Project no. 038644 – BioNorm II

Pre-normative research on solid biofuels for improved European standards

SPECIFIC TARGETED RESEARCH OR INNOVATION PROJECT

PRIORITY [6-1] – Sustainable energy systems

Task IV – Supply chain based properties

Wood log combustion tests - Over-fire boiler

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Involved Participants

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CONTENT

APPENDICES

List of Abbreviations

P	Particle size of fuel, D and L, mm
D	Diameter, mm
L	Length, mm
M	M_{ar} =Moisture content, ar = as received, w-%
A	ash content, dry basis, w-%
$q_{,net, d}$	Net calorific value, dry basis
Q	$q_{,net, ar}$ = Net calorific value, as received, MJ/kg or kWh/kg (1 kWh/kg = 3.6 MJ/kg) used in quality tables of prEN 14961
E_{ar}	Energy density, kWh/m^3 E used in the quality tables of prEN 14961
S	Sulphur, dry basis, w-%
N	Nitrogen, dry basis, w-%
Cl	Chlorine, dry basis, w-%
CO, %	carbon monoxide, reported at 10% oxygen content (%) in dry gas
OGC	organic gaseous compounds, reported at 10% oxygen content, mg/Nm^3 in dry gas (measured in wet flue gas)
Dust	particles, reported at 10% oxygen content, mg/Nm^3 in dry gas

1 The aim of combustion tests

The general aim of the combustion tests was to find out what are the most critical fuel properties that affect emissions and efficiency of different kind of domestic wood burning appliances. This report gives the results of 12 combustion tests carried out using a typical Finnish over-fire wood log boiler and by using wood logs made from birch, pine and spruce. The main normative properties of prEN 14961 (N143) was measured and during the tests dimensions and moisture content of the wood logs were changed.

2 The appliance used in the tests

We chose a typical Finnish over-fire wood log boiler for the tests. The test rig for small boilers at VTT is shown in Figure 1.

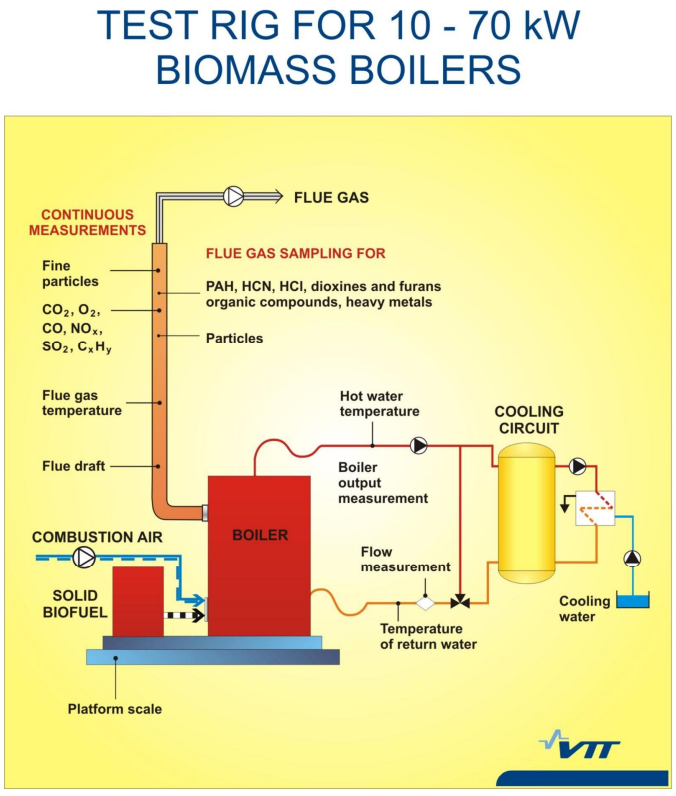

Figure 1. Test rig used in combustion tests of an over-fire wood log boiler.

These kind of boilers are still quite common in Finland and also in many other countries of EU. Usually the boiler is connected to an accumulator tank of 1 – 3 m^3. It allows the boiler to be used at

nominal heat output and only when excess heat is required. In Finnish weather conditions it means that in summer time the boiler is used once a week and in the winter time once or twice a day.

50 cm wood logs were used in the test boiler. Its nominal heat output is 20 – 40 kW. A drawing of the combustion principal is shown in Figure 2.

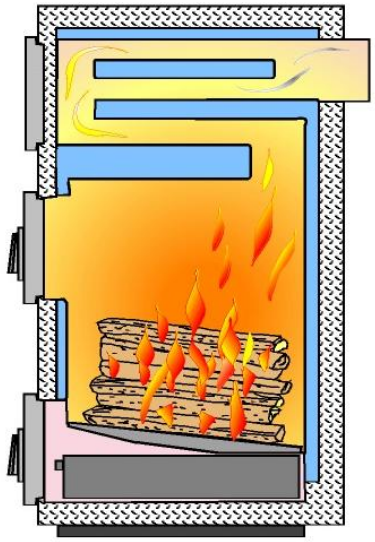

Figure 2. The combustion principle of an over-fire boiler.

3 Test procedure

According to the test plan, two different wood species were used: birch and pine. Target moisture content of logs varied from 15w-% to 30w-%. The diameter (D) of logs was varying, but the length (L) was always 50 cm. The target diameters were the following: D1 from 4 cm to 8 cm and D2 from 8 cm to 16 cm. Both wood species were analysed. Table 1 shows the analysis results.

Table 1. Results of the fuel analysis.

Analysis	Result	Unit	Method
BIRCH			
Ash content (550 °C)	0.4	w-%, dry matter	CEN/TS 14775 (mod.)
Sulphur content	< 0.02	w-%, dry matter	ASTM D 4239-05/mod.)
Net calorific value	18.99	MJ/kg, dry matter	CEN/TS 14918 (mod.)
Carbon	51.2	w-%, dry matter	CEN/TS 15104:2005(mod.)
Hydrogen	6.4	w-%, dry matter	CEN/TS 15104:2005(mod.)
Nitrogen	0.21	w-%, dry matter	CEN/TS 15104:2005(mod.)
PINE			
Ash content (550 °C)	0.3	w-%, dry matter	CEN/TS 14775 (mod.)
Sulphur content	< 0.02	w-%, dry matter	ASTM D 4239-05/mod.)
Net calorific value	19.13	MJ/kg, dry matter	CEN/TS 14918 (mod.)
Carbon	50.9	w-%, dry matter	CEN/TS 15104:2005(mod.)
Hydrogen	6.2	w-%, dry matter	CEN/TS 15104:2005(mod.)
Nitrogen	0.20	w-%, dry matter	CEN/TS 15104:2005(mod.)

The summary of the test plan is given in the Table 2.

Table 2. Test plan for the over-fire boiler.

Test	Wood specie	General properties (other according A1)			Fuel adding criteria
		Dimension D, cm	Dimension L, cm	Moisture w-%	kg
1	birch	D1	50	M15	full
2	birch	D1	50	M20	full
3	birch	D1	500	M30	full
4	birch	D2	500	M15	full
5	birch	D2	500	M20	full
6	birch	D2	500	M30	full
7	pine	D1	500	M15	full
8	pine	D1	500	M20	full
9	pine	D1	500	M30	full
10	pine	D2	500	M15	full
11	pine	D2	500	M20	full
12	pine	D2	500	M30	full

D in the Table 2 means the diameter of a log. D1 means smaller logs (diameter about 9 cm), which burn quicker and D2 logs having bigger diameter (about 16.5 cm). Of course the diameter changed from test to test, because normal chopped fuel was used. Target moisture content was also not always reached. Split in all cases was to four pieces (S4). Smaller log weighed about 1 kg and larger logs about 3 kg.

Fuel addings and actual moisture contents are presented in Table 3. Please note that the order of tests is different compared to the test plan. It is because of practical reasons in testing.

Table 3. Fuel addings.

Test	Wood specie	General properties (other according A1)			Fuel addings
		Dimension D, cm	Dimension L, cm	Actual moisture w-%	kg
1	birch	D2/16.5 cm	50	15.0	24.0 24.7
2	birch	D1/9 cm	50	15.0	23.4 23.4
3	pine	D2/16.5 cm	50	15.4	20.7 20.7
4	pine	D1/9 cm	50	15.4	22.5 22,6
5	birch	D2/16.5 cm	50	27.2	22.3 21.7
6	birch	D1/9 cm	50	27.2	22.4 21.8
7	birch	D2/16.5 cm	50	18.5	23.9 23.2
8	pine	D2/16.5 cm	50	26.8	22.8 22.8
9	pine	D1/9 cm	50	26.8	24.1 23.2
10	pine	D2/16.5 cm	50	19.8	22.2 22.2
11	pine	D1/9 cm	50	19.8	23.5 22.1
12	birch	D1/9 cm	50	20.5	23.9 21.4

First a small amount of kindling was used to start the fire on the grate. After that the fire box was added full of fuel. The following adding was done when the first full batch was burned down so that CO_2-concentration settled down to about 4%.

Emissions and efficiency were predicted from the burning period: from the first fuel adding on the basic firebed until the last fuel adding was burned to CO_2-concentration of about 4%, which means that the basic firebed was reached again. The finishing time was also observed by the platform scale reading.

Dust measurements included four measuring periods, two measurements during each fuel batch burning. Dust concentration is calculated as a mean of these measurements.

4 Measuring equipment

Measuring equipment is listed in the Appendix 1. Flue gas emissions were measured using normal continuously working equipment. Dust emission was measured using a gravimetric filter-method directly from the stack. A principal scheme of the dust measuring system is is shown in the Appendix 2. The test rig of VTT is build according to the requirements of the standard EN 303-5.

5 Fuels

Fuels were bought as chopped in natural moisture content. A special kind of dryer was used to dry wood logs to the target moisture content. The actual moisture content was analysed. Every wood log was weighted before adding into the boiler.

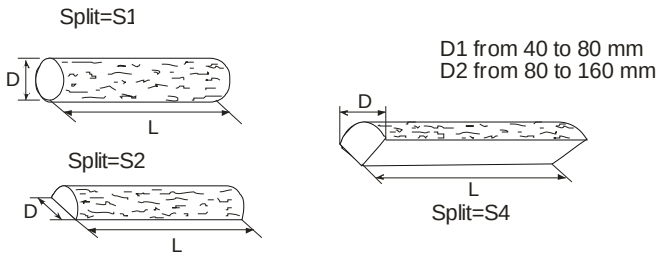

Figure 3. Measurement of wood log dimensions according the prEN 14961 Table 7. S1 means round wood, S2 round wood split to 2 pieces and S4 round wood split to 4 pieces.

Birch wood logs.

Pine wood logs.

Figure 4. Examples of birch and pine wood log batches used in the tests.

Table 4. Measurement and reporting of fuel properties according to prEN 14961 Table 7.

