AX-Consulting

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

Action B1 Emissions of different binder systems during small-scale test casts

De.B1A Results of emission measurements of inorganic binder system chamber test cast in Karhula foundry in Finland

Work 10745Y18A
27.12.2020/Seppo Heinänen

FINAS
Finnish Accreditation Service
T232 (EN ISO/IEC 17025)

Insinööritoimisto AX-LVI Oy | PL 428, 33101 Tampere | Puhelin 03 2680 111 | Y-1836205-0
www.ax.fi | Kuokkamaantie 4 a, Tampere | etunimi.sukunimi@ax.fi | Kotipaikka: Tampere

Client	Karhula Foundry Ltd. Pajatie 91 FI-48600 Kotka Finland
Assignment	Measurement of emissions from the casting mold
Measurement dates and place	Kotka, April 25th 2019 and October 20th 2020
Measurement staff	Perttu Kriikku, Pauli Pellikka and Valtteri Shemeikka
Report writer	Seppo Heinänen

On behalf of
AX-LVI Consulting Ltd
Environmental Engineering Department

Seppo Heinänen
Chief of the Department

Valtteri Shemeikka
Environmental Engineer

CONTENTS

APPENDICES

APPENDIX 1 Karhula Foundry Ltd, Kotka Finland, Concentrations and emission from the exhaust air from test casting

APPENDIX 2 Karhula Foundry Ltd, Kotka Finland, Measured particle concentrations and emissions.

APPENDIX 3 Karhula Foundry Ltd, Kotka Finland, VOC compounds defined from the adsorption samples

APPENDIX 4 Karhula Foundry Ltd, Kotka Finland. Aldehyde compounds defined from adsorption samples

APPENDIX 5 Karhula Foundry Ltd, Kotka Finland. Phenol and cresol compounds defined adsorption samples

APPENDIX 6 Karhula Foundry Ltd, Kotka Finland. CO,CO2,SO2 and VOC concentrations and emission from the exhaust air from test casting

APPENDIX 7 Karhula Foundry Ltd, Kotka Finland. CO, SO2, O2 and CO2 curves from the chamber test exhaust air

APPENDIX 8 Karhula Foundry Ltd, Kotka Finland. Temperatures from the casting

APPENDIX 9 Karhula Foundry Ltd, Kotka Finland. Temperatures from the casting

APPENDIX 10 Karhula Foundry Ltd, Kotka Finland. Mould and iron during tests

1 Introduction

Karhula Foundry Oy is ferrous foundry that produces demanding cast components for process industry, mining, marine, energy and general engineering. The production began at Karhula in 1880's. The melting capacity consists of 8 tons arc furnace and 8 tons, 1,5 ton and 0,5 ton induction furnaces. Karhula Foundry has an 8 tons AOD (Argon Oxygen Decarburization) converter for metal treatment. Karhula Foundry produces high alloyed steels such as duplex, martensite, ferritic and austenitic stainless steel, super-austenitic steel, heat, wear and corrosion resistant steels and low alloyed steel.
Karhula Foundry produces also ductile iron, ADI iron (Austempered Ductile Iron) and special alloyed iron. Typical products are pumps and valves, coilers, gear wheels, segments castings. The binder system for moulds is Alphaset. The cores are made by using Alphaset, Betaset or Cold-Box binder systems. All these methods are based on phenolic resin binders.
The sand used for moulds and cores is high quality silica sand. Some chromite sand is used for the surface part of moulds, when an excellent heat resistance is needed.
The painting of the moulds and cores is made by zircon-based coatings.
The weight range of the castings is between 1 kg to 30 tons.
Karhula Foundry has two mechanical moulding lines for small and medium size castings and a hand moulding for the bigger moulds.
The pouring of the metal into moulds is made from pre-heated ladles.
Cooled moulds are shaken out by vibration. The feeders are removed by cutter, arc-air or powder cutting methods. The surfaces of the castings are refined by steel shot blasting.
Karhula Foundry has 10 furnaces and 2 quenching pools for different heat treatments.
Annual production capacity is 3500 tons of steel castings, but the production in recent years has been 2000..3000 tons. The foundry has about 80 employees.

