the actual particle diameter is to be substituted by another diameter. The aerosol technology has found out that the most important property of an aerosol is, referring to air cleaning or avoid of health defects, consists of the behaviour of the particle and the specific difficulties in separating it from the surrounding air. That means that not the actual size of the specific particle is under observation, but its aerodynamic properties. Independent from their structure and their composition, variously shaped particles can show the same aerodynamic properties. (*Hinds 1999, 8 ff*)

Abstract dimension

Particles do usually not have a geometrical regular shape (sphere, cube...) by which they could be described. Disparity properties, which are connected to the particle size are called "feature of the fineness". The following abstract dimensions are common:

- **Aerodynamic diameter**
- **Area equivalent diameter**

The **aerodynamic diameter** is an abstract dimension to describe the physical property of a non-spherical particle in a viscous fluid such as air. As mentioned before, the particle's behaviour in air is more important than its real size. The

³ <http://www.epa.gov/pm/standards.html>

aerodynamic diameter is defined as the diameter of a perfect sphere with unit-density (1 g/cm^3) and same settling velocity in stationary and non-rational moving air as the observed particle. The aerodynamic diameter is not linked to the shape, density or physical shape of the individual particle, but it is defined by the aerodynamic actions of the particle. Different kind of particles can have an aerodynamic diameter of $1\mu\text{m}$ with the same settling velocity like a $1\mu\text{m}$ water droplet. The aerodynamic diameter is more defined by the activities in air than the shaping properties. The particle behaviour is characterized more by the properties including filtration, inhalation and lung deposition. Therefore, the aerodynamic diameter is the most important quality in aerosol studies.

The equating of the settling velocity of the investigated non-spherical particle with the same settling velocity of the spherical abstract particle leads to the aerodynamic diameter. (*Hinds 1999, 53 ff*)

$$V_{TS} = \frac{\rho_p d_p^2 g}{18\eta\kappa} = \frac{\rho_0 d_a^2 g}{18\eta} \rightarrow d_a = \sqrt{d_e \left(\frac{\rho_p}{\rho_0\kappa} \right)} \quad (1)$$

κ - Dynamic shape factor; v_{TS} -Settling velocity; ρ_p -Density of the particle; ρ_F -Density of the fluid; d_a -Aerodynamic diameter; d_p -particle diameter; η - Viscosity of the fluid

The shape factor κ is applied in cases, if the specific actual form of the particles is of interest. It is defined as the ratio between two different methods of equivalent abstract diameters.

The **stroke's diameter** is also connected to the settling velocity the only difference to the aerodynamic diameter is that it is valid for tough/viscous fluid flows around the particle. (*Hinds 1999, 44 ff*)

The **area equivalent diameter** is also an abstract-just for calculation used-diameter, which is based on the diameter of a sphere with the same middle projection screen (*Stieß, M. 1995, p13*)

Aerodynamic parameters

The behaviour of particles in the air is dependent on parameter, which are presented here. Differently shaped particles can behave similarly, which makes it

easier to calculate parameters without knowing the exact size or shape of the often unshaped particles.

The following descriptions and equations are meant to demonstrate the connections of the influencing factors as they are very detailed, but they cannot be used for the calculations in this study.

The **settling velocity** of particles is an indicator of the deposition of aerosols in a fluid. It depends on the gravitational forces; resistance forces, particle diameter and density of the fluid involved and of course of the particle themselves. It is the velocity with, which a particle is settling down in still air. A particle once released in the air will quickly reach its final speed. This stable state is caused by the balance of the resistance forces and the opposite acting forces of gravity. The settling velocity is defined for particle diameters over 1 μm . (*Hinds 1999, 46 ff*)

$$v_{TS} = \frac{(\rho_p - \rho_F) d^2 g}{18\eta} \quad (2)$$

v_{TS} -Settling velocity; ρ_p -Density of the particle; ρ_F -Density of the fluid; η - Viscosity of the fluid

Particulate matter concentration

When we look at the dust exposure it becomes very important to specify the exact amount of dust diffused in the air. The base for the dust concentration of any kind of particles in the air is a volume unit of air.

Aerosols have a wide size range in the air and so the concentration relative to the mass is important and the most commonly measured aerosol concentration. The **mass concentration** specifies the mass of particles (no matter which size) in a unit of volume of air with common units like $[\text{g}/\text{m}^3]$, $[\text{m}/\text{m}^3]$ and $[\mu\text{g}/\text{m}^3]$.

$$C_M = \frac{m}{V} = \frac{m}{q_V \Delta t} \quad (3)$$

C_M -Mass concentration; V -Volume of the air; q_V -Volume flow ; Δt -time difference

The number concentration is defined as the number of particles per unit volume of air expressed as $[\text{number}/\text{cm}^3]$ or $[\text{number}/\text{m}^3]$

From the perspective of health control the size selective **number concentration** is actually the more significant property.^{4 5}

⁴ http://www.energieportal24.de/fachberichte_artikel_309.htm

⁵ http://www.airinfoNOW.org/pdf/Particulate_Matter.pdf

2.2 Dust Measurement Methods

Dust monitoring can be done with several methods as presented in the following figure (Figure 3). The active and passive methods are explained in this chapter.

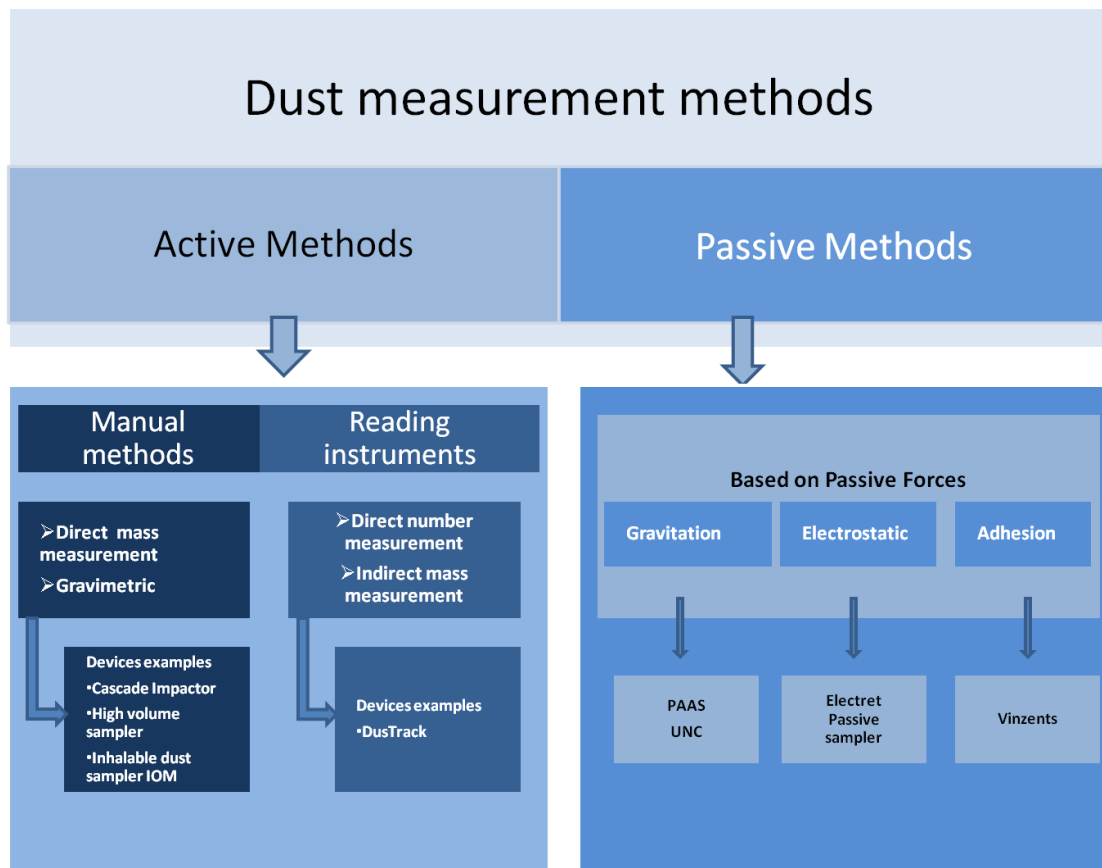


Figure 3 Dust Measurement Methods

2.2.1 Conventional Devices for PM Measurement

Air control measurement is a common way of examining the dust content in work places. General devices are mostly active working devices, which are powered by electricity or using pumps and are measure the indoor air in total. According to the measurement principle the general devices can be divided into three categories such as manual direct measurement, direct reading instruments and indirect measurement instruments.

Direct measurement devices are related to the scanning of the particle mass or the inertia. These devices sample the particles on different filters, which have

to be weighed manually by gravimetric determination after the measurement. The result of the analysis is the total mass. These devices are not directly monitoring the measurement results. For example, an Impactor has different sampling levels with different filters. And all filters are manually analysed by gravimetric method. The calculation of the mass concentration is based on the known volume flow of air through the collecting filters, the sampling time and the gravimetric analysed mass of the sampled dust. (*Hinds 1999, 217 ff*)

Direct-reading Instruments are measuring devices with direct output results. The device has a monitor, which shows the results either during the measurement (real-time) or right after the measurement.⁶

Indirect measurement devices measure another property than particle mass, particle number or particle mass concentration, but the relationship between these properties and the concentration can be established according to Lambert-Beer law. Examples for indirect measurement are light scattering methods to determine the extinction or the transmission with infrared spectrometry. (*Hinds 1999, 218*)

2.2.2 Active Sampler

All personal active dust samplers have the same working mechanism in common. The sampler consists of a sampler head, which hosts the collecting filter and is connected to a pump, which is working with a constant volume flow and ensures that the particles are brought to the collecting surface with the air by a tube. The sampler is positioned near the breathing zone of the monitored person and the constant volume flow simulates the inhalation.

⁶ <http://www.osha.gov/SLTC/directreadinginstruments/index.html>

IOM Personal Inhalable Dust Sampler

This active sampler developed by J. H. Vincent and D. Mark at the Institute of Occupational Medicine (IOM) in Scotland is used for personal inhalable dust sampling.

The cover of the sampling area is made of conductive plastic and contains a reusable filter cassette of $\varnothing 25\text{mm}$. The IOM personal inhalable sampler works in combination with a 2L/min operating pump. The Sampler badge will be fastened on the chest of the worker near the breathing zone. It captures successfully particles up to a size rate of $100\ \mu\text{m}$ in aerodynamic diameter. By pumping the dust polluted air from the breathing zone of a worker into the sampler it simulates the manner of inhaling.

This method is said to measure all collected particles in the course of weighing the filter and cassette before and after by gravimetric determination.⁷

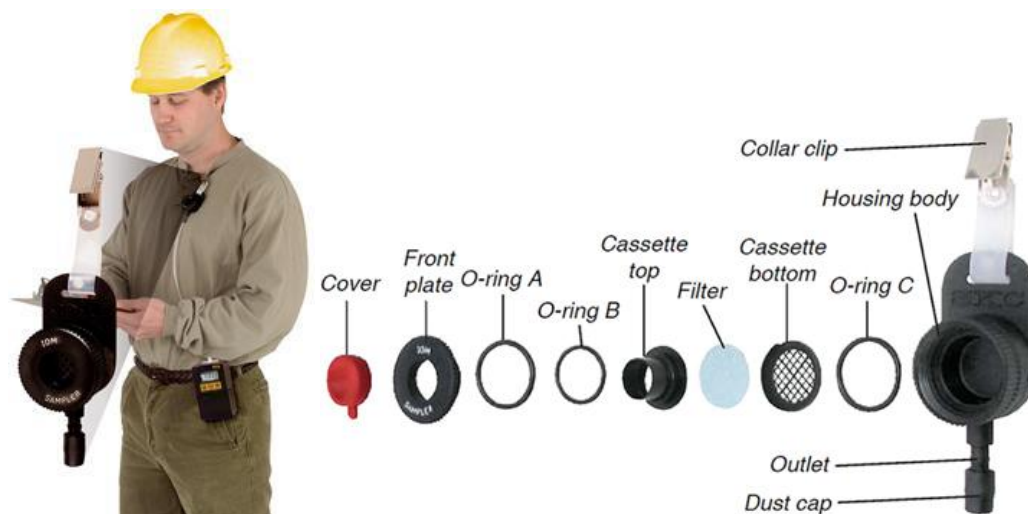


Figure 4 IOM inhalable Dust Sampler and Pump⁸

⁷⁷ <http://www.skcinc.com/instructions/1050.pdf>

2.2.3 General Aspects of Passive Sampler

The main idea of passive samplers is to collect dust particles without any continuous power. Passively sampling means to measure without any forces, which need electricity or pumps. Dust particles undergo diffusive motion but this is not an effective transport process because, compared to molecules particles have a much smaller average velocity. The following presented methods are based on the external passive forces of gravity, adhesive and electrostatic attraction, which are necessary for reliable results.

Measurement principals

Passive sampling methods are based on different principles. The main idea is to catch the dust on a surface and hold it there until the analyzing can be done. The forces to bring the particle to the collecting surface depend on the passive sampling method. Most of the following presenting passive samplers work with gravitation, diffusion, van de Waals, adhesive forces and electrostatic attraction.

Diffusion is the evenly distributing of particles so that a total mixture leads out of two different kinds of particles. This physical process is caused by thermically caused motion of the particles. These particles can be atoms, molecules and charge carrier, as dust particles are. In uneven distributions the particles move from the area with higher concentration to the area with lower concentration.

The random movement of particles caused by Brownian motion alone is not an effective passive sampling force for fine dust particles.

The word **sorption** means generally the incorporation in another material. Absorption is the solving of material in liquids and adsorption the deposit on solid surfaces of gaseous or liquid materials. Many sampling filters have an adsorption surface, which can be analyzed by chromatography or spectrometry depending on the adsorption reaction. This reaction of the samples ensures a complete analyzing of the collected compounds.

Gravitational forces affect all particles but influence the larger particles and their settling behaviour more, as they are dependent on the size and mass. The gravitational sedimentation of particles is dominated by the weight force, which is greater the larger the particle is. This is a commonly known problem for fine

dust measurement and needs to be taken under consideration for all measurements and the analysis of the results.

Electrostatics describes the **electrostatic attraction** from stationary or slow – moving electrical fields. The Coulomb's law describes the conditions of the forces between two electric charges, which can be up to 40 times stronger than the van-der-Waals forces acting between them. A charged electret causes an internal and external electrostatic field with a quasi-permanent charge. In the context of the aerosol measurement the electrets have a permanent polarisation, which is initiated by a corona device. (*Hinds 1999, 320ff*)

2.2.4 Passive Sampler Models

This section is going to introduce the passive sampler models for personal particulate matter monitoring indoors. The following presented models have been selected out of all the passive samplers identified by the research connected to the project. In addition to the two following presented passive samplers developed by Vinzents and the electret passive sampler there is another idea, which is worth mentioning at this point, although not useful for the experimental work, but maybe interesting for later investigations.

This passive sampler is called PAAS, which stands for personal aeroallergen sampler and is developed for sampling airborne coarse particles, but more specifically to measure coarse aeroallergens such as mite fecal pellets, pollens or fungal spores. The working mechanism is gravitational settling. But the mentioned aeroallergens are not in a particulate matter size range and therefore, not useful for this thesis. (*Yamamoto 2006:pp1442-1454*)

Electret Passive Sampler

The following presented sampler called electret passive sampler is based on electrostatic forces. The generated electrical field by the charged electret brings the power source for the passive measurement. The structure of the sampler shown in figure number 5 consists of an electret covered by a plastic casing with latticed sides and solid top and back. The perforated casing protects the electret and fixes the capture effecting electrical field. The electret is kept to the sampler by its own electrical attraction. The collecting surface captures the dust by electrostatic attraction and has the same shape as standard sampling filters (25mm). The lattice structure of the sampler cover provides a capture of a selected particle size.

The electret in this case is a preloaded polymer carried out by a corona device. Due to this stable charge the electret passive sampler does not require a continuous power source during the measurement process. The electret passive sampler can be attached to the breathing zone of a person by a safety pin.⁹

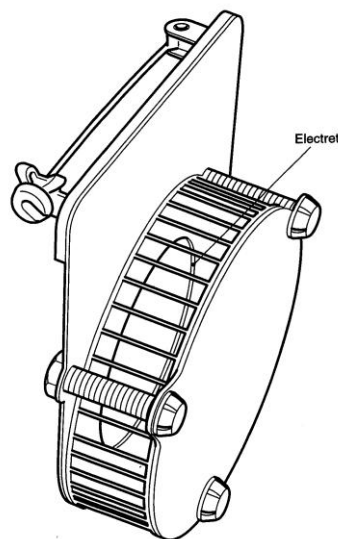


Figure 5 Electret Passive Sampler¹⁰

^{9 9 10}Hemingway/Strudley et al. 1997:pp 653-658

The dust concentration for this model can be calculated with the formula:

$$c = k \cdot \frac{m}{V \cdot t} \quad (4)$$

where **m** is the collected dust, **V** is the surface voltage of the electret and **t** is the exposure time of the measurement process, which are measurable quantities while **k** is a calibration constant, determined by comparing the passive sampler results by a linear regression constrained to pass through zero with a conventional sampler.¹¹

In the past some with field work in different branches of industry was done and the following conclusion have been achieved.¹²

The conclusion of this study is that the electret-based passive sampler shows good correlation to conventional samplers so the airborne concentration measurement with the PS can be considered as an accepted measurement device. But further work is recommended especially in improving the precision of the sampler, as the multiple measurement results have not been good.

Vinzents Passive Sampler

This passive sampler developed by Vinzents for personal monitoring is based on gravitation, Brownian and turbulent diffusion of particles. The capture of dust takes place on sticky, transparent foils, which are arranged at right angles. The analysis is based on the light extinction before and after the measurement. The increase of light extinction on the dust covered foil will be used to calculate the dust concentration by linear regression models and the particles size analysis is done by microscopical determination by using the projected area equivalent diameter. The results presented in relevant literature show the importance of the deposition on the upward facing foil compared to the amount of the forward and downward facing foils, as this is the position with the most significant measured quantity. The measurement results lead to the conclusion, that the determining deposition mechanism is gravitational settling so others can be ignored. The published results from former studies recommend concentrating on

¹² See Appendix A9 for results of [Hemingway/Strudley et al. 1997:pp 653-658]

the ratio between the dynamic and volume shape factor and neglecting information about particle density. Overall the field studies show the reflection of the various deposition mechanisms by the passive sampler model and prove of similar results in comparison to the IOM inhalable dust sampler.¹³

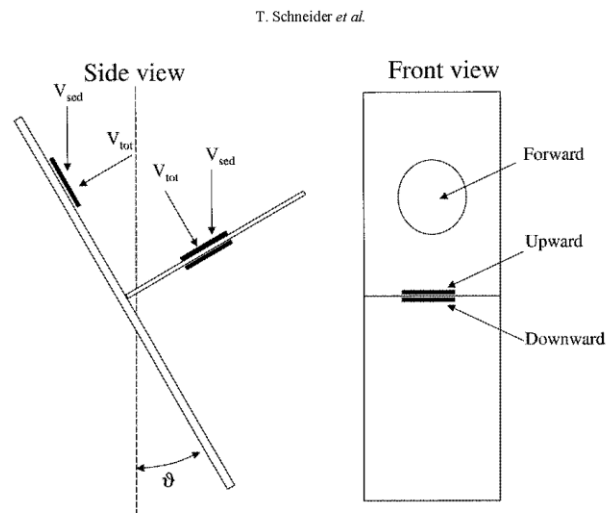


Figure 6 Passive Sampler developed by Vinzents¹⁴

2.2.5 Passive sampling analysis

Passive sampling measurement involves in general the measurement of the mass and the result interesting result is the particle concentration in the first place the mass concentration and secondly the number concentration or at least a statement about the size of the measured particles. The mass can be determined by gravimetric analysis and the particle size analysis can be done with several methods such as:

- Optical microscope
- Light scattering and light extinction
- Laser light refraction

¹³¹³ Schneider 2002:pp187-195

¹²See appendix A8 for the results of the field studies

As the passive sampling technologies are on an experimental level and the analysing equipment limited the focus is on the mass determination and the calculation of the mass concentration and for the particle size analysis the optical microscope and an image tool program can be used.

Basically the mass concentration is calculated with the particle mass per volume air, which is similar the air flow multiplied by the time of the measurement. Since in passive sampling methods the particle motion is more or less not a measureable quantity but caused by passive forces the volume flow of the air is unknown. The determination of the mass concentration in this work has been done with the assumptions that particle velocity is constant and the air flow in the dust tunnel is not turbulent therefore, also constant. The Air flow is substitute by the constant velocity of the particles multiplied by the measured area of the glass plates.

These assumptions are leading to the simplicity of the comparison between the dust mass concentrations of the active devices with the passive mass results.

The passive samplers are calibrated by linear regression models

3. Comparison Study of Passive and Active Sampler

The main work of this thesis is to examine the measurement possibilities of a selected passive sampler in comparison to conventional personal dust measurement devices. As there are two possible passive samplers presented the selection of the passive sampler used for the examination will be the first step of this study before the measurement starts.

The Measurements will be situated in a controlled circumstances to avoid many indefinitely variables, as this is the first step to the measurements of the passive sampler method in this project. The results will be presented in the following sections and the evaluation will be the base of the measurement discussion.

The project team would have like to carry out measurements in the concrete laboratory, but due to reconstructing and move of the laboratory in this period measurements were not possible.

3.1 Selection of the PS Method

During the project the team tried many ways to get passive samplers from other institutions for occupational health for instants from Denmark or Great Britain, as there were no commercially available passive samplers on the market at that time. The project started, because of financial reasons compared to the expected success and availability, with a self-made passive sampler based on the idea of the passive sampler developed by Vinzents.

Comparing the results from the literature field work of the two presented passive samplers the decision for further investigation would be the electret passive sampler, due to its external passive power source of the electrical field. The Vinzents passive sampler shows in the past experimental examinations that the adhesion forces are to be neglected compared to the gravitational forces, which are governing the measurement mechanism. But as the purchase were confronting the team with unsolvable conditions the team members of the project in cooperation with the chemical engineering department of the TAMK and occupational health centre Tampere came to the decision to start at least with

measurements based on the simplest and cheapest passive sampler with the help of given condition. As the construction of the Vinzents passive sampler is very simple and cheap to implement the following experimental work is based on the Vinzents passive sampler model.

3.1 Basics of the Measurements

The selected passive sampling method developed by Vinzents for the following experiments will be analysed in the context of this work.

All the measurements concerning this thesis have been carried out in the laboratories of the University of Applied Sciences Tampere and more precise the implementation of the experiment is approved in the dust tunnel with a concrete dust sample under control circumstances.

Measurement place

As the project has to be started with an unknown passive sampler, the place to start with the measurement has to take place at a controlled situate and under as much as possible known conditions. The dust tunnel, which has been already used for general investigations of dust behaviour is the right place to start.

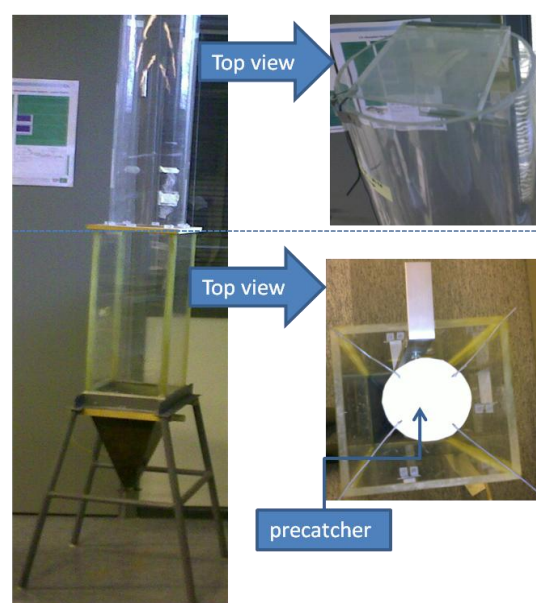


Figure 7 Dust Tunnel

The dust tunnel consists of a transparent plastic casing, with a removable upper part and a funnel shaped substructure, which is connected to the 4-legged metal frame. Dust exposure can be done through the mechanical system on top of the removable plastic tube consisting of a plastic clip-on cover. The size of the clip-on cover limited the homogenous distribution of particles during the exposure.

