Reducing Ultra-Clean Transportation Fuel Costs with HyMelt® Hydrogen

Quarterly Report

January 1 – March 31, 2004

April 2004

Work Performed Under Cooperative Agreement No. DE-FC26-02NT41102

For

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ABSTRACT

This report describes activities for the sixth quarter of work performed under this agreement. MEFOS conducted a third round of atmospheric testing as scheduled on December 9 through December 12, 2003. We reported experimental activities of this testing last quarter. We report process calculations and results this quarter. The test results demonstrated a much-improved rate of carbon dissolution with gas yields close to thermodynamic equilibrium at nearly doubled feed rates of September testing and a commercially viable feed and oxygen injection technique. Additional super-atmospheric testing to perform the last task in the MEFOS experimental program is scheduled for the last quarter of 2004.

TABLE OF CONTENTS

1.0 PROJECT OBJECTIVES, SCOPE AND DESCRIPTION OF TASKS

1. Introduction

EnviRes and DOE executed the cooperative agreement for this work on September 19, 2002. This document is the sixth quarterly progress report under this agreement. Kvaerner, MEFOS and Siemens Westinghouse will conduct most of the significant tasks in this project through subcontracts with EnviRes.

1.1 Scope of Work

Phase I of the work to be done under this agreement consists of conducting atmospheric gasification of coal using the HyMelt technology to produce separate hydrogen rich and carbon monoxide rich product streams. In addition smaller quantities of petroleum coke and a low value refinery stream will be gasified. DOE and EnviRes will evaluate the results of this work to determine the feasibility and desirability of proceeding to Phase II of the work to be done under this agreement, which is gasification of the above-mentioned feeds at a gasifer pressure of approximately 5 bar. The results of this work will be used to evaluate the technical and economic aspects of producing ultra-clean transportation fuels using the HyMelt technology in existing and proposed refinery configurations.

1.1 Phase I Task Description

Task 1.1 Project Management and Planning

This task includes all project planning; experimental test plans; risk analysis; implementation of a bridge loan, purchasing, contracting and accounting systems with requisite auditing; and execution of contracts with MEFOS, Kvaerner and Siemens Westinghouse. This task is being executed.

Task 1.2 Preparation and Shipment of Feedstock Materials

This task consists of procuring 25 tons of coal, 15 tons of petroleum coke and 48 – 55 gal drums of aromatic extract oil; transporting the coke and coal to a pulverizing facility; pulverizing, drying and loading the coke and coal into bags; and shipping the feedstocks to MEFOS in Lulea, Sweden. EnviRes completed this task

Task 1.3 Predictive Modeling of the HyMelt Process

This task consists of generating detailed reactor energy and material balances for each feedstock using the Fact Sage pyrometallurgical thermodynamic modeling program. Kvaerner will perform detailed process simulation using the Aspen Plus process simulator. Kvaerner, MEFOS and EnviRes will evaluate and analyze the results of predictive modeling. This has been completed.

Task 1.4 Combustion Modeling and Analysis

Siemens Westinghouse will perform combustion turbine modeling using fuel gas conditions and compositions provided by task 1.3. This task is being executed.

Task 1.5 Design and Fabrication of Pilot Plant Specific Molten Iron Bath Apparatus

MEFOS will design and fabricate all solid feeding systems and oxygen injection systems required by the testing. EnviRes will assist MEFOS in designing the petroleum liquid feed system. MEFOS will design the shell of the high-pressure reactor. MEFOS and EnviRes completed the originally planned injection system for this task. MEFOS and EnviRes designed and fabricated a tuyere for submerged injection. MEFOS and EnviRes designed and fabricated a commercially feasible tuyere for testing in December. We performed the testing as planned.

Task 2.0 Project Testing

Task 2.1 HyMelt Atmospheric Pressure Testing in a Molten Iron Bath

MEFOS designed and fabricated the petroleum liquid feed system. This injection system was tested in a cold flow environment. The injection systems were hot commissioned. Any equipment revisions indicated by cold flow testing and hot commissioning were made. Process performance testing was performed for each feed. MEFOS and EnviRes completed execution of this task.