Emission measurements of casting mold with two different inorganic binder system were carried out in Karhula Foundry Ltd on 25.4.2019 and 20.10.2020. The first inorganic binder system (Inotec from ASK) is completely inorganic and requires heating to an elevated temperature to cure. The second inorganic binder system is "semi" inorganic (inorganic binder and organic hardener; Cast Clean from Peak) and it hardens at ambient temperature, ie.it is self-setting system. The aim of the measurements was to find out the concentration of components, emissions and mold temperatures during the casting process. During normal casting process, it is not possible to measure released total emission concentrations, so test casting was carried out with special test arrangements, which were the same with both inorganic binder systems.

2 Measurement results

Measurement results are presented in table 1 and In APPENDICES 1-7. Trends from the temperature measurements are presented in APPENDICES 8-9. Test parameters APPENDIX 10.

3 Conclusions

The steel test cast was 200 kg and the sand amount was 210 kg. In this test arrangement the ASK Inotec inorganic binder system and Peak Cast Clean S27 binder system were tested. Measurement arrangement was structurally same as at URV foundry. Because of the measurement arrangements, the exhaust gas coming to analyzer had to be diluted. Results are presented with using the dilution factor. However, it has to be noticed that the dilution air was taken from the same casting hall, to where the exhaust gas from the test casting was extracted. There was also background concentrations in the hall, because it was inside the factory.

During the measurement the exhaust air flow rate was about 60 l/s. The melt was poured to the test cast at 11:10 and total emission measurements continued until 17:15.

Based on the results of the chamber test carried out with a steel test cast and using inorganic binder systems the total emission measurements demonstrated very small emission concentration. Highest concentrations were measured from carbon monoxide (0,13 mg/ton casting) which was very small compared to results when using organic binders (CO average 9,55 mg/to casting). All measurement results are presented in this report.

3.1 Carbon monoxide (CO)

Results show that there was a short-term high concentration of CO when the melt was poured and afterwards the concentrations started to reduce rapidly. CO has the highest concentration, especially during melt was poured.

3.2 Volatile Organic Compounds (VOC)

During the melt was poured, there was also small peak in the concentration of the VOC compounds. Soon after melt was poured VOC concentration decreased. Because the mould was warming up and different compounds have different evaporating temperature, VOC concentration is not going down as linearly than other measured gaseous components.

3.3 Sulphur dioxide (SO_2) and nitrogen oxides (NO_X)

During the measurements no significant concentrations of sulphur dioxide or nitrogen oxides were detected.

3.4 Oxygen (O_2) and carbon dioxide (CO_2)

Oxygen concentration was decreasing for a while the melt was poured from 20.9% to 13.5%. At the same time there was a small amount of carbon dioxide present. Concentrations decreased slowly to the level of normal air concentrations.

3.5 Particles

Particle concentration was also measured from the exhaust air. The average concentration was around 7,7 mg/Nm^3.

4 Procedure

4.1 O_2, CO_2, CO, NO_x and SO_2

Sample from the exhaust air for the measurement of O_2, CO_2, CO, NO_x and SO_2 were taken with heated sond through heated filter and sample tube to the sample unit, where is the sample pump. In the sample unit, water was removed from the sample gas and dry gas was shared to the analyzers. Uncertainty of the concentration is ±15 %.

4.2 Volatile Organic Compounds (VOC)

VOC measurement was made with flame ionization detector analyzer (FID). Sample from the exhaust air to the analyzer was taken with sond through heated sample tube. Measurement was carried out in accordance with the USA Environmental Protection Agency (EPA) Method 25.

Absolut VOC and carbon concentration were defined from the adsorption samples, which were taken at the same time. Quantitative analysis from the hydrocarbon compounds was done one by one and real concentration response of the FID analyzer was defined from that. Measurement was carried out in accordance with the SFS 3861 standard.

Tenax tube samples were analyzed by an accredited laboratory: Eurofins Environment Testing Finland, Lahti (FINAS T039)
Uncertainty of concentration is ±15 %.

4.3 Particles

Particle concentrations from the exhaust air were measured from samples taken with sond and pump in accordance with SFS-EN 13284-1 and SFS

3866 standards. Size of the sond and absorption rate were set so that the speed of the sample rate was as isokinetic with the speed of the exhaust air as possible. Uncertainty of concentration is ±15 %.

4.4 Phenols

Phenols in the gas phase were collected from the exhaust air with the pump into the XAD-2-Supelco adsorption tubes. The analyses were carried out at an accredited laboratory: Eurofins Product Testing Denmark A/S (ISO 17025 DANAK) by Solvent Desorption/Gas Chromatography method.

