Norsk institutt for luftforskning
Norwegian Institute for Air Research

VOC measurements in vicinity of a silicon smelter

Passive air sampling around United Silicon, Iceland

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NILU report 35/2017

NILU report 35/2017		CLASSIFICATION: C C – Confidential
DATE 04.10.2017	SIGNATURE OF RESPONSIBLE PERSON Ole-Anders Braathen, Dep.dir. (sign.)	NUMBER OF PAGES 25
TITLE VOC measurement in vicinity of a silicon smelter Passive air sampling around United Silicon, Iceland		PROJECT LEADER Hilde Thelle Uggerud NILU PROJECT NO. O-117066
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ABSTRACT

On behalf of Multiconsult ASA, a pilot study of VOC within and around a silicon smelter, United Silicon, has been carried out. The silicon smelter is located at Reykjanesbær in Iceland. 10 Tenax tubes were used as passive samplers and placed in a residential area and close to the silicon smelter, both inside and outside the plant. The samples were taken between 21.05.2017 and 23.06.2017. The concentrations found are typical for outdoor air in summertime. High values of anhydrides were found in samples collected inside the baghouse. Otherwise, the concentrations were low.

To identify a possible daily profile of the gas composition in the emissions during startup and shutdown of the silicon smelter, 12 samples were taken from inside the baghouse, by the use of evacuated gas-sampling cylinders. 1-3-5- Trioxane which is a polymerisation product of formaldehyde, are present in these samples. This indicate higher concentrations of formaldehyde, which is not covered by the measurement technique used.

NORWEGIAN TITLE

VOC-målinger rundt et silisiumsmelteverk, Passiv prøvetaking rundt United Silicon, Island

KEYWORDS

[Skriv stikkord] [Skriv stikkord] [Skriv stikkord]

ABSTRACT (in Norwegian)

På oppdrag fra Multiconsult ASA, har det blitt utført en pilotstudie av VOC rundt silisiumsmelteverket United Silicon. Smelteverket er lokalisert i Reykjanesbær i Island. 10 Tenaxrør ble brukt som passive prøvetakere og plassert i et boligområde nær smelteverket, samt inne i fabrikken og på utsiden av denne. Prøvetakingen foregikk i perioden 21.05.2017 til 23.06.2017. Konsentrasjonene funnet i boligområdet er typiske for uteluft ved sommertider. Høye verdier av anhydrider ble funnet i prøvene fra innsiden av posehuset. Ellers var konsentrasjonene lave.
For å identifisere en mulig daglig profil av gassammensetningen i utslippet ved oppstart og nedstenging av verket, ble det tatt 12 luftprøver inne i posehuset, ved bruk av evakuerte gassflasker. I disse prøvene ble det funnet 1-3-5- Trioxane, som er et polymerisasjonsprodukt av formaldehyd. Funnet kan tyde på at formaldehyd er tilstede, men målemetoden som er benyttet her er ikke egnet for bestemmelse av denne forbindelsen.

PUBLICATION TYPE: Digital document (pdf)	COVER PICTURE: Source: NILU

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Summary

On assignment from Multiconsult ASA, a pilot study of VOC within and around a silicon smelter, United Silicon, has been carried out. The silicon smelter is located at Reykjanesbær in Iceland. 10 Tenax tubes were used as passive samplers and placed in a residential area and at the silicon smelter, both inside and outside the plant. The samples were taken between 21.05.2017 and 23.06.2017. The VOC concentrations found in the residential area are typical for outdoor air in summertime. The concentration found in the furnace house is rather low, emissions in the very low milligram per m^3 range can be considered as quite clean industrial processes where combustion of wood or coal is involved. The composition of the samples do not show uncommon compounds for combustion processes where wood is involved. The samples taken inside the baghouse are showing high concentrations of Phenyl maleic anhydride and in addition, other anhydrides at lower concentrations. Anhydrides are irritants to skin, eyes and the respiratory system. The same compounds are also found in the samples taken outside the baghouse, but at far lower concentrations.

To study the daily profile of the gas composition in the emissions during startup and shutdown of the silicon smelter, 12 samples were taken from inside the baghouse, by the use of evacuated gas-sampling cylinders. Overall, the concentration levels of the compounds found are quite low. However, 1-3-5- Trioxane which is a polymerisation product of formaldehyde, is present in the samples. This indicate higher concentrations of formaldehyde, which is not covered by the measurement technique used.

VOC measurements in vicinity of a silicon smelter
Passive air sampling around United Silicon, Iceland

1 Introduction

The purpose of the VOC (volatile organic compounds) measurement campaign was to identify compounds in the emissions from United Silicon's Factory that may have a potential as irritants for the surrounding habitants. The VOC campaign consisted of 3 different parts. One should cover VOC-concentrations at a background site and within the habituated vicinity of the factory, the second should focus on daily VOC-profiles within the factory during startup and shutdown, while the third should focus on VOC-emissions within the furnace house and the baghouse and in addition cover diffusive emissions from the factory as a whole.

1.1 Sampling method

Our approach was based on non-target screening – the choice of sampling and measurement techniques is based on semi-quantitative broadband methods. NILU has more than three decades of extensive experience with VOC measurements in indoor, outdoor, industrial, rural, urban and background environment. Several thousand measurements during that time period have been used to build up a database of several hundred compounds which are common in those environments. The database is used, together with several other commercially available mass spectra databases, to identify VOC's taken on adsorption tubes. Sampling with adsorption tubes can be done by means of a pump (active sampling) or by diffusive sampling (passive sampling). For VOC broadband measurements - Tenax TA is the preferred adsorbent. The content on the sample tubes is thermo desorbed at the laboratory, focused on cold traps (-30° Celsius), separated on a Gas Chromatograph and detected by a Mass Spectrometer.
Because of the very short time between the involvement of NILU into the project and the startup of the measurements, those robust and broad VOC measurement techniques have been chosen.

VOC is a complex group of compounds spreading from hydrocarbons, halocarbons, aromatic compounds, ketones and aldehydes, organic acids, ethers, N and S containing compounds. On Tenax adsorption tubes most of those compounds can be sampled and analyzed – but since the volatility of the compounds is covering a range from a boiling point of 10 to 300 °C not all compounds are sampled in the same quantitative matter. On the other hand - the tubes give on a relative base - very comparable results.

Some compounds that could occur in the emissions of a silicon factory, like Formaldehyde and Acetaldehyde or COS, will not be detected by the chosen measurement technique, because of their high volatility. Compounds bound to particle emissions will also not be detected. The most high-boiling compounds to be detected are 3-ring PAHs.

2 Part 1: VOC in living areas surrounding of the factory

One passive sample was taken in a residential area between the 17 and 27 June 2017 – the sample was marked "Garden South". The results are shown in Table 1.

