Handbook on Mine Occupational Hygiene Measurements

Editors

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Preface

The *Handbook on Mine Occupational Hygiene Measurements* (2007) has been produced for the Mine Health and Safety Council (MHSC) by the Mine Ventilation Society of South Africa (MVSSA) and the Southern African Institute for Occupational Hygiene (SAIOH). The Handbook expands and updates an earlier Chamber of Mines of South Africa publication titled "*Measurements in Mine Environmental Control*".

Handbook History

The Handbook has its origins in a Chamber 1947 publication on the "*Quality of Mine Air: Dust Content and Cooling Power*" which contained recommendations for standard practice on gold mines with regard to thermal precipitator and konimeter practice, a deep-cell method of counting particles in mine water and kata thermometer practice.

Because of changes in techniques, it was decided in 1965 to revise the 1947 handbook and to prepare and incorporate additional recommendations on other routine ventilation measurements. The revised handbook title was "*Quality of Mine Air: Routine Measurements in South African Gold Mines*".

In 1972, the contents were updated, units were converted to the Systèm Internationale and the title of the book was changed to "*Routine Mine Ventilation Measurements*" to conform to the contents. The Executive Committee of the Chamber authorized its publication in printed form for circulation to gold mines, members of the Chamber, as well as to technical and scientific societies and organizations in South Africa and overseas.

In 1982 this book was again revised and further chapters added to cater for the expanded scope of the Environmental Control departments which had then replaced mine ventilation departments. The title of the book changed to "*Measurements in Mine Environmental Control*".

The Chamber publication was last revised in 1988 following the introduction of respirable gravimetric dust sampling. The chapter on "The Modified Thermal Precipitator and Photoelectric Assessor" was deleted and replaced by chapters covering: "The Personal Gravimetric Sampler", "The Electronic Microbalance" and "The High Volume Gravimetric Sampler".

The 2007 handbook greatly expands the Chamber 1988 publication to cover a wide range of occupational hygiene measurements for mines and mineral processing operations. Several new chapters are incorporated dealing with Biohazards, Diesel Particulate, Ergonomics, Ionising Radiation, Report Writing, Skin/Dermal Exposure, Stonedust Sampling, Vibration, Welding Fumes and Ultra Violet Radiation.

David W. Stanton
Johannesburg, South Africa
March 2007

Acknowledgements

The editors would like to express their sincere thanks to all those who have contributed to the development of this handbook and in particular to the MHSC for funding the research project SIM 04-09-03 to update the Chamber of Mines of South Africa publication *Measurements in Mine Environmental Control* (1988). An initial driving force for the development of this Handbook was Mr. Doug Rowe, former Principal Inspector, Occupational Hygiene, Department of Minerals and Energy (DME) and Chairman of the Mining Occupational Hygiene Advisory Committee (MOHAC).

With regard to earlier versions, the 1947 volume comprised of a collection of reports prepared by Sub-Committees of the Gold Producers' Committee of the Transvaal Chamber of Mines for adoption by the gold mines and members of the Chamber.

The Committee responsible for the content of the 1965 handbook comprised of Messrs. J.H. Quilliam (Chamber), D.G. Beadle (Corner House Laboratories), J.A. Drummond (Union Corporation, Limited), R.S.J. du Toit (Government Department of Mines), W.L. le Roux (Gold Mining Company, Limited), J. de V Lambrechts (University of Pretoria), G.H. Kitson (Chamber) and D.F.H. Grave (Anglo American Corporation of South Africa).

The revision and conversion to the metric system of the 1972 edition was done by Mr. J.H.J. Burrows, Chamber and Mr. J.H. Quilliam, in consultation with the Sub-Committee of Group Ventilation Engineers. The final editing was done by Messrs. J.H.J. Burrows, J.H .Quilliam, J.A. Drummond, R. Hemp (Rand Mines, Limited) and F. Lancaster (Chamber).

The 1982 revision and updating was undertaken by Mr. J.H.J. Burrows and Mr. W.L. Roux formerly of Gencor, in consultation with the Sub-Committee of Group Environmental Engineers (GEE).

The 1988 revision was undertaken by Mr. D. Marais, Chamber, Messrs. A.W. Nicoll and A.P.J. Meets of Gencor and the group environmental control training officers, in consultation with the GEE.

The editors for the 2007 handbook are: Dr. David W. Stanton, Occupational Hygienist; Dr. Johan Kielblock, Consultant and Dr. Johan J. Schoeman, Nerscho. The revised and new content for the handbook was written by a number of authors and prepared in consultation with the Safety in Mines Research Advisory Committee (SIMRAC) Occupational Health Technical Task Team (OHTAC), GEE and the MOHAC Occupational Hygiene Technical Task Team (OHTTT). The initial project leader for the MVS and SAIOH on this handbook project was Mr. C. Oberholtzer, NAPAS. The final editing was done by the Editors together with GEE members including D. Mellet (Lonmin), J. du Plessis (Gold Fields Ltd), J. van Rensburg (Impala Platinum) and D. de Villiers (CECS). DME Inspectorate staff who also reviewed the draft Handbook included Messrs. B. Doyle, R. McIntyre and V. Nundlall. Many of the Figures were drawn by Dr. David W. Stanton who also laid out the book for printing.

Special thanks goes to all the authors for their contributions to this handbook and to Dr. Audrey Banyini, Occupational Health Research Programme Manager, MHSC, for her administrative support.

Foreword

The publication of this handbook comes timeously as a welcome and natural sequel to the well-known and respected handbook by the Chamber of Mines of South Africa on "Measurements In Mine Environmental Control" (revised and updated 1988).

If one goes back in history, for a moment, the legislation governing workers' health in the mining industry prior to the promulgation of the Mine Health and Safety Act (MHSA) in 1996 (No. 29 of 1996), focused on controlling environmental conditions at the workplace. It was the considered approach then that if one controlled the working conditions, the health of the workers there would automatically be safeguarded. Unfortunately this was not the case. With all good intentions, compensation costs for ill health kept rising to a point where the burden of occupational diseases outstripped that of occupational injuries. A very sad scenario indeed.

With the advent of the MHSA and its Regulations and Guidelines, emphasis was pertinently placed on identifying worker exposures and the setting of internationally comparable occupational exposure limits, which were compatible with other National health legislation. The process therefore required of the occupational hygienist was not only to address issues around environmental conditions but also that of assessing the exposure of workers to health hazards to determine compliance with occupational exposure limits. The duties of the past professional (i.e. Ventilation Engineer) have thus been dramatically increased to accommodate the new vision.

The old adage "if you don't measure, you won't know" is an important one. It cannot be over emphasised the cardinal importance of selecting the most appropriate instrumentation, the correct use thereof and the confident interpretation of results to assist in making sound professional judgments on the working environment and worker exposures to ensure their health is protected.

I consider this book invaluable if used diligently by learners, professional practitioners and management alike, in ensuring a healthier and safer working environment. The authors of the various chapters are respected professionals, elucidating fundamental and best occupational hygiene practice.

It is my most sincere hope that this publication achieves its intended goal of assisting in making the mining industry a healthier and safer place to work - above all to preserve the dignity of human life and to reduce suffering.

Doug Rowe

Former Principal Inspector, Occupational Hygiene, DME
March 2007

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1. Introduction

Authors: The Editors.

This handbook provides the reader with a basic knowledge on how to take measurements with a variety of instruments commonly available to measure various occupational health hazards in the work environment. Areas covered include the measurement of chemical, physical and biological agents and ventilation. Checklists are provided for ergonomic surveys. The purpose of the measurements is to ensure a healthy and safe working environment.

The previous Chamber publications 1947-1988 on mine environmental control measurements provided guidance on the use of a limited number of specific instruments required for use in mines. Today, the Chamber or the DME does not specify specific occupational hygiene monitoring equipment and there is a wide variety of such equipment in use in mines provided by a number of suppliers. This handbook gives general information on the use of a broad range of instruments. For more detaled and specific information the reader should refer to the equipment supplier operating instructions.

1.1 Precautions to be Taken When Conducting Survey Work

When conducting baseline and periodic monitoring it is important that the mine environmental control specialist/occupational hygienist takes the necessary precautions to avoid overexposure and has the necessary personal protective equipment for the workplace surveyed. In some places intrinsically safe monitoring equipment will be required.

1.2 Further Reading

Many chapters provide a reference or bibliography section for the reader to locate further information sources if required. To assist with the interpretation of terms a Glossary is provided at the end of the Handbook.

1.3 Legislation

The two major laws that govern health and safety in South Africa are given below:

Act	Function	Enforcement Agency
Mine Health and Safety Act (MHSA)	To ensure a healthy and safe environment in mines/quarries	Department of Minerals and Energy (DME)
Occupational Health and Safety Act (OHSA)	To ensure a healthy and safe environment in factories and offices	Department of Labour (DoL)

Both Acts require risk assessment and occupational hygiene monitoring. Specific regulations under the OHSA cover Asbestos and Lead, Hazardous Chemical Substances, Hazardous Biological Agents and Noise Induced Hearing Loss. Lighting and the Thermal Environment are covered under the Environmental Regulations.

The MHSA requires the employer to identify hazards, assess the health and safety risks to which employees may be exposed while they are at work, record the significant hazards identified and risks assessed. The employer must determine how the significant risks identified in the risk assessment process must be dealt with, and as far as reasonably practicable, attempts should first be made to eliminate the risk, thereafter to control the risk at source, thereafter to minimise the risk and thereafter, insofar as the risk remains, to provide personal protective equipment and to institute a programme to monitor the risk.

Where the employer's risk assessment indicates a need to establish and maintain a system of occupational hygiene measurements, or where such system is required by regulation, the following key elements must be addressed:

- Risk assessment and control
- Personal exposure monitoring
- Hierarchy of controls
- Reporting and reviewing

1.4 System of Occupational Hygiene Measurements

Under the MHSA the employer must establish and maintain a system of occupational hygiene measurements of all working places where the following hazard limits prevail:

a) airborne pollutants
   i) particulates ≥10% of the occupational exposure limit;
   ii) gases and vapours ≥ 50% of the occupational exposure limit;

b) thermal stress
   i) heat >25,0°C wet bulb and/or >32,0°C dry bulb and/or >32,0°C mean radiant temperature
   ii) cold <10 °C equivalent chill temperature; and

c) noise: ≥ 82dBL AEq.8h

Where the available historical exposure data is insufficient to enable professional judgement regarding the extent of any risk, acceptable methodologies should be implemented to assess exposure to airborne pollutants e.g. such as stipulated by the National Institute for Occupational Safety and Health (NIOSH), the Occupational Safety and Health Administration in the USA (OHSA) or the Health and Safety Executive (HSE) in the United Kingdom.

1.5 Personal Exposure Monitoring

Personal exposure monitoring is to be conducted to obtain reliable estimates of employee exposures in a workplace. Reporting to the DME on exposures measured is required on a quarterly, six monthly or annual cycle period depending on the exposure category band as indicated on the report sheets in compliance with the MHSA regulation 9.2(7).

Note: The mandatory sampling frequency is stipulated on the statutory report forms 21.9(2) (a) and (b) of the MHSA regulations and in terms of regulation 9.2(7).

1.6 Selection of the Employee or Employees to be Monitored

In an ideal situation each potentially exposed worker should be individually sampled and appropriate decisions should be made regarding exposures. The most reasonable sampling strategy for the most efficient use of sampling resources is to sample the employee presumed to have the highest exposure risk. If there are a number of work operations as a result of different processes where there may be exposed employees, then a maximum risk employee should be selected for each work operation. If a maximum risk worker cannot be selected for an operation with reasonable certainty, then it is necessary to resort to random sampling of the group of workers. The procedure is to randomly sample the group whose members have a similar expected exposure risk.

Where large numbers of workers are exposed to workplace stressors e.g airborne pollutants the numbers involved may make the monitoring exercise prohibitively expensive. So monitoring strategies usually focus on groups of employees who do similar jobs in similar ways. These groups are described as homogeneous exposure groups (HEGs). This refers to a group of employees who experience exposures similar enough that monitoring exposures of any representative sub-group of employees in the group provides data useful for predicting exposures of the remaining employees.

1.7 Grouping of individuals

The grouping of potentially exposed employees can be made by careful observation of such common factors as:

- similarity of the tasks performed (not necessarily the same job);
- exposure to the same range of workplace stressors; and
- similarity of environment (process, exposure source and control measures).

If you have carried out group sampling, the results need to be carefully analysed to ensure that they are equally valid for all employees in the HEG. A wide difference in the results from different individuals indicates considerable variation within the HEG.

1.8 System of Occupational Hygiene Measurements for Airborne Pollutants under the South African Mines Occupational Hygiene Programme (SAMOHP) Codebook

The sequential methodology used for the determination of HEG classification bands is as follows:

STEP 1

Sub-divide the mine into Sampling Areas (i.e. Surface = Sampling Area 1, Underground Section A = Sampling Area 2, Underground Section B = Sampling Area 3, Underground Section 3 = Sampling Area 4, … etc. It should be remembered that in terms of the definition of “Sampling Areas” a sampling area might consist of a combination of ventilation districts.

Step 2

Sub-divide the Sampling Areas into Activity Areas as per the Activity Area Code List found under Part B – Generic Codes of the SAMOHP Codebook Section 3.

Once the personal exposures within each Activity Area have been compared to their respective Occupational Exposure Limit (OEL) values (from historical data or recent measurements), each Activity Area can now be categorized into classification bands to determine the various homogeneous group(s) within that Activity Area. The classification bands for airborne pollutants are depicted in the classification band tables below.

Table 1. 1 Classification Band Table: Particulates

Category	Classification Bands: Personal Exposure Level
A	Exposures ≥ the OEL or mixtures of exposures ≥ 1
B	Exposures ≥ 50% of the OEL and < OEL or mixtures of exposures ≥ 0.5 and < 1
C	Exposures ≥ 10% of the OEL and < 50% of the OEL or mixtures of exposures ≥ 0.1 and < 0.5

Table 1.2 Classification Band Table: Toxic Gases and Vapours

Category	Classification Bands: Personal Exposure Level
A	Exposures ≥ the OEL or mixtures of exposures ≥ 1
B	Exposures ≥ 50% of the OEL and < OEL or mixtures of exposures ≥ 0.5 and < 1

Table 1. 3 Mandatory Frequency of Sampling: Particulates

Category	Minimum Frequency
A	Sample 5% of employees within a HEG on a 3 monthly basis with a minimum of 5 samples per HEG, which ever is the greater.
B	Sample 5% of employees within a HEG on a 6 monthly basis with a minimum of 5 samples per HEG, whichever is the greater.
C	Sample 5% of employees within a HEG on an annual basis with a minimum of 5 samples per HEG, whichever is the greater.

Table 1.4 Mandatory Frequency of Sampling: Toxic Gases and Vapours

Category	Minimum Frequency
A	Sample 5% of employees within a HEG on a 3 monthly basis with a minimum of 5 samples per HEG, which ever is the greater.
B	Sample 5% of employees within a HEG on an annual basis with a minimum of 5 samples per HEG, whichever is the greater.

Not withstanding the above tables, the mine must take further intermediate samples in order to increase the confidence that HEGs are appropriately categorized especially where results are widely divergent.

For the Codebook requirements on Noise and the Thermal Stress see Chapters 15 and 17 respectively.

Occupational Hygiene Compliance Testing

Compliance testing is the minimum amount of monitoring required to demonstrate that you are meeting your legal obligations. It is only one part of an effective monitoring programme. Compliance monitoring means taking measurements according to the procedures laid down in the applicable regulations and comparing your results with the relevant OELs.

It is important to note that these measurements must be carried out, or verified, by an Approved Inspection Authority under the DoL Regulations.

Where your initial appraisal, or risk assessment, has indicated that any employees could be exposed to a hazardous chemical substance by inhalation then you are required to implement a monitoring programme to measure the airborne concentrations of those substances.

Measurements which are representative of typical exposure should be carried out on each and every employee who could be exposed at or above the OEL of any substance. Measurements must be taken at least annually for a substance with a Control Limit and at least every two years for a substance with a Recommended Limit (The different types of OELs are discussed in Chapter 8).

If the specific employees in any workforce who could be exposed at or above the relevant OELs are not readily apparent and cannot be reliably identified in the initial appraisal then a group measurement can be taken.

For a substance with a OEL-Control Limit, Table 1.5 should be used to select a representative sample of the workforce which, with a confidence level of 95%, will contain at least one of the top 10% exposed employees.

Table 1.5 Sample size for top 10% and confidence 0.95 (Use n = N if N ≤ 11)

Size of group (N)	12	13-14	15-16	17-18	19-21	22-24	25-27	28-31	32-35	36-41	42-50	∞
Required number of measured employees (n)	11	12	13	14	15	16	17	18	19	20	21	29

For a substance with an OEL- Recommended Limit, Table 1.6 should be used to select a representative sample of the workforce which, with a 90% confidence level, will contain at least one of the top 10% of exposed employees.

Table 1.6 Sample size for top 10% and confidence 0.90 (Use n = N if N ≤7)

Size of group (N)	8	9	10	11-12	13-14	15-17	18-20	21-24	25-29	30-37	38-39	50	∞
Required number of measured employees (n)	7	8	9	10	11	12	13	14	15	16	17	18	22

After having determined the appropriate number of employees to sample, it is necessary to select those employees at random. The Appendix to this chapter provides a simple method for carrying this out using a Random Number Table.

It should be noted that Tables 1.5 and 1.6 are only tools to identify the “high-risk employee” or a group of “high risk employees”.

If the exposure of the “high risk worker” is above the OEL then it is necessary to investigate further to identify whether there are any other employees whose exposure could be above the OEL.

Once the exposed, or potentially exposed, employees have been identified, you must then ensure that every one of them is regularly monitored on the appropriate schedule and the necessary control measures implemented.

Statistical analysis

For legal purposes it is important to know:

- was an employee exposure result in compliance with the relevant OEL on a particular day?;
- what is an employee’s long-term exposure estimate based on several exposure measurements?; and
- should engineering controls be installed to reduce those exposures?

When an employee is sampled and an average exposure is calculated, this result will rarely be exactly the same as the true average exposure.

The discrepancy will be due to:

- Random sampling errors i.e. variations in the sampling rate, analysis inaccuracies, handling losses etc.; and
- Random fluctuations in the workplace air due to air currents, temperature differences, or the processes occurring during the workshift.

It is not the purpose of this Handbook to give a detailed tutorial on statistical techniques. It is however important for you to realise that all measurements of airborne substances are subject to some degree of uncertainty. This variability can be of a considerable nature in real work situations. This is of particular significance when there is a possibility that you could be prosecuted for non-compliance with legislation and when you are considering implementing, or not implementing, expensive engineering controls.

For further information on Monitoring Strategies see the Bibliography below.

Bibliography

1. Occupational Exposure Sampling Strategy Manual. NIOSH Publication No. 77-173 1977, USA.

2. HSG 173 Monitoring Strategies for Toxic Substances. HSE, UK.

3. South African Mines Occupational Hygiene Programme (SAMOHP) Codebook. DME Reference 16/3/2/1 – A3. DME, South Africa 2003.

4. Air Monitoring Strategies for Hazardous Substances:A Strategic Approach to Assessing Occupational Exposure to Airborne Hazardous Chemical Substances (including Lead and Asbestos). SAIOH 2000, South Africa. Available on the MHSC Silicosis Prevention Information Resources CD.

Appendix: Random Number Table

1. To use the table, start at any location on the table; then, moving in any given direction (across, down or up), identify the employees to be monitored.
2. For example to select 17 out of 45 employees for monitoring, designate each employee with a number from 1 to 45, then moving along in the direction chosen, choose 17 employees.
3. Assuming you start in the left-hand corner of the table, and move down, your first employee is number 10; the second employee is number 22; the third employee is number 06; etc. If you get a duplicate or a number outside the desired range, ignore it. Stop when you have obtained the 17 numbers.

Table 1A Random Number Table

10	15	01	02	81	91	69	14	62	36	20	99	91	90	22
46	25	85	30	89	27	53	93	34	52	19	39	99	24	48
22	97	76	64	15	24	49	32	30	19	63	58	42	93	06
61	07	16	39	53	71	57	00	74	97	16	37	39	81	16
06	91	60	81	49	60	14	06	01	54	77	06	11	42	27
53	18	70	90	15	21	81	44	42	99	72	56	69	98	31
71	18	44	48	63	21	10	12	96	91	05	07	18	20	94
56	69	60	18	84	42	32	89	14	63	10	17	18	57	84
25	12	58	44	05	56	85	36	53	53	53	59	38	62	08
17	16	11	18	64	28	69	88	33	70	79	56	05	90	31
01	85	91	78	63	40	48	03	49	69	18	72	52	20	12
90	33	90	09	93	52	92	88	33	36	17	30	08	84	27
30	74	10	61	87	85	48	52	67	93	01	26	85	20	29
89	07	97	71	08	77	13	47	81	97	85	29	74	28	90
51	12	51	51	77	16	60	92	49	53	70	63	75	40	02
21	52	60	89	19	55	44	01	65	64	44	05	55	01	54
33	94	31	04	18	29	71	85	51	01	92	64	52	53	46
58	23	14	83	98	23	64	94	17	35	35	07	97	33	09
42	06	76	13	51	46	88	19	25	58	48	91	85	14	09
30	90	04	59	22	30	61	99	32	54	58	22	74	47	25
76	26	58	06	21	15	96	11	32	32	05	24	13	38	94
28	35	06	17	64	18	22	29	27	87	87	58	00	45	15
46	41	10	07	36	18	02	33	28	07	19	92	60	61	50
67	32	86	50	94	13	16	74	92	24	36	00	22	02	51
07	79	97	45	21	00	30	03	94	89	41	17	27	63	41
49	82	24	99	47	81	64	66	80	65	83	34	13	30	97
35	91	00	50	98	38	87	94	39	57	67	77	44	11	71
11	60	06	28	37	07	98	98	27	31	80	44	97	70	95
14	50	35	59	87	48	02	00	48	04	21	20	92	90	12
35	01	38	28	68	10	10	54	06	50	65	79	53	10	21
72	77	56	55	87	69	45	00	25	00	96	30	47	23	39
56	20	21	51	33	72	32	41	76	91	21	36	27	73	20
37	63	71	84	52	22	78	17	96	18	70	66	99	72	01
42	11	20	54	36	70	23	65	59	99	94	11	18	81	80
90	52	02	85	88	47	00	82	72	15	43	99	10	76	25
03	21	83	43	90	22	44	34	65	85	55	38	59	13	35
01	39	76	22	83	32	79	29	04	16	15	12	66	38	22
73	88	09	82	05	92	82	27	32	17	27	98	63	11	34
88	56	34	57	23	25	40	67	12	02	14	23	35	99	37
11	35	85	09	96	05	97	28	14	00	80	70	75	76	88
37	40	59	33	26	62	69	76	50	43	86	70	79	93	28
19	68	69	88	49	46	63	56	00	73	91	15	06	57	54
17	00	64	60	88	61	99	30	26	11	44	34	60	60	71
60	63	71	05	43	58	26	32	63	35	57	10	07	54	93
85	64	29	44	14	55	78	34	30	48	51	09	25	27	11
65	52	50	22	05	99	73	85	29	70	60	18	19	42	08
43	47	42	45	00	20	14	49	94	56	59	09	58	29	44
45	70	05	49	26	57	99	24	74	75	28	39	52	62	72
98	67	72	01	13	14	87	89	13	77	69	70	35	34	15
81	58	35	94	75	00	97	96	86	96	86	54	86	55	41

2. Occupational Hygiene Report Writing

Author: Casper J. Badenhorst, Anglo Platinum.