Sample Material

Concrete fine dust from the concrete laboratory of the University of Applied Sciences Tampere (TAMK)

3.2 Preliminary Investigations for the Measurements

3.2.1 Implementation of the Preliminary Investigations

Before starting with the comparison experiments of the dust samplers it is important to observe the behaviour of the used fine dust, to select the adhesive material for the Vinzents passive sampler and the right positioning of the devices. The results of this preliminary investigation serve to optimize the whole measurement process and prove the reproducibility of measurements.

The examinations take place in the dust tunnel (Figure 9), which offers measurements in control circumstances and is further presented in the measurement place. During these tests the project team observed the particle behaviour concerning the appropriate amount of dust for each measuring process to be sure about the device limits and to avoid agglutinating of particles in connection to the amount of used dust. Another point was the observation of the dust settling time meaning the approximate duration until the dust has been settled respectively down or until generally no more particles could be seen by human eyes also the ratio between separately visible dust particles and the dust cloud.

Below the possible adhesive materials for the Vinzents passive sampler are presented:

- Collection Substrate spray Dekati DS-515; +15 - +25°C
(High quality vacuum grease for lubricating collection substrates)
- Adhesive grease; heat supply necessary before usage

The Dekati spray needs to be spread in two steps horizontally and vertically with a 15min break after each procedure, while the adhesive grease need to be heated up to room temperature and every glass plate has to be treated individually with a very thin layer.

3.2.2 Results of the Preliminary Investigations

The amount of **dust** for each measurement process should be around $m_{d0}=5g$ to avoid the agglomeration of particles and not to exceed the concentration limit range of the control device DusTrack, which is 100 mg/m^3 for individual dust exposure. But as it is not possible to avoid completely the agglutinating of the particles a preliminary catcher ("precatcher" Figure 9) will be positioned between release place and measurement devices to avoid that the agglutinating dust particles drop immediately, behaving like big particles, on the sampling surface and falsify the measurement.

For better comparison data and the possibility to compile a calibration curve the duration for each measurement should be in total the same and as observed by the settling behaviour of the fine dust particles from the concrete laboratory it should be approximately 30 minutes.

The decision was in favour of the collection substrate spray Dekati DS-515 due to the simpler handling and quick recovery. The results of the different adhesives were nearly similar with average measurement difference of 19%

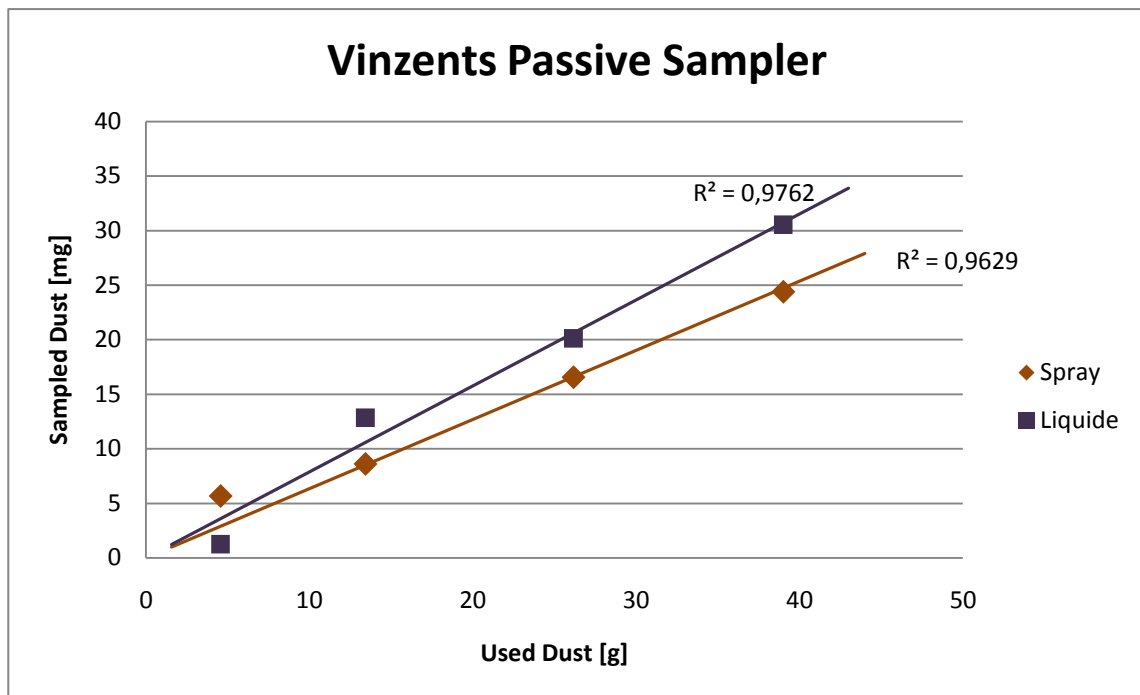


Figure 8 Vinzents Passive Sampler Spray or Liquid

These are the Results of the preliminary experiments:

- Amount of dust for each measurement process $m_{d0}=5g$
- Use of a “**precatcher**”
- Total measurement duration approximately **30 min**
- Collection Substrate spray Dekati DS-515

Proof of Reproducibility

The reproducibility is a basic requirement for scientific measurements and is examined in this section. In general it means that similar results are possible under similar condition by taken under consideration of the calculable measurement errors. The proof of reproducibility involves a good documentation of the measurement conditions, equipment and results.¹⁵ The whole chapter 3 offers a very good possibility for reproduction but in this individual section the following results are meant to show the individual reproducibility of the sampled mass by the Vinzents passive sampler.

¹⁵ <http://de.wikipedia.org/wiki/Reproduzierbarkeit>

The following figure (Figure 9) shows the results of several runs with the same dust exposure to make sure the circumstances are similar for all the experiments and the results are reliable.

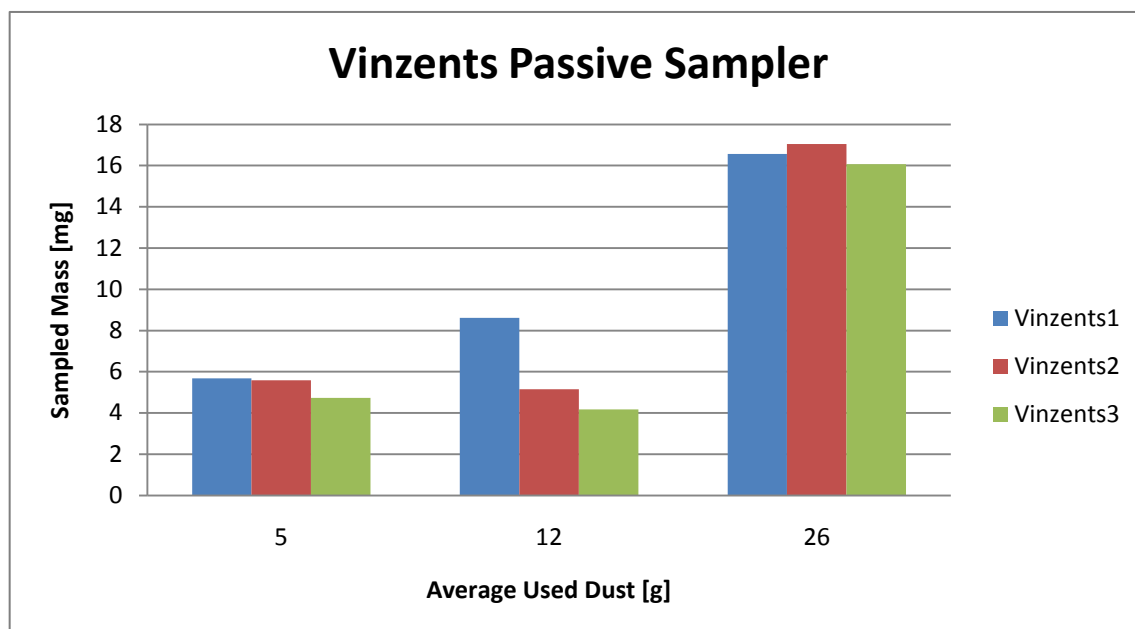


Figure 9 Vinzents Passive Sampler Test Run Results

The results especially for the first and last experimental run provide a base for further experiments with the self-constructed passive sampler based on the development of Vinzents. The sampler is presented in detail in chapter 3.2.3 measurement equipment.

| Average Used Dust [g] | mean value [mg] | relative standard deviation [%] | Mean value \pm standard deviation [mg] |
|-----------------------|-----------------|---------------------------------|--|
| 5,22 | 5,34 | 9,72 | 5,34 \pm 0,51 |
| 12,01 | 6,88 | 35,64 | 6,89 \pm 1,76 |
| 26,12 | 16,31 | 2,16 | 16,31 \pm 0,35 |

Table 1 Passive Sampler Test Run Results

3.2.3 Measurement Equipment

Control device DusTrack Laser Photometer

This portable laser photometer (Figure 10) with real-time measurement and a digital display is the control device for the experiments. Among the features is the concentration limit range of 0.001 to 100 mg/m³, particle size range of 0.1 to 10µm and a flow rate of normally 1.7L/min. The device is connected to the measurement place with a tube as shown in the measurement structure chapter 6.4.2.



Figure 10 DusTrack Laser Photometer¹⁶

Active Sampler

The IOM inhalable dust sampler (Figure 11), which is presented in detail in chapter 3.2 is used for the following experiments as a comparative device. The IOM sampler is placed inside the dust-tunnel while the pump will work outside connected with a tube to the measurement place with a constant volume flow of 2L/min. In chapter 6.4.2 the positioning of sampler and pump are shown in context of the experiment.

¹⁶ <http://www.ierents.com/ProductInfo.aspx?productid=RTSI8520>

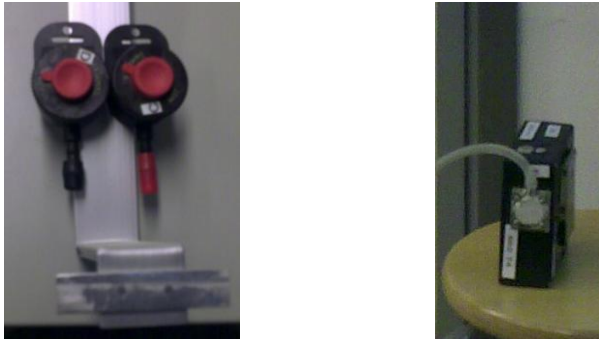


Figure 11 IOM inhalable Dust Sampler and Pump

Passive sampler :

The passive sampler used in the experiments is build based on the passive sampler developed by **Vinzents**.

The basic idea of three transparent collecting surfaces, which are ordered in a forward-, an upward- and a downward-position are replaced with commonly known an simple materials.

The mounting support of the collecting surface is an L-shaped frame made by aluminium, on which the three glass plates are mounted. The glass plates (18x18mm) are coated with an adhesive spray called Dekati DS-515 to replace the sticky foils and are attached to the frame by *Blu-Tack*.

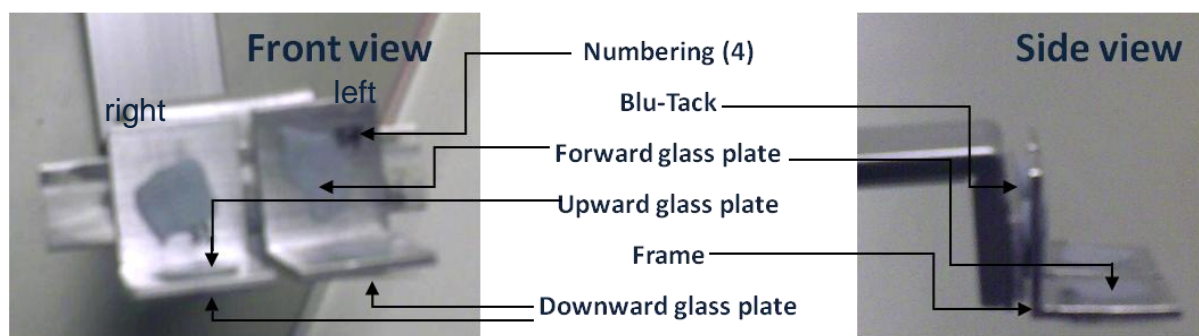


Figure 12 Model of Vinzents Passive Sampler

Beside the Vinzents sampler the IOM sampler is also used passively by just not connecting it to a pump.

Analysis equipment

Analytic balance with an accuracy of $0,01\text{mg} \pm 0,02\text{mg}$

Optical microscope

3.3 Implementation of the Measurement with Vinzents

The following experiments involve the review of the efficiency of the passive sampler developed by **Vinzents** and the **IOM-sampler** used passively in comparison to the active working devices **IOM-inhalable dust sampler** and the aerosol monitor **DusTrack** working as a laser photometer.

The implementation of the measurement contains beside the **pre-measurements** the following main steps for the experiments:

- Preparation of the Measurement
- Structure of the Measurement
- Performance of the Measurement
- Analysis of the Measurement

3.3.1 Preparation of the Measurement

In advance of the measurement the glass plates has to be coated with the adhesive spray, numbered and weighted in order to the gravimetric analysis afterwards. Determination of the measurement and analysing room conditions needs to be carried out due to the influence of temperature and humidity. The chapter 3.3.2 Measurement structure shows the positioning of the individual devices and the place of the simulated dust exposure.

3.3.2 Structure of the Measurement

The dust measurement devices are positioned in the lower part of the dust tunnel as shown in the following image (Figure 13). The IOM dust samplers are arranged vertically side by side fixed at the same aluminium frame as the Vinzents passive sampler. The connection between the actively working IOM dust sampler and the pump (2L/min volume flow) is achieved by a plastic tube. The monitoring laser photometer DusTrack measures the loaded air with the help of the plastic tube, which is the connection between the measurement place and the device. It operates with a constant volume flow of 1.7L/min and measures every minute the dust mass concentration.

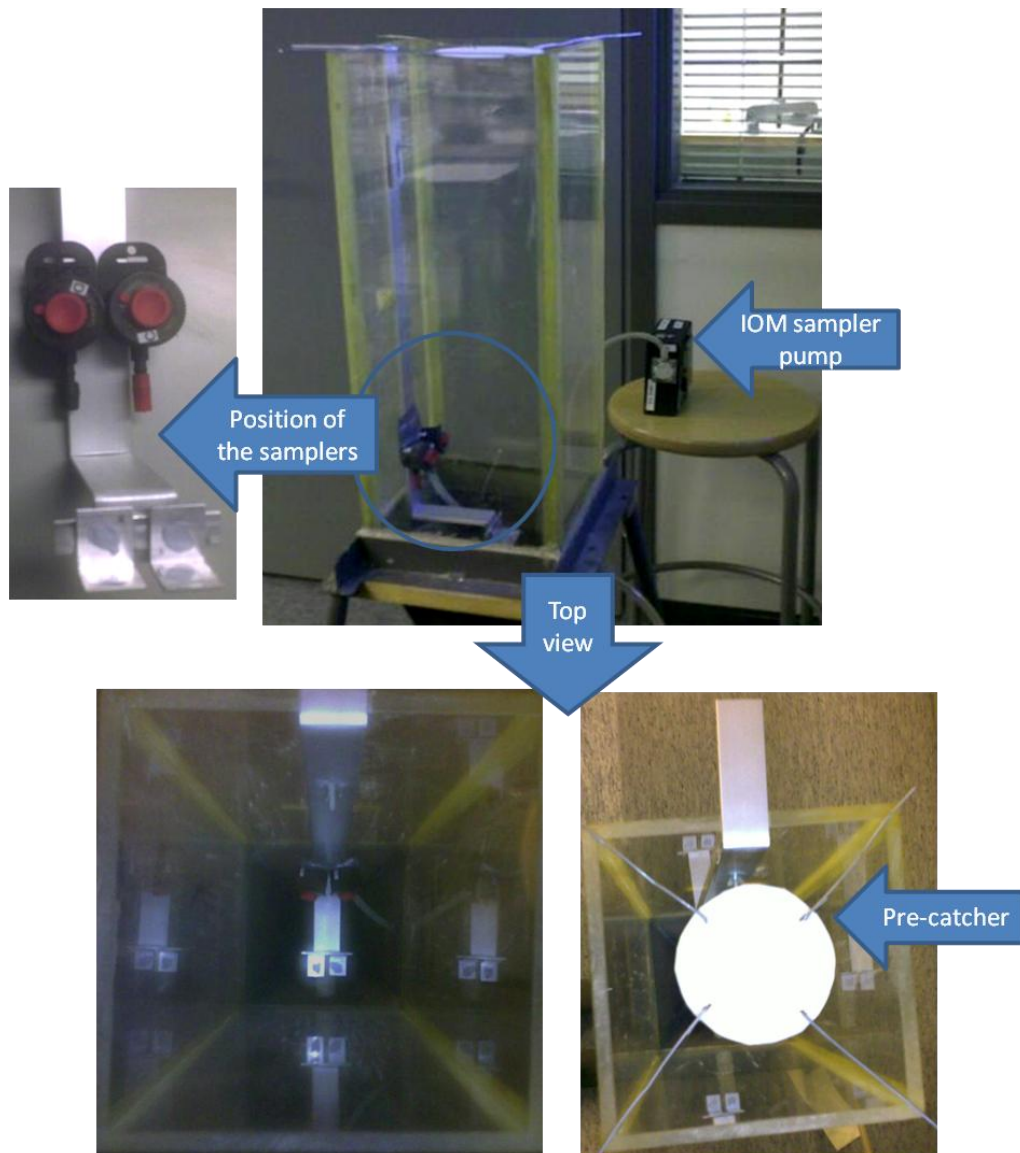


Figure 13 Measurement Structure Position of the Sampler

The imitation of the dust exposure is initiated from top as you can see in the following figure (Figure 14). The dust is distributed on the plastic top and released by the mechanical lever

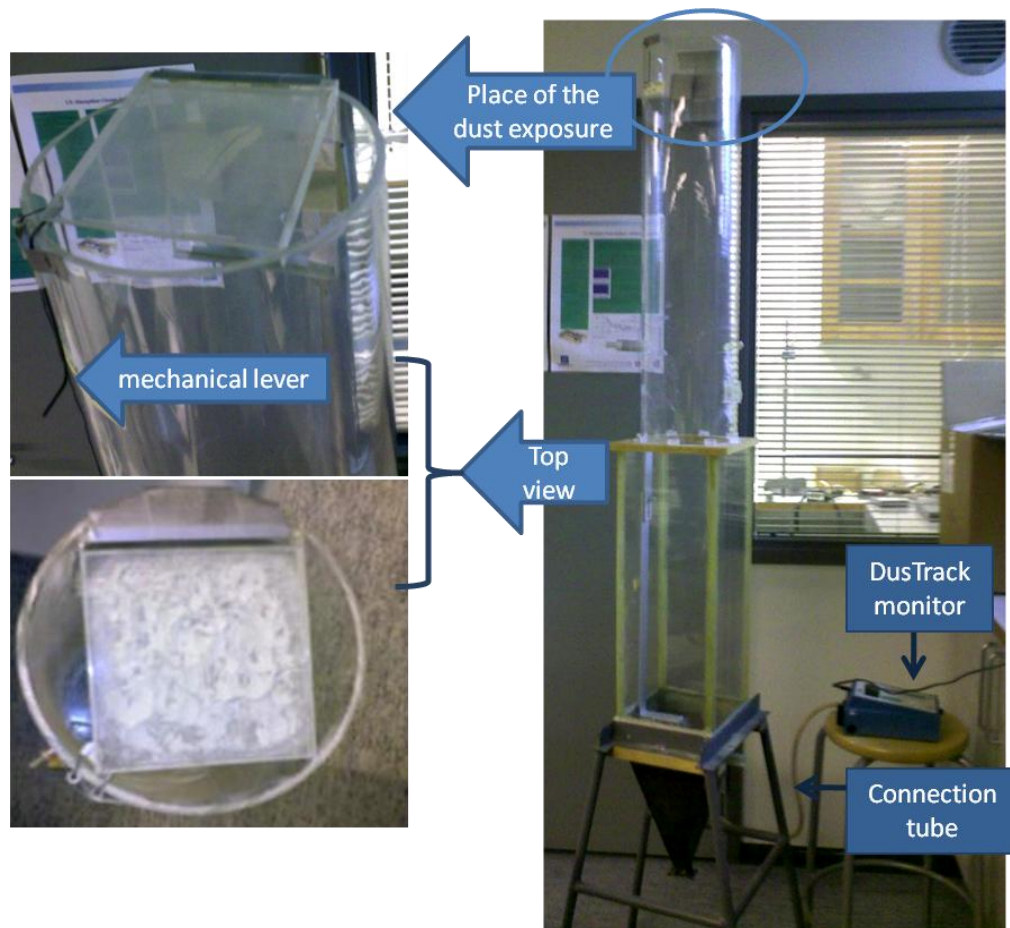


Figure 14 Measurement Structure Positioning of Dust and DusTrack

The flow chart is a short summary about the steps of the experiment process to give a short overview.

3.3.3 Performance of the Measurement

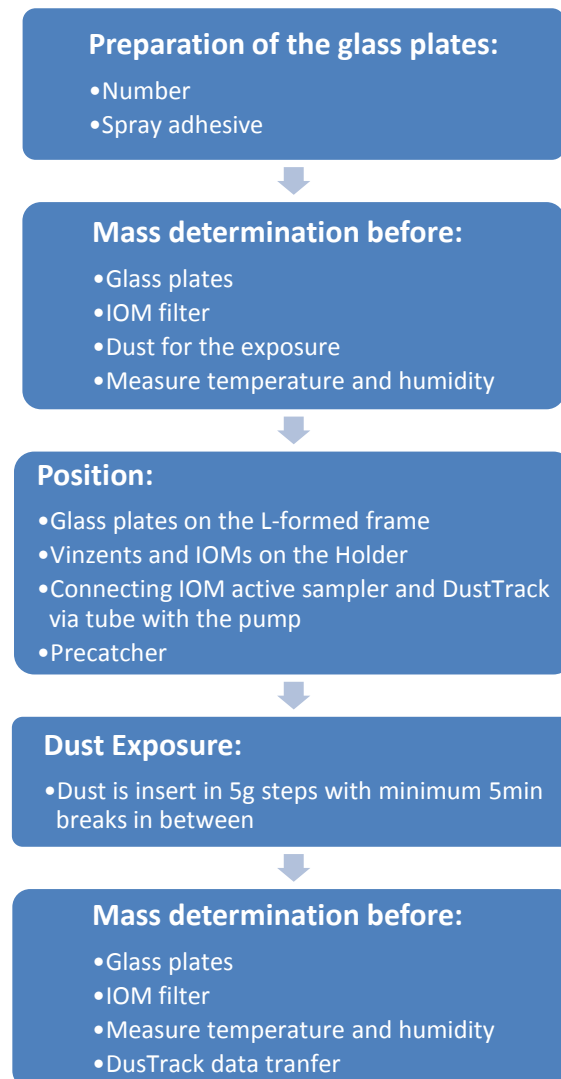


Figure 15 Performance of the Measurement

The following presented measurements consist of 5 experimental runs, whereby for each experimental run the used devices are two Vincent's passive sampler one IOM sampler used passively, one IOM sampler used actively connected with a tube to the 2L/min operating pump and the laser photometer DustTrack operating with 1.7L/min.