4.5 Aldehydes

The aldehyde samples were taken from the exhaust air with the sample pump to the SepPAK-DNPH tubes. The analyses were carried out at an accredited laboratory: Eurofins Environment Testing Finland, Lahti (FINAS T039) by High Performance Liquid Chromatography (HPLC) method. Uncertainty of concentration is ±15 %.

4.6 Flow rate

The flow rate of the exhaust air was measured continuously with the pitot tube and the micromanometer. The result was calibrated with measuring the flow rate randomly from the exhaust air, using multi-point method with the micromanometer and the pitot tube, according to the SFS 5512 standard. The dry and wet temperatures were measured with the instant thermometer. Uncertainty of concentration is ±5 %.

The temperature was measured continuously with the thermoelement and the datalogger. Uncertainty of temperature is approximately ±1 °C.

5 Measurement results from organic binder system and two inorganic binder systems

In the table 1 the results from Alphaset organic binder system tested at URV foundry in Finland and two inorganic binder systems tested at Karhula Foundry in Finland are presented. Based on the results of the chamber tests carried out with the steel test casts and using two inorganic binder systems, the total emission measurements demonstrated very small emission concentrations compared to the organic phenolic binder system. Emission reductions varied from 67% to 99% when using inorganic Inotec inorganic binder system. PEAK binder system is 100% inorganic but the hardener the manufacture uses contains organic substances which explains some higher emissions compared to 100% inorganic Inotec binder system.

Table 1. The test results of the organic binder system and two different inorganic binder systems.

	Test	URV chamber	Karhula chamber	Karhula chamber
	Resin	phenolic Al-phaset	Inorganic Peak	Inorganic Inotec
Emission per casting [g/ton casting]	dust	211	56,10	7,40
	CO	10 129	361	128
	SO_2	203,31	6,51	3,30
	VOC	3 256	111,6	35,2
	BTEX	665	8,50	1,05
	asetaldehyde	81,3	8,76	0,72
	formaldehyde	1,92	6,23	0,63
	phenol	109	0,89	0,13
	o-cresol	152	<1,50	<0,08
	p-cresol	74,1	<1,50	<0,05
Sum		14 883	563	177
Emission per sand [g/ton sand]	dust	210	56,1	7,05
	CO	10 069	361	122
	SO_2	202	6,51	3,14
	VOC	3 237	112	33,5
	BTEX	661	8,5	1,00
	asetaldehyde	80,8	8,8	0,69
	formaldehyde	1,91	6,2	0,60
	phenol	108	0,89	0,13
	o-cresol	151	<1,50	<0,07
	p-cresol	73,7	<1,50	<0,05
Sum		14 794	563	168
Emission per binder [g/kg binder]	dust	7,8	1,33	0,35
	CO	373	8,56	6,10
	SO_2	7,49	0,15	0,16
	VOC	120	2,65	1,68
	BTEX	24,5	0,20	0,05
	asetaldehyde	2,99	0,21	0,03
	formaldehyde	0,07	0,15	0,03
	phenol	4,02	0,02	0,01
	o-cresol	5,59	<0,036	<0,004
	p-cresol	2,73	<0,036	<0,002
Sum		548	13,3	8,4

6 Measurement equipment

The analyzer equipment and used standards and guidance, according to the measurements of the different components that were carried out, are presented in Table 2.

Table 2. The measurement equipment, standards and guidance that were followed in the measurements.

	Device mark	Measurement	Standard
Measurement method is accredited			
O_2	Gasmet DX4000	FTIR	SFS 3869 SFS-EN 14789:2005 ISO 12039
CO_2	Gasmet DX4000	FTIR	SFS 3869 ISO 12039:2001
CO	Gasmet DX4000	FTIR	SFS 3869 SFS 5412 ISO 12039:2001
NO_x	Gasmet DX4000	FTIR	SFS 3869 ISO 5425 SFS-EN 14792:2005
SO_2	Gasmet DX4000	FTIR	SFS 3869 ISO 7935:1992
Flow rate, pressure	Micromanometer and pitot-pipe	Pressure difference, pressure	SFS 3866 SFS 3869 SFS-EN 13284-1:2001
Temperature	Thermoelement	Voltage difference	SFS 3866 SFS 3869 SFS-EN 13284-1:2001
Measurement method is not accredited			
VOC	CAI FID Adsorption equipment	Flame ionization detector analyzer, absorption	EPA 25 SFS 3869
Phenols Aldehydes	Absorption equipment	Absorption	SFS-EN 1948 SFS 3869
Particles	Particle measure-ment equipment	Gravimetric	SFS-EN 13284 SFS 3866 (adjusted)
H_2O	Cooling equipment	Condensation	SFS 5624

