Institutet
För Kemisk Analys Norden AB

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Summary of the report:

HOT WORK RESPIRATORY PROTECTION

A Joint Industry Research, Development and Demonstration Project (JIP)

Participants:
ConocoPhillips, Total E&P Norge, StatoilHydro ASA, Shell U.K. Limited, BP U.K., Aker Kvaerner Offshore Partner AS, Norsk Metallretur AS and AF Decom,

Contractor:

Institutet för Kemisk Analys Norden AB (IFKAN)

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1 Introduction/background

There has been a focus in the industry, governmental bodies and trade unions, regarding the exposure of workers involved in “hot work” during demolition of offshore installations. To investigate and minimize the worker’s exposure and to improve the use of personal protection device, a Joint Industrial Research, Development and Demonstration Project was initiated. The project started September 19, 2006 and ended on May 31, 2008. This report is a condensed version of the full 1539-page report released October 31, 2008.

The project was financed by ConocoPhillips, Total E&P Norge AS, Statoil ASA, Shell U.K. Limited, BP U.K., Aker Kvaerner Offshore Partner AS, AF Decom and Norsk Metallretur AS. The chairman of the steering committee has been Björn-Oscar Tveterås from Total E&P.

During “hot work”, such as welding and thermal cutting, hazardous substances, both organic compounds and metals can be emitted into the air. A main route of exposure for these airborne contaminants is through the respiratory tract. Some of the main concerns during hot work offshore are the formation of organic compounds and emissions of metals, such as mercury, along with a number of other toxic metals into the air.

Organic compounds e.g. isocyanates can exist as both gas and particles, which mean that any protective respirator used, must protect against both gas and particles. Small particles can reach further down in the respiratory tract than gases and be deposited there, causing adverse health effects. Isocyanates are harmful to the airways and can cause asthma and bronchitis. Some isocyanates are even classified as carcinogenic compounds. Uptake may also occur through the eyes and even the skin if protective clothing is not worn.

Metals can be emitted as both particles and vapour. Inhalation of metals such as mercury, chromium, arsenic and lead can have a harmful influence on the nervous system, kidney and liver and can also cause irritation in the respiratory tract. Acute effects can be dyspnea, chest pains and metal fume fever and chronic exposure can lead to medical conditions such as obstructive lung disease. Some heavy metals can also be accumulated in the body, which means that even small exposures, can be dangerous. Over time, the amount of contaminant accumulated in the body can reach a dangerous level.

A number of areas to be studied were identified together with the steering committee: **Testing** of protective respirators used in the offshore industry was performed, both in a laboratory environment and at an actual work place. In connection with testing of respirators, a **questionnaire** regarding the use of protection devices was developed and filled out by workers involved in “hot work”. The results from all these studies were used as a basis for evaluation of respirators, in order to give suggestions for improvements. These improvements would give better protection and better comfort for the user. Suggestions for improvements are listed. The experience gained during testing of respirators is also used to develop an **educational package** for the involved companies, supervisors and workers regarding proper use of respirators.

The **emissions** generated during gas cutting in coated metal parts were studied in detail and the **source strengths** were determined. The **dispersion** of the emitted contaminants was also investigated. To aid isocyanate measurements, a **direct reading instrument** was developed, which makes it possible to continuously monitor the exposure during “hot work”. An easy to handle **dry isocyanate sampler** was developed to facilitate air sampling of isocyanates.

2 Evaluation of representative respiratory protection devices used in the North Sea petroleum industry

2.1 Aim of the study

The aim of this study was to investigate whether twelve respirator models, already in use by participating companies in the JIP, fulfilled their expected protection efficiency according to European standards. Five fan assisted respirators, three compressed air fed respirators, one disposable filter mask and three negative pressure respirators were evaluated regarding their efficiency to protect against toxic substances in the environment. The respirators were initially tested for leakage in a specially designed climate chamber during activities related to hot work. Some respirators were tested at varying temperatures and by test persons with differing length of beard stubble to determine whether these factors had any influence on the safety of a respirator. The respirators that performed satisfactory during these tests were additionally tested during hot work (oxygen cutting) on the work site at Aker Kvaerner Stord AS.

The test persons participating in this study were also interviewed regarding comfort, sense of protection, weight etc. for each respirator. On basis of the findings from these answers, in combination with the testing of protection efficiency, suggestions for improvements of protection and comfort of respirators in general were listed.

2.2 Test Procedure

Three main types of respirators are available on the market today – compressed air fed respirators, fan assisted respirators and negative pressure respirators. The face pieces of the respirators can either be a half-face mask, a full-face mask or a visor. Five fan assisted respirators (Scott ProCap, Sundström SR200 with SR500, Malina Safety Clean air, Sundström SR540 with SR500 and 3M HT-701 with Jupiter Turbo) three compressed air fed respirators (3M 7907S, Sundström SR307 with SR200 and 3M 6100-6300 with S200), one disposable filter mask (3M 4279) and three negative pressure respirators (3M 7501-7503, Sundström SR100 and 3M 6700-6900) and were evaluated. The tested respirator models are presented below.

The respirators were initially tested for leakage in a controlled climate chamber that is presented in Figure 2.1, where the temperature and relative humidity was kept constant at 15°C and 80 %RH to ensure that all tests were comparable with each other. Fit tests are generally carried out to ensure that a respirator does not leak harmful substances from the environment while worn by a specific individual. Such fit tests were carried out by the test persons twice during the testing of each respirator to investigate whether the protection factor changed with time. The fit test was also complemented with some activities related to hot work in order to simulate a normal work load, task and posture to make the test as realistic as possible (see Figure 2.2).

3M 7501-7503, negative pressure half-face mask.

SR 100, negative pressure half-face mask.

3M 6700-6900, negative pressure full-face mask.

Scott ProCap, fan assisted respirator with visor.

Sundström SR 200 with SR 500, fan assisted respirator with full-face mask.

Malina Safety Clean air Chemical, fan assisted respirator with visor.

Sundström SR 540 with SR 500, fan assisted respirator with visor.

3M 7907S, compressed air fed respirator with full-face mask.

Sundström SR307 with SR200, compressed air fed respirator with full-face mask.

3M 4279, disposable negative pressure half-face mask.

3M 6100-6300 with S200, compressed air fed respirator with half-face mask.

3M HT-701 with Jupiter Turbo, fan assisted respirator with visor.

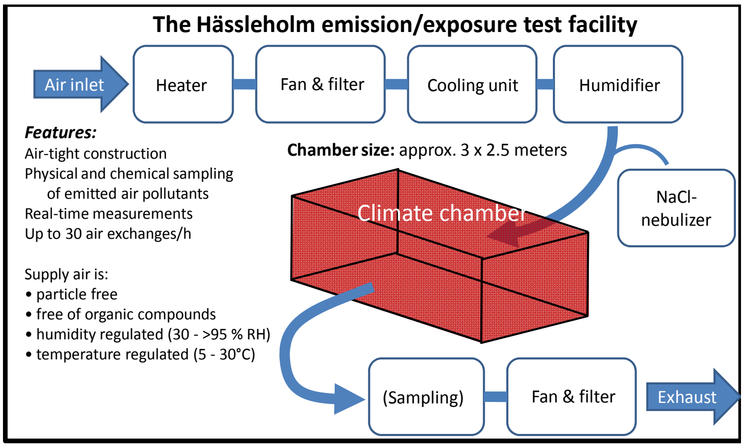


Figure 2.1 Description of the climate chamber in Hässleholm where the respirator tests were performed.

Standard fit test:	
Normal Breathing	40 s
Deep breathing	40 s
Turn head side to side	40 s
Head up and down	40 s
Talking	40 s
Grimace	15 s
Bending over	40 s
Normal breathing	40 s

Additional activities related to hot work:	
Walking	3 min
Walking while talking	2 min
Moving objects	4 min
Thermal cutting	7 min
Walking	3 min
Walking while talking	2 min

Figure 2.2 The OSHA standard fit test (29CFR1910.134) and the additional activities performed during each test of respirators. A second fit test was performed after the additional activities.

The test group consisted of ten test persons of age 22-64 years, two women and eight men. The respirators were tested for leakage by monitoring of the concentration of airborne particles inside and outside the face piece to see how many percent of the number of particles that leaks into the mask. During the fit test, non-toxic salt particles were generated in the surrounding air. How efficiently a specific respirator protects the wearer against metals and toxic substances in the ambient air can be determined by determination of the protection factor, which is the concentration of particles outside the respirator divided by the concentration of particles inside the mask. Hence, the higher protection factor, the more efficiently the respirator protects the wearer against harmful substances in the surroundings. The respirators were also tested by test persons with varying lengths of beard stubble, as well as varying ambient temperatures to see if these factors would have any influence of the protection factor of the respirators.

Three respirators from different producers – Scott ProCap (4), Sundström SR200 with SR500 (5) and 3M 7907 (8) – were tested by three workers during fit testing and oxygen/acetylene cutting at a work site. The concentration of harmful organic substances, airborne aerosols of metals, NO and NO_2 were measured in the ambient air and air inside the mask. To ensure the safety of the workers, the concentrations of particles inside and outside the respirator were continuously monitored to detect any leaks.

2.3 Results

2.3.1 Performance in chamber tests

In general, the protection factor for the tested respirator models was high enough to fulfil assigned protection factors set by the UK and Swedish authorities (Table 2.1). For several activities, most notably “walking while talking”, many of the models failed to meet the nominal protection factor in the tests (Table 2.2). For example, the disposable respirator (3M 4279) did leak up to 1.6% of the ambient air into the mask, thus making it inappropriate for usage during hot work, even though the measured protection factor for this particular model was above the UK assigned protection factor.