Table 1: VOC result from sample taken in residential area

Sampling site	**Garden south**	
Sample id/tube id	Id 214	
Sampling period	17-27 June 2017	
Component	**Concentration** Toluene-equivalents (µg m^{-3})	**CAS no**
Nonanal	16,8	124-19-6
1-Butanol	7,3	000071-36-3
Acetic acid	5,3	000064-19-7
2,2,4,6,6-pentamethyl heptane	5,2	13475-82-6
Hexanal	4,8	000066-25-1
Cyclopentane	4,6	287-92-3
Toluene	4,4	108-88-3
1-Octene	3,6	000111-66-0
Octanal	3,4	124-13-0
hexamethyl cyclotrisiloxane (D3)	3,2	541-05-9
Decane	3,0	124-18-5
Hexane	2,6	110-54-3
3-carene	2,5	13466-78-9
Heptanal	2,2	111-71-7
2-ethyl-1-hexanol	2,2	104-76-7
Cyclopentane, methyl-	2,0	000096-37-7
octamethyl cyclotetrasiloxane (D4)	2,0	556-67-2
2-methylpentane	1,8	107-83-5
2-Hexene	1,8	000592-43-8
decamethyl cyclopentasiloxane (D5)	1,8	541-02-6
Butanal	1,6	000123-72-8
alfa pinene	1,2	80-56-8
Nonane	1,1	000111-84-2
Limonene	1,1	138-86-3
2-hydroxy benzaldehyde (salicylaldehyde)	1,1	90-02-8
p-and m- Xylene (1,4 og 1,3 dimethylbenzene)	1,0	106-42-3
Pentane	0,8	109-66-0
Undecane	0,8	1120-21-4
Dodecane	0,8	112-40-3
1-ethoxy-2-propanol	0,7	1569-02-4
Total concentration of identified compounds	**102,1**	
Number identified components	35	
Total concentration of volatile compounds (TVOC)	**149,8**	
Number of components included in TVOC (conc. > 0,1 µg m^{-3})	202	
Sample received	29 June 2017	
Sample analysed	06 August 2017	

2.1 Results and discussion

The total amount of VOC is 150 µg/m^3. This is a typical concentration for outdoor air in a residential area in summertime. As a comparison, Indoor air concentrations of VOC in European houses are normally between 100 and 250 µg/m^3.

The main sources are emissions from vehicles and building materials and atmospheric degradation products. Vehicles emissions are toluene, xylenes and alkane hydrocarbons ranging from pentane to pentadecane. Building material emissions are mono-terpenes like alfa- pinene , 3- carene and limonene from wood and vegetation; siloxanes are quite common emissions from all kind of artificial material and are to be found both indoors and outdoors; aldehydes like hexanal, heptanal, octanal and nonanal are oxidation products mostly from a reaction of tropospheric ozone with all kind of hydrocarbons and the photochemically induced degradation of hydrocarbons by sunlight.

There are no compounds in the sample which are showing unusually high concentrations and there are no compounds among the 35 with the highest concentrations which are not normal to be found in background air or suburban or urban air.

And most important – the compounds with the highest concentrations measured in the furnace house and inside the baghouse – naphthalenes and anhydrides are not detected in the sample.

3 Part 2: Flask sampling during startup and shutdown of the factory

The samples of the daily profiles during startup and shutdown of the factory were taken with evacuated gas-sampling cylinders and transferred to Tenax tubes at NILU. The samples were taken inside - on top of the bag house - as spot samples within 15 minutes once every day between May 21 and June 1. Sampling using canisters is mostly suited for the light fraction of VOC – starting with light boiling compounds like acetone and ending with naphthalene.
In all of the 12 samples were about 50 compounds which are in a concentration range that enables a positive identification. The results of the most dominating compounds and compounds normally not present in outdoor air are summarized in table 2 In a search for uncommon compounds and known irritants the most common compounds normally to be found in outdoor air like Benzene, Toluene or Xylenes or C7 to C20 Alkanes are excluded in further discussions. Overall - the concentration levels of the compounds are quite low – ranging from a few µg/ m^3 to 3 mg/m^3. The compounds with the highest concentrations are siloxanes and are most probably not from the furnace processes, but from building materials within the factory – most probably the bag house and its inventory.

As an overall evaluation of the 12 samples we would conclude, that we (with the used method) could not identify any compound at concentration levels, which could have effects on the population in surrounding villages. A conservative assumption of the dilution of 10 to 100 thousand would still give very low doses at those sites.

There is however a compound which could be taken into closer considerations for further investigations. 1-3-5- Trioxane (Cas nr 110-88-3) is a polymerization product of formaldehyde. The concentration levels are not very high – between 13 and 53 µg/m^3, but its presence should indicate far higher concentrations of formaldehyde. Formaldehyde is not covered by our measurement method - but there are several quite simple measurement techniques available for both active and passive sampling of formaldehyde. The formation of Formaldehyde within the processes of the factory are very likely and could probably vary to a high extent during the processes of startup and shutdown. Formaldehyde is a known irritant and very much is known about its health effects.

Table 2 Results from analysis of air sampled in evacuated canisters (µg m^{-3})

Component	**Cas no**	**Sampling date**											
		May 21	May 22	May 23	May 24	May 25	May 26	May 27	May 28	May 29	May 30	May 31	June 1
Trioxane	110-88-3	13	12	13	17	16	24	19	56	14	27	23	13
Siloxane-D3	541-05-9	80	212	245	171	930	385	640	1204	248	367	1526	346
Dimethylaminoacetonitrile	926-64-7	0	3	28	10	39	40	61	65	24	26	46	31
Nitroso dimethylamine	62-75-9	0	0	15	0	31	21	26	68	16	24	38	14
Siloxane-D4	556-67-2	59	138	90	128	913	515	498	2387	234	392	3045	247
2-ethyl-1-hexanol	411-44-8	36	43	33	84	25	23	51	109	19	56	52	27
Naphthalene dione	2906-90-3	139	174	188	220	167	161	190	441	122	154	197	194
Naphthalene	91-20-3	5	6	16	17	22	6	22	64	15	9	18	21

4 Part 3: Emissions at the factory

In this sampling approach the focus was on VOC's emissions within the furnace house and the baghouse and in addition cover diffusive emissions from the factory as a whole. Having in mind that the emissions from the top of the bag house are the bulk part of the factory emissions, while the gases measured in the furnace house only contribute to a less extent to the total emissions. The sample taken outside the roof of the baghouse should give a good indication of the factories diffusive emissions.

4.1 Emissions within the furnace house

Inside the furnace house three samples were taken over the periods 21th May to 9th June , 9th June to 16th June and 16th June to 23rd June. The samples were taken on Tenax tubes – based on diffusive sampling. The sampling sites are shown in the pictures following the report.