Concentrations and emission from the exhaust air from test casting

	Test	1	
	period	4,12	h
	casting	200	kg
	sand	210	kg
	air flow	0,06	*Nm³/s*
Concentration	dust	1,8	mg/Nm^3
	CO	30,5	mg/Nm^3
	SO_2	0,8	mg/Nm^3
	VOC	8,4	mg/Nm^3
	asetaldehyde	0,2	mg/Nm^3
	formaldehyde	0,2	mg/Nm^3
	phenol	0,03	mg/Nm^3
	o-cresol	<0,02	mg/Nm^3
	p-cresol	<0,01	mg/Nm^3
Emission	dust	0,4	g/h
	CO	6,2	g/h
	SO2	0,2	g/h
	VOC	1,7	g/h
	asetaldehyde	0,04	g/h
	formaldehyde	0,03	g/h
	phenol	0,01	g/h
	o-cresol	<0,004	g/h
	p-cresol	<0,002	g/h
Emission per period	dust	1,5	g/period
	CO	25,7	g/period
	SO2	0,7	g/period
	VOC	7,1	g/period
	asetaldehyde	0,1	g/period
	formaldehyde	0,1	g/period
	phenol	0,03	g/period
	o-cresol	<0,02	g/period
	p-cresol	<0,01	g/period
Emission per casting	dust	0,01	mg/ton (casting)
	CO	0,13	mg/ton (casting)
	SO2	0,003	mg/ton (casting)
	VOC	0,04	mg/ton (casting)
	asetaldehyde	0,001	mg/ton (casting)
	formaldehyde	0,001	mg/ton (casting)
	phenol	0,0001	mg/ton (casting)
	o-cresol	<0,0001	mg/ton (casting)
	p-cresol	<0,0001	mg/ton (casting)
Emission per sand	dust	0,01	mg/ton (sand)
	CO	0,122	mg/ton (sand)
	SO2	0,003	mg/ton (sand)
	VOC	0,03	mg/ton (sand)
	asetaldehyde	0,001	mg/ton (sand)
	formaldehyde	0,001	mg/ton (sand)
	phenol	0,0001	mg/ton (sand)
	o-cresol	<0,0001	mg/ton (sand)
	p-cresol	<0,00005	mg/ton (sand)

Measuring point	Day	Starting	Ending	Concentration	Flow rate	Emission	
				mg/Nm³	*Nm³/s*	*mg/s*	*g/h*
Exhaust air	25.5	11:07	11:35	14,9			
	25.5	11:45	16:41	0,5			
	average			1,8	0,06	0,1	0,4