2.1 Rationale

All formally published documents follow a format, whether it be a book, a journal article, a survey report or a newspaper article. Book formats are more or less universal. Books published anywhere in the English (and other) language(s) all follow the same conventions; otherwise it would be chaos.

The format of a publication also varies from discipline to discipline, with different disciplines having different conventions that everyone in the discipline comes to know and follow. Also, specific formats are usually specified by different publishing agency. Scientific journals, for example, typically have a "Guide to Authors" which specifies exactly how the journal wants its manuscripts organised and presented.

In the scientific community there exist general conventions for publications and research or survey reports. The guide recommended here is a blend of scientific format, and the conventions used for theses and dissertations. Exactly which format you use depends on your organisation or manager, but the format recommended here is the default position.

2.2 General points

2.2.1 Aim

The main purpose of a scientific survey report is to communicate. A typical structure and style have evolved to convey essential information and ideas as concisely and effectively as possible. Precise formats vary by discipline, but always treat these formats as flexible guidelines that enable clear communication.

2.2.2 Audience

Assume that your intended reader has a general understanding of the topic but no specific knowledge of the details.

2.2.3 Clarity of writing

Good scientific survey reports share many of the qualities found in other kinds of writing. To write is to think, so a report that lays out ideas in a logical order will facilitate the same kind of thinking. Make each sentence follow from the previous one, building an argument piece by piece. Group related sentences into paragraphs, and group paragraphs into sections. Create a flow from beginning to end.

2.2.4 Supporting material

Likewise, use figures, tables, data, equations, etc. to help tell the story as it unfolds. Refer to them directly in the text, and integrate the points they make into your writing. Number figures and tables sequentially as they are introduced (e.g., Figure 1, Figure 2, etc. with

another sequence for Table 1, Table 2, etc.). Provide captions with complete information and not just a simple title. Label all axes and include units. Insert a figure or table after the paragraph in which it is first mentioned, or, gather all supporting material together after the reference section (before any appendices).

2.2.5 Language and style

The report should be grammatically sound, with correct spelling, and generally free of errors. Avoid jargon, slang, or colloquial terms. Define acronyms and any abbreviations not used as standard measurement units. Most of the report describes what you did, and thus it should be in the past tense (e.g., "values were averaged"), but use present or future tense as appropriate (e.g.,
"x is bigger than y" or "that effect will happen"). Employ the active rather than passive voice to avoid boring writing and contorted phrases (e.g., "the software calculated average values" is better than "average values were calculated by the software").

2.2.6 Consistency of Format

Within the report, the exact format of particular items is less important than consistency of application. For example, if you indent paragraphs, be sure to indent them all; use a consistent style of headings throughout (e.g., major headings in bold with initial capitals, minor headings in italics, etc.); write "%" or "percent" but do not mix them, and so on. In other words, establish a template and stick to it. Consult scientific journal papers for examples.

2.3 Typical Sections of a sound occupational hygiene report

There are five major sections to an occupational hygiene report:

- Introduction,
- Methods,
- Results,
- Discussion and
- Recommendations

Respectively, these sections structure your report to say "here's the problem, here's how I studied it, here's what I found, here's what it means and these are my recommendations." There are additional minor sections that precede or follow the major sections including the title, abstract, acknowledgements, references, and appendices. All sections are important, but at different stages to different readers. When flipping through an occupational hygiene survey report, a reader might read the title first, and if interested further then the abstract, then conclusions, and then if he or she is truly fascinated perhaps the entire report. You have to convince the reader that what you have done is interesting and important by communicating appeal and content in all sections.

2.3.1 Report title

Convey the essential point of the report. Be precise, concise, and use key words. Avoid padding with phrases like "A study of ..." or headlines like "Noise will harm you!"

2.3.2 Abstract

Condense the whole report into miniature form. A sentence or two summarising each of the sections should suffice. No new information, no supporting material, limited details, just the essential message that explains what you did and found out. Write this section last of all.

2.3.3 Introduction

Introduce the problem, moving from the broader issues to your specific problem, finishing the section with the precise aims of the report (key questions). Craft this section carefully, setting up your argument in logical order. Refer to relevant ideas/theories and related surveys and findings by others. Answer the question "what is the problem and why is it important?"

2.3.4 Materials and methods (or just Methodology)

Explain how you studied the problem, which should follow logically from the aims. Depending on the kind of data, this section may contain subsections on experimental details, materials and instrumentation used, data collection/sources, analytical or statistical techniques employed, study area, etc. Provide enough detail for the reader to reproduce what you did. Include flowcharts, maps or tables if they aid clarity or brevity. Answer the question "what steps did I follow?" but do not include results yet.

2.3.5 Results

Explain your actual findings, using subheadings to divide the section into logical parts, with the text addressing the study aims. Link your writing to figures and tables as you present the results. For each, describe and interpret what you see (you do the thinking -- do not leave this to the reader). If you have many similar figures, select representative examples for brevity and put the rest in an appendix. Mention any uncertainty in measurement or calculation, and use an appropriate number of decimal places to reflect it. Make comments on the results as they are presented, but save broader generalizations and conclusions for later. Answer the question "what did I find out?"

2.3.6 Discussion

Discuss the importance of what you found, in light of the overall survey aims. Stand back from the details and synthesize what has (and has not) been learned about the problem, and what it all means. Say what you actually found, not what you hoped to found. Begin with specific comments and expand to more general issues. Recommend any improvements for further surveys. Answer the question "what is the significance of the survey?"

Important note: this section is often combined with either the Results section or the Conclusions section. Decide whether understanding and clarity are improved if you include some discussion as you cover the results, or if discussion material is better as part of the broader summing up.

2.3.7 Conclusions

Restate the survey aims or key questions and summarise your findings using clear, concise statements. Keep this section brief and to the point.

2.3.8 Recommendations

As a result of a survey, it is likely that some actions may be required either in terms of obtaining more information, improving the environment or in terms of personal protective equipment. Current control measures, the efficiency of these control measures and any deficiencies in control measures should be included in this section. Diagrams of control measures and / or techniques are proven to be useful and can be included. Compliance with legal requirements should also be highlighted in this section. Any required monitoring strategies and programmes or additional required measurements can be listed. Required actions and the persons responsible for carrying them out can be recorded along with an action date.

2.3.9 Acknowledgments

This is an optional section. Thank people who directly contributed to the survey, by providing data, assisting with some part of the analysis, proofreading, typing, etc. It is not a dedication, so don't thank Mom and Dad for bringing you into the world, or your wife for making your coffee.

2.3.10 References

Within the text, cite references by author and year unless instructed otherwise, for example "Schoeman (1999) stated that ..." or "several studies have found that x is greater than y (De Beer 1997; Smith 2002)." For two authors, list both names, and for three or more use the abbreviation "et al." (note the period) following the first name, for example "Segoli and Smith (1999)" or "Modise et al. (1995)." Attribute every idea that is not your own to avoid plagiarism.

In this reference section itself, list alphabetically only the people and publications that you cited in the report (if none, omit the section). Provide sufficient detail to enable somebody to actually track down the information. List all authors for the "et al." publications. Follow a standard format such as the examples below, and note the distinctions regarding italics, capitalization, volume/page numbers, publisher address, etc. between the various kinds of references.

- Personal (unpublished) communications
  Cited in the text only, e.g., "... x is greater than y (Comrie 1999, pers. comm.)."

- Lecture Notes
  Comrie, A.C., 1999: The climate of Tucson. April 1 lecture, GEOG 230 Our Changing Climate, University of Arizona.

- Web Site
  Comrie, A.c., 1999: The climate of Tucson. Internet: <http://geog.arizona.edu/~comrie/tucson.html> .

- Single Author Journal Paper
  Comrie, A.C., 1999: The climate of Tucson. Climate JournalS, 123-132.

- Multiple Author Journal Paper
  Comrie, A.C., B.C. Smith and C.D. Jones, 1999: The climate of Tucson. Climate Journal, 123-132.

- Book
  Comrie, A.C., 1999: The Climate of Tucson. Academic Publishers, Boston.

- Government/Technical Report
  Comrie, A.C., 1999: The climate of Tucson. Report ABC-001, Institute for Climate Studies, University of Arizona.

- Chapter in an Edited Volume
  Comrie, A.C., 1999: The climate of Tucson. In Smith, B.C. and Jones, C.D., eds., The Climate of the Southwest. Academic Publishers, Boston.

2.3.10 Appendix

If necessary, one or more appendices containing raw data, figures not used in the body of the paper, sample calculations, etc. may be included. They are considered as additional material to the report, and may not be examined by the reader at all.

2.4 Checklist for occupational hygiene survey report

The points below are a summary of the contents of this chapter. You can use this checklist to evaluate your report's quality as it nears completion. You should be able to answer "yes" to all these questions.

Title

- Does the title accurately describe the contents of the report?
- Is the title specific enough (i.e. give enough information)?
- Is the title concise enough (i.e. not give too much information)?

Abstract

- Is it ten sentences, or fewer, in length?
- Does it contain a statement of the research problem?
- Does it contain a statement of the methods used?
- Does it contain a statement of the major results?
- Does it contain a statement of the conclusion(s)?

Introduction

- Is the research problem clearly stated?
- Is the rationale for the experiment included?
- Is the history/background included, and in sufficient detail?
- Are citations used properly, rather than footnotes?

Materials and Methods

- Are materials and equipment described in sufficient detail for repetition, if necessary?

- Are methods described in sufficient detail for repetition, if necessary?
- If a lab manual was used as a reference, was it paraphrased and properly cited?
- Are methods of statistical analysis included here?
- Is this section free of results or discussion?
- Has the author avoided listing the materials?
- Has the author avoided making the methods appear as a series of directions, as though this were a lab manual rather than a research paper where methods are properly a historical description?

Results

- Have all of the results been described in the text of the results section?
- Have only the most relevant data been selected to be reported as tables and figures?
- Have all figures and tables been cited in the text of the results section?
- Have the most effective graphical or tabular formats been chosen to present important data?
- Can all figures and tables be understood without having to refer to the text?
- Are figures properly titled and captioned (below figure)?
- Are tables properly titled and captioned (above table)?
- Where applicable, does dependent variable appear on vertical axis, independent variable on horizontal axis?
- Are tables and figures numbered independently, and are they numbered according to the sequence in which they are cited in the text?
- Have appropriate statistics been reported, and are they correct?
- Is the results section well-organized?
- Is the results section free of methodology or interpretation?

Discussion

- Has the author avoided claiming that results "prove" or "disprove" the hypothesis?
- Are the conclusions supported by the data?
- Have all possible conclusions been drawn from the data, i.e. have all of the data's repercussions been discussed?
- Where applicable, have anomalies been reported and addressed?
- Have assumptions been identified and justified?
- Where applicable, has the relationship between these and previous findings been discussed?
- Are possibilities for further research presented, and are they realistic in the context of this course?
- Is the discussion section well-organized?
- Is the discussion section free of methodology or results?

Recommendations

- Are control measures, and the efficiency of these control measures and any deficiencies
- in control measures discussed in this section?

- Is compliance with legal requirements highlighted in this section?
- Are required monitoring strategies and programmes or additional required
- measurements listed?
- Are required actions and the persons responsible for carrying them out recorded along with an action date?

Acknowledgments

- Where applicable, are intellectual contributors identified?
- Are sources of borrowed equipment/supplies/organisms identified?
- Where applicable, are sources of funding identified?
- Where applicable, are contributors of donated services (i.e. typing, reviewing, editing, etc.) identified?

Literature Cited

- Do all references cited also appear in the text?
- Are all citations consistently presented in the same format?
- Are citations presented in an established format, including Internet citations?
- Do citations appear wherever authors make statement of scientific results that were not part of the authors' current research?

General

- Is the report consistently written in the past tense?
- Are all foreign words (inc. scientific binomials) italicized or underlined?
- Have typos been eliminated?
- Have misspellings been eliminated?
- Is the word "significantly" always used in association with a statistical level of certainty?
- Does the entire paper exhibit stylistic consistency?
- Did the authors use citations rather than footnotes?

2.5 Occupational Hygiene Reporting in terms of the MHSA

In terms of regulation 9.2(3); Report to the employer, the competent person engaged by the employer in terms of section 12(1) of the MHSA must, as part of the compliance with section 12(2)(b), report to the employer on:

(d) the occupational hygiene risk assessment, with specific reference to planning, design, implementation and management of occupational hygiene at the mine; and

(e) the occupational hygiene hazards that may cause illness or adverse health effects to persons, assess the results in terms of the implementation of control systems and the management thereof, and recommend remedial actions to the employer.

In terms of regulation 9.2(7); Report to Regional Principal Inspector, of the MHSA, the employer must submit to the relevant regional principal inspector of mines, on forms 21.9(2)(a); 21.9(2)(b); 21.9(2)(c); 21.9(2)(d), 21.9(2)(e), and 21.9(2)(f), prescribed in chapter 21 of the regulations of the MHSA, and within 60 days from the end of the relevant reporting period as indicated on each form, reports which contain information on the airborne pollutant, thermal stress and noise aspects of the system of occupational hygiene measurements, established and maintained in terms of regulation 9.2(2) of the MHSA.

2.6 Typical Content for an Approved inspection Authority (AIA) Report

The Typical content for an AIA (under the DoL) Report is given below:

1. TITLE PAGE

Name of Company
Physical Address
Date
Title e.g. Noise Evaluation Report
Unique (or serial number) number of report
Surveyor's name and signature
If AIA - Name or who verified the report
Executive summary

2. INTRODUCTION

Who did the survey/investigation
Why it was done (include purpose of survey/investigation)
Who initiated the survey/investigation
Where it was done
The date(s) on which it was performed
Limitations (e.g. Mixtures other exposures, limitations)
In short the out come of the survey/ investigation

3. METHOD

Describe the methods/procedures used, include any legal aspects.

4. RESULTS

Indicate the results - include plans to indicate sampling/measuring positions on plan(s).
Indicate those areas/positions where problems occur.
Include tables, figures, histograms or other methods
of displaying the results.

5. DISCUSSIONS/REMARKS

Interpretation of results/Other studies/ Effects

6. RECOMMENDATIONS

State control measures, include diagrams of control
measures/techniques, monitoring strategies.

7. SUMMARY

8. REFERENCES

9. APPENDIX

- Plan(s)
- Figures (diagrams)
- Tables
- Calibration certificates
- AIA certificate
- Standard method
- Legislation

10. GENERAL

Number of pages [page 3 of 25]
The hygienist should sign each page;
Quality control: Name and signature
Keep it simple and technical: Explain terminologies!

2.7. Bibliography

1. Comrie, A.C., 1999: Scientific Report Writing. Internet:
http://geog.arizona.edu/~comrie/geog230/reportr.htm

2. Department of Geology and Environmental Science, James Madison University. Formats for writing scientific reports and papers. Internet:
http://csmres.jmu.edu/geollab/studresrch/format.html

3. University of Washington, College of Forest Resources. Scientific report writing. Internet:
http://depts.washington.edu/esc322/field%20trips/reports/reportwriting.htm

4. Texas Technical University: Checklists for scientific reports. Internet:
http://www2.tltc.ttu.edu/dini/BIOL1402/Regular/checklist.htm

3. Inhalable and Respirable Dust

Authors: B. K. Belle, Anglo American plc and David W. Stanton, Consultant.

3.1 Purpose

The primary purpose of airborne dust sampling is to protect worker health by measuring personal dust exposures to ensure they are in compliance with occupational exposure limits. Other reasons include evaluating the effectiveness of engineering controls and changes in dust levels as a result of process changes, and as a measure of dose in epidemiological studies.

3.2 Principle

The air to be sampled is drawn by means of a mechanical pump through a filter contained in a filter holder. The dust present in the sampled air is deposited on the filter and can be weighed to determine the mass concentration of airborne dust and/or sent to a laboratory for analysis to determine the airborne concentration of a particular element or compound present in the dust e.g. lead, quartz, or vanadium pentoxide.

3.3 Inhalable and Respirable Dust

Suspensions of solid or liquid particles in air are often referred to as aerosols or particulates. Dust is generally considered an aerosol of solid particles mechanically produced, with individual particle diameters of 0.1 μm upwards (Figure 3.1). Fume is an aerosol of solid particles generated by condensation from the vapour state usually following the volatilisation of molten metals. The individual particle diameters of fume are typically less than 1 μm, though the existence of multi-particle aggregates is common.

The behaviour, deposition and fate of particles after entry into the human respiratory system, and the response that they elicit, depends on the nature and size of the particles. Thus the mass concentrations of airborne particles for occupational hygiene purposes are generally measured in terms of different size fractions (Figure 3.2) such as the inhalable fraction (particles < 100 μm) or respirable fraction (particles < 10 μ). In the case of inhalable dust this approximates to the fraction of airborne material that enters the nose and mouth during breathing, and is therefore available for deposition in the respiratory tract. Examples of dusts for which the inhalable fraction would be sampled includes certain hardwood dusts (which may cause nasal cancer) and dusts from grinding lead-containing alloys (which can be absorbed and cause systemic poisoning). Respirable dust approximates to the fraction of airborne material that penetrates to the gas exchange region of the lung. Examples of dusts for which the respirable fraction would be sampled includes dusts containing the various forms of free crystalline silica such as Cristobalite, Quartz and Tridymite. Coal dust is also measured as the respirable fraction.

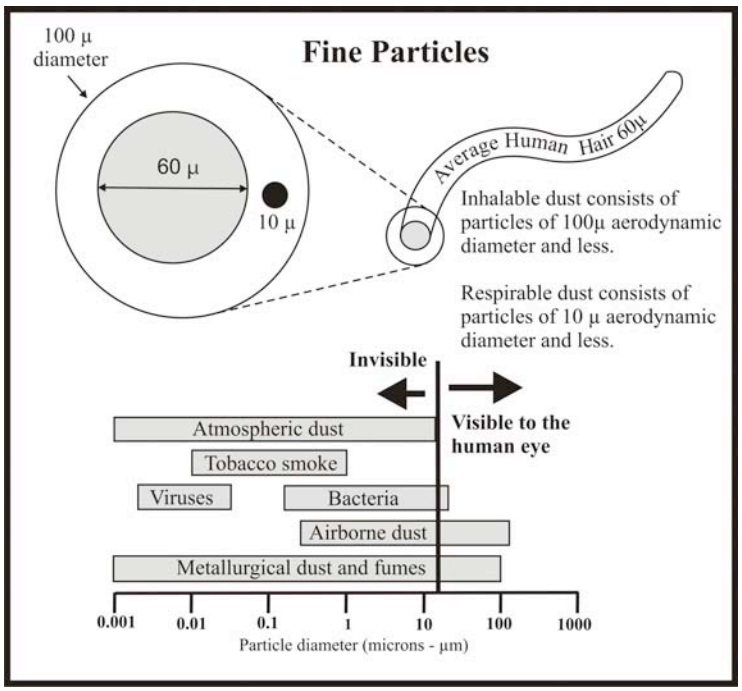

Figure 3.1 Fine Particles

3.4 Methodology

3.4.1 Dust Sampling Equipment

Different sampling instruments are utilised according to whether inhalable or respirable dust fractions are to be measured (Figures 3.2 and 3.3). The essential features of all systems are a collection substrate such as a filter and a pump for pulling the air through it; the collection substrate may be held within a cassette system placed within the respirable or inhalable sampler. In personal sampling the sampler is attached to the wearer within his or her breathing zone, and the pump is connected to it by a length of flexible tubing and worn on a belt, harness, or in a pocket.

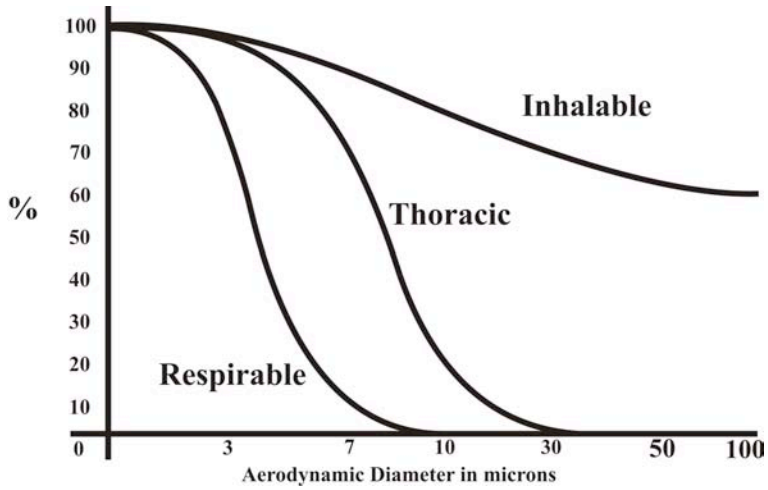

Figure 3.2 ISO/CEN/ACGIH Sampling Convention for Aerosols[1]

3.4.1.1 Inhalable Dust

Two examples of personal samplers for inhalable dust are the multi-orifice sampler (Figure 3.4) and the Institute of Occupational Medicine (IOM) sampler (Figure 3.5). The multi orifice and IOM-sampler require a pump capable of maintaining a smooth flowrate of 2.0 ± 0.1 litre/ min throughout the sampling period. The IOM sampler utilises an internal cassette made of plastic or metal that is weighed together with the filter it contains as dust is collected on the walls of the cassette as well as on the filter. The IOM sampler can be used for Inhalable and Thoracic dust sampling by inserting the appropriate foam plug into the entry or front part of the cassette (A longer version of the IOM cassette must be used when sampling with foam plugs). The foam size selects the dust that passes through it and allows the correct type of dust to be collected on the filter.

NOTES: For many years the closed-face plastic cassette has been widely used for monitoring "total dust" in working atmospheres (Figure 3.3). Studies have shown, however, that these may underestimate inhalable dust exposures compared to the IOM sampler depending on the particle size distribution of the dust. The terms "total dust" or "total inhalable dust" have now generally been replaced by the term "inhalable dust".