4.2 Results and discussion

The results are an average concentration over the whole sampling period of 19 days for the first period and one week for the others. A compound could be emitted in very high concentrations at a shorter time period and low concentrations at others, but still show an average concentration like another compounds which is not variating at all during the whole period. Another important fact is that the calculated concentration using diffusive sampling is very temperature dependent. The known uptake rates for Tenax tubes are normally valid for

ambient temperatures. A temperature of 20 degrees higher could lower the uptake rate by 50 % so that the reported concentrations are underreported by a factor of 2.

The results are shown in the detailed sample reports at the end of this section.

The total concentration of about 200 detectable compounds is about 750, 850 and 1100 µg/m^3.

In all three samples, the 40 compounds with the highest concentrations account for about 66% of the total VOC concentration. There are two groups of components - which account for over 80 % of the concentration of the identified compounds. The first group are Naphthalene and its derivatives together with light PAHs and the other group consists of alkane hydrocarbons and light aromatic compounds.

The total concentration is rather low, emissions in the very low milligram per m^3 range can be considered as quite clean industrial processes where combustion of wood or coal is involved. The composition of the samples do not show uncommon compounds for combustion processes where wood is involved.

The bulk part of the exhaust from the furnace house, as it is measured here, will not be emitted to the outdoors and it undergoes an extensive oxidation process before it enters the baghouse. Only diffusive emissions from the furnace house will show the pattern of the samples taken inside the furnace house.

Naphthalenes, light PAHs and aromatic compounds show low odour threshold to humans. The composition and concentration levels of the three samples would definitely be detectable by humans and the odour could definitely be associated with “burnt materials”. And even a dilution of some tens to hundreds could still be detected by a human nose. We cannot exclude that there could be certain meteorological conditions where diffusive emissions from the factory could be noticed in the surroundings of the factory – but in average – the dilution would be several factors higher and it will not be possible to smell those emissions. The sample taken at Garden South shows no evidence for long term conditions of naphthalene emissions.

Table 3 VOC from sample taken inside the furnace house

Sampling site	USI-2 Furnace house	
Sample id/tube id	Id 701	
Sampling period	21 mai-9 June 2017	
Component	**Concentration** Toluene-equivalents (µg m^{-3})	**CAS no**
Naphthalene	51,3	000091-20-3
Naphthalene, 1-methyl-	36,6	000090-12-0
styrene (ethenylbenzene)	34,5	100-42-5
Dibenzofuran	26,0	000132-64-9
Acenaphthene	25,0	000083-32-9
Naphthalene, 2-methyl-	22,9	000091-57-6
Biphenylene	15,7	000259-79-0
tetradecane	15,0	629-59-4
hexadecane	13,6	544-76-3
phenol	13,3	108-95-2
toluene	12,9	108-88-3
Naphthalene, 1,6-dimethyl-	12,0	000575-43-9
tridecane	11,5	629-50-5
pentadecane	11,4	629-62-9
o-xylene (1,2-dimethylbenzene)	11,3	95-47-6
Naphthalene, 2,3-dimethyl-	10,7	000581-40-8
dodecane	10,6	112-40-3
Biphenyl	10,6	000092-52-4
Anthracene	10,1	000120-12-7
octadecane	8,5	593-45-3
benzene	8,4	71-43-2
benzaldehyde	8,4	100-52-7
Naphthalene, 1,4-dimethyl-	7,7	571-58-4
undecane	7,3	1120-21-4
Naphthalene, 2-ethyl-	7,0	000939-27-5
nonadecane	6,2	629-92-5
acetophenone	6,1	98-86-2
octamethyl cyclotetrasiloxane (D4)	6,0	556-67-2
1,1'-Biphenyl, 4-methyl-	6,0	000644-08-6
1H-Inden-1-one, 2,3-dihydro-	5,6	000083-33-0
1-methoxy-2-propyl acetate	5,5	108-65-6
2,6,10-Trimethyltridecane	5,2	003891-99-4
Naphthalene, 1,2,3,4-tetrahydro-1,4-dimethyl-	5,2	004175-54-6
1,2-Naphthalenedione	5,2	000524-42-5
Benzene, 1-ethenyl-2-methyl-	5,1	000611-15-4
Benzene, 2-ethenyl-1,4-dimethyl-	4,9	002039-89-6
p-and m- Xylene (1,4 og 1,3 dimethylbenzene)	4,7	106-42-3
Total concentration of identified compounds	**468,1**	
Number identified components	37	
Total concentration of volatile compounds (TVOC)	**763,4**	
Number of components included in TVOC (conc. > 0,1 µg m^{-3})	212	
Sample received	16 June 2017	
Sample analysed	19 June 2017	

Table 4 VOC from sample taken inside the furnace house

Sampling site	USI-2 Furnace house	
Sample id/tube id	Id 427	
Sampling period	9 -16 June 2017	
Component	**Concentration** Toluene-equivalents (µg m^{-3})	**CAS no**
naphthalene	39,0	91-20-3
o-xylene (1,2-dimethylbenzene)	39,0	95-47-6
Acenaphthene	32,4	000083-32-9
2-methylnaphthalene	28,6	91-57-6
Heptadecane	28,2	000629-78-7
1-methylnaphthalene	19,1	90-12-0
tetradecane	18,6	629-59-4
tridecane	15,4	629-50-5
hexadecane	14,8	544-76-3
pentadecane	14,5	629-62-9
dodecane	13,3	112-40-3
Toluene	13,0	000108-88-3
nonanal	13,0	124-19-6
phenol	12,7	108-95-2
Biphenylene	12,6	000259-79-0
Naphthalene, 2,7-dimethyl-	12,5	000582-16-1
Naphthalene, 2,3-dimethyl-	12,4	000581-40-8
Octadecane	11,9	000593-45-3
2-phenoxyethanol	10,7	122-99-6
benzaldehyde	10,3	100-52-7
undecane	10,2	1120-21-4
1,1'-biphenyl	9,5	92-52-4
p-and m- Xylene (1,4 og 1,3 dimethylbenzene)	9,2	106-42-3
nonadecane	8,4	629-92-5
decane	8,1	124-18-5
Naphthalene, 1,6-dimethyl-	7,8	575-43-9
octamethyl cyclotetrasiloxane (D4)	7,6	556-67-2
Naphthalene, 1,3-dimethyl-	7,1	000575-41-7
3-methyltetradecane	7,0	18435-22-8
acetophenone	6,8	98-86-2
Benzene, 1-methyl-4-(2-propenyl)-	6,7	003333-13-9
1H-Indene, 2,3-dihydro-1,1,3-trimethyl-3-phenyl-	6,5	003910-35-8
Naphthalene, 1,2,3,4-tetrahydro-6-methyl-	6,4	001680-51-9
benzene	6,4	71-43-2
Nonadecane, 9-methyl-	6,1	013287-24-6
2-methyltridecane	6,1	1560-96-9
2,2,4,6,6-pentamethyl heptane	5,5	13475-82-6
Phenanthrene	5,2	000085-01-8
1-Butanol	5,2	000071-36-3
Total concentration of identified compounds	**507,7**	
Number identified components	39	
Total concentration of volatile compounds (TVOC)	**858,9**	
Number of components included in TVOC (conc. > 0,1 µg m^{-3})	215	
Sample received	16. June 2017	
Samples analysed	6.August.2017	