Compressed air fed respirators with full face masks had the highest protection factor of the tested models. The protection factor for the compressed air fed respirator with half-face mask (11) was however much lower than for most other respirators, with a constant leakage during the fit test, regardless of which activity that was performed. The fan assisted respirator with full-face mask (5) did also perform well, which can be seen in Figure 2.3. Even though the average protection factor for the entire fit test is high for the negative pressure and fan assisted respirators with visors, during some activities of the fit test the protection factor is significantly reduced as compared to fan assisted respirator with full-face mask and compressed air fed respirators with full-face mask. Examples of such activities are grimacing and when the test person is talking (Table 2.2).

Table 2.1 Assigned protection factors for UK and Sweden (does not exist in Norway) and nominal protection factors with the regulating standard.

Model		**UK**	**Sweden**	**Nominal**	**Standard**
Disposable half-mask P3	(10)	10	-	33	EN405
Half-mask with filter P3	(1, 2)	20	20	50	EN140
Full face mask P3	(3)	40	500	2000	EN136
Fan assisted visor TH3	(4, 6, 7, 12)	40	200	500	EN12941
Fan assisted full face mask TM3	(5)	40	1000	2000	EN12942
Half-mask with compressed air	(11)	10	-	50	EN138
Full face mask with compressed air	(8, 9)	40	500	2000	EN138

- = not defined for the particular respirator model
Source: EN529:2005

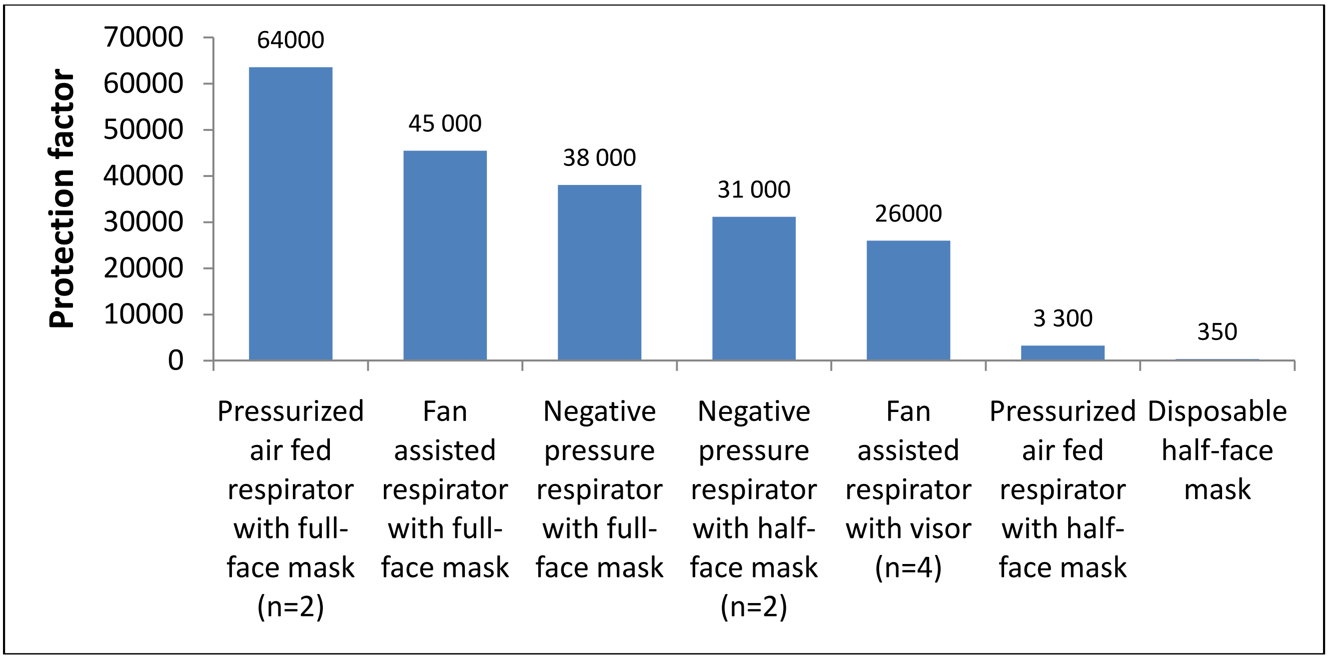


Figure 2.3 Average protection factor for the different respirator types from entire fit test.

Respirators are generally more prone to leak during certain movements – which was detected during the fit tests, as the protection factor was significantly reduced during some activities. Examples of such activities are: walking while talking, grimacing, talking and moving objects. The protection factor was especially reduced during “walking while talking” or “talking clearly”. For respirators with full-face masks (either compressed air fed or fan assisted), this reduction in protection factor was however less apparent. There are also differences in protection factors between various visor models, especially during the activity “walking while talking”. The respirator model Malina Safety Clean air (6) had especially low protection factor during this activity as compared to the other visors. Sundström SR 540 with SR500 (7) had the highest protection factor of the 4 visors during this activity of the fit test.

Two main factors influence how much ambient air that will leak into the respirator: the amount of negative pressure inside the face piece (caused by inhalation) and the imperfect seal of the mask/visor to the face.

No respirator is ideal and protects all persons with the same efficiency. It has been found that the protection factor varies considerably between different test persons testing the same respirator model. The test person’s facial dimensions and how the person is breathing during the various activities will influence the individual protection factors. As may be expected, the variation between the test persons was smaller for compressed air fed respirators than for negative pressure respirators. The compressed air fed and fan assisted respirators efficiently stops particles from entering the face piece if a small leakage should occur, while a small leakage for negative pressure respirators causes a large decrease in the protection factor.

Table 2.2 Respirator performance compared to assigned (APF) and nominal (NPF) protection factors for clean shaven test persons. Please note that the protection factors (Table 2.1) differ between the models (page 5).

		Number of tests failed			**Total number of tests**
Model	**Task**	**APF (UK)**	**APF (SE)**	**NPF**	
1	*all*	*4*	*4*	*5*	*132*
	head up and down	2	2	2	12
	bending forward	0	0	1	12
	grimace	1	1	1	12
	moving objects	1	1	1	6
2	*all*	*0*	*0*	*1*	*132*
	head side to side	0	0	1	12
3	*all*	*0*	*4*	*33*	*132*
	normal breathing	0	0	4	24
	deep breathing	0	0	2	12
	head side to side	0	0	2	12
	head up and down	0	0	4	12
	talking clearly	0	0	3	12
	grimace	0	1	3	12
	bending forward	0	2	4	12
	walking	0	0	4	12
	walking while talking	0	1	4	12
	moving objects	0	0	2	6
	cutting	0	0	1	6
4	*all*	*0*	*3*	*9*	*132*
	deep breathing	0	1	1	12
	grimace	0	0	1	12
	bending forward	0	0	1	12
	walking while talking	0	2	4	12
	moving objects	0	0	2	6
5	*all*	*0*	*0*	*0*	*132*
6	*all*	*5*	*12*	*12*	*132*
	bending forward	0	1	1	12
	deep breathing	1	1	1	12
	walking while talking	4	10	10	12
7	*all*	*0*	*0*	*0*	*132*
8	*all*	*0*	*0*	*0*	*132*
9	*all*	*0*	*0*	*0*	*132*
10	*all*	*0*	-	*12*	*88*
	head side to side	0	-	1	8
	head up and down	0	-	1	8
	grimace	0	-	5	8
	bending forward	0	-	2	8
	walking while talking	0	-	2	8
	moving objects	0	-	1	4
	cutting	0	-	1	4
11	*all*	*0*	*0*	*0*	*66*
12	*all*	*0*	*4*	*5*	*66*
	deep breathing	0	1	2	8
	walking while talking	0	2	2	4
	moving objects	0	1	1	4
all					**1408**

2.3.2 *Beard*

The two respirator models, Sundström SR100 (2) and Sundström SR200 with SR500 fan unit (5), were tested by three test persons with 0, 1, 2, 4 and 7 days beard stubble. The protection factor for the negative pressure respirator SR100 was somewhat reduced by beard growth, while for the fan assisted full-face mask respirator (SR200 with SR500) it was not affected. Beard stubble causes a space between the mask and face and hence causes leakages. The protection factor was generally somewhat improved during the last fit test, compared to the first, since the test person was warmer and moisture sealed some of the leaks. This leads to the conclusion that sweating while testing the negative pressure half-face mask may actually improve its performance due to blockage of leakages arising between the mask and the face. As a consequence from these results, it is recommended to be clean shaved especially when wearing a negative pressure respirator to obtain an optimal protection factor.

2.3.3 *Temperature effects*

During most tests, the temperature in the climate chamber was kept constant at 15°C. However, the respirator models SR100 (2) and 3M 6700-6900 (3) were tested at three different temperatures (5, 15 and 25°C) by three test persons to investigate whether variation in temperature affected the performance of these respirators. In general, the protection factor was lower at 5°C than at 15 and 25°C, even though the test persons answered in the questionnaire that the sense of protection was impaired at higher temperatures when they were sweaty and the mask “slipped” on the face. The reduced protection factor at 5°C is probably due to the material in the mask becoming less flexible at lower temperatures, causing it to adapt less well to the face of the wearer than at higher temperatures. The protection factor was actually higher the second time the fit test was carried out at 5°C than during the first time. This fact is probably due to the mask becoming warmer after it has been worn for a while and thereby adapting better to the face. No such improvement in protection factor could be seen during the second time the fit test was carried out at 15 and 25°C. It is worth keeping in mind that a respirator provides more efficient protection after it has been worn for a while and that this is especially true at lower temperatures, such as 5°C.