Property	**Standard for measurement**	**prEN 14961 category**	**Actual measured value (min-max)**
Origin	prEN 14961 (N143) Table 1	1.1.3 Stem wood	1.1.3 Stem wood
Length (L), mm	Measuring tape	P500 (L 500 mm±20 mm)	min 500 mm max 505 mm
Diameter (D), mm	Measuring tape	(D 40 mm ≤160 mm)	D1: 90 mm D2: min 30 mm max 165mm
Moisture of whole fuel batch, M, w-%	CEN/TS 14774	M15 M20 M30	M15: 15.0 - 15.4 M20: 18.5 - 19.8 M30: 26.8 - 27.2 see Table 5
Wood	Table 1 in prEN 14961	Birch and Pine	Birch and Pine
Volume, m^3 or	Weight was measured	not measured	not measured
Energy density (kWh/m^3)	Weight was measured	not measured	not measured
Weight of whole fuel batch, kg and each batch kg added during the combustion	Alternative to volume	see Table 3	see Table 3
Port of split	all should be split	round and split	All S4 split
Cut-off surface	photo of each batch and visual inspection	even and smooth	even and smooth
Mould and decay	photo of each batch, report visible mould and decay	no visible mould or decay	no visible mould or decay

Wood species (birch and pine) were analysed in the laboratory for net calorific value, elemental analysis and ash content. Analysis reports are given in appendices 3 – 5 (in Finnish).

6 Results of combustion tests

Burning of wood logs in the boiler was not very good. However, the boiler represents still very common wood log boilers used in Finland and also in many other countries. Modern under-fire boilers are much better in respect of emissions.

Results of the tests (according to the EN 303-5) are given in Table 5.

Table 5. Flue gas concentrations(calculated in dry flue gas), flue gas temperature, efficiency according to the standard EN 303-5, heat output and fuel burning time.

Fuel species, diameter and moisture content		CO_2	O_2	CO	OGC	Dust	Flue gas temperature	Efficiency	Heat output	Fuel burning time
		%	%	mg/m^3 at 10% O_2	mg/m^3 at 10% O_2	mg/m^3 at 10% O_2	^oC	%	kW	min
BIRCH										
Test 1	Birch D2 M15.0	9.5	11.0	7781	1847	463	212	67.5	26.5	326
Test 2	Birch D1 M15.0	11.1	9.1	12640	2604	166	264	68.2	34.1	245
Test 5	Birch D2 M27.2	7.2	13.3	9885	3294	679	200	61.1	20.6	286
Test 6	Birch D1 M27.2	9.9	10.3	8438	1567	173	275	72.3	29.2	240
Test 7	Birch D2 M18.5	10.1	10.4	7493	1551	205	276	60.2	28.9	246
Test 12	Birch D1 M20.5	12.4	7.6	10799	2063	160	276	67.1	27.0	274
PINE										
Test 3	Pine D2 M15.4	7.8	12.7	7198	2068	246	209	65.7	22.2	323
Test 4	Pine D1 M15.4	11.3	8.7	12068	2472	370	284	65.6	30.8	253
Test 8	Pine D2 M26.8	7.6	12.9	7615	1891	215	253	62.3	23.5	269
Test 9	Pine D1 M26.8	8.7	11.7	10052	2436	298	276	62.0	26.0	248
Test 10	Pine D2 M19.8	8.87	11.58	6320	1101	97	272	65.0	24.2	296
Test 11	Pine D1 M19.8	11.62	7.96	11377	2667	236	296	62.0	28.0	252

Draught measured after the boiler during all tests was kept in the value of about 20 Pa. EN 303-5 requires that tests are done using forced draught. Combustion air temperature was 19 – 20 ^oC.

D1 in the table means smaller logs (about 9 cm), D2 bigger logs (about 16.5 cm) and M analysed moisture content of fuel. Every fuel adding was weighed. Comparison of CO-concentrations is shown in Figure 5.

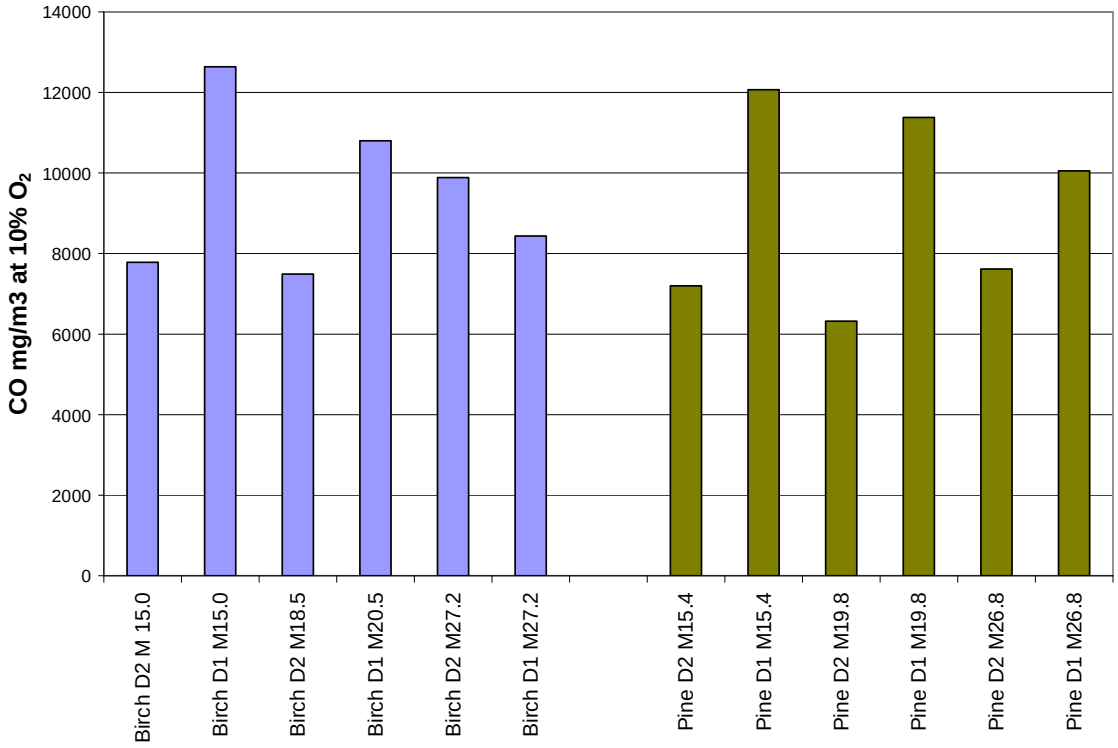

Figure 5. Comparison of CO-concentrations. D1 is about 90 mm and D2 about 165 mm.

Comparison of hydrocarbon concentrations is shown in Figure 6.

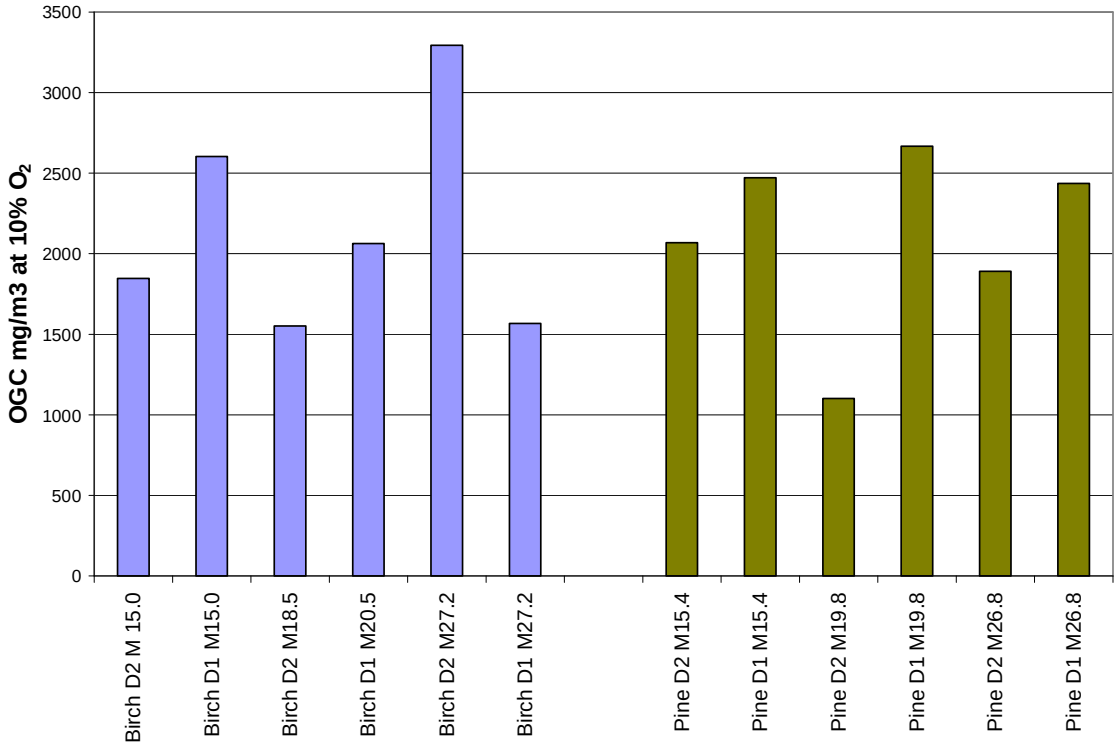

Figure 6. Comparison of hydrocarbon concentrations. D1 is about 9 cm and D2 about 16.5 cm.

Comparison of total dust concentrations is shown in Figure 7.

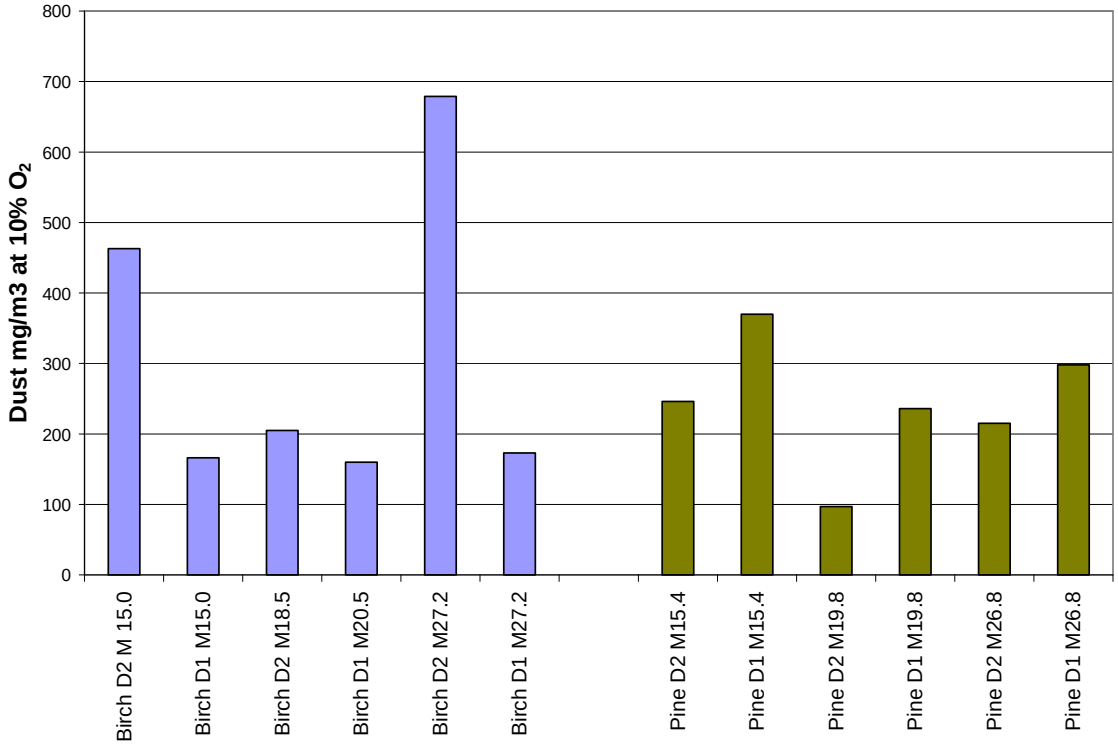

Figure 7. Comparison of total dust concentrations. D1 is about 9 cm and D2 about 16.5 cm.