Table 5 *VOC from sample taken inside the furnace house*

Sampling site	USI-2 Furnace house	
Sample id/tube id	Id 142	
Sampling period	16-23June 2017	
Component	Concentration Toluene-equivalents (µg $m^{-3)}$	CAS no
Nonadecane	81,0	000629-92-5
Naphthalene, 1,2,3,4-tetrahydro-5-methyl-	45,0	002809-64-5
octamethyl cyclotetrasiloxane (D4)	38,8	556-67-2
Octadecane	35,6	000593-45-3
Naphthalene, 1-methyl-	29,2	000090-12-0
Biphenyl	25,4	000092-52-4
Naphthalene, 1,2,3,4-tetrahydro-1,4-dimethyl-	24,9	004175-54-6
benzaldehyde	24,8	100-52-7
Naphthalene	24,7	000091-20-3
1,1'-Biphenyl, 3-methyl-	23,4	000643-93-6
4-methyltetradecane	18,9	25117-24-2
Phenol, 2-methyl-	18,3	000095-48-7
Naphthalene, 2,3-dimethyl-	15,8	000581-40-8
acetophenone	15,7	98-86-2
Naphthalene, 2,6-dimethyl-	13,6	000581-42-0
Naphthalene, 2-methyl-	13,3	000091-57-6
p-and m- Xylene (1,4 og 1,3 dimethylbenzene)	12,2	106-42-3
Heptadecane, 2-methyl-	11,8	001560-89-0
undecane	11,7	1120-21-4
toluene	11,6	108-88-3
pentylcyclohexane	11,5	4292-92-6
Naphthalene, 2,3-dimethyl-	11,2	000581-40-8
2-methyldodecane	10,5	1560-97-0
hexadecane	9,8	544-76-3
Heptadecane	9,8	000629-78-7
pentadecane	9,6	629-62-9
Acenaphthene	9,5	000083-32-9
Tridecane	9,3	000629-50-5
Naphthalene, 2,7-dimethyl-	8,8	000582-16-1
benzene	8,7	71-43-2
4,6,6-trimethyl-bicyclo[3.1.1]hept-3-en-2-one (verbenone)	8,6	80-57-9
phenol	8,3	108-95-2
dodecane	8,0	112-40-3
tetradecane	7,4	629-59-4
o-xylene (1,2-dimethylbenzene)	7,4	95-47-6
2-methyltridecane	7,3	1560-96-9
Biphenylene	7,1	000259-79-0
Total concentration of identified compounds	**648,5**	
Number identified components	37	
Total concentration of volatile compounds (TVOC)	**1076,6**	
Number of components included in TVOC (conc. > 0,1 µg m-3)	209	
Sample received	29 June 2017	
Sample analysed	6 August 2017	

4.3 Emissions within the baghouse

Inside the Baghouse two samples were taken over the periods 21 May to 9 June and 16 June to 23 June. The sampling sites are shown in the pictures following the report.

4.4 Results and discussion

The samples taken inside the baghouse are showing high concentrations of Phenyl maleic anhydride (cas nr 36122-35-7). This compound should stay as a solid until its melting point at 160°C. So very little of this compound should be airborne at temperatures below 100 °C. The fact that the concentration in the gas phase is so high is pointing towards a much higher overall concentration – since most of the compound will be particle bound or as crystals. There are other anhydrides in the sample – like Phthalic anhydride (cas nr 85-44-9) pointing to the fact that anhydrides could form during the process.

In both samples benzoic acid and acetophenone are among the compounds with highest concentrations – both can be formed as a sampling artefact when Tenax is exposed to both high temperatures and high concentrations of oxidants like ozone. But both can also be formed by oxidation of aromatic compounds - which are definitely in the gases from the furnace house and ozone or other oxidants.

Like in the furnace house the overall concentrations are low – 600 and 1300 µg/m^3. The inflow of naphthalenes, PAHs and hydrocarbons from the furnace house is mirrored within the sample composition. Also here the same argumentation for both the odour potential and dilution towards the vicinity of the factory is valid.

Anhydrides are irritants to skin, eyes and the respiratory system. The high boiling point favours transport in the particle phase. We recommend to follow up the presence of anhydrides in both emissions and deposition in the surrounding areas. Using methods especially suited for the sampling and analysis of those compounds.

4.5 Phenylmaleic anhydride

Written by NILU's toxicologist, Dr. Espen Mariussen

There is very little information available about health effects and toxicity of phenylmaleic anhydride. We have not been able to find any information about the compound in the scientific literature by search on Google, PubMed or Web of Knowledge. The compound can be purchased from commercial suppliers, from which safety data sheet (SDS) has been obtained. According to the SDS from one of the distributors (Fisher scientific) the chemical is considered hazardous by the 2012 OSHA Hazard Communication Standard (29 CFR 1910.1200). According to Globally Harmonized System of Classification and Labelling of Chemicals (GHS), the chemical has a relatively low acute toxicity and defined as a category 4 chemical. A category 4 chemical has estimated oral lethal concentration of 300-2000 mg/kg body weight. As gas, the chemical is presumed to be lethal at 2500-5000 ppm, and between 10 and 20 mg/l as vapour and between 1 and 5 mg/l as dust/mist. The chemical is categorized as a skin and eye irritant, which by definition is a chemical, which is not corrosive, but which

causes a reversible inflammatory effect on living tissue by chemical action at the site of contact. The respiratory system is considered the main target organ. According to the classification criteria of GSH for specific target organ toxicity (single exposure) the chemical is a category 3 chemical, which is defined as a chemical that following a single acute exposure temporarily may cause narcotic effects such as dizziness and drowsiness, and respiratory tract irritation, such as sore throat and cough.