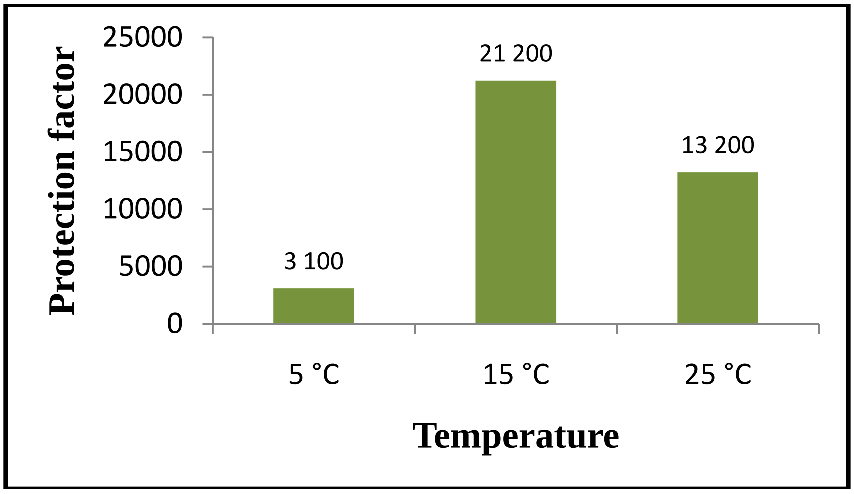


Figure 2.4 Average protection factor (n=3) while testing respirator number 2 (SR100 negative pressure half-face mask) in the climate chamber at various temperatures.

2.3.4 *Site test*

Three respirators from different producers – Scott ProCap (4), Sundström SR200 with SR500 (5) and 3M 7907 (8) – were tested by three workers during fit testing and oxygen/acetylene cutting at a work site. During these tests, the particle concentration in the ambient air was about 100 times higher than during the controlled tests in the climate chamber where salt particles were generated at desired concentrations. The concentration of particles during hot work was measured up to well above 150 000 particles/cm^3, which were above measuring range of the instruments used. The compressed air fed respirator 3M 7907S performed the best, as expected due to the pressurized air. Low levels of particles were found on the inside of the fan assisted full-face respirator Sundström SR200 with SR500 during hot work. The average protection factor was still well above the assigned value.

Figure 2.5 Cutting operation Stord2.

The risk of leakages for respirator model Scott ProCap seems to be influenced by the facial dimensions of the wearer. For one worker, this visor exhibited extensive leakages during the fit test. This worker was excluded from the study of Scott ProCap respirator. During another test, leakage could be detected when the worker turned the head abruptly directly after cessation of work. When tested by the two other workers, the visor did, however, protect well against inward leakage during hot work.

A controlled test with a non-toxic aerosol should be used as first step to ensure that the respirator provides adequate protection for the wearer.

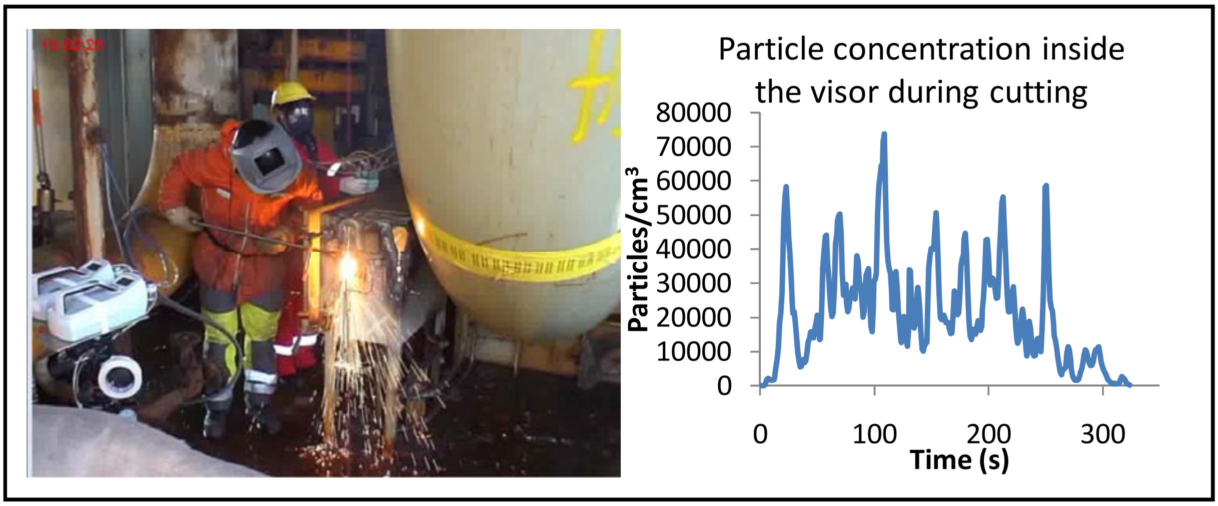


Figure 2.6 Cutting operation Stord19 and a graph displaying the measured particle concentration during cutting inside the respirator.

Aerosols of metals such as Arsenic, Cadmium, Cobalt, Chromium, Cupper, Iron, Manganese, Mercury, Nickel, Lead, Zinc, Vanadium and Molybdenum were found in the breathing zone of the worker during thermal cutting. The concentrations differed to a great extent, which is to be expected due to changes in wind direction during sampling etc. Small amounts of organic substances, such as ICA were found, but in lower levels than expected. Isocyanates were however found present in the fumes as the coating of the pipe on which the cutting was performed was heated to 400°C in the laboratory. The temperature at thermal cutting is much higher than 400 °C, which could lead to degradation of these toxic compounds as well.

2.3.5 Biological monitoring

Biological monitoring using urine samples from workers involved in hot work at Stord revealed that some of the workers had been exposed to isocyanates, even though respiratory protection is always used by workers. In addition, some urine samples from the reference group among the Stord personnel also showed isocyanate exposure, even though the reference group was not expected to be exposed. In some urine samples from IFKAN personnel performing the measurements during hot work tests, biomarkers for isocyanate exposure were also found. Respiratory protection was always used by IFKAN personnel at the work site.

2.3.6 Questionnaire

Each test person answered a questionnaire after testing of a respirator. The questionnaire involved questions regarding donning and doffing, weight, sense of protection, comfort against the skin, size and fit, field of vision, speech transmission, clarity of vision and overall applicability of the respirator. For compressed air fed and fan assisted respirators, the test persons were also asked questions regarding manoeuvrability, placement of switches and flow regulators, air quality and comfort regarding the noise level. From these questions, a number of conclusions can be drawn about the comfort and sense of protection of these respirator models.

An issue with most respirators have been the incompatibility with glasses and helmets. The workers using these respirators are often required to wear such additional equipment and it poses a problem with respirators that are not compatible with such equipment. The 3M HT-701 respirator (12) had however an integrated helmet with the visor, which the test persons appreciated.

The sense of protection was better for fan assisted and compressed air fed respirators than for negative pressure respirators. A problem often encountered with these two respirator types was the noise level from the compressed air regulator or the fan unit being too loud, thereby also impairing the transmission of speech. In one occasion, the test person actually had to terminate a test in advance because of the loud noise. These two types of respirators did also receive complaints about limited manoeuvrability since the fan unit was clumsy to wear and because of the tube of compressed air connected to the compressed air fed respirators. It was also frequently commented on the belt of the fan unit sliding down. Another problem associated with the compressed air fed respirators was donning and doffing. Problems were experienced with donning and doffing of the compressed air fed respirators due to the tube of compressed air and it was commented on that it involved too many steps putting the respirators on, since this tube needed to be connected to the regulator as well.

Problems associated with the negative pressure respirators were mainly that the sense of protection was bad and had a high breathing resistance, especially during hard work. On the other hand, these respirators were easy to put on and needed no exchange of batteries.

Visors generally had a more limited field of vision than other masks and problems associated with condensed water inside the visor were experienced. For some visors the sense of protection was impaired due to holes in the fabric located underneath the chin, since it was thought that air would leak in.

Beard stubble may have had some impact on the comfort of the respirators. The sense of protection was somewhat worse for test persons wearing a beard than the clean shaved ones, with no discrimination between various respirator types. For Sundström SR200 with SR500 it was commented on formation of air pockets between the mask and face by a test person with beard stubble, which made the mask more likely to slide and thus impaired the sense of protection of the mask. SR100 was commented on being more able to slide while wearing beard stubble than for a clean shaved person.

While testing SR100 and 3M 6700-6900 at 5°C it was commented on the material of the mask being stiff in the beginning of the test, but became more flexible with time. The different temperatures did also seem to have an effect on the comfort of breathing, size and fit, comfort against the skin and sense of protection with varying results.

2.3.7 Problem identification and presentation of suggestions for improvements of respirators

The optimal respirator would be light weight, good vision, no noise, smooth against the skin, long battery life, easy to take on, off and to handle, easy maintenance and compatible with other equipment such as eye glasses, communication equipment, hearing aids, helmets etc. There is of course no respirator on the market today that will fulfil all these requirements. New respirators should be designed in order facilitate the use of additional equipment, for example should it be easy to wear glasses underneath the mask or not need specially designed protection glasses together with half-face masks.

Filters should be equipped with an indication of the condition of the filters. Filters used today in negative pressure or fan assisted respirators lack any indication of whether they have been used or not. During hot work nitric oxide and carbon monoxide can be emitted. Regular filters in filter respirators do not trap these compounds efficiently. The magnitude of the emission of these substances during hot work should be further investigated and manufacturers of filters should be encouraged to develop filters that protect against these substances.

