Höganäs REPORT BILAGA 7

Dept:	Application. Area:	Project:
Reduction & Annealing – Global Technology	Other Areas	PLATIS

Title:

Summary of PLATIS trials - External

SUMMARY

The PLATIS project partly funded by Energimyndigheten, coordinated by Jernkontoret, Scanarc supplies the technology and practical realisation, KTH and Swerim supports with research, and in cooperation with companies from the Swedish steelmaking community; SSAB Borlänge, SSAB Oxelösund, Höganäs AB, Ovako Sweden AB, Linde Gas AB, LKAB and Sandvik Materials Technology AB.

The project aims to investigate if plasma heating systems could be used within the steelmaking industry. Five trials were performed with different carrier and plasma gases to determine what impact it had on material samples. Since Höganäs did not participate with material samples which were to be studied, the process parameters, such as temperature, power usage and gas consumptions, were most important. Höganäs AB provided a small muffle piece used in a pilot furnace to be used in the plasma trials. During the trials the temperature measurements did not vary much between the three thermocouples attached to the muffle, which rejects the main concerns of having hot spots on the muffle due to the intensity of the plasma torch.

Other applications within the Höganäs group which might be of interest for larger or full-scale tests of plasma heating systems is tunnel kilns where natural gas burners can be replaced, and the plasma torch's variable power output can be further utilised. Melting and atomising of steel, in process steps where the smelt is being held at set temperatures, e.g. tundish, or where the process atmosphere is to be controlled. Utilising the plasma system adaptivity to different carrier gases.

Although very short trials, the project have shown implications that plasma heating can be utilised in heating applications for manufacturing of metal powder in belt furnaces. The lack of high temperature heating systems for utilising in steel manufacturing in general makes plasma heating a viable contender to fossil-fuelled solutions when the fight against climate change must be stepped up and the incentives increase.

A continuation to investigate above mentioned points of interest to further evaluate the technology and its potential is therefore desirable.

Höganäs, May 17, 2021

Author:

....

Kristoffer Lundkvist

TABLE OF CONTENTS

1. INTRODUCTION

The Höganäs group is a large emitter of greenhouse gases and with the climate road map aims to lower our carbon footprint. The Alternatives for replacing fossil fuelled power sources in furnace heating applications are scarce, but techniques are emerging as the incentives and societal pressure for cleaner solutions are increasing.

To reduce natural gas consumption by replacing conventional natural gas with electrical solutions are often hailed as the silver bullet. But retrofitting existing furnaces with electrical heating elements are not always straight forward as the process atmosphere may pose constraints as e.g. being reducing. In some instances, it might desirable to phase out old burners little-by-little, rather than a complete rebuild.

The PLATIS project is a collaboration between many different companies within the Swedish steelmaking industry, the project is owned and managed by Jernkontoret, partly funded by the Swedish energy agency, Energimyndigheten, and in collaboration with KTH, Swerim and the plasma system developer and manufacturer Scanarc. The participating companies from the Swedish steel making industry are: Höganäs, SSAB, LKAB, Outokumpu, Linde, Ovako and Sandvik.

2. MATERIAL & METHODS

2.1 Furnace layout

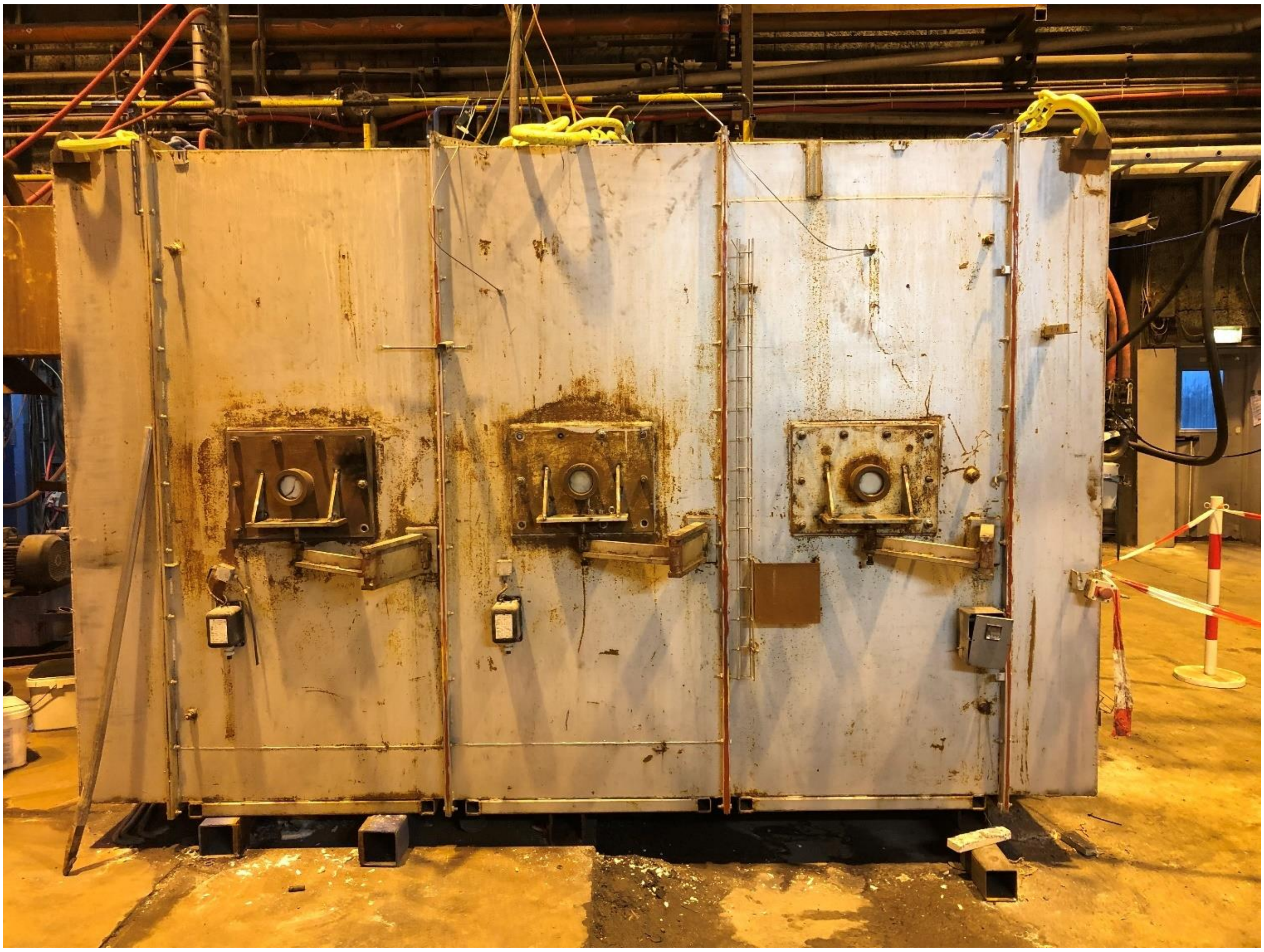

Figure 1 Trial furnace at Scanarc, seen from the side with three inspection hatches

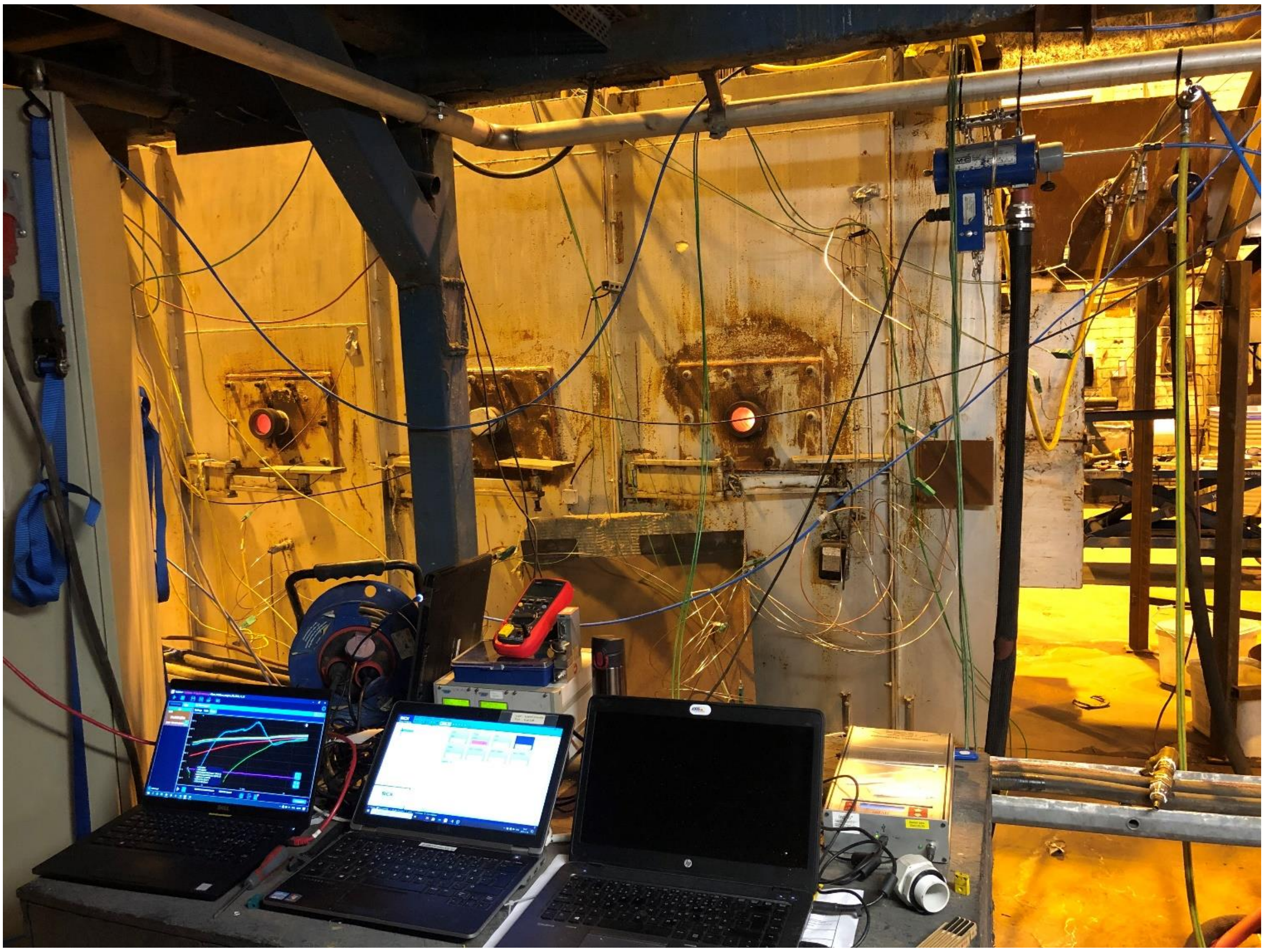

Figure 2 Trial furnace at Scanarc as seen from the opposite side compared to previous picture

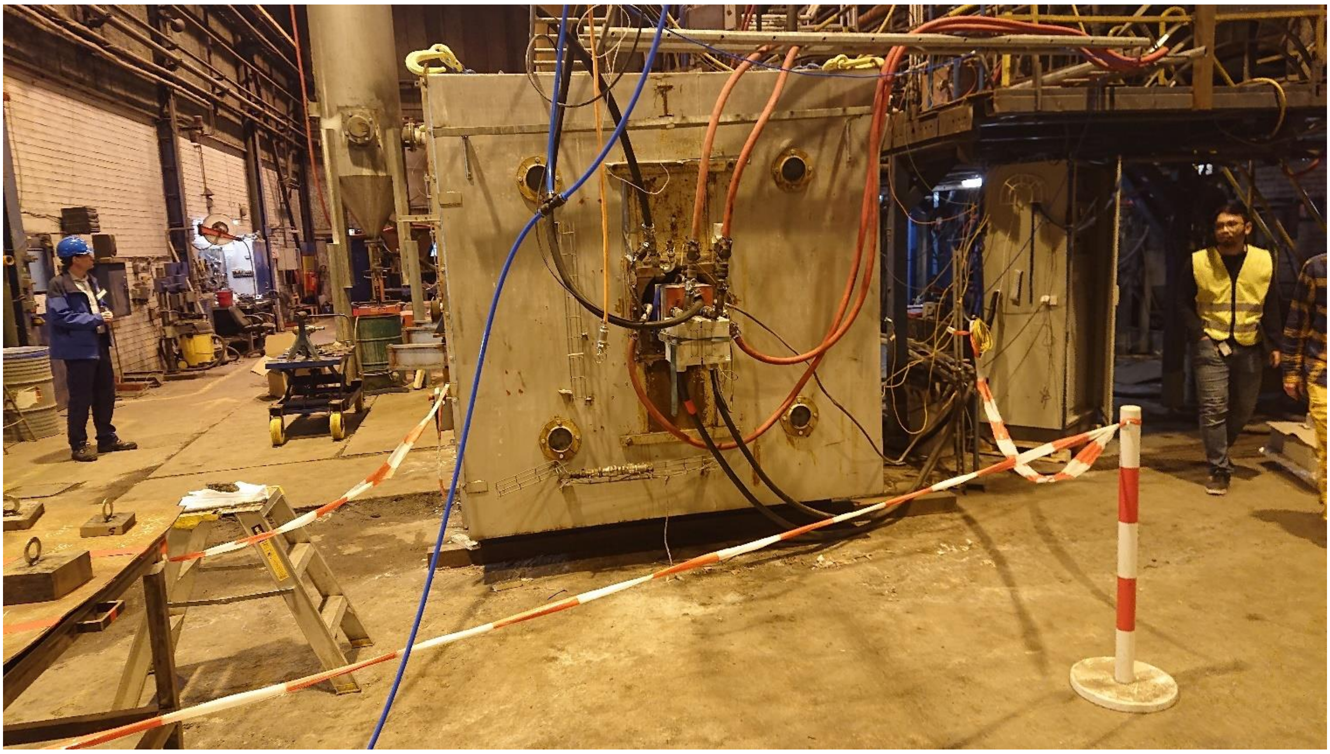

Figure 3 View of trial furnace at Scanarc, as seen from the gable. The plasma torch installed in the middle

2.2 Trials

Five different trials were scheduled, and the setup was shaped from the desires and prerequisites of the project group. The main scope of each trial was to try out different plasma and carrier gases at 1200 degrees and having test sample at given holding time to evaluate the oxide formation. The oxide formation is however not of interest for us at Höganäs.

The final trial planning established the five configurations as summarised in Table 1 below. The selection of gases was narrowed down to the selected ones due to the atmospheres of the various processes of the companies involved and the availability of such gases at respective production site.

Table 1 Matrix over planned field trials

	Plasma Gas	Carrier Gs
Trial 1	Air	Air + Gasol
Trial 2	CO_2	CO_2
Trial 3	N_2	N_2
Trial 4	CO_2	CO_2 + Steam
Trial 5	N_2	N_2 + Steam

2.3 Configuration test muffle

The muffle selected to be used in trials was a decommissioned muffle from a pilot furnace, two sections of 500 mm each was cut. Six pieces of tubing the similar material was welded to the top surface as pictured in Figure 4 below. A muffle from a pilot furnace was selected due to physical constraints from the test furnace, the hatches were rather small.

Six sockets made from tubing were welded to the top of the muffle as shown in Figure 4 below to enable thermocouples to be attached to the muffle.