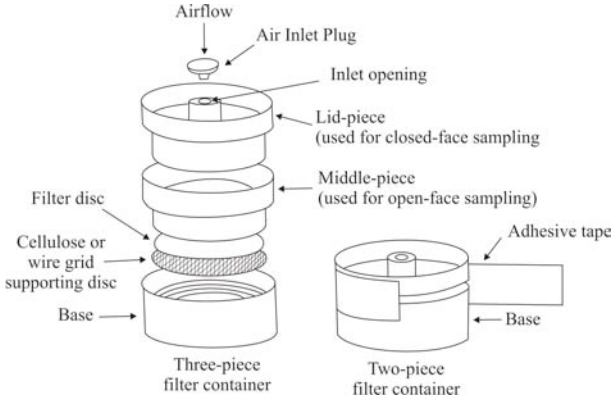

Figure 3.3 Filter Cassette Assembly

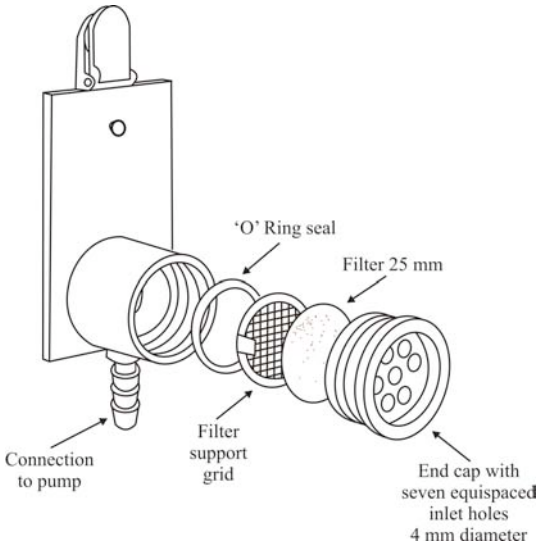

Figure 3.4 Multi-orifice Inhalable Sampler[1]

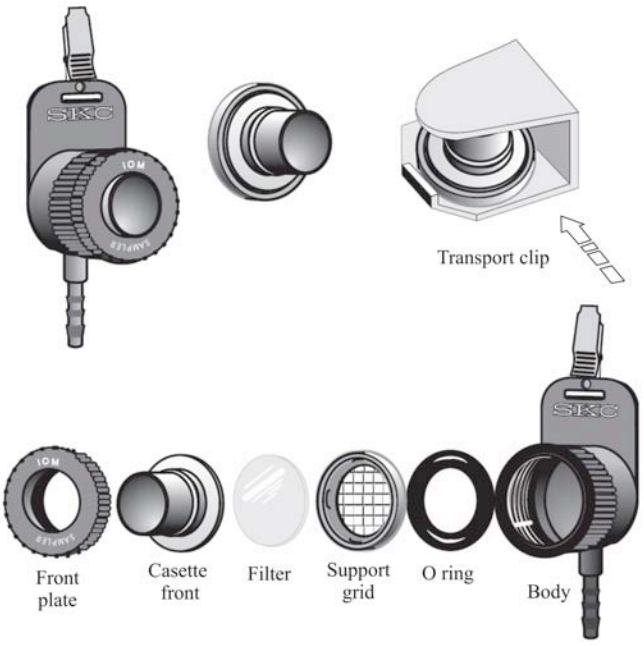

Figure 3.5 Institute of Occupational Medicine (IOM) Inhalable Sampler[2]

3.4.1.2 Respirable Dust

The respirable fraction is generally collected on a filter substrate using a cyclone to remove the coarse or non-respirable dust from the sampled air (Figures 3.6). The cyclone type typically used in South Africa is the generic Higgins-Dewell design, which should operate at a flowrate of 2,2 litre/min for optimal agreement with the ISO/CEN/ACGIH respirable convention (Figure 3.6).

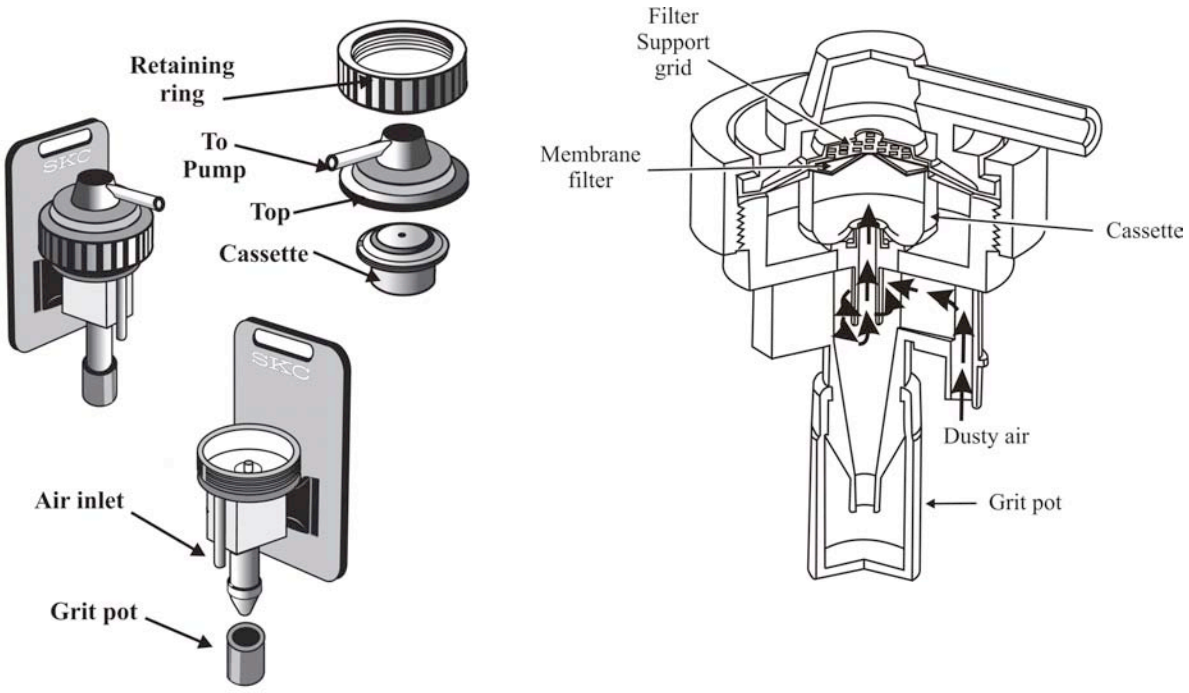

Figure 3.6 Cyclone and Airflow in Cyclone Respirable Dust Sampler

Alternative cyclone types that also agree with the respirable convention at specified flowrates can also be used. An example is the 10-mm Dorr-Oliver cyclone which is used at 1,7 litre/ min.

3.4.2 Personal Sampling

3.4.2.1 Apparatus Required

- A battery powered personal sampling pump capable of maintaining a sustained flow rate of at least 2,2 L/min over a full working shift.
- A clean filter holder capable of holding a 25 mm or 37 mm diameter filter.
- One metre of 5 mm or 6 mm internal diameter thick walled tubing suitable for connecting the personal sampling pump to the sampling head.
- 25 mm or 37 mm diameter filter media. The pore size should be selected to suit the specific application (e.g. 0,8 m for respirable dust.)
- Where respirable dust is to be sampled a cyclone separator to remove coarse dust is also required.
- A clip-on holder, which allows the filter holder to be attached to the worker's clothing.
- Belts or harnesses to which the sampling pumps can be conveniently fixed, unless they are small enough to fit inside worker's pockets.
- A calibrated rotameter or electronic air flow calibrator for the measurement of the flow rate through the sampling pump.
- Flat-tipped Tweezers.
- Micro-balance.
- Petri dishes.
- A charging system to charge the air sampler batteries.
- A stopwatch.
- A means to transport the filter samples from the workplace to the laboratory, which minimises the possibility of accidental transfers of collected dust to or from the filter media.

Figure 3.7 Early Model Personal Respirable Dust Sampler Attached via a Harness

3.4.2.2 Description of Apparatus

Pump: Several types of positive displacement personal air sampling pumps with built-in flow rate compensation for varying filter pressure drop conditions are available. The pump should be capable of maintaining a constant air-flow rate to within 5% of the calibrated airflow rate over a full sampling shift.

NOTE: Sampling instruments should be intrinsically safe for use in fiery mines and flammable atmospheres.

Filter Holder: The filter holder usually consists of a two part case, a filter disk and a filter support pad. The assembled unit in some instances requires the unit to be sealed with an adhesive cellulose band before use.

Cyclone Separator: The cyclone separator is used where respirable dust is to be sampled. The cyclone is attached to the filter holder and acts as a pre-separator to remove the coarse or non-respirable dust which is collected in a grit pot.

Clip-on Holder: The clip-on holder is designed to hold the filter holder in position, and is usually attached to the worker's lapel as close to the breathing zone as possible. It allows the filter/cyclone assembly to be suspended in a vertical position in which the cyclone operates most efficiently.

Filter Media: The filter disks utilised are generally either 25 mm or 37 mm in diameter, depending on the type of filter holder being used. If sampling is carried out solely for the measurement of the gravimetric concentration, without analysis, glass fibre filters may be used. Fibre loss from such filters may occur during handling and may be significant if less than 1 mg of dust is collected. At such concentrations silver, teflon or membrane filters should be used. Some types of filter (e.g. cellulose nitrate) can show excessive weight change due to moisture absorption, and other types (e.g. PVC, teflon) can show excessive static build-up. Filters made up of mixed esters of cellulose do not have these drawbacks to the same degree. If analysis of the collected material is required, this is likely to determine the choice of filter and the appropriate sampling and analytical method should be consulted.

Electronic Air Flow Calibrator: This can be used to calibrate rotameters, or to determine the flow rate of air sampling pumps, sampling trains, or virtually any device that involves air flow through tubing. It is based on the use of infrared sensors to measure the flow of a liquid film between two points in a precision tube. As the soap film passes two infrared sensors, the time spent between the sensors is fed to a microprocessor, which uses this data to calculate the flow rate.

Rotameter: Rotameters are variable area flowmeters that provide field accuracy in an easy-to-read instrument. The rotameter is a secondary standard and should be calibrated by a primary standard calibrator such as a laboratory film flowmeter or electronic air flow calibrator to ensure the correct pump flowrate is set when using a rotameter. It should be noted the calibration is for a given density and that the performance of the rotameter will be affected significantly by changes in elevation (and hence air density).

3.4.2.3 Preparation Before Use

Preparation of filter holders

- Assemble the filter holders in a clean environment.
- Only clean filter holders must be used. Use flat-tipped tweezers to handle the filter and filter support pad or grid.
- Place the filter and the filter support pad or grid in the filter holder, with the filter on the air intake side.
- Close the inlet and outlet ports of the filter holder with the plugs or covers provided with the filter holder.

- Seal the filter holder joints with shrinkable cellulose band or tape to prevent leakage where applicable.

Calibration of Pump

Before a pump and filter holder assembly is used to measure the dust level, it is necessary that the pump is correctly adjusted (Figure 3.8).

- Take a filter holder which is fitted with a clean filter and attach it to the pump tubing in the correct way, (i.e. "outlet" side connected to the pump tubing).
- Connect a calibrated rotameter or electronic air flow calibrator to the intake side of the filter holder.
- Switch the pump on and note the rotameter or electronic air flow calibrator reading.
- If required, adjust the pump flow rate to the required rate.
- Once the pump has been calibrated, a filter holder which has been prepared for actual sampling is connected to the pump and the assembly used to measure dust levels as required.

Figure 3.8 Sampling Train for Pump Calibration[2]

3.4.2.4 Personal Sampling Procedure

(a) Assemble the sampling train by fixing one end of the flexible tubing to the inlet port of the pump and the other end to the outlet port of the filter holder.

(b) Check for air leaks in the sampling train. This is usually done by turning on the pump and inserting a clean plastic plug into the inlet port of the filter holder. The air flow indicator on pumps with a flow meter must drop to the zero flow position and oscillate slightly. If this does not occur, find and either repair the leak if possible, or re-place the faulty component.

(c) Where respirable dust is to be measured, fit the cyclone separator to the inlet side of the filter holder where required, or use a filter holder specifically designed for this purpose.

NOTE: Care should be taken to ensure that the correct flowrate for the cyclone separator is utilised. Where the flow rate through the cyclone differs from the correct or rated flow rate, the efficiency of the cyclone is affected.

(d) Label the filter holder and the filter media with an appropriate sample number.

(e) Attach the pump, preferably to the worker's belt or place it in his pocket; place the flexible tubing over his shoulder and clip the filter holder to the clothing with the inlet port facing downwards, as near as possible to the breathing zone. Ensure that the equipment will not interfere with the worker's movements.

(f) Check again that all equipment is properly assembled, remove the plastic plug from the filter holder's inlet port where applicable and switch on the pump.

(g) Note the following information for each sample:
(i) date of sampling;
(ii) company name;
(iii) model and serial number of pump;
(iv) calibration date of the sampling pump;
(v) name of employee;
(vi) job title;
(vii) work performed including any abnormal activities such as stone dusting;
(viii) filter holder or sample number;
(ix) air flow rate; and
(x) time of initiation and termination of sampling.

(h) The ambient air temperature and pressure in the sampling area must be recorded at least once.

(i) To terminate sampling, perform the following sequence of steps:
(i) Check that the pump is operating prior to termination of air sampling;
(ii) Record the time of termination of sampling;
(iii) Switch off the pump and carefully remove the entire sampling train from the worker;
(iv) Check that the assembly still handles the pre-set flowrate with a maximum allowable variation of 5%;
(v) Remove the filter holder and seal with the protective cover or plugs to prevent contamination.

For samplers that use an internal cassette (e.g. the IOM sampler) remove the cassette from each sampler and fasten with the transport clip supplied by the manufacturer.

NOTES:

Where the cyclone pre-selector is used, particular care should be taken that the cyclone unit is not turned upside-down or handled in such a way that the dust is dislodged from the grit pot and falls onto the filter.

Sampling may be carried out for a total duration of six to eight hours, if feasible, to obtain a time-weighted average concentration. Where necessary, sequential air samples may be taken as opposed to single air samples. The total sampling duration may or may not include lunch breaks, depending on the nature of the work exposure to be measured. Total sampling

duration may be shorter than six hours, provided that the individual air samples taken during the selected periods are representative of the employee's exposure over the entire work shift. In practice a minimum sampling period of 5 hours is advised for an 8-hour shift.

For determination of risk assessment on mines and works the current requirement is that full working shifts have to be sampled.

During the sampling interval, the sampling train must be checked periodically to ensure that it is functioning properly. The airflow rate must not be re-adjusted after the flow rate is set.

3.4.3 Fixed Point Air Sampling

Fixed point or static air sampling may be used to determine background levels of airborne dust in the workplace. For the purpose of fixed point air sampling personal sampling equipment may be used. The sampling heads should be sited at about head height and as near as possible to the job locations, or failing this as near as is possible to major sources of airborne dust to which employees in that workplace are exposed. Due consideration should be given to the direction of air currents in the workplace in relation to sources of dust and to job locations when siting the static samplers. The number and location of sampling points in each workplace should be such that the results as a whole would provide a good description of the background airborne dust concentration in the workplace. In general it is not appropriate to compare dust concentrations determined by fixed point (background) sampling with occupational exposure limits.

3.5 Laboratory Analysis

The procedure for determining the amount of dust sampled for gravimetric mass determination is described in the chapter on the electronic microbalance. For analysis of the filter deposit, the filter is generally sent to an accredited laboratory. Techniques used for laboratory analysis to determine dust composition include atomic absorption techniques, ion selective electrode or ion chromatography, infra-red analysis, inductively coupled plasma-mass spectrometry, X-ray diffraction, X-ray fluorescence spectrometry and scanning electron microscopy.

3.6 Calculating Concentrations

The airborne dust concentration is expressed as mass (mg) per cubic meter (m^3) of air or number of particles per cubic meter of air (m^3) and generally referred to as “dust concentration or dust count” in the air. For example, coal dust concentration is expressed in mg/m^3; mineral fibre concentrations in f/ml.

Using the sampling period, flow rate and mass of sample collected on the filters, the sample concentration is obtained as follows:

$$\text{Sample Concentration (DC)} = \frac{(C_f - C_i)}{Fl \times T_s}$$

Where,

DC = dust concentration measured in mg/m3

C_i = corrected initial filter mass in mg

C_f = corrected final filter mass containing dust in mg
Fl = sample flow rate in m3/min
T_S = sampling time in minutes

If the sampling period is not an 8-hour period, a calculated 8-hour time-weighted average dust concentration (TWA-8h) is obtained as follows:

$$\text{TWA - 8h} = \frac{(DC \times T_S)}{480}$$

Where,
DC = dust concentration measured in mg/m^3
TS = sampling time in minutes

The above assumes that minimal dust exposure occurs during the unsampled portion of the shift.

3.7 Real-time Area and Personal Dust Monitors

Assessment of workplace exposures is important to help minimize dust-related occupational illness and diseases. Real-time airborne particulate monitoring can effectively locate areas where dust controls are needed and determine how well they are working.

Currently, there are a wide variety of direct reading real-time monitoring instruments available commercially specifically for area and personal sampling purposes. However, it is difficult to compare the manufacturers' specifications. Also, currently there is no consensus standard on the selection of a suitable instrument. Real-time hand held dust-monitoring instruments based on the light scattering principle include the: Microdust pro (Casella CEL) , TM-data respirable dust measuring instrument (Helmut Hund GmbH) and the TSI Dust track. The PersonalDataRam (Thermo Electron Corporation) was designed for personal and area dust sampling.

Real time monitors include a built-in data logger to store individual dust readings and will, depending on the sampling time, store averaged individual readings ranging from 1-60 seconds. The real-time monitoring system consists of a computer program into which measured data are entered and time-related concentrations can be displayed and printed. The program also allows for captured data to be manipulated in spreadsheet programs for statistical analyses.

Most of the available real-time instruments are not yet fully portable or applicable for underground operations. Instruments are calibrated using "mono-disperse" particles (e.g. Arizona road dust) in the laboratory. However, each instrument requires a user-determined "correction factor" obtained from a side-by-side gravimetric size-selective sampler, evaluated with "poly-disperse" dust having wide size-distribution curves appropriate to the specific mine. There is no "absolute correction factor" available for individual sampling instruments. The "correction factor" changes with the history of the sampling data obtained in side-by-side comparisons of the real-time monitoring instrument and the type of gravimetric size-selective sampler used. Finally, in order to determine the quartz content of the exposed dust, the real-

time monitoring instruments must be used in conjunction with respirable dust samplers in active sampling mode.

3.8 Peak Dust Concentrations

The average dust concentration levels to which workers are exposed provides an important measure of dustiness in relation to pneumoconiosis, but should be supplemented by information on the variability of dust exposures where possible. There is a growing awareness of the importance of peak concentrations and their effects on the human body. Any information on peak dust levels and their frequency in relation to average dust levels will assist in quicker reactive measures to improve the dust control systems and their effectiveness in ultimately reducing worker exposures. Figure 3.9 illustrates peak dust levels measured with a direct reading instrument.

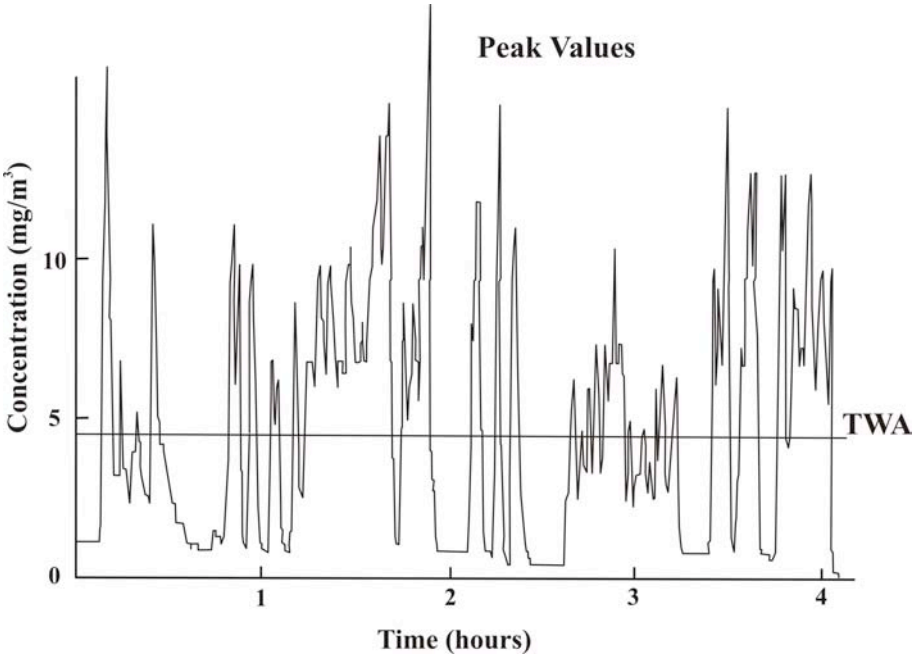

Figure 3.9 Real-time measurement of airborne dust

3.9 State of the Art Real-time Airborne Dust Monitors

A number of new instruments for real-time monitoring of airborne dust should be available commercially following development under the NIOSH mining research program (USA).

3.9.1 SKC Dust Detective

An affordable, person-wearable, real-time dust monitor called the SKC, Inc., Dust Detective (SKCDD) has been developed through a Cooperative Research and Development Agreement between NIOSH and SKC, Inc. (USA).

The SKCDD consists of a disposable sampling tube (Figure 3.10) connected to a small handheld sampling pump and provides short-term measurement of the cumulative personal

dust exposure of a worker during a shift. The dust detector tube models itself after the concept of a radiation dosimeter or, more precisely, after sorbent detector tubes used to measure exposure to various gases. The device measures the increasing back pressure across a glass fibre filter as the respirable fraction of dust is collected on the filter. This equipment has been evaluated in South Africa under SIMRAC Project Health 704.

A version of the SKCDD has been developed for diesel particulate measurements in raw diesel exhaust and is called the SKC Diesel Detective.

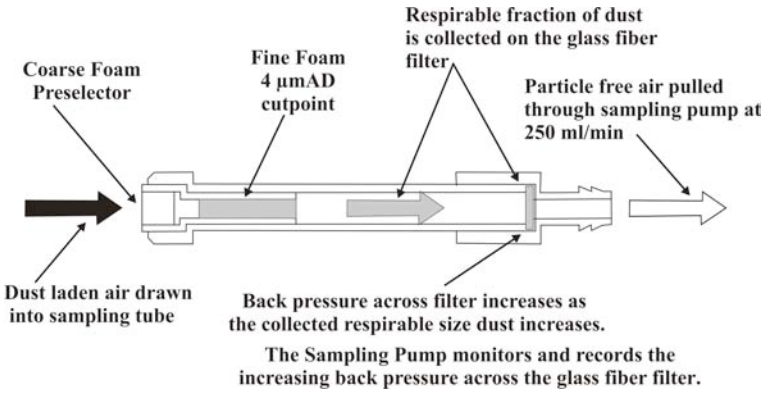

Figure 3.10 Dust Detective Sampling Tube[3]

3.92 Personal Dust Monitor (PDM)

The PDM was developed by Rupprecht & Patashnick Co., Inc. (R&P - now Thermo Electron Corporation) under contract to NIOSH for personal exposure measurements of respirable coal dust. It has as its mass sensor, a Tapered Element Oscillating Microbalance (TEOM), which continuously measures the mass of particles from the mine atmosphere collected on a sample filter.