Total dust values shown in figure 6 are averages of four measurements. Two dust measurements were done during the period of one fuel batch burning. Two large fuel batches were burned. First measurement was done just after fuel adding and the other one when the combustion was more stable.

In Figure 8, 4 dust measurements of one test are shown. It clearly shows how much dust concentrations vary between four samples.

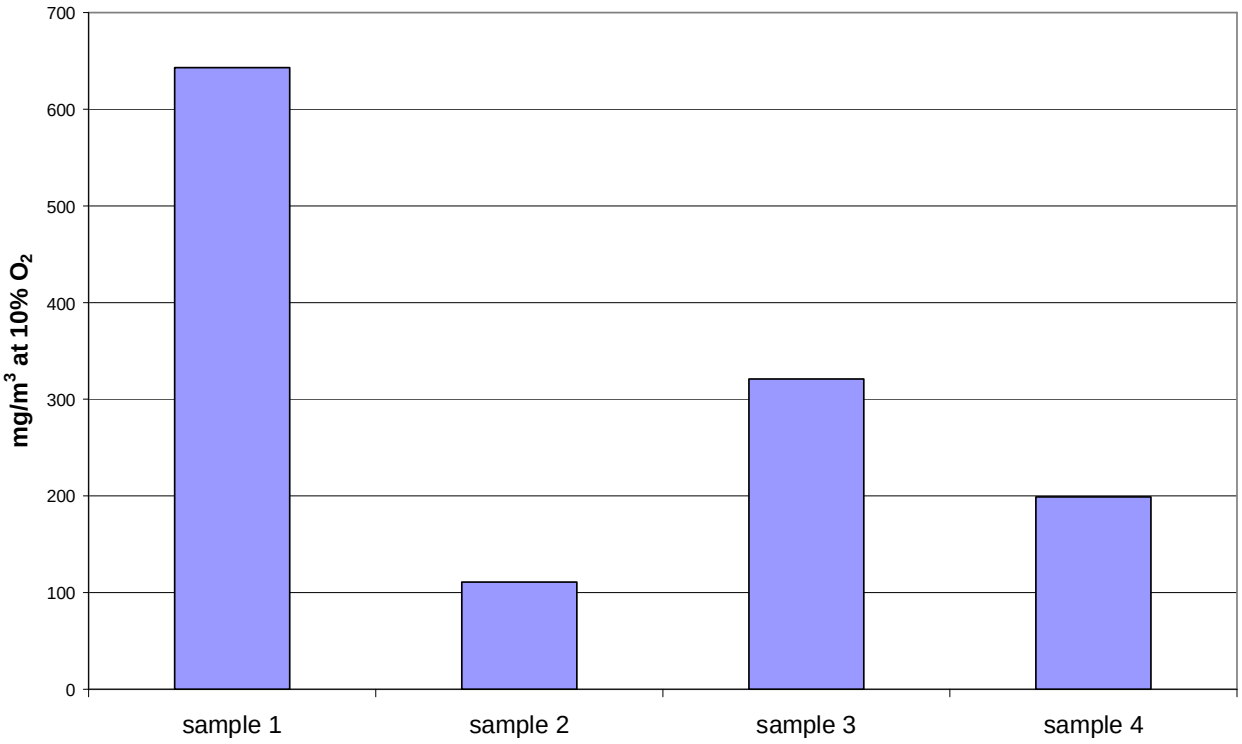

Figure 8. Four dust samples from the test 3.

NO_x-analyser did not work properly during the tests. It is known that all nitrogen oxides are formed from fuel nitrogen, because temperatures are lower than the thermal-NO_x formation temperature in small scale wood burning appliances. High CO-concentration normally lowers NO_x-emissions. O_2- and CO-concentrations versus time from each test are shown in appendices 5 - 16. These graphs illustrate clearly combustion behaviour in batch type wood log burning.

7 Conclusions

Combustion experiments were carried out using an over-fire wood log boiler having a nominal heat output of 40 kW. This type of boiler is still quite common in Finland and in many other countries, because it is quite cheap to buy and easy to use. It is always connected to a heat accumulator.

When the moisture content of fuel is between 15 and 20%, it is recommend to use large diameter logs. Then emissions of CO, OGC and particulates seems to be a little lower. However, power output is then also lower, because burning of wood logs is slower. When the moisture content of fuel was near 30%, there is a higher risk for higher emissions. However the trend is not clear.

Birch and pine do not differ when taking emissions in consideration. It is safer to keep fuel moisture content between 20 to 25%. Then it more easy to avoid high peaks of emissions, which may be caused from burning too dry and small diameter or too wet and too large diameter logs.

8 Recommendations to prEN 14961

- Fuel moisture should be limited to 25% or it must be clearly stated that delivered fuel has to further dried if the moisture content is higher.

- Fuel moisture content should not be also too low. Lower limit should be around 15%. This is especially important for thermal dried wood logs.

- Seasoned wood and thermal dried wood logs should be clearly marked.

- High quality wood logs have lower bark content. Bark results in higher NO_x-emissions and for higher risk of particulate formation.

MAIN MEASURING EQUIPMENT

Pos	Measured parameter	Type	Model	Range	Output	Manufacturer
24	**CO-concentration**					
	Analyser	NDIR	URAS 10 E	0-1 % ja 0-5 %	1-5 V	H&B
24	**CO_2- concentration**					
	Analyser	NDIR	URAS 10 E	0-20 %	1-5 V	H&B
24	**O_2- concentration**					
	Analyser	Electrochemical	URAS 10 E	0-5 % ja 0-25 %	1-5 V	H&B
25	**NO- concentration**					
	Analyser	Chemiluminesense	Thermo 42i-HL	NO 0-500 ppm	1-5 V	Thermo
				NO2 0-100 ppm	1-5 V	Fisher Scientific Inc.
				NOx 0-500 ppm	1-5 V	
23	**CxHy- concentration**					
	Analyser	FID	Multi-FID 100	0-100 mgOGC/m3	1-5 V	H&B
				0-1000 mgOGC/m3		
				0-10000 mgOGC/m3		
				0-100000 mgOGC/m3		
14	**FG cooler (2 pc.)**		CGEK 6			H&B
15	**Condense remover (2 pc.)**		CGKA 1			H&B
16	**Pump (2 pc.)**		N4			H&B
17	**Pump (1 pc.)**		N 022 AV.E		K.N.Neuberger	
10	**Probe**		ES 1 / FE 1			H&B
12.1	**Sample line**		510505	(length 10 m)		PSG
12.2	**Sample line**		510505	(length 2 m)		PSG
12.3	**Sample line**		510505	(length 2 m)		PSG
TIC	**Temp. controller (4 pc.)**		D3			PSG

STL Combi Dust Sampler

- Easy to handle - easy to transport
- Control unit capacity: 0,1-10 m^3/h
- Pump sizes: 3, 6 and 10 m^3/h
- Allows accurate determination of low dust concentrations
- Sampling probe with exchangeable nozzles of diamdiameter 6-20 mm
- Both in-duct and out-duct filter housings available
- Safe filter handling cassette system
- Gas volume meter and zero pressure nozzles calibrated before delivery
- Condensate bottle (2 l) can be filled up and emptied during sampling

Dust measurement with manual gravimetric method

The manual gravimetric method for dust concentration measurements is commonly used when checking emission against a limit value or when calibrating automatic dust measuring instruments. The dust concentration is calculated as the increase in weight of the sampling filter divided with the sampled gas volume.

The STL Combi Dust Sampler is constructed according to the swedish standard SS 028426, based on ISO 9096:1992, which specify minimum requirements and procedures for the gravimetric method. The equipment also complies with the preliminary European Standard prEN 13284-1.

With the STL Combi Dust Sampler the sampling can be carried out isokinetically with the use of a zero-pressure nozzle. The nozzle size which gives maximum sample flowsize is normally choosen. Filter housing can be mounted in-duct or out-duct. The filtered sample flow is transported in a vacuum hose to the a control unit and pump unit, normally kept on the ground. The control unit includes a condensate bottle and drying tower, gas volume meter, needle valve for flow adjustment, temperature meter and pressure gauges.

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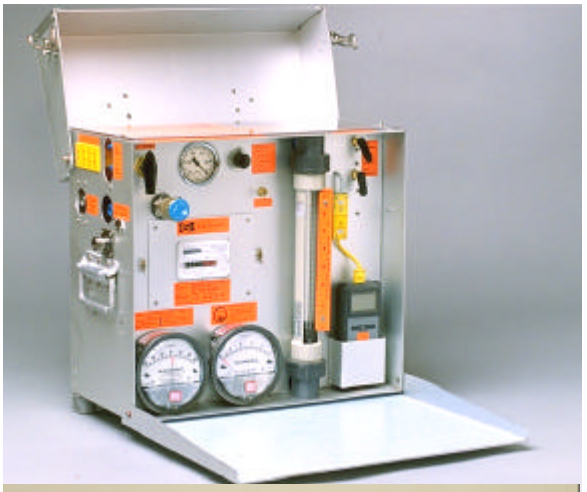
STL Combi Dust Sampler

1. Control unit

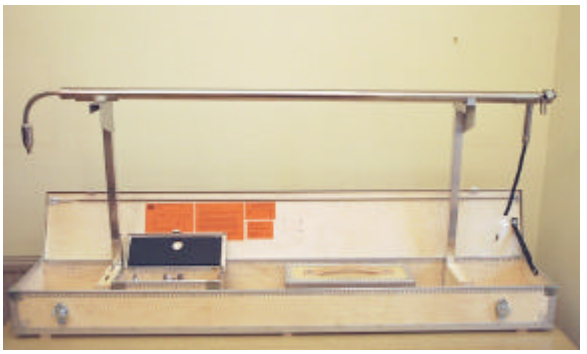


The photo shows the opened control unit ready for operation. The front cover is used as a writing desk for protocols. On the left side are connections for vacuum hose, twin hose from the probe and thermocouple cables for filter housing and gas temperatures. A condensate separator with a 2-litres condensate bottle is mounted close to the inlet connector when sampling wet gases. Choose between the following pump unit capacities: 3, 6 and 10 m^3/h. The equipment is easily carried and operated by one man.

2. Automatic motor valve

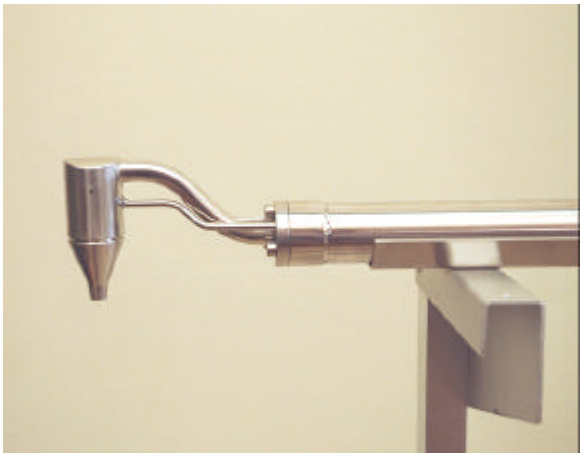
With a motor-valve for automatic isokinetic sampling the need for manual continuous observation of the sampling equipment can be reduced. The motor valve is recommended whenever there is a risk for gas flow variations during the sampling. Improved controlling technique has resulted in higher sensitivity and precision.