Task 2.4 Above Atmospheric Pressure Testing in a Molten Metal Bath

MEFOS completed a preliminary design for this work. Work on a detailed design is in progress

2.0 EXECUTIVE SUMMARY OF WORK DONE DURING THIS REPORTING PERIOD

EnviRes and MEFOS performed additional atmospheric pressure testing on December 9-12, 2003 to demonstrate a commercially feasible tuyere system for HyMelt operation. We presented preliminary reporting of the testing performed in December in the last quarterly report

As reported earlier, December testing demonstrated the ability to operate with high specific feed rates of coal and petroleum coke. Results presented in this document show that the product gas composition closely resembles that predicted by thermodynamic equilibrium calculations. Carbon conversion, trace impurities and dust losses appear to be acceptable.

Decarburization with submerged tuyeres demonstrated the expected benefit of lower FeO in the slag resulting in less CO contamination in the hydrogen rich stream. We feel that successful atmospheric testing has been accomplished. We are now ready to perform super atmospheric pressure testing.

3.0 Experimental

MEFOS Activities

MEFOS did not conduct any experimental activities during the reporting period. Experimental activities during the previous quarter are presented in Appendix I along with the complete report from MEFOS for this testing. We presented a preliminary discussion of these activities in the previous quarterly report for this project.

Kvaerner Activities

No activities were performed pending completion of atmospheric testing.

Siemens Westinghouse Power Corporation Activities

No activities were performed pending completion of atmospheric testing.

4.0 Results and Discussion

MEFOS Activities

In the following discussion the reader should refer to the MEFOS report in Appendix I. Only one or two tests of questionable value were made during HyMelt 11 and 12. Testing during HyMelt 13 and 14 exhibited smoother operation and more test periods.

Figure 3 shows that feed injection rates were the highest attained to date and approached 30 kg/min for both coal and coke. We did not anticipate that this feed injection rate could be achieved at atmospheric pressure. We expect to be able to achieve a higher feed injection rate as we increase system pressure. PCIG (Pressurized Coal Iron Gasification) tests performed by MEFOS 25 years ago exhibited this behavior. We believe that for the same gas thoughput, higher pressure will result in a longer residence time for the feed.

The small tuyere diameter limited the oxygen injection rate to approximately 8 m^3n/min. Oxygen injection with the top entry lance had been 10 m^3n/min. This lower oxygen injection rate precluded operating the reactor in heat balance as had been done in previous testing.

Figure 8 of the MEFOS report shows FeO in the slag to be 1 to 2%. In previous testing FeO in the slag averaged 3 to 4%. During coal or coke injection in previous testing, a pronounced spike of CO appeared in the initial minute product gas analysis. We inferred that this spike was the result of FeO in the slag reacting with carbon to from CO. In HyMelt 13 and 14 the CO spike appears to be much smaller and in some tests non-existent.

In each test campaign the analytical equipment and methods were improved. In the December campaign we measured trace constituents much more reliably. Figures 11 to 19 of the MEFOS report show that the level of HCN seldom rose above 10 ppm during coal or coke injection with a maximum value of approximately 30 ppm. During oxygen blowing the HCN level stayed below 10 ppm. Similarly the concentration of COS in the product gas always stayed below 60 ppm and usually below 20 ppm. The concentration of COS in the product gas during oxygen blowing was generally lower that during feed injection. The concentration of methane in the product gas generally stayed below 1% although it sometimes exceeded 1%. In several injection periods the concentration of methane rose in a near linear fashion during the injection. Thermodynamic equilibrium calculations predict this behavior as the activity of carbon in the metal increases.

Section 6 of the MEFOS report presents the results of process calculations that show that nearly all of the deviation of gas analysis from that predicted by thermodynamic equilibrium can be accounted for by air leakage into the converter and/or sample train. Figures 21 and 22 present the carbon yield to metal for coke and coal injection as a function of injection rate. These yields do not account for carbon reacting with injection air for either coal or coke, nor do they account for oxygen contained in the feed reacting to remove carbon. For both coal and coke the carbon yield to metal does not seem to fall off as the feed rate increases in this campaign.

It is interesting to note that the carbon content of some dust samples contained more carbon than 1 minus the ash content. If these analyses are correct this implies that carbon must have formed in the gas space of the converter or in the sample train. Carbon formation at reactor temperature is not possible, but if the gas sample remains at approximately 900°C for several seconds, such a reaction is possible. The carbon content of the dust during oxygen injection typically stayed below 5%.