The samplers are positioned as shown in chapter 3.3.2 after the weight of all individual glass plates for the Vincent's PS and the filters of the two IOM samplers have been determined. Then IOM active sampler is connected with a tube to the pump and the control device DustTrack laser photometer is connected with a tube to the sampling place. The "precatcher" is positioned and the whole

tunnel is combined and now the dust is to be distributed in maximum 5g steps as good as possible on the plastic cover, taken care to ensure that not too many agglomerates arise. The initiation of the dust exposure, the time measuring and the power up of the active devices are taken place at the same time. The dust concentration is not constant but decreasing during the experiment duration. The duration is approximately the same for each experimental run and the exposure happened every 5min. The dust exposure is taken place in the following amount steps 2,5g; 5g; 10g; 15g; 25g, whereby the order does not match with the experiment numbers. That means for the first run just 2.5g is insert into the dust tunnel and than just waited until the time was over, while in experiment number three the total dust amount of 26g is insert into the system in five steps with approximately 5g per step with a minimum of 5minutes break in between every exposure.

| Experiment no | dust mass used for experiment [g] | duration of experiment [min] |
|---------------|-----------------------------------|------------------------------|
| 1 | 2,7161 | 32 |
| 2 | 5,3094 | 30 |
| 3 | 26,0736 | 39 |
| 4 | 10,5917 | 32 |
| 5 | 16,2283 | 39 |

Table 2 Experiment Procedure Details

3.3.4 Analysis of the Measurement

The analysis of the measurement process is described in this chapter and all the results of these analyses are shown in chapter 3.4.

Gravimetric determination

The individual glass plates of the Vinzents passive sampler and the filter of the two IOM dust samplers are measured before and after the measurement. The mass determination in the weighing room is carried out under observance of the temperature and humidity (Figure 16). Every collecting surface is analyzed three times and the average is used for the evaluation.

The following figure shows the instability of the room conditions concerning temperature and relative humidity during the gravimetric determination in the weighing room.

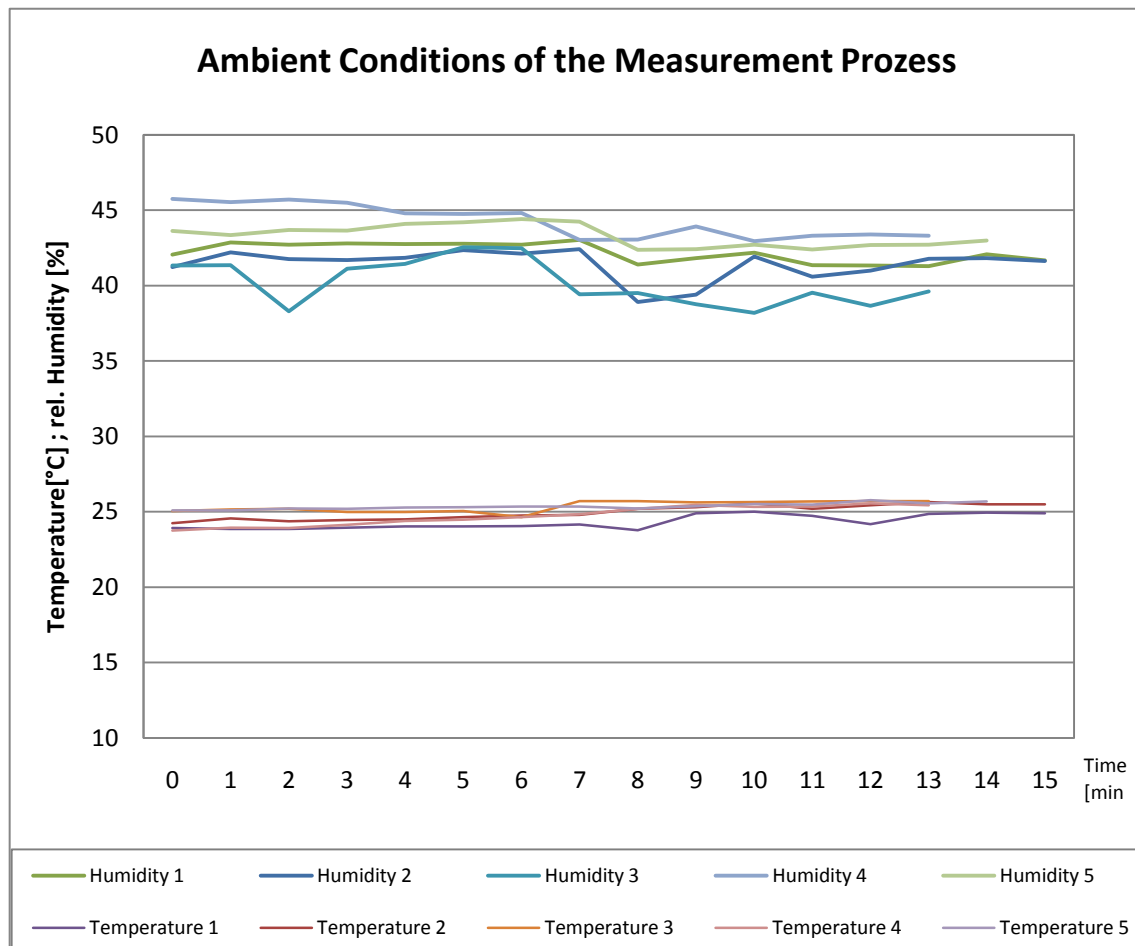


Figure 16 Ambient Condition

Picture analysis

After the mass determination the glass plates of the Vinzents passive sampler are analyzed with the microscope and afterwards with image tools to have an idea about the particulate matter sizes and numbers.

Data transmission

DusTrack is transferred directly with a software tool to the excel data base after the measurement. The data consists of around 30-39 single measurements of the dust mass concentration, depending on the experiment duration. The device

measures every minute the mass concentration with an 1.7L/min operating pump and gives as output data the date, the time and the mass concentration in [mg/m³].

Particle size analysis

The concrete dust for the experiments is analysed with the particle size analyser in the University of Applied Sciences and Arts Hannover (FHH). Required for this analysis is a representative sample of dust, which has been easily taken by dividing the sample in several steps in equal parts and continuing with one of the divided parts for each step until a small sample was delivered. The amount needed for the analysis was very small, which means around 1g so the representation of the sample was even more important.

3.4 Results of the Measurement

The measurement results are presented in the following chapter as tables ordered by the single measurement devices to gain an overview about the individual experiment data.

3.4.1 Particle Size analysis

The particle size is analysed by using a laser particle size analyser¹⁷ and the data is presented in this section.

The following frequency distribution has been determined:

| | | | | | | | | |
|---------------|------|------|-----|------|------|------|------|------|
| Diameter [µm] | 1 | 1,5 | 2 | 3 | 4 | 6 | 8 | 12 |
| Cumulativ [%] | 3,4 | 3,8 | 4,2 | 6,5 | 9,6 | 15,1 | 20,2 | 29,3 |
| Frequency [%] | 3,4 | 0,4 | 0,4 | 2,3 | 3,1 | 5,5 | 5,1 | 9,1 |
| Diameter [µm] | 16 | 24 | 32 | 48 | 64 | 96 | 128 | 192 |
| Cumulativ [%] | 37,1 | 54 | 67 | 80,5 | 88,5 | 92,2 | 98 | 100 |
| Frequency [%] | 7,8 | 16,9 | 13 | 13,5 | 8 | 3,7 | 5,8 | 2 |

Table 3 Particle Size Analysis Concrete Dust Sample

¹⁷ Disperse Laser Particle Size Analyser CILAS 715(Laser Granulometer)

The particle analysis implies an average particle size of **21.15 μm** a specific surface area of $0.46 \text{ m}^2/\text{cm}^3$ with assumed shape of a spherical particle. The particle size range is between **1-192 μm** .

The following presented chart shows the relative distribution of the particles density concerning the frequency of the particle size of the representative sample of the used concrete dust for the measurements.

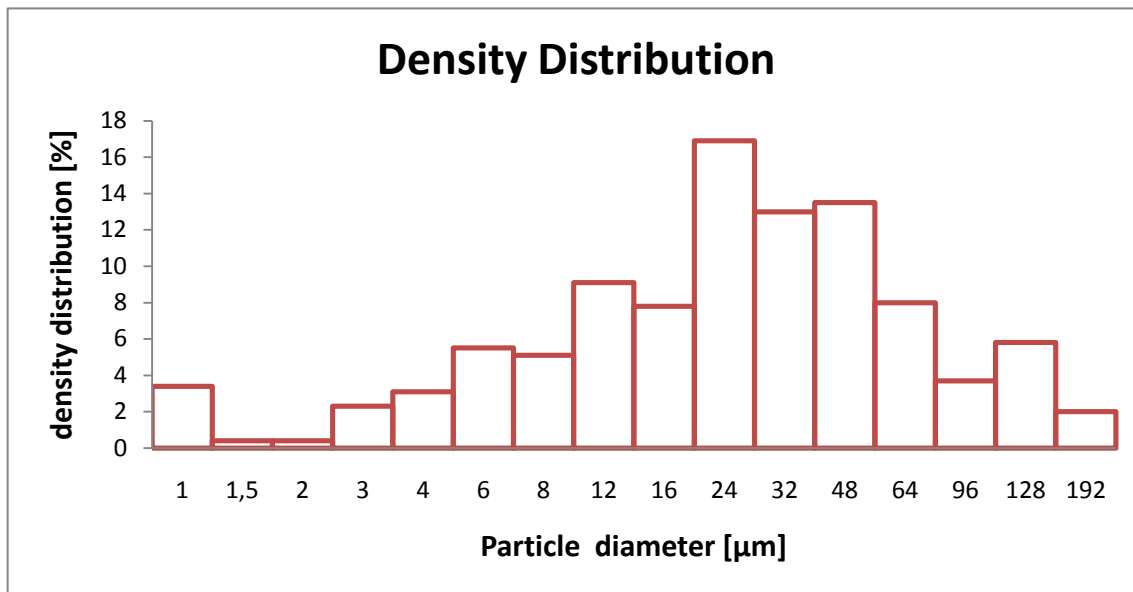


Figure 17 Density Distribution Concrete Dust Samplej

The pass-distribution constitutes the cumulative frequencies

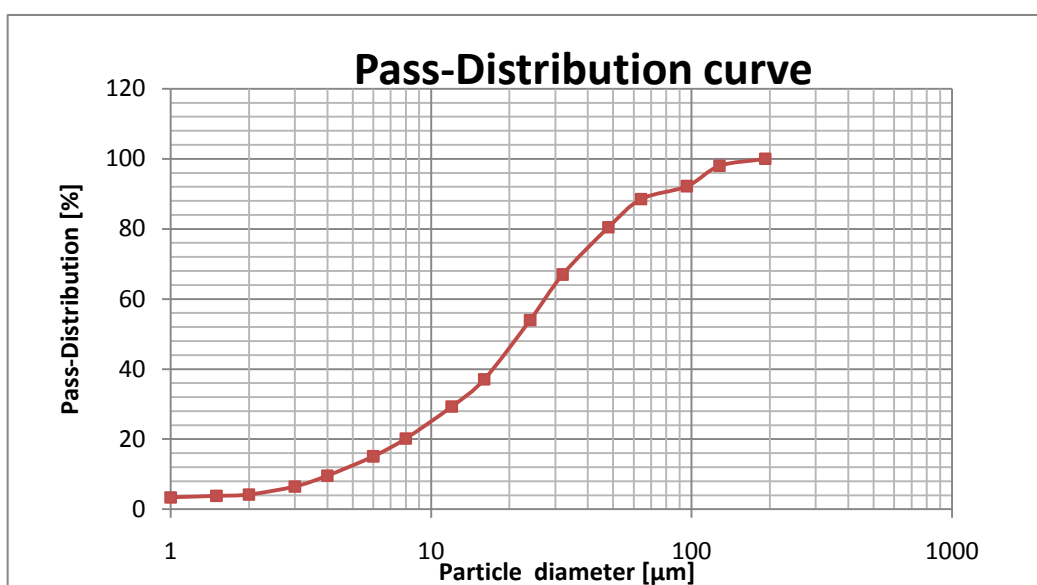


Figure 18 Pass-Distribution Concrete Dust Sample

3.4.2 Active Devices

The following presented results in table number 4 are based on the results of the active IOM inhalable dust sampler working with a constant volume flow of 2L/min to simulate the inhalation of the human lung. This data is the reference value for the Vinzents passive sampler. The proportional increase of sampled dust mass with the increase of deployed dust can be seen clearly.

| IOM Active Dust-Sampler | | | | | | |
|-------------------------|-----------------------------------|----------------------|------------------------|---------|-------------------|---------|
| Experiment no | dust mass used for experiment [g] | device specification | mass of the filter [g] | | sampled dust mass | |
| | | | before | after | [g] | [mg] |
| 1 | 2,7161 | c | 4,46662 | 4,48222 | 0,00786 | 7,8600 |
| 2 | 5,3094 | d | 4,89077 | 4,89863 | 0,01559 | 15,5923 |
| 3 | 26,0736 | c | 4,72133 | 4,76963 | 0,04830 | 48,3000 |
| 4 | 10,5917 | d | 4,66363 | 4,68430 | 0,02068 | 20,6767 |
| 5 | 16,2283 | d | 4,63536 | 4,67674 | 0,04138 | 41,3800 |

Table 4 Results IOM Active Dust Sampler

The results of the active sampler are required as improved despite the potential measurement errors.

The DusTrack data is here shown as an average mass concentration over the individual experiment and presented in table number 5

| DusTrack | | |
|---------------|-----------------------------------|------------------------------------|
| Experiment no | dust mass used for experiment [g] | average dust concentration [mg/m3] |
| 1 | 2,7161 | 2,85481 |
| 2 | 5,3094 | 5,22803 |
| 3 | 26,0736 | 13,23391 |
| 4 | 10,5917 | 6,06948 |
| 5 | 16,2283 | 8,76212 |

Table 5 Results DusTrack

3.4.3 Passive Sampler

The passive sampling results from the Vinzents and passively used IOM inhalable dust sampler are presented below.

IOM Passive Sampler

| IOM Passive Sampler | | | | | | |
|---------------------|-----------------------------------|----------------------|------------------------|---------|-------------------|--------|
| Experiment no | dust mass used for experiment [g] | device specification | mass of the filter [g] | | sampled dust mass | |
| | | | before | after | [g] | [mg] |
| 1 | 2,7161 | c | 4,42806 | 4,42863 | 0,00057 | 0,5667 |
| 2 | 5,3094 | d | 4,87992 | 4,88118 | 0,00126 | 1,2567 |
| 3 | 26,0736 | d | 4,63556 | 4,63878 | 0,00323 | 3,2267 |
| 4 | 10,5917 | c | 4,65458 | 4,65639 | 0,00181 | 1,8133 |
| 5 | 16,2283 | c | 4,72147 | 4,72328 | 0,00181 | 1,8067 |

Table 6 Results IOM Passive Sampler

The Table 6 shows a very low proven sampled dust mass with the passively used IOM sampler.

Vinzents Passive Sampler

The Vinzents passive sampler shows a growth of sampled mass with the growth of deployed dust mass. The following results Table 7 clearly indicates the importance of the positioning of the Vinzents. The Vinzents passive sampler positioned on the right site samples during all the experimental runs more dust than the left positioned sampler. Further execution is to be found in Chapter 8.2.

| Vinzents Passive Sampler | | | | |
|--------------------------|-------------------------|-----------------------------------|-------------------|----------|
| Experiment no | position of the sampler | dust mass used for experiment [g] | sampled dust mass | |
| | | | [g] | [mg] |
| 1 | V1right | 2,7161 | 0,00282 | 2,81667 |
| 1 | V1left | 2,7161 | 0,00243 | 2,42667 |
| 2 | V2left | 5,3094 | 0,00474 | 4,74000 |
| 2 | V2right | 5,3094 | 0,00559 | 5,59000 |
| 3 | V3left | 26,0736 | 0,01606 | 16,06467 |
| 3 | V3right | 26,0736 | 0,02174 | 21,74000 |
| 4 | V4right | 10,5917 | 0,00515 | 5,15000 |
| 4 | V4left | 10,5917 | 0,00418 | 4,18000 |
| 5 | V5left | 16,2283 | 0,01121 | 11,20667 |
| 5 | V5right | 16,2283 | 0,01569 | 15,68667 |

Table 7 Results Vinzents Passive Sampler

Image results

The image results are presented here in combination to the results from the image particle size analysing. The glass plates of the Vinzents passive sampler were microscope images are presented below in combination to the results of the picture analysing program ImageTool concerning particle size distribution.

Three examples are chosen out of 30 glass plates of two Vinzents passive sampler of the 5 measurements presented above. The marked lines on the images are the scale and correspond to 100 μ m in reality. The images were processed by the image tool Corel Graphics Suite X3 to give a clearer presentation for the particle size analysing program ImageTool¹⁸. Therefore, the background is black and the particles are either white or light grey. The following presented examples for each glass plate position are a part of the whole glass plate area.

Forward facing glass plate

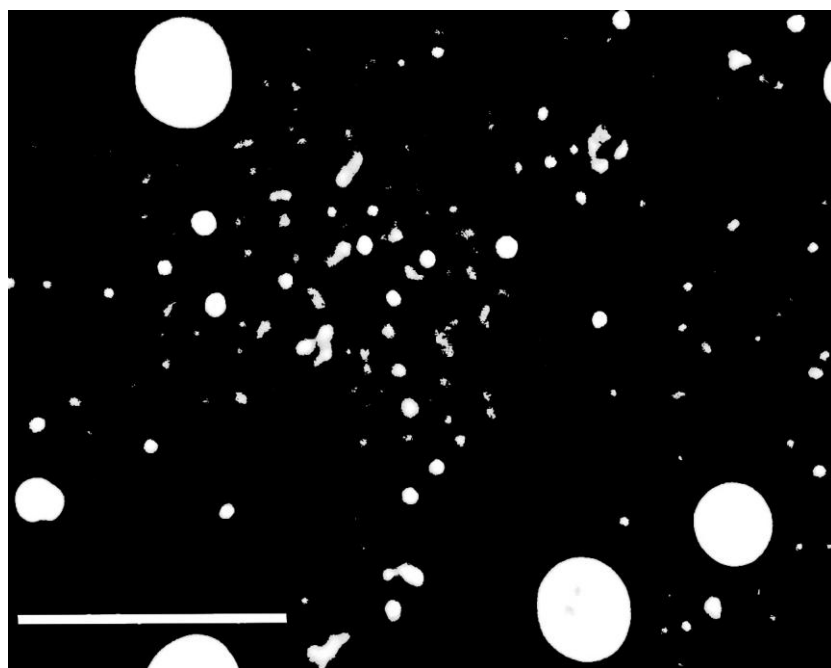


Figure 19 Forward GP Vinzents Passive Sampler T3_38¹⁹

¹⁸ <http://ddsdx.uthscsa.edu/dig/itdesc.html>

¹⁹ T3_38 means it is the glass plate number 38 from the experimental run number 3.

The size range in table 8 was selected with the help of older data and can be changed with better experiences. Counted value of the particles in the individual size ranges are as well presented as the mean values and the standard deviation.

| T3_38 | Value Range [µm] | Count | Mean Value [µm] | Std. Dev [µm] |
|---------------------------------|------------------|-------|-----------------|---------------|
| Mean Std. Dev. | | 23,18 | 25,9 | 2,97 |
| | | 36,87 | 45,13 | 5,72 |
| | - 1.00 | 0 | 0 | 0 |
| | 1.00 - 3.00 | 115 | 1,76 | 0,56 |
| | 3.00 - 5.00 | 27 | 3,82 | 0,54 |
| | 5.00 - 10.00 | 33 | 7,83 | 1,41 |
| | 10.00 - 30.00 | 66 | 17,74 | 5,38 |
| | 30.00 - 50.00 | 10 | 38,3 | 5,88 |
| | 50.00 - 100.00 | 1 | 71,14 | 0 |
| | 100.00 - 300.00 | 3 | 144,3 | 18,93 |
| | 300.00 - 500.00 | 0 | 0 | 0 |
| | 500.00 - 1000.00 | 0 | 0 | 0 |
| | 1000.00 - | 0 | 0 | 0 |

Table 8 Results Particle Size Analysis T3_38

The relative frequency of the particles analysed on the forward glass plate illustrated in Figure 20 below show a greatly marked size range of 1-3µm and 10-30µm.

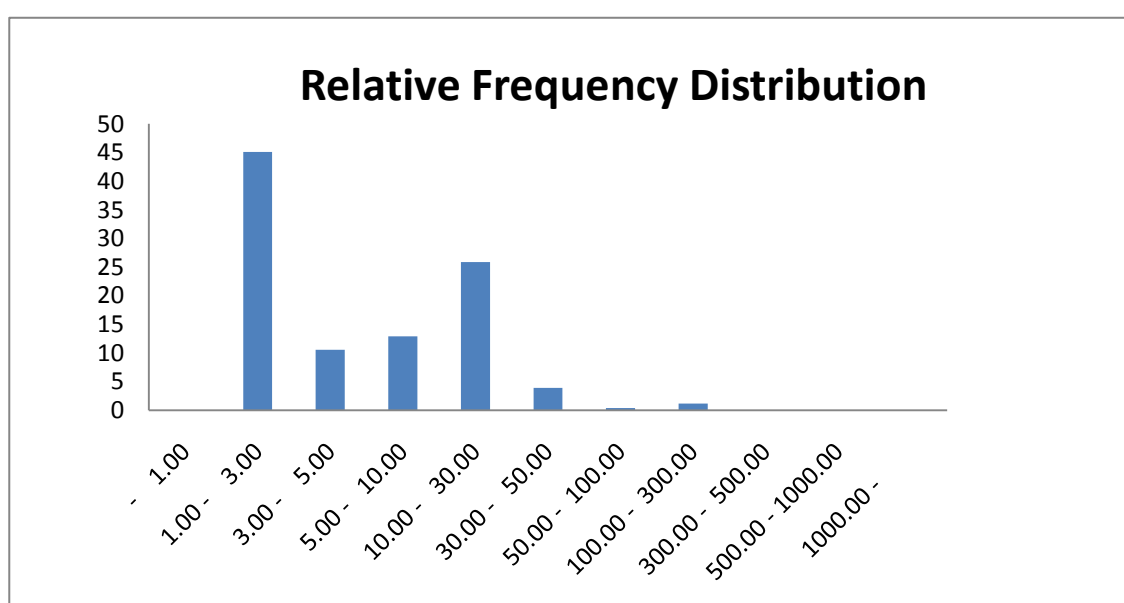


Figure 20 Relative Frequency Distribution T3_38

Upward facing glass plate

The upward facing foil captured most of the dust as already expected, so that the following image barely shows individual particles but big areas with obviously agglomerated particles.

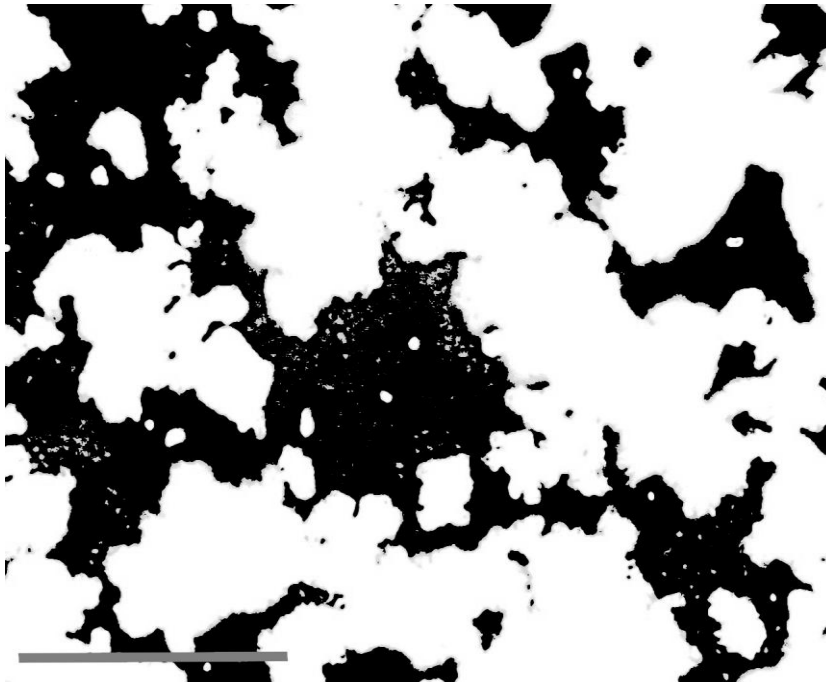


Figure 21 Upward GP Vinzents Passive Sampler T4_33²⁰

Although the image does not reflect the real possible size range it is interesting to see how the results looked like and the counted particle results in Table 9 offers even particles under $1\mu\text{m}$ but obviously the program could just recognize particles under $30\mu\text{m}$.

