DEMOSOFC
FCH2-JU PROJECT

Project n° 671470

"DEMOnstration of large SOFC system fed with biogas from WWTP"

Deliverable number 4.3-a

Analysis of the emissions from the DEMO

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Introduction

To validate the environmental impact of SOFC technology, detailed emission measurements need to be carried out for demonstration-plants on-site. In the DEMOSOFC-project, three SOFC-systems supplied by Convion, are installed and operated at waste water treatment plant at Turin, Italy. Emissions from these plants are measured at several stages and this report summarizes the methodology and provides the data from the first on-site measurement campaign. During the first measurement campaign, the first of the three units had been installed and was operational.

Measurement setup

General

On-site emission measurements from the first installed C50 unit were measured using a laboratory-in-a-van approach. All the measurement equipment, computers, calibration gases, etc. were installed into a van and the van was driven to the SMAT Collegno site in Turin, Italy. This is a standard approach at VTT when measuring emissions from different power-production plants and it allows for dedicated and custom-made setups to be used on-site with relatively easily. Figure 2 shows the site with Convion C50 unit at the front and VTT's van with all the measurement equipment behind it.

Figure 1 shows the simplified measurement setup. A heated sampling line was placed inside the C50 units exhaust chimney. The extracted gas was then fed through separate sampling line to FTIR for measuring gaseous species and to ELPI for particulate measurement. The sample flow to ELPI was diluted with bottled air using ratio of 1:7.

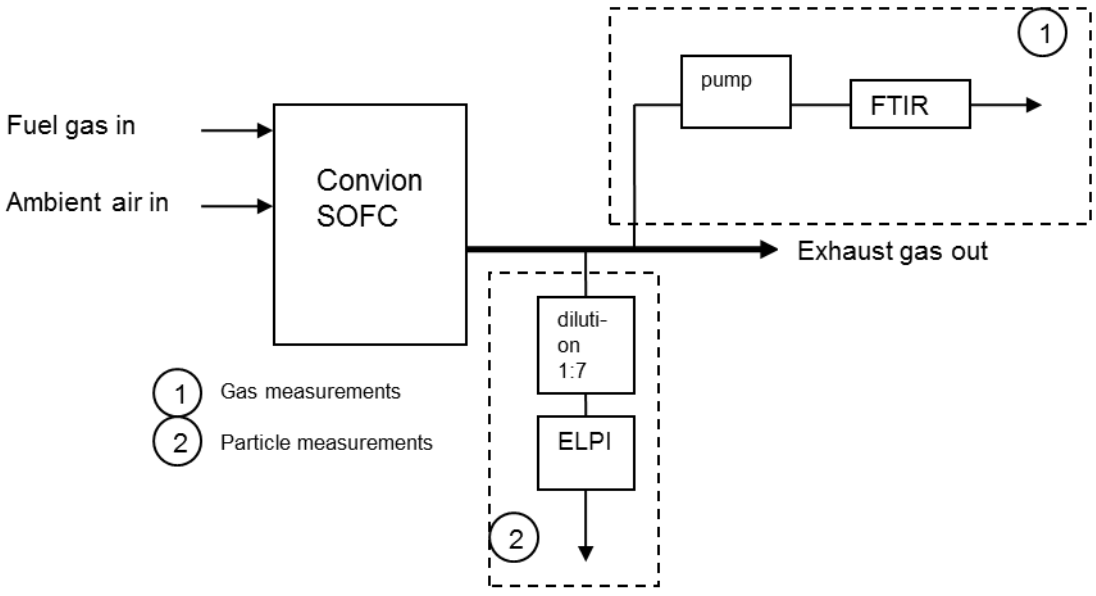

Figure 1. Process diagram of the emission measurement setup .

Figure 2. Setting up emission measurements. Convion C50 system in the front with VTT van with all the emission measurement equipment behind it.

Particulate measurement

Particle number size distributions were measured with the ELPI instrument (Electrical Low Pressure Impactor), manufactured by Dekati Ltd. The main parts of the ELPI are charger and low pressure impactor. Inside the charger the particles are charged and the aerodynamic size classification is done inside the impactor. The current values are measured from each stage of the impactor and transformed to number of particles using calculations. ELPI measures particle size distribution and concentration in real-time of particle size range from 8 nm to 10 µm. Particle mass concentration was calculated using particle density of 1 kg/dm^3.

Sampling flow from exhaust pipe was diluted to 1:7 with purified compressed air before ELPI. Background (zero) was measured at least twice a day using, HEPA-filtered air.

