



Green Foundry LIFE project (LIFE17 ENV/FI/173)

Action B2 Total emission and indoor air quality measurements of pilot foundries

DeB1B Results of indoor air quality and occupational hygiene measurements in organic binder system Karhula Foundry in Finland



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1 Introduction

1.1 Green Foundry Project

The goal of the Green Foundry Project (LIFE17 ENV/FI/173) is to demonstrate the new clean technology of moulding systems in practice. The new inorganic moulding system is based on the use of aluminum phosphate or silicate basis, which reduces the amount of harmful components indoors, in ambient air, and in the surplus foundry sand. The techniques and methods demonstrated in this project are aimed to improve the EU-wide uptake of more environmentally friendly casting processes. The demonstrations will be carried out on a transnational level to increase the dissemination and awareness of the project.

The occupational hygiene measurements are part of the Green Foundry LIFE project activities (Action B2 Total emission and indoor air quality measurements of pilot foundries) and they were carried out in Karhula foundry on 24-25TH April 2019, 21.4.2019 and 21.1.2020.

1.2 Karhula Foundry

Karhula Foundry Ltd in Finland is one of the five pilot foundries in the project where the total emissions and one of the four pilot foundries where indoor air quality is measured. Karhula foundry locates in the city of Kotka, east coast Finland, at the industrial area of Karhula. The foundry was originally founded in 1880´s and is currently owned by three Finnish foundry and machine shop specialists.

Karhula Foundry currently produces steel casting products. Current production is approximately 1200 tons/a, technical production capacity being 12000 tons/a. Casting products are primarily unique pump and mixer parts.

1.3 Primary processes of the Karhula Foundry

Mould cores are primarily made of extremely pure quartz sand (SiO_2). Chromite sand (Cr_2O_3) is used in smaller quantities in mould cores when higher heat tolerance is required. The sand is dried, cooled and dust is removed before mixing the sand and adhesive in a sand mixer. Most of the sand is recycled from the casting process.

Casting moulds and some of the mould cores are primarily produced by Alphaset ® -method, where Quartz or Chromite sand is mixed with phenol resin and ester hardener in a closed mixer. The sand-adhesive mixture is pressed either manually or mechanically on a casting model and dried. After the model is removed a Zircon-based surface agent is applied to the mould surface in order to improve the heat tolerance of the casting moulds. After casting and cooling the moulds are removed in closed, under pressured vibrator/shake-out containers that have separate dust exhaust system and a

sand collection system, where the used sand is crushed, screened and pneumatically moved to storage silos for recycling.

Casting moulds are also produced by the Cold-Box method, where sand is mixed with a phenol resin, MDI-isocyanate and iron powder in a closed mixer. The sand-adhesive mixture is blown into a casting mould box with pressurized air. Heated DMEA (Dimethyl diamine) gas is then blown through the tightly formed mould in order to cause the phenol resin and MDI-isocyanate to react and form a solid urethane resin that binds the sand granules. Casting mould boxes are dried, and a Zircon-based surface agent is applied before casting. Odorous amine fumes that form within the closed Cold-Box process are washed with Sulfuric acid solution in an amine scrubber that operates by reverse-flow principal.

Melting is done in load-operated electric arc furnace (8 tons) and mid-frequency induction furnaces (0,5 tons, 1,5 tons and 8 tons). The melt contains primarily scrap iron and ferro mixtures as 85-90 % of the melt load is recycled material. The melt can also be processed in AOD (Argon-Oxygen-Decarburization) converter (8 tons), where cheaper raw-materials containing more carbon can be used. Each of the furnaces and the converter are equipped with fume- and dust extraction hoods, that collect to the smelter filter unit.

Melted steel is casted to moulds by fireproof crucibles that are pre-heated by Methane-Oxygen burners. After the cast some of the adhesives of the moulds and casting moulds are vaporized to the indoor air and the fumes collected by the general ventilation of the foundry building. Indoor air quality of the foundry is measured regularly by mandatory occupational hygiene measurements. Indoor air quality is also monitored by automatic Carbon Monoxide (CO) and natural gas detectors.