3. Dust sampling probe ESS



The photo shows a 1,3 m ESS-probe with a standard probe head with a 90 ° bending. The probe is placed on the foldable stand of the transport box. The stand allows safe and comfortable handling of the probe on site during non-sampling periods. A small box with exchangeable zero-pressure nozzles of sizes 6, 8, 10, 12, 15 and 20 mm can be seen inside the box. The probe head can easily be moved between straight heated suction tubes of different lengths.

4. Straight probe head



The optional probe head allows straight insertion of the ESS probe through 3” portholes. This probe head is needed for sampling in thick-walled ducts or when a bending insertion movement of the probe with a standard probe head is not possible.

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STL Combi Dust Sampler

Control unit
19 kg, 490 x 450 x 260 mm (pump unit excl.).
When sampling in wet gases a condensate separator and a two litres condensate bottle is mounted at the inlet to the control unit. Internal main components are: needle valve for manual flow adjustments, drying tower for 1,7 kg of silica gel, rotameter, temperature meter for internal and external thermocouples, differential pressure gauges for zero-pressure and static pressure.

Probe unit ESS
The heated suction tube is available in standard lengths in steps from 360 up to 2360 mm. Longer suction tubes can be delivered on request.
Exchangeable zero-pressure nozzles of size 6, 8, 10, 12, 15 and 20 mm. Two types of nozzle head: standard 90° curved and straight.

Port hole adapter: for ISO RP 2,5" or RP 3" (or other sizes on request). The probe is easily traversed and kept at the sampling position.

Thermocouple type K for gas temperature and filtration temperature. Other temperature sensors are delivered on request.

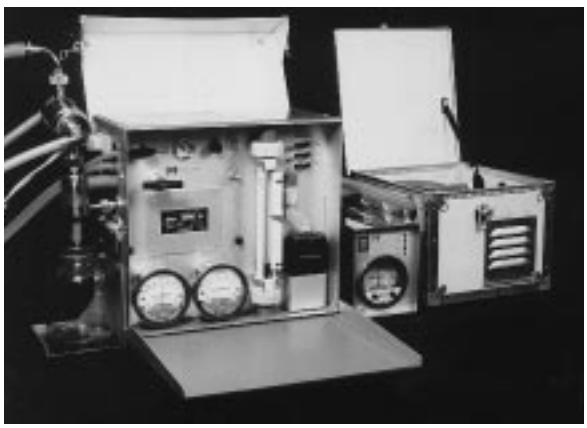
Connection set
Vacuum hose of para gum 14/25 mm
Twin hose for zero-pressure
Thermocouple wires type K
Electric cable for suction tube heating

Pump unit
18 kg, 340 x 280 x 370 mm (mean size).
Pump capacities: 3, 6 and 10 m^3/h. The pump sizes are chosen for accurate determination of dust concentration at different concentration intervals: > 20 mg/m^3n dry gas, 5-20 mg/m^3n dry gas and < 5 mg/m^3n dry gas respectively. The pump together with connection hoses is mounted in a rigid wooden transport box that is normally placed on the floor or on the ground close to the control unit.

Filter housings
Out-duct filter housing for 90 mm or 142 mm plane filters. Filtration temperature is controlled by regulating suction tube heating. An insulating cover prevent cooling.

In-duct filter housings for 47 mm plane filters or filter thimbles 30 x 110 mm. Plane filters are safely handled in cassettes.

Accessories
Heat exchanger for increased drying capacity
Automatic motor valve for isokinetic control
Temperature control regulator for automobile probe heating
Power regulator for manual temp control
Pre-drying unit for ice plugprevention
Insulating cover for filter housing
Hot air gun for pre-heating of filter housing
Filter cassettes and filter transport boxes
Filters of glass fibre, quartz fibre or Teflon
Pitot tubes type L and S



Control unit with heat exchanger for increased drying capacity and motor valve for automatic isokinetic sampling

Probe unit ESS with zero-pressure nozzles, out-duct filter housing for 90 mm filters, cassettes and transport container, insulating cover, port hole adapter for RP 3"

11.12.2007

Tilaaja VTT
proj. 16161-1.4

PL 1009
02044 VTT

Näytetiedot Koivuklapi, D2, L330, D2, W-% 12

Tilausnumero
Näyte otettu 20071120

Näytetyyppi Polttoaine-Biomassa

Saapumispvm 20.11.2007
Tutk. valmistumispvm 11.12.2007

Analyysi	Tulos	Yksikkö	Menetelmä
Kokonaiskosteus	17.6	m-%	CEN/TS 14774-2 (mod.)
Tuhkapitoisuus (550 °C)	0.4	m-% k-a	CEN/TS 14775 (mod.)
Rikkipitoisuus	<0.02	m-% k-a	ASTM D 4239 - 05 (mod.)
Kalorimetrinen lämpöarvo	20.39	MJ/kg k-a	CEN/TS 14918 (mod.)
Kalorimetrinen lämpöarvo	5.664	MWh/t k-a	
Tehollinen lämpöarvo	18.99	MJ/kg k-a	
Tehollinen lämpöarvo	5.275	MWh/t k-a	
Tehollinen lämpöarvo saapumistilassa	15.22	MJ/kg	
Tehollinen lämpöarvo saapumistilassa	4.227	MWh/t	
C	51.2	m-% k-a	CEN/TS 15104:2005 (mod.)
H	6.4	m-% k-a	CEN/TS 15104:2005 (mod.)
N	0.21	m-% k-a	CEN/TS 15104:2005 (mod.)

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Kemisti/Chemist

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08.01.2008

Tilaaja VTT
proj. 16161-1.4

PL 1009
02044 VTT

Näytetiedot Mänty, D1, W25%, KOE 15

Tilausnumero
Näyte otettu 20071212

Näytetyyppi Polttoaine-Biomassa

Saapumispvm 12.12.2007
Tutk. valmistumispvm 08.01.2008

Analyysi	Tulos	Yksikkö	Menetelmä
Kokonaiskosteus	30.4	m-%	CEN/TS 14774-2, ISO 589 (mod.)
Tuhkapitoisuus (550 °C)	0.3	m-% k-a	CEN/TS 14775 (mod.)
Rikkipitoisuus	<0.02	m-% k-a	ASTM D 4239 - 05 (mod.)
Kalorimetrinen lämpöarvo	20.48	MJ/kg k-a	CEN/TS 14918, ISO 1928 (mod.)
Tehollinen lämpöarvo	19.13	MJ/kg k-a	CEN/TS 14918, ISO 1928 (mod.)
Tehollinen lämpöarvo	5.314	MWh/t k-a	
Tehollinen lämpöarvo saapumistilassa	12.57	MJ/kg	CEN/TS 14918, ISO 1928 (mod.)
Tehollinen lämpöarvo saapumistilassa	3.492	MWh/t	
C	50.9	m-% k-a	CEN/TS 15104, ISO/TS 12902
H	6.2	m-% k-a	CEN/TS 15104, ISO/TS 12902
N	0.20	m-% k-a	CEN/TS 15104, ISO/TS 12902

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Teh. lämpöarvo ensisij. määritetyillä arvoilla/muulloin:
Net calorific value calculated from det. values/otherwise:
H% = 5,6 / (O%+N%) = 35 -Turve/Peat
H% = 6,2 / (O%+N%) = 41 -Kokopuu/Whole trees
H% = 6,0 / (O%+N%) = 41 -Hakkuutähteet/Logging residues
H% = 5,9 / (O%+N%) = 41 -Kuori/Bark
H% = 6,0 / (O%+N%) = 41 -Kasvit/Straw etc.