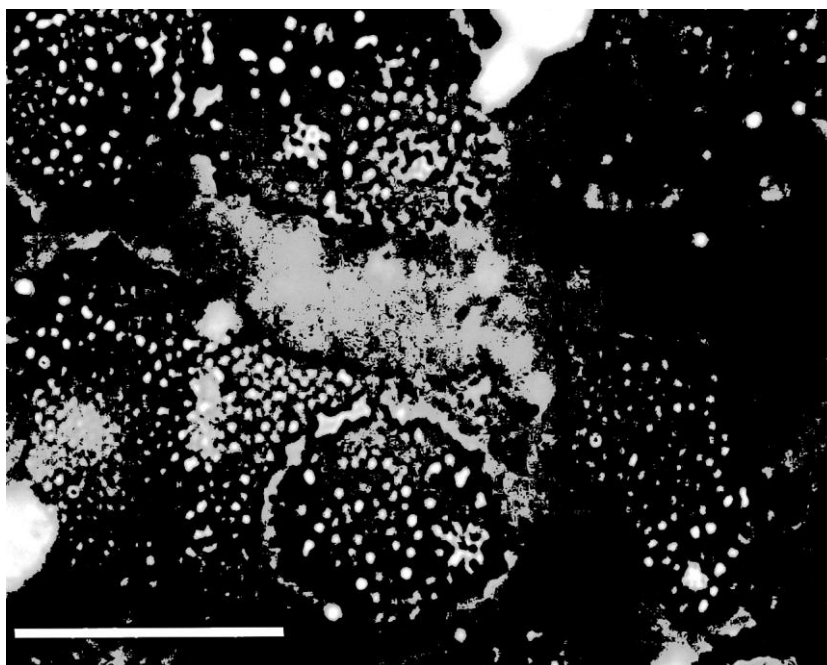
²⁰ T4_33 means it is the glass plate number 33 from the experimental run number 4 performed in the dust tunnel.

| T4_33 | Value Range [μm] | Count | Mean Value [μm] | Std. Dev [μm] |
|---------------------------|---------------------|--------|-----------------------|---------------|
| Mean Std. Dev. | | 48,18 | 3,12 | 0,36 |
| | | 124,06 | 6,64 | 0,54 |
| | | | | |
| | - 1.00 | 411 | 0,43 | 0,19 |
| | 1.00 - 3.00 | 102 | 1,7 | 0,47 |
| | 3.00 - 5.00 | 10 | 3,72 | 0,66 |
| | 5.00 - 10.00 | 4 | 6,32 | 1,04 |
| | 10.00 - 30.00 | 3 | 22,16 | 1,61 |
| | 30.00 - 50.00 | 0 | 0 | 0 |
| | 50.00 - 100.00 | 0 | 0 | 0 |
| | 100.00 - 300.00 | 0 | 0 | 0 |
| | 300.00 - 500.00 | 0 | 0 | 0 |
| | 500.00 - 1000.00 | 0 | 0 | 0 |
| | 1000.00 - | 0 | 0 | 0 |

Table 9 Results Particle Size Analysis T4_33

Downward facing glass plate

The downward facing foil captured the least amount of dust but therefore, relatively much more fine dust particles as the sampling effect for this glass plate was not governed by gravitational settling

Figure 22 Downward GP Vinzents PS T5_46²¹

²¹ T5_46 means it is the glass plate number 46 from the experimental run number 5.

| T5_46 | Value Range [µm] | Count | Mean Value [µm] | Std. Dev [µm] |
|---------------------------------|------------------|--------|-----------------|---------------|
| Mean Std. Dev. | | 248,91 | 51,08 | 2,34 |
| | | 531,9 | 95,41 | 4,38 |
| | - 1.00 | 0 | 0 | 0 |
| | 1.00 - 3.00 | 1798 | 1,65 | 0,56 |
| | 3.00 - 5.00 | 286 | 3,88 | 0,54 |
| | 5.00 - 10.00 | 290 | 7,08 | 1,43 |
| | 10.00 - 30.00 | 334 | 15,54 | 4,23 |
| | 30.00 - 50.00 | 18 | 35,37 | 4,46 |
| | 50.00 - 100.00 | 10 | 65,4 | 14,56 |
| | 100.00 - 300.00 | 1 | 116,08 | 0 |
| | 300.00 - 500.00 | 1 | 316,89 | 0 |
| | 500.00 - 1000.00 | 0 | 0 | 0 |
| | 1000.00 - | 0 | 0 | 0 |

Table 10 Results Particle Size Analysis T5_46

The results of the particle size analysis of the downward facing foil are presented here and are meant to show the high relative proportion of fine dust particle PM_{2,5} of 65% of the whole amount of counted particles in this image.

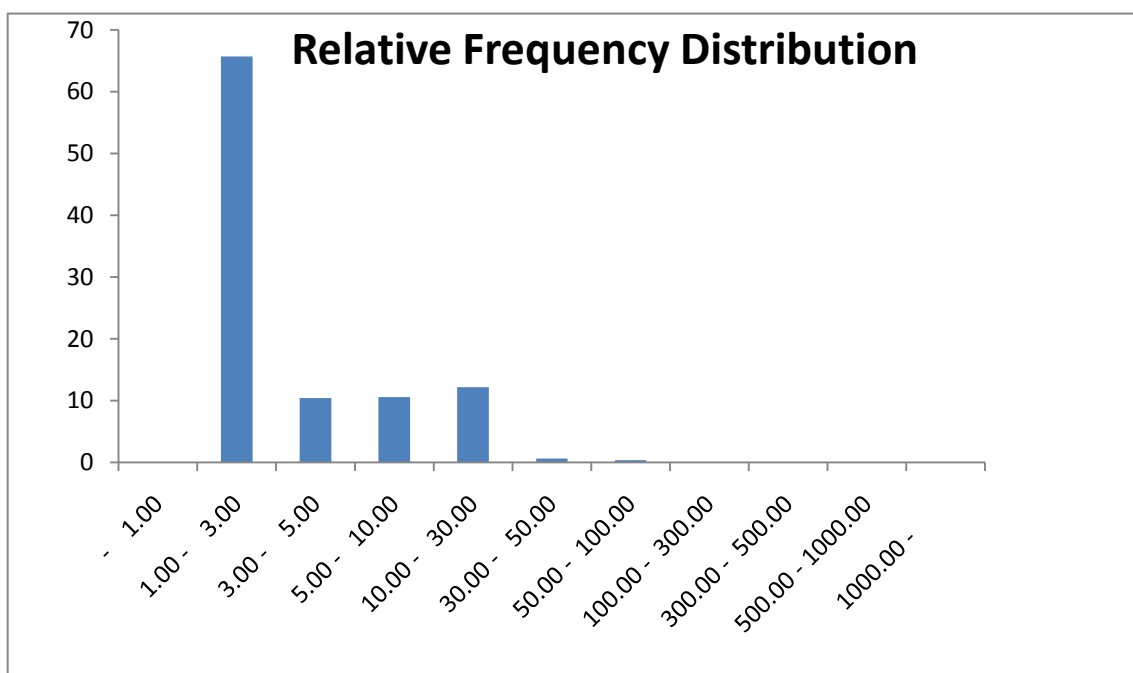


Figure 23 Relative Frequency Distribution T5_46

3.5 Evaluation of the Measurement

3.5.1 Calculation

In order to evaluate the results of the measurements it is necessary to find a base quantity. The sampling methods are analysed gravimetrically so the quantity for them is the mass in mg, while the control device laser photometer DusTrack measures directly the mass concentration in $[\text{mg}/\text{m}^3]$, which can be transferred directly as digital data from the device to an excel sheet. The dust concentration used for the following evaluation is an average over the measured time of the experiment with a constant volume flow of $1.7 [\text{l}/\text{min}]$, which is similar to $0.0017 [\text{m}^3/\text{min}]$ and an every minute measurement. To allow a comparison of the employed devices some conversions are required.

The calculated quantities are for the DusTrack results the mass, for the IOM active dust-sampler the mass concentration and for the Vinzents PS the deposition of the dust.

DusTrack

$$m_{DT} = c_{mDT} \cdot q_{DT} \cdot \Delta t \quad (5)$$

Where m_{DT} is the calculated mass $[\text{mg}]$, c_{mDT} is the average dust mass concentration $[\text{mg}/\text{m}^3]$, q_{DT} is the volume air flow $[\text{m}^3/\text{min}]$ and t is the experiment duration in $[\text{min}]$.

The calculated mass results of the control device DusTrack are presented in Table 11. As the mass were calculated over experiment duration without a constant dust exposure the expectations of very low mass results with the calculation presented above have been fulfilled.

| DusTrack | | | |
|---------------|-----------------------------------|---|----------------------|
| Experiment no | dust mass used for experiment [g] | average dust concentration [mg/m ³] | calculated mass [mg] |
| 1 | 2,7161 | 2,85481 | 0,15530 |
| 2 | 5,3094 | 5,22803 | 0,26663 |
| 3 | 26,0736 | 13,23391 | 1,19237 |
| 4 | 10,5917 | 6,06948 | 0,40241 |
| 5 | 16,2283 | 8,76212 | 0,72988 |

Table 11 DusTrack Calculated Mass

IOM-Active-Dust-Sampler

The mass concentration of the manually analysed sampler can be calculated simply by the following formula:

$$C_{mIOM} = \frac{m_{IOM}}{q_{IOM} \cdot \Delta t} \quad (6)$$

Where C_{mIOM} is the dust mass concentration, m_{IOM} is the sampled mass by IOM active dust Sampler, q_{IOM} is the volume flow of the IOM pump and t is the experiment duration.

The calculated quantities are shown in table 12 and the calculated dust concentration is based on the sum of sampled mass for each individual experimental run.

| IOM Active Dust-Sampler | | | | | |
|-------------------------|-----------------------------------|----------------------|-------------------|---------|---------------------------------------|
| Experiment no | dust mass used for experiment [g] | device specification | sampled dust mass | | calculated dust concentration [mg/m3] |
| | | | [g] | [mg] | |
| 1 | 2,7161 | c | 0,00786 | 7,86 | 243,63021 |
| 2 | 5,3094 | d | 0,01559 | 15,5923 | 122,8125 |
| 3 | 26,0736 | c | 0,0483 | 48,3 | 754,6875 |
| 4 | 10,5917 | d | 0,02068 | 20,6767 | 323,07292 |
| 5 | 16,2283 | d | 0,04138 | 41,38 | 646,5625 |

Table 12 IOM Active Sampler Calculated Concentration

Vinzents PS Deposition

The deposition of the dust on the glass plate's areas is defined as:

$$D = \frac{m}{A \cdot t} \quad (7)$$

Where **m** is the sampled mass, **A** is the glass plate's area and **t** the duration of the experiment.

The Deposition is a more transferable quantity compared to the mass itself, as it is depending on the mass, experimental time and sampled area, which can be variable values. These criteria are the reason why the deposition is a good comparable value and will be the base for the calibration later.

| Experiment no | position of the sampler | sampled dust mass [mg] | Deposition $D=m/(A*t)$ [mg/(m ² *s)] |
|---------------|-------------------------|------------------------|---|
| 1 | V1right | 2,8167 | 1,5093 |
| 1 | V1left | 2,4267 | 1,3003 |
| 2 | V2left | 4,7400 | 2,7092 |
| 2 | V2right | 5,5900 | 3,1950 |
| 3 | V3left | 16,0647 | 7,0630 |
| 3 | V3right | 21,7400 | 9,5582 |
| 4 | V4right | 5,1500 | 2,7596 |
| 4 | V4left | 4,1800 | 2,2398 |
| 5 | V5left | 11,2067 | 6,0049 |
| 5 | V5right | 15,6867 | 6,8968 |

Table 13 Vinzents PS Calculated Deposition

3.5.2 Comparison of the device results

The comparison of the results is necessary for later assumption concerning the calibration of the passive sampler developed by Vinzents.

Passive Samplers

The comparison of the IOM passively sampler and the Vinzents passive sampler is an indicator for the efficiency of the working mechanism of the Vinzents sampler. The employ of the IOM dust sampler as passive sampler was one idea of the first passive sampler studies and in this case the project team decided to try to use it in the experiment. But as the results in table 6 and the following figure (Figure 24) show the sampled mass is due to the position and the cover of the sampler not significant in the observation of the mass, but it still shows a constant increase of sampled mass with the increase of deployed dust mass.

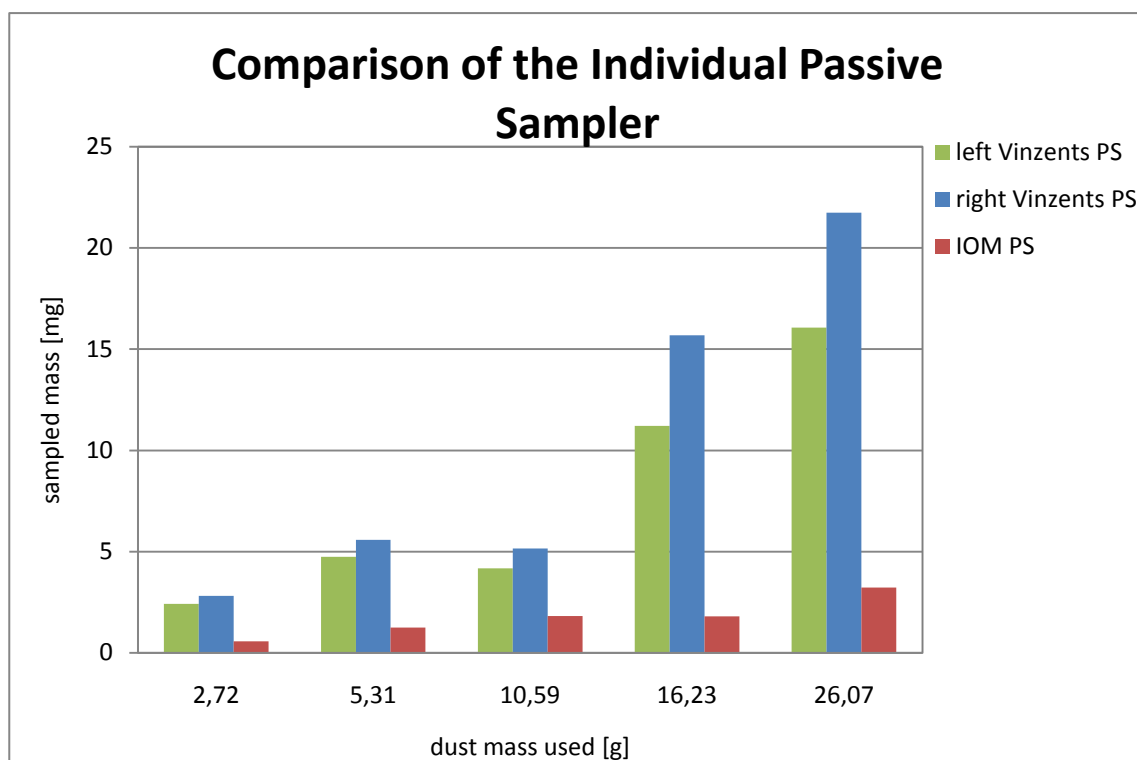


Figure 24 Comparison of Passive Samplers

The Vinzents passive samplers display a much more significant increase in the amount of sampled dust with the increase of sampled dust than the IOM passively used sampler.

Both Vinzents samplers indicate an irregularity by measurement number. 4 (dust mass 10.5917 g) but the IOM sampler shows an irregularity by measurement number 5. While the amount of employed dust is extending first in 50% steps and then in around 40% steps, the passive samplers behave differently as shown in the following table number 14.

| dust mass used for experiment [g] | Increase of employed dust [%] | Increase of sampled dust [%] | | |
|-----------------------------------|-------------------------------|------------------------------|----------------|--------|
| | | Vinzents left | Vinzents right | IOM PS |
| 2,72 | | | | |
| | 49 | 49 | 50 | 55 |
| 5,31 | | | | |
| | 50 | -13 | -9 | 31 |
| 10,59 | | | | |
| | 35 | 63 | 67 | 0 |
| 16,23 | | | | |
| | 38 | 30 | 28 | 44 |
| 26,07 | | | | |

Table 14 Increase of Sampled Dust PS

Active Devices

The two active devices are here compared to each other shortly just to give an idea about the differences in the individual concentration quantities between the two different measurement methods. The DusTrack results are multiplied with the factor 10 to make this presentation in figure number 25 possible. The chart shows the continuous behaviour of the mass concentration results of the DusTrack laser photometer, but the IOM inhalable active dust sampler shows irregular behaviour in experiment no 2 (5.31g). This is an indicator that the active sampler results can be fallible and this needs to be taken into consideration in the discussion.

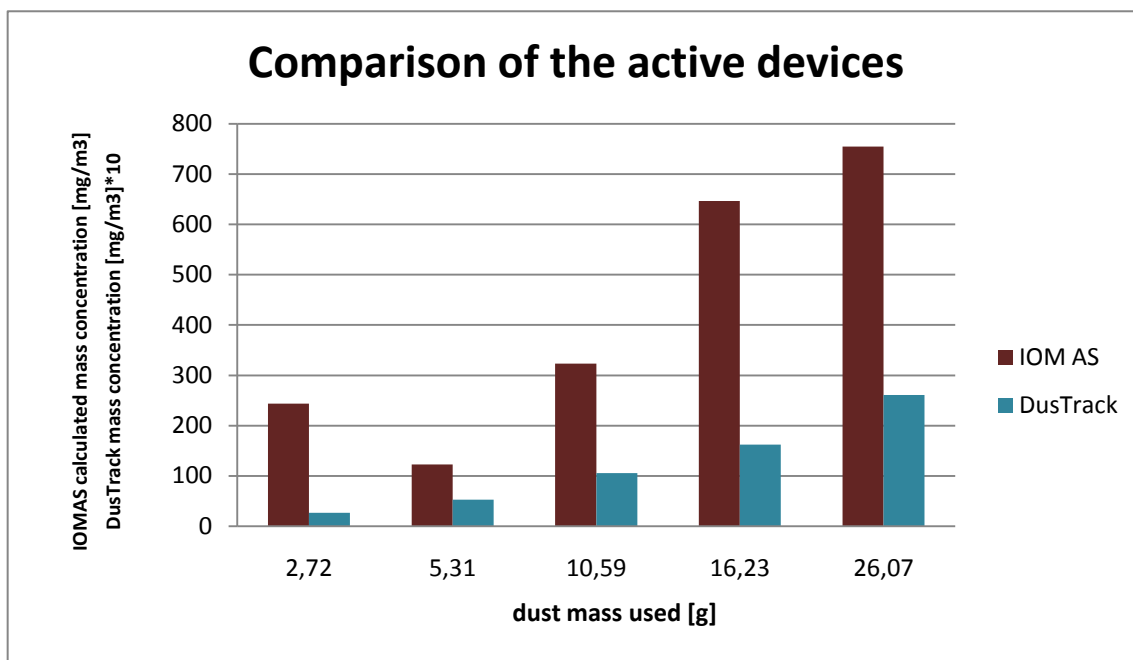


Figure 25 Comparison Active Devices

Comparison of Active to Passive Devices

The individual device results are compared to each other in the following section to reflect the experiment itself and to determine the similarities or inequality in the dust measurement focused on the parameters total sampled mass, mass concentration and deposition. As the dust measurement methods used in the experiment are based on different methods the direct comparison is not an indicator for the efficiency.

The IOM samplers are compared to each other in the below presented figure number 26. The sampled mass of the two IOM samplers show a correlation of $R^2=0.7886$, which is actually a good correlation, although obviously the measured value of the experiment no 5 shows a strong irregularity.

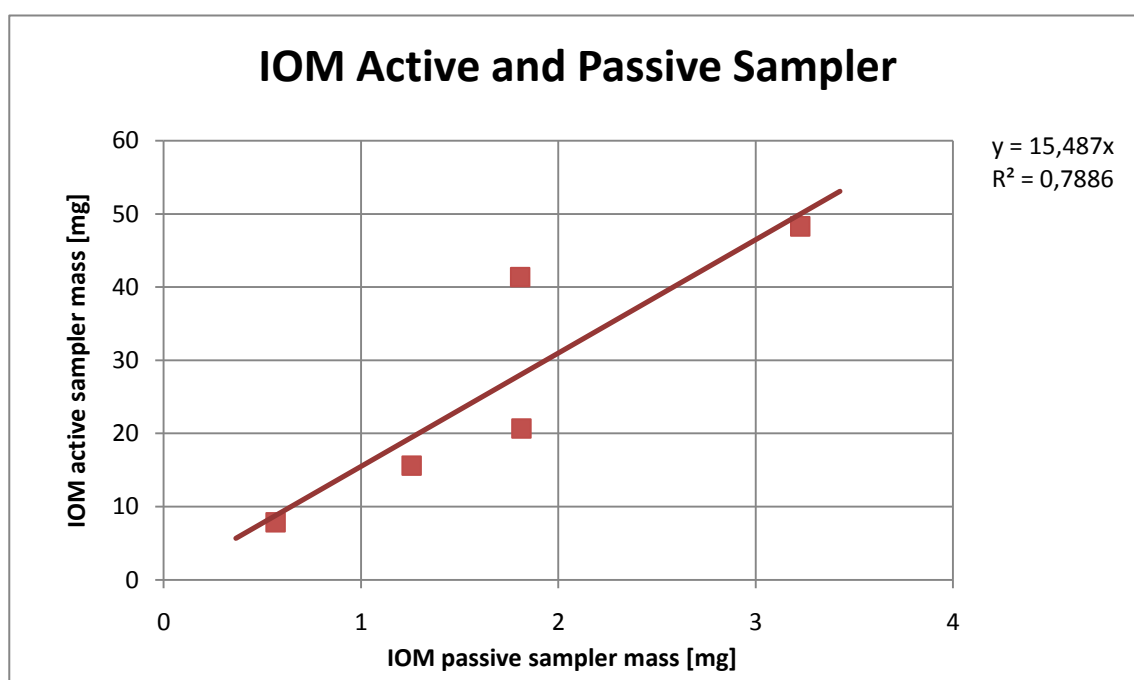


Figure 26 IOM Active and Passive Sampler

The comprehensive of the measured mass of IOM active sampler and the Vinzents passive sampler delivers a very good coefficient of determination with $R^2=0.9208$. The figure number 27 shows the regression line of both passive samplers together in comparison with the IOM sampler, means that the regression is based on the average of each experimental value of the two Vinzents in comparison to the results of the one IOM active sampler. The two different shaped points in the figure are just for the better understanding of the differ-

ences between the two samplers. The Correlation between the IOM mass value and the Vinzents mass average value is better than the correlation of the single left or right positioned Vinzents sampler.