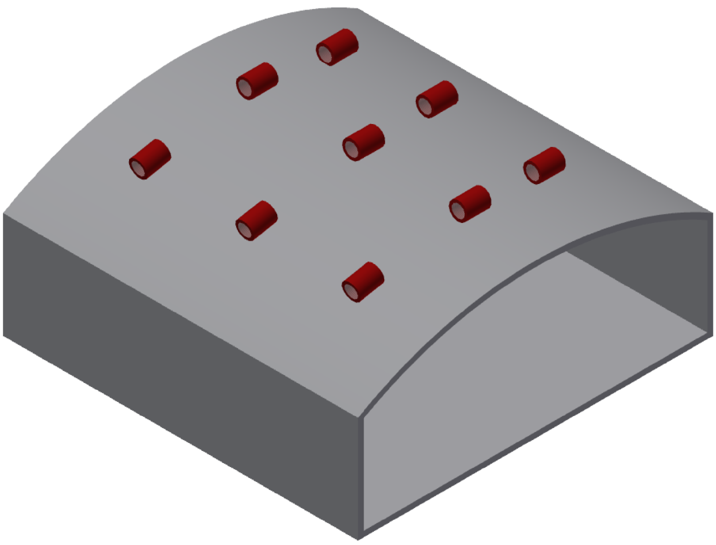

Figure 4 Visualisation of muffle with tubing welded to the top surface

2.4 Setup measurements

The three thermocouples are connected to an Intab PC-logger 31000 and a laptop running Easyview to visualise the temperature loggings live.
The thermocouples used are of type K, with a diameter of 3 mm and 5 000 mm long.
The thermocouples are lodged in place in the sockets and led out the furnace wall to data logging station.

3. RESULTS

In the following sections results for the five different trials and days will be presented. The data of interest for Höganäs will be shown. The other participants of the project were mainly interested in the material properties of their samples as opposed to Höganäs where the process performance is critical. Therefore, the presented data below will mainly consist of temperature, temperature derivate and the power usage.

Scanarc has supplied data from their control system and is clearly marked next to each figure and table. Mainly temperature profiles and net power usage.

The data collected by Höganäs equipment are filtered into the appropriate days, and further divided into chunks according to the three phases; heating phase, continuous heating and cooling phase.

The table at the beginning of each section summarises plasma and carrier gas and power usage.

Figure 5 Plasma torch during heat up phase

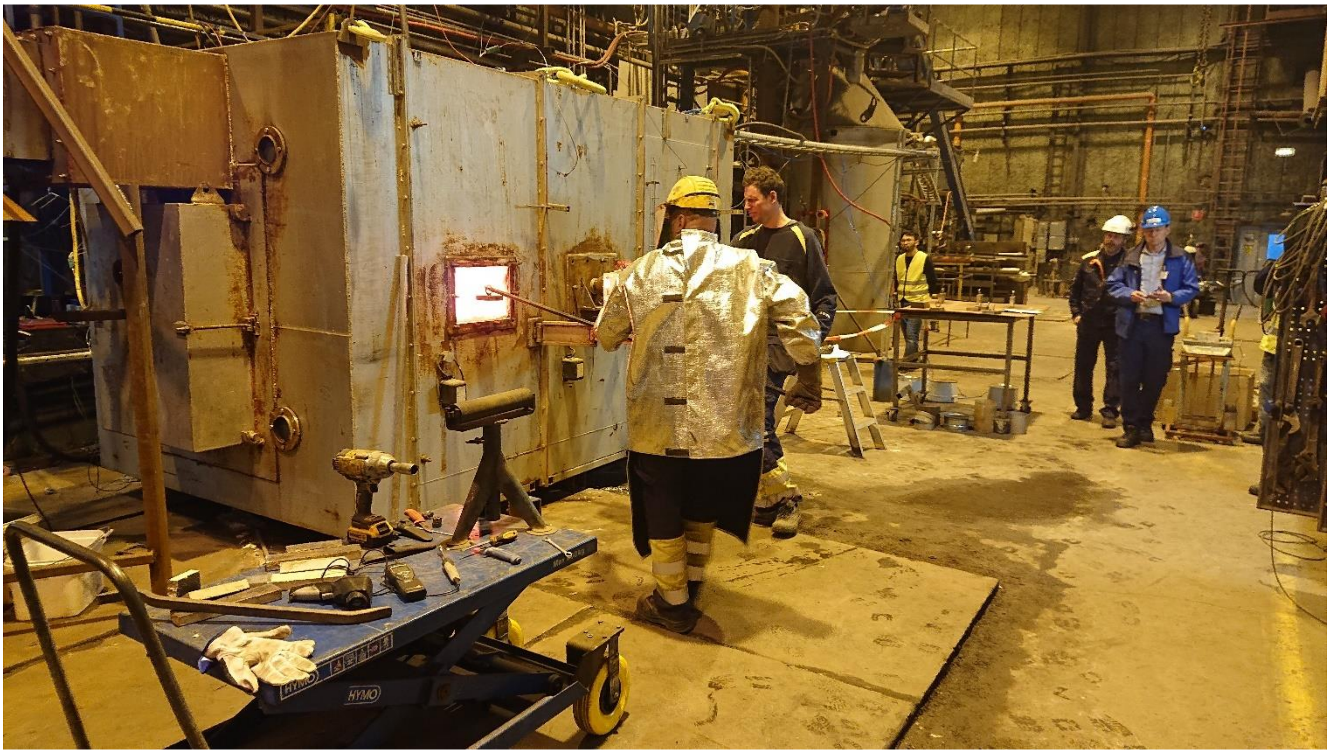

Figure 6 Unloading of steel samples during the trials from the test furnace.

3.1 Trial day 1

During the first day of trials, the temperature logging for Höganäs measurements was not started until approximately 1 hour after the initial furnace start up. The graphs and diagrams for this day is therefore lacking the heating phase and a portion of the continuous heating.

Table 2 Key process data trial day 1, data from Scanarc

Date	2020-11-10	Plasma gas	Air
Material in	kl 9.15	Carrier gas	Air + Gasol
Power	121 + 90* kW	Plasma gas	37,6 Nm3/h
Cooling power plasma	23 kW	Carrier gas	39,1 Nm3/h
Cooling power Carrier	27 kW	Carrier gas Gasol	2,8 Nm3/h
Net power	161 kW	Net enthalpy	2,0 kWh/Nm3
Efficiency	77 %		

*Added power from Gasol, 25 MJ/Nm3.

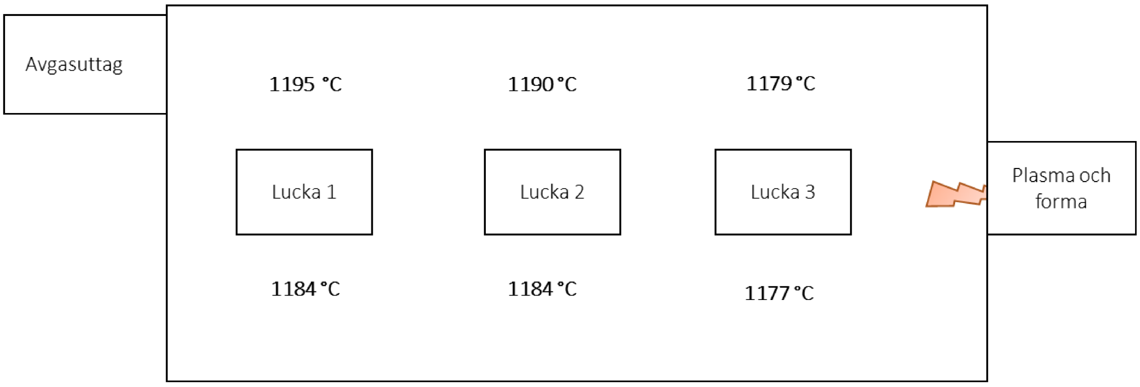

Figure 7 Temperature average during trial 1, data from Scanarc

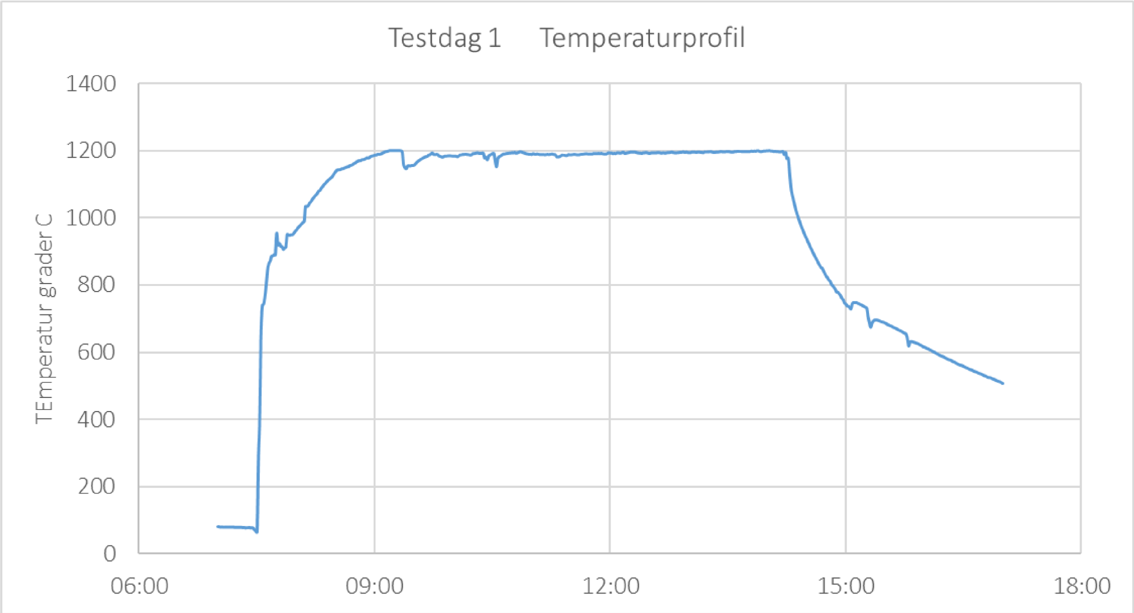

Figure 8 Temperature profile during trial 1, data from Scanarc

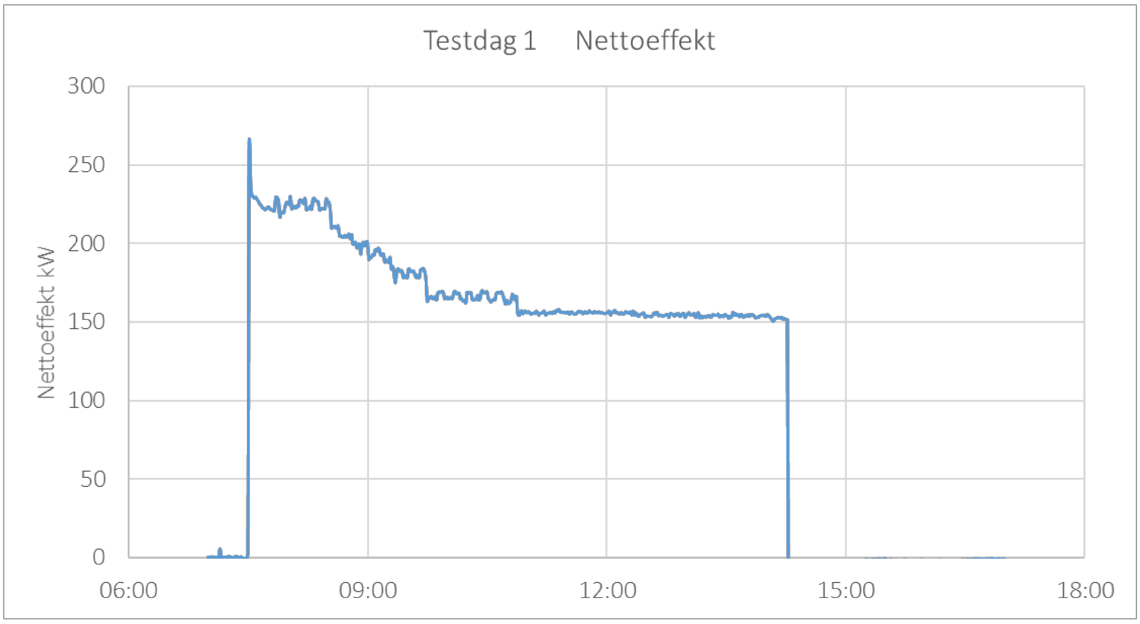

Figure 9 Net power during trial 1, data from Scanarc

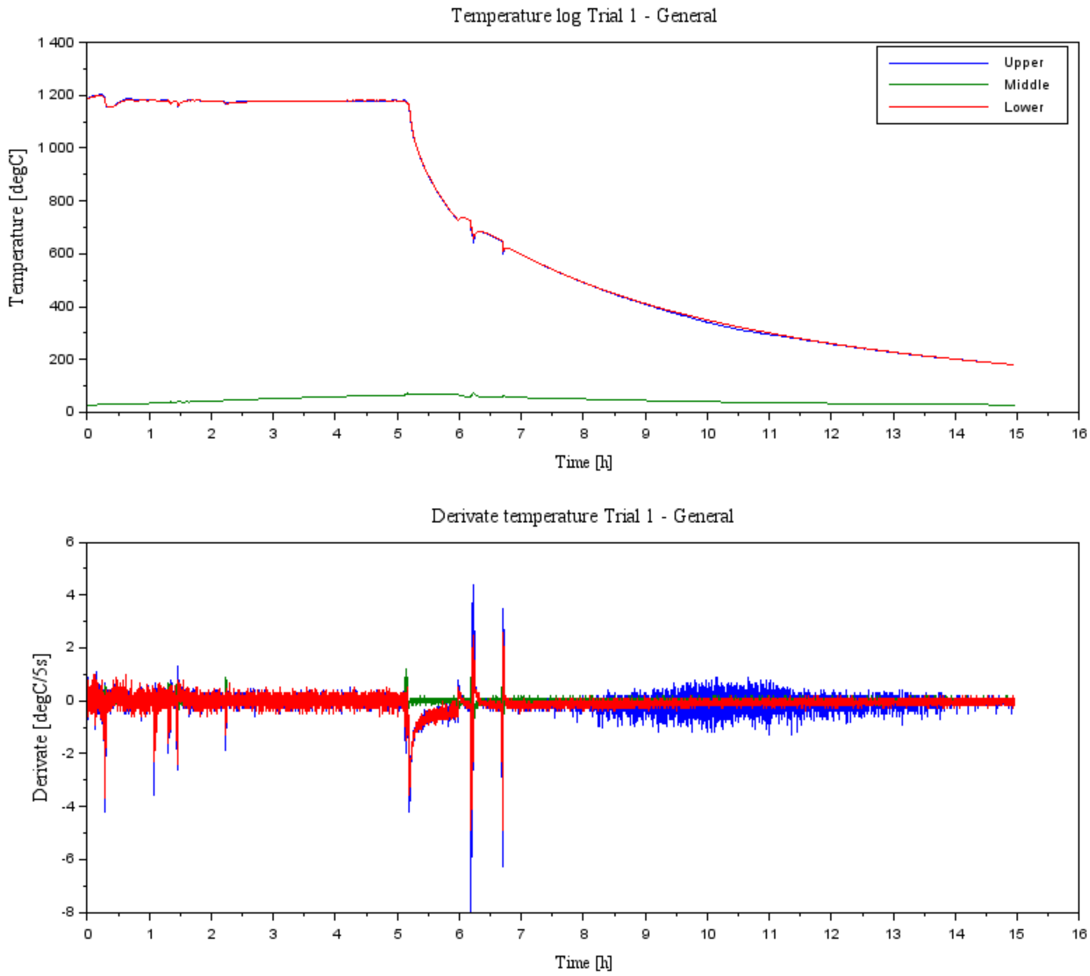

Figure 10 Temperature curve, upper graph, and temperature derivate, lower graph, during the trial on day one