According to standard CEI/IEC 62282-3-200[1] the particulate concentration measurements should be performed using gravimetric method based on standard ISO 9096:2003[2]. Typical limit of quantification for this gravimetric method is 2 mg/m^3 dry gas, at NTP. Particle concentrations in the fuel cell were expected to be significantly below this limit and therefore, particulate concentration measurements were performed using ELPI so that relevant data could be obtained. Limit of quantification with ELPI is 0.05 mg/m^3 for particle sizes of 0.007…10 µm.

[1] IEC 62282-3-200 Fuel cell technologies –Stationary fuel cell power systems – Performance test methods.
[2] ISO 9096:2003. Stationary source emissions – Manual determination of mass concentration of particulate matter.

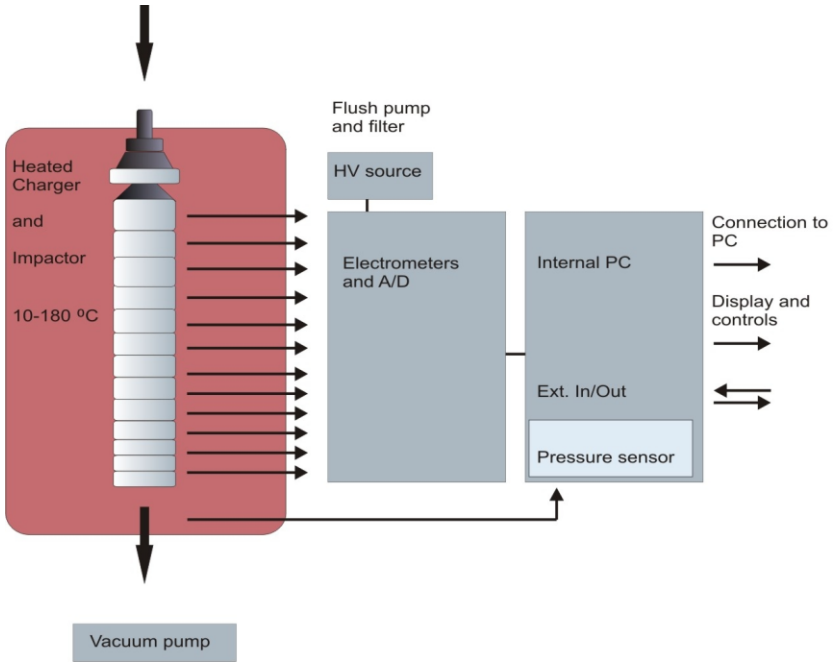

Figure 3. Measurement principle of the electronic low-pressure impactor (ELPI).

Gas emissions

Measured gas components were,H_2O CO_2, CO, CH_4, N_2O, NO, NO_x (as NO_2), SO_2, C_2H_6, HCHO, HF, HCl and O_2. Sampling flow through gas analysing system was three litres per minute with measuring average time of two minutes. Oxygen analysis was performed with zirconium oxide cell built-in to Gasmet Portable Sampling System. The determination limit for O_2 is 0,1 vol-%. Other gas concentrations were analysed using Gasmet Dx4000N which is based on Fourier Transform Infra Red (FTIR) –technique. Analyser's sample cell absorption length was 5 meters and temperature of the cuvette was 180 ºC.

Results

Particulate emissions

Figure 4 presents measured particle concentration as a function of particle size. Ambient air concentrations are shown with black bars and concentrations measured from C50 system exhaust are shown with grey bars. It can be noticed that the concentrations measured from the fuel cell system exhaust are several orders of magnitude lower than the ambient particle concentration. This is caused by the very effective filtering of incoming air inside the system as well as the fact that in this aspect fuel cells as electrochemical conversion devices differ very significantly from e.g. internal combustion engines.

Figure 6 contains average ambient particulate concentrations measured on-site on 12-13th of December 2017. The ambient particulate concentrations can be considered fairly high, but it should be noted that during the time of measurement, weather was unusually cold with night-time temperatures below zero centigrade and no rainfall. These conditions in urban environment usually result in higher particulate concentrations in air. For comparison, Lonati et al. measured average particulate concentration of 25 000 1/cm^3 in Milan during winter 2003-2004[3].