Table 6 *VOC from sample taken inside the baghouse*

Sampling site	USI-3 Baghouse inside	
Sample id/tube id	Id 724	
Sampling period	21 May-09 June 2017	
Component	Concentration Toluene-equivalents (µg m^{-3})	CAS no
Phenylmaleic anhydride	187,6	036122-35-7
acetophenone	60,6	98-86-2
Phthalic anhydride	45,7	000085-44-9
benzoic acid	31,0	65-85-0
Dibenzofuran	17,2	000132-64-9
naphthalene	17,0	91-20-3
Benzoylformic acid	15,7	000611-73-4
benzonitrile	15,5	100-47-0
Benzeneacetonitrile,alpha oxo	13,3	613-90-1
Anthracene	11,6	000120-12-7
benzaldehyde	11,5	100-52-7
Biphenyl	10,4	000092-52-4
phenol	7,9	108-95-2
sulfur dioxide	7,2	7446-09-5
3-phenyl-2-propenal	6,8	104-55-2
Diphenyl ethanedione	4,8	134-81-6
1,2-Naphthalenedione	4,5	524-42-5
Phenol, 2-nitro-	4,4	000088-75-5
tridecane	4,3	629-50-5
1H-Indene, 2,3-dihydro-1,1,3-trimethyl-3-phenyl-	3,8	003910-35-8
Biphenylene	3,4	000259-79-0
1H-Indene-1,3(2H)-dione	3,4	000606-23-5
1,3-Isobenzofurandione, 4-methyl-	3,2	004792-30-7
Diethyl Phthalate	2,8	000084-66-2
acetic acid	2,8	64-19-7
tetradecane	2,7	629-59-4
octamethyl cyclotetrasiloxane (D4)	1,9	556-67-2
9,10-Phenanthrenedione	1,9	000084-11-7
4-Methylphthalic anhydride	1,8	019438-61-0
Phenol, 4-methyl-2-nitro-	1,7	000119-33-5
1,4-Naphthalenedione	1,6	000130-15-4
Total concentration of identified compounds	**508,0**	
Number identified components	31	
Total concentration of volatile compounds (TVOC)	**608,0**	
Number of components included in TVOC (conc. > 0,1 µg m-3)	182	
Sample received	16 June 2017	
Sample analysed	19 August 2017	

Table 7 *VOC from sample taken inside the baghouse*

Sampling site	USI-3 Baghouse, inside	
Sample id/tube id	Id 63	
Sampling period	16 -23 June 2017	
Component	Concentration Toluene-equivalents (µg m^{-3})	CAS no
Benzoic acid	353,4	000065-85-0
Phenylmaleic anhydride	144,0	036122-35-7
Acetophenone	119,9	000098-86-2
Benzonitrile	48,7	000100-47-0
Naphthalene	42,6	000091-20-3
Phthalic anhydride	40,7	000085-44-9
Benzaldehyde	26,6	000100-52-7
Benzeneacetonitrile,alpha oxo	21,6	613-90-1
sulfur dioxide	19,2	7446-09-5
Cyclotrisiloxane, hexamethyl-	16,3	000541-05-9
Diethyl Phthalate	16,2	000084-66-2
Phenol, 2-nitro-	14,5	000088-75-5
1-Butanol	13,8	000071-36-3
Ethanedione, diphenyl-	13,6	000134-81-6
Acetic acid	13,3	000064-19-7
Phenol	11,5	000108-95-2
Dibenzofuran	10,8	000132-64-9
Octanoic acid	9,7	000124-07-2
Cyclotetrasiloxane, octamethyl-	9,5	000556-67-2
5-Methyl-2-nitrophenol	8,3	000700-38-9
Biphenyl	8,2	000092-52-4
Tridecane	7,9	000629-50-5
Nonanenitrile	7,0	002243-27-8
Phenanthrene	5,7	000085-01-8
Toluene	5,4	000108-88-3
Dodecane	5,2	000112-40-3
Undecane	5,0	001120-21-4
2-methylhexane	5,0	591-76-4
Ethanedione, diphenyl-	4,5	000134-81-6
decamethyl cyclopentasiloxane (D5)	4,5	541-02-6
Total concentration of identified compounds	**1012,7**	
Number identified components	30	
Total concentration of volatile compounds (TVOC)	**1297,1**	
Number of components included in TVOC (conc. > 0,1 µg m-3)	187	
Sample received	29 June 2017	
Sample analysed	06 August 2017	

4.6 Emissions from outside the baghouse

On the outside of the baghouse three samples were taken over the periods 21 May to 9 June , 9 June to 16^{h} June and 16 June to 23^{d} June. The samples were taken on Tenax tubes based on diffusive sampling

4.7 Results and discussion

The results are an average concentration over the whole sampling period of 19 days for the first period and one week for the others. The samples are taken outside – meant to cover diffusive emissions from leaks and vents of the factory. Meteorological conditions like wind speed would have a major influence on the total concentrations taken up by the passive samplers.

The concentrations are lower, as expected. The samples do show the same compounds as the emissions from the baghouse and furnace house. The concentrations of phenylmaleic anhydride are 4.4 µg/m^3, 4.5 µg/m^3 and 2.5 µg/m^3. It should be noticed - that already here so close to the main emission vents from the baghouse - the dilution is already quite big and there are no compounds showing a concentration level higher than 20 µg/m^3.

Table 8 *VOC from sample taken outside the baghouse*

Sampling site	USI-1 Baghouse, outside	
Sample id/tube id	Id 221	
Sampling period	21 may-9 June 2017	
Component	Concentration Toluene-equivalents (µg m^{-3})	CAS no
acetophenone	12,8	98-86-2
benzaldehyde	12,4	100-52-7
hexamethyl cyclotrisiloxane (D3)	9,5	541-05-9
octamethyl cyclotetrasiloxane (D4)	9,0	556-67-2
phenol	8,4	108-95-2
Phenol, 3-methyl-	6,9	000108-39-4
pentadecane	6,6	629-62-9
naphthalene	6,1	91-20-3
heptadecane	5,1	629-78-7
Sulfur dioxide	4,7	7446-09-5
toluene	4,6	108-88-3
acetic acid	4,5	64-19-7
Phenylmaleic anhydride	4,4	036122-35-7
hexadecane	4,2	544-76-3
p-and m- Xylene (1,4 og 1,3 dimethylbenzene)	4,1	106-42-3
2-methylnaphthalene	3,6	91-57-6
decane	3,5	124-18-5
2-furancarboxaldehyde	3,3	98-01-1
2,2,4,6,6-pentamethyl heptane	3,3	13475-82-6
benzonitrile	3,2	100-47-0
dodecamethyl cyclohexasiloxane (D6)	3,1	540-97-6
tridecane	3,0	629-50-5
Benzene	2,8	000071-43-2
1-methylnaphthalene	2,6	90-12-0
Phenol, 4-methyl-2-nitro-	2,6	000119-33-5
1,2-propanediol	2,6	57-55-6
decamethyl cyclopentasiloxane (D5)	2,6	541-02-6
octadecane	2,5	593-45-3
undecane	2,4	1120-21-4
Naphthalene, 1,6-dimethyl-	2,3	000575-43-9
2-phenoxyethanol	2,2	122-99-6
nonane	2,2	111-84-2
1,2,4-trimethylbenzene	2,1	95-63-6
dodecane	2,1	112-40-3
o-xylene (1,2-dimethylbenzene)	2,1	95-47-6
Total concentration of identified compounds	**157,5**	
Number identified components	35	
Total concentration of volatile compounds (TVOC)	**277,8**	
Number of components included in TVOC (conc. > 0,1 µg m-3)	209	
Sample received	16 June 2017	
Sample analysed	19 June 2017	