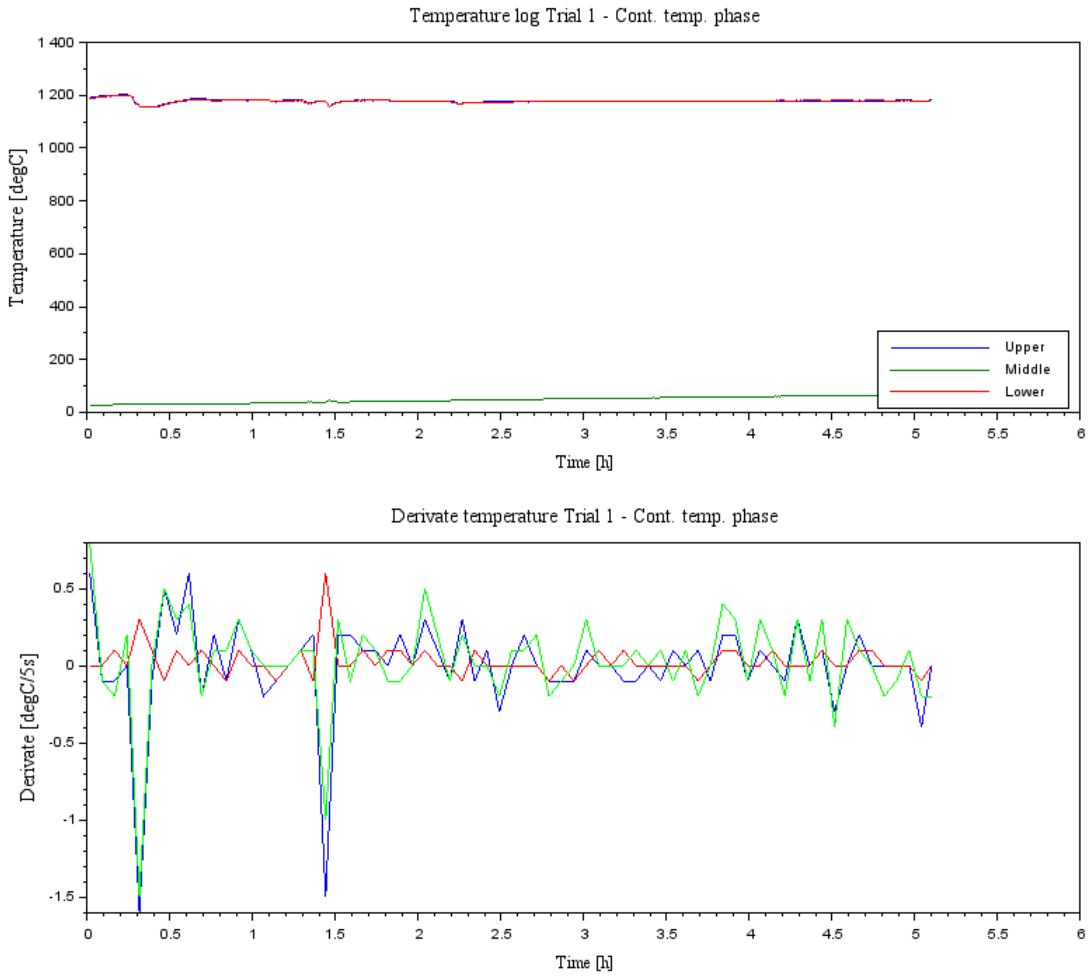

Figure 11 Temperature curve, upper graph, and temperature derivate, lower graph, during the heating phase of trial on day one

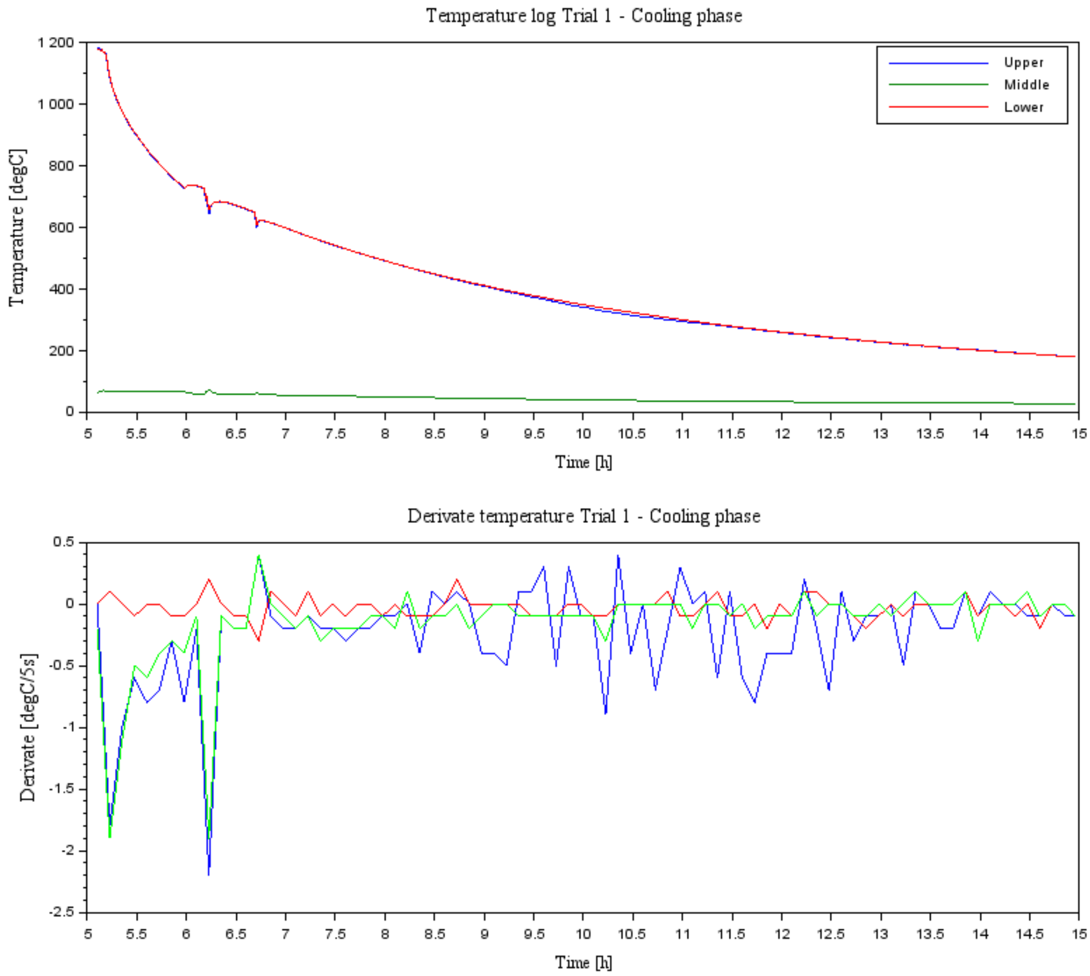

Figure 12 Temperature curve, upper graph, and temperature derivate, lower graph, during the cooling phase of trial on day one

3.2 Trial day 2

Table 3 Key process data trial day 2, data from Scanarc

Date	2020-11-11	Plasma gas	CO2
Material in	kl 11.25	Carrier gas	CO2
Power	187 kW	Plasma gas	47,4 Nm3/h
Cooling power plasma	23 kW	Carrier gas	30,0 Nm3/h
Cooling power Carrier	21 kW	Carrier gas Gasol	
Net power	143 kW	Net enthalpy	2,3 kWh/Nm3
Efficiency	76 %		

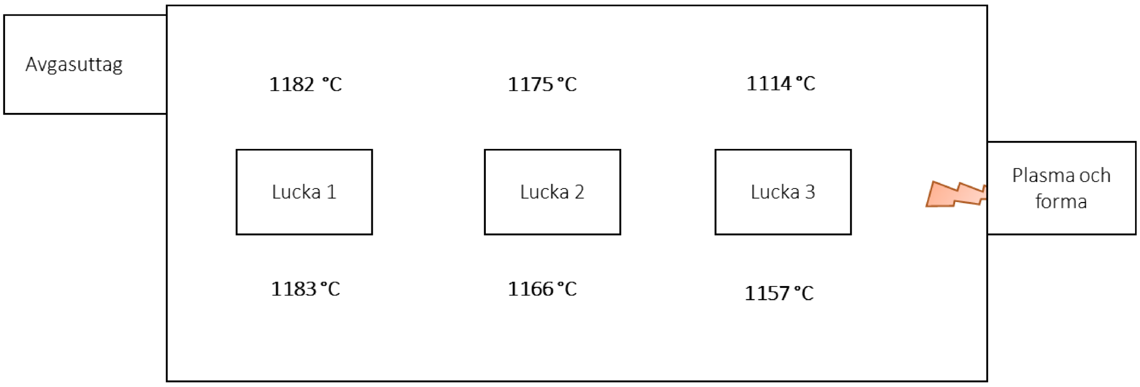

Figure 13 Temperature average during trial 2, data from Scanarc

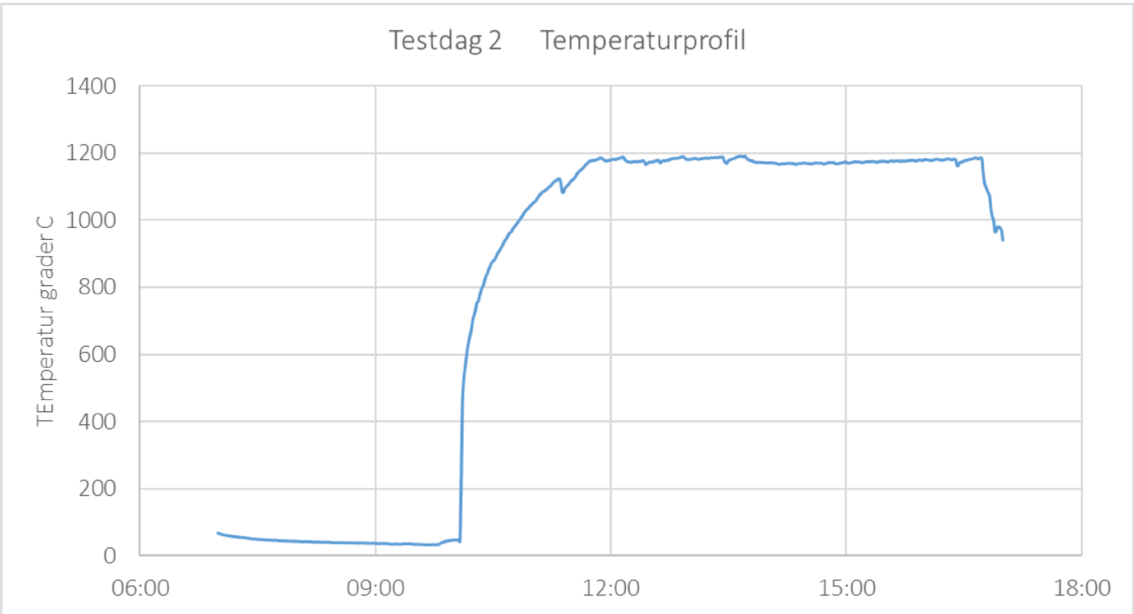

Figure 14 Temperature profile during trial 2, data from Scanarc

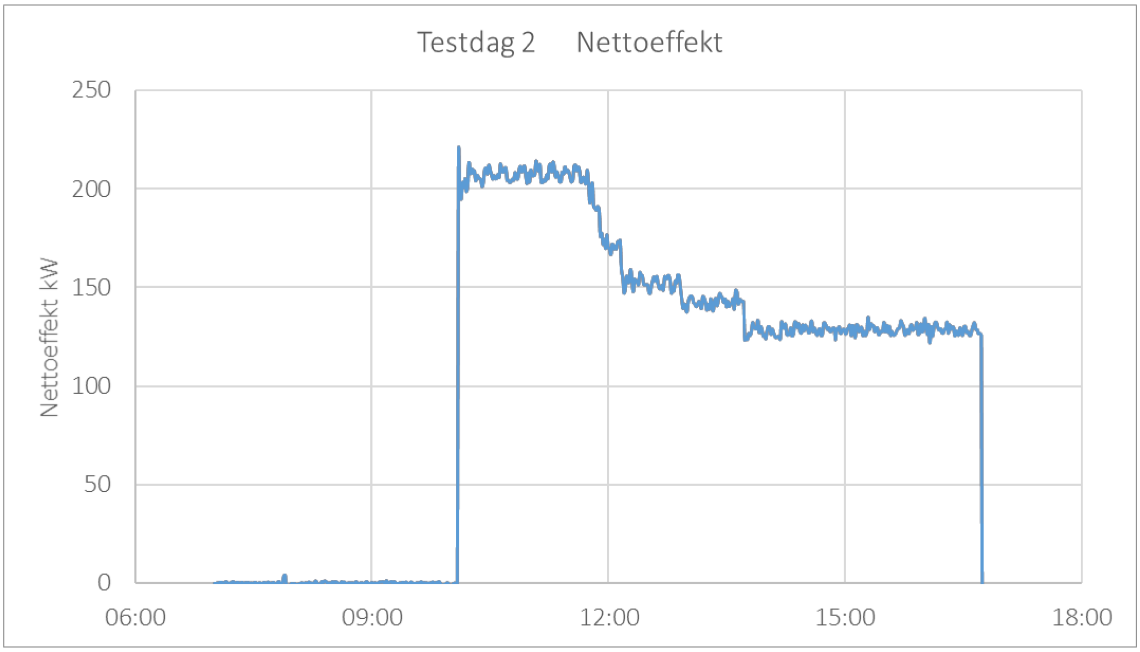

Figure 15 Net power during trial 2, data from Scanarc

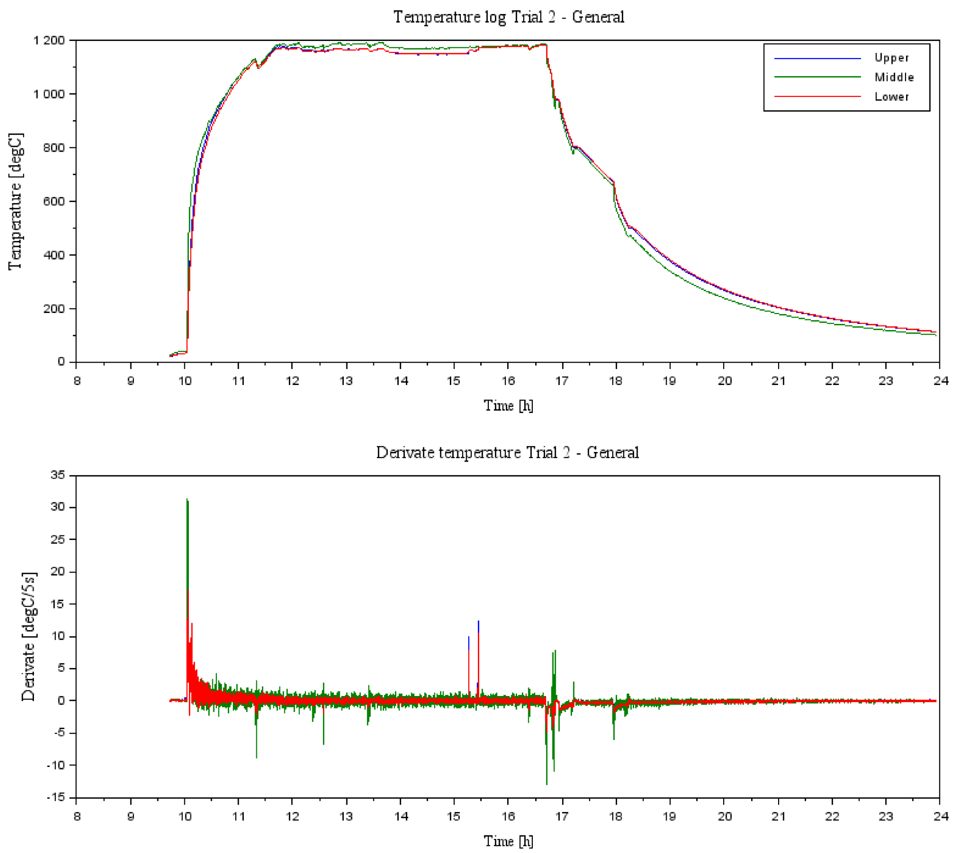

Figure 16 Temperature curve, upper graph, and temperature derivate, lower graph, during the trial on day two