Issues commonly mentioned in the questionnaire have been the weight, balance and size of the fan units in these types of respirators. The fan units could be made smaller and lighter by the use of for example rechargeable lithium batteries. For the fan unit to be easier to wear, it could be designed to be worn like a back pack rather than to be worn with a belt around the waist, which would probably cause less strain on the back of the wearer.

High airflow in fan assisted and compressed air fed respirators provides better protection against leakage into the mask than a low air flow. Users often lower the air flow in compressed air fed respirators for better comfort due to cold, dry air and loud noise from the flow regulator. During hard work however, too low air flow through respirator may cause an inward leakage of harmful substances from the outside. To ensure that the air flow in compressed air fed respirator does not drop below an acceptable level for the specific work load, a system that prevents this should be implemented. In fan assisted respirators, users seem to be more comfortable operating the respirator at a high air flow, which shortens the life span of the filters. This is not a problem as long as the usable time limit for the filters is not exceeded.

During heavy rain or decontamination of for example asbestos, water can leak into the air intake of the filter and reduce the capacity of the filters or even cause fan unit failure. Manufacturers of respirators should be encouraged to design more water resistant respirators and filters. During acetylene/oxygen cutting the filters must be protected from sparks.

Another suggestion of improvements is regarding the organization around the usage and maintenance of respirators. Respirators are a part of a system to ensure air of good quality for employees. Many different parts of a company using such respirators may be involved in this system. This will be further discussed in Chapter 3.

2.4 Conclusions

A test procedure that in addition to standard fit tests also includes activities related to hot work has been used to test 12 respirators commonly used in the North Sea petroleum industry. As expected, compressed air fed respirators had the highest protection factors. Respirators were found to be more prone to leak during certain movements or activities – especially during walking while talking. Beard growth and a cold mask will influence the performance of the respirator negatively.

Three respirators from different producers were tested by three workers in a site test. During fit testing one fan assisted visor failed for one test person. This demonstrates the need for an objective quantitative fit test for each worker before a new respirator is used and also testing at regular intervals. Biomarkers were found to be an effective method to identify workers' exposure when oxygen/acetylene cutting in coated metal parts was performed.

Comments from the users have been compiled from the questionnaire to recommend improvements of respirators.

3 Educational package

In this section, important decisions, questions and information was brought together regarding the education of all personnel involved in respiratory protection equipment for hot work. As recommended in section 2.3.7, not only persons wearing the respirators need education, but also work supervisors, HMS-personnel, inspectors, decision makers and personnel responsible for purchase of respirators. This would ensure that respiratory protection is used correctly in terms of maintenance of the respirators and selection of appropriate respiratory protection for intended work situation. An organization that is dependent on respiratory protection to keep their workers safe from hazardous exposure during hot work, is required to obtain competence to create a program for respiratory protection.

Procedures for identification of hazardous substances in the work place, selection of suitable respiratory protection, education of personnel regarding usage and maintenance of respiratory protection, surveillance and system for maintenance must be composed.

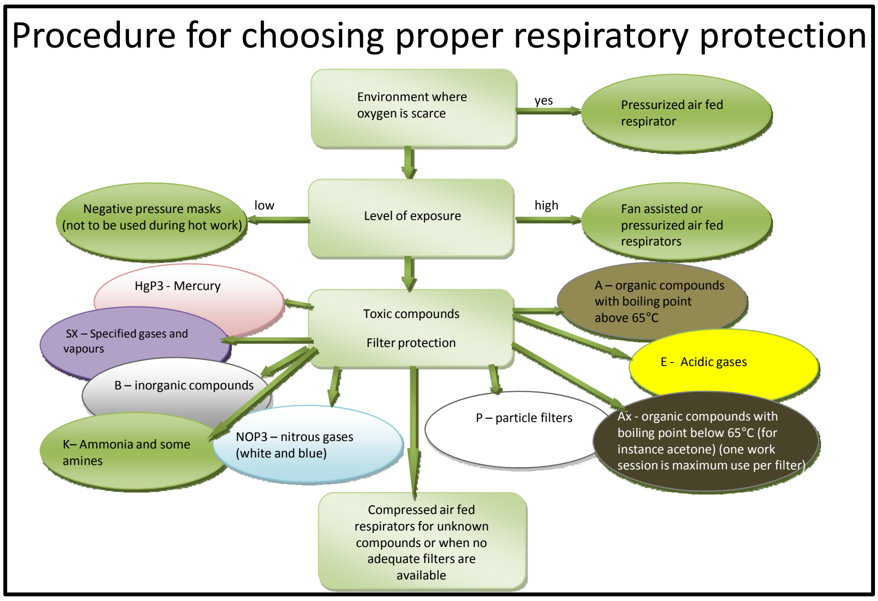


Figure 3.1 A flow sheet describing the procedure for choosing proper respiratory protection in regard of level of exposure, which toxic compounds that can be expected etc.

Regarding the **selection** of appropriate respirators, compressed air fed respirators and fan assisted respirators are the most appropriate respiratory protection available today. For compressed air fed respirators, a system for surveillance of the generation of compressed air must be developed.

Regarding the **maintenance** of the respirators (cleaning, control, exchange of filters for filter respirators etc.), it needs to be addressed whether each user should be responsible for the maintenance of his/her own respirator or if all maintenance of respirators should be carried out by a central unit.

Fit tests validate that the respiratory protection provides sufficient protection for intended user. One should take into account that aspects such as ambient temperature and length of beard stubble influence the protection factor of respirators. Workers should be informed about these limitations in respirator performance for optimal protection during usage. The following should also be taken into consideration, health hazards such as the respirators being removed too early after cessation of hot work, leading to exposure of the workers from remaining pollutants in the air.

Dust that is deposited in the clothes during hot work and dust that settles onto the floor, which may become airborne later on, must also be taken into consideration and procedures to avoid health hazards coupled to these events should be developed. Contaminated clothes from hot work require appropriate decontamination procedure.

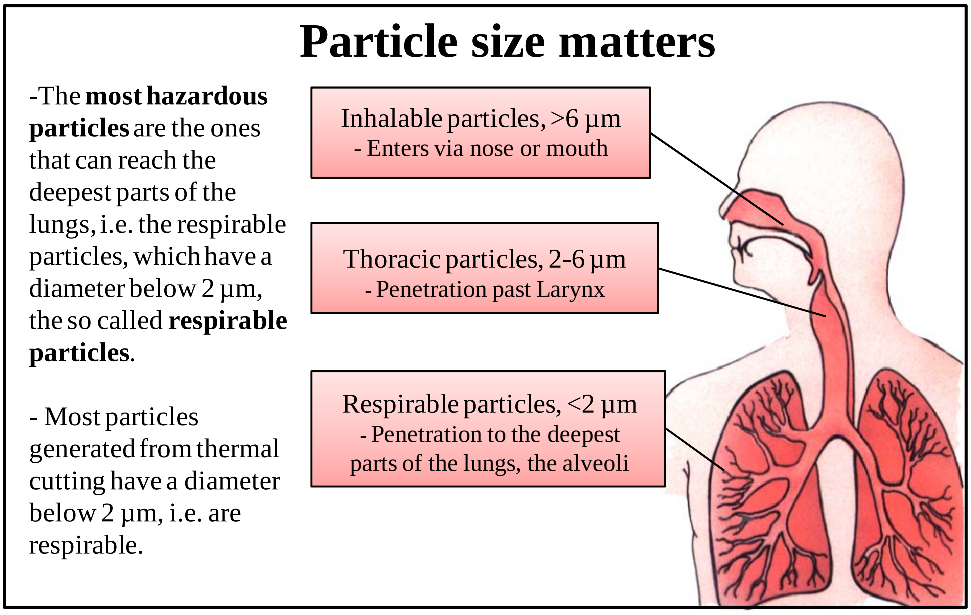
Based on the information in this educational package an interactive learning program in Norwegian and English is in progress (MINTRA & IFKAN).

4 Emissions from hot work in coated metal parts

4.1 Aim of the study

There has been a focus in the industry, governmental bodies and trade unions regarding the exposure of workers involved in “hot work” during demolition of offshore installations. In recently performed studies by IFKAN it has been concluded that traditional occupational measurements only give limited information about the presence of airborne compounds at the work place. In addition, it has been shown that the airborne compounds are both in gas and particle phase. The penetration of particles in the human respiratory tract is dependent on the particle size, see Figure 4.1. Topics for further investigations are:

1. The emissions from hot work in coated metal parts need to be investigated thoroughly, both regarding chemical composition and particle size distribution.
2. The source strength of the different contaminants produced during work operations is essential to know in order to predict the magnitude of exposure.



Particle size matters

-The **most hazardous particles** are the ones that can reach the deepest parts of the lungs, i.e. the respirable particles, which have a diameter below 2 µm, the so called **respirable particles**.

- Most particles generated from thermal cutting have a diameter below 2 µm, i.e. are respirable.