Table 9 *VOC from sample taken inside the baghouse*

Sampling site	USI-1 Baghouse, outside	
Sample id/tube id	Id 139	
Sampling period	9.-16.June 2017	
Component	Concentration Toluene-equivalents (µg m-3)	CAS no
Phenol, 2-nitro-	17,9	000088-75-5
hexanoic acid	16,6	142-62-1
Phenol	14,5	000108-95-2
Naphthalene, 2-methyl-	13,9	000091-57-6
tetradecane	11,8	629-59-4
hexamethyl cyclotrisiloxane (D3)	10,2	541-05-9
Phenol, 3-methyl-	9,7	000108-39-4
Nonanal	8,6	000124-19-6
p-and m- Xylene (1,4 og 1,3 dimethylbenzene)	8,5	106-42-3
Dibenzofuran	8,3	000132-64-9
nonane	7,7	111-84-2
2,4-dimethylheptane	7,5	2213-23-2
Toluene	7,0	000108-88-3
Ethanol, 2-phenoxy-	6,8	000122-99-6
Isonitrosoacetophenone	6,6	000532-54-7
Benzene	6,3	000071-43-2
Benzaldehyde	6,3	000100-52-7
Diethyl Phthalate	6,0	000084-66-2
Heptane, 2,2,4,6,6-pentamethyl-	5,9	013475-82-6
Acetic acid	5,0	000064-19-7
decamethyl cyclopentasiloxane (D5)	4,9	541-02-6
n-Hexane	4,7	000110-54-3
Nonanoic acid	4,7	112-05-0
octamethyl cyclotetrasiloxane (D4)	4,5	556-67-2
Phenylmaleic anhydride	4,5	036122-35-7
Pentadecane	4,2	000629-62-9
Phthalic anhydride	4,1	000085-44-9
Benzaldehyde, 2-hydroxy-	4,0	000090-02-8
1-Phenoxypropan-2-ol	3,7	000770-35-4
Phenanthrene	3,5	000085-01-8
Naphthalene	3,2	000091-20-3
Butanoic acid	3,2	000107-92-6
Decane	3,2	000124-18-5
Acetophenone	3,1	000098-86-2
Furfural	3,1	000098-01-1
1-Butanol	3,0	000071-36-3
Total concentration of identified compounds	**246,7**	
Number identified components	36	
Total concentration of volatile compounds (TVOC)	**528,2**	
Number of components included in TVOC (conc. > 0,1 µg m-3)	199	
Sample received	29 June 2017	
Sample analysed	06 August 2017	

Table 10 *VOC from sample taken inside the baghouse*

Sampling site	USI-1 Baghouse, outside	
Sample id/tube id	Id 505	
Sampling period	16-23 June 2017	
Component	Concentration Toluene-equivalents (µg m-3)	CAS no
1-Butanol	12,6	000071-36-3
decamethyl cyclopentasiloxane (D5)	10,3	541-02-6
Phenol	8,4	000108-95-2
toluene	7,4	108-88-3
1-Phenoxypropan-2-ol	5,7	000770-35-4
Acetophenone	5,7	000098-86-2
nonane	5,5	111-84-2
Dibenzofuran	5,2	000132-64-9
cyclohexane	4,9	110-82-7
Phenol, 2-nitro-	4,7	000088-75-5
sulfur dioxide	4,5	7446-09-5
hexamethyl cyclotrisiloxane (D3)	4,2	541-05-9
heptane	3,1	142-82-5
Ethanol, 2-phenoxy-	2,8	000122-99-6
MALEIC ANHYDRIDE, PHENYL-	2,5	36122-35-7
Anthracene	2,3	000120-12-7
pentadecane	2,3	629-62-9
propylcyclopentane	2,1	2040-96-2
hexane	2,1	110-54-3
Diethyl Phthalate	2,1	000084-66-2
Cyclopentane, methyl-	2,1	000096-37-7
benzonitrile	2,1	100-47-0
2,2,4,6,6-pentamethyl heptane	2,0	13475-82-6
o-xylene (1,2-dimethylbenzene)	1,8	95-47-6
Benzene	1,8	000071-43-2
Acetic acid	1,8	000064-19-7
Butyrolactone	1,8	000096-48-0
benzaldehyde	1,8	100-52-7
Naphthalene	1,7	000091-20-3
Phthalic anhydride	1,6	000085-44-9
octamethyl cyclotetrasiloxane (D4)	1,6	556-67-2
hexanoic acid	1,5	142-62-1
tridecane	1,5	629-50-5
p-and m- Xylene (1,4 og 1,3 dimethylbenzene)	1,5	106-42-3
decane	1,4	124-18-5
Nonanal	1,4	000124-19-6
TXIB (2,2,4-Trimethyl-1,3-pentanediol diisobutyrate)	1,3	6846-50-0
Total concentration of identified compounds	**127,1**	
Number identified components	37	
Total concentration of volatile compounds (TVOC)	**211,8**	
Number of components included in TVOC (conc. > 0,1 µg m-3)	200	
Sample received	29 June 2017	
Sample analysed	06 August 2017	

5 Literature

1- Safety data sheet Phenylmaleic anhydride, Thermo Scientific, 26th may 2017
2- OSHA (2016). US Occupational safety and health administration. Hazard Classification Guidance for Manufacturers, Importers, and Employers. OSHA 3844-02 2016. www.osha.gov.