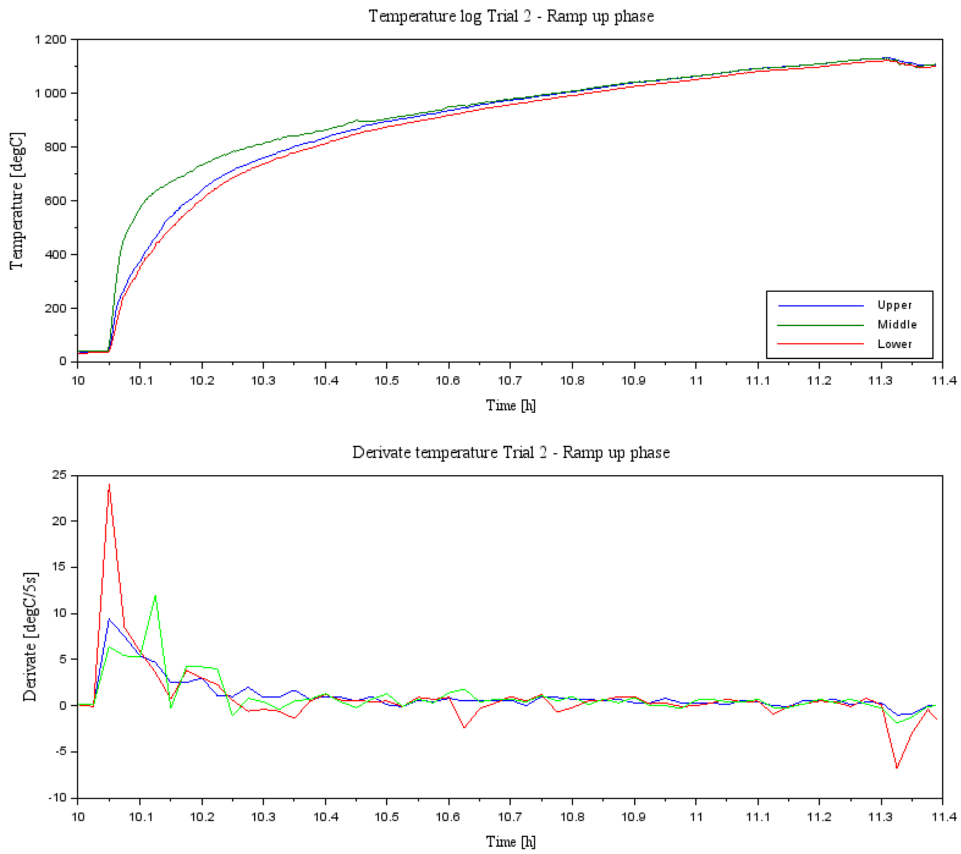

Figure 17 Temperature curve, upper graph, and temperature derivate, lower graph, during the heating phase of trial on day two

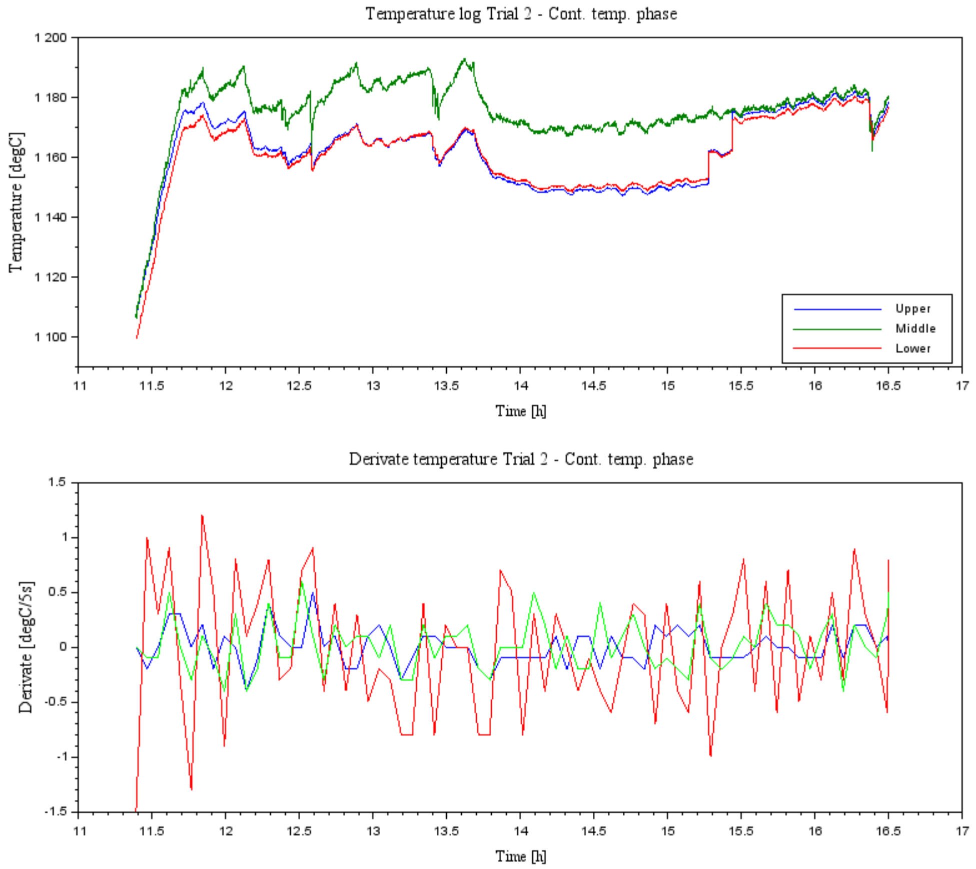

Figure 18Temperature curve, upper graph, and temperature derivate, lower graph, during the continuous heating phase of trial on day two

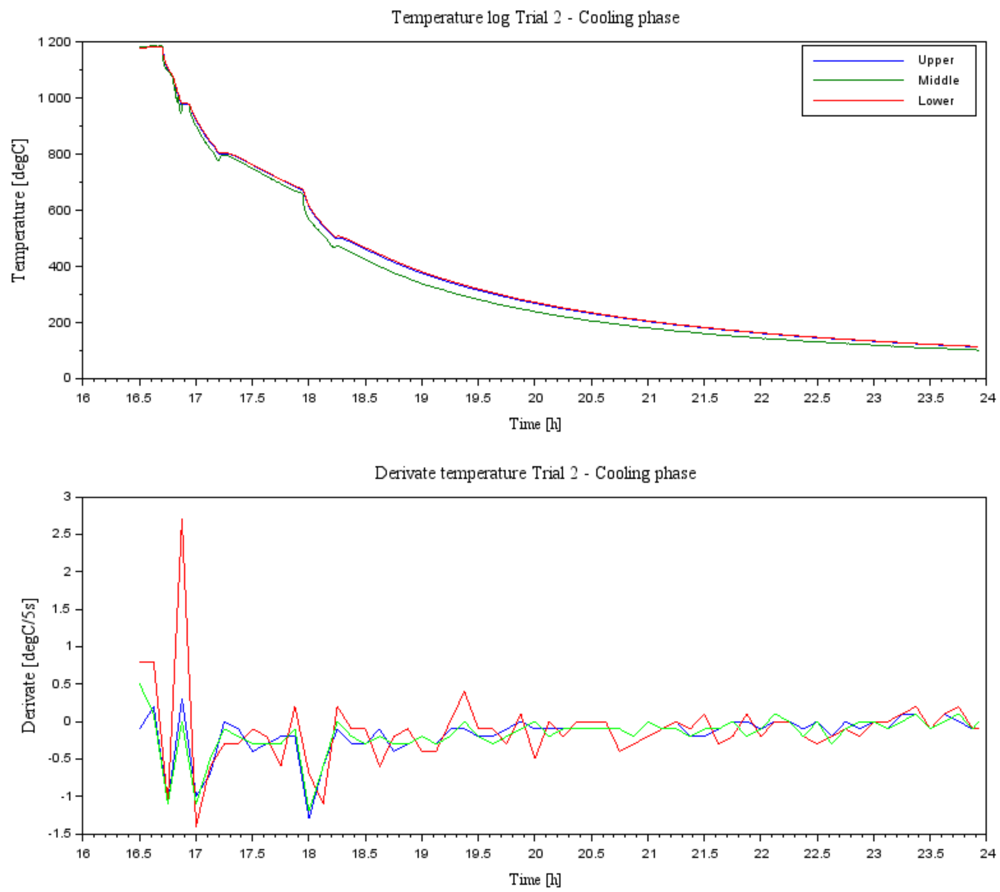

Figure 19 Temperature curve, upper graph, and temperature derivate, lower graph, during the cooling phase of trial on day two

3.3 Trial day 3

Table 4 Key process data trial day 3, data from Scanarc

Date	2020-11-17	Plasma gas	N2
Material in	kl 10.30	Carrier gas	N2
Power	209 kW	Plasma gas	64,9 Nm3/h
Cooling power plasma	48 kW	Carrier gas	1,2 Nm3/h
Cooling power Carrier	37 kW	Carrier gas 2	
Net power	124 kW	Net enthalpy	1,9 kWh/Nm3
Efficiency	59 %		