The main components of the device include a cap lamp and sample inlet located on the end of an umbilical cable, a belt-mounted enclosure containing the respirable dust cyclone, sampling, and mass measurement system, and a charging and communication module used to transmit data between the monitor and a PC while charging its lithium ion batteries for the next shift. Figures 3.11 and 3.12 illustrates the components typically carried by the miner. Figure 3.12 also shows a version of the PDM for general occupational hygiene monitoring.

The PDM calculates the shift exposure and allows exposure data continually to be displayed during the shift to enable workers and management to react to changes in dust exposure.

The instrument is designed to withstand the harsh conditions found in the mine environment, and to meet intrinsic safety type approval requirements.

A 2.2 liter per minute flow of particle-laden air from the mine atmosphere enters an inlet mounted on the bill of the miner's hard hat, and passes through conductive tubing before reaching the Higgins and Dewell (HD) cyclone at the entrance of the PDM. The sample stream with respirable particles that exits from the cyclone is then conditioned in a heated section of tubing to remove excess moisture. As the air stream subsequently passes through the mass sensor, an exchangeable filter cartridge collects the respirable particles. The mass

sensor can be removed from the PDM by a mine's dust technician who changes its particle collection filter and cleans the unit after the end of each work shift.

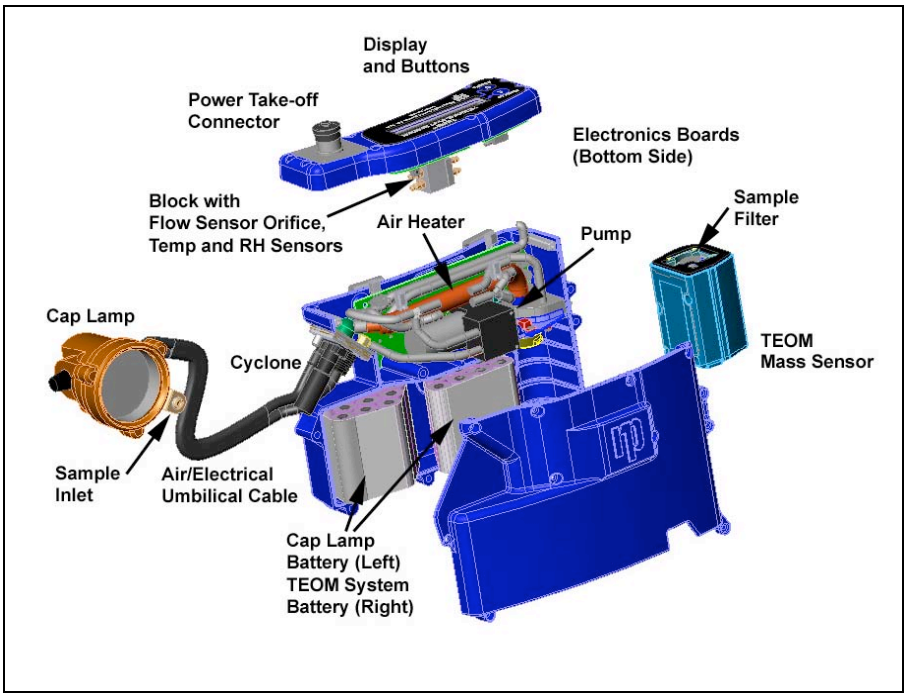

Figure 3.11 Major components of the PDM[4]

Downstream of the mass sensor, the filtered air sample flows through an orifice used in conjunction with a differential pressure measurement to determine the volumetric flow rate. The system computer uses this information to maintain a constant volumetric sample flow by varying the speed of a DC pump.

Figure 3.12 Series 3600 monitor with integrated cap-lamp for mining and Series 3700 monitor for general occupational hygiene monitoring

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4. Diesel Particulate Matter

Authors: David W. Stanton Consultant; Dave Unsted, Consultant and B. K. Belle, Anglo American plc.

4.1 Purpose

To measure diesel particulate matter in mine air.

4.1 Introduction

The use of diesel powered fleets for mining large tracts of ore in underground mining operations appears to be expanding. These vehicles are very flexible in operation and are proving their worth in mechanised mining operations. However, the downside of using diesel-powered vehicles is the potential to emit toxic and irritating exhaust emissions into the sometimes very confined spaces of underground workings. It is therefore obvious that to prevent exposures of personnel to exhaust emissions, the exhaust emissions and the operation of the diesel fleet have to be well managed. To this end there are basic guidelines, practices and control technologies that may be followed. One way to test the overall effectiveness of these strategies is to evaluate exposures of the working force to airborne pollutants associated with diesel engines including exposure to diesel particulate matter.

4.2 Diesel Particulate Matter[1]

Diesel exhaust emissions contain a complex mixture of gases and vapours: carbon monoxide, carbon dioxide, sulphur dioxide, nitrous oxides, polycyclic aromatic hydrocarbons (PAH), aldehydes, unburned hydrocarbons and carbonaceous particles (soot).

Diesel particulate matter (DPM) is considered that portion of diesel exhaust which is made up of solid carbon particles and the attached chemicals including organic chemicals such as polycyclic aromatic hydrocarbons (PAHs) and inorganics such as sulphate compounds.

The elemental carbon (EC) is the pure carbon particles that are the basic building blocks of diesel particulate.

The particulate fraction of diesel exhaust consists mainly of very small particles (typically 15-30 nm) which agglomerate together to form “chains” of particles which are themselves typically < 1 μm. High resolution electron microscopy has demonstrated that the basic particles consist of an irregular stacked graphitic structure, nominally called elemental carbon (EC).

The graphitic nature and high surface area of these very fine particles means they have the ability to absorb significant quantities of hydrocarbons (the organic carbon fraction) originating from the unburnt fuel, lubricating oils and the compounds formed in the complex chemical reaction during the combustion cycle. From extensive research many government agencies treat diesel emissions as likely human carcinogens.

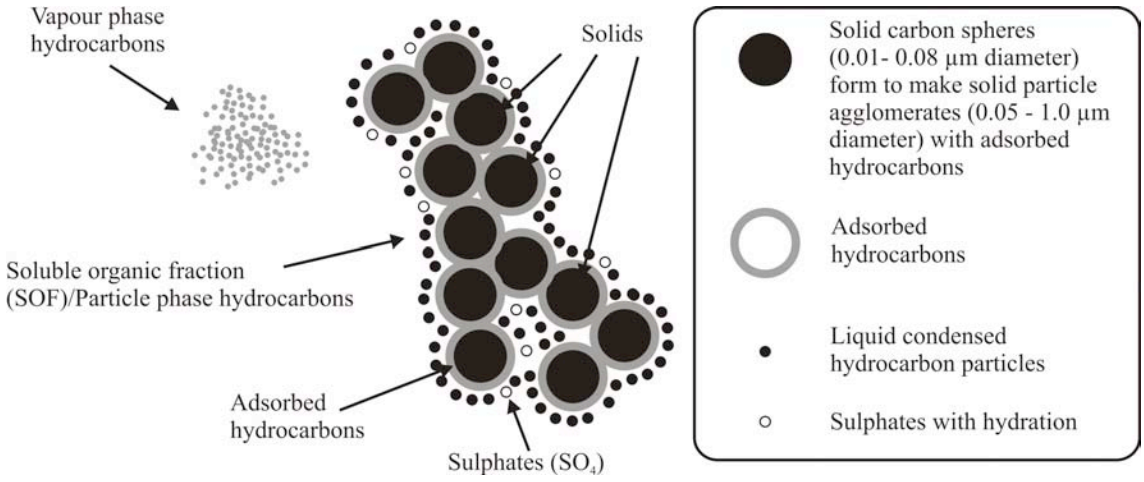

Figure 4.1 Diesel Particulate Matter[1]

4.3 Standardised Air Sampling Methods

Considerable research on DPM has been conducted in Australia, Canada, Germany and the USA. In some Canadian provinces respirable combustible dust (RCD) has been used as a measure of the exposure of miners to DPM. RCD is that portion of a respirable dust sample (collected with a cyclone pre-separator) that can be burnt off a silver membrane filter when exposed to a temperature of 400 °C for two hours. The filter is weighed before and after heating with the amount of material being lost deemed RCD.

NIOSH researchers in conjunction with Sunset laboratories developed a thermo-optical technique for the analysis of the EC fraction of DPM which is now the commonly accepted analytical method - known as NIOSH Method 5040 (First published in 1999).

The Australian Institute of Occupational hygienists published in 2004 a useful Guideline for the Evaluation and Control of Diesel Particulate in the Occupational Environment.

4.4 Occupational Exposure Limits for DPM

In most of Canada, DPM is not specifically regulated. Some provinces use an old limit recommended by the federal government"s mine research centre, CANMET, of 1.5 mg/m^3 of respirable combustible dust. CANMET has now recommended reducing the respirable combustible dust limit by half, to 0.75 mg/m^3.

In 1995, the ACGIH proposed that the particulate fraction of diesel exhaust emissions be categorized as an A2 level carcinogen (suspected human carcinogen) and suggested a TLV - TWA of 0.15 mg/m^3) for particulates with an aerodynamic diameter of less than 1 micrometre. The documentation supporting the proposed TLV did not specify what measuring method should be used. Below are the three methods that were discussed:

- gravimetric analysis of the respirable fraction,
- elemental carbon measurement using thermo-optical analysis of the respirable fraction, and
- analysis of respirable combustible dust (RCD).

In 1999 the ACGIH changed their proposed TLV-TWA for DPM to 0.05 mg/m^3 . The ACGIH in 2002 published a draft standard of 0,02 mg/m^3 (EC) and suggested that the TC is approximately equal to 85% of DPM and 30-70 % for EC. The DPM TLV proposal was withdrawn from their notice of intended changes in 2003.

The Mine Safety and Health Administration (MSHA)[2] in the USA are currently phasing in a DPM limit of 160 µg/m^3 TC or 123 µg/m^3 EC (average 8-hour TWA) to become effective on May 20, 2008. For the recommended exposure limits, the TC/EC ratio used by the MSHA is 1.3. The first phase involved a limit of 400 µg/m^3 TC or 308 µg/m^3 EC which became effective on May 20, 2006. On January 20, 2007, the DPM limit was reduced to 350 µg/m^3 TC or 270 µg/m^3 EC.

Currently the DME and DoL listing of OELs do not include an OEL for diesel particulate matter (DPM) but the DME are currently investigating possible OELs for DPM.

Some mining companies have adopted a DPM OEL of 0,2 mg/m^3 or 0,1 mg/m^3 (as EC) sampled as the submicron fraction.

4.5 Sub-Micron Size Selective Sampling

To reduce interferences when diesel particulate monitoring is conducted in coal mines, cyclones and impaction devices are used to remove the larger particles. Figure 4.2 shows the particle size distribution in a diesel equipped mine.

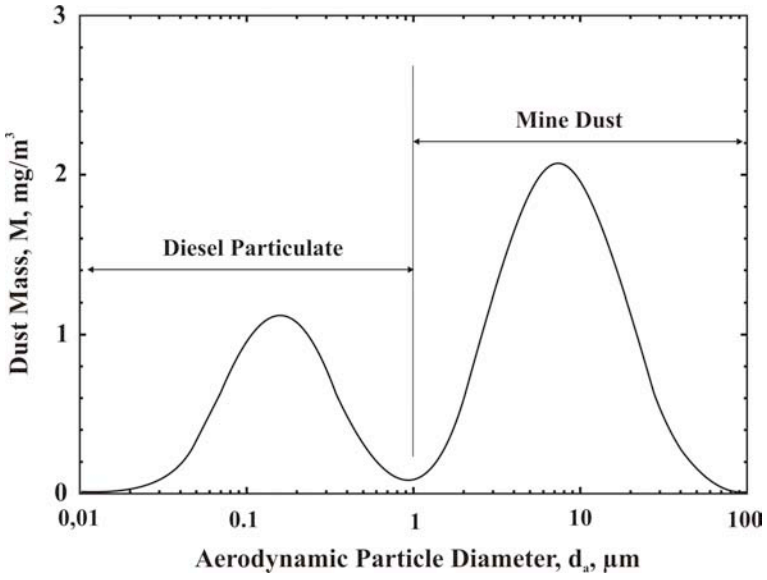

Figure 4.2 Airborne Particle Size Distribution in a Diesel Equipped Mine

Figure 4.3 illustrates the removal of particles by impaction.

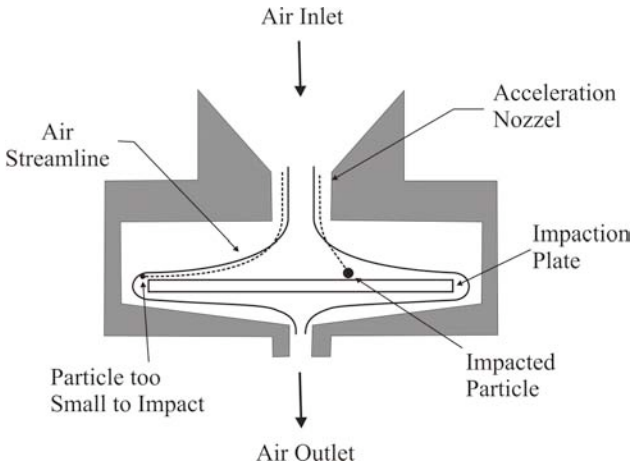

Figure 4.3 Size-selective Sampling Using Impactor

Research on diesel particulate has been conducted in South Africa under the MHSC Research Project SIM 02-06-02. This project included a component to develop a cost effective impactor that has the required size separation specifications and which can be reused in standard filter cassettes. However, the current commonly used cassette for DPM in South Africa is marketed by SKC.

4.6 SKC Cassette[3]

The SKC Cassette is designed for sampling in atmospheres where it is necessary to differentiate DPM based on particle size. This differentiation is performed using a specially designed precision-jeweled impactor built into the cassette. The cassette is designed for one-time use and contains a heat treated quartz filter for sample collection, and a second quartz filter to be used as a blank. The impactor removes respirable particles ≥1.0 μm.

4.6.1 Specifications

Cassette size:	37 mm.
Filter:	Two heat-treated quartz fiber with cellulose support pad.
Filter collection area:	8.04 $cm^{2.}$
Impactor:	Four-nozzle, precision jeweled.
Flow rate:	Calibrated at 1.7 and 2.0 L/min for sampling of sub-micron particles.

4.6.2 Setting up the Air Sampling Train Without a Cyclone

The following is based on the SKC Operating Instructions.

a) Remove the plug from the outlet of the cassette (Figure 4.4)
b) Attach one end of a length of Tygon tubing to the cassette outlet and the other end to the inlet of an air sampling pump capable of maintaining the desired flowrate.
c) Secure the cassette on a worker by using a cable tie and collar clip.
d) Remove plug from the cassette inlet immediately before sampling.

4.6.3 Air Sampling

a) Calibrate pump flow rate according to the pump operating instructions.

Note: Do not use filter cassette holder during calibration.

a) Replace representative cassette with a fresh cassette and insert assembly into the holder.
b) Sample for the appropriate time.
c) When sampling is completed, turn off the pump, remove the cassette from the holder, and immediately plug both the inlet and outlet of the cassette with the provided plugs.

4.6.4 Shipping

a) Package the cassettes for shipment to a laboratory for analysis. It is not necessary to send a blank. The DPM cassette contains a built-in blank filter.

Notes[4]**:**The quartz fibre filter used in this cassette is that required for analysis of carbon species as per NIOSH 5040, and is not suitable for gravimetric determinations due to problems with fragility and localized electrostatic charge. In almost all industrial situations it is necessary to have a cyclone pre-separation phase to prevent dust blocking the impaction holes. In situations where there is high dust concentrations or even high instantaneous dust concentrations, overloading of the separation process occurs and there is particle bounce on the plate impactor, with subsequent overestimation of exposure conditions.

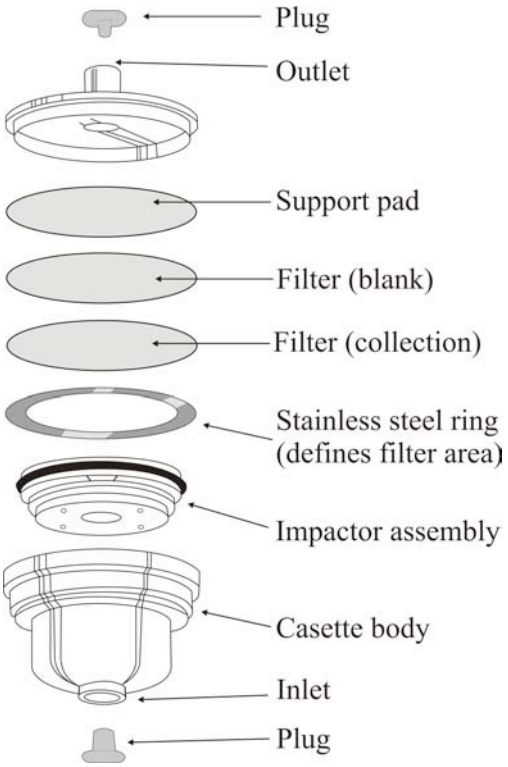

Figure 4.4 Exploded View of DPM Cassette

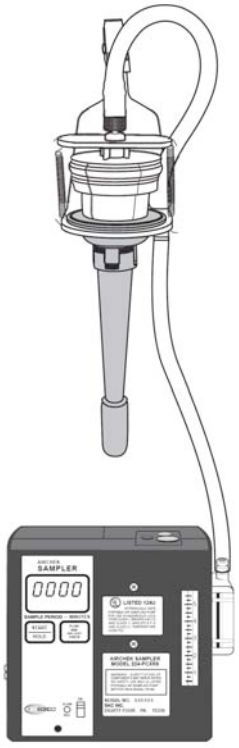

Figure 4.5 DPM Cassette With Cyclone

4.7 NIOSH Analytical Method 5040 For Elemental Carbon in Diesel Particulate[4,5]

Carbon speciation analysis is carried out by placing a punched section of a quartz glass fibre filter in an open oxygen free helium atmosphere flow furnace. The temperature is increased stepwise (500 °C to 700 °C) to remove firstly all organic carbon followed by carbonates. Pyrolised products are flushed off as CO_2 which is catalytically converted to CH_4 for detection by FID. The oven is cooled to 25 °C, a mixture of 2% O_2/He introduced and the temperature raised in steps to 850 °C to oxidize elemental carbon which is then converted to CH_4 for detection. Monitoring laser transmission through the filter during the cycle allows minimisation of interferences caused by elemental carbon formed during the pyrolysis of organic carbon. At the end of the cycle a known volume of CH_4 is injected into the furnace for calibration purposes. Given the air volume sampled, the software calculates the total carbon (TC) in the air sample. Analysis time is less than 10 minutes per sample.

The working range is approximately 6 to 630 µg/m^3, with an lower limit of detection (LOD) of ~ 2 µg/m^3 for a 960-L air sample collected on a 37-mm filter with a 1.5 cm^2 punch from the sample filter. If a lower LOD is desired, a larger sample volume and/or 25-mm filter may be used (e.g., a 1920-L sample on 25-mm filter gives an LOD of 0.4 µg/m^3).

4.7.1 Calculations

Multiply the reported (or area-corrected) EC result (µg/cm^2) by filter deposit area, cm^2, (typically 8.5 cm^2 for a 37-mm filter) to calculate total mass, µg, of EC on each filter sample (W_{EC}). Do the same for the blanks and calculate the mass found in the average field blank (W_b). The mass of OC is calculated similarly, but the mean OC field blank may underestimate the amount of OC contributed by adsorbed vapor. A quartz filter placed beneath the sample filter can provide a better estimate of the adsorbed OC.

Calculate the EC concentration (C_{EC}) in the air volume sampled, V (L):

$$C_{EC} = \frac{W_{EC} - W_b}{V} \quad mg/m^3$$

Note: The SKC DPM cassette filter deposit area is reported as 8.04 cm^2. It is recommended the laboratory conducting the analysis determines the actual deposition area, and this area should be used for calculation purposes.

The following equation[6] can be used to determine the DPM concentration in µg/m^3:

$$DPM_{ST} = \frac{(M - B)\ x\ A\ x\ 1000}{FL\ x\ ST}$$

Where DPM_{ST} = Sample DPM concentration measured in µg/m^3
M = Corrected DPM mass (EC or OC) in µg/cm^2
B = Blank DPM mass from control filter in µg/cm^2
FL = Sample flow rate in litres per minute
ST = Sampling time in minutes
A = DPM filter deposition area on filter in cm^2

4.9 Raw Exhaust Monitoring[4,7]

The routine monitoring of raw exhaust gases from diesel engines has been a statutory requirement for many years in mines in a number of countries. The principle is to use the measurement of raw exhaust gases as a means of controlling operator exposure to toxic exhaust gases. Mobile gas laboratories have been developed to carry out routine montoring for CO, CO_2 and oxides of nitrogen. Portable analysers and indicator tubes are also used.

The measurement of raw exhaust particulate levels is more complex than the measurement of raw exhaust gases. Historically Bosch Smoke meters and Opacity meters have been used. Diesel particulate analysers such as the Rupprecht & Patashnick Series 5100 Diesel Particulate Analyzer are available to directly measure organic carbon, elemental carbon and total carbon on one sample. A vacuum pump is used to draw a sample of raw exhaust through a heated probe that has been placed in the exhaust stream. The incoming particulate laden gas stream travels through a specialized switching valve to a quartz filter, where the particles are trapped for analysis within the instrument by heating and CO_2 analysis. Such instrumentation is currently suitable for use in mobile trailers and for research purposes but not for use under routine operating conditions.

To address this gap, research on hand-held instrumentation has been undertaken by NIOSH and conducted jointly through a Cooperative Research and Development Agreement with SKC, Inc. A device developed based on differential pressure, known as the Diesel Detective, will enable front-line personnel to determine quickly the particulate emission levels of an engine and determine if control technology maintenance may be required. Because of this NIOSH research, the Department of Minerals Resources, New South Wales, Australia, has tested the prototype Diesel Detective in laboratory and field trials and has recommended use of the technology in Australian mines.

Another portable hand-held instrument that showed promise following extensive dynometer and field trials was the TSI Dust track with moisture removal system. This instrument is based on light scattering.

A component of the MHSC Research Project SIM 02-06-02 is to establish diesel tailpipe emission standards to form a framework for an engine certification programme.

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5. Airborne Asbestos

Author: David W. Stanton, Consultant.

5.1 Purpose

To measure the exposure of workers to airborne asbestos fibres to assess compliance with the occupational exposure limits for airborne asbestos fibres.

5.2 Principle

A measured volume of air is drawn through a membrane filter, which is subsequently mounted on a microscope slide and rendered transparent. Fibres on a measured area of filter are counted using phase contrast microscopy (PCM), and the number concentration of fibres in the air is calculated. The result is expressed as fibres per millilitre of air, calculated from the number of fibres on the filter and the measured volume of air sampled.