5.0 Conclusions

We believe that this testing successfully meets all criteria for atmospheric testing. We plan no further atmospheric testing.

6.0 References

Malone, D.P. and Renner, W R, “Reducing Ultra-Clean Transportation Fuel Costs with HyMelt Hydrogen”, Quarterly Report, October 1 – December 31, 2003, Agreement Number DE-FC26-02NT41102, January 2004

7.0 PLAN FOR THE NEXT QUARTER

We plan to complete the design for the pressurized converter and begin its fabrication. Data from atmospheric testing should be adequate for most of the work to be performed by Kvaerner and Siemens Westinghouse.

APPENDIX I

MEFOS DATA

CONFIDENTIAL

MEFOS

Box 812, 971 25 LULEÅ

Dokument:	MEFOS-rapport	*Reg nummer:*	MEF04010K
Fo-uppgift:		*Datum:*	2004-02-27
Konto:	388160	*Rev datum:*	
Ämnesomr:		*Avdelning:*	MM

HYMELT, CAMPAIGN III,

9-12 DECEMBER 2003

by

Sten Ångström

Godkänd av forskningschef:		*Slutlig:*	Y
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HYMELT, Campaign III, 9-12 December 2003

Sten Ångström

MEFOS

SUMMARY

A third HyMelt pilot campaign has been performed at Mefos.

Compared to previous campaigns the converter profile had a narrower lining to achieve an increased metal height. The injection feed was further split into two bottom tuyeres. The arrangement showed that prolonged residence time of coal/coke particles in the melt improves the process performances. The feeding rate can, compared to previous campaigns, be almost doubled at maintained or improved material yields.

The top lance was removed and oxygen blowing was also made by use of the bottom tuyeres. The process is thereby more stable and lower amounts of reducible slag oxides decrease the initial CO formation in the coke/coal feeding period.

A new system for process gas analysis together with a tighter sampling system improved the sampled gas quality and simplified the evaluation.

The expected number of tests could not be made because of equipment failures. The problems occurred do not influence the HyMelt development and were partly compensated by an additional test day.

TABLE OF CONTENTS **Page**

1 Introduction

In the HyMelt II campaign, TM03054K, it was demonstrated that side wall injection improved the generated gas quality compared to the results the from top lance injection in the HyMelt I, TM03037K. The results also indicated a possibility for further improvements if the injected particles could be kept submerged in the melt for longer time and if a more intense particle contact with the melt could be established

Thus, HyMelt III was designed with two bottom tuyeres and the metal bath height was increased by a reduced lining diameter of the converter.

The tuyeres were also used for oxygen injection. The oxygen lance was removed because of scull problem. Bottom blowing is further expected to decrease the amount of reducible oxides in the slag and thereby shortening the turn-around time between oxygen blowing and hydrogen gas production.

2 Equipment

The set up was focused on residence time of the material in the metal and two major changes were made:

– The injection flow was split into two bottom tuyeres of new design

– Increased metal bath depth

Further modifications were:

– The oxygen lance was removed and replaced by oxygen injection through the two bottom tuyeres.

– The mass spectrometers for gas analysis were replaced by a single instrument of later design.

– A new lance, in parallel with the gas sampling lance, was dedicated for larger dust samples from the process gas

– Nitrogen was used as material transport gas

2.1 Converter lining

The converter lining was made with an inner layer decreasing the diameter to 1100 mm. The bath height at 5,5 ton was thereby increased from approximately 500 to 800 mm. The design was a compromise between an increased bath height and the necessity to keep the tuyeres above the melt surface at tilted position. The refractory used was MagCarbon Radex PLE12.