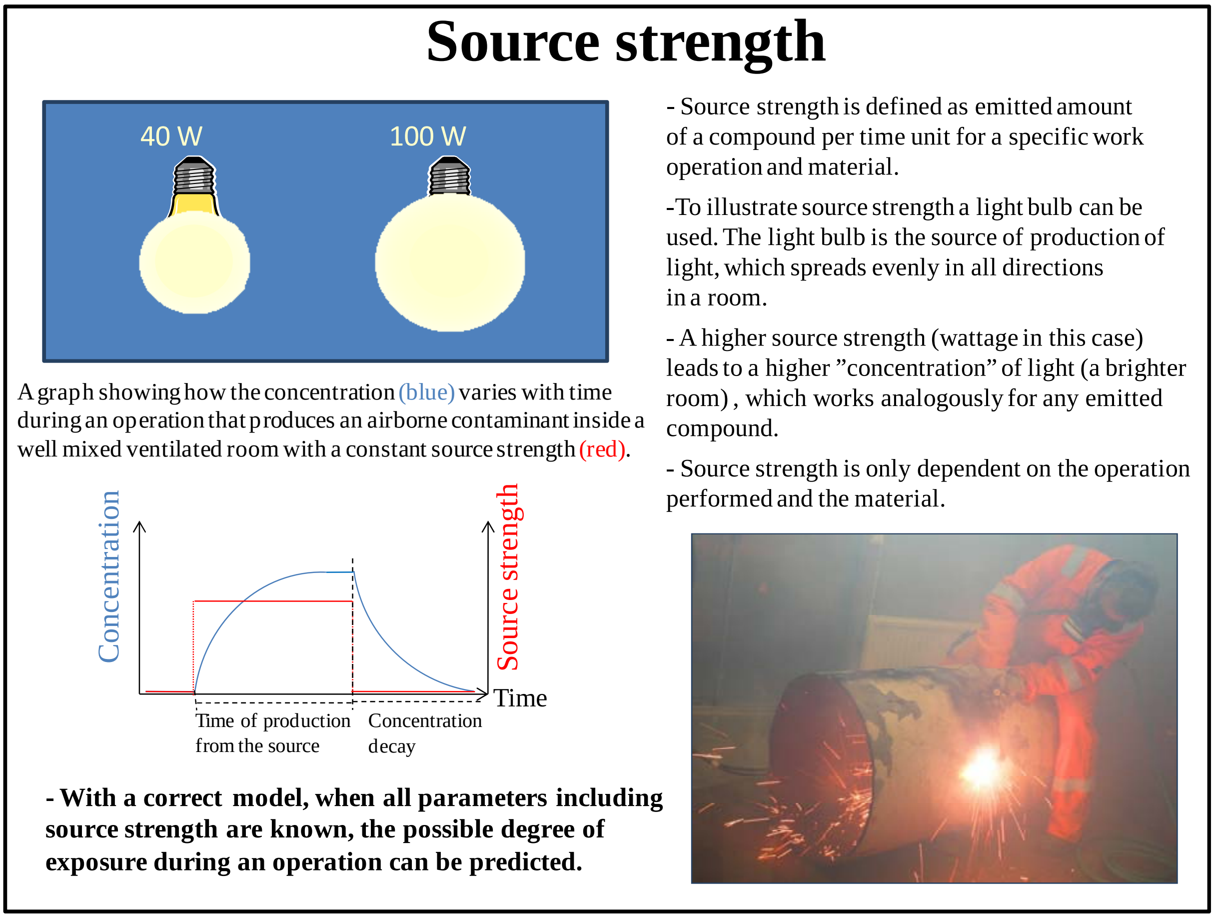
Figure 4.1 Penetration depth of different particle sizes in the human respiratory tract.

4.2 Test procedure

Five representative coated metal parts, see Figure 4.2, were taken from a dismantled off shore installations to the IFKAN test facility in Hässleholm. The test facility consists of a walk-in climate chamber that can be controlled regarding temperature, humidity and ventilation air flow and a control room. This enables simulation of North Sea offshore weather conditions.

Figure 4.2 Metal parts tested during the source strength measurements.

The source strengths, see Figure 4.3, during different work operations using the coated metal parts were measured. During occupational measurements in the work place the exposure levels are dependent on a number of factors such as ventilation, room size, wind velocity and direction; factors that are often difficult to predict. In order to compare different work operations and materials a controlled environment is needed. This was made possible by measuring the source strength during the experiments in the climate chamber.



Source strength

A graph showing how the concentration (blue) varies with time during an operation that produces an airborne contaminant inside a well mixed ventilated room with a constant source strength (red).

- Source strength is defined as emitted amount of a compound per time unit for a specific work operation and material.
-To illustrate source strength a light bulb can be used. The light bulb is the source of production of light, which spreads evenly in all directions in a room.
- A higher source strength (wattage in this case) leads to a higher ”concentration” of light (a brighter room) , which works analogously for any emitted compound.
- Source strength is only dependent on the operation performed and the material.

- With a correct model, when all parameters including source strength are known, the possible degree of exposure during an operation can be predicted.

Figure 4.3 Explaining the concept and applications of source strength.

Acetylene/oxygen cutting was used for metal parts 1-4; the fifth was a stainless steel pipe, for which plasma cutting was used. In order to compare the results from the different cutting operations and material samples, a very specific work operation procedure designed, see Table 4.1.

Table 4.1 Event table for source strength tests.

Time	Event
0	Start air sampling
15 s	Flame ignition
1 min	Start flame cutting
3 min	Stop flame cutting
15 min	Stop air sampling

The test facility is also equipped with a sampling setup which enables simultaneous sampling of a number of organic compounds (isocyanates, amines, aldehydes, organic acid anhydrides, and tin organic compounds), metals and sampling with direct reading instruments for nitric oxide (NO), nitrous oxide (NO_2), mercury vapour and particle concentration and size distribution. The sampling point is located in the outgoing ventilation channel in the climate chamber in order to ensure representative sampling.

4.3 Results

Analysis of the surface coating from the tested metal parts showed that two of them (1 and 2) were painted with a polyurethane (PUR) based coating. Metal analysis on the coating indicated presence of mercury in all painted metal parts and arsenic in two of them (1 and 2). Rust samples showed that two pipes (3 and 4) had mercury and arsenic deposits on the inside of the pipes. Examples of metals that were found were, iron, copper, nickel, mercury, chromium, lead, manganese, cobalt and zinc. Air samples from both direct reading instruments (mercury, see Figure 4.4) and samplers for metals (see Figure 4.5) showed that the metals found during material analysis in the different metal parts were emitted into the air during thermal cutting.

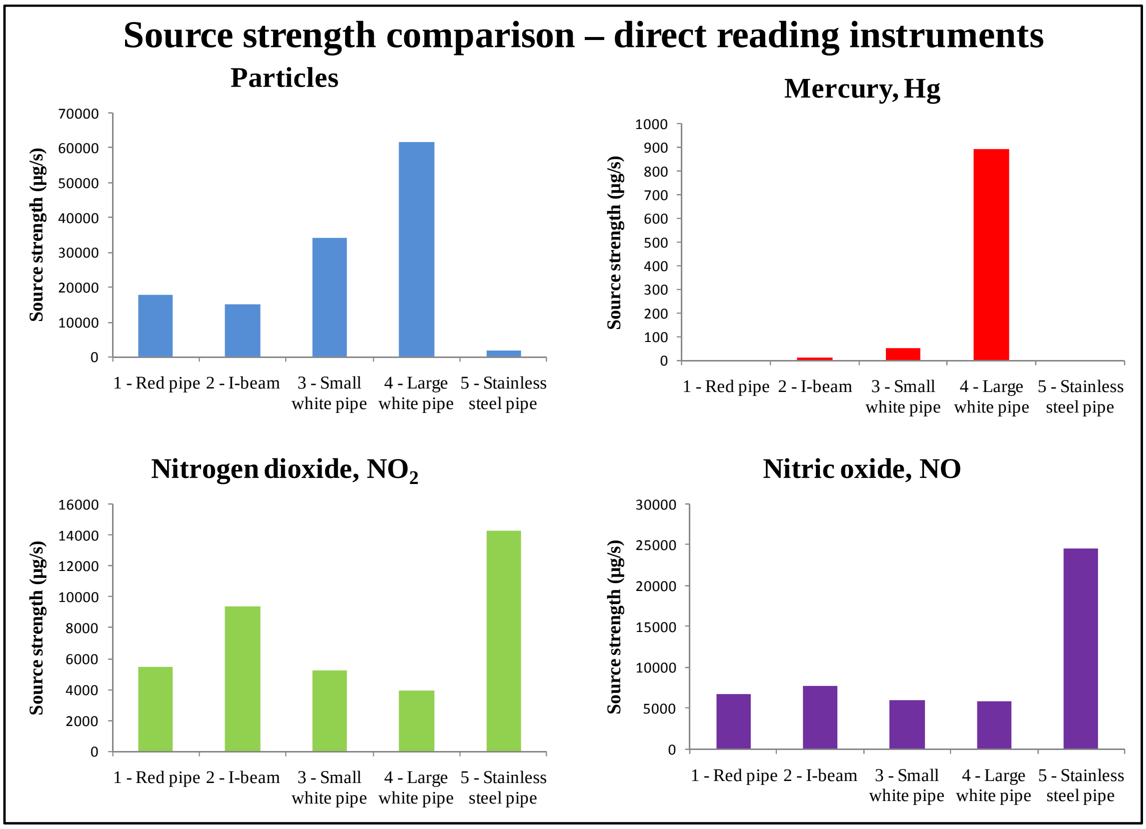


Figure 4.4 Charts showing the source strength calculated for some contaminants, using direct instruments for air sampling.

The source strength for nitric oxide, NO, and nitrogen dioxide, NO_2, covariate closely. The source strength for NO is typically larger than for NO_2 during both acetylene/oxygen and plasma cutting. The source strength for both NO and NO_2 are higher during plasma cutting, than during acetylene/oxygen cutting.