5.3 Background Information on Asbestos

Asbestos is a natural occurring fibrous mineral that is widely distributed in rock outcrops and deposits throughout the world. Asbestos has been exploited commercially for their useful properties of flexibility, high tensile strength, incombustibility, low thermal conductivity and resistance to chemical attack. The asbestos minerals fall into two groups, the serpentine group, which includes chrysotile, and the amphiboles, which include crocidolite, tremolite, amosite and anthophyllite. The various asbestos minerals differ in the following characteristics: the crystalline structure, chemical and surface characteristics and the physical characteristics of their fibres, usually described in terms of length - to width ratio. The different fibres also differ in their biological potency.

In South Africa three types of asbestos were mined commercially; chrysotile (white) and the amphiboles crocidolite (blue) and Amosite (brown).

5.4 Occupational Exposure Limits

Under the Department of Labour (DoL) Asbestos Regulations (2001) "asbestos" means any of the following minerals: Amosite, Chrysotile, Crocidolite, Fibrous Actinolite, Fibrous Anthophyllite; and Fibrous Tremolite, or any mixture containing any of these minerals. The DoL "regulated asbestos fibre" means a particle of asbestos with a length-to-diameter ratio greater than 3 to 1, a length greater than 5 micrometres and a diameter less than 3 micrometres.

The DoL "occupational exposure limit for asbestos" is 0,2 regulated asbestos fibres per milliliter of air averaged over any continuous period of four hours measured in accordance with the UK Health and Safety Executive (HSE) Methods for the Determination of Hazardous Substances (MDHS) 39/4 Asbestos fibres in air. Sampling and evaluation by Phase Contrast Microscopy (PCM).

The DoL "short-term exposure limit" for asbestos means the concentration to which workers can be exposed continuously for a short period of time, which should not be exceeded at any time during the working day even if the 4-hour Time Weighted Average (TWA) is within the OEL-TWA. The DoL "short term exposure limit for asbestos" means an exposure limit of 0,6 regulated asbestos fibres per milliliter of air averaged over any 10 minutes.

In 2006 the Department of Minerals and Energy (DME) reduced their 8-hour TWA for asbestos fibres from 1 fibre/ml to 0,2 fibres/ml (all forms). No STEL was published.

5.5 Standard Sampling Method

For many years the standard method in South Africa for the determination of asbestos fibre concentrations in air was the Asbestos International Association (AIA), Recommended Technical Method No. 1 (RTM 1). (Light microscopy and Membrane filter method). The Asbestos Regulations published by the DoL in 2001 stipulated that the concentration of airborne asbestos fibres should be determined by means of the HSE MDHS 39/4. The MDHS method 39/4 as updated from time to time is recommended in this Handbook.

5.5.1 Other Relevant MDHS Publications

The following HSE (UK) sampling method can also be consulted to discriminate between fibre types:

MDHS 87 Fibres in air. Guidance on the discrimination between fibre types in samples of airborne dust on filters using microscopy

To carry out bulk sampling of asbestos in surveying workplace premises for asbestos-containing materials refer to the following MDHS method:

MDHS 100 Surveying, sampling and assessment of asbestos-containing materials

The MDHS documents can be downloaded from the HSE website:

www.hse.gov.uk/pubns/mdhs

The U.S. equivalent of MHSD 39/4 is the National Institute for Occupational Safety and Health (NIOSH) Manual of Analytical Methods (NMAM) Number is 7400: Asbestos and Other Fibres by PCM available at:

http://www.cdc.gov/niosh/nmam/

5.5.2 Scope and Limitations

The MDHS 39/4 method measures the airborne concentration of countable fibres using PCM. Countable fibres are defined as particles with length >5 μm, width <3 μm and aspect ratio (length: width ratio) >3:1. Fibres having widths <0.2 μm may not be visible using this method, and the PCM count represents only a proportion of the total number of fibres present. Therefore the count is only an index of the numerical concentration of fibres and not an absolute measure of the number of fibres present. The method does not permit the determination of chemical composition or crystallographic structure of fibres, and therefore

cannot be used on its own to distinguish unambiguously between different fibre types. Hence, use of this method requires all fibres meeting the size definition to be counted.

5.5.3 Sampling Equipment

To comply with the standard method, an open-faced filter holder fitted with an electrically-conducting cylindrical cowl extending between 33 mm and 44 mm in front of the filter, exposing a circular area of filter at least 20 mm in diameter, should be used for sampling. This type of holder is intended to protect the filter, while still permitting a uniform deposit. The cowl will point downwards when sampling. If O-rings are used, they should be made of PTFE or similar material. Flexible tubing is required to connect the filter holder to the pump, and a cap or bung is needed for the cowl entrance to protect the filter from contamination during transport.

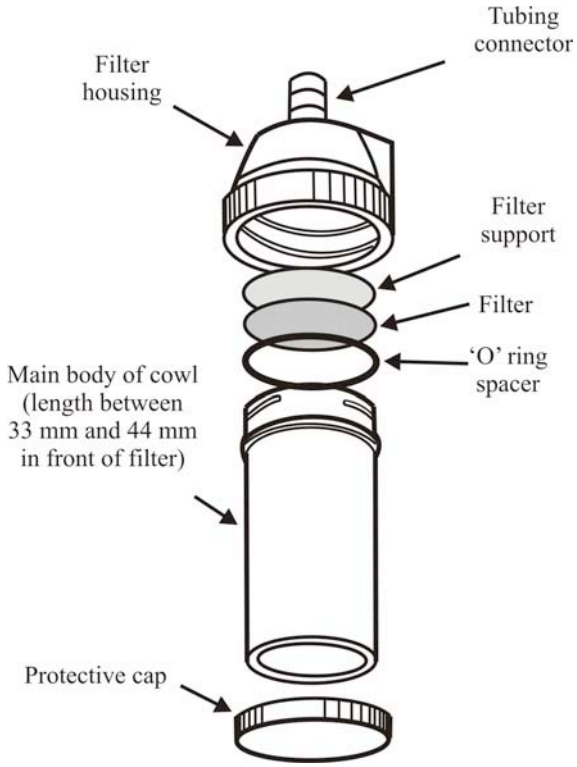

Figure 5.1 Asbestos Sampling Head[1]

5.5.4 Personal Sampling

The filter holder should point downwards and be fixed to the upper lapel or shoulder of the worker's clothing, as close to the mouth and nose as practicable, and preferably within 200 mm. Due regard must be given to localized concentrations: in such cases, the sampling head should be positioned on the side expected to give the higher result.

If a respirator is worn, the sampling head should be positioned away from the clean air exhaust.

5.5.5 Sample Duration

Sample duration is influenced primarily by the reason for sampling, the level of fibre concentration to be measured, the concentration of non-fibrous dust and the requirements of the analytical method. This may result in more than one single sample being required. For

compliance with an 8-hour TWA the Total Sample Duration should generally never be less than four hours, and preferably over an entire shift.

5.5.6 Sampling Pump

A portable battery powered pump must be used for personal sampling. The capacity of the battery must be sufficient to operate continuously over the chosen sampling time. The pump should be capable of maintaining the required flow rate with a variation within and±5% (10% spread) for the entire sampling duration, allowing for increasing filter loads. Pumps with automatic flow control facilities are recommended.

The performance characteristics of field sampling pumps vary considerably and reference should be made to experienced laboratories for selection of pumps for specific sampling applications.

The flow must be sufficiently free from pulsation. As a minimum and tentative criterion there must be no visible vibration of a rotameter float if such a flow meter is connected to the filter holder with the filter inserted. It may be necessary to install a pulsation damper between the pump and the filter if an internal pulsation damper has not been included or if the pump shows significant pulsation.

Connecting tubing must be constriction-proof and the connections leak proof.

5.5.7 Flow rate

If a 25mm filter is used, the flow rate should be selected in the range 0.4 to 2 litres/min such that a volume of 100 litres ± 20% is collected over the desired Single Sample Duration. As a minimum, the flow rate through the filter holder must be checked both before and after sampling. If the difference is greater than 10% of the initial flow rate, the sample must be rejected.

For personal sampling in relation to the 10 min STEL, a flowrate of 4 litres/min (with a minimum of 1 litre/min) is recommended.

5.5.8 Filters

Membrane filters (mixed esters of cellulose or cellulose nitrate) of 0.8 µm to 1,2 µm pore size with printed grids must be used, and a diameter of 25mm is preferred. Airborne dust should be collected on the upper (grid) surface of the filter.

It is acceptable to use 13mm filters and filter holders provided that flow rates and sample volumes are adjusted to give identical sampling volumes per square centimetre of effective filter area.

5.5.9 Filter Blanks

For each batch of filters used in a specific field sampling exercise or for every twenty-five filters in the batch, select one unused filter and subject it to the same treatment of handling and transport as for normal samples, but do not draw any air through it, or attach it to the worker.

5.5.10 Filter Holder

It is necessary to use an open faced filter holder fitted with a protective cowl. The cowl helps to protect the filter from accidental contamination. A metallic or conductive coated cowl is preferred because of the possible risk of fibre loss due to electrostatic charge when using plastic cowls. This is especially true when operated under conditions of low relative humidity.

Filter holders and cowls must be meticulously washed with detergent and water and thereafter rinsed thoroughly. After exposure to high asbestos concentrations it may be necessary to dispose of the holders and cowls, or only re-use in environments with high dust concentrations where any potential contamination would not have a significant effect upon results. Filter holders which have previously been used with fibreglass filters should never be used for asbestos work because of the risk of cross-contamination.

The design of the filter support utilised in some filter holders requires that a secondary support pad should be used. The purpose of this support pad is to ensure an even distribution of air passing through the primary membrane. These support pads are usually made of pure cellulose and have a much larger pore size than the primary filter upon which the fibres are collected.

5.5.11 Filter Storage and Transport

Fixatives must not be used. Experience has shown that fixing fibres to the filter surface with cytological or other types of fixatives is unnecessary and should be avoided.

Filters should be transported in the closed holders in which the samples were collected.

An alternative is to transfer the filter to a petri dish in the following way. In a dust-free area, using forceps, carefully remove each exposed filter from its holder, taking care to grasp only the unexposed filter edge. Place the filter, dust side up, in a plastic petri dish or similar container. Fasten the filter to the bottom of the dish with one or two pieces of adhesive tape attached to the unexposed edge. After transportation, the filter can easily be removed from the dish with a surgical scalpel.

The filter holders or petri dishes should be packed into a rigid container with some soft packing material to prevent both crushing and vibration of the filter. Samples should be clearly and unambiguously labelled, taking care to ensure that filters cannot be accidentally re-used. The filters should not be marked for this purpose because of the risk of damaging the filter.

5.5.12 Equipment for Filter Clearance

Filter clearing should be accomplished by the acetone/triacetin hot block method. In this, just enough acetone to clear a filter is injected into a block with an integral heater. The acetone is vaporised and emerges as a vapour jet from an orifice below which the filter is placed. A washer (or ring of metal or plastic) may be used to form a well, restricting the spread of acetone vapour.

Fine-tipped pipettes, or other suitable droppers, are needed to dispense triacetin.

5.5.13 Optical Microscopy

Optical Microscopy is the method used for analysing air samples for fibrous dusts such as asbestos and super fine man-made mineral fibres. The results are obtained in terms of numbers of particles rather than weight. The technique is based on an examination and identification of the collected fibres by shape, size and optical properties.

Full details on the equipment for filter clearance and optical microscopy are given in MDHS 39/4.

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6. Welding Fumes and Gases

Author: David W. Stanton, Consultant.

6.1 Purpose

To measure worker exposure to welding fumes and gases to assess compliance with occupational exposure limits.

6.2 Occupational Exposure Limits (OELs)

Most open arc or oxy-fuel processes give off both particulate fume and gases. Under the Mine Health and Safety Act (No. 29 of 1996), employers have to carry out a risk assessment to identify any potential exposure to hazardous substances in the work place, and devise and hazards from any fumes and gases that can arise from welding and cutting.

In a number of countries, including South Africa, exposure to welding fume must not exceed 5 mg/m^3 when averaged over an eight hour reference period, but with the proviso that none of the fume constituents exceeds its own exposure limit. Thus, if fume contains substances with exposure limits less than 5 mg/m^3, e.g. nickel, chromium, cobalt, manganese etc., it is possible that the total fume will require control to levels significantly less than 5 mg/m^3 to maintain control of these more toxic elements. Thus, fume of different compositions will require control to different levels and the requirements for extraction will vary accordingly, e.g. fume from stainless steel welding will require control to lower levels than fume from carbon steel welding. Gases present in the fume will require control to their respective exposure limits.

A listing of OELs for airborne pollutants likely to be encountered in welding and allied processes are given in Table 6.1.

6.3 Verification of compliance with OELs

A visual assessment of exposure to welding fume may be all that is needed to establish a requirement for extraction. For MMA welding of stainless steel or nickel alloys, then extraction will be required in almost all situations. Additional protection in the form of respiratory protection may be required in some cases. Only when the duration of exposure is very low, will extraction not be required.

The assessment of exposure, and therefore the requirement for extraction, will often be difficult. This is particularly the case with toxic gases where visual assessments are impossible and guidance or experience is required. Measurement may be necessary to establish whether extraction is required, or indeed, if extraction is already installed, whether additional control methods are necessary. In such cases, measurement should be performed by breathing zone (BZ) sampling (inside the welder’s face shield, when one is worn) according to the International Standards Organization ISO 10882 (2000/ 2001).

Table 6.1 Relevant DME 2006 OELs for Welding and Associated Processes

Substance	Formula	OEL ppm	OEL mg/m³	STEL ppm	STEL mg/m³
Aluminum metal: Inhalable particulate Respirable particulate	Al	 - -	 10 5	 - -	 - -
Aluminium Welding Fumes	-	-	5	-	-
Barium compounds, soluble	-	-	0.05	-	-
*Beryllium and beryllium compounds [as Be]	Be	-	0.002	-	-
Boron oxide	B_2O_3	-	10	-	20
Cadmium oxide fume [as Cd]	CdO	-	0.01	-	0.050
Calcium oxide	CaO	-	2	-	-
Chromium, metal and inorganic compounds [as Cr] Cr (II) compounds, Metal and Cr(III) compounds *Cr(VI) compounds	Cr	 - - -	 0.5 0.5 0.05	 - - -	 - - -
Cobalt & cobalt compound [as Co]	Co	-	0.05	-	-
Copper fume	Cu	-	0.2	-	-
Fluorides [as F]	F	-	2.5	-	-
Iron oxide , dust & fume [as Fe]	Fe_2O_3	-	5	-	10
*Lead, elemental, and inorganic compounds [as Pb]	Pb	-	0.1	-	-
Manganese fume [as Mn]	Mn	-	1	-	3
Manganese, elemental, and inorganic compounds [as Mn]	Mn	-	1	-	-
Molybdenum compounds [as Mo] soluble compounds insoluble compounds	Mo	 - -	 5 10	 - -	 10 20
*Nickel Nickel, organic compounds [as Ni] *Nickel, inorganic compounds [as Ni] soluble compounds insoluble compounds	Ni	- - - - -	0.5 1 - 0.1 0.5	- - - - -	- - - - -
Nitric oxide	NO	25	30	35	45
Nitrogen dioxide	NO_2	3	5	5	9
Ozone	O_3	-	-	0.2	0.4

Substance	Formula	OEL ppm	OEL mg/m³	STEL ppm	STEL mg/m³
Selenium & compounds, except hydrogen selenide [as Se]	Se	-	0.1	-	-
Silica, amorphous	SiO_2	-	-	-	-
Inhalable particulate		-	6	-	-
Respirable particulate		-	3	-	-
*Silica, crystalline respirable particulate					
Cristobalite		-	0.1	-	-
Quartz		-	0.1	-	-
Tridymite		-	0.1	-	-
Tripoli		-	0.1	-	-
Silica fume respirable particulate		-	2	-	-
Silica, fused respirable particulate		-	0.1	-	-
Tin compounds, inorganic except SnH_4 [as Sn]	-	-	2	-	4
Titanium dioxide	TiO_2				
Inhalable compounds		-	10	-	-
Respirable compounds		-	5	-	-
Vanadium pentoxide	V_2O_5				
Inhalable particulate		-	0.5	-	-
Fume & Respirable particulate		-	0.05	-	-
Welding Fumes	-	-	5	-	-
Zinc oxide fume	ZnO	-	5	-	10

Notes - the OEL for welding fumes is without prejudice to any occupational exposure limits for individual components in the fume. Some welding processes generate fume that contains components, which have specific OELs, these limits should be applied to control exposure if these substances are present in the fume.

Exposure to a substance demarcated with an asterix (*) must be kept as far below the OEL as is reasonably practicable.

6.4 Air Monitoring

Routine air monitoring should be conducted to determine the levels of hazardous materials in the atmosphere of the welding area.

Gases are invisible. However, in general, the highest concentration will be found in the vicinity of the visible plume of particulate fume (if there is one). The exception is ozone, which can form remote from the arc and is less likely to be affected by convection currents arising above the arc. NOx and the inert shielding gases are usually heavier than air, and therefore can sink into low level pockets, compartments, recesses etc, creating dangerous concentrations there.

Sampling for the common pollutant gases can be carried out quickly and cheaply using a chemical indicator method and a simple bellows pump, for example as those sold by Dräger, SKC etc. The actual readings obtained are only representative of the concentration at the sampling point and the instant of sampling, and as such do not give a true measure of the time weighted average (TWA) concentrations. As a compromise, it is usual to take the average of at least three measurements made with the chemical indicator tube method during consecutive operations of the process. More accurate measurements for gases require longer sampling times, and more expensive equipment and expertise.

Particulate fume exposure is generally measured using a battery powered air sampling pump to draw air through a filter located inside the helmet. Shift exposure studies on arc welders were performed in this way by the Laboratory of the Danish Labour Inspectorate in the 1960's. Examples of in-helmet sampling are given in Figures 6.1 and on the Air Monitoring page of the SIMRAC Welding OHS Resources CD.

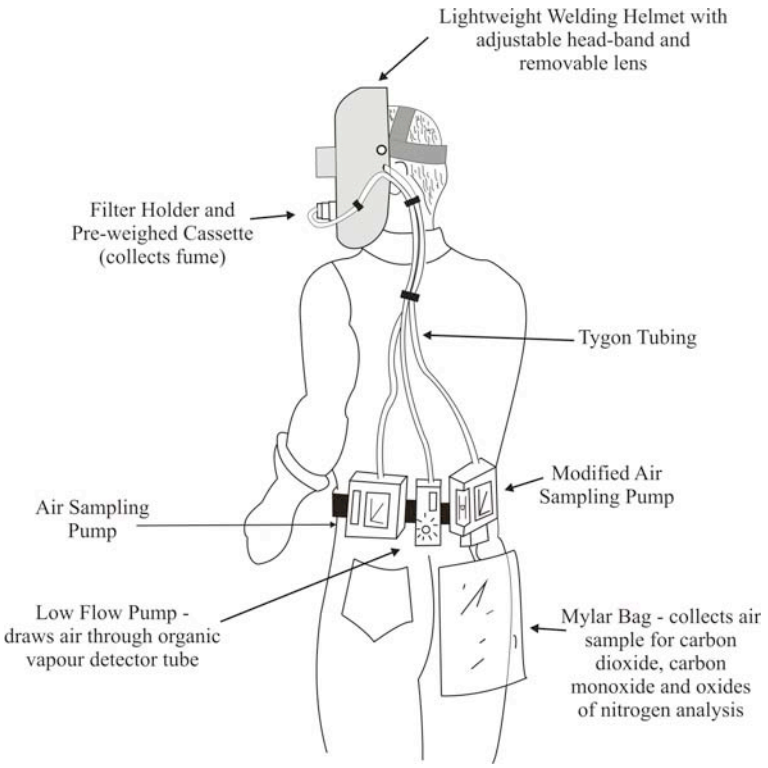

Figure 6.1 Example In-Helmet Sampling for Gases, Vapours and Fume Conducted by NIOSH in the 1970s

6.5 ISO 10882 Part 1 (2001): Sampling of airborne particles

6.5.1 Principle

This ISO standard is based on the common occupational hygiene practice to assess welding fume exposure e.g. BZ sampling. Welding fume is collected by drawing a known volume of air through a preweighed filter or filter cassette, mounted in a sampler designed to collect the inhalable fraction of airborne particles. For personal sampling, the sampler is positioned in the operator's BZ, which is inside the welder's face shield, when one is worn. At the end of

the sampling period, the mass of welding fume collected is determined by reweighing the filter or filter cassette. The mass concentration of welding fume in air is calculated by dividing this by the volume of air sampled.

Exposure to specific chemical agents in welding fume may be determined by chemical analysis of the sample. Alternatively, it may be estimated from the mass concentration of the welding fume in air using fume analysis data for filler materials, e.g. from fume analysis data sheets.

6.5.2 Filters

They must be compatible with the analytical technique, have good collection efficiency, be sufficiently resistant to moisture retention and not be excessively friable.

6.5.3 Sampling pumps

They must give a pulsation free flow, have adjustable flow rate, incorporate a flow meter or a flow fault indicator, and be capable of maintaining the required flow rate to within ± 5% of the nominal value throughout the sampling period. For personal sampling, the pumps shall be capable of being worn without impeding the operator's normal work activity. The sampling pump can be conveniently fitted to a waist belt, unless it is small enough to fit in the operator's pocket.

6.5.4 Analytical balance

It should be capable of weighing to an accuracy of ± 0,01 mg, able to accommodate the filter used, and calibrated with weights traceable to national standards.

6.5.5 Sampling position

The highest concentration of fume usually occurs in the immediate vicinity of the operator and it is therefore essential that measurement of personal exposure is performed in the operator's BZ. Welders' face shields can provide some degree of protection from exposure by physically deflecting the welding plume away from the BZ. It will usually be necessary for the operator to wear apparatus that enables the sampler to be maintained in the BZ throughout the sampling period without impeding normal work activity. The BZ is considered to be preferably adjacent to the operator's nose and mouth, at mouth level, a maximum of 50 mm to the right or left of the mouth and in a horizontal position with the sampler inlet facing forwards.

6.5.5.1 Sampling head attached to the welder's face shield by means of a removable clip

A specially designed, removable clip may be used to attach the sampler inside the welder's face shield.

6.5.5.2 Sampling head attached to the headband of the welder's face shield harness

A specially designed mounting may be used to attach the sampler to the headband of the welder's face shield harness (Figure 6.2).