Measuring point	Test casting	Test casting	Test casting
Sample	1	2	average
Starting time	11:07:00	11:45:00	
Ending time	11:36:00	16:41:00	
VOC-concentration	*mg/Nm³*	*mg/Nm³*	*mg/Nm³*
Bentsaldehyde	0,01	0,03	0,02
Methyl ethyl ketone	0,01	0,01	0,01
Nonanale	0,01	0,04	0,03
Hexane	0,00	0,02	0,01
Heptane	0,01	0,01	0,01
Octane	0,01	0,06	0,04
2-Ethyl-1-heksanole	0,03	0,21	0,13
1,2,3-Trimethyl bentzene	0,00	0,01	0,00
1,2,4-Trimethyl bentzene	0,01	0,01	0,01
1,3,5-Trimethyl benzene	0,00	0,07	0,04
Ethyl benzene	0,02	0,01	0,01
m,p-Xsylene	0,04	0,10	0,07
Naphtalene	0,01	0,06	0,04
o-Xylene	0,01	0,01	0,01
Styrene	0,03	0,05	0,04
Toluene	0,13	0,19	0,16
Ethyl acetate	0,01	0,02	0,01
Methyl acetate	0,05	0,03	0,04
1-Hexene	0,03	0,00	0,01
1-Oktene	0,13	0,03	0,08
a-pinene	0,00	0,01	0,01
Limonene	0,13	0,07	0,10
Other VOCs	0,0	0,0	0,00
total	**0,7**	**1,1**	**0,9**
Part of the compound	*%*	*%*	*%*
Bentsaldehyde	1,3	2,6	2,2
Methyl ethyl ketone	1,9	1,0	1,3
Nonanale	0,9	4,0	2,9
Hexane	0,6	2,2	1,6
Heptane	1,4	1,0	1,1
Octane	1,2	5,6	4,1
2-Ethyl-1-heksanole	4,1	20,0	14,5
1,2,3-Trimethyl bentzene	0,5	0,5	0,5
1,2,4-Trimethyl bentzene	1,2	1,1	1,1
1,3,5-Trimethyl benzene	0,6	6,6	4,5
Ethyl benzene	2,4	1,1	1,6