The cast articles are cleaned in a closed shot blasting machines that are equipped with filters. Cast residuals are removed either by closed abrasive cutoff machines, or in closed cutoff cells equipped with filter units by powder- and Arc-Air methods that produce large amounts of metallic fumes and dust.

1.4 Occupational Hygiene

According to the International Occupational Hygiene Association, the term occupational hygiene refers to the discipline of anticipating, recognizing, evaluating and controlling health hazards in the working environment with the objective of protecting worker health and well-being and safeguarding the community at large. Occupational Hygiene can also be defined as the practice of identifying hazardous agents; chemical, physical and biological; in the workplace that could cause disease or discomfort, evaluating the extent of the risk due to exposure to these hazardous agents, and the control of those risks to prevent ill-health in the long or short term.

Exposure agents can be examined by measurements and the health risks are evaluated in respect, in this case, to guideline values presented in the current Finnish legislation, such as HTP (Haitalliseksi Tunnettu Pitoisuus i.e. “Known Harmful Concentration”) -values provided by the Finnish Ministry of Social and Health Services. The Finnish reference values, as well as the Finnish legislation concerning occupational hygiene in general, are aligned with EU legislation (for example IOELV and BOELV). The occupational hygiene measurements were executed and evaluated according to SFS-EN:689 (2018)¹, SFS-EN 481:2001² and SFS 3861:2000³-standards.

1.5 Occupational Hygiene measurements at the Karhula Foundry

Occupational hygiene measurements were carried out on 24-25th of April 2019 during the normal foundry production. Measurements were done in the production area of the foundry’s Cold-Box -method Core Making unit, Pouring/Cooling line and large Vibrator/Shake-out machine. Measurement staff selected the most suitable and representative measurement points in co-operation with the foundry staff.

The measurement range covered all relative components in respect to the foundry’s current production and operations.

Pictures of the occupational hygiene measurement arrangements are presented in the end of this report.

2 Measurement Results

2.1 Main results

In most parts, worker exposure levels are relatively low, with levels below 10% of HTP values. The exception is formaldehyde, the HTP value of which is exceeded by vibrating and carbon monoxide with an HTP value exceeded in casting.

The particle concentration in the formula is also moderately high at 35 % of the HTP.

All analysis results are presented in Table 1-5 and Figure 1-4.

2.2 TVOC and Hydrocarbons

Hydrocarbon concentrations were measured in Core Making/Cold-box working station and in Pouring/Cooling line. Measurement results are presented in Table 1.

Table 1. Measured TVOC and Hydrocarbon concentrations

Measurement time	24.4.2019 at 08:17-14:50		24.4.2019 at 10:28-17:44	
Measurement Point	Core Making Cold-Box	Percentage of HTP(8h)-value	Cooling Line	Percentage of HTP(8h)-value
Volatile Organic Compound (VOC)	mg/Nm ³	%	mg/Nm ³	%
Acetone	0,1	0	0,7	0,1
Benzofuran	0,02	n/a	0,0	n/a
Benzene	0,02	n/a	1,2	n/a
Butanes	0,05	0	0,2	0
Ethyl acetate	0,1	0	0,1	0
Ethyl benzene	0,02	0	0,02	0
Ethanol	21,1	1,1	8,0	0,4
2-Ethyl-1-Hexanol	0,05	0,9	0,1	1,7
Ethylhexyl acetate	0,05	n/a	0,0	n/a
Glyceryl triacetate	0,1	n/a	0,7	n/a
3-Carene	0,02	n/a	0,02	n/a
Xylene	0,02	0	0,2	0,1
Methyl acetate	0,7	0,1	0,5	0,1
2-Butanone	0,2	n/a	0,1	n/a
Alfapinene	0,02	n/a	0,0	n/a
2-Propanol	7,8	n/a	3,8	n/a
Styrene	0,02	0	0,1	0,1
Toluene	0,02	0	0,2	0,3
1,3,5-Trimethyl benzene	0,02	n/a	0,2	n/a
Other VOCs	0,1	0	0,9	0,1
TVOC	30	2	15	3

2.3 Aldehydes

Aldehyde concentrations were measured in Core Making/Cold-box and large Vibrator/Shake-out -machine working stations and in Pouring/Cooling line. Measurement results are presented in Table 2.