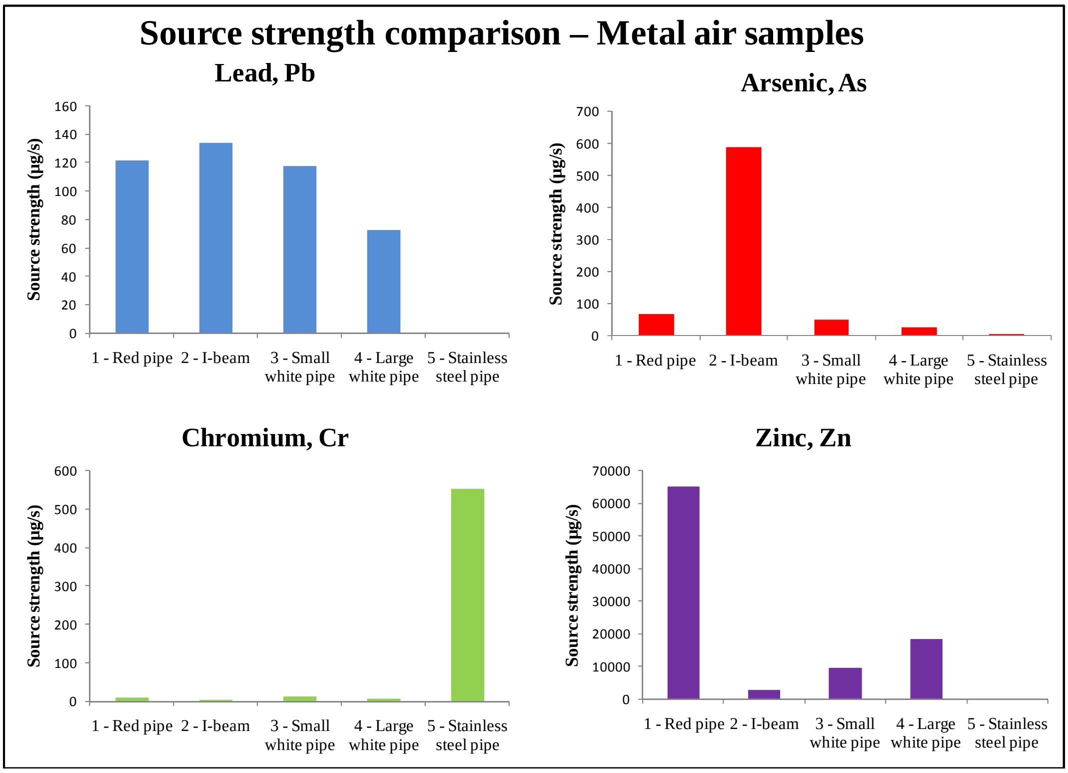
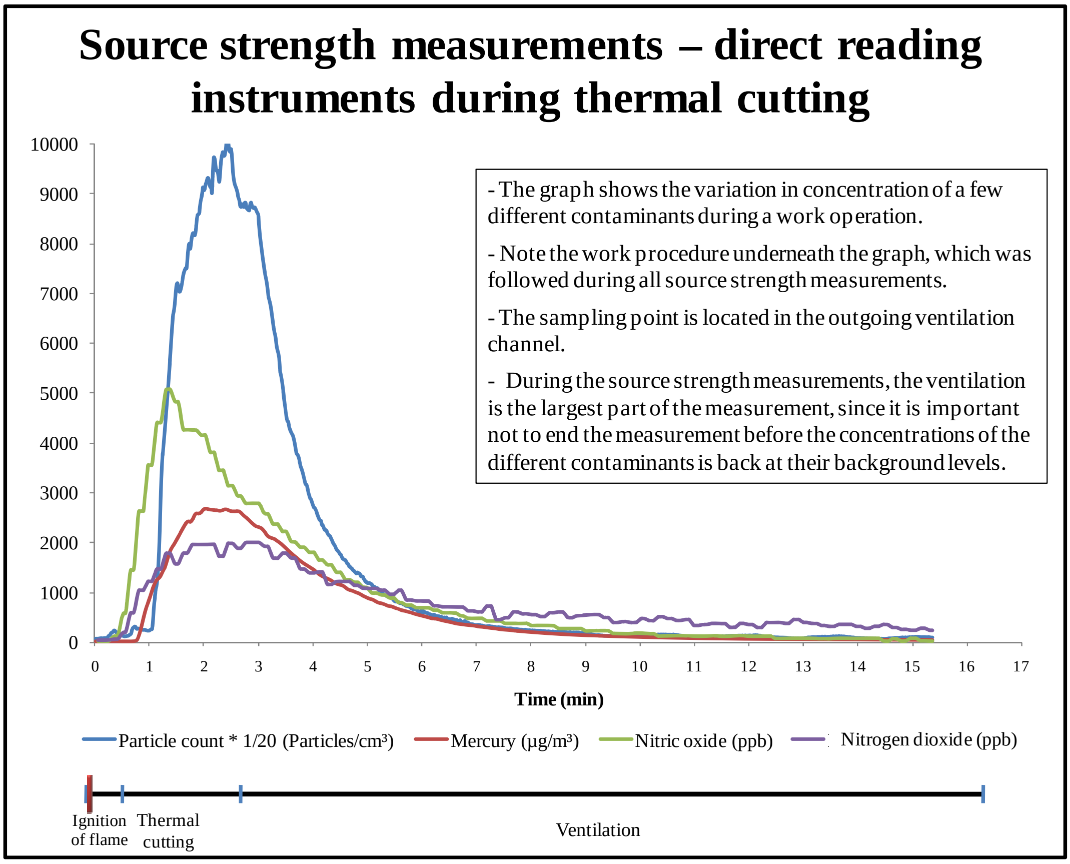


Figure 4.5 Charts showing the source strength for some metal contaminants, using filter samplers for air sampling of metals.

During these measurements only small amounts of isocyanates were found in the emissions from the tested metal parts during thermal cutting, although two of the metal parts were painted with a PUR based coating. This differs from results from earlier tests with both thermal cutting and welding, where PUR based coatings have yielded emissions of isocyanates during hot work. In fact, the amounts of organic compounds found in the emissions from thermal cutting were low. Only formaldehyde and isocyanic acid was found in any substantial amounts in the emissions from the thermal cutting.

Results from a source strength measurement can be seen in Figure 4.6. The particle concentration rises during the thermal cutting (the time of production) and declines when the cutting stops (ventilation). The decline is dependent on the efficiency of the ventilation. The source strength has been calculated by measuring the entire amount of contaminants, emitted during the work operation. This is done by sampling during the entire interval, ignition of flame, thermal cutting and ventilation. By studying the concentration decay curves it can be seen that the production of mercury did not, in all cases, stop when the cutting ceased. The heat caused by the cutting could cause an after-production of mercury vapour several minutes after the cutting has stopped. This has also been observed for isocyanates in earlier studies, which makes it important not to take off the respirator too soon after the cutting operation has stopped.

Impactor samples as well as real time measurements using a scanning mobility particle sizer showed that the largest fraction of the particles emitted during thermal cutting has a diameter smaller than 2 µm, i.e. are respirable. An example of this is shown below in Figure 4.7, where the particle size distribution for chromium is shown. All metals found in the emissions during these measurements showed similar patterns in their particle size distributions.



Source strength measurements – direct reading instruments during thermal cutting

- The graph shows the variation in concentration of a few different contaminants during a work operation.

- Note the work procedure underneath the graph, which was followed during all source strength measurements.

- The sampling point is located in the outgoing ventilation channel.

- During the source strength measurements, the ventilation is the largest part of the measurement, since it is important not to end the measurement before the concentrations of the different contaminants is back at their background levels.

Figure 4.6 An example graph of the variation in concentration during a thermal cutting operation.

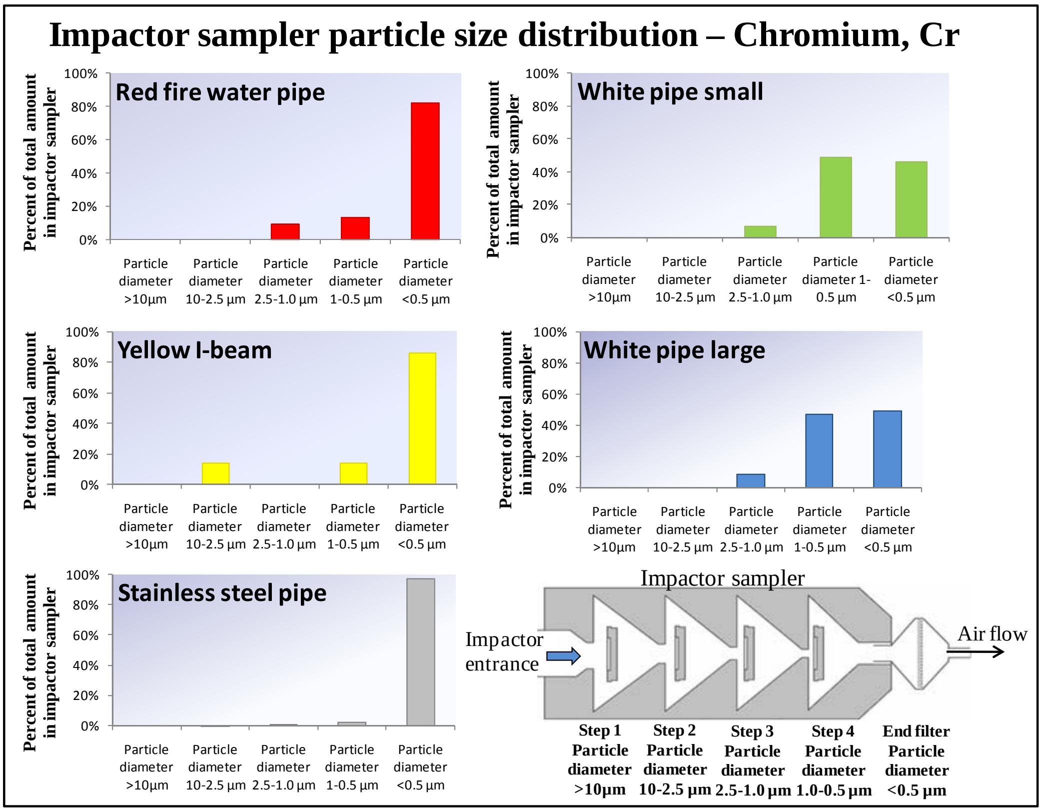


Figure 4.7 The particle size distribution for chromium particles emitted from the five different metal parts.