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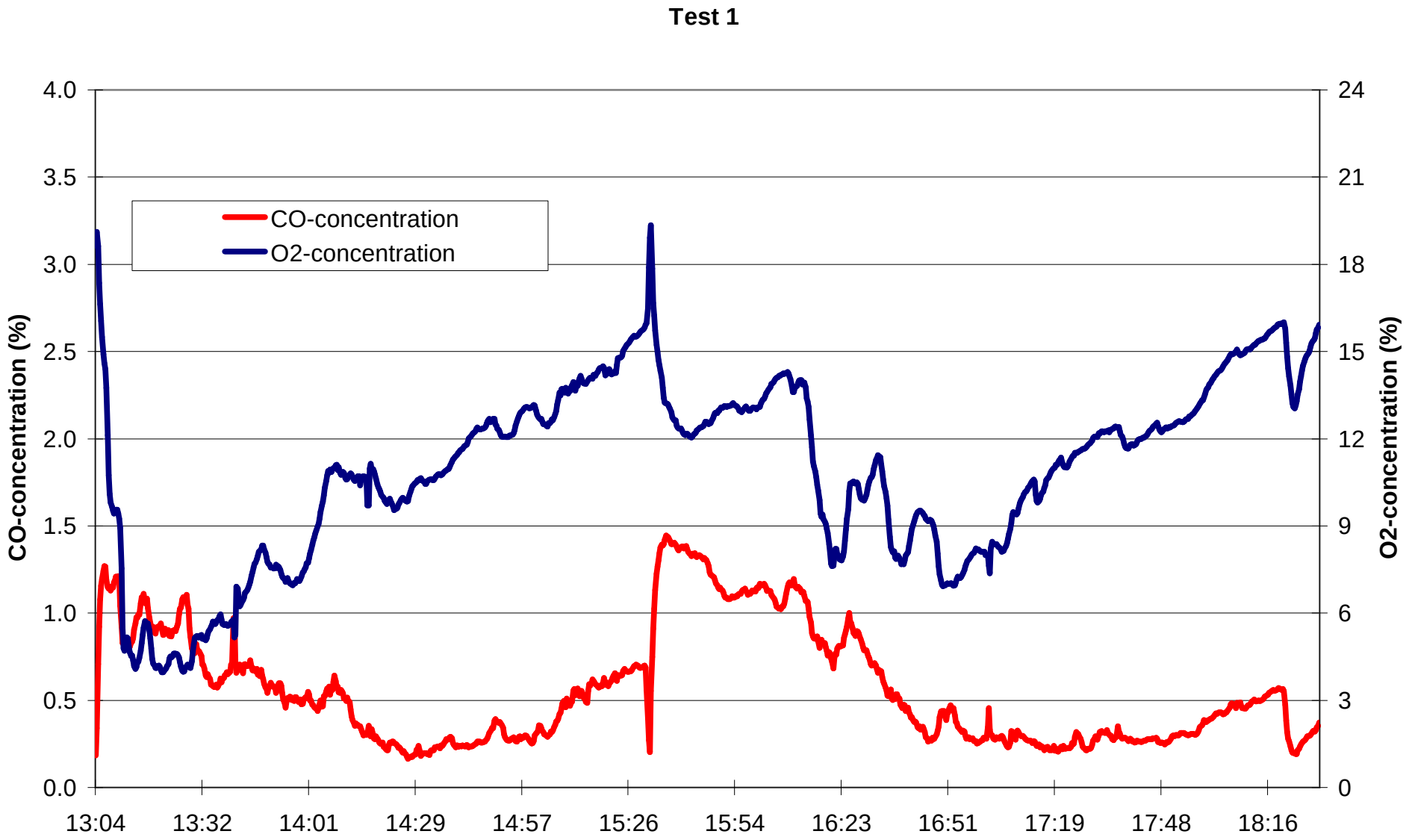
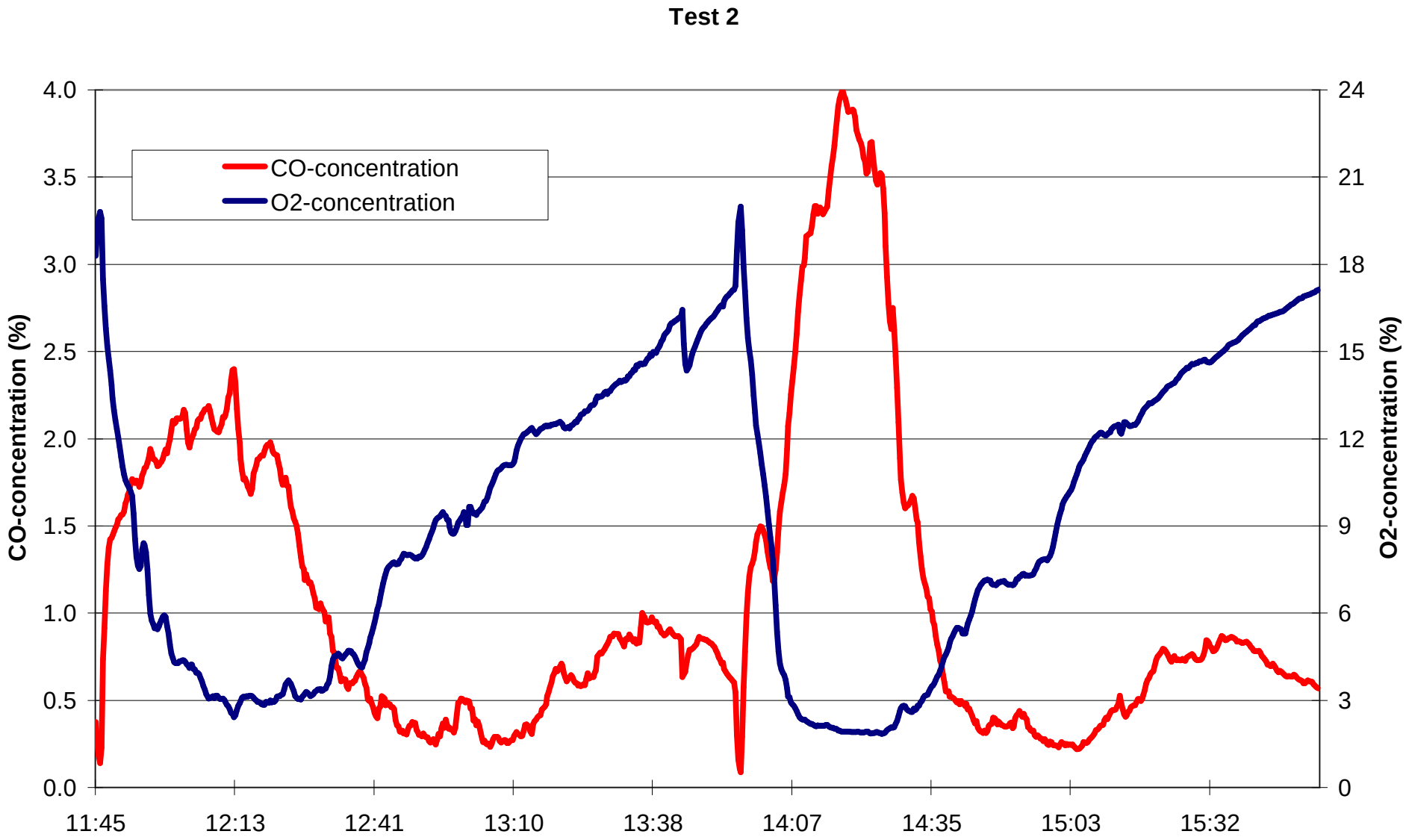
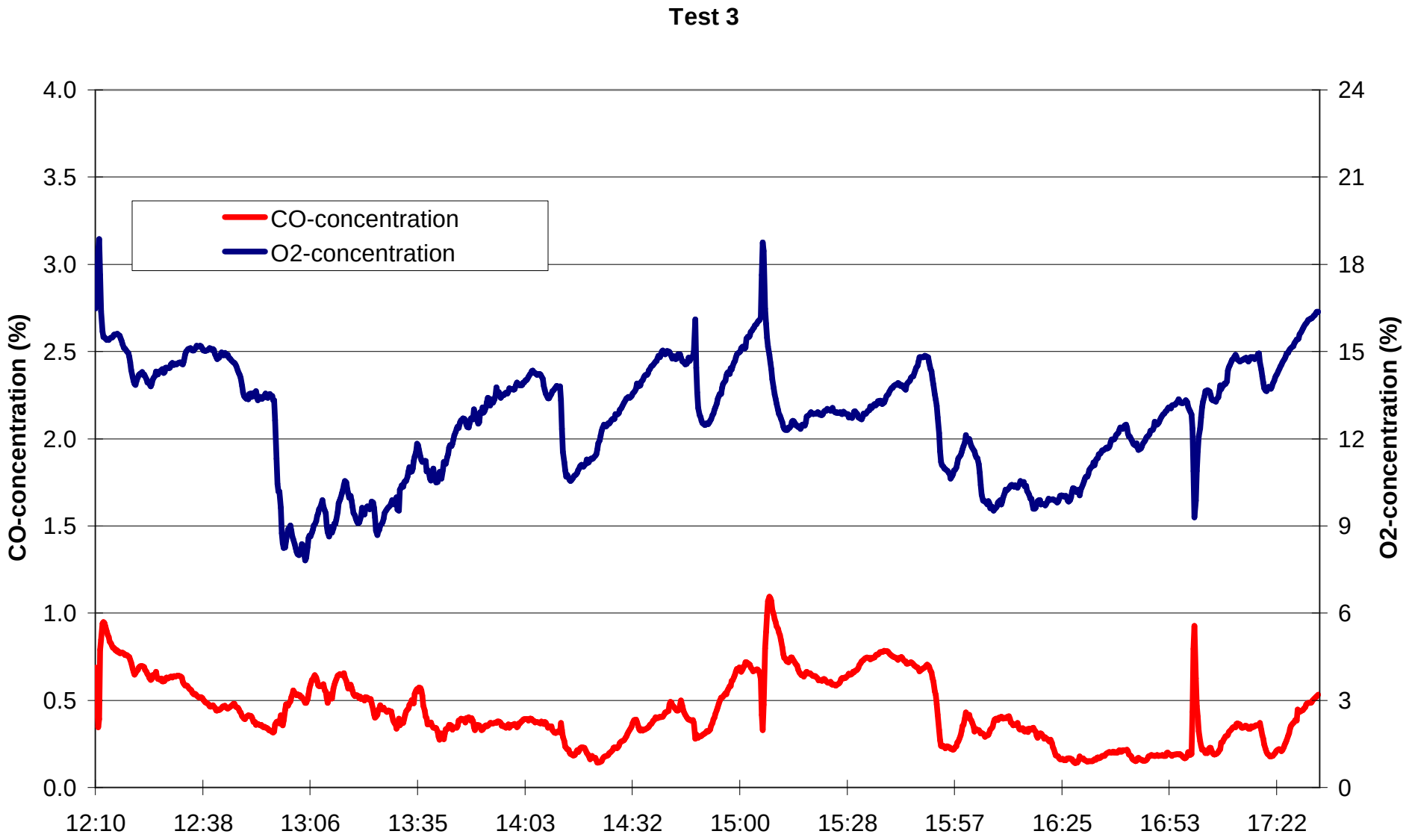
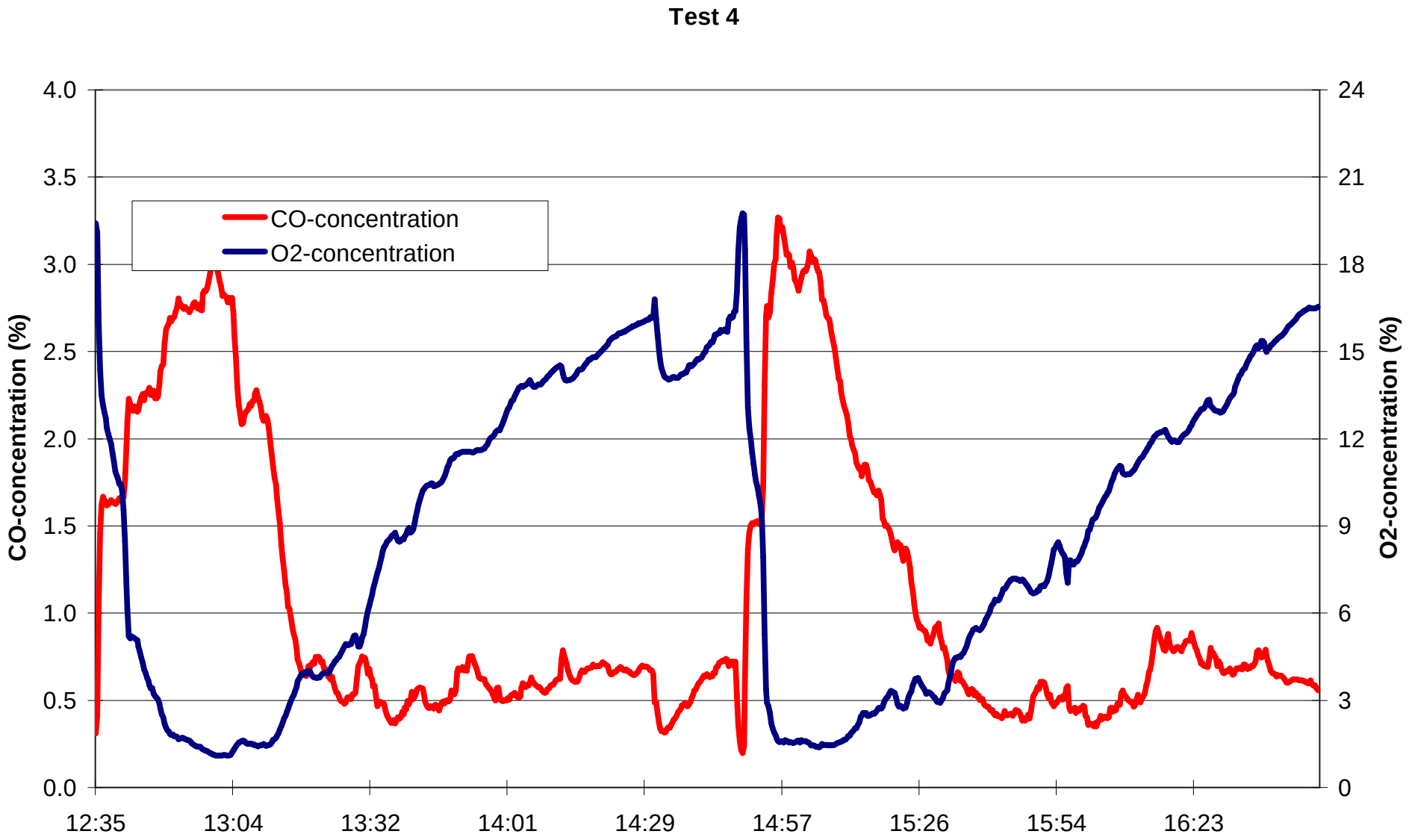
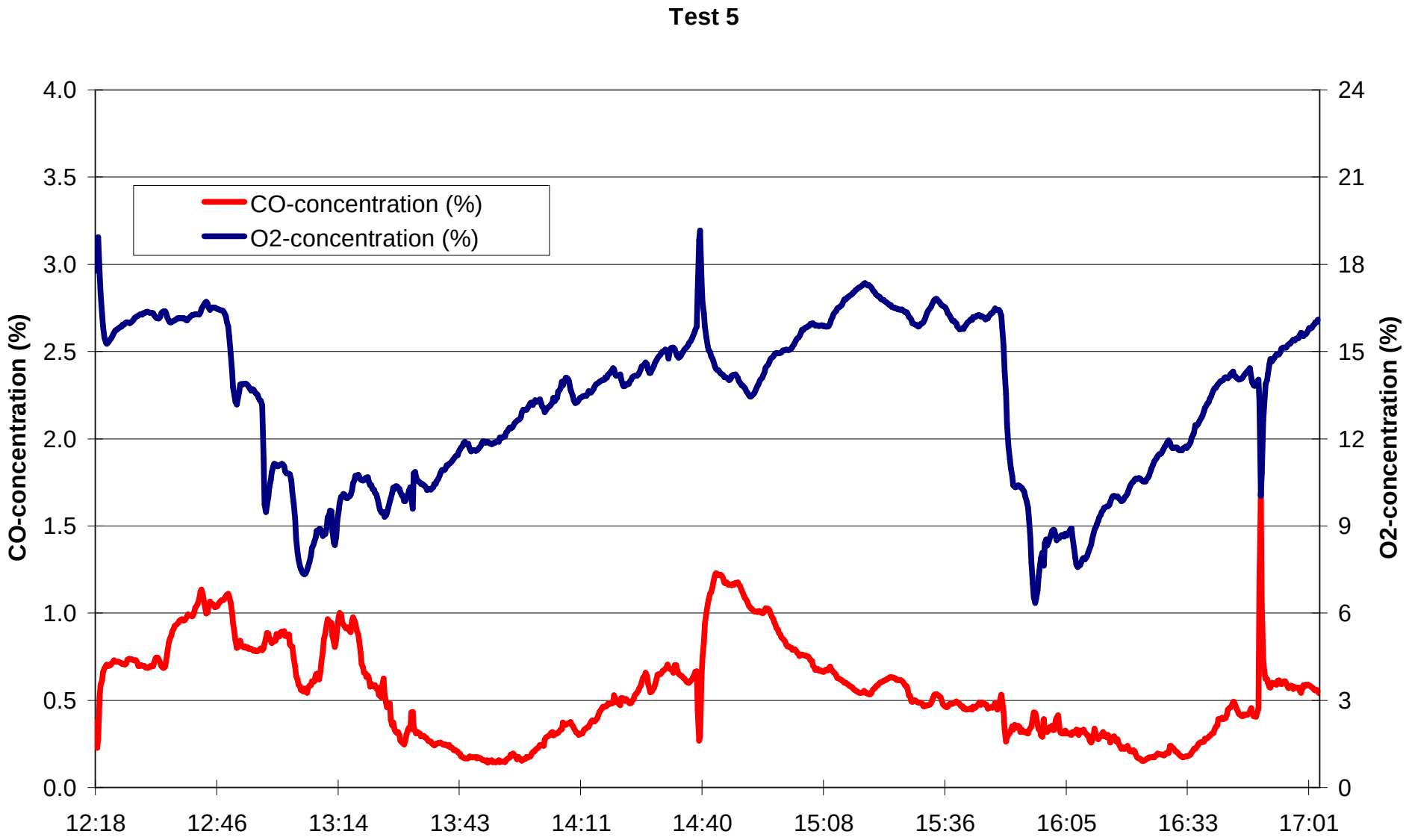
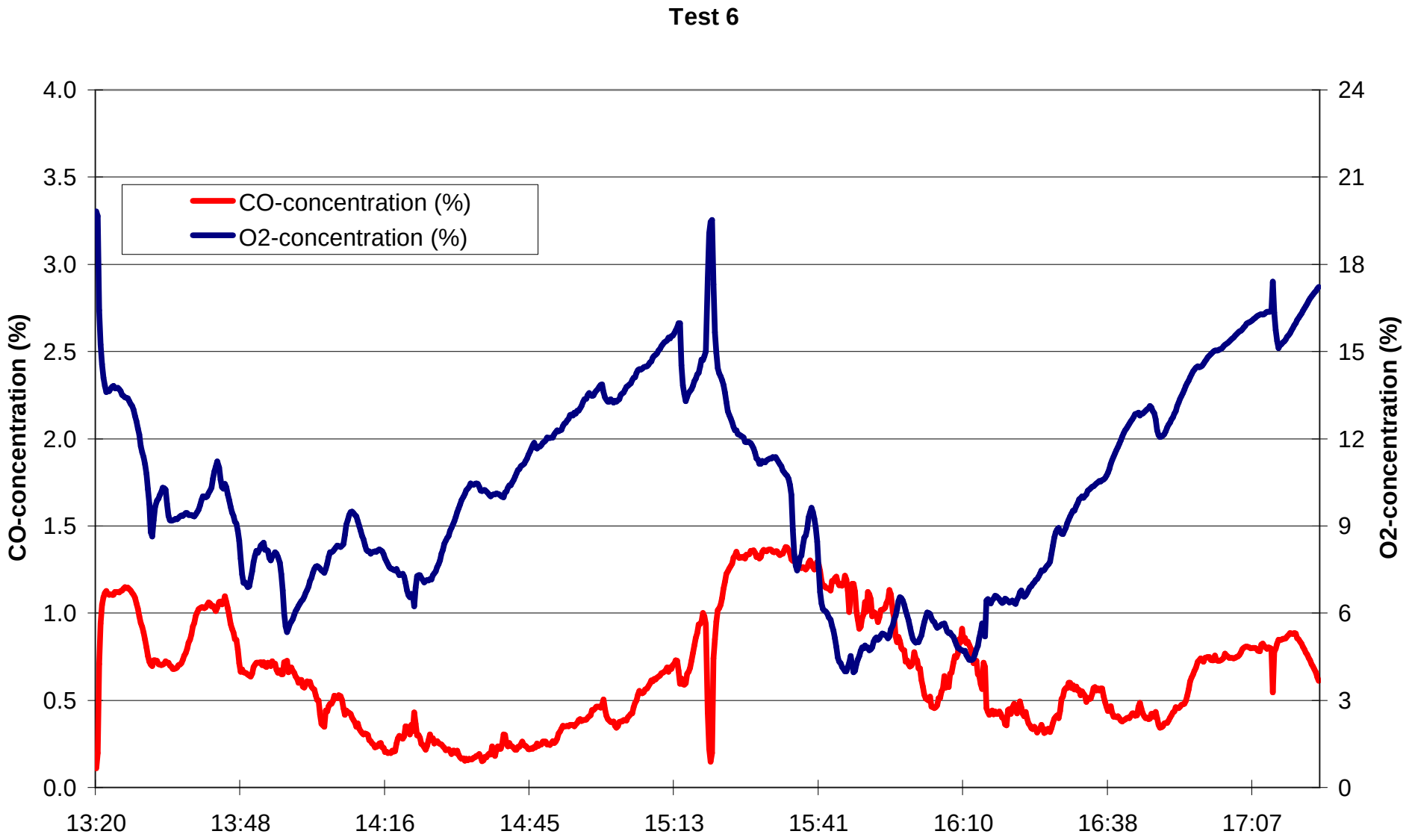