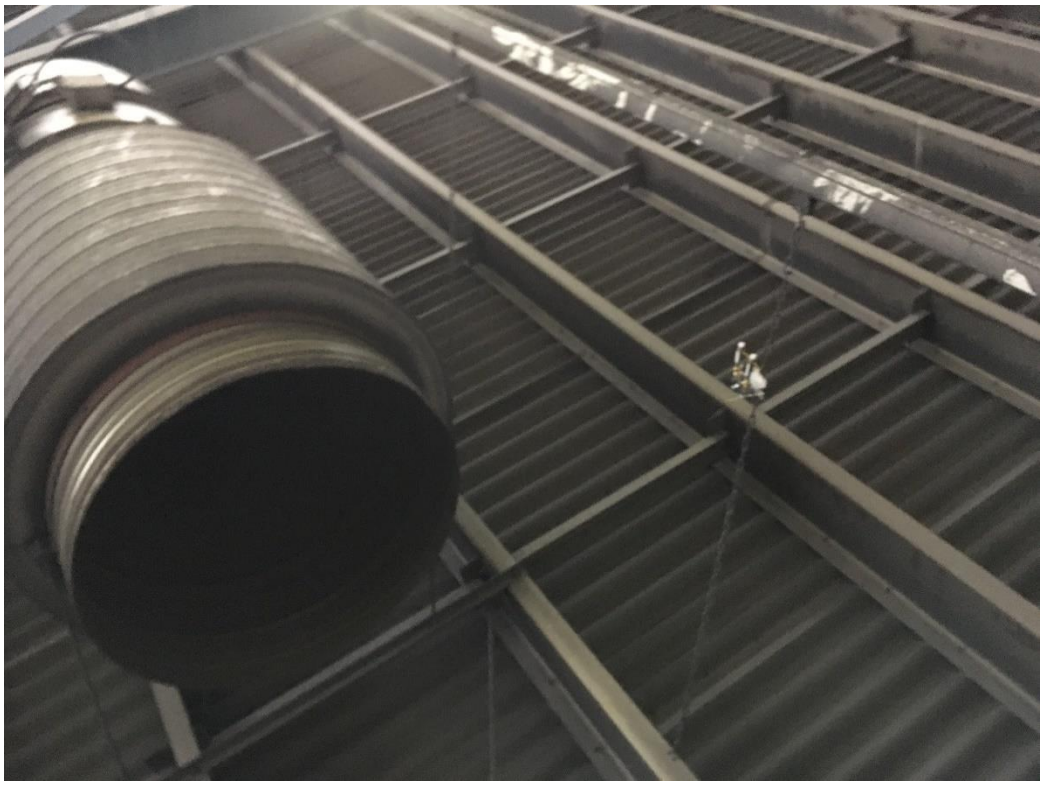

Figure 1 Location of samplers besides vents inside furnace house at site USI-2.

Figure 2 Tenax tubes at site USI-2

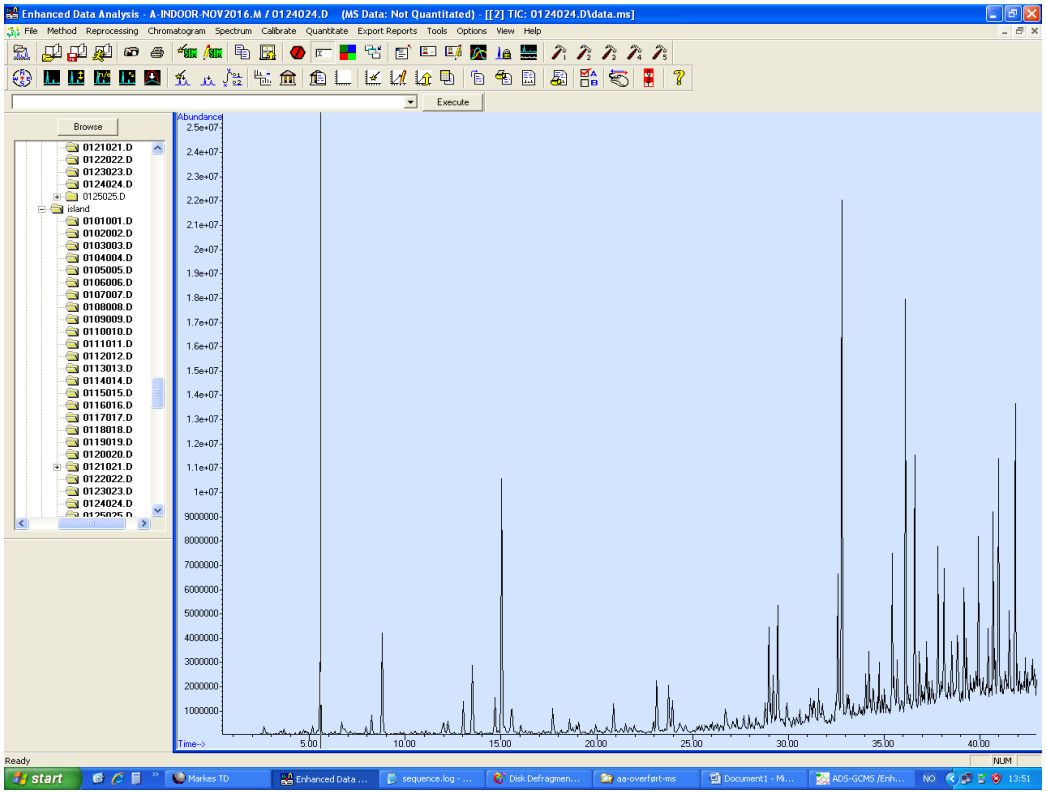

Figure 3 Spectrum from sample taken inside furnace house (site USI-2)

Figure 4 Sampling site USI-1, outside baghouse. The samplers are marked with red circle.