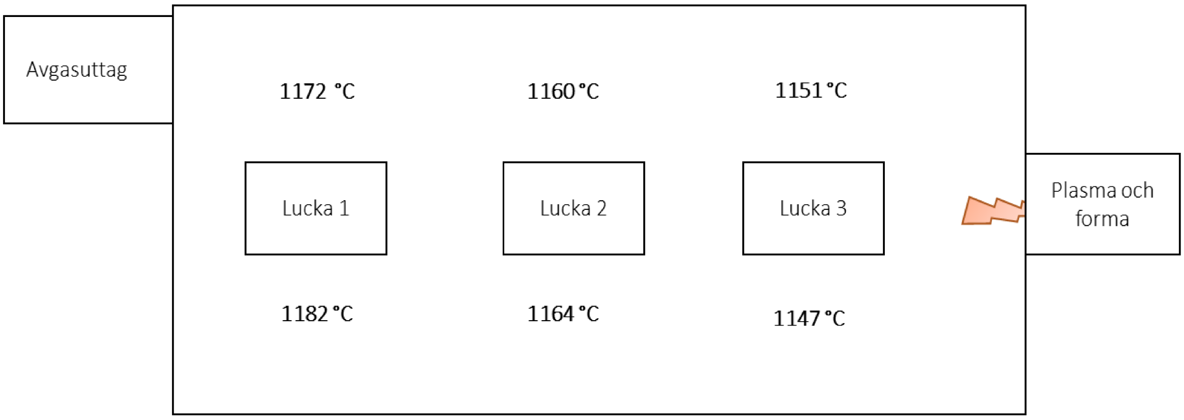

Figure 20 Temperature average during trial 3, data from Scanarc

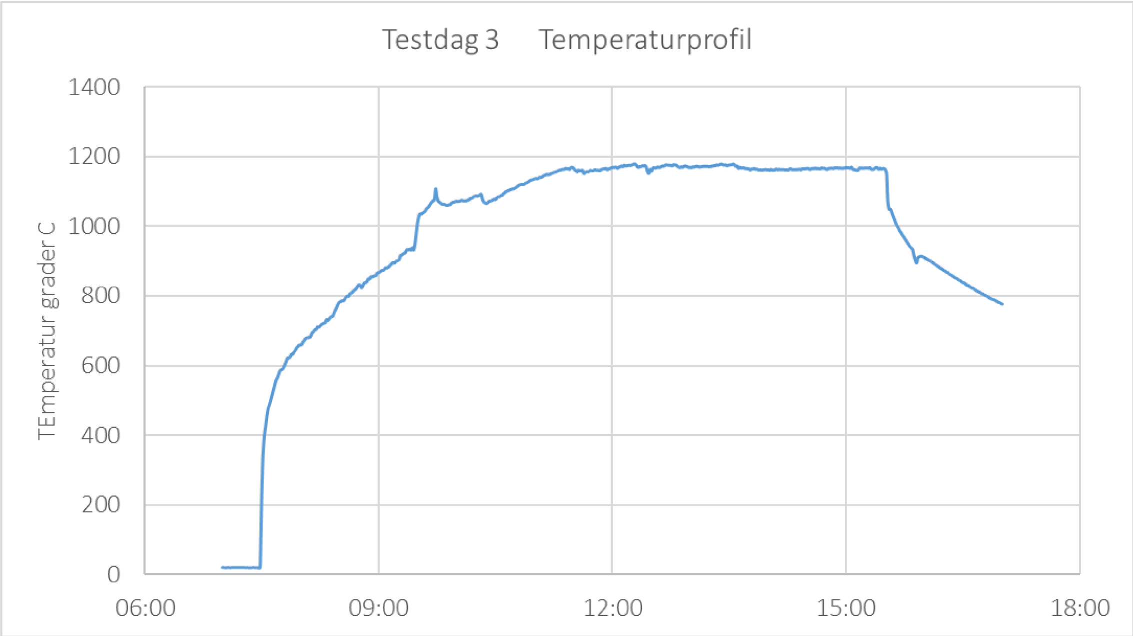

Figure 21 Temperature profile during trial 3, data from Scanarc

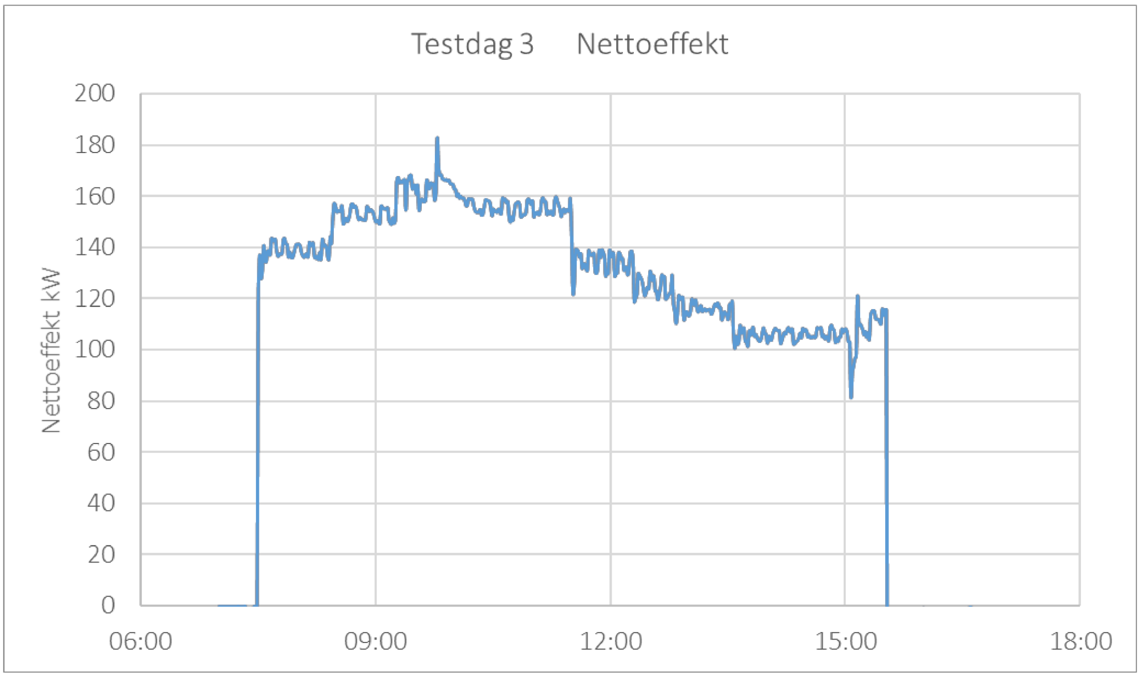

Figure 22 Net power during trial 3, data from Scanarc

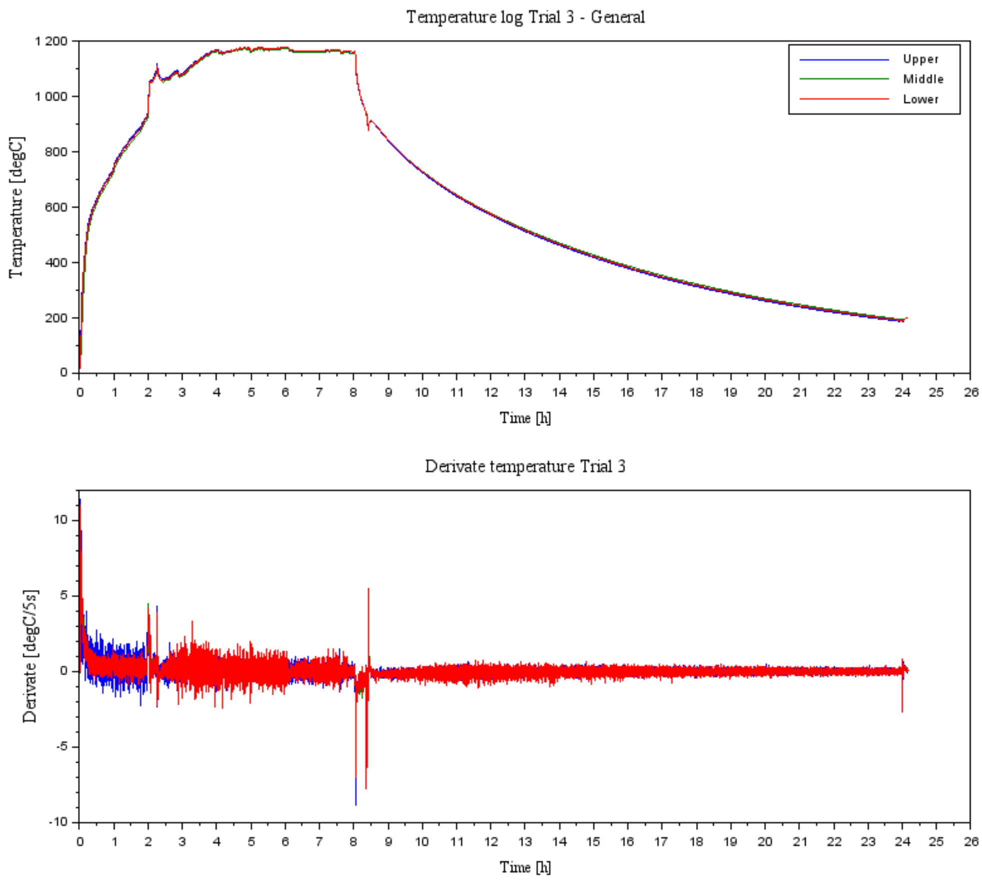

Figure 23 Temperature curve, upper graph, and temperature derivate, lower graph, during the trial on day three

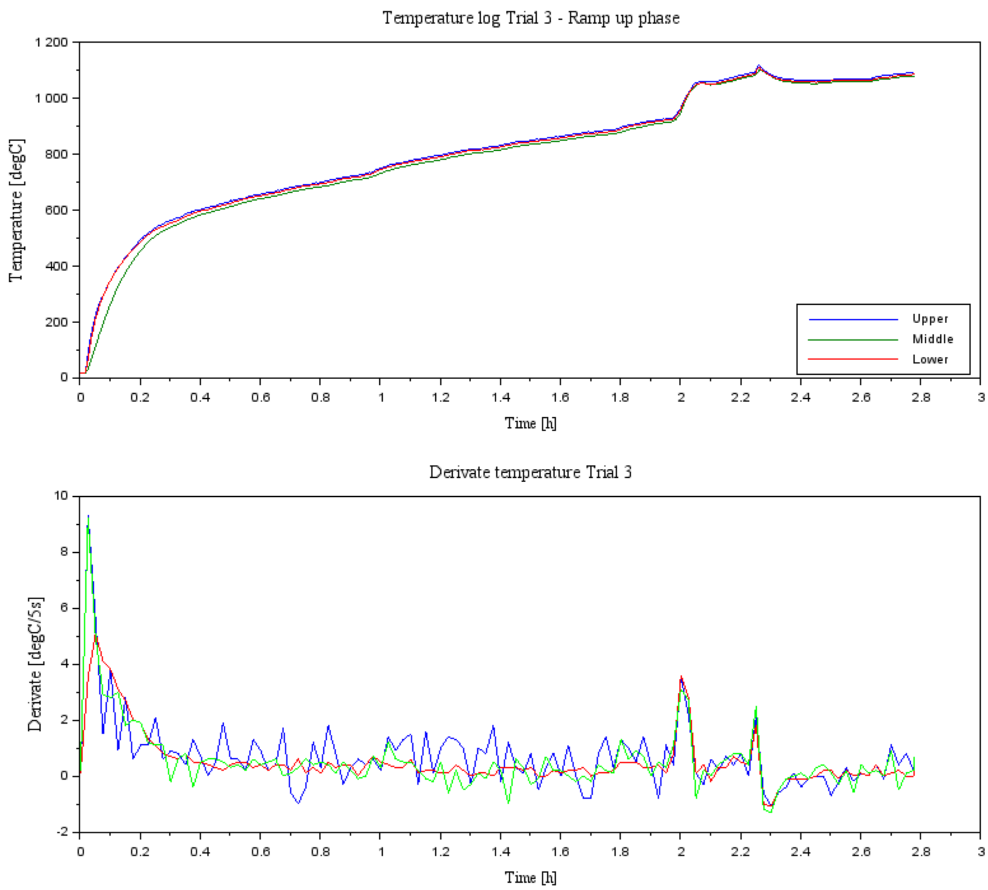

Figure 24 Temperature curve, upper graph, and temperature derivate, lower graph, during the heating phase of trial on day three

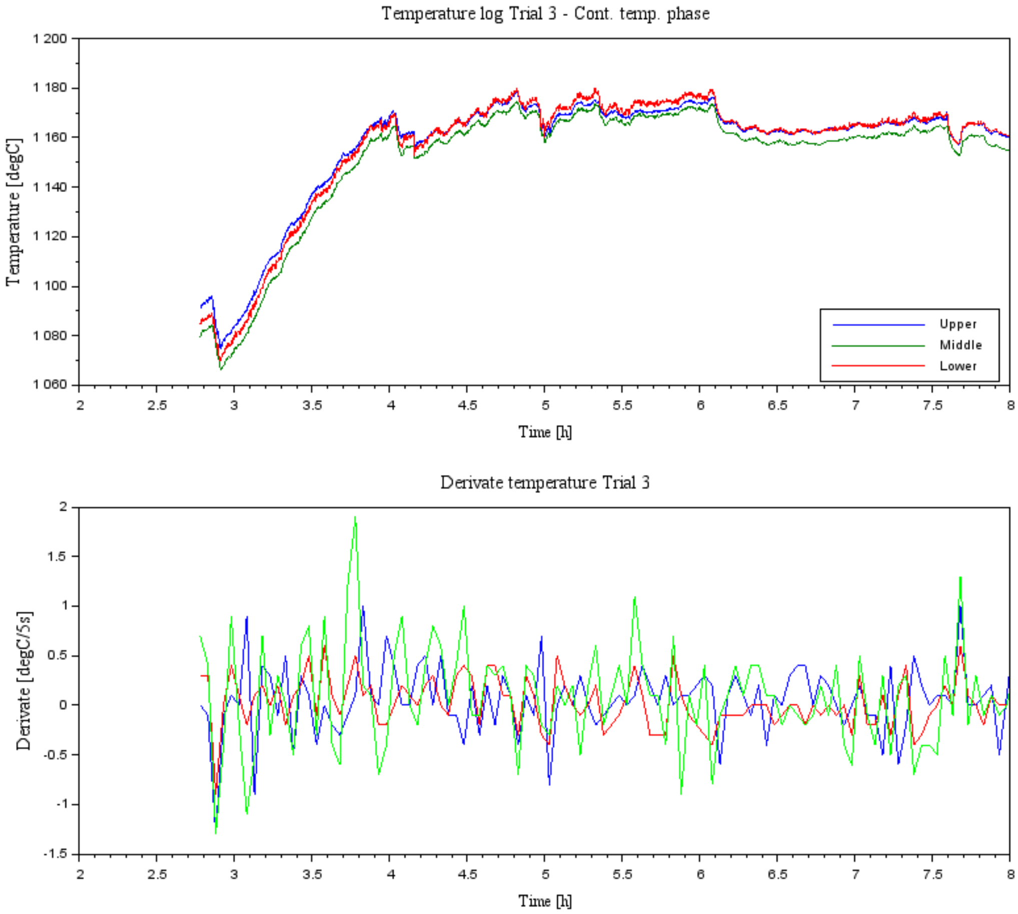

Figure 25 Temperature curve, upper graph, and temperature derivate, lower graph, during the continuous heating phase of trial on day three

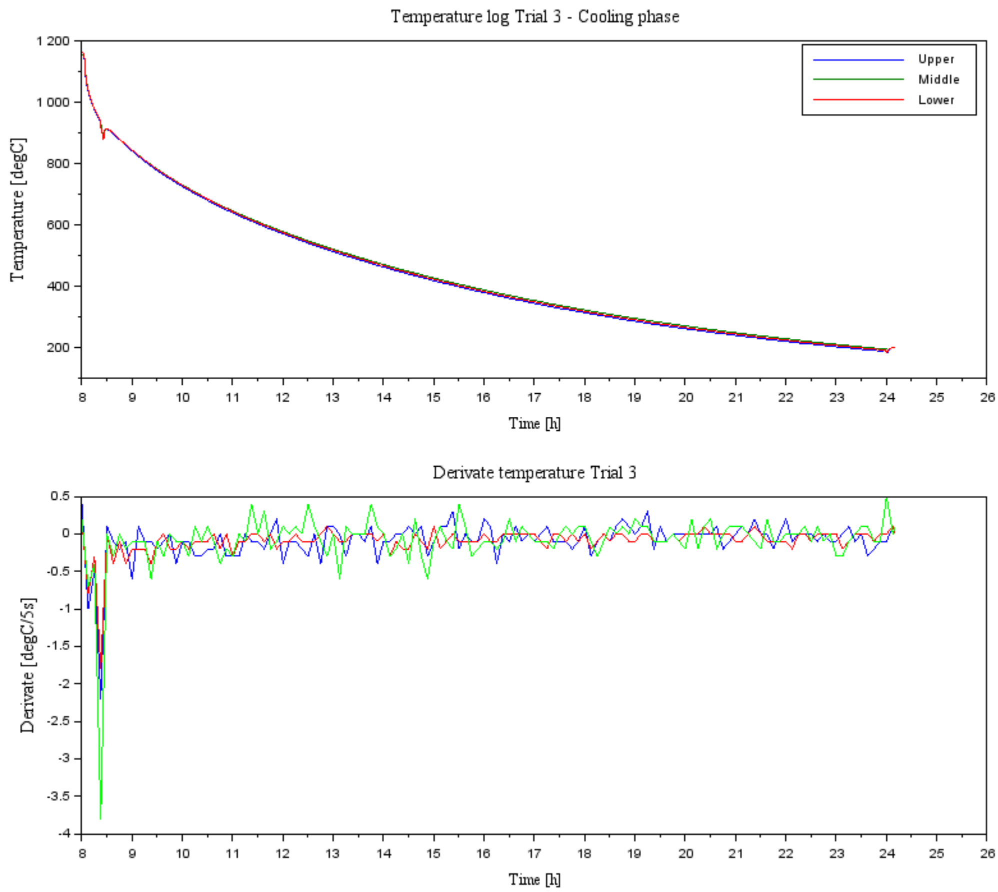

Figure 26 Temperature curve, upper graph, and temperature derivate, lower graph, during the cooling phase of trial on day three

3.4 Trial day 4

Table 5 Key process data trial day 4, data from Scanarc

Date	2020-11-18	Plasma gas	CO_2
Material in	kl 10.40	Carrier gas	CO_2 + Steam
Power	191 kW	Plasma gas	44,2 Nm3/h
Cooling power plasma	23 kW	Carrier gas	16,2 Nm3/h
Cooling power Carrier	20 kW	Carrier gas 2	
Net power	148 kW	Net enthalpy	2,4 kWh/Nm3
Efficiency	77 %		