Test 1
CO-concentration
O2-concentration
CO-concentration (%)
O2-concentration (%)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
24
21
18
15
12
9
6
3
0
13:04
13:32
14:01
14:29
14:57
15:26
15:54
16:23
16:51
17:19
17:48
18:16

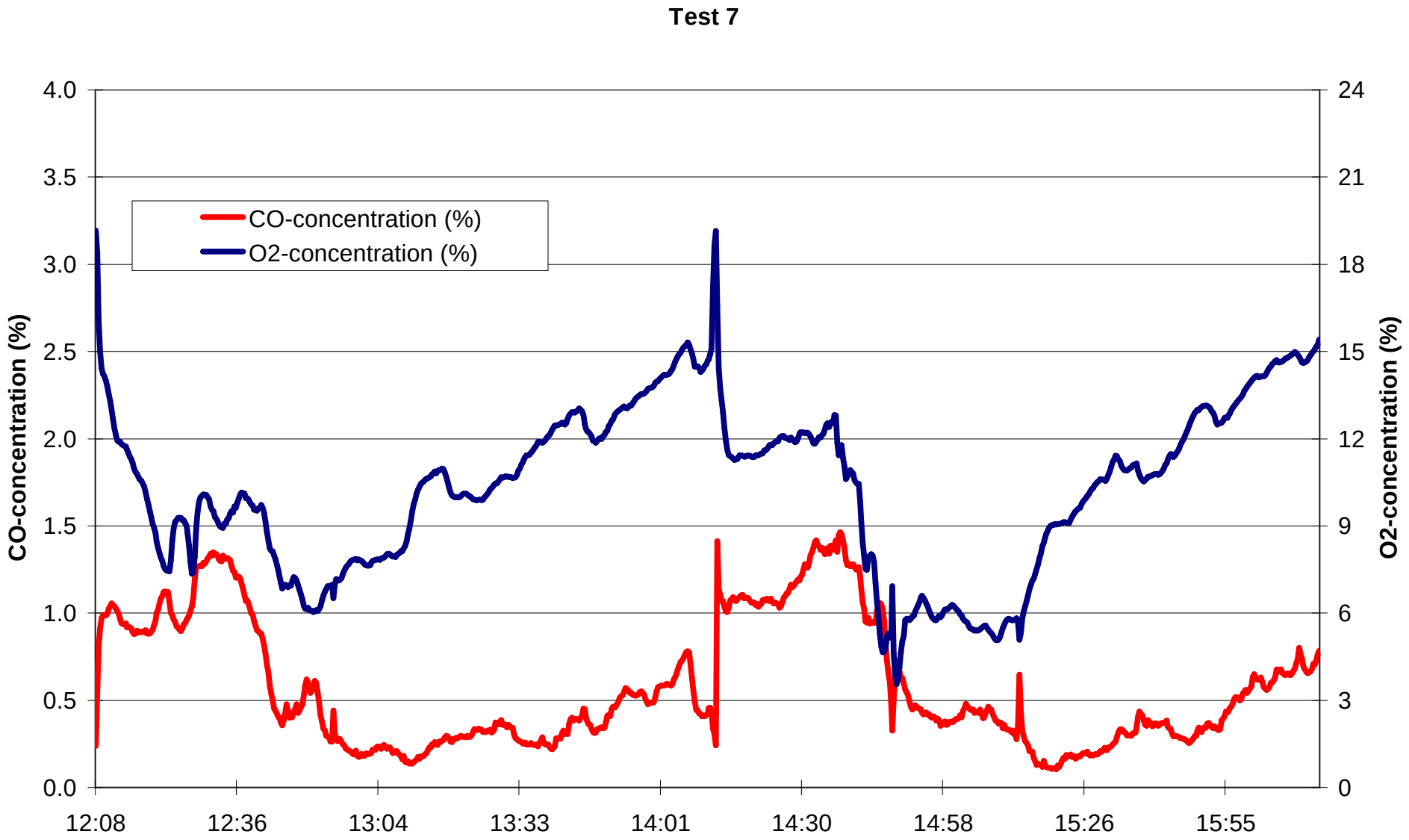

Test 2
CO-concentration
O2-concentration
CO-concentration (%)
O2-concentration (%)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
24
21
18
15
12
9
6
3
0
11:45
12:13
12:41
13:10
13:38
14:07
14:35
15:03
15:32