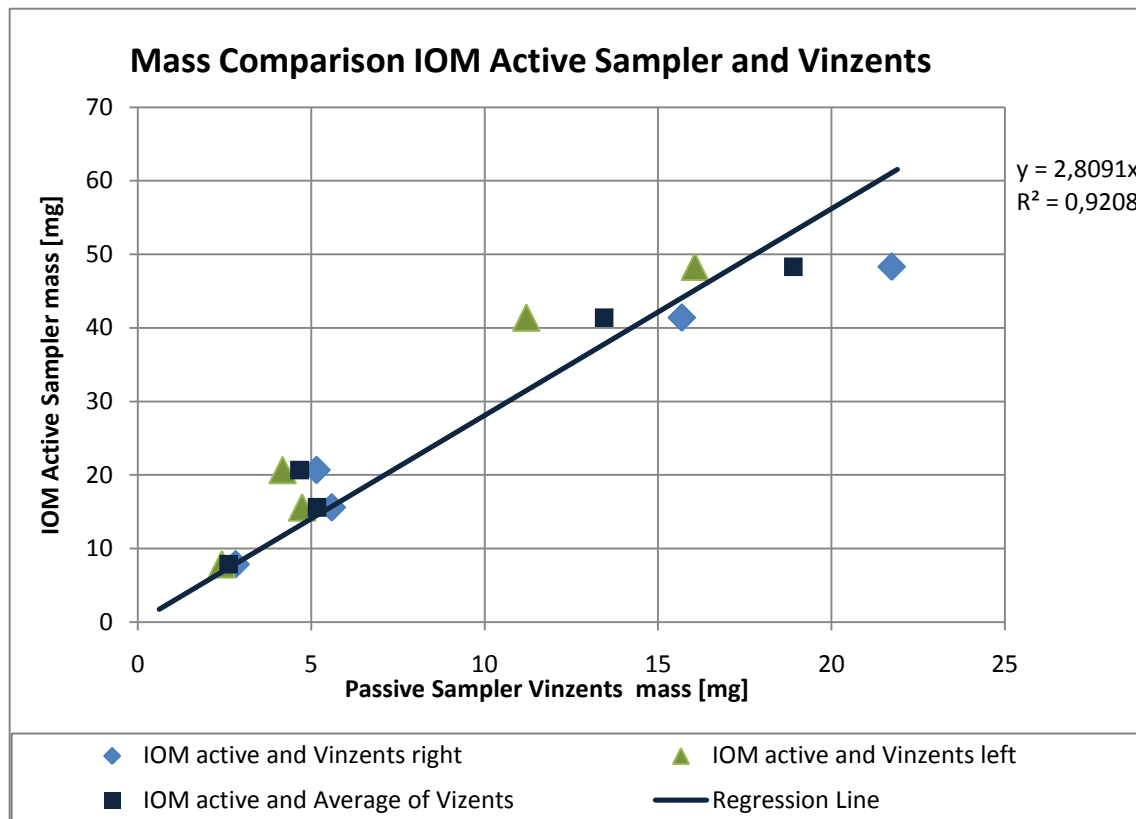


Figure 27 Mass Comparison IOM Active and Vinzents PS

As the DusTrack laser photometer is the control device the results of the Vinzents sampled mass needs to be compared as well to the mass concentration results from the direct reading instrument. This figure number 28 shows the regression line based on the same average Vinzents passive sampler values of both samplers per experiment. The correlation coefficient to the linear regression amounts to $R^2 = 0.8167$, which indicates a good correlation.

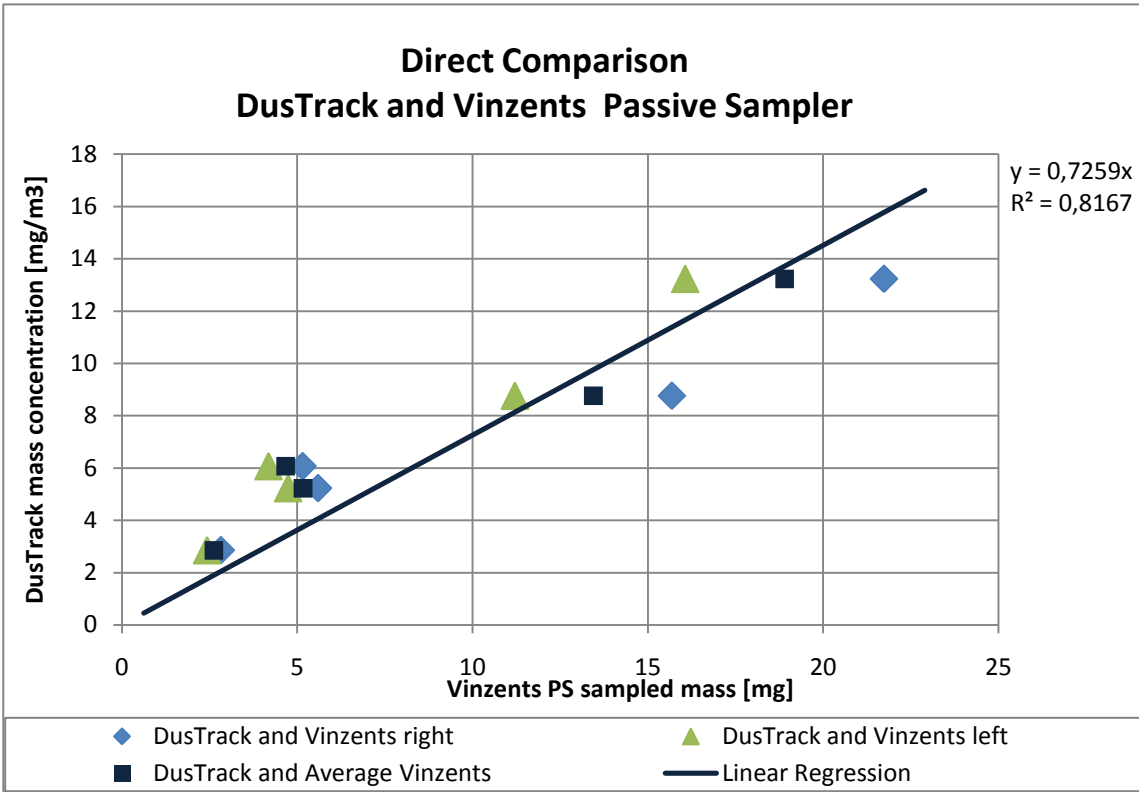


Figure 28 Comparison DusTrack and Vinzents PS

3.6 Calibration

A possible calibration of the Vinzents passive sampler is one of the objectives of such a comparison study. The here presented connection between the passive and active sampler is the calculated mass concentration of the IOM active sampler plotted against the calculated deposition of the Vinzents passive sampler.

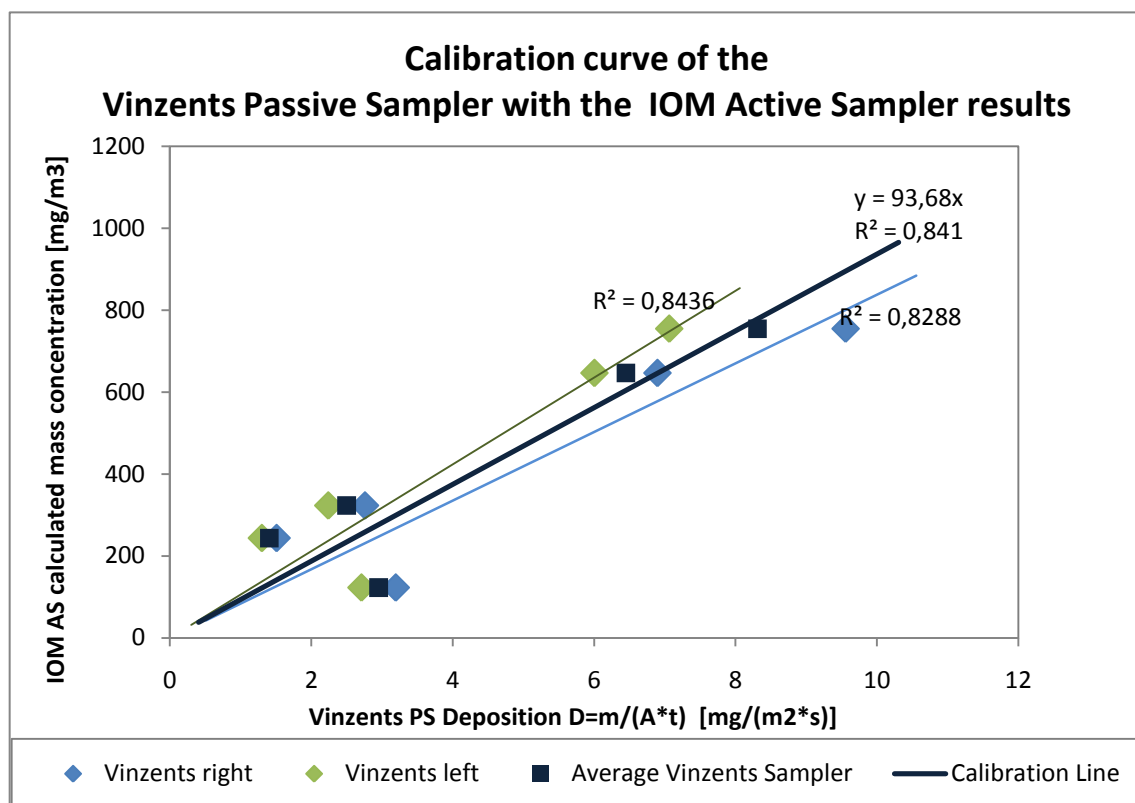


Figure 29 Calibration Line Vinzents Passive Sampler

The idea for this calibration line is to calculate the deposition after gravimetric analysis of the measurement with the Vinzents passive sampler and then read out the mass concentration with the help of this calibration line or calculate it with the formula $y=93.68 \cdot x$, which would have been calculated with the measured mass of an IOM inhalable active dust sampler and a constant volume flow of 2L/min.

The influence of the position is obvious concerning the sampled mass, but the correlation of the left positioned Vinzents passive sampler, which offers a coefficient of $R^2=0.8436$ is just 2% better than the right positioned Vinzents sampler. The calibration based on the deposition allows an influence of the measurement

sample area and the time or duration of the measurement. Therefore, this calibration line can even be used as a base for further investigation on different shaped Vinzents passive sampler and different measurement durations.

3.7 Discussion of the Measurement

The measurements were successful. As far as the reproducibility, the similarities between the individual measurement methods and - most important - were concerned, the passive sampling results made it possible to detect fine dust particles even under $1\mu\text{m}$ and show a good correlation compared to the active sampler.

Image Analysis and Particle Size Analysis

The images and the results of the image particle size analysing program offer a very good representation of the measurable particles. The results of the laser analysing were confirmed by the results of the passive sampler related to the display of similar size ranges. Finally it can be stated that of course the images could not show the whole range of the particles on the individual glass plates but the area chosen were quite representative. It was established that all the above presented glass plates were able to record particles in fine dust range of $1\text{-}3\mu\text{m}$ with a relative frequency over 50%. Noticeable is that the upward facing glass plate show a lot of agglomerated particles, which cannot be considered in the analysis, but the fine dust particles are recorded instead much better and in more detail, even particles under $1\mu\text{m}$.

In the appendix A1 you can find a coloured image, which shows the size range for every classified particle in the same colour so that you get an idea about the analysing method.

The Mass Comparison

It should not be forgotten, that the precatcher sampled a big amount of the used dust so that the ratio between deployed dusts and sampled dust is not an indicator for the efficiency of the used devices. The results of the IOM inhalable dust sampler are of special importance because this examination is meant to

prove the same efficiency of the Vinzents passive sampler. The correlation between the sampled mass of IOM active and Vinzents passive sampler is very good as the value for the coefficient of determination is $R^2=0.9208$. This value has to be considered critically in statistical contexts but as it is a part of a direct correlation of an examination in the same place at the same time and the same base values the correlation can be taken for granted.

Calibration

The calibration curves are based on the deposition, as the concentration cannot be determined just by the measured mass. The particles are also in a critical size so that the settling velocity of the particles cannot be determined by experimental observation. Therefore, the deposition is a good choice for the calibration as it includes the sample area and the measurement duration as relevant factors. The regression factor between the Vinzents passive sampler and the active device IOM inhalable dust sampler is significant and the value is $R^2=0.841$ in average.

Source of Measurement Errors

The measurements are not quite perfect so that for further investigations it is important to designate the possible sources for measurement errors.

The human mistakes are quite difficult to record but should always be taken into account, as the gravimetric determination is done manually. Mistakes can happen in the weighing process but also in the time measurement and by the positioning and preparation of the devices. Of course all devices have their calculable errors but additional to them obviously they can show individual errors just for some experimental runs as shown in figure number 25, where the IOM inhalable dust sampler shows an irregularity in experiment number 2.

The ambient condition should be constant as some devices react otherwise with errors. Temperature and humidity are recorded and shown in figure number 16.

All in all the measurement results of the self-made Vinzents passive sampler constructed by the idea of the passive sampler developed by Vinzents under the given circumstances have been successful. But further research is definitely needed on this topic to reach the goal of a possible application in monitoring workers in reality. There are many measurements needed especially the examination of the efficiency of the passive sampler in field studies and with different kind of dusts to give a meaningful general possibility for monitoring particulate matter in general. The optimization of this passive sampler model can also be a point in further investigations, for example the sampler should be covered somehow as the surface is absolutely unprotected, which would maybe help to measure just fine dust particles and to avoid falsifications of the results. The analysis should be optimized as well as the handling of the glass plates is very difficult for gravimetric determination. In relevant literature about this passive sampler the possibility to analyse it with light extinction is mentioned and also the better possibilities for image particle size analysis.

4. Conclusion

This thesis examined the possibility of using the passive sampler developed by Vinzents for dust measurement. So far, passive sampling has not been sufficiently investigated since there were no commercially available passive samplers on the market. Comparative studies discussing the efficiency of passive sampling methods are rare and not widely known. There has been no comprehensive investigation of these problems so far. This thesis is a first step into a continuous project of personal passive samplers, which offer reliable measurement results for air-borne fine dust particles by using a very cheap and simple passive sampler constructed after the model developed by Vinzents.

The results of the experiments lead to the conclusion that passive sampling is an easier and cheaper method of measuring the amount of air-borne pollutants such as fine dust. The Vinzents passive sampler offers the possibility to analyze the particle size of the sampled dust which is determined by gravimetric method.

Under really simple circumstances the Vinzents passive sampler constructed by the Passive Sampler team has reached results which show a very good correlation. The concept of the passive sampler developed by Vinzents seems to be promising and maybe it will take passive sampler one step further. All in all the results are clear and lead to the conclusion that passive samplers are the future of personal fine dust monitoring.

For further investigation in this area of research there should be more and – if possible – more detailed measurements with a passive sampler system. Perhaps it will be possible to optimize the passive sampling technology, as there are a lot of factors influencing the measurement which should be improved in further work before necessarily making experiments in field work. For instance different kind of dusts should be observed because in this work just concrete dust was used. The electret passive sampler is a good alternative to the model presented here, as mentioned in chapter 3.1. Selection of the passive sampler. Therefore, the electret passive sampler should be involved in further investiga-

tions as well, because it offers a passive external force by electrostatic attraction which can be up to 40 times stronger than the gravitational forces.

The study presented here is a beginning of a very good alternative for personal measurement of particulate matter and, by using very simple and cheap equipment, shows that this work needs to be continued.

5. List of Literature

Articles

1. Brown, R.C. (1997): *Passive Dust Sampler and Method of Dust estimation*. In: United States Patent 5607497, March 4.1997
2. Brown, R.C./Wake, D./Thorpe, A./et al. (1992): *A Passive Sampler for Airborne Dust Using an Electret*. In: Journal of Aerosol Sciences, Vol. 23, Suppl. 1, pp. S623-S626
3. Hemingway, M.A. (2002): *Environmental Use of the Passive Dust Sampler: Final Report*. Project R42.804-Report, Sheffield
4. Hemingway/Strudley et al. (1997): *An Electret-Based Passive Sampler Used for Sampling Airborne Pigment Dust, Rubber Dust and Flour Dust*. In: *The Annals of Occupational Hygiene*, Vol. 41, pp 653-658
5. Holler, B.(1999): *Einfluss der Individuellen Feinstaub- und Ozonbelastung auf die Lungenfunktion von Schulkindern*.Inaugural-Dissertation, Freiburg
6. Leith,D./Sommerlatt,D./Boundy,M.G. (2007): *Passive Sampler for [PM.sub. 10-2.5] aerosol*. In: Journal of the Air & Waste Management Association, March 2007, Technical Paper, Report
7. Sally Liu,L.-J./Olsen III,M.P./Allen,G.A/et al. (1994): *Evaluation of the Havard Ozone Passive Sampler on Human Subjects Indoors*. In: *Environmental Sciences and Technology*, 28(5), pp. 915-923
8. Schneider, T/Schlünssen, V. /Vinzents P.S/et al. (2002): *Passive Sampler Used for Simultaneous Breathing Zone Size Distribution, Inhalable Dust Concentration and Other Size Fractions Involving Large Particles*. In: *The Annals of Occupational Hygiene*, Vol. 46, No. 2, pp. 187-195
9. Wagner, J/Leith, D. (2001): *Passive Aerosol Sampler. Part I: Principle of Operation*. In *Aerosol Science and Technology* 34, pp. 186.192

10. Wagner, J./Macher, J.M. (2003): *Comparison of a Passive Aerosol Sampler to Size-Selective Pump Samplers in Indoor Environments*. In: AIHA (American Industrial Hygiene Association) Journal (64) September/October 2003, pp. 630-639
11. Yamamoto, N./Hikono, M./et al. (2006): *A Passive Sampler for Airborne Course Particles*. In: Journal of Aerosol Sciences, 37, pp. 1442-1454

Printed Sources

12. Hinds, William C. (1999): *Aerosol Technology: Properties, Behavior and Measurements of Airborne Particles*. Los Angeles
13. Spengler J.D./ Samet, J.M./ McCarthy, J.F. (2001): *Indoor Air quality Handbook*. U.S. Part I, 9.2, Part IV, 50, 51
14. Stieß, M. (1995): *Mechanische Verfahrenstechnik 1*, Berlin

Electronic Sources

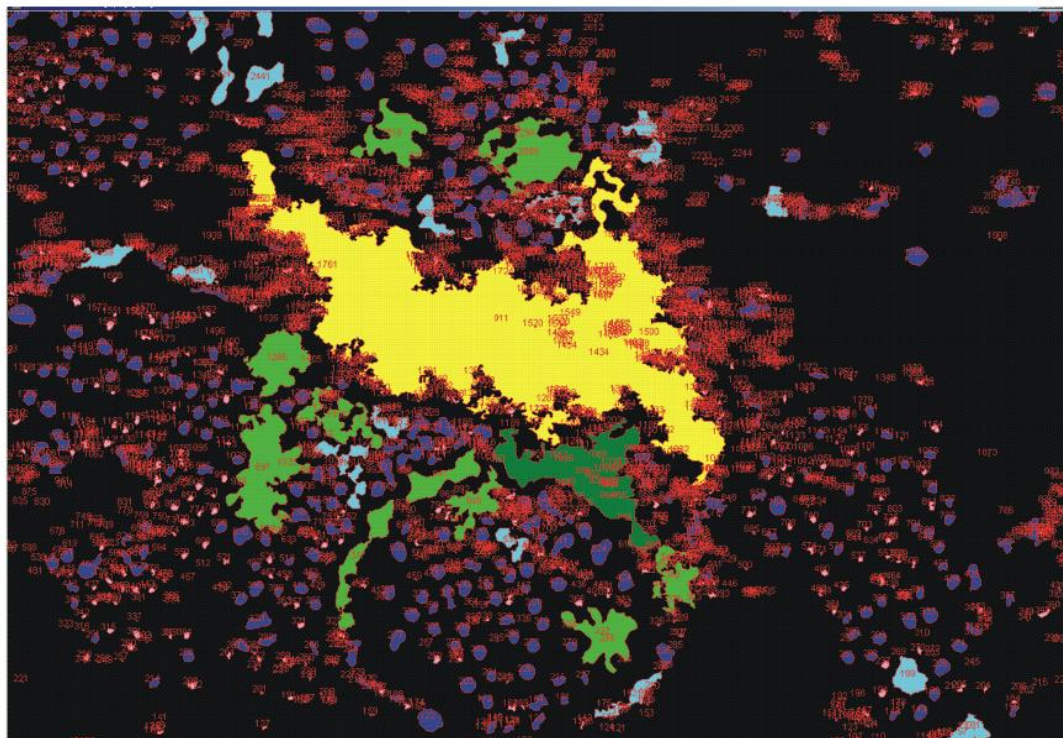
15. Canadian Centre for Occupational Health & Safety (2002): *What are the Effects of Dust on the Lungs?* URL: http://www.ccohs.ca/oshanswers/chemicals/lungs_dust.html, 17.09.10
16. Energieportal24 (2010): *Feinstaub - unsichtbar und höchst gefährlich*. URL: http://www.energieportal24.de/fachberichte_artikel_309.htm, 18.08.2010
17. Fierro, Marian (2001): *Particulate Matter* URL: http://www.airinflow.org/pdf/Particulate_Matter.pdf, 04.01.2011
18. Giles, Jim (2010): *Reproduzierbarkeit*. URL: <http://de.wikipedia.org/wiki/Reproduzierbarkeit>, 06.02.11

19. ITRC (Interstate Technology & Regulatory Council) (2005): *Technology Overview of Passive Sampler Technologies*. DSP-4. Washington, D.C.: Interstate Technology & Regulatory Council, Authoring Team. www.itrcweb.org.
20. McGowan, Wes (2001): *Particles size removal range by filtration*. URL: http://www.h2odistributors.com/global/productpics/misc/chart_particle-size_xl.gif, 05.02.2011
21. OSHA (2010): *Workplace safety & Health*. URL: <http://www.osha.gov/SLTC/directreadinginstruments/index.html>, 08.07.11
22. SKC (2010) : *IOM Sampler*. URL: <http://www.skccinc.com/instructions/1050.pdf>, 06.12.10
23. TSI Incorporated Health and Safety Instruments (2000): *DusTrack Aerosol Monitor*. URL: <http://www.ierents.com/Spec%20Pages/dusttrak%208520%20specs.pdf>, 07.01.2011
24. U.S. Environmental Protection Agency (2006): *PM Standards Revision – 2006*. URL: <http://www.epa.gov/oar/particlepollution/naaqsrev2006.html>, 05.02.2011
25. Wissen, Author= at [<http://de.wikipedia.org> de.wikipedia] (2005): *Definitionen und Einteilung von Staub*. URL: <http://upload.wikimedia.org/wikipedia/commons/2/24/Staub-Definitionen.png>, 06.01.2011

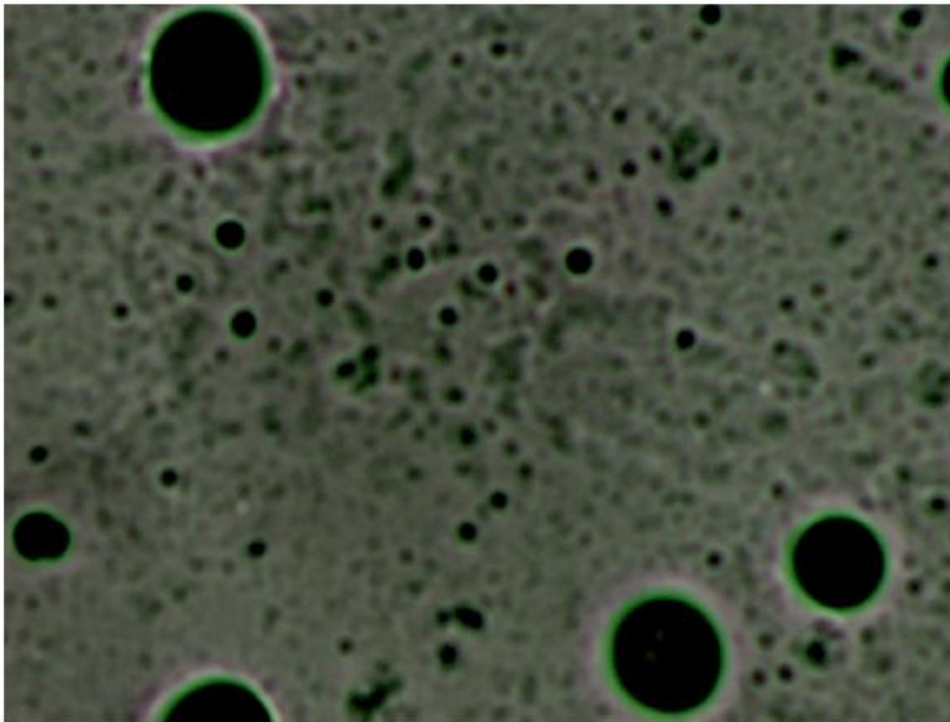
6. Appendix

| | | |
|----|--|---------|
| A1 | Sample Image T5_46 Upward Facing Glass Plate | Sheet A |
| A2 | Microscope Sample Pictures | Sheet B |
| A3 | Results of Experiment 1 | Sheet D |
| A4 | Results of Experiment 2 | Sheet F |
| A5 | Results of Experiment 3 | Sheet H |
| A6 | Results of Experiment 4 | Sheet J |
| A7 | Results of Experiment 5 | Sheet L |
| A8 | Relevant Literature Results <i>Passive Sampler Developed by Vinzents</i> | Sheet N |
| A9 | Relevant Literature Results <i>Electret Passive Sampler</i> | Sheet R |