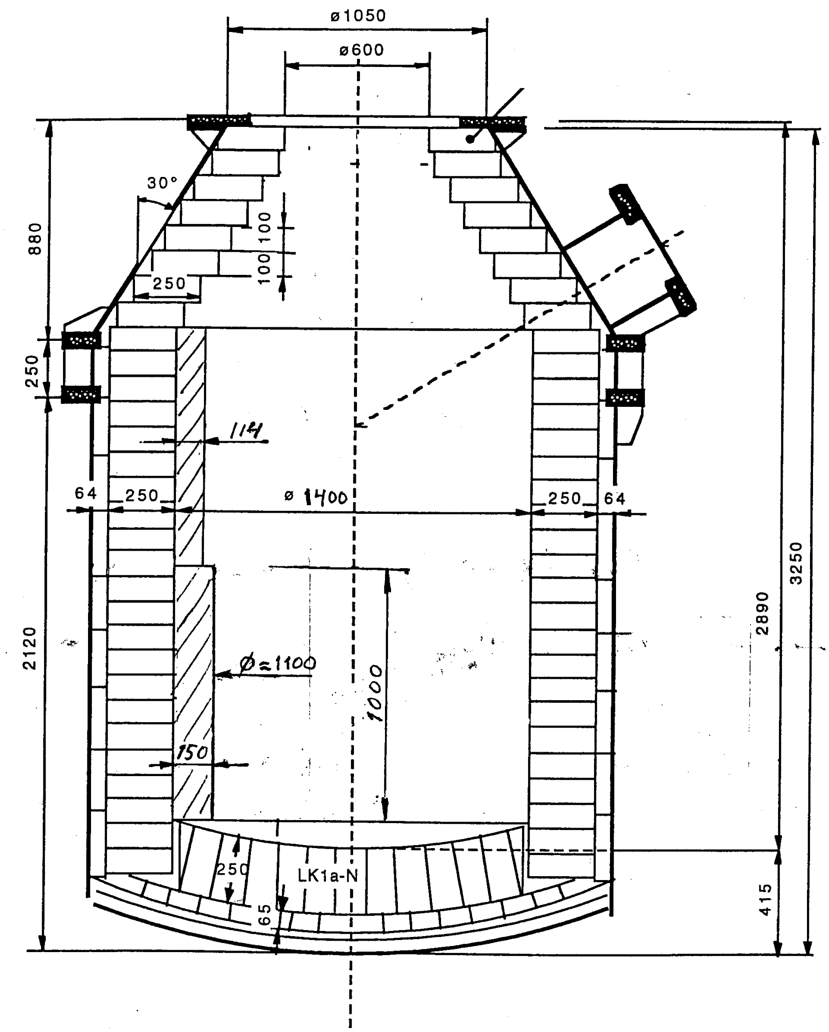


Figure 1 – Converter lining

2.2 Tuyere design

Note: This section appears in the confidential report.

2.3 Process gas analysis

The process gas was analysed by mass spectrometer (AirSense Compact) and for comparison by conventional CO, CO_2 and H_2 analysers.

2.4 Dust collection system

Since the oxygen lance was removed it was possible to separate the dust sampling from the process gas sampling and to use a dedicated dust sampling lance. Thus, larger dust samples could be collected.

3 Material

The same materials as for previous tests were used. For detailed information see TM03037K.

4 Test Procedure

Differently from previous tests, described in TM03037K, the converter was tilted for rearrangement of connecting hoses to the tuyeres between oxygen and material feed.

5 Results

5.1 Heats

5.1.1 HyMelt 11

Date 031209

Heat S1792

Failure in the tilting function of the EAF delayed start of tests. Two injection periods with coke were made.

5.1.2 HyMelt 12

Date 031210

Heat S1793

One coke injection period was made. A smaller explosion in gas feeding pipes damaged the propane measuring device.

5.1.3 HyMelt 13

Date 031211

Heat S1794

Four periods with coal and one with coke were made.

5.1.4 HyMelt 14

Date 031212

Heat S1795

Three periods with coal were made. The operation was mainly made without in-blow temperatures and samples.