Table 2. Measured Aldehyde concentrations.

Measurement time	24.4.2019 at 08:17-14:50		24.4.2019 at 10:28-17:44		25.4.2019 at 07:44-12:04	
Measurement point	Core Making Cold-Box	Percentage of HTP(8h)-value	Pouring/ Cooling Line	Percentage of HTP(8h)-value	Vibrator/ Shake-out	Percentage of HTP(8h)-value
Aldehydes	mg/m ³	%	mg/m ³	%	mg/m ³	%
Asetaldehyde	0,05	n/a	0,0	n/a	0,1	n/a
Benzaldehyde	0,003	0,1	0,003	0,1	0,002	0
Butanal	0,02	n/a	0,007	n/a	0,07	n/a
Dekanal	0,004	n/a	0,004	n/a	0,002	n/a
Formaldehyde	0,33	88	0,26	69	0,38	103
Hexanal	0,004	n/a	0	n/a	0	n/a
Heptanal	0,002	n/a	0	n/a	0	n/a
Nonanal	0,006	n/a	0	n/a	0	n/a
Octanal	0,001	n/a	0	n/a	0	n/a
Pentanal	0,001	n/a	0	n/a	0	n/a
Propanal	0,003	n/a	0	n/a	0	n/a
total	0,4	88	0,4	70	0,7	103

2.4 Phenols and Cresols

Phenol and Cresol concentrations were measured in Core Making/Cold-box and large Vibrator/Shake-out -machine working stations and in Pouring/Cooling line. Measurement results are presented in Table 3.

Table 3. Measured concentrations of Phenols and Cresols.

Measurement time	24.4.2019 at 08:17-14:50		24.4.2019 at 10:28-17:44		25.4.2019 at 07:44-12:04	
Measurement Point	Core Making Cold-Box	Percentage of HTP(8h)-value	Cooling Line	Percentage of HTP(8h)-value	Vibrator/ Shake-out	Percentage of HTP(8h)-value
Phenols and Cresols	<i>mg/Nm³</i>	%	<i>mg/Nm³</i>	%	<i>mg/Nm³</i>	%
2-Methylphenol	0,0001	n/a	0,012	n/a	0,0001	n/a
Phenol	0,001	0	0,004	0	0,0002	0
3- and 4-Methylphenol	0,00005	n/a	0,004	n/a	0,00003	n/a
total	0,001	0	0,02	0	0,0003	0,0

2.5 Amines

The results are not available due to the false sample tubes.

2.6 Inorganic Dust

Inorganic dust concentrations were measured in Core Making/Cold-box and large Vibrator/Shake-out -machine working stations. Inorganic dust is not significantly present in Pouring/Cooling line. Measurement results are presented in Table 4.

Table 4. Measured Inorganic Dust concentrations.

Measurement Point	Measurement			Measured concentration	Percentage of HTP(8h)-value
		start	stop		
	<i>date</i>	<i>time</i>	<i>time</i>	<i>mg/m³</i>	%
Core Making/Cold-box	24.4.2019	8:19	14:50	0,4	4
Vibrator/Shake-out	25.4.2019	7:44	12:04	1,5	15

Measurement Point	Measurement			Measured concentration	Percentage of HTP(8h)-value
		start	stop		
	<i>date</i>	<i>time</i>	<i>time</i>	<i>mg/m³</i>	%
Core Making/Cold-box	21.1.2020	7:46	14:35	0,49	5
Vibrator/Shake-out	21.1.2020	7:49	14:36	0,48	5

2.7 Fine Quartz Dust

Fine Quartz Dust concentrations were measured in Core Making area during the making of large cores as part of previous occupational hygiene measurements done on February 19th 2019 by AX-Consulting. Report of the measurements (AX-Raportti 12989Y19A)⁹ is available upon request. Measurement results are presented in Table 5.