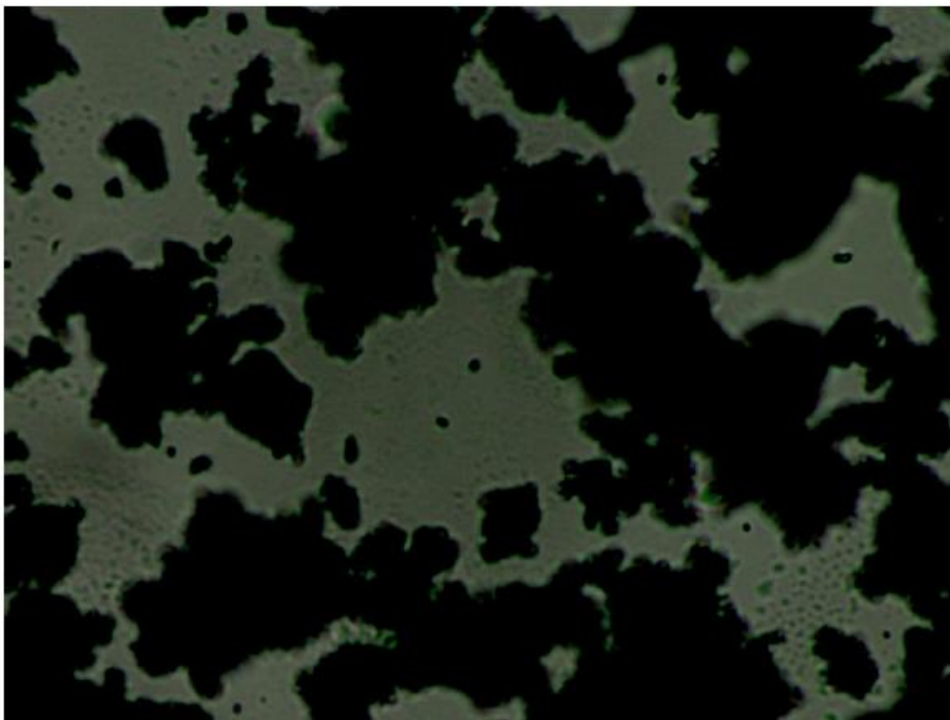
A1: Sample Image T5_46 Upward Facing Glass Plate

**A**

A2: Microscope Sample Pictures:

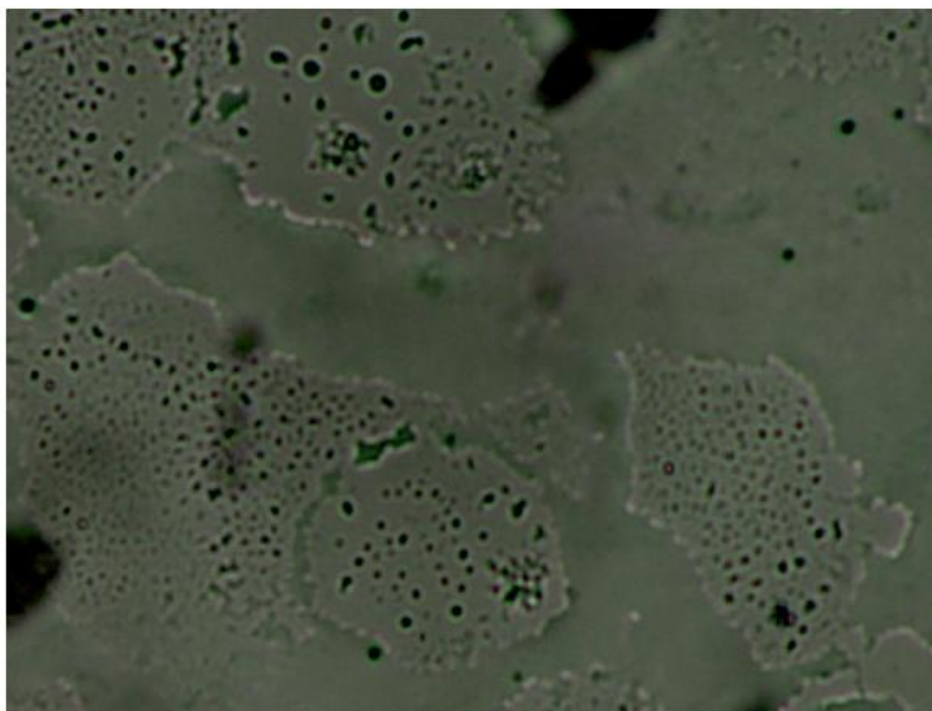


T3_38



T4_33

B



T5_46

A3: Results of Experiment 1

| | | | | | | |
|-----------------------------|----------------------------------|----------------------------|-------------|----------------|---------------|--|
| Measurement no. | 1 | Place | Dust-Tunnel | | | |
| Responsible Person | Mahnaz Soltani Mari Kimpangpa | Date | 07.09.2010 | | | |
| Measurement room conditions | | | | | | |
| rel. humidity [%] | Temperature [°C] | dust concentration [mg/m3] | min | max | used dust [g] | |
| 42,6 | 23,1 | 0,007 | 0,001 | 0,248 | 2,71605 | |
| Start Time | 10:00 | End Time | 10:32 | Duration [min] | 32 | |

| | | | | | | | |
|--------|-------------|-----------------------|-------------------|------------------|-------------------------|--------------------------|-------------------------|
| Number | Device Name | Position | weight before [g] | weight after [g] | sampled dust weight [g] | sampled dust weight [mg] | sampled dust weight [g] |
| | Vinzents1 | | | | | | |
| 9 | | blank | 0,11419 | 0,11415 | -0,00004 | -0,04333 | |
| 12 | | forward | 0,11351 | 0,11402 | 0,00051 | 0,51333 | |
| 11 | | upward | 0,11402 | 0,11632 | 0,00230 | 2,30333 | |
| 13 | | downward | 0,11454 | 0,11450 | -0,00004 | -0,04333 | |
| | Vinzents2 | | | | 0,00282 | 2,81667 | |
| 12 | | blank | 0,11391 | 0,11387 | -0,00004 | -0,04000 | |
| 11 | | forward | 0,11318 | 0,11346 | 0,00028 | 0,28333 | |
| 13 | | upward | 0,11345 | 0,11559 | 0,00214 | 2,14333 | |
| 16 | | downward | 0,11451 | 0,11447 | -0,00004 | -0,04333 | |
| | | | | | 0,00243 | 2,42667 | |
| | | concentration [mg/m3] | | | | | |
| | | average | min. | max. | | | |
| 17 | Dustrack | 2,855 | 0 | 50,929 | | 0,15530 | |
| Device | Pump | | | before | after | | |
| c | | 18 | IOM 1 | 4,48862 | 4,48222 | 0,01559 | 15,58233 |
| d | | 18 | IOM as passive | 4,87892 | 4,88118 | 0,00128 | 1,25667 |

D

A4: Results of Experiment 2

| | | | | | | |
|--------------------|-------------|----------|-------------------------|----------------|-------|----------------|
| Measurement no. | 2 | | | | | |
| Responsible Person | | | | | | |
| Place | Dust-Tunnel | | | | | |
| Date | | | | | | |
| Measurement room | | | | | | |
| Humidity | Temperature | Pressure | room dust concentration | min | max | Total dust [g] |
| 41 | 24,40 | | 0 | 0 | 0,014 | 5,30943 |
| Start Time | 12:36 | End Time | 13:06 | Duration [min] | 30 | |

| Number | Device Name | before | after | | | |
|--------|----------------|-----------------------|------------|-------------------------|----------|--------------------------|
| | | weight [g] | weight [g] | sampled dust weight [g] | Position | sampled dust weight [mg] |
| | Vinzents1 | | | | | |
| 17 | 17 | 0,11328 | 0,11322 | 0,00000 | blank | |
| 23 | 23 | 0,11241 | 0,11159 | 0,00000 | forward | |
| 19 | 19 | 0,11160 | 0,11634 | 0,00474 | upward | |
| 20 | 20 | 0,11351 | 0,11349 | 0,00000 | downward | |
| | Vinzents2 | | | 0,00474 | | 4,74 |
| 21 | 21 | 0,11283 | 0,11278 | 0,00000 | blank | |
| 25 | 25 | 0,11176 | 0,11592 | 0,00416 | forward | |
| 26 | 26 | 0,11127 | 0,11270 | 0,00143 | upward | |
| 27 | 27 | 0,11269 | 0,11143 | 0,00000 | downward | |
| | | | | 0,00559 | | 5,59 |
| | | concentration [mg/m3] | | | | |
| | | average | min. | max. | | |
| 28 | Dusttrack | 5,237 | 0 | 89,398 | | 0,20663 |
| | | | | | | |
| 89 | IOM1 | 4,89077 | 4,89863 | 0,00786 | | 7,86 |
| 62 | IOM as passive | 4,42806 | 4,42863 | 0,00057 | | 0,56667 |

| Date | Time | Aerosol |
|------------|----------|---------|
| 09.07.2010 | 12:36:50 | 44,480 |
| 09.07.2010 | 12:37:50 | 25,305 |
| 09.07.2010 | 12:38:50 | 13,824 |
| 09.07.2010 | 12:39:50 | 9,079 |
| 09.07.2010 | 12:40:50 | 6,968 |
| 09.07.2010 | 12:41:50 | 20,114 |
| 09.07.2010 | 12:42:50 | 12,712 |
| 09.07.2010 | 12:43:50 | 7,704 |
| 09.07.2010 | 12:44:50 | 6,247 |
| 09.07.2010 | 12:45:50 | 4,011 |
| 09.07.2010 | 12:46:50 | 3,185 |
| 09.07.2010 | 12:47:50 | 2,479 |
| 09.07.2010 | 12:48:50 | 1,813 |
| 09.07.2010 | 12:49:50 | 1,306 |
| 09.07.2010 | 12:50:50 | 0,937 |
| 09.07.2010 | 12:51:50 | 0,528 |
| 09.07.2010 | 12:52:50 | 0,466 |
| 09.07.2010 | 12:53:50 | 0,278 |
| 09.07.2010 | 12:54:50 | 0,213 |
| 09.07.2010 | 12:55:50 | 0,112 |
| 09.07.2010 | 12:56:50 | 0,079 |
| 09.07.2010 | 12:57:50 | 0,062 |
| 09.07.2010 | 12:58:50 | 0,048 |
| 09.07.2010 | 12:59:50 | 0,026 |
| 09.07.2010 | 13:00:50 | 0,040 |
| 09.07.2010 | 13:01:50 | 0,020 |
| 09.07.2010 | 13:02:50 | 0,009 |
| 09.07.2010 | 13:03:50 | 0,007 |
| 09.07.2010 | 13:04:50 | 0,007 |
| 09.07.2010 | 13:05:50 | 0,006 |
| 09.07.2010 | 13:06:50 | 0,004 |

| | before | | | | | | | | | | | Average | | | | |
|------------------|---------|---------|---------|---------------------|------|----------------------|------|--------------|------|--------------|------|----------|-------------|---------|----------|-------------|
| N0. Glasplate | 1 | 2 | 3 | humidity1 device | | humidity 2 device | | temperature1 | | temperature2 | | Position | Sampler 1/2 | weight | humidity | temperature |
| 17 | 0.11326 | 0.11327 | 0.11320 | 41.2 | 41.2 | 41.3 | 41.2 | 23.9 | 24.5 | 24.0 | 24.6 | blank | 1 | 0.11320 | 41.2 | 24.3 |
| 23 | 0.11242 | 0.11242 | 0.11240 | 41.9 | 42.0 | 42.5 | 42.4 | 24.9 | 24.2 | 24.2 | 24.9 | forward | 1 | 0.11241 | 42.2 | 24.6 |
| 19 | 0.11161 | 0.11161 | 0.11159 | 41.9 | 41.4 | 42.1 | 41.6 | 24.0 | 24.7 | 24.1 | 24.7 | upward | 1 | 0.11160 | 41.8 | 24.4 |
| 20 | 0.11351 | 0.11351 | 0.11352 | 41.0 | 41.4 | 42.0 | 41.5 | 24.1 | 24.8 | 24.1 | 24.8 | downward | 1 | 0.11351 | 41.7 | 24.5 |
| 21 | 0.11283 | 0.11282 | 0.11283 | 42.0 | 41.5 | 42.2 | 41.7 | 24.1 | 24.8 | 24.2 | 24.9 | blank | 2 | 0.11283 | 41.9 | 24.5 |
| 25 | 0.11177 | 0.11176 | 0.11175 | 42.6 | 42.1 | 42.6 | 42.1 | 24.3 | 25.0 | 24.3 | 25.0 | forward | 2 | 0.11176 | 42.4 | 24.7 |
| 26 | 0.11127 | 0.11126 | 0.11127 | 41.6 | 42.3 | 42.6 | 42.0 | 25.1 | 24.4 | 24.4 | 25.1 | upward | 2 | 0.11127 | 42.1 | 24.8 |
| 27 | 0.11269 | 0.11269 | 0.11269 | 42.7 | 42.1 | 42.8 | 42.1 | 24.4 | 25.2 | 24.4 | 25.2 | downward | 2 | 0.11269 | 42.4 | 24.8 |
| | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |

| | After | | | | | | | | | | | Average | | | | |
|------------------|---------|---------|---------|-----------|------|------------|------|--------------|------|--------------|------|----------|-------------|---------|----------|-------------|
| NO. Glasplate | 1 | 2 | 3 | humidity1 | | humidity 2 | | temperature1 | | temperature2 | | position | Sampler 1/2 | weight | humidity | temperature |
| 17 | 0.11321 | 0.11323 | 0.11323 | 38.5 | 38.9 | 38.1 | 38.2 | 24.0 | 25.5 | 24.8 | 25.7 | blank | 1 | 0.11322 | 38.93 | 25.20 |
| 23 | 0.11158 | 0.11159 | 0.11159 | 39.5 | 38.7 | 40 | 39.4 | 24.9 | 25.7 | 24.9 | 25.7 | forward | 1 | 0.11159 | 39.40 | 25.30 |
| 19 | 0.11635 | 0.11634 | 0.11634 | 42.4 | 41.5 | 42.2 | 41.0 | 25.2 | 25.9 | 25.2 | 25.9 | upward | 1 | 0.11634 | 41.93 | 25.55 |
| 20 | 0.11350 | 0.11348 | 0.11348 | 41.1 | 39.9 | 41.1 | 40.3 | 25 | 25 | 25 | 25.8 | downward | 1 | 0.11349 | 40.60 | 25.20 |
| 21 | 0.11278 | 0.11278 | 0.11277 | 41.4 | 40.5 | 41.5 | 40.6 | 25 | 25.8 | 25.1 | 25.8 | blank | 2 | 0.11278 | 41.09 | 25.43 |
| 25 | 0.11592 | | | 42.2 | 41.3 | 42.3 | 41.3 | 25.3 | 26 | 25.3 | 26 | forward | 2 | 0.11592 | 41.78 | 25.05 |
| 26 | 0.11272 | 0.11270 | 0.11268 | 42.2 | 41.4 | 42.2 | 41.5 | 25.1 | 25.9 | 25.1 | 25.9 | upward | 2 | 0.11270 | 41.83 | 25.50 |
| 27 | 0.11142 | 0.11145 | 0.11143 | 42 | 41.3 | 42 | 41.2 | 25.1 | 25.9 | 25.1 | 25.9 | downward | 2 | 0.11143 | 41.63 | 25.50 |
| | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |

IDM

| from | before | | | | | | | | | | average | | | | |
|---------|--------|------------|-----------|-----------|--------------|--------------|--------|----------|-------------|------|---------|------|---------|--------|--------|
| | number | weight [g] | humidity1 | humidity2 | temperature1 | temperature2 | weight | humidity | temperature | | | | | | |
| Active | 89 | 4.89079 | 4.89079 | 4.89074 | 42.6 | 42.6 | 42 | 42.1 | 24.3 | 25 | 24.4 | 25.1 | 4.89077 | 42.325 | 24.7 |
| passive | 62 | 4.42006 | 4.42005 | 4.42005 | 42.6 | 41.8 | 42.5 | 41.7 | 24.4 | 25.1 | 24.4 | 25.1 | 4.42006 | 42.15 | 24.75 |
| after | | | | | | | | | | | | | | | |
| Active | 89 | 4.89867 | 4.89862 | 4.89861 | 39.7 | 39.2 | 39.7 | 39.3 | 25 | 25.8 | 25.1 | 25.8 | 4.89863 | 39.475 | 25.425 |
| passive | 62 | 4.42063 | 4.42064 | 4.42061 | 39.1 | 38.2 | 39.4 | 38.0 | 25.1 | 25.8 | 25.1 | 25.9 | 4.42063 | 38.875 | 25.475 |

A5: Results of Experiment 3

| | | | | | | |
|--------------------|-------------|---------------------------|-------------------------|----------------|------|----------------|
| Measurement no. | 3 | Dusttrack was too late on | | | | |
| Responsible Person | | | | | | |
| Place | Dust-Tunnel | | | | | |
| Date | | | | | | |
| Measurement room | | | | | | |
| Humidity | Temperature | Pressure | room dust concentration | min | max | Total dust [g] |
| 40,6 | 23,80 | | 0,024 | 0 | 4,87 | 26,07364 |
| Start Time | 15:14 | End Time | 16:07 | Duration [min] | 53 | |

| Number | Device Name | before | after | | | |
|--------|-------------|-----------------------|------------|------------------------|----------|-----------------|
| | | weight [g] | weight [g] | sampld dust weight [g] | Position | total mass [mg] |
| | Vinzents1 | | | | | |
| 1 | 37 | - | - | - | blank | |
| 2 | 38 | 0,11323 | 0,11253 | 0,00000 | forward | |
| 3 | 39 | 0,11245 | 0,12743 | 0,01498 | upward | |
| 4 | 36 | 0,11359 | 0,11467 | 0,00108 | downward | |
| | Vinzents2 | | | 0,01606 | | 16,06467 |
| 5 | 42 | 0,11467 | 0,11359 | 0,00000 | blank | |
| 6 | 35 | 0,11356 | 0,11472 | 0,00116 | forward | |
| 7 | 40 | 0,11459 | 0,13514 | 0,02055 | upward | |
| 8 | 34 | 0,11373 | 0,11376 | 0,00003 | downward | |
| | | | | 0,02174 | | 21,74 |
| | | concentration [mg/m3] | | | | |
| | | average | min. | max. | | |
| 9 | Dusttrack | | | | | 1,19237 |
| | | | | | | |
| 10 | IOM active | 4,72133 | 4,76963 | 0,04830 | c | 48,3 |
| 11 | IOM passive | 4,63556 | 4,63878 | 0,00323 | d | 3,22667 |

| Date | Time | Aerosol |
|------------|----------|---------|
| 09.07.2010 | 15:15:10 | 37.282 |
| 09.07.2010 | 15:16:10 | 24.208 |
| 09.07.2010 | 15:17:10 | 30.939 |
| 09.07.2010 | 15:18:10 | 54.121 |
| 09.07.2010 | 15:19:10 | 37.904 |
| 09.07.2010 | 15:20:10 | 39.689 |
| 09.07.2010 | 15:21:10 | 49.067 |
| 09.07.2010 | 15:22:10 | 29.914 |
| 09.07.2010 | 15:23:10 | 29.925 |
| 09.07.2010 | 15:24:10 | 52.127 |
| 09.07.2010 | 15:25:10 | 29.420 |
| 09.07.2010 | 15:26:10 | 21.734 |
| 09.07.2010 | 15:27:10 | 24.222 |
| 09.07.2010 | 15:28:10 | 12.798 |
| 09.07.2010 | 15:29:10 | 13.648 |
| 09.07.2010 | 15:30:10 | 26.953 |
| 09.07.2010 | 15:31:10 | 12.751 |
| 09.07.2010 | 15:32:10 | 12.022 |
| 09.07.2010 | 15:33:10 | 23.865 |
| 09.07.2010 | 15:34:10 | 13.191 |
| 09.07.2010 | 15:35:10 | 11.898 |
| 09.07.2010 | 15:36:10 | 19.728 |
| 09.07.2010 | 15:37:10 | 11.048 |
| 09.07.2010 | 15:38:10 | 9.209 |
| 09.07.2010 | 15:39:10 | 16.507 |
| 09.07.2010 | 15:40:10 | 8.118 |
| 09.07.2010 | 15:41:10 | 8.095 |
| 09.07.2010 | 15:42:10 | 10.952 |
| 09.07.2010 | 15:43:10 | 8.557 |
| 09.07.2010 | 15:44:10 | 4.495 |
| 09.07.2010 | 15:45:10 | 2.552 |
| 09.07.2010 | 15:46:10 | 1.019 |
| 09.07.2010 | 15:47:10 | 0.905 |
| 09.07.2010 | 15:48:10 | 0.755 |
| 09.07.2010 | 15:49:10 | 0.403 |
| 09.07.2010 | 15:50:10 | 0.338 |
| 09.07.2010 | 15:51:10 | 0.234 |
| 09.07.2010 | 15:52:10 | 0.224 |
| 09.07.2010 | 15:53:10 | 0.156 |
| 09.07.2010 | 15:54:10 | 0.133 |

| No. Glassplate | before | | | | | | | | | | | Average | | | | |
|-------------------|---------|---------|---------|---------------------|------|---------------------|------|--------------|------|--------------|------|----------|-------------|---------|----------|-------------|
| | 1 | 2 | 3 | humidity1 device | | humidity2 device | | temperature1 | | temperature2 | | Position | Sampler 1/2 | weight | humidity | temperature |
| 37 | | | | | | | | | | | | blank | 1 | | | |
| 38 | 0.11246 | 0.11245 | 0.11479 | 40.9 | 41.6 | 41.1 | 41.7 | 24.9 | 25.2 | 24.9 | 25.2 | forward | 1 | 0.11323 | 41.3 | 25.1 |
| 39 | 0.11245 | 0.11245 | 0.11245 | 41.0 | 41.7 | 41.0 | 41.7 | 25.0 | 25.3 | 25.0 | 25.3 | upward | 1 | 0.11245 | 41.4 | 25.2 |
| 36 | 0.11359 | 0.11359 | 0.11359 | 41.3 | 41.0 | 41.4 | 42.0 | 25.0 | 25.3 | 25.0 | 25.3 | downward | 1 | 0.11359 | 38.3 | 25.2 |
| 42 | 0.11469 | 0.11464 | 0.11467 | 40.8 | 41.3 | 40.8 | 41.6 | 24.8 | 25.1 | 24.8 | 25.2 | blank | 2 | 0.11467 | 41.1 | 25.0 |
| 35 | 0.11355 | 0.11357 | 0.11356 | 41.4 | 42.0 | 40.8 | 41.6 | 24.8 | 25.1 | 24.8 | 25.2 | forward | 2 | 0.11356 | 41.5 | 25.0 |
| 40 | 0.11450 | 0.11450 | 0.11460 | 41.1 | 41.3 | 44.8 | 43.0 | 25.0 | 25.0 | 25.2 | 25.0 | upward | 2 | 0.11450 | 42.6 | 25.1 |
| 34 | 0.11374 | 0.11372 | 0.11373 | 41.3 | 44.3 | 41.3 | 43.0 | 25.1 | 24.1 | 25.1 | 24.3 | downward | 2 | 0.11373 | 42.5 | 24.7 |
| | | | | | | | | | | | | | | | | |