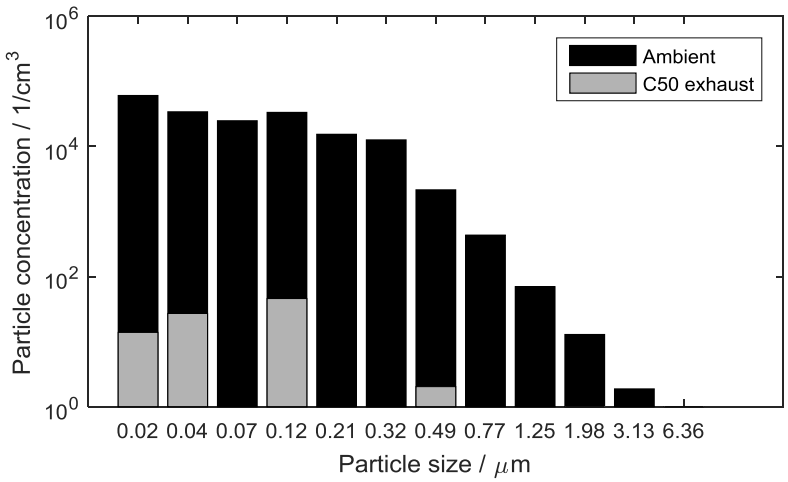

Figure 4. Particle size distribution measured from ambient air and Convion C50 exhaust.

[3] Milan, Italy 2003-2004: cold season average 25000 1/cm3, warm season average 13000 1/cm3
G. Lonati, M. Crippa, V. Gianelle, and R. van Dingenen, "Daily patterns of the multi-modal structure of the particle number size distribution inMilan, Italy," Atmospheric Environment, vol. 45, no. 14, pp. 2434–2442, 2011.

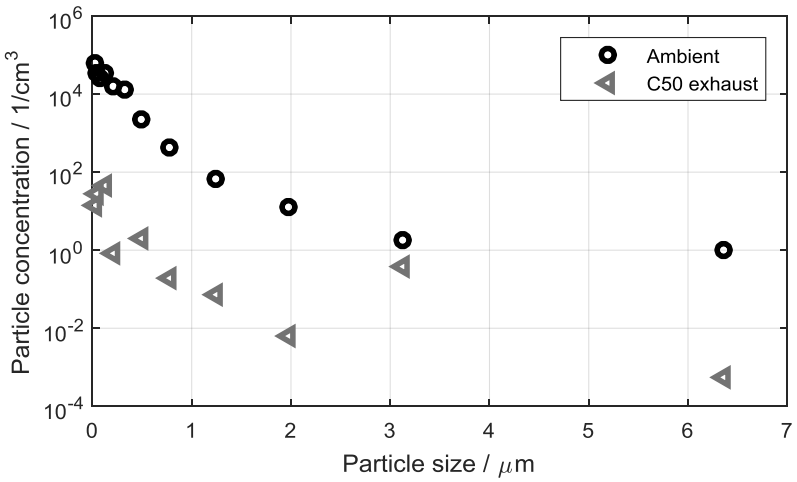

Figure 5. Particle concentration measured from ambient air and from Convion C50 exhaust.

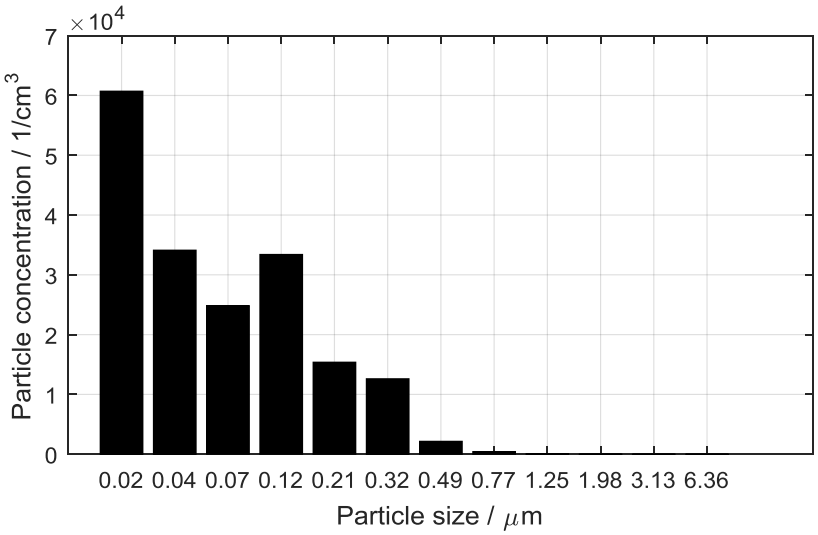

Figure 6. Measured particulate concentration in ambient air at SMAT Collegno 12-13th of December 2017.

Gas emissions

At nominal operating conditions, no other gaseous emissions were measured except water vapour (4.7±0.4%), CO_2 (3.4±0.2%) and O_2 (18.3±1.0%). All of the other measured components were below limits of quantification (Table 1). The measurement uncertainties quoted here are based on previous uncertainty analysis carried out at VTT for similar gas matrix. In case any other emissions stated in Table 1 were found, a more detailed uncertainty analysis should be carried out using the procedure defined in CEN/TC 264 N 2719[4].