m,p-Xsylene	6,0	9,2	8,1
Naphtalene	1,5	5,8	4,3
o-Xylene	1,7	1,1	1,3
Styrene	4,9	5,0	5,0
Toluene	18,8	17,6	18,0
Ethyl acetate	1,4	1,8	1,6
Methyl acetate	7,5	2,6	4,3
1-Hexene	3,8	0,2	1,5
1-Oktene	18,8	3,0	8,5
a-pinene	0,5	1,0	0,9
Limonene	19,2	7,0	11,2
Other VOCs	0,0	0,0	0,0
total	**100,0**	**100,0**	**100,0**

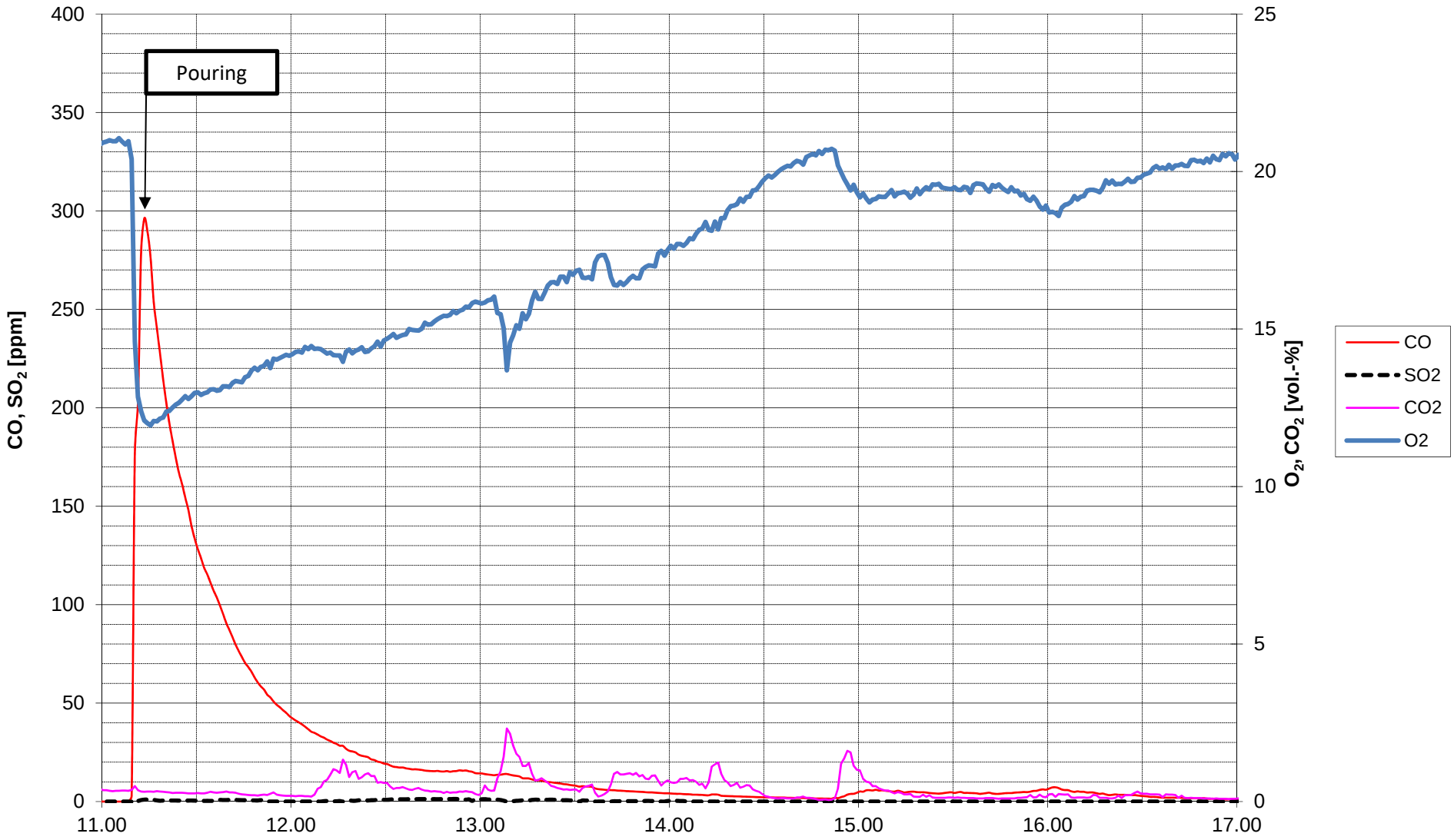
Measuring points	Test casting	Test casting	Test casting
Sample	1	2	
Time started	11:07:00	11:45:00	average
Time finished	11:36:00	16:41:00	
Concentration	*mg/Nm³*	*mg/Nm³*	*mg/Nm³*
Acetaldehyde	0,26	0,16	0,17
Bentsaldehyde	0,05	0,01	0,01
Butanale	0,05	0,07	0,07
Decanale	0,05	0,01	0,02
Formaldehyde	0,31	0,13	0,15
Heksanale	0,05	0,02	0,02
Heptanale	0,05	0,01	0,01
Nonanale	0,05	0,01	0,02
Octanale	0,05	0,01	0,01
Pentanale	0,05	0,01	0,01
Propanale	0,05	0,02	0,02
sum	**1,05**	**0,47**	**0,52**
Part of the compound	*%*	*%*	*%*
Acetaldehyde	25,0	34,9	33,1
Bentsaldehyde	5,0	2,2	2,7
Butanale	5,0	16,1	14,1
Decanale	5,0	2,8	3,2
Formaldehyde	30,0	28,8	29,0
Heksanale	5,0	3,3	3,6
Heptanale	5,0	2,2	2,7
Nonanale	5,0	2,5	3,0
Octanale	5,0	1,6	2,2
Pentanale	5,0	2,1	2,6
Propanale	5,0	3,5	3,8
sum	**100,0**	**100,0**	**100,0**