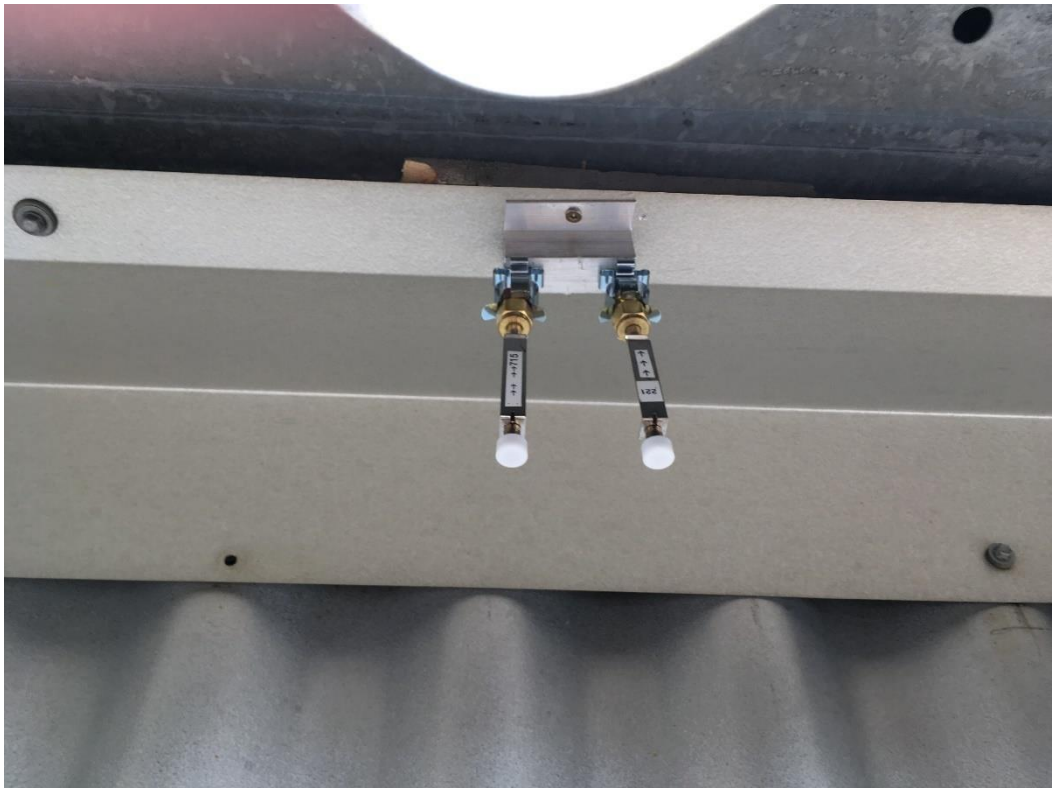

Figure 5 Tenax tubes at site USI-1, outside baghouse.

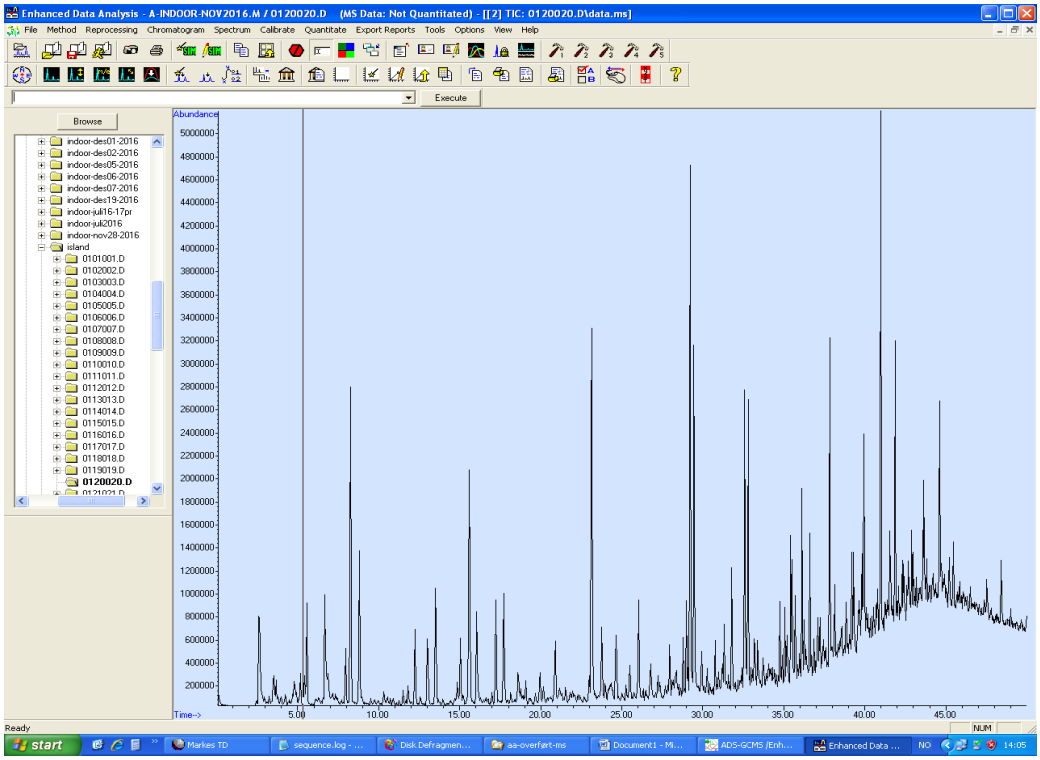

Figure 6 Spectrum from sample taken at site USI-1.

Figure 7 Sampling site USI-3, inside baghouse. The samplers are marked with red circle.

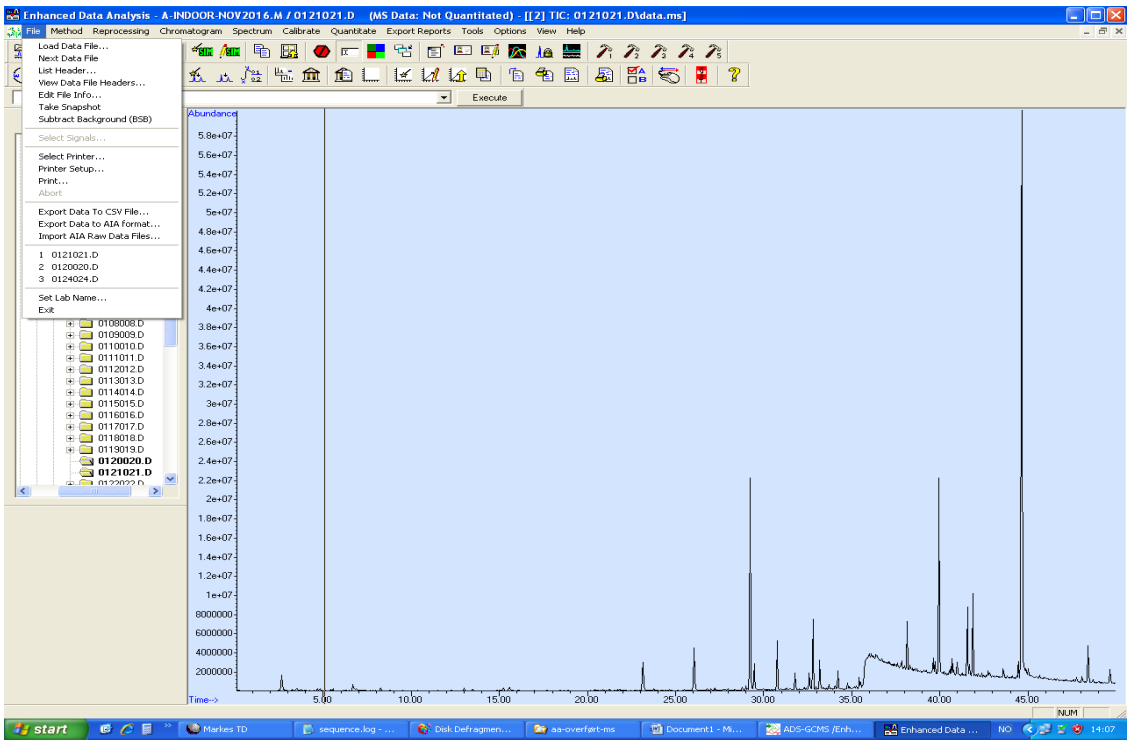

Figure 8 Spectrum from sample taken at site USI-3, inside baghouse.

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