[4] Stationary Source Emissions — Determination of mass concentration of multiple gaseous species — Fourier transform infrared spectroscopy", CEN/TC 264 N 2719 (Official CEN/TS documentation to be published during 2018).

Figure 7 shows gaseous emissions during start up of the C50 fuel cell system from hot standby -state. At the start of the measurement run the system was held at hot standby-mode. Then the system was started and electrical power was ramped up. It can be noted that the emissions stabilize quickly and no significant emission peaks are seen during start-up.

Table 1. Measurement results for gaseous species (NTP: 0 °C, 1013.25 hPa). Species that were below limit of quantification are indicated with "<".

Species	Unit	Measured value
H_2O	Vol-%	4.7
CO_2	Vol-%	3.4
CO	mg/m^3	<9
CH_4	mg/m^3	<2
N_2O	mg/m^3	<8
NO	mg/m^3	<20
NO_x (as NO_2)	mg/m^3	<20
SO_2	mg/m^3	<8
C_2H_6	mg/m^3	<14
HCHO	mg/m^3	<7
HF	mg/m^3	<3
HCl	mg/m^3	<5
O_2	Vol-%	18.3

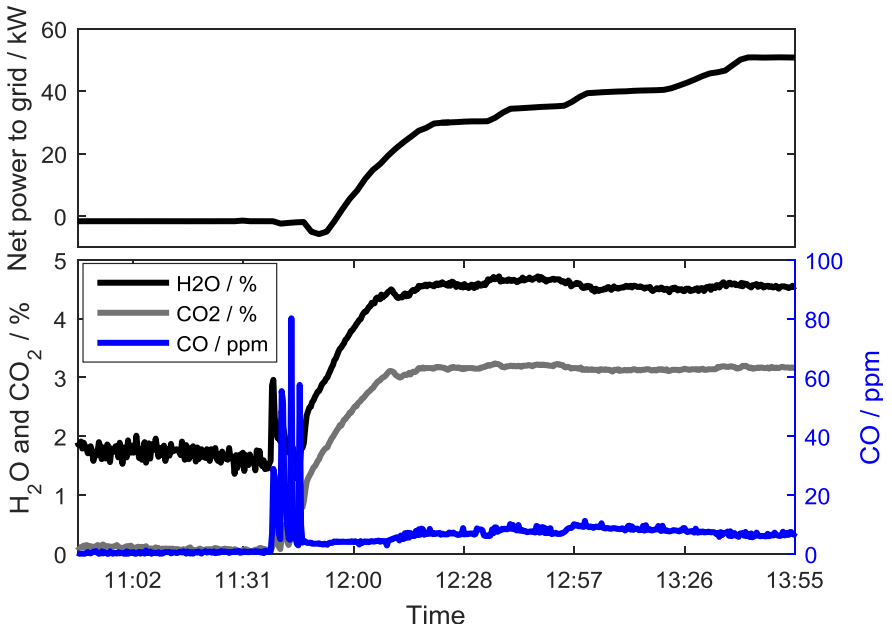

Figure 7. Gas emissions during C50 system startup.

Summary

Table 2 summarizes the measured emissions at steady-state conditions. All of the measured emissions are below quantification limits except H_2O, CO_2 and particles. Particle emissions are lower than the EU reference values quoted for ambient air, so it can be concluded that SOFC technology does not increase particle pollution. Table 2 also contains emission limits for gas engines and turbines which can be used for comparison.

Table 2. Summary of the measured steady-state emissions from the Convion C50 unit operated at the WWTG plant in Turin, Italy.

Species	Unit	Measured value	Typical emission limits of gas engines and turbines[5] [6]
H_2O	Vol-%	4.7	
CO_2	Vol-%	3.4	
CO	mg/m^3	<9	100
CH_4	mg/m^3	<2	
N_2O	mg/m^3	<8	
NO	mg/m^3	<20	
NO_x (as NO_2)	mg/m^3	<20	75…200
SO_2	mg/m^3	<8	15…60
C_2H_6	mg/m^3	<14	
HCHO	mg/m^3	<7	
HF	mg/m^3	<10	
HCl	mg/m^3	<10	
O_2	Vol-%	18.3	
Particulate	mg/m3	0.01	Ambient air EU reference values[7] 0.025 (PM2.5), 0.05 (PM10)

[5] Limitation of emissions of certain pollutants into the air from medium combustion plants (MCP-directive), DIRECTIVE (EU) 2015/2193

[6] Industrial emissions (integrated pollution prevention and control) (IED-directive), DIRECTIVE 2010/75/EU

[7] Air quality in Europe — 2016 report, EEA Report No 28/2016