Measuring points	Test casting	Test casting	Test casting
Time started	11:07:00	11:45:00	average
Time finished	11:36:00	16:41:00	
Concentration	*mg/Nm³*	*mg/Nm³*	*mg/Nm³*
Fenoli	0,14	0,02	0,03
o-Kresoli	<0,0	0,02	0,02
p-Kresoli	<0,0	0,01	0,01
kresolit yht.	0,06	0,03	0,03
summa	**0,20**	**0,05**	**0,06**
Kokonaisepävarmuus mittausarvosta (%)	±17	±17	±17
Yhdisteen osuus	*%*	*%*	*%*
Fenoli	71,2	43,3	51,1
o-Kresoli	9,6	37,3	29,6
p-Kresoli	19,2	19,4	19,4
summa	**100,0**	**100,0**	**100,0**
VOC-pitoisuus	*mgC/Nm³*	*mgC/Nm³*	*mgC/Nm³*
Fenoli	0,1	0,0	0,0
o-Kresoli	0,0	0,0	0,0
p-Kresoli	0,0	0,0	0,0
summa	**0,2**	**0,0**	**0,0**
Keskimääräinen	*%*	*%*	*%*
hiiliosuus	76,9	77,3	77,2

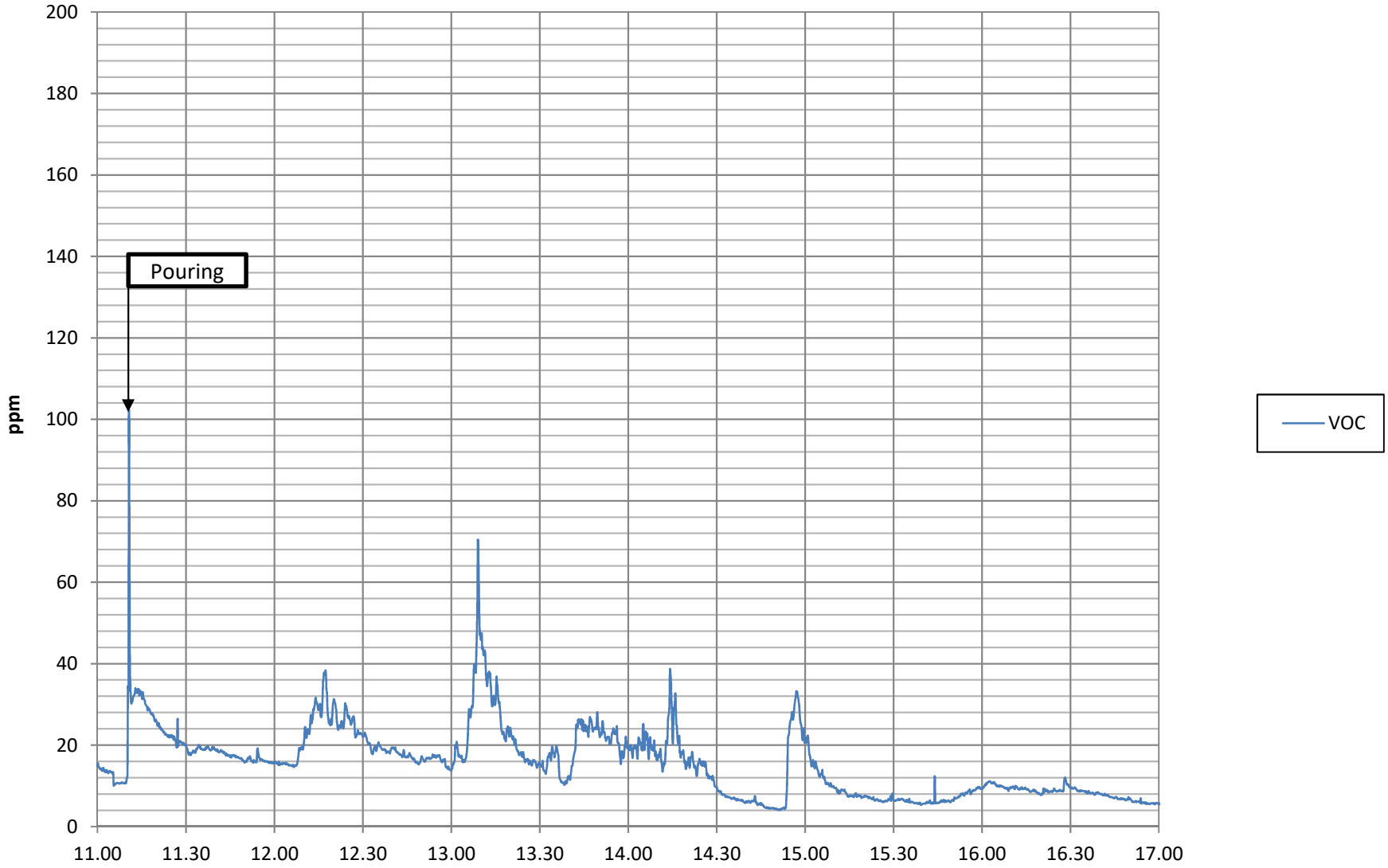
CO, CO2,SO2 and VOC concentrations and emission from the exhaust air from test casting

Situation			Concentration					Flow rate		Emission			Incombustible		
		time	O_2	CO	CO_2	SO_2	VOC	flow rate	exhaust air temperature	CO	SO_2	VOC	CO	VOC	total
			%	*ppm*	*%*	*ppm*	*ppm*	*Nm³/s*	*°C*	*mg/s*	*mg/s*	*mg/s*	*mgC/s*	*mgC/s*	*mgC/s*
Chamber test	pouring	11:08-11:23	13,5	201	0,33	0,62	27,6	0,06	38,7	15	0,11	0,93	6,6	0,74	7,3
25.4.2019	entire measurement	11:08-17:15	17,4	24,4	0,38	0,28	15,3	0,06	51,8	1,73	0,04	0,48	0,7	0,02	0,8