| | After | | | | | | | | | | | | Average | | | |
|-------------------|---------|---------|---------|-----------|------|------------|------|--------------|------|--------------|------|----------|-------------|---------|----------|-------------|
| NO. Glassplate | 1 | 2 | 3 | humidity1 | | humidity 2 | | temperature1 | | temperature2 | | position | Sampler 1/2 | weight | humidity | temperature |
| 37 | | | | | | | | | | | | blank | 1 | | | |
| 38 | 0.11255 | 0.11254 | 0.11251 | 39.7 | 39 | 39.8 | 39.2 | 25.3 | 26.1 | 25.3 | 26.1 | forward | 1 | 0.11253 | 39.43 | 25.70 |
| 39 | 0.12744 | 0.12743 | 0.12743 | 40.3 | 39.6 | 39.4 | 38.7 | 25.3 | 26.1 | 25.3 | 26.1 | upward | 1 | 0.12743 | 39.50 | 25.70 |
| 36 | 0.11467 | 0.11467 | 0.11467 | 39 | 30.3 | 39.3 | 38.5 | 25.2 | 26 | 25.3 | 26 | downward | 1 | 0.11467 | 38.78 | 25.63 |
| 42 | 0.11359 | 0.11358 | 0.11359 | 39.4 | 30.9 | 35.6 | 38.9 | 25.3 | 26 | 25.3 | 26 | blank | 2 | 0.11359 | 38.20 | 25.65 |
| 35 | 0.11472 | 0.11473 | 0.11471 | 40 | 39.4 | 39.7 | 39 | 25.3 | 26.1 | 25.3 | 26 | forward | 2 | 0.11472 | 39.53 | 25.68 |
| 40 | 0.13516 | 0.13513 | 0.13513 | 38.9 | 30.3 | 39 | 38.4 | 25.3 | 26.1 | 25.3 | 26.1 | upward | 2 | 0.13514 | 38.65 | 25.70 |
| 34 | 0.11377 | 0.11375 | 0.11377 | 39.9 | 39.3 | 40 | 39.5 | 25.3 | 26.1 | 25.3 | 26.1 | downward | 2 | 0.11376 | 39.63 | 25.70 |
| | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |

| IOM | | | | | | | | | | | | | | | |
|---------|--------|------------|---------|---------|-----------|------|------------|------|--------------|------|--------------|---------|---------|----------|-----------------|
| | | before | | | | | | | | | | average | | | |
| | number | weight (g) | | | humidity1 | | humidity 2 | | temperature1 | | temperature2 | | weight | humidity | temperatu re |
| Active | c | 4.72132 | 4.72132 | 4.72134 | 40.9 | 41.8 | 41.1 | 41.6 | 24.9 | 25.2 | 24.9 | 25.2 | 4.72133 | 41.35 | 25.05 |
| passive | d | 4.63558 | 4.63555 | 4.63554 | 40.8 | 41.5 | 40.9 | 41.6 | 24.9 | 25.2 | 25 | 25.2 | 4.63556 | 41.2 | 25.075 |
| | | after | | | | | | | | | | | | | |
| Active | c | 4.76962 | 4.76964 | 4.76962 | 38.2 | 37.4 | 38.9 | 38 | 25.2 | 25.9 | 25.2 | 25.9 | 4.76963 | 38.125 | 25.55 |
| passive | d | 4.63879 | 4.63878 | 4.63878 | 38 | 37.9 | 37.9 | 38.4 | 24.9 | 25.7 | 25.1 | 25.8 | 4.63878 | 38.05 | 25.375 |

A6: Results of Experiment 4

| | | | | | | | |
|--------------------|-------------|----------|------------------------|----------------|-------|----------------|--|
| Measurement no. | 4 | | | | | | |
| Responsible Person | | | | | | | |
| Place | Dust-Tunnel | | | | | | |
| Date | 08.09.2010 | | | | | | |
| Measurementroom | | | | | | | |
| Humidity | Temperature | Pressure | room dustconcentration | min | max | Total dust [g] | |
| 44,6 | 23,80 | | 0,004 | 0,001 | 0,056 | 10,59169 | |
| Start Time | 13:06 | End Time | 13:45 | Duration [min] | 39 | | |

| | | before | after | | | |
|--------|----------------|-----------------------|------------|-------------------------|----------|-----------------|
| Number | Device Name | weight [g] | weight [g] | sampled dust weight [g] | Position | total mass [mg] |
| | Vinzents1 | | | | | |
| 1 | | 0,11240 | 0,11237 | 0,00000 | blank | |
| 2 | | 0,11203 | 0,11202 | 0,00000 | forward | |
| 3 | | 0,11272 | 0,11787 | 0,00515 | upward | |
| 4 | | 0,11147 | 0,11140 | 0,00000 | downward | |
| | Vinzents2 | | | 0,00515 | | 5,15 |
| 5 | | 0,00000 | 0,00000 | 0,00000 | blank | |
| 6 | | 0,11181 | 0,11184 | 0,00003 | forward | |
| 7 | | 0,11168 | 0,11583 | 0,00415 | upward | |
| 8 | | 0,11403 | 0,11400 | 0,00000 | downward | |
| | | | | 0,00418 | | 4,18 |
| | | concentration [mg/m3] | | | | |
| | | average | min. | max. | | |
| 9 | Dusttrack | | | | | 0,40241 |
| | | | | | | |
| 89 | IOM1 | 4,66363 | 4,68430 | 0,02068 | | 20,67667 |
| 62 | IOM as passive | 4,65458 | 4,65639 | 0,00181 | | 1,81333 |

| Date | Time | Aerosol |
|------------|----------|---------|
| 09.08.2010 | 13:00:02 | 29,82 |
| 09.08.2010 | 13:07:02 | 15,307 |
| 09.08.2010 | 13:08:02 | 10,089 |
| 09.08.2010 | 13:09:02 | 6,633 |
| 09.08.2010 | 13:10:02 | 5,145 |
| 09.08.2010 | 13:11:02 | 24,533 |
| 09.08.2010 | 13:12:02 | 15,767 |
| 09.08.2010 | 13:13:02 | 9,532 |
| 09.08.2010 | 13:14:02 | 7,796 |
| 09.08.2010 | 13:15:02 | 5,621 |
| 09.08.2010 | 13:16:02 | 21,622 |
| 09.08.2010 | 13:17:02 | 14,635 |
| 09.08.2010 | 13:18:02 | 9,415 |
| 09.08.2010 | 13:19:02 | 6,863 |
| 09.08.2010 | 13:20:02 | 5,850 |
| 09.08.2010 | 13:21:02 | 10,581 |
| 09.08.2010 | 13:22:02 | 15,437 |
| 09.08.2010 | 13:23:02 | 7,641 |
| 09.08.2010 | 13:24:02 | 5,138 |
| 09.08.2010 | 13:25:02 | 3,604 |
| 09.08.2010 | 13:26:02 | 2,620 |
| 09.08.2010 | 13:27:02 | 2,033 |
| 09.08.2010 | 13:28:02 | 1,599 |
| 09.08.2010 | 13:29:02 | 1,222 |
| 09.08.2010 | 13:30:02 | 1,145 |
| 09.08.2010 | 13:31:02 | 0,685 |
| 09.08.2010 | 13:32:02 | 0,54 |
| 09.08.2010 | 13:33:02 | 0,374 |
| 09.08.2010 | 13:34:02 | 0,302 |
| 09.08.2010 | 13:35:02 | 0,218 |
| 09.08.2010 | 13:36:02 | 0,190 |
| 09.08.2010 | 13:37:02 | 0,143 |
| 09.08.2010 | 13:38:02 | 0,12 |

| | before | | | | | | | | | | | Average | | | | |
|------------------|---------|---------|---------|---------------------|------|----------------------|------|--------------|------|--------------|------|----------|-------------|---------|----------|-------------|
| N0. Glasplate | 1 | 2 | 3 | humidity1 device | | humidity 2 device | | temperature1 | | temperature2 | | Position | Sampler 1/2 | weight | humidity | temperature |
| 22 | 0.11241 | 0.11241 | 0.11239 | 45.8 | 46.1 | 44.8 | 46.3 | 23.5 | 23.8 | 23.8 | 23.9 | blank | 1 | 0.11240 | 45.8 | 23.8 |
| 28 | 0.11202 | 0.11204 | 0.11204 | 44.4 | 46.4 | 45.1 | 46.3 | 23.9 | 23.9 | 24.0 | 24.0 | forward | 1 | 0.11203 | 45.6 | 24.0 |
| 29 | 0.11272 | 0.11272 | 0.11273 | 44.9 | 46.5 | 44.5 | 46.9 | 24.0 | 24.1 | 23.9 | 23.7 | upward | 1 | 0.11272 | 45.7 | 23.9 |
| 31 | 0.11145 | 0.11147 | 0.11148 | 45.1 | 46.3 | 44.7 | 45.9 | 24.0 | 24.2 | 24.0 | 24.3 | downward | 1 | 0.11147 | 45.5 | 24.1 |
| | | | | | | | | | | | | blank | 2 | | | |
| 32 | 0.11185 | 0.11179 | 0.11179 | 44.3 | 44.9 | 44.8 | 45.2 | 24.1 | 24.7 | 24.1 | 24.7 | forward | 2 | 0.11181 | 44.8 | 24.4 |
| 33 | 0.11169 | 0.11167 | 0.11168 | 45.3 | 44.6 | 44.3 | 44.8 | 24.1 | 24.8 | 24.2 | 24.8 | upward | 2 | 0.11168 | 44.8 | 24.5 |
| 41 | 0.11402 | 0.11404 | 0.11404 | 44.5 | 45.3 | 44.4 | 45.1 | 24.4 | 24.9 | 24.3 | 25.0 | downward | 2 | 0.11403 | 44.8 | 24.7 |
| | | | | | | | | | | | | | | | | |

| | After | | | | | | | | | | | | Average | | | |
|------------------|---------|---------|---------|-----------|------|------------|------|--------------|------|--------------|------|----------|-------------|---------|----------|-------------|
| N0. Glasplate | 1 | 2 | 3 | humidity1 | | humidity 2 | | temperature1 | | temperature2 | | position | Sampler 1/2 | weight | humidity | temperature |
| 22 | 0.11286 | 0.11237 | 0.11237 | 43.2 | 43 | 43 | 42.9 | 24.6 | 25.3 | 24 | 25.4 | blank | 1 | 0.11237 | 43.03 | 24.03 |
| 28 | 0.11201 | 0.11201 | 0.11201 | 43 | 43 | 43 | 43.2 | 24.8 | 25.4 | 25.1 | 25.5 | forward | 1 | 0.11202 | 43.05 | 25.20 |
| 29 | 0.11788 | 0.11786 | 0.11788 | 44.8 | 43.7 | 43.8 | 43.4 | 25.1 | 25.8 | 25.1 | 25.8 | upward | 1 | 0.11787 | 43.93 | 25.45 |
| 31 | 0.11142 | 0.11140 | 0.11138 | 42.9 | 43 | 42.8 | 43.1 | 25 | 25.6 | 25.1 | 25.6 | downward | 1 | 0.11140 | 42.95 | 25.33 |
| | | | | | | | | | | | | blank | 2 | | | |
| 32 | 0.11184 | 0.11184 | 0.11184 | 43 | 43.1 | 43.9 | 43.2 | 25 | 25.7 | 25 | 25.7 | forward | 2 | 0.11184 | 43.30 | 25.35 |
| 33 | 0.11583 | 0.11594 | 0.11582 | 43 | 43.3 | 44.1 | 43.2 | 25.2 | 25.8 | 25.3 | 25.9 | upward | 2 | 0.11583 | 43.40 | 25.55 |
| 41 | 0.11396 | 0.11403 | 0.11400 | 43.4 | 43.1 | 43.5 | 43.2 | 25.1 | 25.7 | 25.1 | 25.8 | downward | 2 | 0.11400 | 43.30 | 25.43 |
| | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |

| IOM | | | | | | | | | | | | | | | |
|---------|--------|------------|-----------|-----------|--------------|--------------|--------|----------|-------------|------|------|---------|---------|--------|--------|
| | number | before | | | | | | | | | | average | | | |
| | | weight [g] | humidity1 | humidity2 | temperature1 | temperature2 | weight | humidity | temperature | | | | | | |
| Active | 89 | 4.66368 | 4.66361 | 4.66359 | 44.6 | 45.8 | 44.3 | 45.6 | 24.1 | 24.4 | 24.1 | 24.5 | 4.66363 | 45.075 | 24.275 |
| passive | 62 | 4.65462 | 4.65456 | 4.65455 | 44.6 | 45.5 | 44.9 | 45.4 | 24.1 | 24.6 | 24.2 | 24.7 | 4.65458 | 45.1 | 24.4 |
| after | | | | | | | | | | | | | | | |
| Active | 89 | 4.68433 | 4.68431 | 4.68427 | 42.8 | 41.8 | 43.3 | 42.4 | 24.5 | 25.7 | 24.7 | 25.7 | 4.68430 | 42.575 | 25.15 |
| passive | 62 | 4.65642 | 4.65638 | 4.65637 | 43.1 | 42.3 | 43 | 42.2 | 24.8 | 25.7 | 25.1 | 25.8 | 4.65639 | 42.65 | 25.35 |

A7: Results of Experiment 5

| | | | | | | |
|--------------------|-------------|----------|-------------------------|--------------|------|----------------|
| Measurement no. | 5 | | | | | |
| Responsible Person | | | | | | |
| Place | Dust-Tunnel | | | | | |
| Date | 08.09.2010 | | | | | |
| Measurement room | | | | | | |
| Humidity | Temperature | Pressure | room dust concentration | min | max | Total dust [g] |
| 41,8 | 25,00 | | 0,028 | 0 | 2,51 | 16,2283 |
| Start Time | 14:56 | End Time | 15:45 | Duration [h] | 49 | |

| Number | Device Name | before | after | | | |
|--------|----------------|-----------------------|------------|-------------------------|----------|-----------------|
| | | weight [g] | weight [g] | sampled dust weight [g] | Position | total mass [mg] |
| | Vinzens1 | | | | | |
| | | 0,11430 | 0,11438 | 0,00008 | blank | |
| | | 0,11949 | 0,12001 | 0,00051 | forward | |
| | | 0,11634 | 0,12703 | 0,01069 | upward | |
| | | 0,11559 | 0,11567 | 0,00008 | downward | |
| | Vinzens2 | | | 0,01121 | | 11,20667 |
| | | 0,11283 | 0,00000 | 0,11283 | blank | |
| | | 0,11582 | 0,11615 | 0,00032 | forward | |
| | | 0,11556 | 0,13088 | 0,01533 | upward | |
| | | 0,11223 | 0,11227 | 0,00004 | downward | |
| | | | | 0,01569 | | 15,68667 |
| | | concentration [mg/m3] | | | | |
| | | average | min. | max. | | |
| | Dusttrack | | | | | 0,72988 |
| | IOM1 | 4,63536 | 4,67674 | 0,04138 | | 41,38 |
| | IOM as passive | 4,72147 | 4,72328 | 0,00181 | | 1,80667 |

| Date | Time | Aerosol |
|------------|----------|---------|
| 09.08.2010 | 14:56:22 | 23,652 |
| 09.08.2010 | 14:57:22 | 13,162 |
| 09.08.2010 | 14:58:22 | 8,727 |
| 09.08.2010 | 14:59:22 | 6,934 |
| 09.08.2010 | 15:00:22 | 4,975 |
| 09.08.2010 | 15:01:22 | 6,726 |
| 09.08.2010 | 15:02:22 | 46,735 |
| 09.08.2010 | 15:03:22 | 24,458 |
| 09.08.2010 | 15:04:22 | 13,639 |
| 09.08.2010 | 15:05:22 | 9,646 |
| 09.08.2010 | 15:06:22 | 15,259 |
| 09.08.2010 | 15:07:22 | 24,758 |
| 09.08.2010 | 15:08:22 | 12,936 |
| 09.08.2010 | 15:09:22 | 7,987 |
| 09.08.2010 | 15:10:22 | 6,593 |
| 09.08.2010 | 15:11:22 | 14,798 |
| 09.08.2010 | 15:12:22 | 21,989 |
| 09.08.2010 | 15:13:22 | 12,816 |
| 09.08.2010 | 15:14:22 | 7,187 |
| 09.08.2010 | 15:15:22 | 5,917 |
| 09.08.2010 | 15:16:22 | 20,608 |
| 09.08.2010 | 15:17:22 | 25,548 |
| 09.08.2010 | 15:18:22 | 14,196 |
| 09.08.2010 | 15:19:22 | 6,74 |
| 09.08.2010 | 15:20:22 | 4,605 |
| 09.08.2010 | 15:21:22 | 11,504 |
| 09.08.2010 | 15:22:22 | 13,677 |
| 09.08.2010 | 15:23:22 | 8,193 |
| 09.08.2010 | 15:24:22 | 4,549 |
| 09.08.2010 | 15:25:22 | 3,292 |
| 09.08.2010 | 15:26:22 | 9,153 |
| 09.08.2010 | 15:27:22 | 9,484 |
| 09.08.2010 | 15:28:22 | 5,617 |
| 09.08.2010 | 15:29:22 | 3,808 |
| 09.08.2010 | 15:30:22 | 2,713 |
| 09.08.2010 | 15:31:22 | 1,810 |
| 09.08.2010 | 15:32:22 | 1,477 |
| 09.08.2010 | 15:33:22 | 1,092 |
| 09.08.2010 | 15:34:22 | 0,776 |
| 09.08.2010 | 15:35:22 | 0,65 |

| | before | | | | | | | | | | | Average | | | | |
|------------------|---------|---------|---------|---------------------|-------------------------|--------------|--------------|----------|-------------|--------|----------|-------------|---|---------|------|------|
| N0. Glasplate | 1 | 2 | 3 | humidity1 device | humidity 2 device | temperature1 | temperature2 | Position | Sampler 1/2 | weight | humidity | temperature | | | | |
| 53 | 0,11429 | 0,11433 | 0,11428 | 44,6 | 43,2 | 43,4 | 43,3 | 24,6 | 25,6 | 24,6 | 25,6 | blank | 1 | 0,11430 | 43,6 | 25,1 |
| 48 | 0,11948 | 0,11954 | 0,11946 | 43,4 | 43,3 | 43,3 | 43,4 | 24,5 | 25,6 | 24,6 | 25,7 | forward | 1 | 0,11949 | 43,4 | 25,1 |
| 47 | 0,11632 | 0,11635 | 0,11635 | 43,3 | 43,6 | 44,2 | 43,7 | 24,8 | 25,7 | 24,7 | 25,7 | upward | 1 | 0,11634 | 43,7 | 25,2 |
| 49 | 0,11559 | 0,11560 | 0,11558 | 43,4 | 43,8 | 43,6 | 43,8 | 24,7 | 25,7 | 24,6 | 25,8 | downward | 1 | 0,11559 | 43,7 | 25,2 |
| 43 | 0,11283 | 0,11284 | 0,11281 | 44,2 | 43,8 | 44,4 | 44,0 | 24,7 | 25,8 | 24,8 | 25,8 | blank | 2 | 0,11283 | 44,1 | 25,3 |
| 54 | 0,11583 | 0,11583 | 0,11581 | 44,7 | 44,0 | 44,1 | 44,0 | 24,8 | 25,8 | 24,8 | 25,8 | forward | 2 | 0,11582 | 44,2 | 25,3 |
| 52 | 0,11555 | 0,11555 | 0,11557 | 45,4 | 44,0 | 44,3 | 44,0 | 24,8 | 25,8 | 24,9 | 25,9 | upward | 2 | 0,11556 | 44,4 | 25,4 |
| 46 | 0,11225 | 0,11222 | 0,11222 | 44,7 | 44,0 | 44,3 | 44,0 | 24,8 | 25,9 | 24,8 | 25,9 | downward | 2 | 0,11223 | 44,3 | 25,4 |
| | | | | | | | | | | | | | | | | |