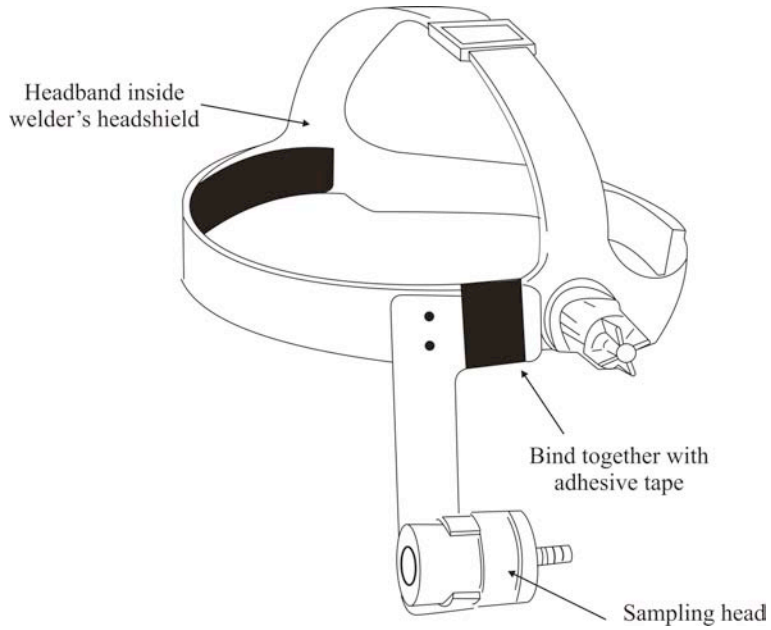

Figure 6.2 Sampling Head Attached to Welders Headband

6.5.5.3 Sampling head attached to a separate headband

A specially designed mounting may be used attached to a separate headband that is worn in addition to the headband of the welder's face shield harness e.g. a sports person's headband (sweatband).

6.5.6 Analytical techniques

For elemental analysis (e.g. Ag, Al, Ba, Be, Cd, Co, Cr, Cu, Fe, Mg, Mn, Mo, Ni, Pb, V, Zn), a variety of analytical techniques are available and include:

- Inductively coupled plasma – Atomic emission spectrometry (ICP-AES)
- Inductively coupled plasma – Mass spectrometry (ICP-MS)
- Atomic absorption spectrometry (AAS)
- Atomic fluorescence spectrometry (AFS)
- X-ray fluorescence spectrometry (XRFS)

For Fluoride (F-) analysis, Ion chromatography (IC) and Ion selective electrode (ISE) are used. In the case of Hexavalent chromium (CrVI), two analytical techniques are Ion chromatography (IC) and Spectrophotometry.

It is essential that the filters used are suitable for collection of hexavalent chromium. Many filter materials (e.g. mixed cellulose ester membrane filters) react with hexavalent chromium, resulting in its reduction to the trivalent state and poor analytical recoveries. Quartz fibre filters, glass fibre filters and PVC filters have been found to be satisfactory and are widely used.

6.5.7 Part 2 (2000): Sampling of gases

6.5.7.1 General

Gases and vapours covered in this standard include ozone (O_3), carbon monoxide (CO), carbon dioxide (CO_2), nitric oxide (NO) and nitrogen dioxide (NO_2), and vapours produced in the welding or cutting of metals having paint or other surface coatings. Fuels, oxidant and shielding gases used in welding and allied processes are not covered.

Personal exposure to gases and vapours in welding and allied processes is generally determined using:

- Direct reading electrical instruments (O_3, CO, CO_2, NO, NO_2)
- Detector tubes (short term or long term) (CO, CO_2, NO, NO_2); or
- Indirect methods involving laboratory analysis (vapours)

Direct reading electrical apparatus or detector tubes are generally most applicable for the measurement of gases. Indirect methods, which involve laboratory analysis of samples collected using a suitable solid or liquid sorbent, are most applicable for the determination of vapours which can be produced in the welding or cutting of metal having paint or other coating.

A complex mixture of particulates and gases is produced in welding and allied processes, and, whatever method of analysis is selected, it is necessary to confirm that techniques, which might have been successful in other applications, are suitable for the welding situation.

In selecting any of the methods described, due regard should be paid to the possibility of interference with the determinations of one gas or vapour by the presence of another, which could result in either enhancement or reduction of the result.

6.5.7.2 Personal Exposure Measurements

Measurements of very short duration, e.g. for screening purposes, can be made by directly positioning the sampling line or sampler in the BZ and maintaining it in position by hand. However, to obtain time weighted average concentrations of gases and vapours, e.g. for comparison with OEL values, it will usually be necessary for the operator to wear apparatus that enables the sampler to be maintained in position in the BZ throughout the sampling period, without impeding normal work activity.

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Part 2: 2000 Sampling of gases
International Organization for Standardisation (http://www.iso.ch).

7. Gravimetric Weighing

Author: Renier Cornelissen, CSIR.

7.1 Purpose

The purpose of this chapter is to identify factors that could adversely affect the accuracy of the determination of the mass of dust on a gravimetric sampling filter. It describes precautionary measures to control and minimize these influences.

Silicosis has been with the mining industry since mining started. Early after the turn of the century the disease was discovered and the first cases in South Africa were diagnosed in 1907. Thousands of mine workers have lost their lives as a result of the exposure to airborne respirable silica dust.

An international drive has been initiated to eliminate the occurrence of silicosis in employees. In order to achieve this goal it is essential that the exposure of employees be measured accurately. It is also important to accurately measure the efficacy of existing and newly developed control measures.

Three parameters are to be measured when assessing the potential hazard of a dust sample. These are:

- the size distribution of the dust particles to determine the respirable fraction of the dust in the sample
- the silica content of the respirable dust in the sample to determine it's toxicity and
- accurate weighing of the sample, to determine the mass of the respirable dust in the sample.

The weighing of gravimetric samples, one of the three essential parameters, is of utmost importance. The current OEL for silica exposure is 0.1 mg/m³.

7.2 Methodology

7.2.1 Apparatus and Facilities

7.2.1.1 The weighing room

Certain aspects of the weighing room are important for the accuracy of the weighing results.

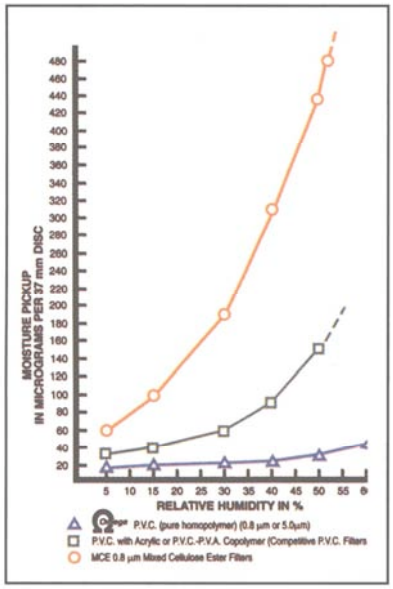

Figure 7.1 Filter moisture pickup

The environmental conditions in the room are to be kept constant within preset limits with the use of an automatic air-conditioner. The air-conditioner is to be designed to maintain the temperature and humidity inside the room automatically within preset limits. The temperature in the weighing room should be set at a level comfortable for the technician. This would normally be approximately 22˚C. The actual temperature value is not important but the tolerable variation should be limited to ± 0.5˚C. Gravimetric filters absorb moisture from the air. The higher the humidity, the more moisture is absorbed and consequently the mass of the filter is affected accordingly. Filters of different materials absorb different quantities of moisture. PVC filters are not affected as much as MCE filters by changes in humidity. Another reason for controlling the humidity is static electricity. The lower the level of humidity the more static electricity is generated. PVC filters are less prone to be affected by static electricity. Relative humidity can be set at 45% ± 5%. The temperature and humidity setting, once set, should not be altered, because the sampling filters should be weighed at the same environmental conditions, pre- and post-sampling.

The weighing room should preferably not have windows. Air leakage through the window and solar heat from direct sunlight on windows could affect the weighing room environment. Solid brick walls, without windows, are therefore recommended. The ceiling should preferably be of solid concrete or otherwise constructed of air tight and dust-proof material and insulated with good quality insulation.

Carpets are not to be used in weighing room. Carpets can generate static electricity which is transferred to sampling filters. Carpets also collect dust, which is then later liberated, into the atmosphere from where it can settle back onto the weighing apparatus. Floor tiles of vinyl can be used as an alternative.

A table of high inertia, mounted on vibration absorbers, such as high-density rubber pads is required for the balance. The table is not to be fixed to the wall of the room.

Chairs of ergonomic design are to be provided for the technician to prevent fatigue. The chair should have arm rests high enough for the technician to rest his arms on to prevent leaning on the balance table as this is will affect the balance.

Airlock doors are required to prevent loss of conditioned air from the room. These doors should be fitted with automatic closing devices and should open inwards into the weighing room to prevent being opened by the positive pressure inside the room. Leakage of air through the airlock should be minimised. This will assist in preventing ingress of dust and minimize fluctuations in the environmental conditions load caused by loss of conditioned air.

Whilst weighing is in progress a sign should be conspicuously displayed on the entrance door to prevent persons from entering the weighing room. Body heat and moisture from the exhaled breath of persons will affect the environment in the room. A call bell should be fitted to the doors for the use of visitors to draw the attention of the technician. Glass panes may also be fitted in the doors to enable visual communication with the technician, where appropriate.

7.2.1.2 The balance and other apparatus

The microbalance is obviously the heart of the weighing process. A balance capable of weighing accurately to at least five or preferably six decimals of a gram should be used. The balance must be fitted with a levelling indicator. Modern balances are manufactured to compensate automatically for temperature changes. The technician should confirm that this is the case for his balance and if not, apply temperature change compensation manually to results. The specification for this is published in the balance operating manual.

Anti-static mats, electrical earthed, are to be used on all the work areas where samples are prepared and on the balance table.

Sampling filters become charged with static electricity. Antistatic ionizers are recommended to neutralise the charge on the filters. Static-electricity will disrupt the weighing process. Static-electrically charged filters are difficult to handle as they tend to be repelled by objects of similarly-charged polarity. As a consequence dust from the sample may be dislodged and lost off the filter, resulting in inaccurate determination of the sample mass. Different types of ionisers are available. Ionising blowers are used to electrically neutralise the air in the room and another design may be used to neutralise items such as the gravimetric sampling filters. A selection, best suited for the specific application, is to be made.

Every individual balance has its own settling time. This settling time, for example 30 seconds, is determined as part of the calibration. The balance will have an indicator, indicating when the balance has reached stability, the settling time normally takes longer and changes to the weighing result still occur after stability is reached. A count down timer is used to indicate to the technician that the settling time has expired. A weighting reading is taken only after the settling time has expired and for consistency all readings are to be taken immediately after expiry of the same settling time period.

Tweezers of non-serrated tip design are to be used to prevent damage to the filters during handling. A clean glass dish for placing the tweezers onto is to be kept next to the balance. The technician should avoid handling the tweezers when not handling filters and take special

care not to touch the tips of the tweezers with bare hands. If plastic gloves are used, they are to be of the non-powdered type to prevent powder contamination of the sample.

Petri slides, glass or plastic, are to be used for the storage of sample filters. Re-used Petri slides are to be cleaned properly with mild soap and rinsed with distilled water before drying.

There is considerable advantage in connecting the balance to a computer. The balance can be controlled in this way to open and close the balance door. The weighting results can also be transferred directly to a computer programme and in this way, avoid human error and save time. It is important that the computer and printer not be placed in the weighing room. The key-board, mouse and monitor may be placed in the room on antistatic mats.

The environmental conditions in the laboratory should be monitored permanently. Data-logging monitors suitable for this purpose are readily available from instrumentation supply companies. The data is logged and downloaded to a computer and a histogram of the previous 24 hours can be viewed. A real-time reading can also be taken from the instrument.

Principle of operation of the balance

The modern microbalance is an electronic device. The principle of operation is movement of the weighing dish assembly in an electromagnetic field. The position of the weighing dish changes the electronic characteristic of the magnetic field in proportion to the mass and this is translated into the mass display of the balance.

Preparation of Apparatus and sampling filters

Before a weighing session of gravimetric sampling filters is started, the following actions are to be performed.

The balance is to be left turned on permanently with doors slightly open when not in use to allow for the internal cavity to have the same environmental conditions as the room. If the balance is not left turned on permanently then it should be allowed at least 30 minutes to warm up prior to use.

Ensure that the environment in the weighing room has stayed stable and within the preset limits for the previous 24 hours. This can be done by downloading data from the data-logging environmental monitor. The technician should also ensure that the conditions are within the required limits immediately prior to and after weighing.

Exercise the balance by weighing a mass of 10 to 20 grams repetitively until repeatability is reached which can be accepted when the minimum and maximum of three consecutive weightings do not differ by more than 1% of the minimum.

Do the internal calibration of the microbalance.

Weigh a calibrated mass of known weight. The results of the weighing of the calibrated standard are to be kept and a running standard deviation of the last five weightings calculated. A tendency of the standard deviation to increase will be an indication that the balance is to be serviced and re-calibrated.

Every new batch of filters is to be inspected for quality assurance. A representative sample of filters (± 10%) is to be taken from a new batch and inspected. The filters are to be inspected visually against a bright light for presence of pinholes. The masses of the selected filters are to be determined by weighing and are to be compared. If an unacceptable variation (possibly > 1%) is detected then the batch is to be discarded. A large variation in mass of the filters could be indicative of different thicknesses, which will affect the X-Ray diffraction analysis process and could also indicate possible differences of porosity and aperture size.

Filters for sampling are to be selected carefully. The filter material is important for the analysis method to achieve the result required. Glassfibre filters for example, cannot be dissolved and can therefore not be used for sampling if more than one sample is to be combined and redeposited onto a single filter for X-Ray diffraction. MCE filters are more suitable for this purpose. PVC filters are less susceptible to the effect of humidity changes than MCE filters. PVC filters may therefore be used for smaller sample masses, provided the static electricity is controlled effectively. The size of the filter should be selected to suite the mass of the sample. If a too small size filter is used, the filter may be overloaded at the risk of the loss of some of the sample matter prior or during the weighing process.

Pre-sampling filters are to be placed in clean cassettes. A backing pad is to be placed in the cassette behind the filter as a means of support to prevent the filter from collapsing during sampling. The number of the filter inside the cassette is to be clearly displayed on the outside of the cassette. The cassette joints are to be sealed with a “shrinkseal” or glued insulation tape. The cassettes are to be sealed with different coloured sealing stoppers on both sides. The stoppers are colour coded, red and blue. Red stoppers are put on the inlet side of the cassette pre sampling. After sampling the stoppers are swopped by the field technician to indicate to the laboratory technician which filters were actually sampled on. Cassettes with filters are at all times to be transported with the sample side of the filter facing upwards. This is to prevent loss of sample dust that may not be fixed to the surface of the filter.

Cassettes are to be transported in robust cases with foam rubber inserts. The cases are to be marked conspicuously to clearly indicate “THIS SIDE UP” and “FRAGILE”. Figure 7.2 shows two cassettes in such a suitable carrying case. In order to prevent rough handling and consequent damage to samples, cases with filters are not to be transported by commercial courier services.

Figure 7.2 Filter cassette transport case

Pre-sampling preparation of the filters is to be done meticulously according to quality assurance procedures. The correct number of filters required for sampling, together with three

reference filters, is to be selected from the same batch, and acclimatised together. It is important that all the filters are taken from the same batch to ensure that they have the same moisture absorbing characteristics. The reference filters are to remain in the laboratory. The reference and sampling filters are to be acclimatised together for at least 24 hours, prior to weighing, under controlled environmental conditions whilst being protected to prevent settling of dust onto the filters. Matched-weight batches of filters can be acquired from suppliers but at considerable increased cost. The record of the environmental conditions pertaining during the 24 hours of acclimatisation is to be obtained from the data-logging monitor and should be filed with the results of the weighing.

Filters are to be numbered uniquely in accordance with a preset convention using a fine writing ballpoint pen. The numbering is to be done close to the edge of the filter on the non-sampling side with as small as possible lettering.

The balance is to be levelled by adjusting the levelling screws under the base of the balance whilst simultaneously observing the spirit level.

Post-sampling filters are to be carefully removed from the cassettes. A blunt object is to be inserted into the cassette from the backing pad side to lift both the backing pad and filter from the cassette. The filter is to be removed carefully with tweezers.

Post-sampling Sample filters are to be inspected for any signs of overloading, loose dust, evidence of water on the filter, uneven distribution of the dust on the filter or any evidence that the collection of the sample may have been interfered with.

Figure 7.3 Filters with uneven deposits

Figure 7.3 shows examples of filters with obviously uneven deposition of the sample on the filter. These particular examples were likely to have been caused by leaking cassettes.

The sampling filters and reference filters are to be acclimatised together for at least 24 hours, prior to weighing, under controlled environmental conditions whilst being protected to prevent settling of dust onto the filters.

Calibration

A certificate of calibration of the balance should be obtained at intervals not exceeding one year. The OEM of the balance should accredit the service provider calibrating the balance. The service provider should be in possession of a valid certificate of accreditation of compliance with ISO/IEC 17025 and preferably SANS 9000.

The calibration certificate should include the following:

The environmental conditions prevailing in the laboratory at the time of the calibration and a record indicating that the conditions had been stable, and within limits, for at least 30 minutes prior to the calibrating.

Calibration points at values below and above the mass range of the filters to be weighed as well as a number of points, evenly distributed, in between.

Care and maintenance of balance and equipment

The weighing laboratory is to be kept as clean and dust free as possible. Domestic vacuum cleaners may not be used, as the filter materials used in these are not of adequate quality and dust is consequently reintroduced into the weighing room atmosphere.

The balance cavity can be dusted using a good quality fine brush to remove loose dirt. A damp cotton cloth may be used to wipe the interior and exterior of the balance to remove dirt. This should only be done with the balance turned off.

The balance should never be moved unnecessarily and in the event that moving is unavoidable a thorough test should be done to ensure that the balance calibration has not been adversely affected. Ideally the balance should be re-calibrated after moving.

The tweezers are to be cleaned by wiping with an alcohol (laboratory grade) soaked cloth of good quality cotton and dried. The alcohol should be allowed to evaporate from the tweezers completely prior to use.

Sampling pumps are to be cleaned in accordance with the OEM prescriptions. A damp cloth and soft-soap should normally be adequate. Pumps should never be submerged in water.

Filter cassettes should be cleaned in water with soft soap to remove coarse dirt. Final cleaning can be done in an ultrasonic bath. It is essential that cassettes be cleaned thoroughly to prevent contamination of pre-sampling filters.

7.2.2 Measurement Procedure

7.2.2.1 The weighing procedure

The number of persons present in the weighing room during the weighing process is to be limited to two. Persons moving into and out of the room during weighing are to be prohibited as this could affect the environment in the room.

After performing the steps described in the paragraph “Preparation of Apparatus and sampling filters” the weighing procedure as described in the paragraph “laboratory analysis” should be followed.

Download the logged data from the data-logging environmental monitor and ensure that the conditions for the previous 24 hours had been maintained within the prescribed limits. Record the environmental conditions in the laboratory immediately prior to weighing.

Weigh the three reference filters together before weighing the sampling filter. Reference filters are weighed together and the result divided by the number of reference filters is the average weight of one reference filter.

Check that the temperature and humidity have not changed to outside the preset limits. Select a sample filter and weigh.

The weighing of the sampling filters should be done in batches of no more than 10 in the shortest possible time period.

Reweigh the reference filters. If the results of the first and second weighing of the reference filters differ from the first weighing of the reference filters by more than a preset tolerance (possibly 5%) then discard all the results obtained after the first weighing of the reference filters and restart.

7.2.2.2 Limitations and Precautions

The accuracy of the weighing process is limited by the accuracy of the balance, the control of the environment in the laboratory and the compliance with quality assurance procedures.

Quality assurance testing is essential to demonstrate to the laboratory staff and clients that the laboratory is functioning properly and to standard. As a method of quality control and in order to demonstrate accuracy and repeatability and also test the performance of the analyst the following is recommended: A sampling session is to be emulated by preparing a filter and reference filters as if sampling were to be done. Instead of sampling onto the filter, the sample mass is simulated by placing a calibrated standard mass of known weight on the filter. The weighing process if then followed as if sampling had been done on the filter. The end result of the process should then return the weight of the known standard. An investigation should be initiated if the deviation is more than a preset limit, for example 5%, and no further weighing is to be performed until the cause has been identified and resolved. This procedure can be performed once a week or as often as the technical manager of the laboratory requires. The procedure can also be used to test the proficiency of the laboratory technician.

Laboratory Analysis

The weighing of reference filters, sampling filters, pre and post sampling, ass well as standards masses are always to be done in the same way and as follows:

- Close all the balance doors to prevent drafts affecting the balance and tare the balance.
- Open the balance door and place a filter/standard on the O-ring on the balance pan.
- Close the balance door and start the countdown timer.
- Wait for the settling period to expire.
- Take the reading on the balance display immediately when the settling time has expired.
- Apply the balance calibration correction, temperature correction (if not done automatically by the balance) and buoyancy correction to the result.
- Open the balance door and remove the filter/standard from the balance pan.
- Place the filter/standard on an O-ring next to the balance pan inside the balance.
- Close the balance door and wait for the balance to return to zero.

- If the balance does not return to zero then discard all the weighting and inspect the balance pan for dust or any obstacle that may be affecting the reading, tare the balance, and reweigh. The balance should otherwise not be tarred between weightings.
- After the balance display has returned to zero, open the balance door and place the filter/ standard on the O-ring on the balance pan again for the next weighting.
- Repeat this process three times for each filter/standard.

Ensure that the minimum and maximum of the three consecutive weightings do not differ by more than 1% of the minimum. If this is found to be the case, discard the weightings and reweigh.

It is recommended that a spreadsheet be set up to be used for capturing all the weightings and to do the averaging as well as the corrections for calibration, temperature and boyancy automatically.

7.2.3 Calculation and Evaluation of Results

The purpose of weighing reference filters is to establish any change in the weight of the filters due to a change in moisture content of the filter caused by a change in humidity in the laboratory from the time of the pre-sampling weighing to the post-sampling weighing.

An increase in the average weight of one reference filter will indicate an increase in moisture content of the filter and an amount equal to the increase must therefore be subtracted from the weight of the sample of dust on the sampling filter. Conversely, an amount equal to the decrease in the average weight of one reference filter must be added to the weight of the dust sample.

The DME currently requires a risk monitoring management plan for exposure of employees of in excess of 10% of the OEL of airborne pollutants. The procedure for assessment of the occupational risk, of which weighing of gravimetric dust samples forms and integral part should be capable of accurately determining an exposure of 10% of the risk. As an example the OEL for silica exposure is currently 0.1 mg/m³. The accurate detection limit of 0.01 mg/ m³ must therefore be achievable by the laboratory for the purpose of occupational risk assessment on mines.

For research and for determination of the efficacy of dust filtration apparatus, accurate determination of the weight of a smaller dust sample should be possible. For these purposes the infrastructure and procedure in the laboratory should be such that the accurate determination of the weight of a dust sample as low as 0.0001 mg should be possible.

After each weighing the result is to be corrected by applying the calibration correction of the balance, buoyancy correction. Temperature correction should also be done if the balance does not do it automatically.

The following equation can be used to calculate the weight of the dust sample.

Insert equation here

Reference to determination of accuracy of weighing

7.3 Bibliography

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4. Health and Safety Executive (HSE), Methods for determination of Hazardous Substances. General methods for sampling and gravimetric analysis of respirable and inhalable dust, February 2000

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6. U.S. Department of Labour method PV2121, Gravimetric determination

7. Department of Minerals and Energy of South Africa guidelines for gravimetric sampling, GME 16/2/3/2/3

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7.4 Acknowledgements

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8. Gases and Vapours

Author: David W. Stanton, Consultant.