Sedimentation samplers were placed at different distances around the metal parts being worked on. Particles much larger than respirable particles will settle within a few seconds. The sedimentation samples showed that the metal particles generated during the cutting could be transported away from the cutting spot before settling onto horizontal surfaces inside the chamber and ventilation channel. However, the results also showed that large amounts of metal particles were deposited in the near vicinity of the cutting spot. The pipes containing mercury also showed large amounts of mercury in the sedimentation samples taken during cutting. This could present a risk since the metal particles could be stirred up and become airborne later when no protective respirators are used.

The fabric samples showed the same result as the sedimentation samples: the metals found in the sedimentation samples and air samples were also found in the fabric samples. This could present a risk since the respirator most often is removed before the protective clothing is. Exposure could also occur when storing contaminated clothes in the same place as clothes that are used when no respirator is worn.

4.4 Conclusions

In order to compare different work operations and materials a controlled environment is needed. This was made possible by measuring the source strength during the experiments in the climate chamber with simultaneous sampling of a number of organic compounds, metals and sampling with direct reading instruments for nitric oxide (NO), nitrous oxide (NO_2), mercury vapour and particle concentration and size distribution.

The metals found in the coating and rust samples taken from the different metal parts tested, were also found in the air samples taken during thermal cutting. Examples of metals found in the emissions were mercury, arsenic, chromium and lead.

The impactor samples showed that the particles generated during acetylene/oxygen cutting was small (d_a<2 µm), i.e. are respirable and that the particles generated during plasma cutting on the stainless steel pipe were even smaller.

The sedimentation samples showed that the metal particles generated during the cutting could be transported away from the cutting spot before settling onto the horizontal surfaces. Samples of clothing were also analyzed regarding metals and these showed that the metals emitted during the work operation were deposited on the clothes as well.

5 Dispersion

5.1 Aim of the study

An important step in assessing exposure risks during “hot work” offshore is to investigate how far from the work site contaminants can spread and explore the possibility of providing a computer based model for the determination of a boundary zone. Previously, only limited studies have been performed and knowledge regarding the dispersion of the compounds emitted during “hot work” is missing. Dispersion calculation is a very intricate problem that is dependent upon a number of parameters, such as wind speed, wind direction and size and design of the work site.

The following studies were performed:

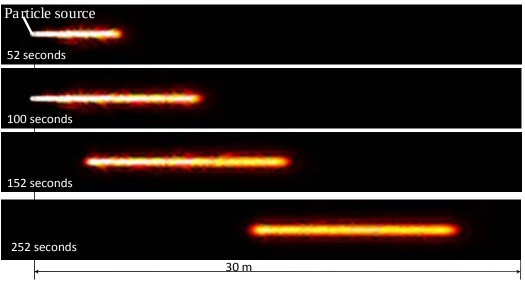
1. A computer model for simulation of how particles are dispersed directly after they have been emitted was developed.
2. Actual particle measurements during thermal cutting were performed to investigate the compliance with the computer simulated model.

5.2 Procedure and results

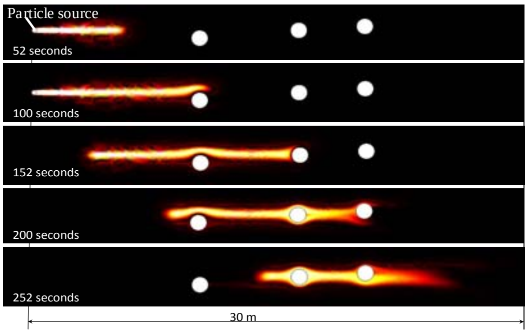
To achieve a better understanding of how particles are distributed directly after they have been emitted from a source, such as thermal cutting, a simple theoretical model has been used to predict the behaviour of an aerosol cloud in a corridor with a modest air velocity, see Figure 5.1.Three different scenarios were used in the simulation model for particle dispersion:

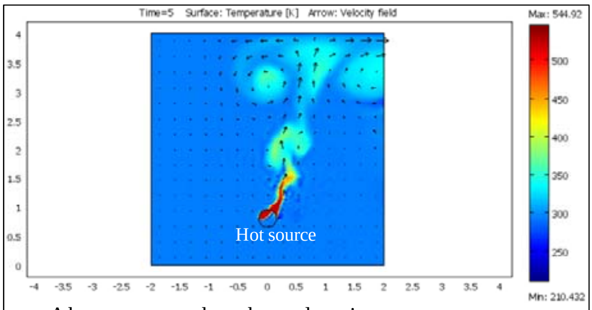
1. An empty corridor.
2. A corridor with obstacles.
3. A closed room with 4 metres to the ceiling.

Computer simulated model - Dispersion



-The two images to the left show a particle cloud being emitted and propagating over time in a corridor, as seen from above.
- The top image shows a simulation of the dispersion in an empty corridor, no significant dispersion occurs.
- The bottom image shows a simulation of the dispersion, but with obstacles inside the corridor. Some dispersion occurs, which leads to a dilution of the particle concentration.





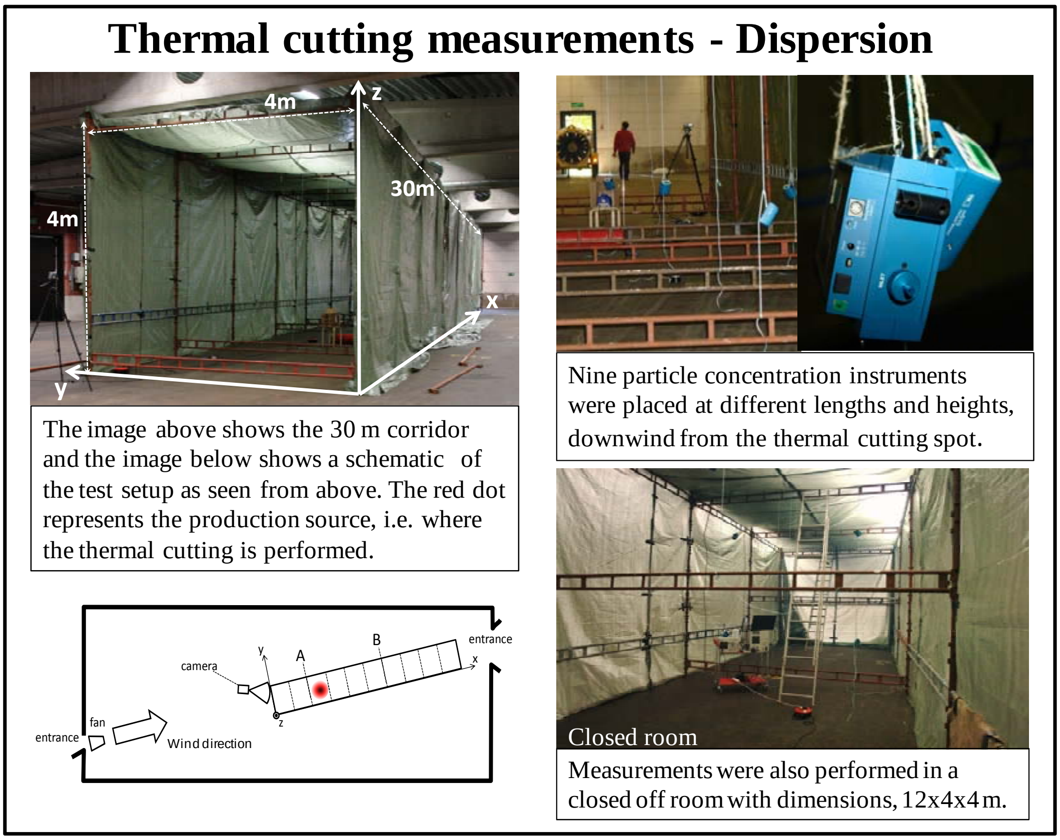
- A hot source, such as thermal cutting, causes movements in the surrounding air as the heat rises upwards.
-The image above shows a side view of heat dispersion and air velocity induced by a hot source.
-The arrows indicate the direction and the size of the air movements.

Figure 5.1 Some results of the computer model simulations

The most important results are: - no particles will appear upstream from the emitting source, and - the particle dispersion in practice will depend only on the initial shape of the cloud and on the geometry of the room. Without prior knowledge of the initial condition and the room, it is not possible to fully predict the dispersion. It is however possible to conclude that the downstream concentration will never be fully reduced if no obstacles are present.

In order to test the scenarios of the computer model two different geometries were built: a corridor (30x4x4 m) and one closed room (12 x 4 x 4 m). An industrial size fan (diameter 1.2 m) with an approximate capacity of 23 000 m^3/h was used to generate a wind speed of about 1 m/s in the corridor, see Figure 5.2.

Eight different studies were performed (four in the corridor and four in the closed room) during thermal cutting in coated metal parts. Studies were performed at higher wind speed (turbulent) and at lower wind speed (laminar). Particle concentration measurements were made using 9 optical aerosol monitors simultaneously.


Thermal cutting measurements - Dispersion

The image above shows the 30 m corridor and the image below shows a schematic of the test setup as seen from above. The red dot represents the production source, i.e. where the thermal cutting is performed.

Nine particle concentration instruments were placed at different lengths and heights, downwind from the thermal cutting spot.

Measurements were also performed in a closed off room with dimensions, 12x4x4 m.

Figure 5.2 The test designs for the thermal cutting measurements.