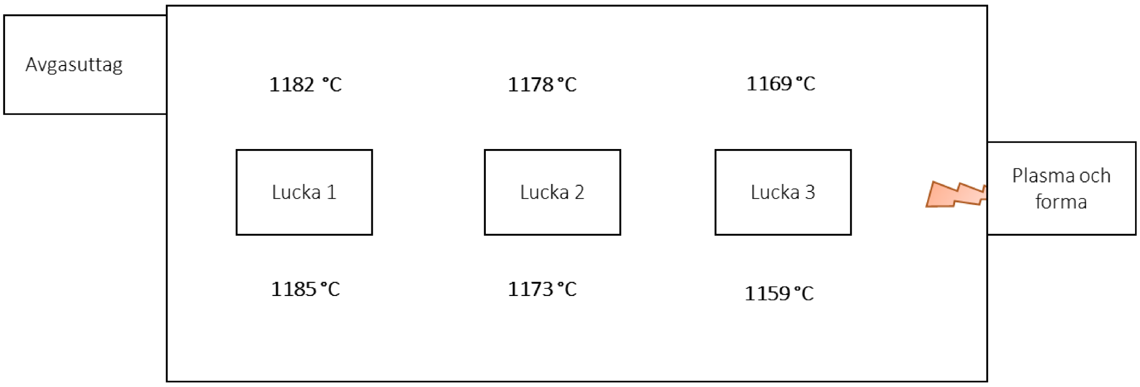

Figure 27 Temperature average during trial 4, data from Scanarc

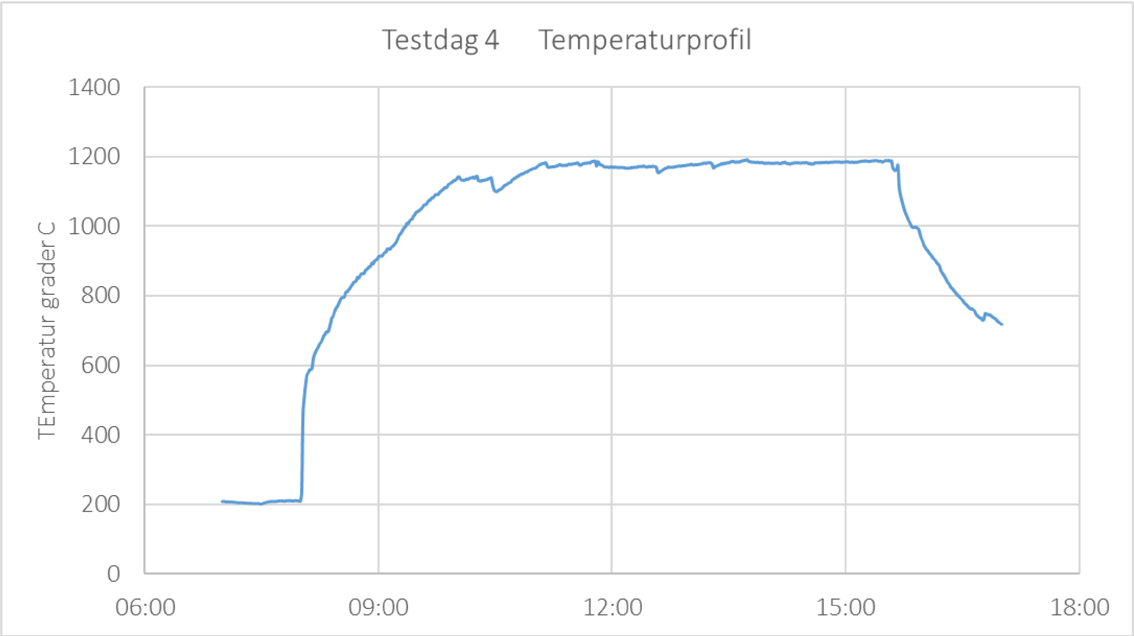

Figure 28 Temperature profile during trial 4, data from Scanarc

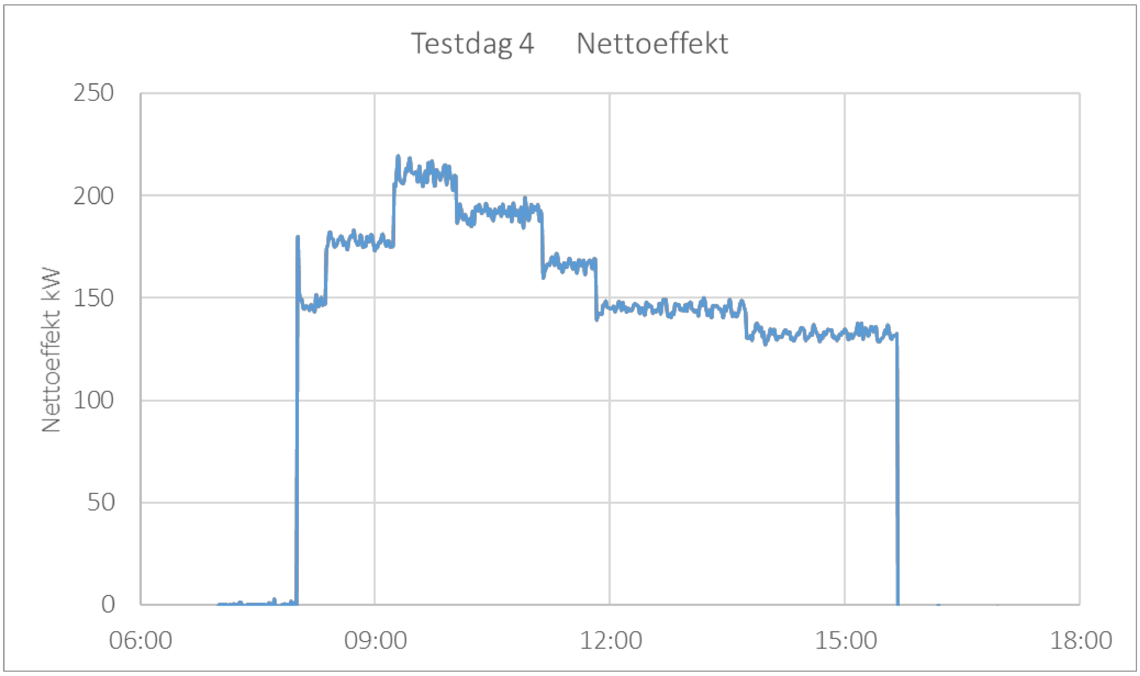

Figure 29 Net power during trial 4, data from Scanarc

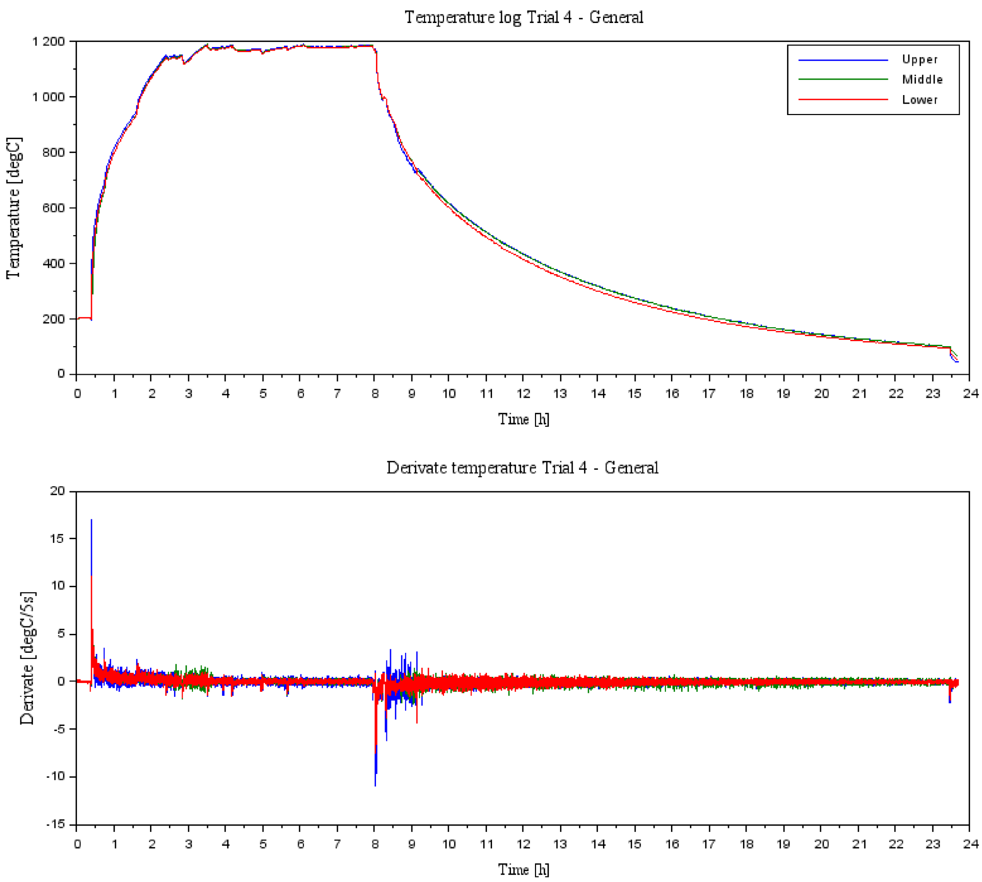

Figure 30 Temperature curve, upper graph, and temperature derivate, lower graph, during the trial on day four

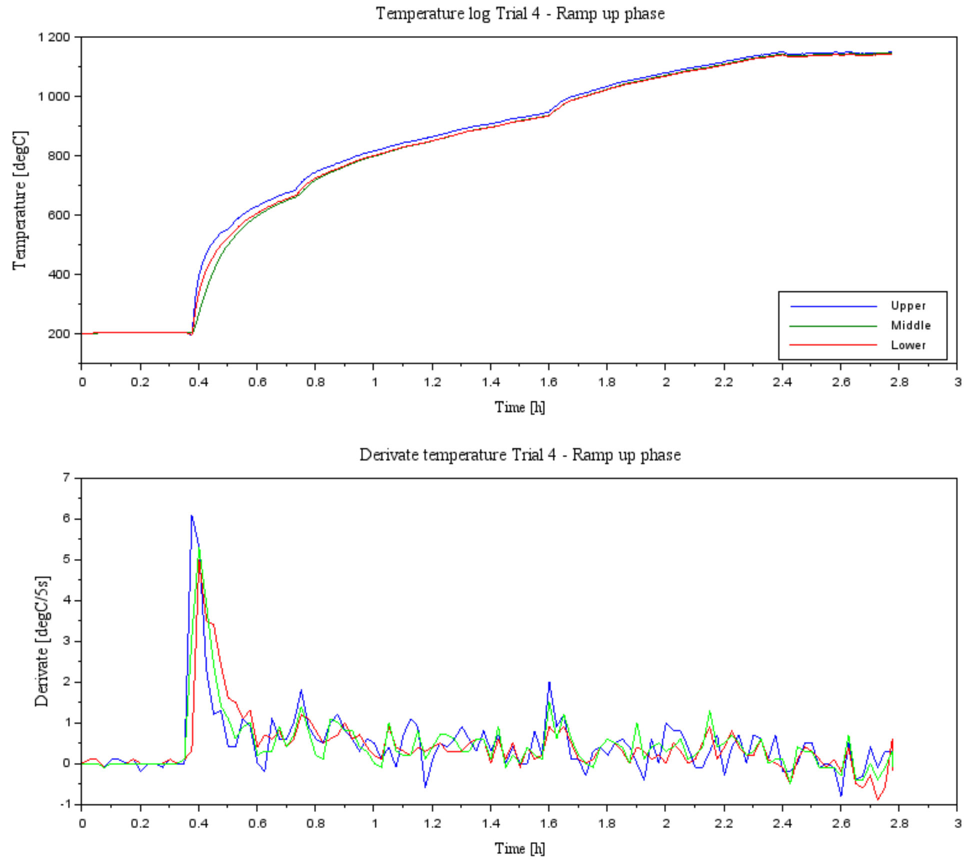

Figure 31 Temperature curve, upper graph, and temperature derivate, lower graph, during the heating phase of trial on day four

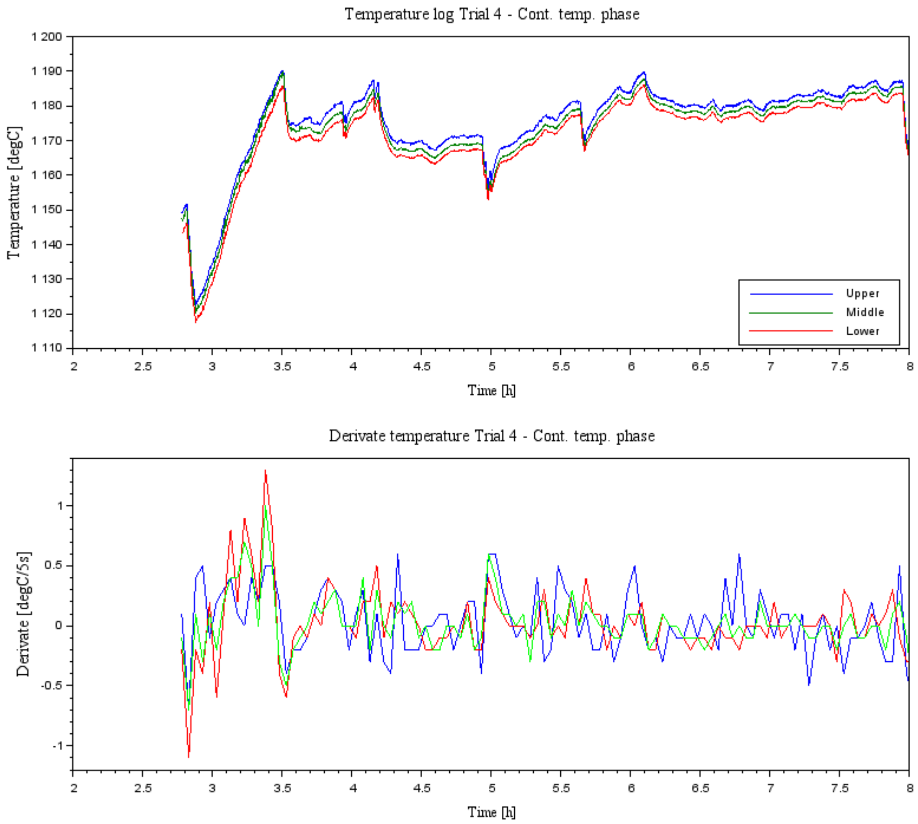

Figure 32 Temperature curve, upper graph, and temperature derivate, lower graph, during the continuous heating phase of trial on day four

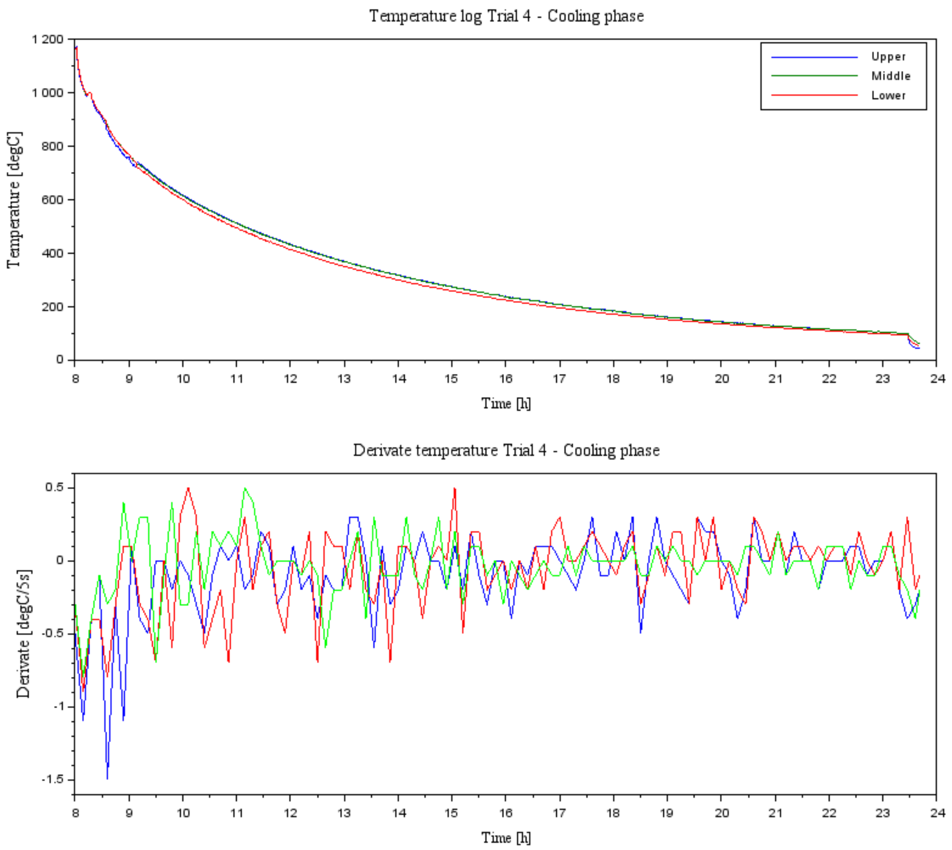

Figure 33 Temperature curve, upper graph, and temperature derivate, lower graph, during the cooling phase of trial on day four