8.1 Purpose

To measure the concentrations of gases and vapours in workplace air and in particular to assess compliance with occupational exposure limits.

8.2 Nature of Gases and Vapours

Gases are generally understood to be non-condensible at room temperature and under ordinary conditions exist in the gaseous state even when present at high concentrations. Vapours are derived from volatile liquids and may condense at high concentrations, and an aerosol (particulate) form may coexist with a vapour. However unless an aerosol is produced for example as in a spray operation, atmospheric concentrations of vapour pollutants rarely reach saturation conditions except in enclosed spaces. With these exceptions, gases and vapours can be considered similar, and the same devices are used to collect them.

Vapour density is defined as the relative weight of a gas or vapour compared to air, which has an arbitrary value of one. At ordinary temperatures gases and vapours will both diffuse rapidly and form true solutions in air. With inadequate mixing if a gas is released which has a vapour density of less than one it will generally rise in air. If the vapour density is greater than one, the gas or vapour released will generally sink in air and be found in low lying areas.

Typical gases lighter than air include:

Acetylene, Ammonia, Carbon Monoxide, Ethylene, Hydrogen, Hydrogen Cyanide and Methane.

Typical gases heavier than air include:

Argon, Butane, Carbon Dioxide, Chlorine, Ethane, Hexane, Hydrogen Chloride, Gasoline, Hydrogen Sulphide, Methyl Ethyl Ketone, Methyl Mercaptan, Nitrogen Dioxide, Nitrous Oxide, Oxygen, Propane and Sulfur Dioxide.

8.3 Occupational Exposure Limits

Occupational Exposure Limits (OELS) for gases and vapours are prescribed in the Department of Minerals and Energy (DME) Regulations under the MHSA and in the Department of Labour (DoL) Regulations for Hazardous Chemical Substances (1995) under the Occupational Health and Safety Act (No. 85 of 1993). Eight-hour time Weighted Average (TWA) Limits, Short Term Exposure Limits (STEL) and Ceiling Limits are prescribed.

“Occupational exposure limit” (OEL) means the time weighted average concentration for a 8 hour work day and a 40 hour work week to which nearly all workers may be repeatedly exposed without adverse health effects.

"Occupational exposure limit - Ceiling limit" (OEL - C) means an instantaneous value, which must never be exceeded during any part of the working exposure.

"Occupational exposure limit – Short term exposure limit" (OEL-STEL) means a 15-minute TWA exposure that should not be exceeded at any time during a workday even if the 8-hour TWA is within the OEL-TWA. Exposures above the OEL-TWA up to the STEL should not be longer than 15 minutes and should not occur more than four times per day. There should be at least 60 minutes between successive exposures in this range. An averaging period other than 15 minutes may be recommended when observed biological effects warrant this. For those substances for which no OEL-STEL have been specified a figure of three times the occupational exposure limit is to be used when controlling short-term excursions in exposure.

Examples of the the above three categories of OELs are given in Figure 8.1. Under the DME Regulations the action level for measurements of gases and vapours is ≥ 50% of the OEL. The main gases found underground and in surface works are listed in Table 8.1.

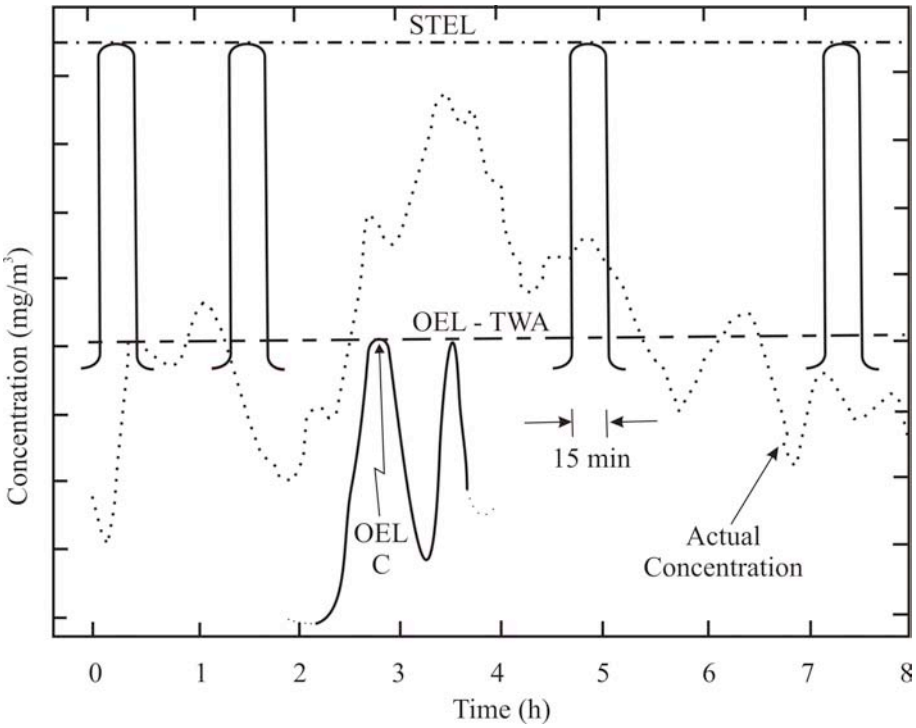

Figure 8.1 The Three Categories of OELs: TWA, STEL and C

8.4 Testing Under Specific Conditions

8.4.1 Unventilated Places

Unventilated places should always be treated with the greatest care as the composition of the atmosphere may change over a short distance from one which which is comparatively safe to one totally unsafe, without there being any obvious indication of such a change. In an unventilated place the most likely hazard is a deficiency of oxygen, but such places may also contain dangerous accumulations of methane, nitrous fumes, carbon monoxide, carbon dioxide or hydrogen sulphide.

Table 8.1 Main Gases Found Underground in Mines and in Surface Works

Gas	Chemical composition	Character	SG	Sources and occurence	OEL ppm	Methods of Detection
Oxygen	O_2	Necessary to life. Deficiency caused by oxidation of timber and pyrites, fires and explosions, causes asphyxia.	1,1	Constituents of air.	Not less than 19 %	NMAM 6601 Portable direct-reading oxygen meter.
Carbon dioxide	CO_2	Asphyxiant. High percentages are usually associated with oxygen deficiency. Causes headaches.	1,5	Slow oxidation of organic matter, breathing, fires and explosions, operation of diesel locos. Occurs in poorly ventilated working places.	5000 C 30000	NMAM 6603 Gas Sampling Bag. Detector tubes.
Carbon monoxide	CO	Poisonous. Explosive 12,5% to 74,2%	0,97	Fires, explosions, blasting operations, exhaust gases from diesel locomotives.	30 C 100	NMAM 6604 Portable Direct Reading CO Monitor. Detector tubes.
Oxides of nitrogen (nitrous fumes)	NO NO_2 N_2O_4 N_2O_3	Poisonous.	1,04 1,6 3,2 1,3	Blasting operations, exhaust gases from diesel locos, arc welding, burning of explosives.	30 C 100	NMAM 6014 Sorbent Tubes (NO and NO_2) Detector tubes.
Methane	CH_4	Non-toxic. Explosive 5% to 15%. High concentrations can be associated with an oxygen deficiency	0,55	Water fissures, dykes and faults, "blowers" and coal strata.	C 1,4 %	Methanometers.
Hydrogen sulphide	H_2S	Poisonous. Explosive 4,0% to 44,0%.	1,2	Stagnant water, water fissures, faults and dykes. (Often associated with methane)	10 STEL 15	Direct reading H_2S Monitor. NMAM 6013 Filter plus solid sorbent tube. Detector tubes.
Chlorine	Cl	Poisonous. Causes intense irritation of eyes, nose and throat.	2,5	Water purification plants.	0,5 STEL 1	NMAM 6011 Prefilter + filter Detector tubes.
Hydrogen	H_2	Non-toxic. Explosive 4% to 75%. High concentrations can be associated with an oxygen deficiency.	0,07	Battery charging stations. Sometimes associated with methane.	C 1,4 %	Laboratory analysis. Detector tubes.

Table 8.1 Main Gases Found Underground in Mines and in Surface Works (Continued)

Gas	Chemical composition	Character	SG	Sources and occurence	OEL ppm	Methods of Detection
Sulphur dioxide	SO_2	Poisonous irritant. High concentrations poisonous. Burns throat, eyes, nose and lungs.	2,22	Smelting operations.	2 STEL 5	NMAM 6004 Filter + treated filter. Detector tubes.
Hydrogen cyanide (Also known as prussic acid gas)	HCN	Poisonous. Can be absorbed through skin. Explosive 5,6 - 40,0%	0,94	Gold recovery using cyanide process. Burning of plastics.	C 10	NMAM 6010 Solid sorbent tube. NMAM 7904 Filter plus bubbler (aerosol and gas) MDHS 56/2
Ammonia	NH_3	Poisonous irritant. Burns eyes, nose, throat and lungs.	0,59	Explosives based on ammonia, ammonia used as refrigerant (leakage), additive to refining process.	25 STEL 35	NMAM 6015 Solid sorbent tube. Detector tubes.
Arsine	AsH_3	Colourless, disagreeable garlic odour, highly poisonous. (250 ppm is instantly lethal) 25 ppm - ½ hour.	2,71	Arsenic in acid solutions used in refining processes (platinum). Byproduct from chemical processes	0,05	NMAM 6001 Solid sorbent tube Detector tubes
Hydrogen chloride	HCl	Poisonous, irritant, eyes, nose, throat and skin. Severe exposures result in pulmonary oedema	1,27	Burning of PVC products. Ignition of platinum salts used in refining processes.	C 5	NMAM 7903 Solid sorbent tube. Detector tubes.
Sulphuric acid mist	H_2SO_4	Poisonous irritant, eyes, nose, throat and skin. Colourless oily liquid.	-	Chemical processes using sulphuric acid. Pickling processes.	1 mg/m^3	NMAM 7903 Solid sorbent tube. Detector tubes.
Mercury vapour	Hg	Poisonous. Can be absorbed through skin.	-	Gold smelting.	0,025 mg/m^3	NMAM 6009 Solid sorbent tube MDHS 16/2. Detector tubes.

8.5 Air Sampling Procedures

The diversity of gases and vapours that may be found in workplace air is extensive and there is a wide diversity of air sampling equipment available. Sampling and analysis can be performed together in a single instrument (direct reading instrument), which provides a direct measurement of the gas or vapour concentration present in the workplace air. Direct reading instruments can be used for personal or area monitoring, leak detection and for short-term or long-term sampling.

Gases and vapours can also be collected from known volumes of air for subsequent analysis. There are two basic methods for collecting gaseous samples. In one, called grab sampling, an actual sample of air is collected over a short time period in a flask, bottle, bag or other suitable container for subsequent analysis. In the other, called continuous or integrated sampling, gases or vapours are removed from the air over a measured time-period and concentrated by passage through a solid or liquid sorbent for subsequent laboratory analysis. The correct choice of sampling and analytical method is very important, as this will affect the type and quality of information obtained.

8.6 Selection of Sampling and Analytical Method

The first step in the selection of a sampling device and analytical procedure is to search the available literature. Primary sources are the specific methods recommended by the US National Institute for Occupational Safety and Health (NIOSH) in their Manual of Analytical Methods (NMAM) and the U.K. Health and Safety Executive (HSE) in their Methods for the Determination of Hazardous Substances (MDHS).

An Air Sampling Guide is provided by SKC in their annual “Comprehensive Catalog & Air Sampling Guide” and Air Sampling Guide Databases are maintained on their website at:

http://www.skcinc.com

Generally speaking, non-reactive and non-sorbing gaseous substances may be collected as grab samples. Water-soluble gases and vapours, and those that react rapidly with reagent solutions, can be collected in simple gas washing bottles. Volatile and less soluble gaseous substances and those that react slowly with a reagent require a longer liquid contact time. For such substances, more elaborate sampling devices may be required such as gas washing bottles of the spiral type or fritted bubblers. Insoluble and non-reactive gases and vapours are collected by sorption onto activated charcoal, silica gel, or other suitable sorbent. Frequently for a given contaminant, there may be a choice of sampling equipment.

8.7 Direct Reading Instruments

Direct-reading instruments provide real-time quantification of airborne contaminants; the air sample is analysed within the equipment and does not require off-site laboratory analysis. Concentration is read directly from a meter, display, strip chart recorder and data logger, or from a colour change. Instruments vary in cost, complexity, reliability, size, sensitivity and specificity. They include simple devices, such as colorimetric tubes, that use a colour change

to indicate concentration; dedicated instruments that are specific for a chemical, such as carbon monoxide indicators, combustible gas indicators (explosimeters) and mercury vapour meters; and survey instruments, such as organic vapour analysers used to measure classes of compounds and infrared spectrometers that are sensitive and specific for a wide range of compounds. Portable multi-gas detectors are commonly available for confined space or personal monitoring applications to simultaneous measure the concentration of mixtures of gases such as hydrogen sulphide, carbon monoxide, oxygen and the lower explosive level (LEL). Battery powered gas chromatographs are available that with appropriate detectors are specific and sensitive, and can quantify airborne contaminants at very low concentrations.

Direct-reading instruments use a variety of physical and chemical methods to analyse gases and vapours, including conductivity, ionization, potentiometry, photometry, radioactive tracers and combustion. They may include an audible alarm for warning of high concentrations of gases or vapours. Initial selection of the instrument is normally made by which gases/vapours are to be detected, whether the monitor is intended for portable use, as a personal monitor or as a fixed system and whether it has to be intrinsically safe for use in potentially explosive atmospheres.

Small direct-reading personal monitors are available for a few common gases (carbon monoxide, chlorine, hydrogen, hydrogen chloride, hydrogen cyanide, hydrogen sulphide, hydrazine, methane (LEL), nitrogen dioxide, oxygen, phosgene and sulphur dioxide). They can provide detailed information on the contaminant concentrations during the measurement period and can provide a direct readout of time-weighted-average concentration.

8.7.1 Colorimetric Detector Tubes

Colorimetric tubes (detector tubes) are simple to use, cheap and available for a wide variety of gases and vapours. The colorimetric detector tube usually consists of a glass tube sealed at both ends, and filled with porous granules of an inert material impregnated with a chemical compound which changes colour when it reacts with the contaminant it is designed to detect and measure. For measurement, both tips of a tube are broken off and the tube is inserted into the appropriate sampling pump. The pump can be either manually operated (e.g. hand held bellows pump) or electrically powered. The correct volume of air is drawn through the tube, which results in discolouration due to the presence of the nominated contaminant. The length of the colour change is proportional to the contaminant concentration, which is interpreted from the scale on the tube.

This type of device is a quick and convenient technique for establishing on the spot concentrations; however, it does have certain limitations including the following: -

- Cross-sensitivity with other contaminants;
- Influence of pressure, temperature and humidity;
- Gas or vapour concentrations being measured may not be within the measuring range of the detector tube.
- Limited shelf life.

When selecting a detector tube, an estimate of the anticipated concentration may be needed to select the correct concentration range and the volume of air (number of pump strokes) required. It is important to carefully read the instructions applicable to each tube to determine

if any special conditions may apply (e.g. NOx gas detector tubes require several desorption strokes after sampling).

These devices can have an accuracy of up to 40%. There are tubes for measurement of most gases and vapours found on mines. Sampling takes from 20 seconds up to 8 hours.

There are two main types of hand-operated pumps in common use for short-term sampling:

- Bellows pumps
- Piston pumps

The required volume of air is drawn through the detector tube by operating the hand pump one or more times. For most pumps used for short-term sampling, the volume of air drawn through the detector tube per stroke is approximately 100 ml.

Some colorimetric tubes have been adapted for long duration sampling, and are used with battery-powered pumps that can run for at least eight hours. The colour change produced represents a time-weighted-average concentration.

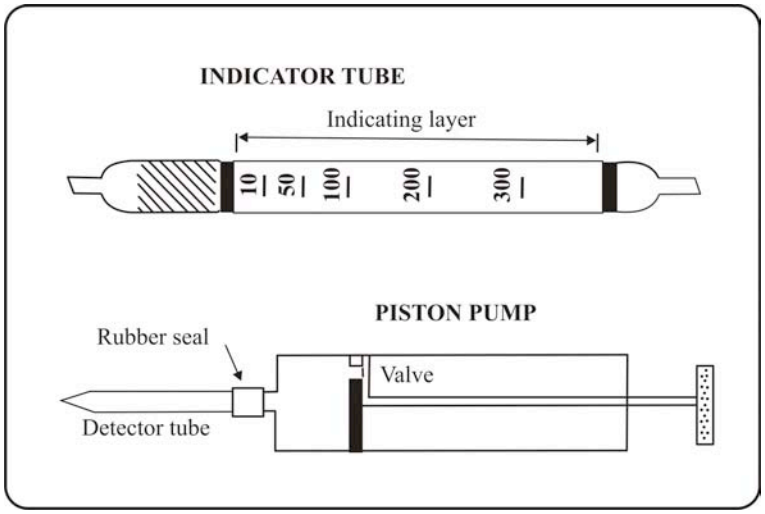

Figure 8.2 Indicator Tube and Piston Pump[1]

8.8 Capture of Gases and Vapours for Analysis

8.8.1 Grab Samplers

Grab sampling involves the collection of air samples in a container by blowing or suction over a period of a few seconds up to a minute or two. In some circumstances samples can be collected over longer periods by filling the container slowly (integrated sampling). The most common grab sampling methods are described below:

8.8.2 Evacuated Flasks

A gas-sampling pipette or flask fitted with glass-stoppered cocks on each end (Figure 8.3) is suitable for partial evacuation, and also for displacement sampling. Evacuation is achieved by drawing a vacuum through one stem while the other is kept closed, and then closing the open

stem before the vacuum is turned off. Similar containers are also available in plastic and metal, and are to be preferred to glass containers as there is a potential safety hazard with the latter. Except for heavy walled containers no attempt is made to reduce the pressure to zero. However, the degree of evacuation must be known and is determined from the manometer pressure or vacuum gauge. This information, along with the barometric pressure and temperature at the sampling site, is used to calculate the actual volume of air or gas collected.

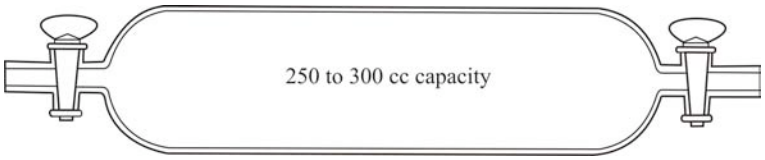

Figure 8.3 Evacuated Flask[2]

8.8.3 Gas or Liquid Displacement

Any ordinary sealable container can be used as a displacement sampler. Original air is replaced by test air by pumping or aspirating through the container with a double acting rubber bulb aspirator or a battery or electrically operated vacuum pump. The volume of air swept out should be 10-15 times the container volume to achieve a sample collection efficiency of more than 99%.

An alternative method for sampling with these containers is to fill them with water and allow the water to drain out slowly in the test area. The liquid becomes replaced by the test air. Obviously, this procedure is not suitable for collecting water-soluble gases.

For soluble and reactive gases, a liquid sorbent or reagent solution may be introduced into the gas displacement sampler. The usual procedure is to fill the sampler with test air and then to add the sorbent. The container is then rotated to ensure an even distribution of the reagent on the inside surface of the sampler.

8.8.4 Flexible Plastic Containers

Plastic bags can also be used as grab samplers (and also for integrated sampling). Bags are commercially available in sizes up to 250 litres, but 5 to 15 litre bags are typically used. The bags are constructed from a number of plastic materials including polyester, polyvinylidene chloride, Teflon, or fluorocarbons. Plastic bags have the advantage of being light, non-breakable, and simple to use. But they should be used with caution since storage stabilities for gases; memory effects from previous samples, permeability, precision and accuracy of sampling systems vary considerably.

Each bag should be evaluated for the specific gas or gas mixture for which it will be used. In addition, all bags should be leak tested, flushed with clean air and conditioned before use.

8.9 Continuous or Integrated Samplers

Integrated sampling equipment consists of a pump connected to a collection device such as a liquid sorbent (e.g. bubbler), impregnated filter, plastic sampling bag or sorbent tube. Sampling flow rates for gases and vapours are typically:

For Liquid Bubblers: 100 – 500 ml/minute
Sorbent Tubes: 20 – 200 ml/minute

8.9.1 Liquid Sorbents (Bubblers)

Four basic types of sampler using liquid sorbents for the collection of gases and vapours are: simple gas washing bottles, spiral and helical sorbers, fritted bubblers, and glass bead columns. The function of the different types is to provide an appropriate level of contact between the contaminant in the air and the liquid sorbent.

Substances that can be sampled with liquid sorbets include:

- Ammonia
- Formaldehyde
- isocyanides,
- Nitrogen dioxide
- Ozone
- Sulphur dioxide etc

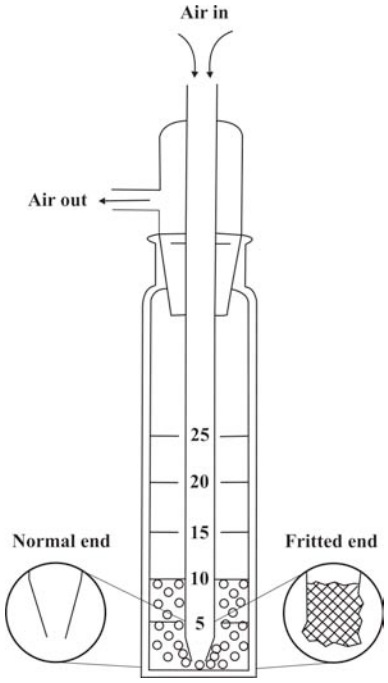

Figure 8.4 Bubbler (Impinger)[1]

(a) Equipment Required

- Air sampling pump capable of sampling at the recommended flow rate with the sampling medium in line,
- Airflow calibrator such as an Electronic Calibrator or a Film Flow Meter.
- Bubbler as specified in the method.
- Sorbent trap such as: a Trap for Midget Impinger; or In-Line Trap or any other appropriate trap.
- Bubbler holder for attaching to the pump or holster for attaching to the worker such as: Single Impinger Holder, or Double Impinger Holder, or Impinger Holster, or any other appropriate holder or holster.

(b) Preparing the Bubbler

Fill the bubbler with the recommended volume of collecting liquid for sampling as specified in the analytical method.

To protect the pump from splash over or spillage of the bubbler liquid, it is important to install a solution trap between the bubbler and the pump. Solid sorbent may be added to the trap if a volatile liquid is used in the bubbler; sorbent traps will protect the pump from both organic and inorganic vapours.

(c) Setting Up the Sampling Train

Some bubbler holders can be attached to the pump (Figure 8.6), alternatively, the bubbler can be placed in a lightweight holster and clipped near the breathing zone (Figure 8.5). With flexible tubing, connect the outlet (side arm) of the bubbler to the inlet (top) of the trap and the outlet (side arm) of the trap to the intake of the pump.