Table 5. Measured Fine Quartz Dust concentrations

Measurement point	Measurement			Measured concentration <i>mg/m³</i>	Percentage of HTP(8h)-value %
	date	start time	stop time		
Core making	19.2.2019	8:09	14:49	0,0075	15
Core making, area	19.2.2019	during active work		0,0177	35

Measurement Point	Measurement			Measured concentration <i>mg/m³</i>	Percentage of HTP(8h)-value %
	date	start time	stop time		
Core Making/Cold-box	21.1.2020	7:46	14:35	0,0069	14
Vibrator/Shake-out	21.1.2020	7:49	14:36	0,0069	14

2.8 Carbon Monoxide

Carbon Monoxide (CO) levels were measured 24.4.2019 with a recording measurement device in the Pouring/Cooling -line, where CO emissions are primarily induced. Measurement results are presented in Figure 1.

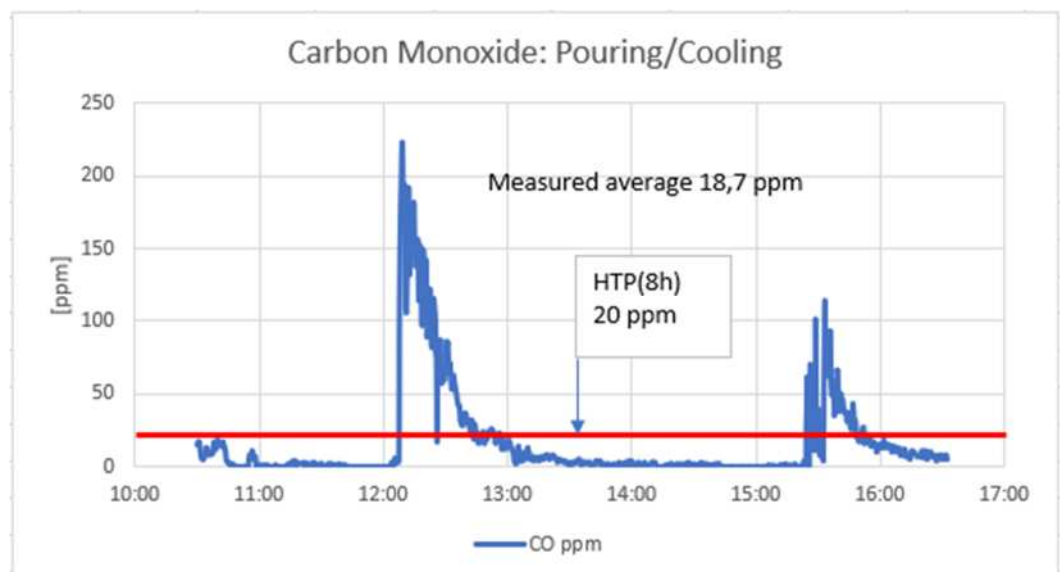


Figure 1. Measured CO levels in Pouring/Cooling working area

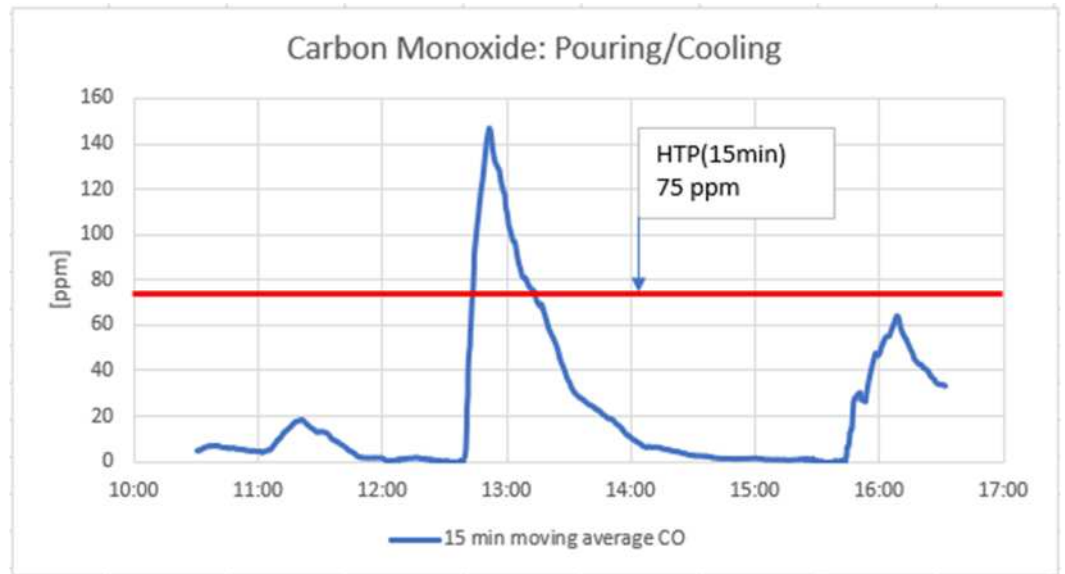


Figure 2. Measured fifteen minutes moving average CO levels in Pouring/Cooling working area

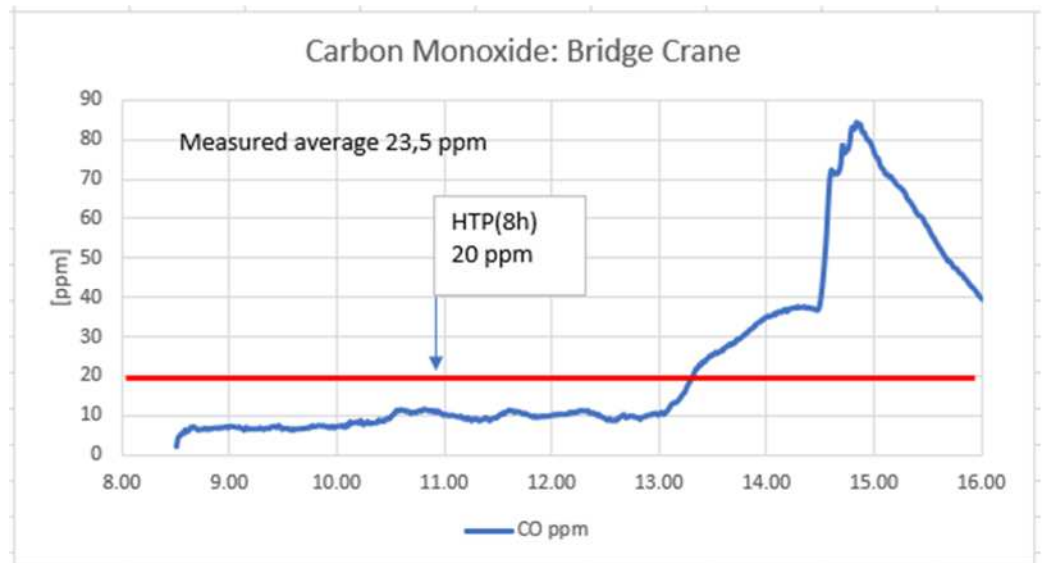


Figure 3. Measured CO levels in Bridge Crane in Control Cabine

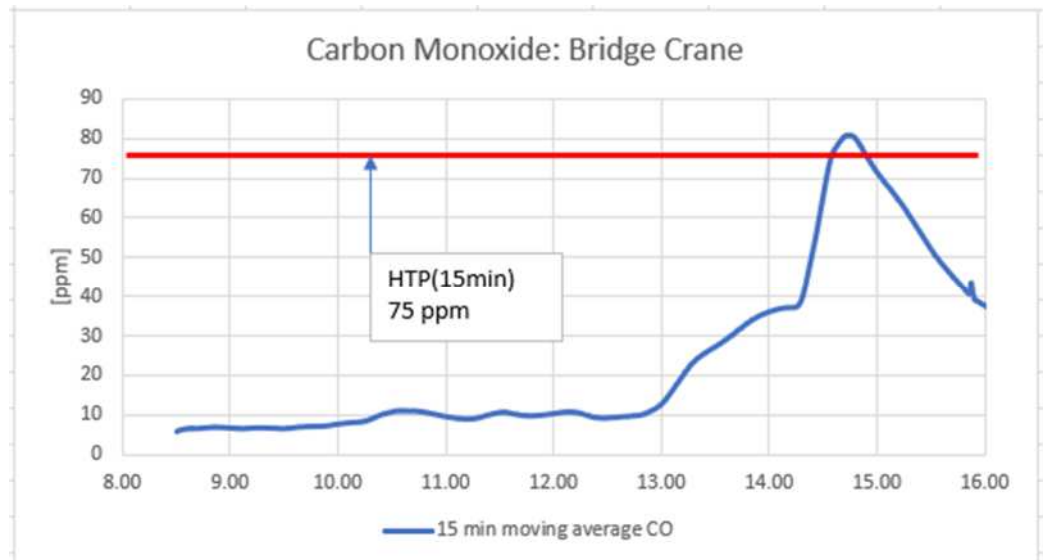


Figure 4. Measured fifteen minutes moving average CO levels in Bridge Crane in Control Cabine