3.5 Trial day 5

Table 6 Key process data trial day 5, data from Scanarc

Date	2020-11-19	Plasma gas	N2
Material in	kl 11.05	Carrier gas	N2 + Steam
Power	241 kW	Plasma gas	77,6 Nm3/h
Cooling power plasma	58 kW	Carrier gas	30,0 Nm3/h
Cooling power Carrier	34 kW	Carrier gas 2	
Net power	149 kW	Net enthalpy	1,4 kWh/Nm3
Efficiency	62 %		

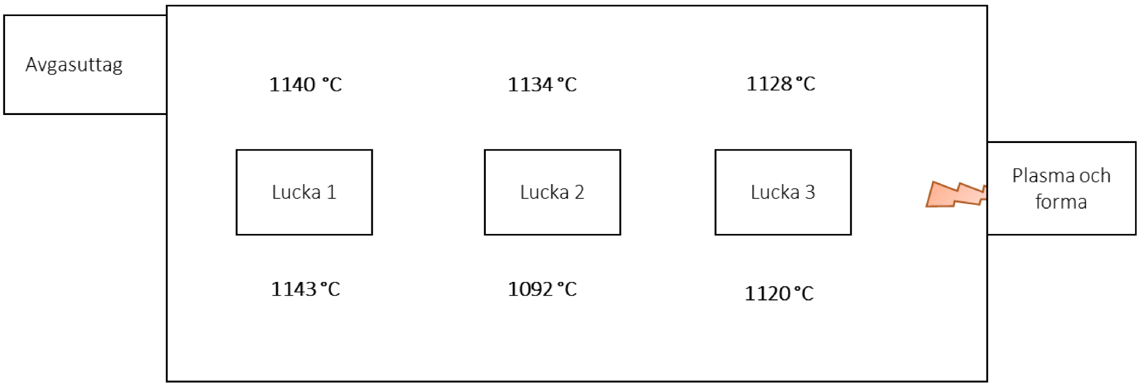

Figure 34 Temperature average during trial 5, data from Scanarc

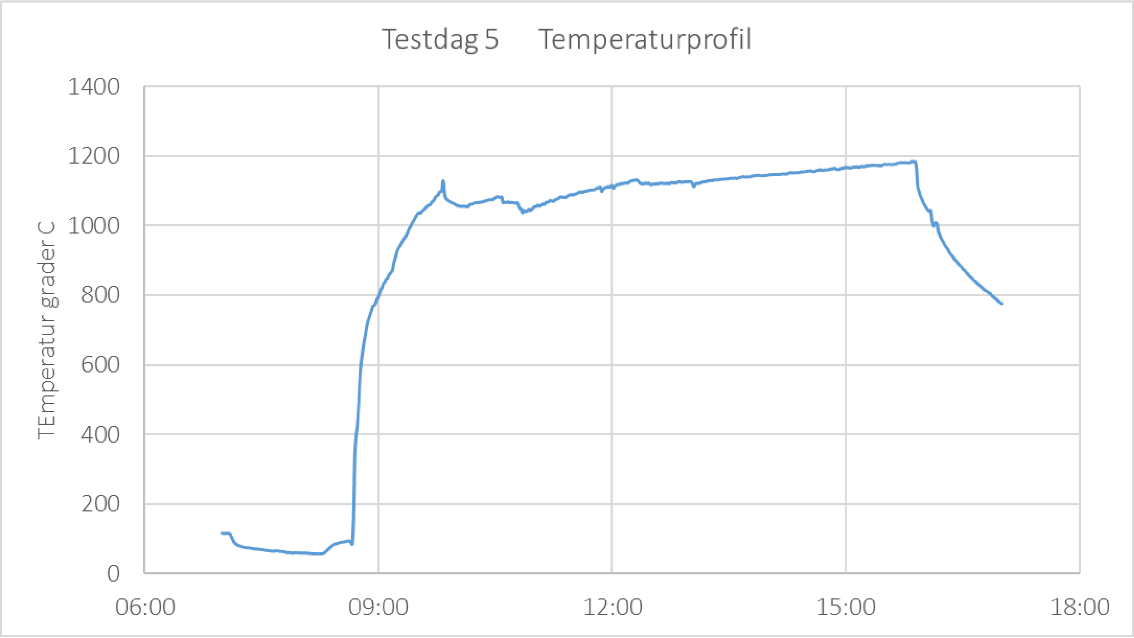

Figure 35 Temperature profile during trial 5, data from Scanarc

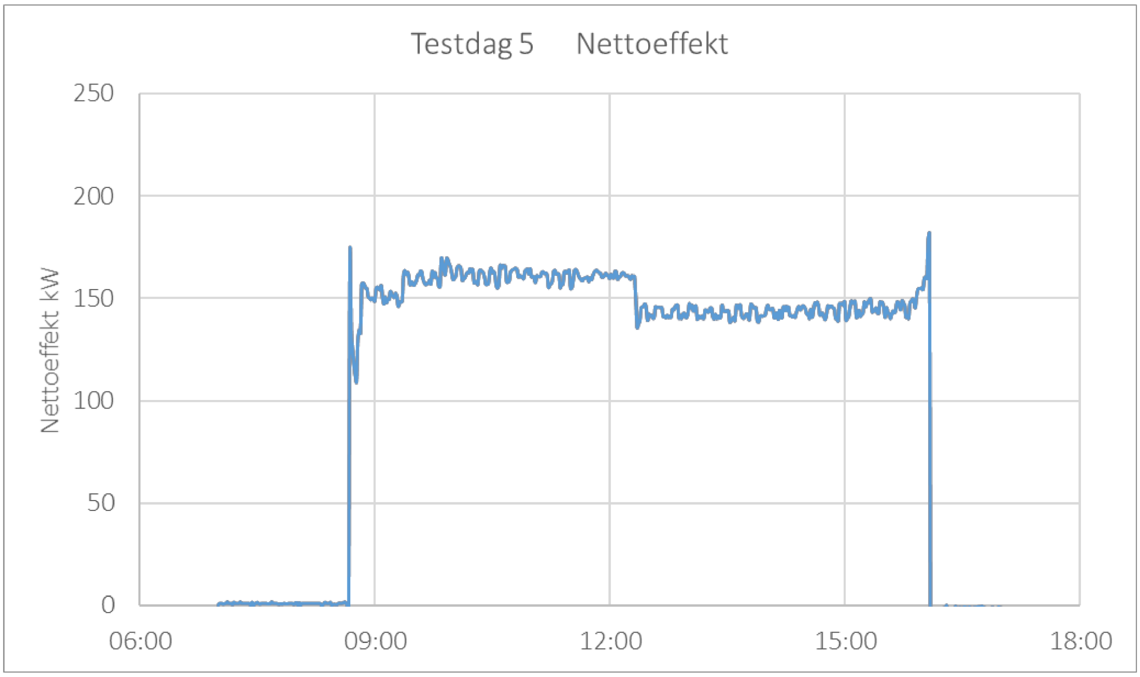

Figure 36 Net power during trial 5, data from Scanarc

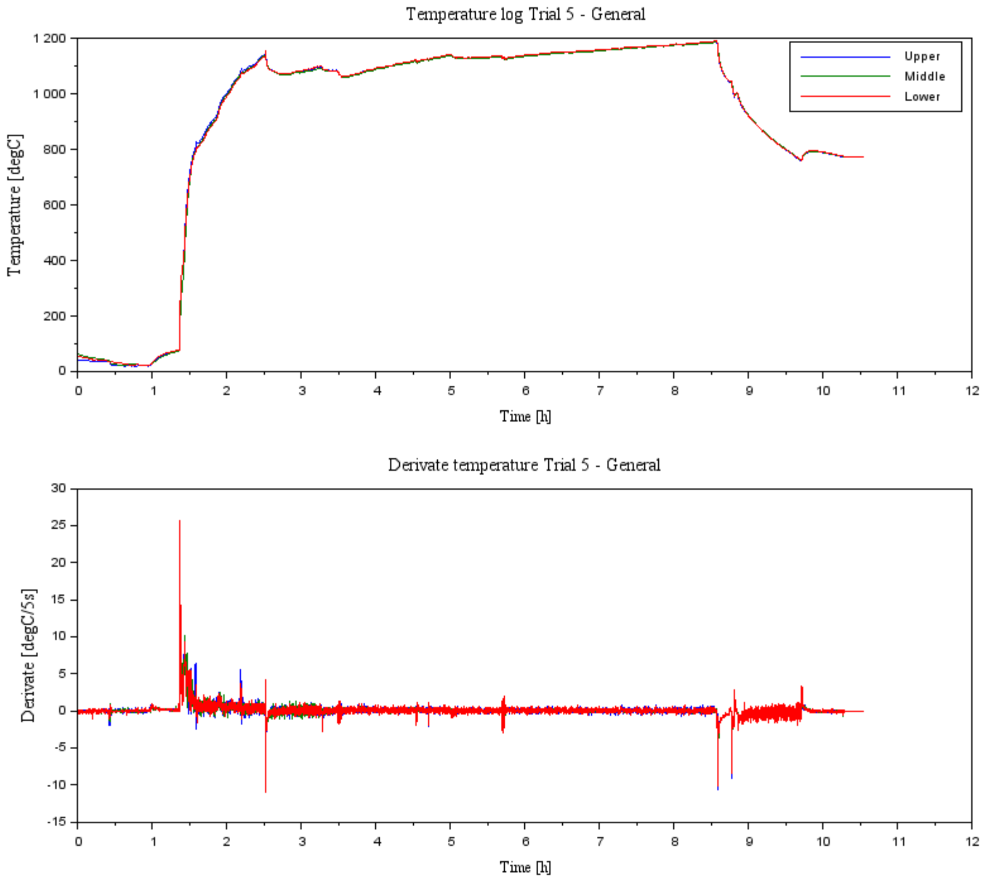

Figure 37 Temperature curve, upper graph, and temperature derivate, lower graph, during the trial on day five

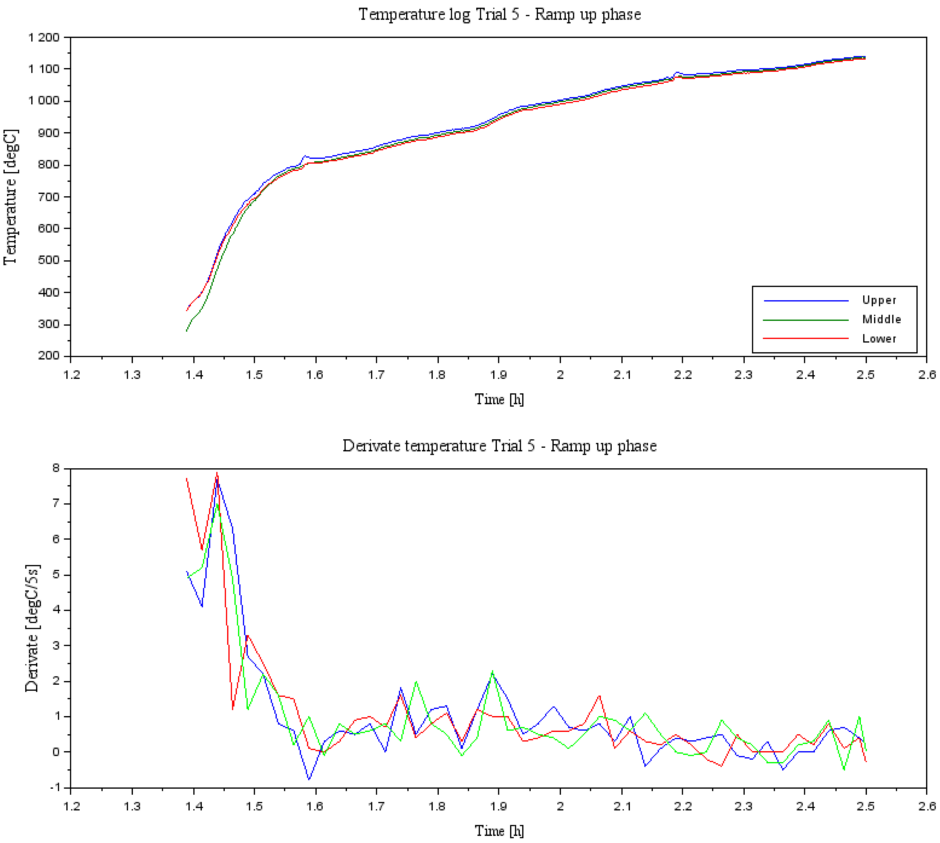

Figure 38 Temperature curve, upper graph, and temperature derivate, lower graph, during the heating phase of trial on day five

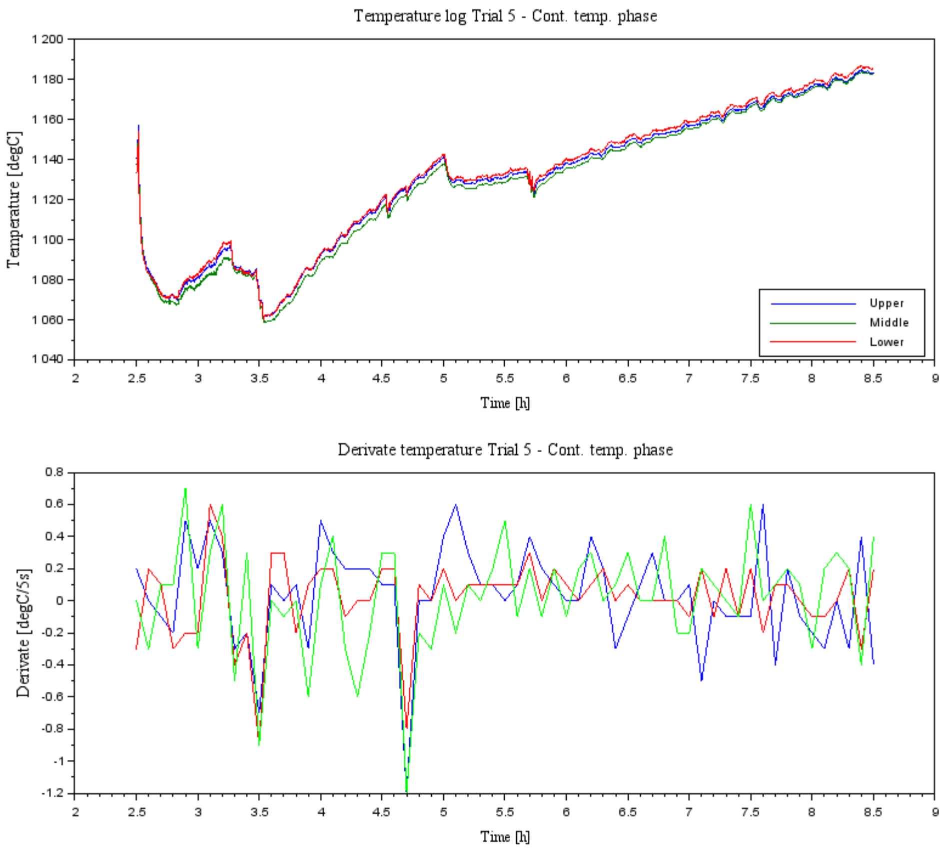

Figure 39 Temperature curve, upper graph, and temperature derivate, lower graph, during the continuous heating phase of trial on day five