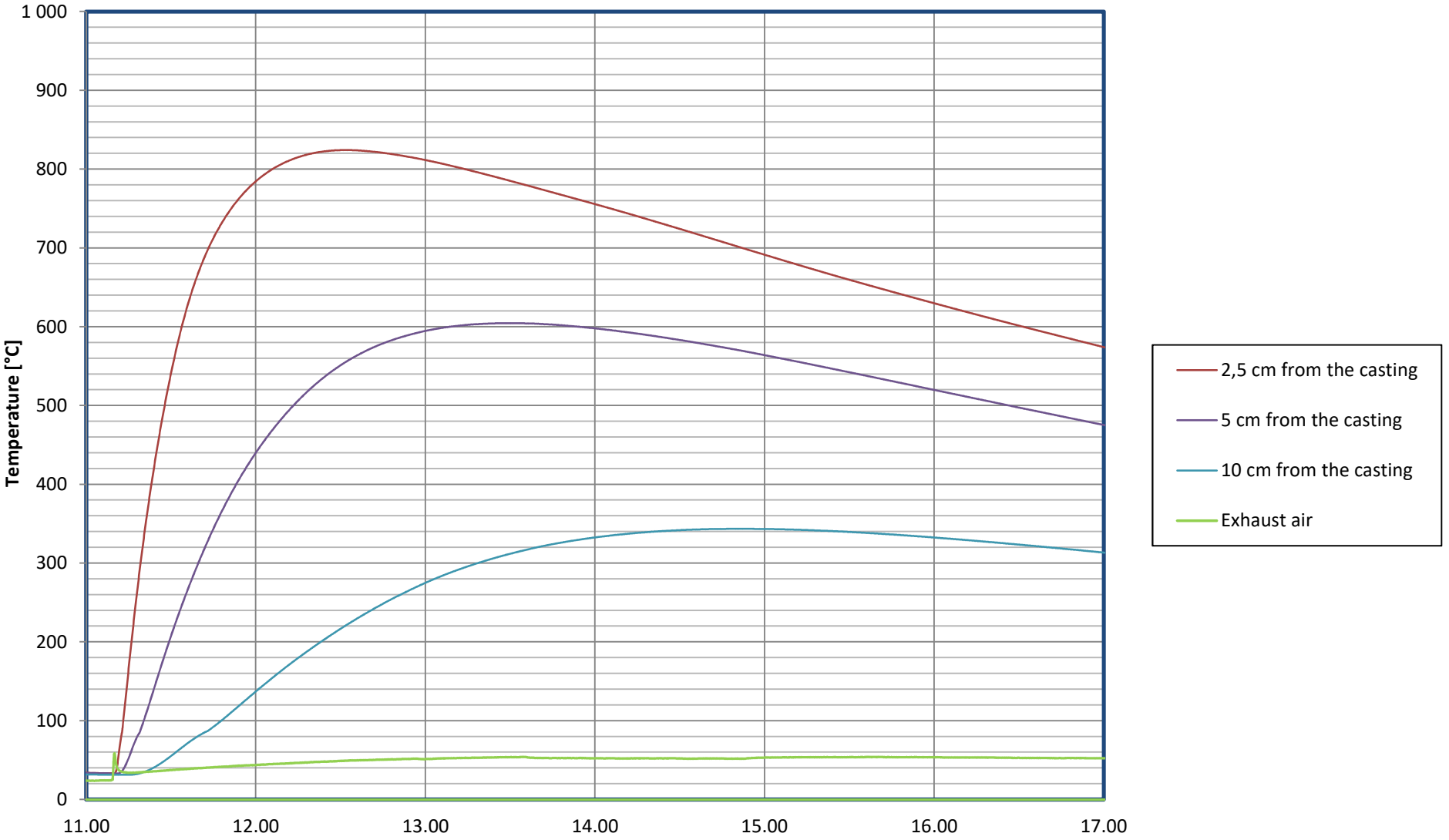
CO, SO_2, O_2 and CO_2 curves from the chamber test exhaust air



Exhaust air VOC
curve of the test casting



Temperatures from the casting



Weight of mixed mould sand:

Sand 210kg + promoter 1,26kg + binder 4,20kg = 215,46kg

(Real weight a bit less in mould since a bit of sand went outside the mold)

Weight of hard mould sand during breaking the mould = 207,92kg

Weight of dust during breaking the mould = 2,68kg

Hard sand + dust = 210,60kg

Weight of the casting with lifting hooks included = 201kg

Karhula Foundry
Profitability from castings