Pouring in the Pouring/Cooling line began at approximately 12:00, that can clearly be seen in Figure 1. A smaller series of pouring took place at around 15:15. During the pouring the CO levels rose well above the reference values (HTP_{8h} 20 ppm and HTP_{15min} 75 ppm) and decreased below the recommended 20 ppm level in approximately one hour. Pouring took place also in other parts of the factory during the day of the measurements.

3 Reference Values

Measured concentrations have been compared to available national reference values.

Guideline values i.e. HTP -values (Haitalliseksi Tunnettu Pitoisuus i.e. “Known Harmful Concentration”) according to the current Finnish legislation are presented in Table 6. HTP-values are provided by the Finnish Ministry of Social and Health Services⁴. All compounds measured at the Karhula Foundry’s occupational hygiene measurements are not presented in the table, because HTP -values are not provided for all compounds in question.

Table 6. National guideline values applied in Finland.

HTP-values			
	Compound	HTP value	
		8 h	15 min
		mg/m ³	
	Inorganic Dust	10	n/a
	Respirable Dust *	0,5	
	Carbon Monoxide	23	87
	<i>Carbon Monoxide</i>	<i>20 ppm</i>	<i>75 ppm</i>
	Quartz	0,05	n/a
	Creosol	22	45
	Phenol	8	16
Aldehydes	Acetaldehyde	n/a	46
	Benzaldehyde	4,4	17,4
	Formaldehyde	0,37	1,2
	Hexanal	n/a	42
	Propionaldehyde	48	n/a
VOC	Acetone	1200	1500
	Butane	1900	2400
	Ethanol	1900	2500
	Ethyl acetate	730	1470
	Ethyl benzene	220	880
	2-Ethyl hexanol	5,4	n/a
	Methyl acetate	610	770
	Propanol	500	620
	Styrene	86	430
	Toluene	81	380
	Trimethylbenzene	100	n/a
	Xylene	220	440
TVOC *	Desired value	300	
	Reference value	3000	

* Finnish Institute of Occupational Health

Finnish Institute of Occupational Health^{5,6} (Työterveyslaitos, TTL) provides reference values for respirable dust and TVOC -levels based on current research knowledge. Desired values for respirable dust and TVOC and a reference value (for actions in order to investigate and limit the exposure) for TVOC are also presented in Table 6. These values are not given in respect to 8h or 15 min exposure, and contain certain limitations concerning for example applying the values for workplaces where solvents or such are used in large amounts.

National respiratory tract exposure scale classification⁷ in respect to HTP - values is presented in Table 7 in order to clarify the interpretation of the measurement results.

Table 7. Respiratory exposure scale.

Exposure % of HTP-value	Exposure scale
less than 10%	low
10...50 %	moderate
50...100 %	significant
over 100 %	excessive

Required minimum level of the ventilation system operation is that the impurities remain below the given HTP -values. In general, it is considered that decent level for the indoor air compound concentrations in industrial facilities is 10 % of the HTP -values⁸.

4 Production During the Measurements

The measurements were carried out during two normal production days. The production amounts according to the information provided by the melting shop operators are presented in Table 8.

Table 8. Production amounts during the measurements.

		Melted	Casted	
Date	Time (casting)	kg	kg	note
Apr.24th	10:00-10:15	1900	1200	
	12:40-12:55	1900	1900	
	16:10-16:25	1680	1460	
	19:10-19:15	602	292	
Apr.25th	11:00	1800	1800	
	11:00-11:15		30	Chamber Test
	14:00-14:20	9900	6800	
	14:45-14:55	1800	1800	

5 Measurement Staff

Occupational hygiene measurements were executed by Mr. Tommi Granroth (B.Sc. Environmental Engineering) and Mr. Mikael Fingerroos (M.Sc. Environmental Sciences) from AX-LVI Consulting Ltd.