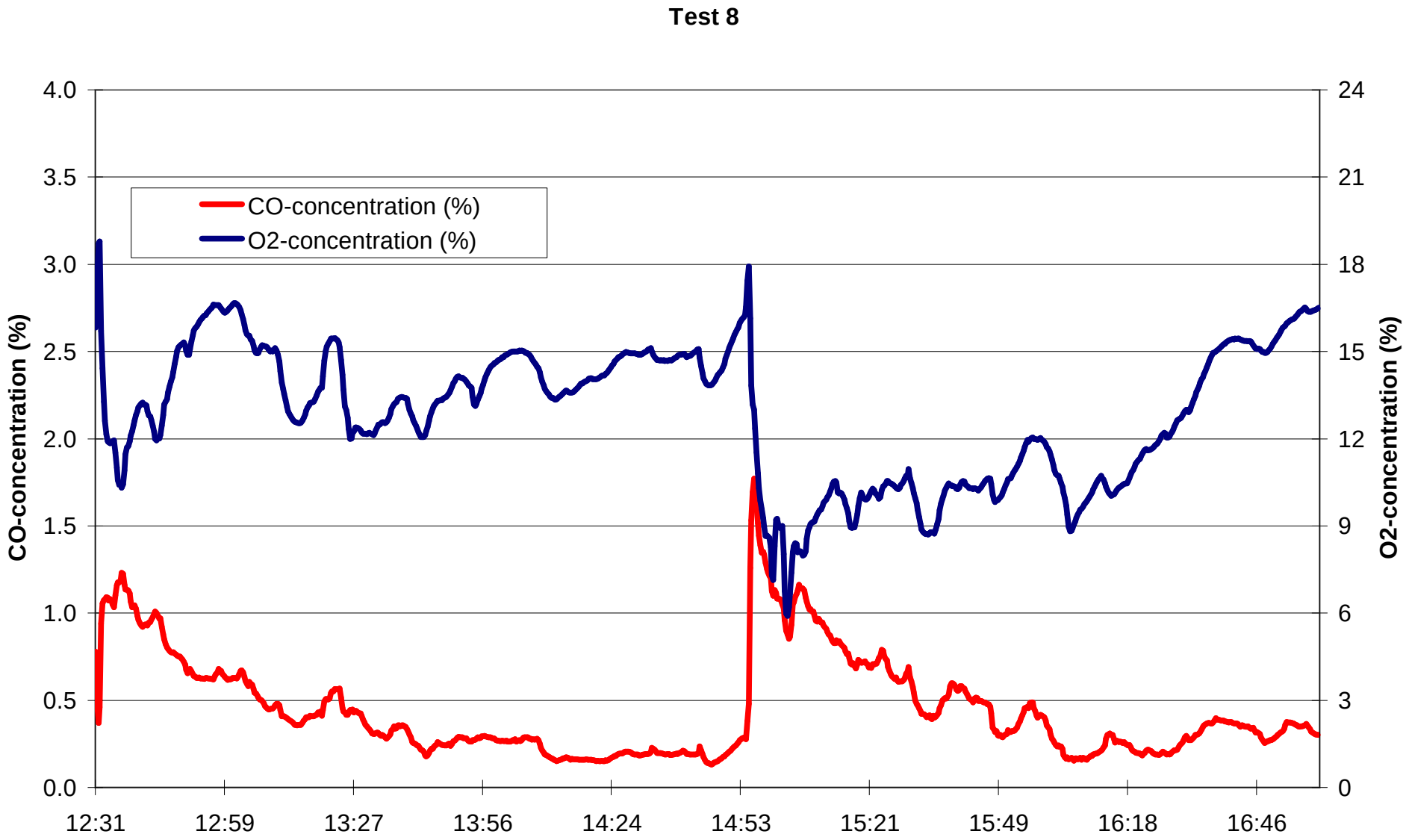

Test 3
CO-concentration
O2-concentration
CO-concentration (%)
O2-concentration (%)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
24
21
18
15
12
9
6
3
0
12:10
12:38
13:06
13:35
14:03
14:32
15:00
15:28
15:57
16:25
16:53
17:22

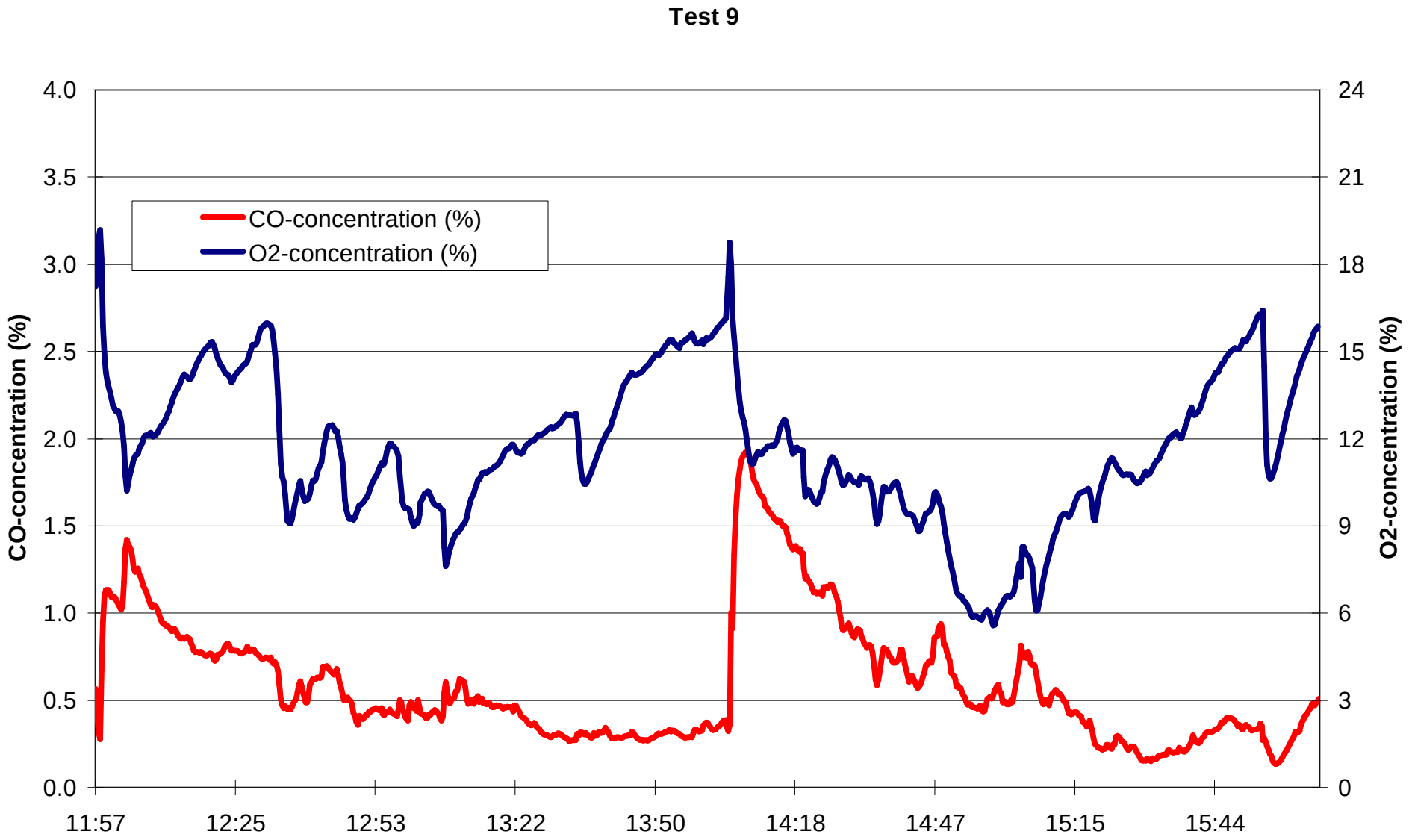

Test 4
CO-concentration
O2-concentration
CO-concentration (%)
O2-concentration (%)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
24
21
18
15
12
9
6
3
0
12:35
13:04
13:32
14:01
14:29
14:57
15:26
15:54
16:23