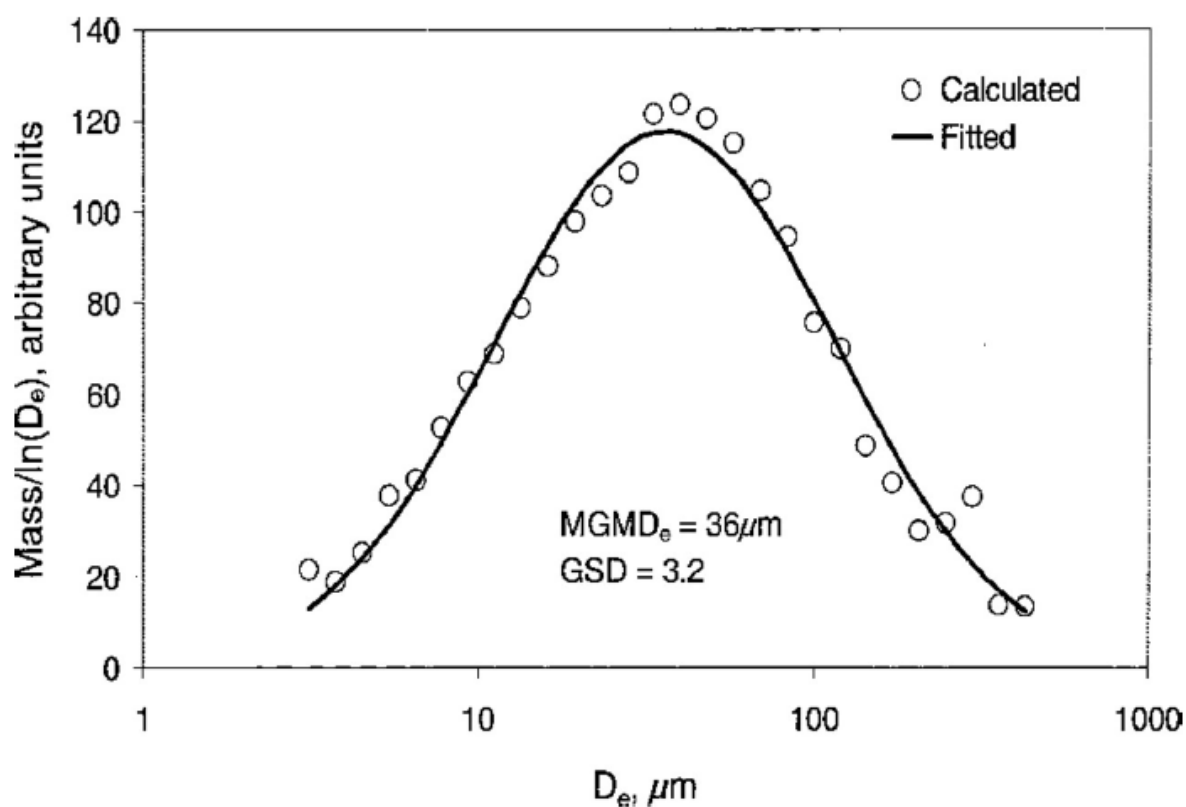
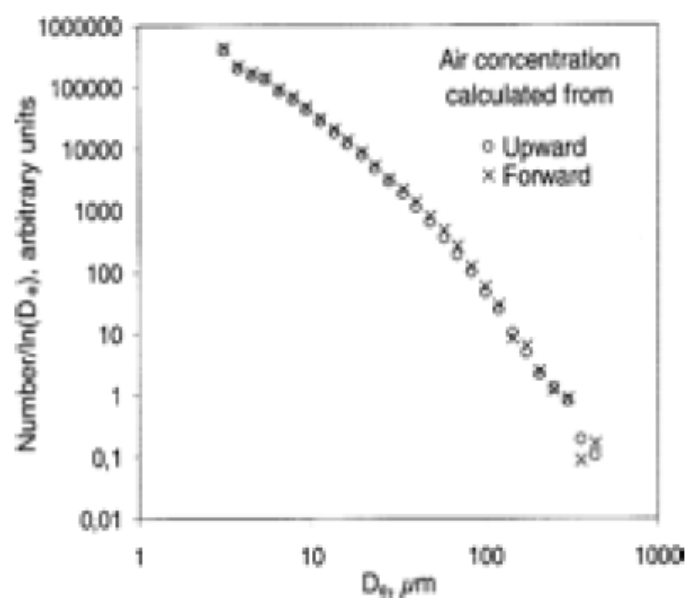
| N0. Glasplate | After | | | | | | | | | | | | Average | | | |
|------------------|---------|---------|---------|-----------|---------------|--------------|--------------|----------|-------------|--------|----------|-------------|---------|---------|-------|-------|
| | 1 | 2 | 3 | humidity1 | humidity 2 | temperature1 | temperature2 | position | Sampler 1/2 | weight | humidity | temperature | | | | |
| 53 | 0.11437 | 0.11439 | 0.11437 | 42,5 | 41,8 | 43,3 | 41,9 | 24,7 | 25,7 | 24,8 | 25,7 | blank | 1 | 0.11438 | 42,38 | 25.23 |
| 48 | 0.12001 | 0.12000 | 0.12001 | 42,7 | 42,1 | 42,7 | 42,2 | 24,9 | 25,8 | 25 | 25,8 | forward | 1 | 0.12001 | 42,43 | 25.38 |
| 47 | 0.12703 | 0.12703 | 0.12703 | 43,3 | 41,9 | 43,6 | 42,1 | 25 | 26 | 25,1 | 26 | upward | 1 | 0.12703 | 42,73 | 25.53 |
| 49 | 0.11567 | 0.11566 | 0.11568 | 42,3 | 42,2 | 42,5 | 42,6 | 25,1 | 25,8 | 25,1 | 25,9 | downward | 1 | 0.11567 | 42,40 | 25.48 |
| 43 | | | | | | | | | | | | blank | 2 | | | |
| 54 | 0.11615 | 0.11615 | 0.11614 | 42,8 | 42,7 | 42,5 | 42,8 | 25,5 | 25,9 | 25,7 | 26 | forward | 2 | 0.11615 | 42,70 | 25.78 |
| 52 | 0.13089 | 0.13087 | 0.13089 | 43,2 | 42,4 | 43,4 | 41,9 | 25,2 | 26 | 25 | 26 | upward | 2 | 0.13088 | 42,73 | 25.55 |
| 46 | 0.11227 | 0.11226 | 0.11227 | 42,4 | 42,8 | 44,4 | 42,4 | 25,5 | 26 | 25,2 | 26 | downward | 2 | 0.11227 | 43,00 | 25.68 |

| IOM | | | | | | | | | | | | | | | |
|---------|--------|------------|---------|---------|-----------|------|-----------|------|--------------|------|--------------|---------|---------|----------|-------------|
| | | before | | | | | | | | | | average | | | |
| | number | weight [g] | | | humidity1 | | humidity2 | | temperature1 | | temperature2 | | weight | humidity | temperature |
| Active | c | 4,63543 | 4,63531 | 4,63535 | 43,4 | 42,9 | 43,9 | 43 | 24,5 | 25,4 | 24,6 | 25,5 | 4,63536 | 43,3 | 25 |
| passive | d | 4,72152 | 4,7215 | 4,72139 | 43,7 | 42,7 | 43,7 | 42,9 | 24,3 | 25,2 | 24,4 | 25,3 | 4,72147 | 43,25 | 24,8 |
| | | after | | | | | | | | | | | | | |
| Active | c | 4,67679 | 4,67674 | 4,6767 | 43,1 | 42,2 | 42,4 | 42,6 | 25,3 | 26 | 25,4 | 26,1 | 4,67674 | 42,575 | 25,7 |
| passive | d | 4,72331 | 4,72326 | 4,72326 | 43 | 42,4 | 40 | 42,6 | 25,4 | 26,1 | 26,7 | 26,1 | 4,72328 | 42 | 26,075 |

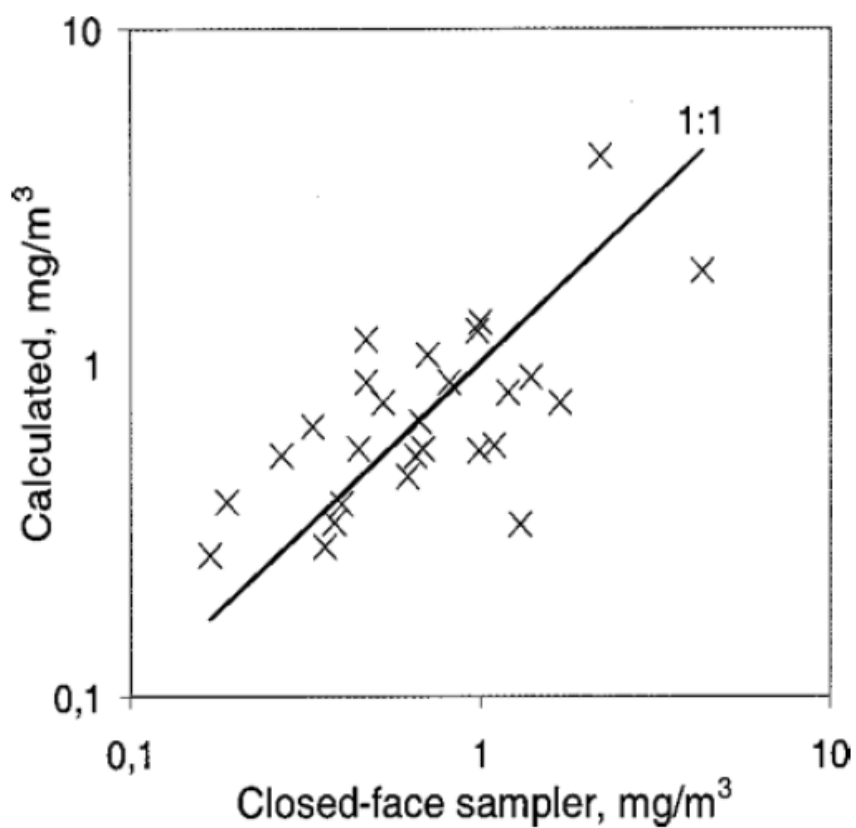
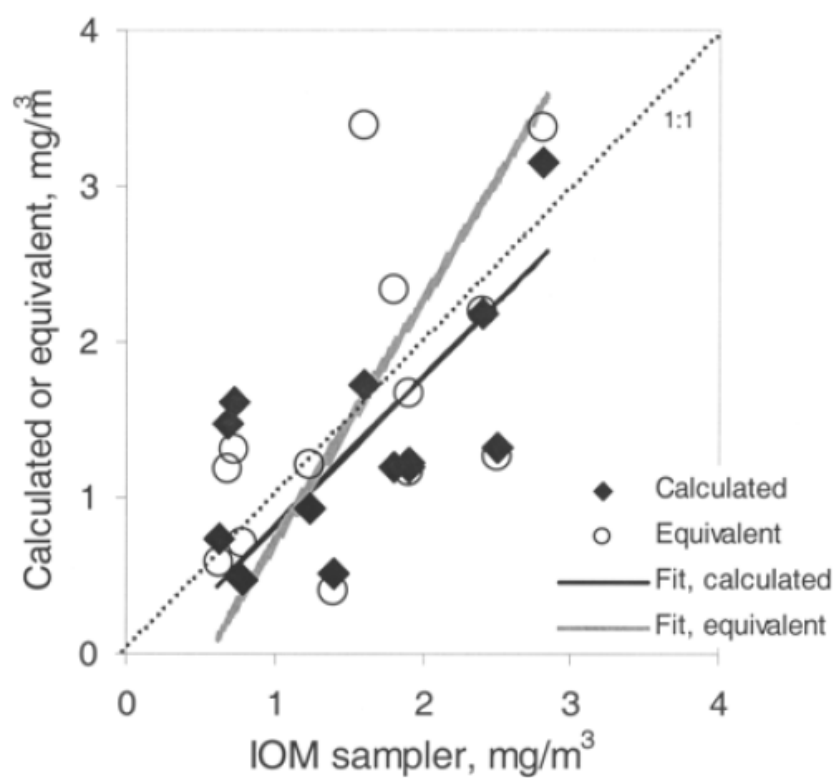
A8: Relevant Literature Results

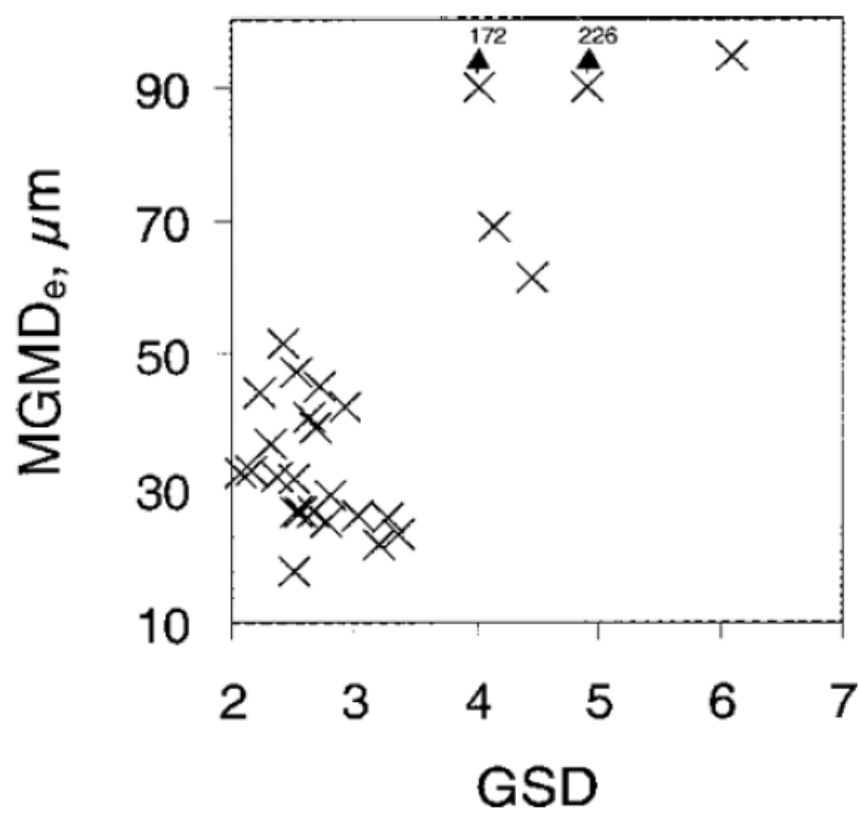
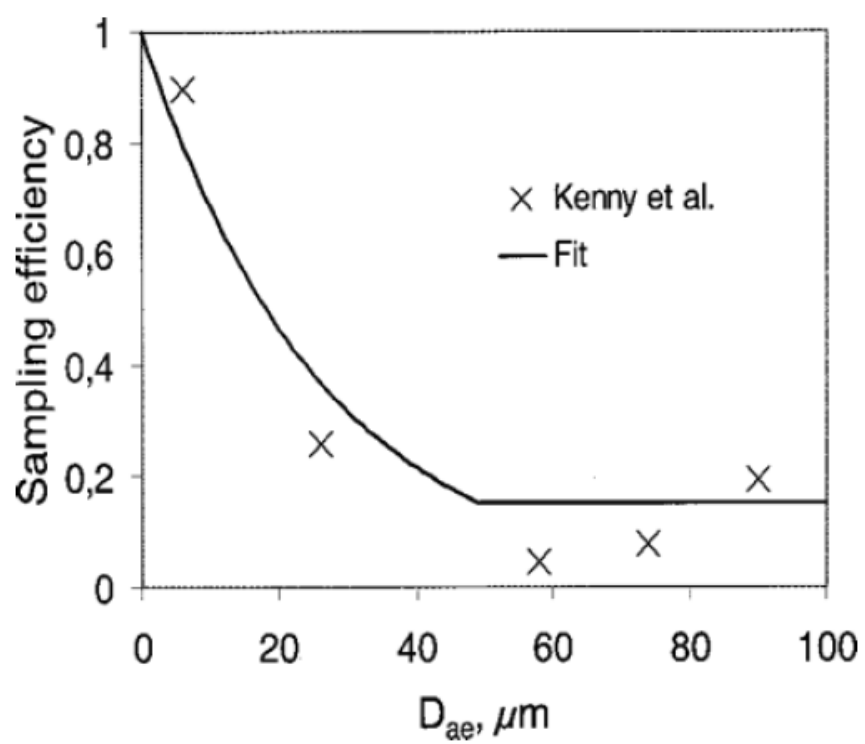
Passive Sampler Developed by Vinzents

(Schneider 2002:pp187-195)



N





CONCLUSIONS

An internally consistent relation between the sampling velocity onto the forward and upward facing foils was found, indicating that the model reflects the relative contribution of the various deposition mechanisms.

For calculating airborne mass, particle density information is not needed, and only a broad knowledge of the volume and dynamic shape factors, in particular their covariance, is needed.

Good agreement was found between the calculated inhalable dust concentration and the concentration measured with the IOM inhalable dust sampler.

Agreement with the IOM sampler results was improved compared with the equivalent concentration determined with the original passive sampler approach

The sampling characteristics even for very large ($>100\ \mu\text{m}$) particles is well characterized. Thus, any hypothetically biologically relevant size fraction can be calculated.

Overall, the results of this study have demonstrated the validity of the passive sampling principle and the ability to determine size distributions and inhalable and 'total' mass concentrations involving even large particles, based on optical microscopy of particles sampled on the upward facing foil.

Acknowledgements—The authors wish to thank E. Holst for advice on statistical analysis and I. Schaumburg for support during our work.

A9: Relevant Literature Results

Electret Passive Sampler

(Hemingway/Strudley et al. 1997:pp 653-658)

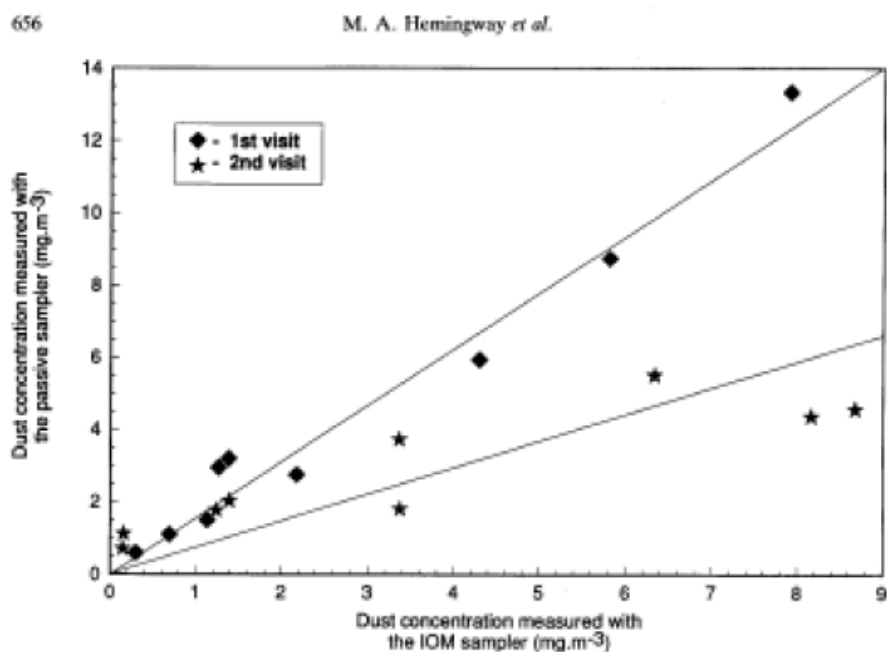


Fig. 3. Dust concentrations measured with the passive sampler and the IOM sampler at rubber factory site 2.

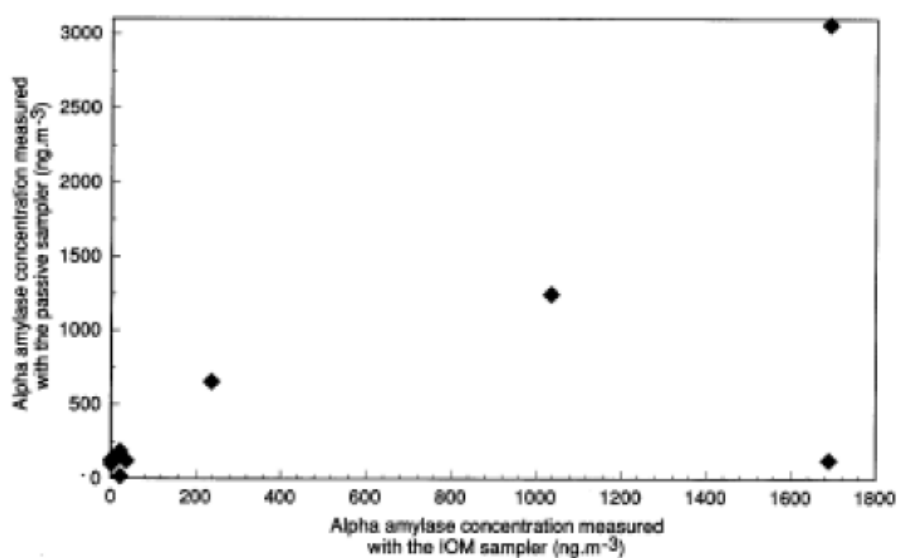


Fig. 4. Alpha amylase concentrations measured with the passive sampler and the IOM sampler at a bakery.

An electret-based passive sampler

657

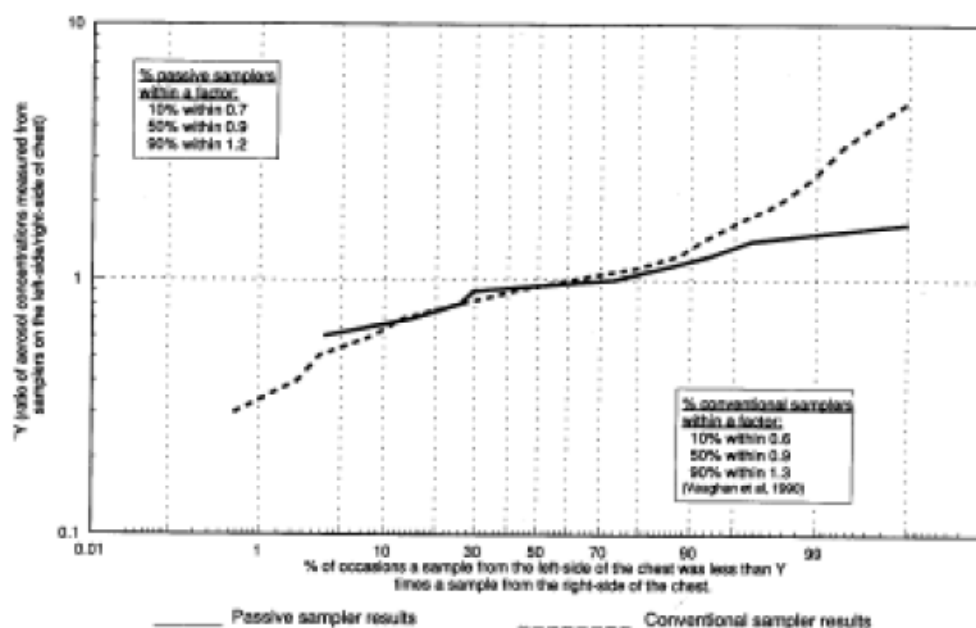


Fig. 5. Cumulative distribution of sampler aerosol concentration ratios for simultaneous passive sampling from opposite sides of the chest.

Table 1. Statistical analysis of the passive sampler results

| Aerosol type | Location | Number of visits to each site | Calibration constant, k | Number of samples | Correlation coefficient, r^2 | Comments |
|----------------------|---------------|-------------------------------|---------------------------|-------------------|--------------------------------|---|
| Flour dust | site 1 | 2 | 1785 | 13 | 0.904 | gravimetric results |
| | site 1 | 2 | 8949 | 9 | 0.419 | α -amylase results, see Fig. 4 |
| Pigment dust | site 2 only | 3 | 2286 | 7 | 0.788 | see Fig. 2 |
| | all 7 sites | 3 | 2286 | 118 | 0.548 | calibrate with site 2 results |
| | | 3 | | 27 | 0.841 | comparison of paired passive samplers. See Fig. 5 |
| Rubber fume and dust | site 2 only | 1 | 2969 | 9 | 0.971 | see Fig. 3 |
| | site 2 only | 2 | 4723 | 18 | 0.524 | see Fig. 3 |
| | sites 1 and 2 | 2 | 2913 | 39 | 0.151 | calibrated with site 2 results |
| | site 3* | 1 | | 32 | 0.773 | 7-hole sampler results compared to those from paired IOM samplers |

* Not one of the passive sampler visits but included as a comparison of conventional sampler measurements. Data from Vaughan *et al.* (1990).

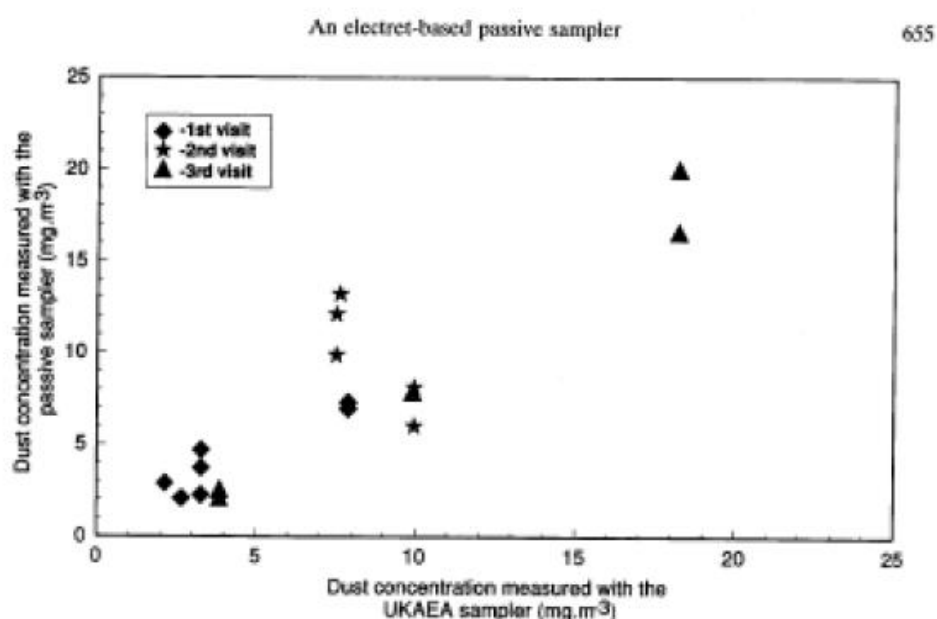


Fig. 2. Dust concentrations measured with the passive sampler and the UKAEA sampler at pigment factory site 2.

CONCLUSIONS

The electret-based passive sampler shows considerable promise in measurements of airborne dust concentrations. It has proved very acceptable to the wearers. Correlations between the passive sampler and conventional samplers have been good for single visits to single factory sites but tend to be less good for multiple visits or visits to more than one factory site. Further work will be aimed at improving the precision of the sampler and accounting for day to day variation in the electrical properties of dust.