Mr. Pekka Kempainen, President of the Karhula Foundry, represented the client concerning measurement arrangements.

6 Procedure

The measurements were conducted according to SFS-EN 689 (2018)¹, SFS-EN 481 (2001)² and SFS-3861 (2000)³ -standards.

6.1 TVOC and hydrocarbons

Total Volatile Organic Carbon (TVOC) concentrations and hydrocarbons were measured from a sample taken from the indoor air with a sample pump in a Tenax -adsorbent tube. Simultaneous samples were taken with charcoal tubes from the Core Making and Pouring measurement points. Vibration/Shake-out was not measured because of the nature of the process, that produces practically no hydrocarbon emissions to the indoor air.

Tenax tube samples were analyzed by an accredited laboratory: Eurofins Environment Testing Finland, Lahti (FINAS T039) that fulfils the requirements of SFS-EN ISO/IEC 17025:2017 -standard, whereas charcoal tube samples were analyzed by an accredited laboratory: Työterveyslaitos, Helsinki (FINAS T013) that fulfils the requirements of SFS-EN ISO/IEC 17025:2005 -standard. The hydrocarbon compounds were detected with Gas Chromatograph -analysis.

Tenax sample tube results have not been used, because the quantification limit of the analyzing method was too low. Thus, the concentrations were analyzed only from charcoal sample tubes.

6.2 Aldehydes

The concentrations of aldehydes were measured from a sample taken in a Sep-Pak (DNPH) sample tube from the indoor air with a sample pump. The analyses were carried out at an accredited laboratory: Eurofins Environment Testing Finland, Lahti (FINAS T039) that fulfils the requirements of SFS-EN ISO/IEC 17025:2017 -standard, by High Performance Liquid Chromatography (HPLC) method.

6.3 Phenols and Cresols

The concentrations of Phenols and Cresols were measured from a sample taken in a XAD-II sample tube from the indoor air with a sample pump. The analyses were carried out according to ISO 16200-1 (2001) -standard at an accredited laboratory: Eurofins Product Testing Denmark A/S that fulfils the requirements of ISO 17025 DANAK -standard, by Solvent Desorption/Gas Chromatography method.

6.4 Amines

The concentrations of amines were measured from a sample taken with a XAD-II Supelco sample tube from the indoor air with a sample pump.

The analyses could not be carried out because the provided sample tubes were not suitable for Dimethylethylamine (C₄H₁₁N).

6.5 Inorganic Dust

Inorganic dust concentration was measured from a sample taken with a cellulose filter with a sample pump. The samples were analyzed by the accredited testing laboratory of AX-Consulting (FINAS T232), that fulfils the requirements of SFS-EN ISO/IEC 17025:2005 -standard.

6.6 Fine Quartz Dust

Respirable dust sample was taken with a cellulose filter with an aluminum cyclone and a sample pump. The analyses were carried out at an accredited laboratory: Työterveyslaitos, Helsinki (FINAS T013) that fulfils the requirements of SFS-EN ISO/IEC 17025 -standard. Samples were analyzed by FT-IR -method by NIOSH -standard procedure 7602.

6.7 Carbon Monoxide

Carbon Monoxide (CO) and Carbon Dioxide (CO₂) concentrations, temperature and relative humidity were measured with directly indicating measurement devices according to standardized procedures applied in occupational hygiene measurements. CO₂, temperature and relative humidity levels were merely observed during the measurements, whereas CO levels were also recorded.