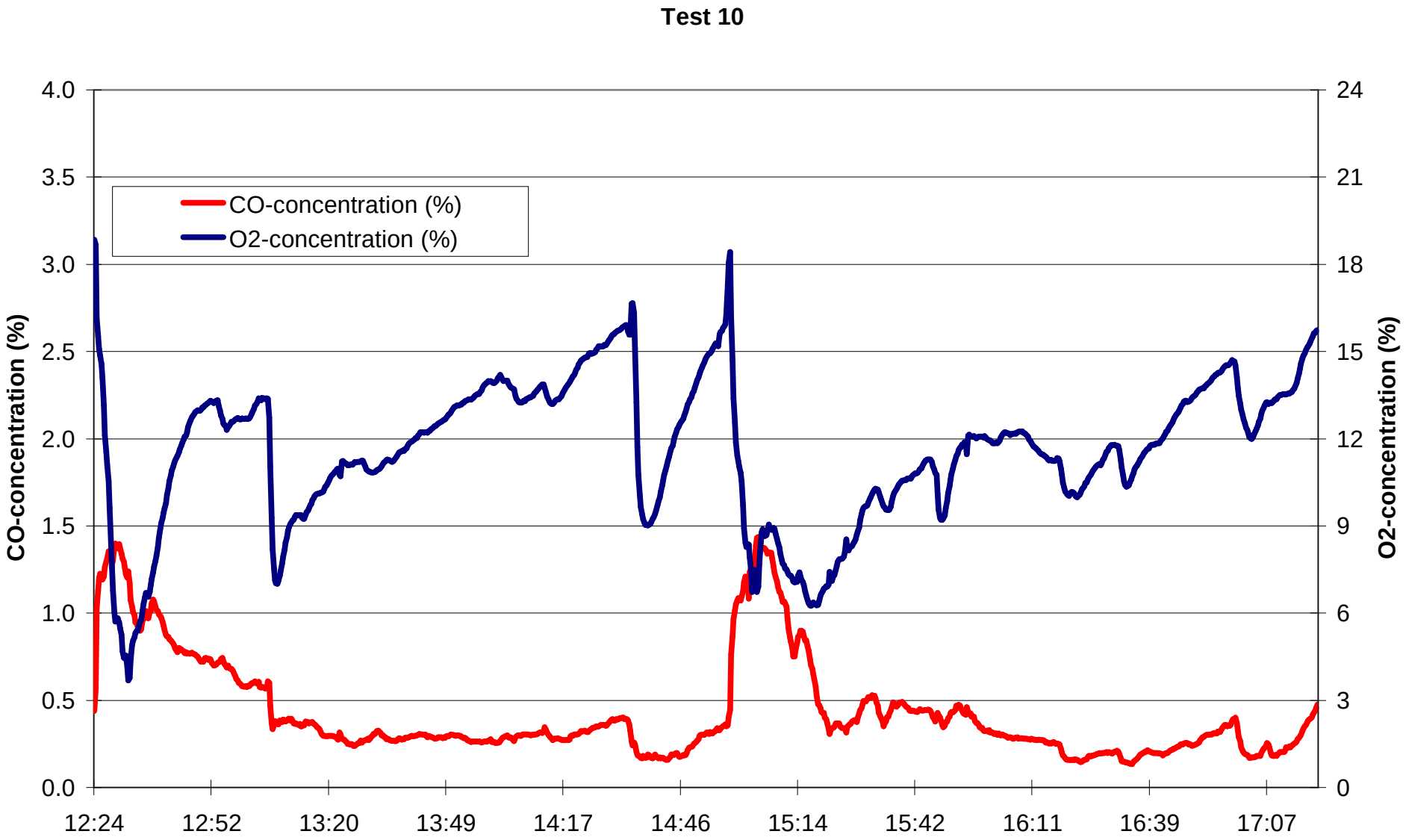

Test 5
CO-concentration (%)
O2-concentration (%)
CO-concentration (%)
O2-concentration (%)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
24
21
18
15
12
9
6
3
0
12:18
12:46
13:14
13:43
14:11
14:40
15:08
15:36
16:05
16:33
17:01

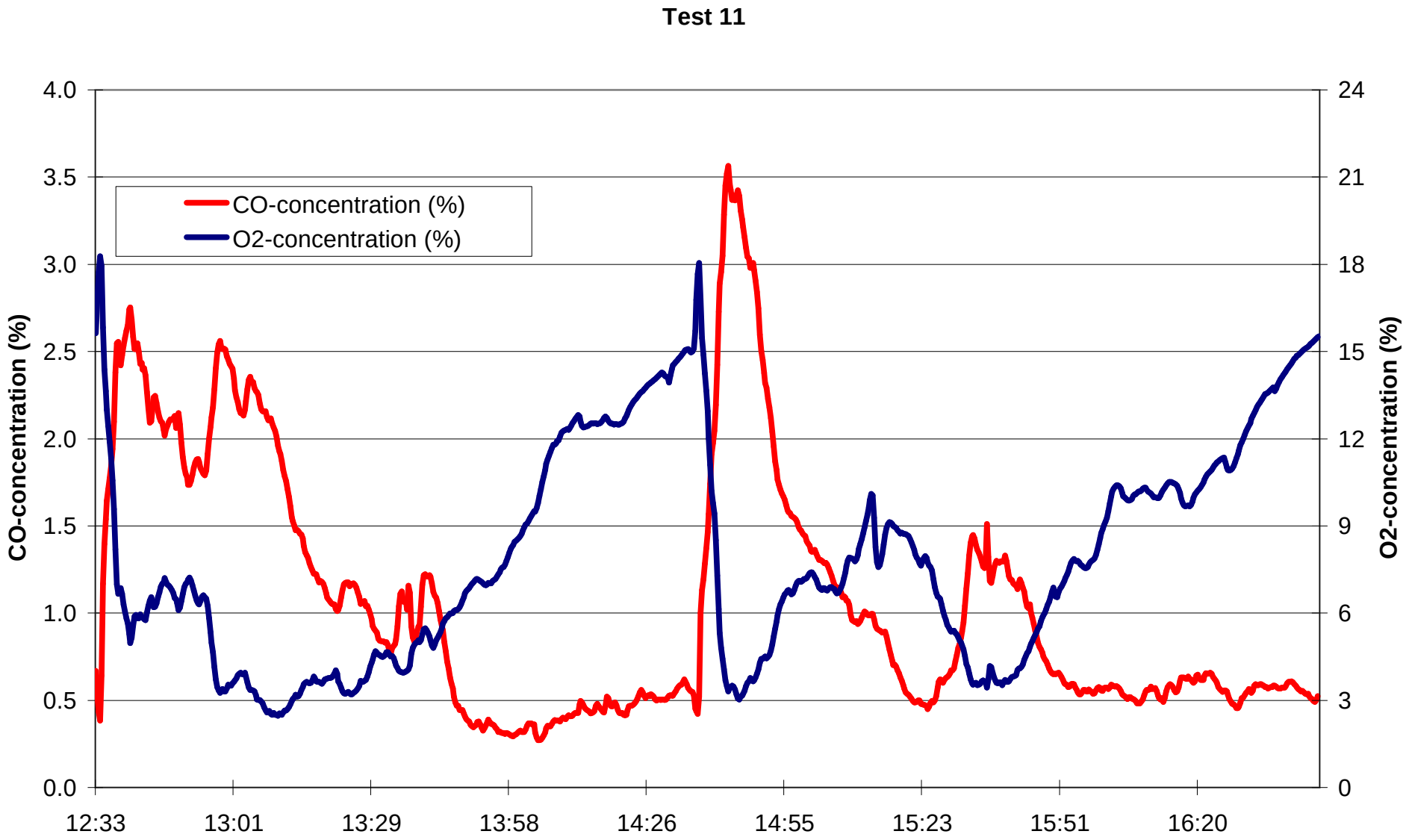

Test 6
CO-concentration (%)
O2-concentration (%)
CO-concentration (%)
O2-concentration (%)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
24
21
18
15
12
9
6
3
0
13:20
13:48
14:16
14:45
15:13
15:41
16:10
16:38
17:07

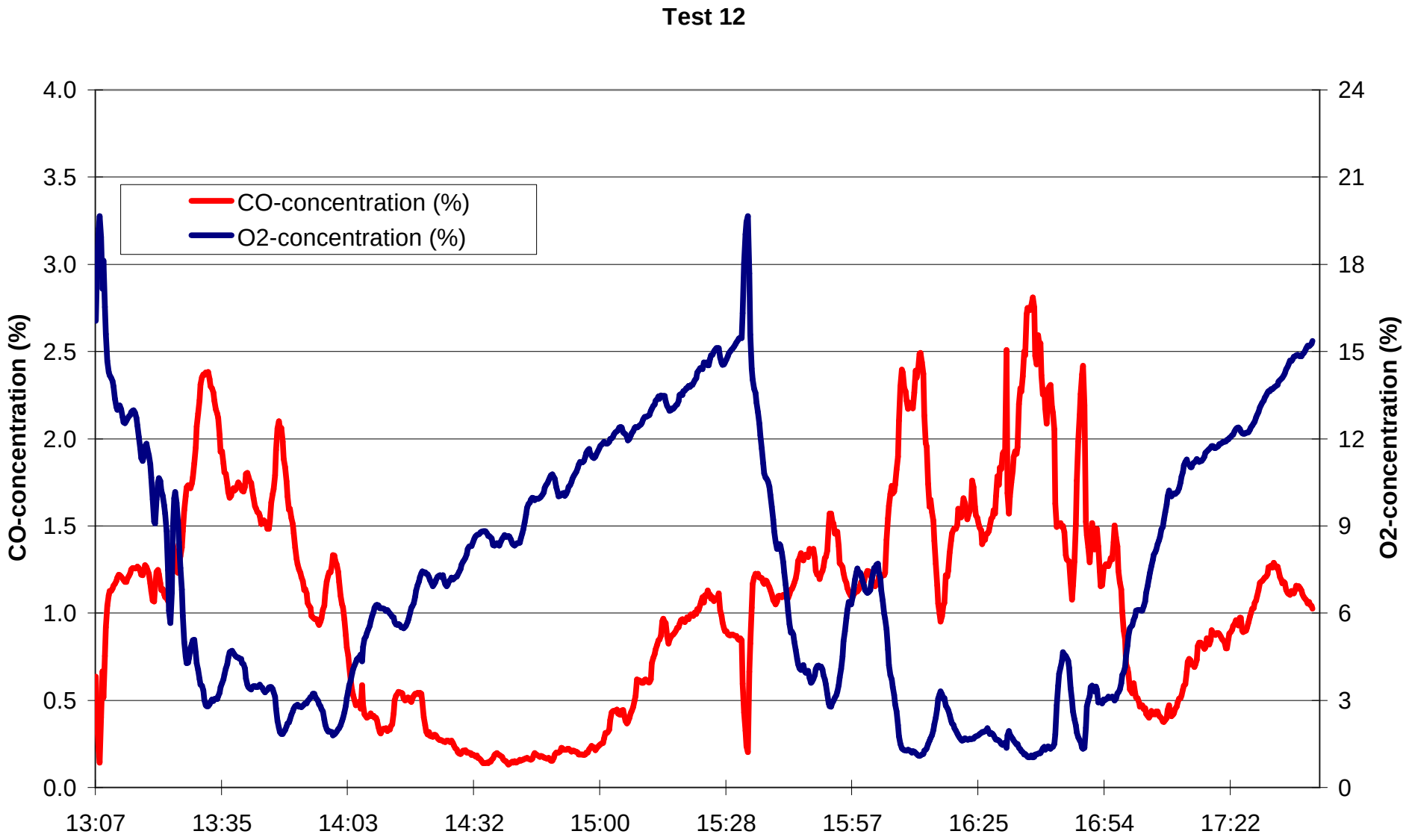

Test 7
CO-concentration (%)
O2-concentration (%)
CO-concentration (%)
O2-concentration (%)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
24
21
18
15
12
9
6
3
0
12:08
12:36
13:04
13:33
14:01
14:30
14:58
15:26
15:55


Test 8
CO-concentration (%)
O2-concentration (%)
CO-concentration (%)
O2-concentration (%)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
24
21
18
15
12
9
6
3
0
12:31
12:59
13:27
13:56
14:24
14:53
15:21
15:49
16:18
16:46


Test 9
CO-concentration (%)
O2-concentration (%)
CO-concentration (%)
O2-concentration (%)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
24
21
18
15
12
9
6
3
0
11:57
12:25
12:53
13:22
13:50
14:18
14:47
15:15
15:44


Test 10
CO-concentration (%)
O2-concentration (%)
CO-concentration (%)
O2-concentration (%)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
24
21
18
15
12
9
6
3
0
12:24
12:52
13:20
13:49
14:17
14:46
15:14
15:42
16:11
16:39
17:07


Test 11
CO-concentration (%)
O2-concentration (%)
CO-concentration (%)
O2-concentration (%)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
24
21
18
15
12
9
6
3
0
12:33
13:01
13:29
13:58
14:26
14:55
15:23
15:51
16:20


Test 12
CO-concentration (%)
O2-concentration (%)
CO-concentration (%)
O2-concentration (%)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
24
21
18
15
12
9
6
3
0
13:07
13:35
14:03
14:32
15:00
15:28
15:57
16:25
16:54
17:22