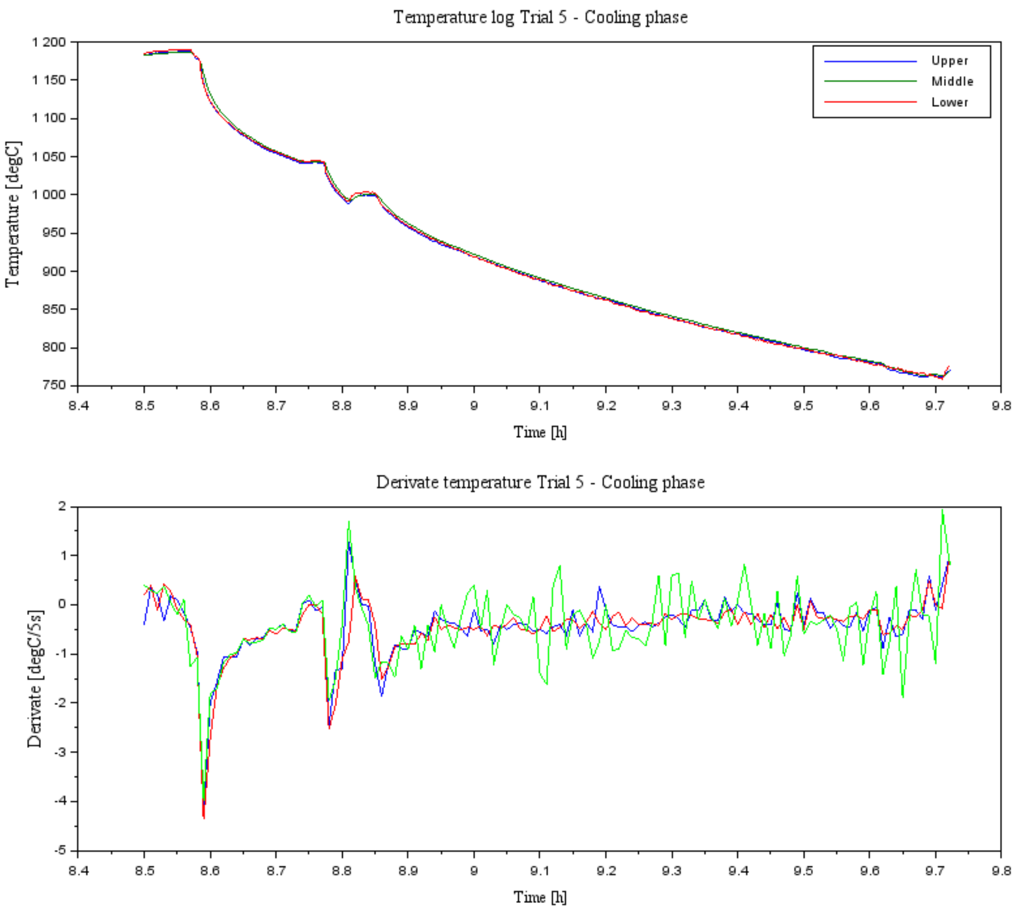

Figure 40 Temperature curve, upper graph, and temperature derivate, lower graph, during the cooling phase of trial on day five

3.6 Data analysis

Temperature profiles

Comparing Scanarc's temperature profiles to the measurements from Höganäs equipment, shows that the trends are very similar. Deviations between the measurements exists, but the overall trends are very similar. The major difference between the measurements are during the heating and cooling phases where there is a slight time delay between the both systems.

Comparing the average temperatures, most of Höganäs' measurements are comparable with Scanarc's temperature measurements in the bottom of zone 2, which are quite close to each other inside the pilot furnace.

The derivate graphs although using a smooth function appear rather noisy, but in practice show very low deviations, particularly during the continuous holding time, as would be expected. At the start of each new phase the curves have rapid response to rather quick dampen and smooth out to a relatively stable curve.

Comparison temperature measurements

Below are comparisons of temperature loggings, averaged.

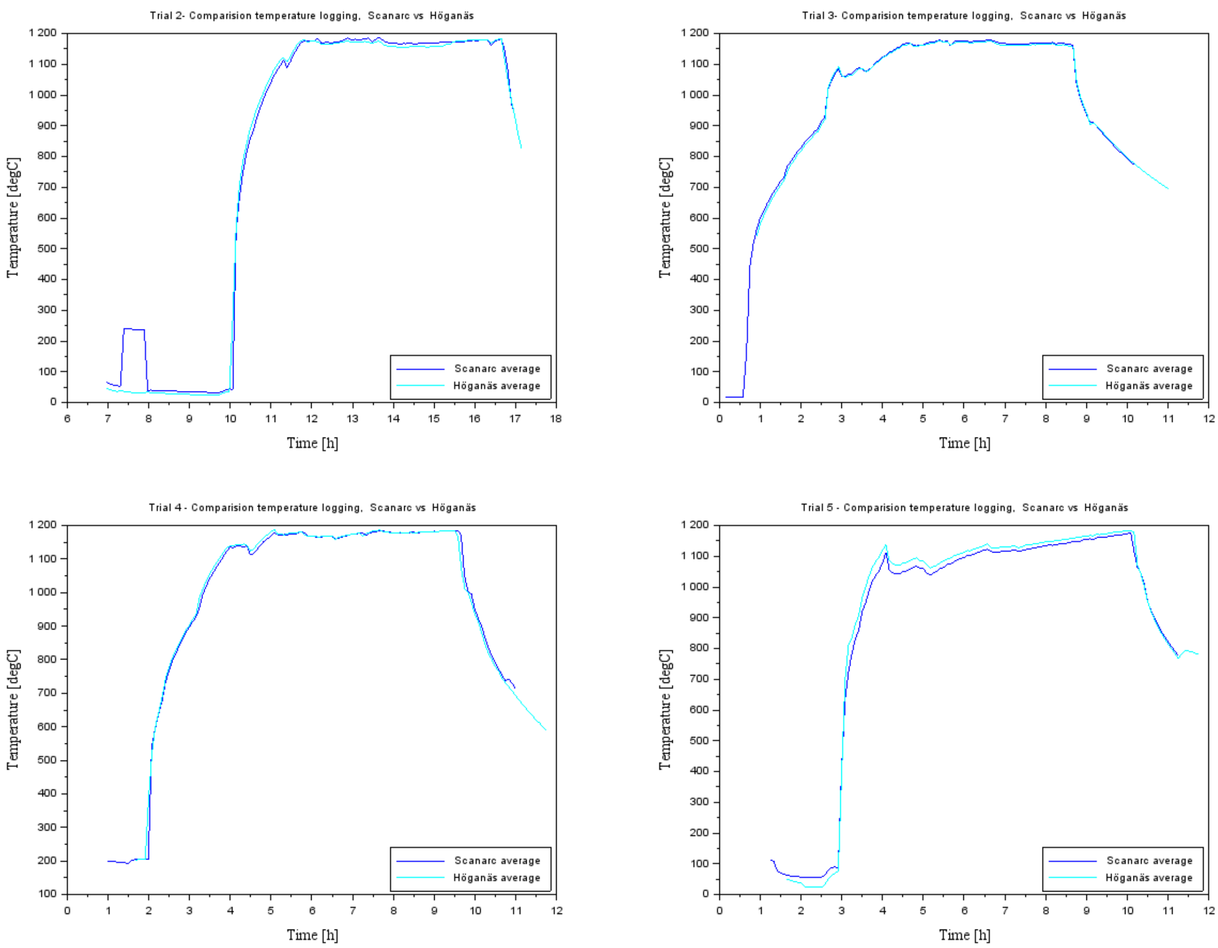

Figure 41 Temperature profile comparisions between Höganäs and Scanarc for trials 2-5

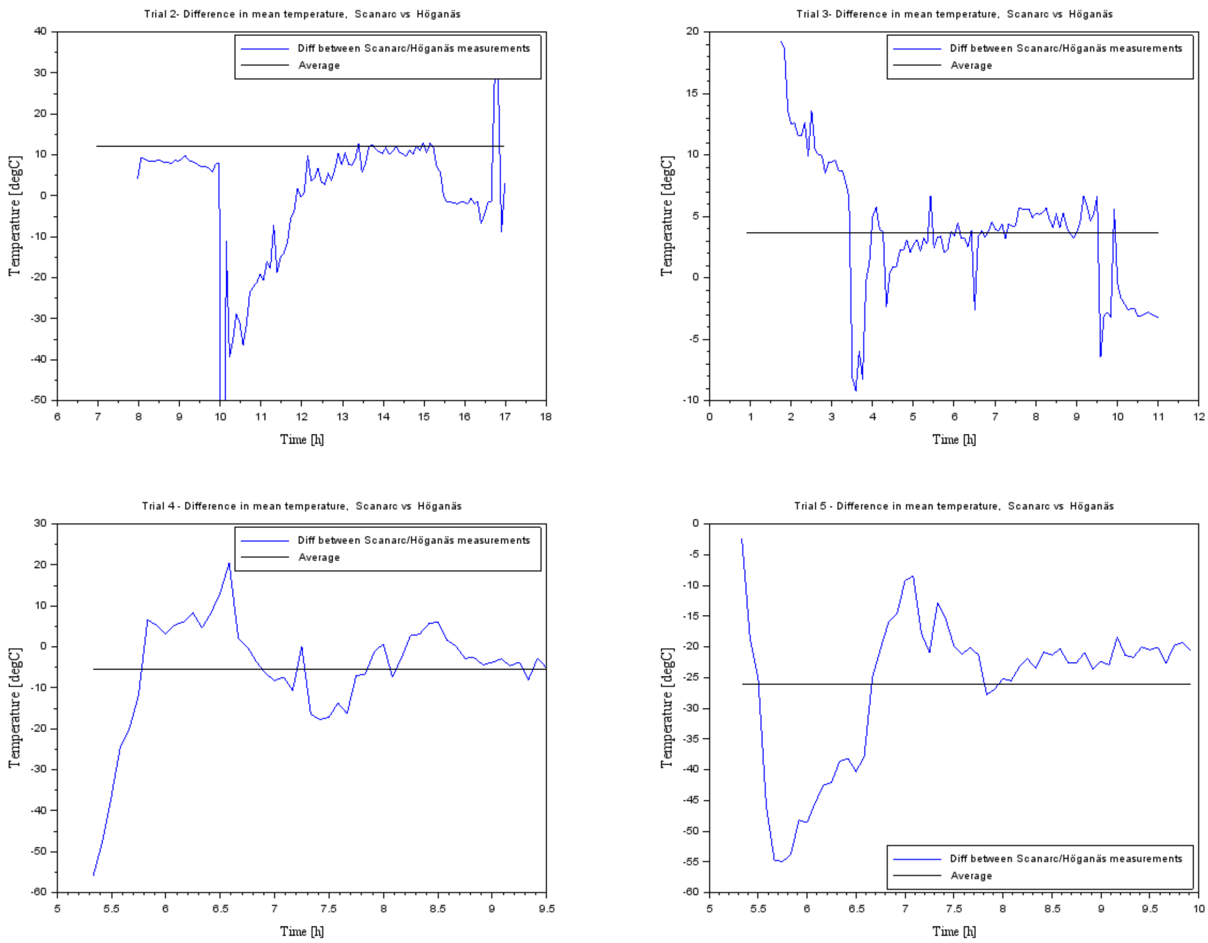

Figure 42 Difference in temperature between Scanarc and Höganäs measurements, averaged values, for trials 2-5

3.7 Muffle

The muffle was mainly visually inspected and measured. A microstructural analysis was performed but deemed inconclusive and will therefore not be presented in detail.

The visual comparison of the muffle used in the trials compared to the sample muffle, shows a layer of soot on the “trials’ muffle”. This is likely due to trial number one when LPG was added to the plasma. The deformation measured on the muffle was rather small, it’s hard to quantify to what degree the deformations are due to the trials and which are from before. The trials were rather short and no mechanical load was applied to the muffle, but larger deformations were expected.

<u>Microstructure analysis</u>

The microstructure of the muffle was analysed by the internal Metallography department at Höganäs, to determine if any changes had occurred due to the use of a plasma torch.
A set of three samples were taken from the test muffle which had been in the furnace during the entire trial, two from the “thermocouple” side and one from the back. Two samples were taken from the backup muffle as reference. The result was deemed inconclusive as the investigated oxide layers differed much from each other, even the reference samples. This might be due to the materials tested in the pilot furnace during the several years of operation has affected the microstructure of the muffle.

4. FUTURE

The technology is still relatively untested in steel manufacturing process, but this small-scale test has given indication of feasibility and implementation possibilities. However, uncertainties remain, which the Swedish steelmaking community as a whole could benefit from investigating collectively in a follow-up project to PLATIS. A project which more in-depth investigates and research the usage of plasma heating systems in a more industry-like batch process, for an extended period of time. This could also mean to further investigate the possibility of recirculating flue gases to determine how well the system works and how the formation of NOx can be further reduced and to increase the systems overall efficiency. Other aspects of interest to investigate in future trials are service intervals, ability to retrofit to existing equipment and infrastructure, impact on process control and underlying infrastructure requirements which deviates from the industry standard today.

The possibility of trialing a plasma heating system over an extended period of time to verify the effectiveness and performance in a process like environment would further help motivate retrofitting existing equipment by adding more data to economic calculations and evaluations.

Other than belt furnaces, tunnel kiln and furnace involved with melting might be of interest for the Höganäs group to further evaluate if plasma heating is a viable solution.

The aspect of short maintenance intervals poses an increased demand for manpower if a belt furnace with e.g. 60 burners need an overhaul every 400h. An increased and prolonged maintenance is desirable for the plasma heating system to be long-term profitable.

Retrofitting multiple furnaces or process equipment, especially in Höganäs and Halmstad, puts strain on the already limited electricity infrastructure in the southern parts of Sweden. This is a problem which can be attributed to all electrification attempts rather than the plasma solutions but must be taken into considerations before an upgrade is made.

5. DISCUSSION

The power added to the furnace via the plasma torch varies as predicted with the carrier and plasma gas and over time depending on the process phase. The variation of supplied power has not affected the temperature readings of the muffle notably, other than the overall trends during the three main phases. The temperature derivates are of such small magnitude that the variation between thermocouples are negligible.

The distance between the plasma torch and the muffle are greater than usually applicable for burners in belt furnaces and the muffle is from a pilot furnace and therefore much smaller than a normal-sized "production" muffle. There does probably exist some scale up effects which are not known presently.

6. CONLCUSION

During the trials the temperature measurements did not vary much between the three thermocouples attached to the muffle, which rejects the main concerns of having hot spots on the muffle due to the intensity of the plasma torch.

Other applications within the Höganäs group which might be of interest for larger or full-scale tests of plasma heating systems is tunnel furnaces where natural gas burners can be replaced, and the plasma torch's variable power output can be further utilised. Melting and atomising of steel, in process steps where the melt is being held at set temperatures, e.g. tundish, or where the process atmosphere is to be controlled. Utilising the plasma system adaptivity to different carrier gases.

Although very short trials, the project have shown implications that plasma heating can be utilised in heating applications for manufacturing of metal powder in belt furnaces. The lack of high temperature heating systems for utilising in steel manufacturing in general makes plasma heating a viable contender to fossil-fuelled solutions when the fight against climate change must be stepped up and the incentives increase.

A continuation to investigate above mentioned points of interest to further evaluate the technology and its potential is therefore desirable.