7 Measurement Equipment

- Measurement pumps: A011-8, SKC Pocket Pump 2/3/4, Gillian 2/4/5/9/10/11/12
- Sample tubes (presented in detail in procedure description)
- Gas analyzer: Dräger X-am 5600
- Condition meter: SenseAir pSENSE

8 Uncertainty of the Measurements

Given uncertainties of the measurements:

- TVOC and Hydrocarbons, Aldehydes, Phenols and Cresols, Amines, Inorganic and Respirable Dust ± 20 % of the measurement result
- Carbon Monoxide ± 5 ppm

Uncertainties of the analyzes:

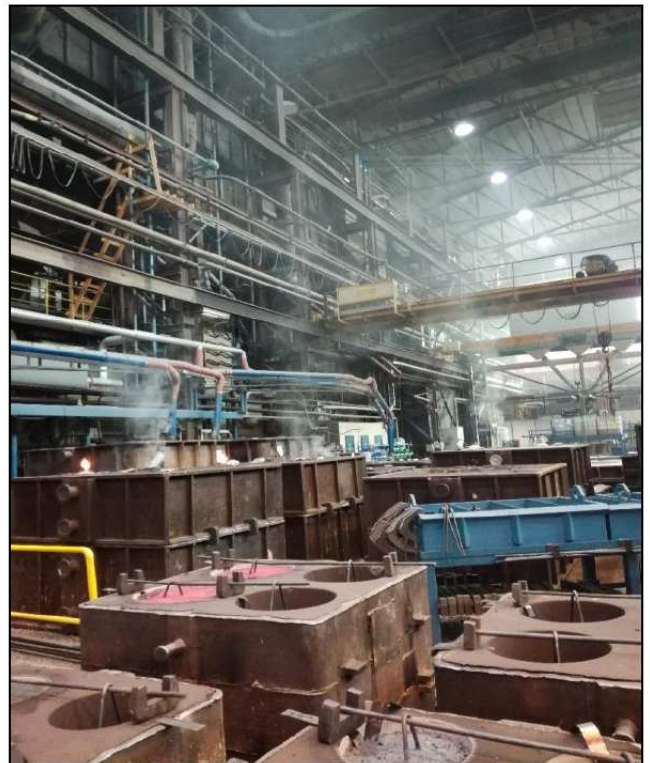
- Total uncertainty of the VOC analyze is $\pm 17\%$ and the quantification limit, depending on the compound and sampling method, is 0,001...0,02 mg/sample.
- Total uncertainties of the Aldehyde, Phenol and Creosol analyzes are not enclosed to the analyze responses but are estimated to $\pm 40\%$.
- Total uncertainty of the Quartz analyze in given concentrations is $\pm 40\%$. Quantification limit of the analyze is 6,5 $\mu\text{g}/\text{sample}$.

References

- 1) SFS-EN 689:2018 + AC:2019:en. Workplace exposure. Measurement of exposure by inhalation to chemical agents. Strategy for testing compliance with occupational exposure limit values; Comité Européen de Normalisation. Brussels.
- 2) SFS-EN 481:2001. Workplace atmospheres. Size fraction definitions for measurement of airborne particles; Comité Européen de Normalisation. Brussels.
- 3) SFS 3861:2000. Työpaikan ilman liuotinpitoisuuden määrittäminen hiiliputkimenetelmällä; Suomen Standardoimisliitto SFS.
- 4) HTP-arvot 2018, Sosiaali- ja terveysministeriön julkaisu 2018:9
- 5) Haihtuvien orgaanisten yhdisteiden kokonaispitoisuuden (TVOC) tavoitetasot teollisten työympäristöjen yleisilmassa. Työterveyslaitos: 2012
- 6) Hengittävän ja alveolijakeisen pölyn tavoitetasoperustelumustio. Työterveyslaitos: 2016
- 7) Ahonen I., Pääkkönen R., Rantanen S. Työhygieeniset mittaukset opas, Tampereen aluetyöterveyslaitos, Tampere 2005.
- 8) Pienyrityksen työympäristö tuloksentekijänä, Sosiaali- ja terveysministeriö, Työsuojeluoppaita ja ohjeita 2005.
- 9) AX-raportti 12989Y19A: 26.3.2019



Pictures 1 and 2. Measurement set-up at the Core Making/Cold-box -method working station.



Pictures 3 and 4. Large Vibrator/Shake-out machine and molds cooling nearby the Vibrator.



Pictures 5 and 6. Casting molds produce clearly visible and odorous fumes. In general, the facilities are rather tidy.



Pictures 7 and 8. Measurement staff adjusting the measurement set-up at the Pouring/Cooling line.