The measurements during thermal cutting showed that a low air speed (0.2-0.35 m/s) in the corridor resulted in a higher particle concentration at higher altitudes along the corridor, the same was found to be true at both 6 m and 12 m from the thermal cutting spot. This shows that at a low air speed the emitted aerosol quickly rises to the ceiling during cutting. At a higher air speed, that yields higher turbulence along the corridor, this phenomenon is less evident since the aerosol was dispersed more evenly across the entire cross section of the corridor. The concentration declined to one third after 24 m, because of the dispersion of the particles. In the closed room the aerosol first levitated to the ceiling, then followed the interior boundaries of the room; first along the ceiling and then downwards along the walls and eventually it reached the floor. The thermal cutting operations in the closed room also showed that after 4 hours, the particle concentration was still 50 % of the concentration during thermal cutting.

5.3 Conclusions

The simulation model for the closed room showed similar results compared to the experimental findings, while for the corridor, there were larger discrepancies. The computer model and the real life particle measurements both showed that there will be no exposure upstream from the thermal cutting spot. It can also be concluded that at a high wind speed, the larger turbulence will result in a greater dispersion of the plume.

To establish criteria for boundary zones from this limited study is not realistic. However, the study suggests that with enough time and resources, it seems possible to establish a computer model for boundary zones using empirical data from a number of experiments of some typical cases. There will still be a need for knowledge of the wind direction, wind speed and turbulence and the geometries of the work sites.

6 Development of a direct reading isocyanate instrument prototype with additionals

6.1 Aim of the study

Recent results from measurements in offshore petroleum industry show that emission during hot work is complex. Organic compounds such as isocyanates, aldehydes and anhydrides will be emitted due to the thermal decomposition of surface coatings. A fast, direct reading instrument can be used as an alarm instrument when the isocyanate concentrations rise above a certain level. It would also be of great use when performing occupational measurements and to determine the boundary zone.

The goal was to develop a prototype of a direct reading instrument for all types of isocyanates. Previous direct reading instruments have only been able to measure aliphatic and aromatic diisocyanates.

6.2 Development of prototype

The direct reading instrument is based on a new sensitive reagent which changes colour when it reacts with isocyanates. The intensity of the colour is dependent on the isocyanate concentration. Filter paper is impregnated with the reagent solution, the filter paper strips are inserted into a detector unit, which can measure the colour change when the isocyanates react with the reagent on the filter paper. A specially designed miniaturized UV-detector was developed, see Figure 6.1.

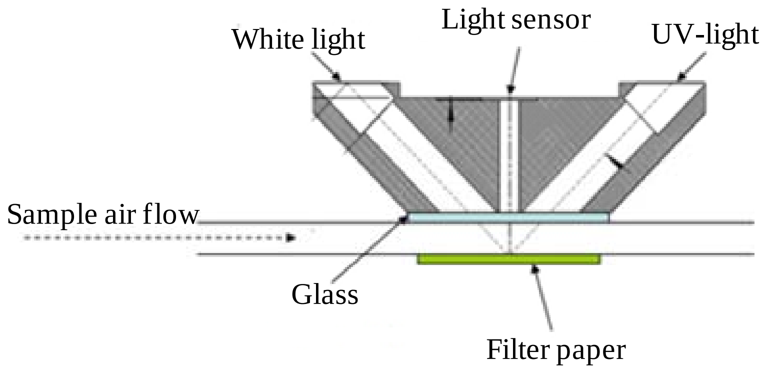


Figure 6.1 Schematic picture of the isocyanate detector part of the prototype.

The prototype consists of: a filter paper impregnated with a reagent solution, an air pump, isocyanate detector, control unit, data logging unit, interface to an external computer and optional connections to camcorders and other direct reading instruments. During the development four generations of prototypes have been made.

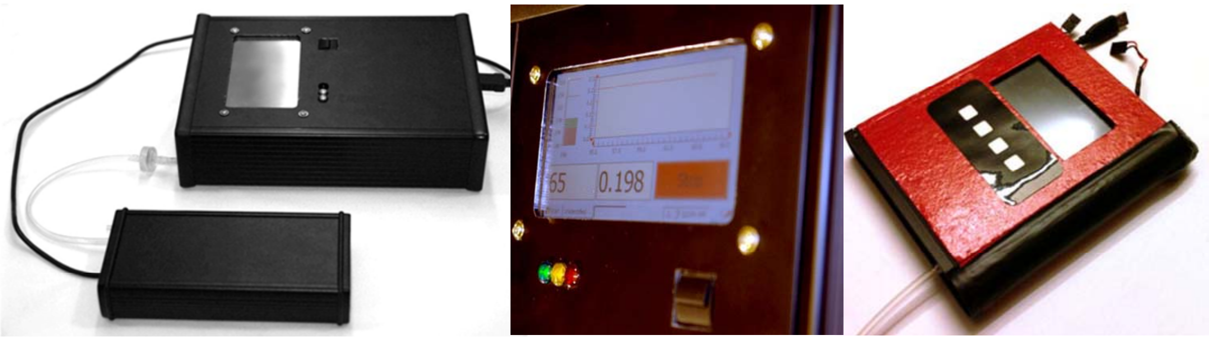


Figure 6.2 The second and third generation of the prototype.

When sampling isocyanates, which are very reactive compounds, the materials used in the sampler have to be chosen carefully. Extensive testing of what materials are suitable for sampling of isocyanates have been made at IFKAN and this research was used when the prototype was constructed.

6.3 Conclusions

The direct reading instrument is able to measure concentrations of isocyanates in air, including monoisocyanates, such as isocyanic acid (ICA) and methyl isocyanate (MIC). However, the direct reading instrument needs further development to be commercially available.

7 Evaluation of a dry sampler for isocyanates

7.1 Aim of the study

The concentration of isocyanates in air is traditionally measured through sampling using impinger flasks. Drawbacks associated with impinger flasks are that they are inconvenient to attach on the worker during work, they break easily and they contain flammable solvents. In order to overcome these drawbacks a dry sampler was developed, see Figure 7.1.

Isocyanates are present in the air in both gaseous form and as particles (aerosols), hence a sampler needs to be able to collect both phases. The dry sampler (EasySampler) consists of a denuder and glass filter impregnated with DBA (dibutylamine) in a solution of acetic acid. Gas phase isocyanates in the air passing through the sampler are absorbed onto the inner walls of the denuder and react with DBA to stable derivatives. Meanwhile, isocyanate particles are deposited on the glass fibre filter where they react with DBA.

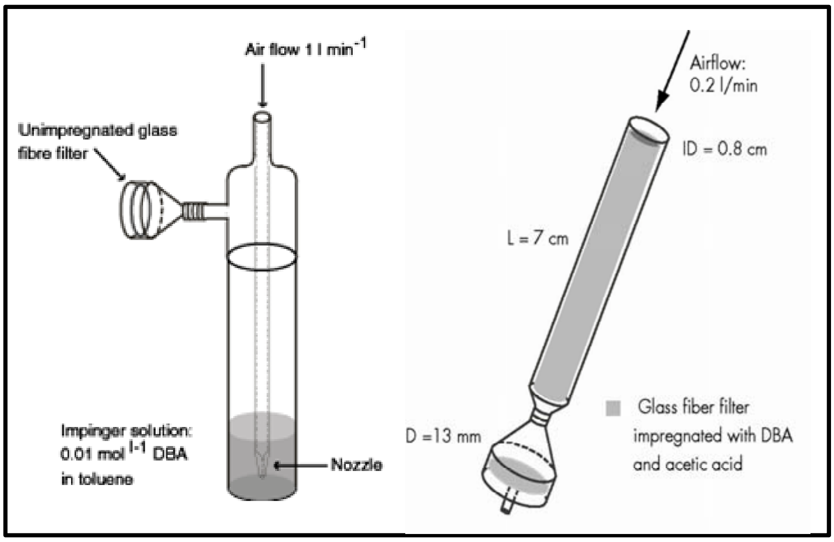


Figure 7.1 An impinger flask (left) and an Easysampler (right). Grey areas of the Easysampler show impregnated filters.

7.2 Test Procedure

The EasySampler was validated using impinger flasks as reference at various relative humidity (20, 40, 60 and 90 %RH). Isocyanates were generated by heating of polyurethane (PUR) in a test chamber (300 l) in order to create a realistic simulation of particles and compounds formed during cutting of, for instance, PUR coated pipes and measurements using EasySamplers were performed. The samples were then stored in darkness at room temperature for 0, 1, 2, 3, 7 and 15 days prior to work up.

7.3 Results

The measured concentration of various isocyanates – Isocyanic acid (ICA), Methyl isocyanate (MIC), Ethyl isocyanate (EIC), Propyl isocyanate (PIC), Phenyl isocyanate (PhI), Hexamethylene diisocyanate (HDI), 2,6-Toluene diisocyanate (2,6-TDI), 2,4-Toluene diisocyanate (2,4-TDI) and Methylenediphenyl diisocyanate (MDI), using the Easysampler compared to impinger flasks. At 20, 40 and 60% relative humidity at room temperature in the ambient air, the measured concentration of these isocyanates using EasySamplers correlates well with the impinge results. At 90 %RH, however, the ICA levels in the impinge samples are significantly lower compared to EasySamplers.

After storage of the EasySamplers for 15 days prior to work up, the measured concentration, of a number of various isocyanates did not differ compared to EasySamplers that were worked up the same day as the samples were taken.

7.4 Conclusions

The EasySampler has been shown to be a convenient alternative to impinger-filter sampling. Several important benefits using this dry sampler are: easy handling in the field, easy transport to the laboratory and storage possibilities up to 15 days before analysis.

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