(d) Calibrating the Flow Rate

With flexible tubing, connect the bubbler inlet (top) to the external flow meter (Figure 8.6) and set the flow rate specified in the analytical method for the chemical being sampled. Typically, bubbler samples are taken at 1 litre per minute. Refer to pump and flow meter operating instructions for calibrating the flow rate. When the flow rate has been calibrated and verified, remove the bubbler used to calibrate the flow.

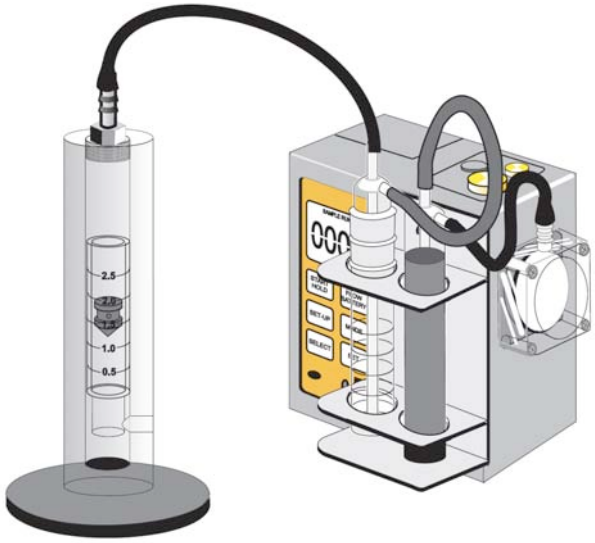

Figure 8.6 Calibrating Bubbler Flow Rate

Figure 8.5 Personal Sampling With Bubbler

(e) Sampling

When ready to start sampling, prepare a new bubbler with the recommended volume of collecting liquid. Place the bubbler and trap in a holster and attach it near the worker's breathing zone. Attach the pump to the worker's belt. Care should be taken if the bubbler is mounted on a worker; the glass and, in some cases, the liquid can be a hazard.

Turn the pump on and note the start time and any other pertinent sampling information.

(f) After Sampling

At the end of the sampling period, turn the pump off and note the stop time. Quantitatively transfer the sample solution into a glass vial, ensuring that all of the solution is out of the stem of the bubbler.

Using a flow meter, check the flow rate with the representative bubbler in line to verify that the flow has not changed by more than 5%.

Along with the sample bubbler vials, submit blank samples of the bubbler solution. Blank samples should be subjected to exactly the same handling as the sample except that no air is drawn through them.

Pack the samples, blanks and all pertinent information securely for transportation to the laboratory for analysis.

(g) Cleaning the bubblers

Wash bubblers thoroughly before re-use. Some sampling methodologies require a special preparation such as an acid wash before use.

8.10 Impregnated Filters

Filters impregnated with a chemical, which captures or adsorbs the vapour, can in some cases replace cumbersome bubbler methods. This technique is similar to that used for dust sampling except the filter is chemically treated and flow rates are linked to adsorption characteristics rather than particle size.

One example is for sampling isocyanates with a preloaded 3-piece cassette. Stage one contains an untreated PTFE (Teflon) filter to collect the aerosol phase and stage two holds a glass fibre filter impregnated with 9-(N-methylaminomethyl) anthracene (MAMA) for the vapour phase of isocyanates. Aerosols are trapped on the PTFE filter while gases pass through to the next filter. Vapours are trapped on the fibre glass filter impregnated with MAMA. A chemical reaction occurs on this filter resulting in the formation of a highly detectable urea derivative.

8.11 Plastic Sampling Bags

Plastic bags (as used for grab sampling) can also be used for collecting integrated air samples. Samples can be collected for 8 hours, at specific times during the day, or over a period of several days. The bags may be mounted on workers as personal samplers or may be located in designated areas unattended.

The sampling pump used for bag sampling must be both a suction and pressure sampler, i.e. the sampler must be able to pull air as well as push air into the

Figure 8.7 Bag Sampler[3]

sampling bag. If taking a grab sample, the flow rate is not important, as long as the bag is not overfilled. Never fill a bag more than 80% of its maximum volume. If taking a bag sample according to a specific analytical method, which specifies a flow rate, it will be necessary to set the flow rate using a flow meter.

Sample bags sent for analysis should be packed loosely and padded to minimise the danger of being punctured during transportation. Bag samples should not be transported by air unless the cargo cabin is pressurised as a significant decrease in barometric pressure may cause sample bags to burst.

8.12 Solid Sorbents

8.12.1 Charcoal

Activated charcoal is an excellent sorbent for most organic vapours. The relative ease with which organic vapours can be extracted from activated charcoal by carbon disulphide and be analysed subsequently by gas chromatography are reasons for its popularity. Air sampling procedures using activated charcoal are widely used and form the basis of many of the official analytical methods for organic materials recommended by HSE and NIOSH.

The charcoal tube method is generally adequate for hydrocarbons, chlorinated hydrocarbons, esters, ethers, alcohols and glycol ethers that are commonly used as industrial solvents. Compounds with low vapour pressure, and reactive compounds such as amines, phenols, nitrocompounds, aldehydes and anhydrides generally have low desorption efficiencies from charcoal and require alternative sorbents such as silica gel, porous polymers or reagent systems for collection. Inorganic compounds such as ammonia, ozone, nitrogen dioxide, chlorine, hydrogen sulphide and sulphur dioxide react chemically with activated charcoal and cannot be collected for analysis by this method.

Several types of charcoal are commercially available. The products most frequently used for air sampling are derived from coconut shells. NIOSH recommends 20/40-mesh coconut shell charcoal. Sampling tubes for activated charcoal vary in shape and size. HSE and NIOSH recommend tubes measuring 7 cm long with 6 mm o.d. The tubes contain two sections of 20/40-mesh activated charcoal separated by a 2 mm portion of urethane foam. The front end contains 100 mg of charcoal, the back up section 50 mg. These tubes are commercially available from many chemical suppliers, and are usually known as ‘NIOSH’ tubes (Figure 8.8).

Larger tubes are also available that contain 600 mg of charcoal, 400 mg in the front section and 200 mg in the back section. So-called “Jumbo” tubes contain 800 and 200 mg. These tubes are used for the more volatile organic compounds such as methylene chloride that have limited capacity on 100 mg tubes. Other sizes of tube can be ordered or prepared in the laboratory.

Sampling tubes need not always be made of glass. Many in use are constructed of stainless steel.

The volume of air that can be collected without loss of contaminant depends on the sampling rate, sampling time, volatility of the contaminant, air temperature and humidity, and the

concentration of contaminant in the workplace air. It is always best to refer to an established procedure for proper sampling rates and air sample volumes.

When conducting field sampling the ends of the charcoal tube are broken, and the tube placed in a protective holder. Tubing is connected to the back-up end of the charcoal tube (via the holder), and air is drawn through the sampling train with a calibrated suction pump. A personal or area sample may be collected. The duration of sampling may be several minutes or up to 7-8 hours depending on tube capacity, the work pattern and the information desired. Afterwards, when sampling is completed, plastic caps or masking tape (but not rubber caps) are placed on the ends of the tube.

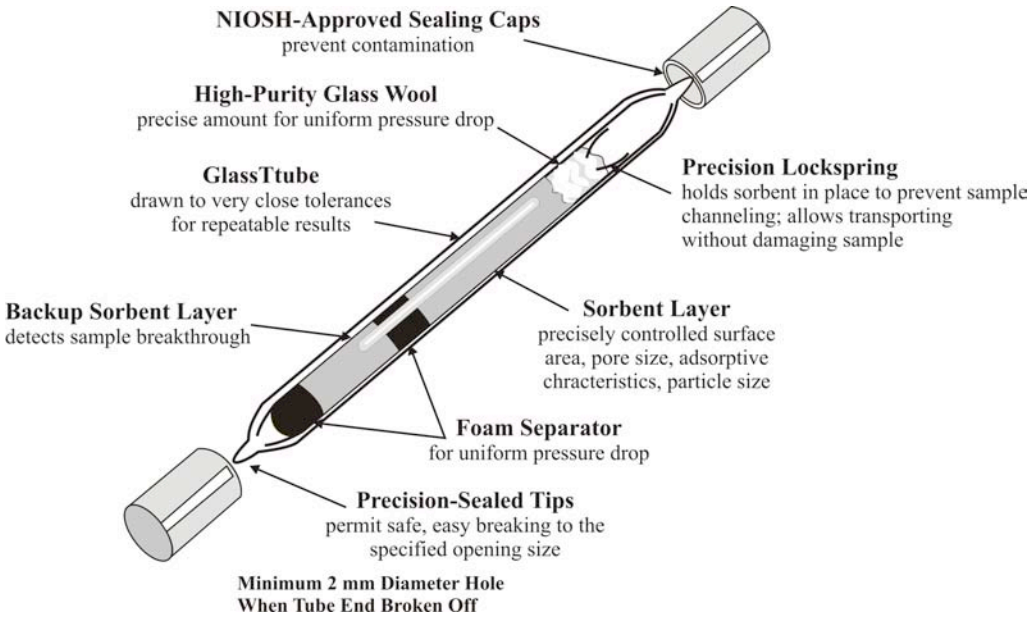

Figure 8.8 Example of Charcoal Tube[3]

8.12.2 Thermal Desorption

Because of the high toxicity and flammability of carbon disulphide and the labour intensive nature of the solvent desorption procedure, a useful alternative is to desorb the collected analyte thermally. Except in a few cases, this is not practical with charcoal as sorbent, as the temperature needed for desorption would result in some decomposition of the analytes. Carbon molecular sieves, or more frequently, porous polymer sorbents, in particular Tenax, porapak Q and chromosorb 106, are used instead.

The thermal desorption procedure typically uses larger tubes than the NIOSH method; usually 200-500 mg of sorbent are used, depending on type. Desorption can be made fully automatic and analysis is usually carried out by gas chromatography.

8.12.3 Sampling Train For Sorbent Sampling Tubes

(a) Equipment Required

1. An air sampling pump capable of sampling at the recommended flow rate with the sampling medium in line.
2. An air flow calibrator such as an Electronic Calibrator or a Film Flowmeter.
3. The sorbent sample tubes as specified in the method.
4. The appropriate tube holder or protective tube cover.

Figure 8.8 shows a sampling train with a constant flow pump with an adjustable low flow holder for sampling at flow rates below 750 ml/min. If using a low flow pump, it is not necessary to use a low flow holder. To determine the correct flow rate for the chemical being sampled, refer to the appropriate analytical method. Please see the operating instructions for your pump to ensure that it is capable of sampling at the correct flow rate.

(b) Preparing the Sorbent Tube

Use a tube breaker to break both ends of a sorbent tube to provide an opening at least one-half the internal diameter. This tube will be used for calibrating the flow and not for collecting the sample.

(c) Setting Up the Sampling Train With Low Flow Holder

If using a constant flow pump with different flow modes, ensure that it is in the low flow mode. With flexible tubing, connect the low flow holder to the pump intake. Place the sorbent tube into the rubber sleeve of the low flow holder. The printed arrow on the sorbent tube shows the direction of the air flow and should point toward the pump. If there is no arrow printed on the tube, the sorbent sections should be closer to the pump.

(d) Without Low Flow Holder

Using a low flow pump, connect flexible tubing from the pump intake to the tube holder. Place the sorbent tube into the rubber sleeve of the tube holder. The printed arrow on the sorbent tube shows the direction of the air flow and should point toward the pump. If there is no arrow printed on the tube, the sorbent sections should be closer to the pump.

(e) Calibrating the Flow Rate

To measure the flow rate, connect the open end of the sorbent tube to an external flow meter. Calibrate the flow rate specified in the analytical method for the chemical being sampled. Please see your pump and flow meter operating instructions for calibrating the flow rate. When the flow rate has been calibrated and verified, remove the sorbent tube used to calibrate the flow.

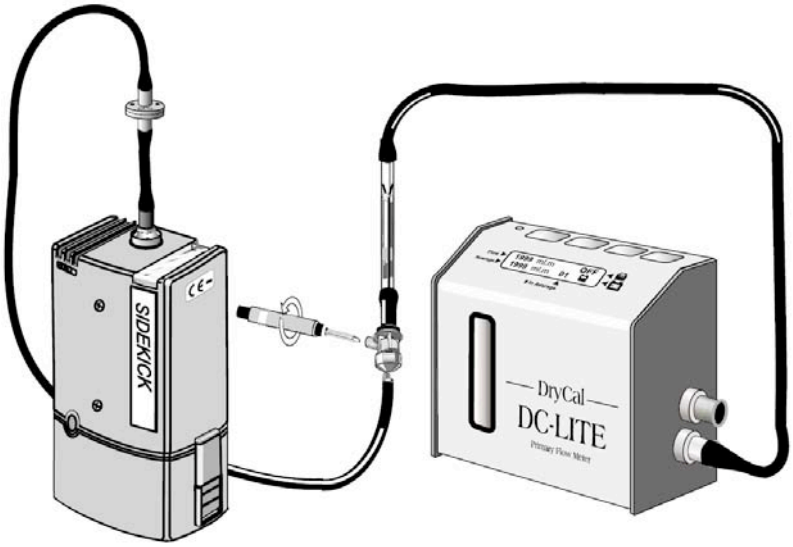

Figure 8.9 Sampling Train with Pump and Low Flow Holder With Tube Connected to an Electronic Flow Meter

Note: Figure 8.9 illustrates a DC-Lite DryCal flow calibrator which is based on near-frictionless piston technology and primary photo-optic sensor design to obtain volumetric flow readings quickly and accurately. DryCal technology provides highly accurate flow calibration without the inconvenience of soap film solutions and the design makes it immune to flow source pulsation without the need for in-line dampers. The SKC DC-Lite was discontinued at the end of 2006 and replaced with the Defender series of primary flow calibrators which provide further improvements including increased durability and portability, easier operation and a simpler range of flow rates. The Defender 520 series also displays ambient temperature and pressure.

(f) Sampling

When ready to start sampling, break open both ends of a new sorbent tube as you did with the sorbent tube used for calibrating the flow. Insert the sorbent tube into the rubber sleeve of the low flow holder or tube holder with the sorbent sections closer to the pump. Then place the protective cover over the sorbent tube. Attach the tube holder clip to the worker's collar and the pump to the worker's belt (Figure 8.10). The sorbent tube should be placed in a vertical position during sampling. Turn the pump on, and note the start time and any other pertinent information.

(g) After Sampling

At the end of the sampling period, turn the pump off and note the stop time. Remove the sorbent tube, seal the ends of the tube with the caps supplied and record pertinent sample information.

Using a flow meter, check the flow rate with a representative sorbent tube in line to verify that the flow has not changed by more than 5%.

Along with the sample tubes, submit field blanks from the same lot number as the sample tubes. Field blanks should be subjected to exactly the same handling as the samples (break, seal and transport) except that no air is drawn through them.

Pack the sample sorbent tubes, field blanks and all pertinent information securely for transportation to the laboratory for analysis.

Figure 8.10 Worker Wearing a Pump Connected to a Tube Holder

8.13 Diffusive Samplers

A diffusive sampler (or 'passive') sampler is a device which is capable of taking samples of gas or vapour pollutants from the atmosphere at a rate controlled by a physical process such as diffusion through a static air layer or permeation through a membrane, but which does not involve the active movement of the air through the sample.

Diffusive samplers can either two-stage devices where the sample analysis is completely separate from the collection stage, or they can be direct reading – essentially long-term detector tubes.

There are two categories of diffusive samplers:

- Badge
- Tube

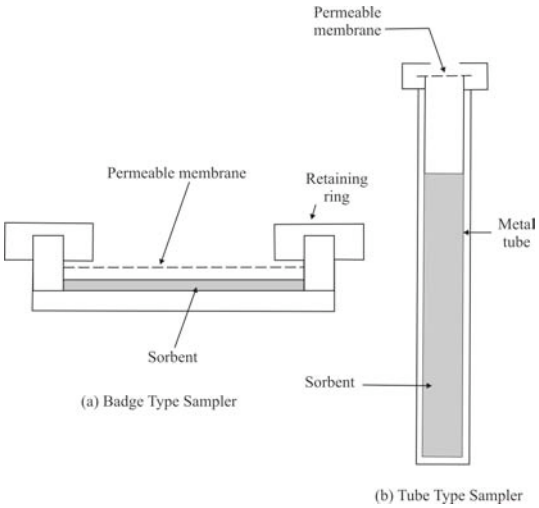

Figure 8.11 Diffusive Samplers[2]

Diffusive samplers are easy to use. They are simply placed where the sample is to be taken and the protective cover removed. After sampling, the cover is replaced to protect the sample. In the laboratory, the sample is analysed usually by gas chromatography.

Diffusive samplers have considerable advantages over conventional techniques. They are easy to use, relatively cheap, require little supervision and are more acceptable to workers as well as being intrinsically safe. There are however some problems. If there is no air movement across the face of the sampler, a stagnant region may develop and the sampler will not be in intimate contact with the atmosphere to be measured. This is more of a problem with the badge type of samplers and they are not recommended for static sampling. The normal movement of people usually ensures sufficient movement and both badge and tube types are acceptable for personal monitoring. Because it takes a finite time at the beginning of sampling for the vapours to reach the adsorption medium, there is a tendency for the sampler to underestimate the true concentration. This is likely to be important when short-term samples are taken. The water vapour in high humidity situations interferes with some adsorbents. If charcoal is used, the effect is greater with diffusive samplers than conventional charcoal tubes as they contain less charcoal. The use of porous polymers such as Tenax as an adsorbent overcomes this problem.

8.13.1 Application

Diffusive samplers are presently used for two main reasons:

1. For screening purposes where accuracy is of secondary importance, to pinpoint areas where problems may exist.

2. In large-scale monitoring surveys where a specific device has been validated for the particular gas or vapour and circumstances.

The general view is that, provided good quality validation data has been established for the substance to be monitored and the conditions in which it is to be used, a diffusive sampler provides acceptable results.

8.14 Analysis of Gases and Vapours

There are many available methods for analysing laboratory samples for contaminants. Some of the more commonly used analytical methods for quantifying gases and vapours in air samples include gas chromatography, colorimetry, ultraviolet (UV)/visible spectrometry, volumetric analysis, infra-red, mass spectrometry and polarography. Brief descriptions of the various analytical methods are given below.

8.14.1 Gas Chromatography

Gas chromatography (GC) is the most common analytical method used for the accurate analysis of volatile organic compounds such as solvents. The general principle on which it operates is based on the separation of molecules as they move at different rates through an adsorbing media. A sample containing different compounds is injected into a tube packed with an adsorbent material through which a stream of gas is passing. The tube is usually referred to as a column. The molecules of the entire compound in the sample are carried

down the column by the carrier gas but each type of molecule will travel at a different speed through the packing. Therefore, molecules of each compound in the sample will begin to separate and eventually the compounds in the sample will separate into narrow bands of individual compounds.

When a detector is placed at the end of the tube it will respond to each band of compound molecules as it passes out of the column. By passing known substances through the column the analyst can determine how long it takes each to pass through the detector and from this can identify the substances in the sample. This is a very simplified description of the principles of the GC and there are many variations of packings and detectors available, various temperature cycles can be selected and many methods of quantifying the traces obtained. Samples may be injected automatically and results interpreted with computer assistance.

Various types of sensors are available to detect the sample at the end of the column but the most popular detector is the flame ionisation detector (FID)

8.14.2 Colorimetry

The variation in colour of a liquid with the concentration of compounds in the liquid forms the basis of colorimetric analysis and this has widespread use in the analysis of gases and vapours. The colour is either due to the formation of a coloured compound when a reagent is added, or it may be inherent in the sample collected.

Colours are a result of the absorption by materials of light in different parts of the visible spectrum. Colorimetry thus involves the absorption of light. For this two things are needed. Firstly, a light source, which is often visible light, although for more sophisticated analysis ultra-violet light is used. Secondly, a means of measuring colour intensity (or selective light absorption) is required. A photoelectric cell is usually used to measure the light intensity.

8.14.3 Ultraviolet/Visible Spectrometry

This instrument represents the most accurate form of colorimetric analysis. The name spectro-photometer reflects the two parts of the instrument:

The spectrometer provides a narrow band of light within the UV-visible range. The physical law relating concentration and absorption really works for monochromatic light (e.g. light of a single wavelength) hence the narrower the bands of light the better. The photometer measures the intensity of the light after it passes through the sample.

The source of visible light is a tungsten filament lamp. A prism or grating is positioned in the beam of the light to provide a narrow band of light at the wavelength the sample absorbs most, or which is least likely to be absorbed by other substances.

The sample or measuring container is a narrow cell into which a small portion of the sample is poured and the photometer measures the intensity of light, which passed through the sample cell.

The sample is usually collected in a bubbler and the liquid transferred directly to the measuring cell. Simplicity is a feature of the analysis and this is reflected in its relatively low cost but the method may be subject to interference from other substances collected.

Examples of gases and vapours commonly analysed in this way are:

- Formaldehyde
- Nitrous oxides
- Ozone
- Phenols
- Sulphur dioxide

This method has an application for the analysis of some dusts and fumes e.g. lead by dissolving them and forming a colour complex.

8.14.4 Volumetric Analysis

This is a very simple technique used for measuring acid or alkaline gases, vapours or mists. You may sometimes see it referred to as titametric analysis.

A sample of acid from the air would typically be collected in a bubbler, thus increasing the acidity of the capturing liquid. In the laboratory, known quantities of alkaline solution would be added until the liquid becomes neutral. By knowing how much alkali has been added, the analyst can calculate how much acid was present.

8.14.5 Infrared

Many gases, liquids and their vapours absorb light in the infrared region. This offers scope for identifying substances as well as measuring the concentrations of known ones.

The general principles are when infrared light is passed through the sample for analysis; the constituent molecules will absorb some of the incoming radiation. Each substance has a unique absorption pattern (i.e. it absorbs more strongly at specific wavelengths). Although infrared has an important application in direct reading instruments for field use, its main use in the laboratory is to identify the constituents of samples.

8.14.6 Mass Spectrometry

Mass spectrometry involves the measurement of the masses of the ions of compounds of interest. A high-energy electron beam fragments the sample components and the fragments are then separated according to their mass by magnetic spectrometry and are separately detected. These fragments can be used to identify each compound.

8.14.7 Polarography

Polarographic methods are based upon the electrolysis of a sample solution using an easily polarized electrode and a nonpolarizable electrode. They are used for qualitative and quantitative analysis of aldehydes, chlorinated hydrocarbons and metals.

8.15 Deciding on Analysis

Decisions on analysis need to be taken before sampling commences. To summarise briefly:

1. Decide which exposure limits are most appropriate,

2. Select a standard method whenever possible,

3. Decide who will analyse the samples – look for a laboratory which is familiar with the analysis method and selectively engaged in ensuring quality control.

Liase directly with the analyst to discuss appropriate methods for required accuracy and sensitivity and other substances, which may be present and discuss logistics such as timescale and transport.

8.16 Acknowledgments

This Chapter has been prepared based on the publications included in the References section below.

8.17 References

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