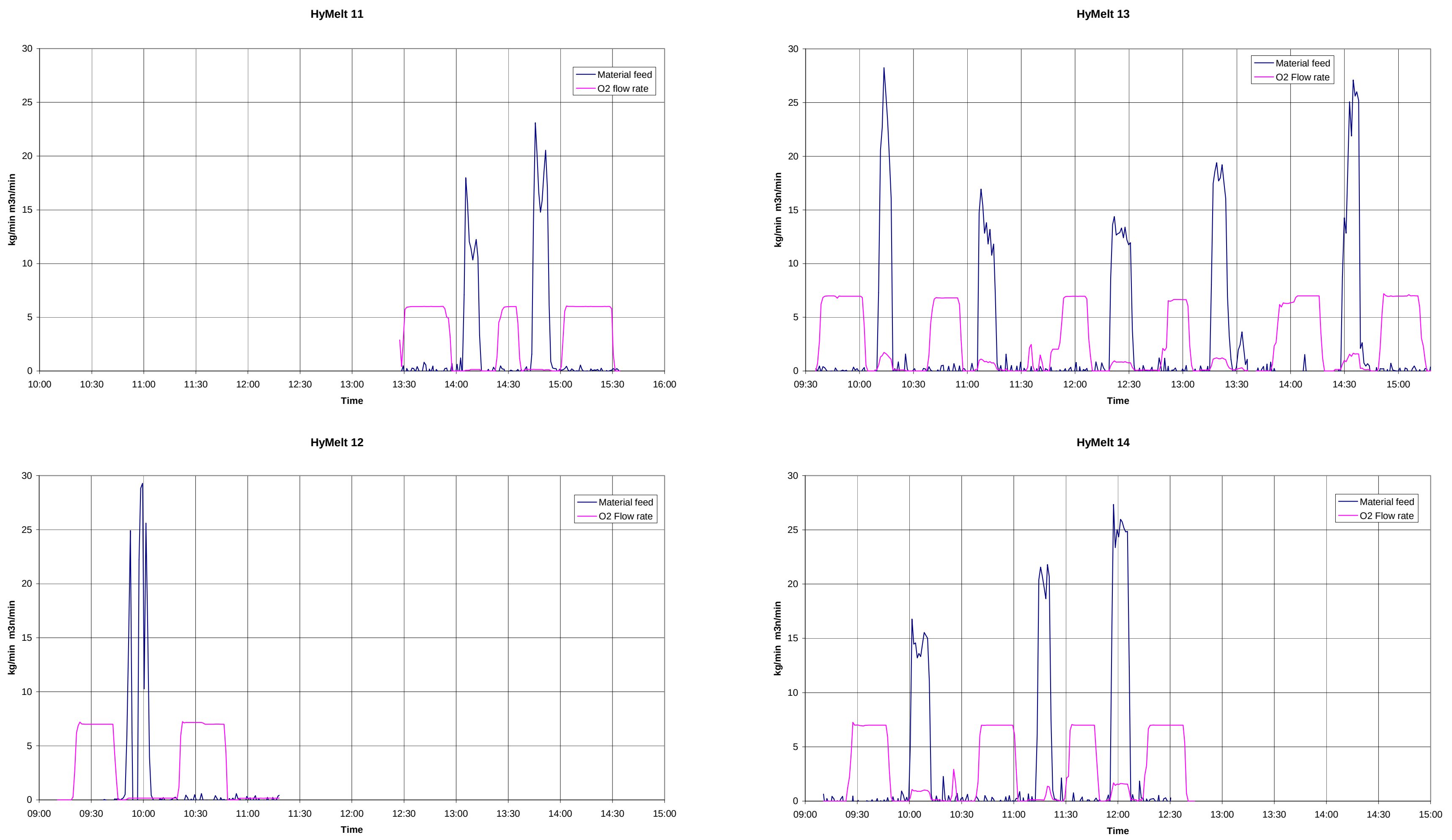
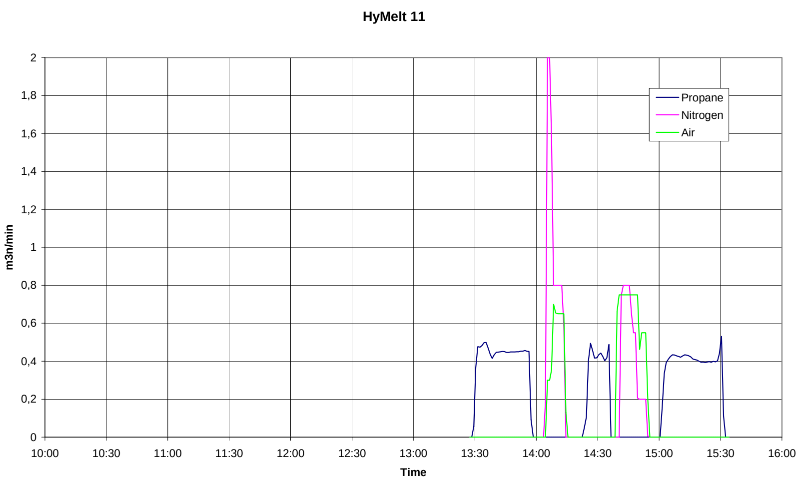
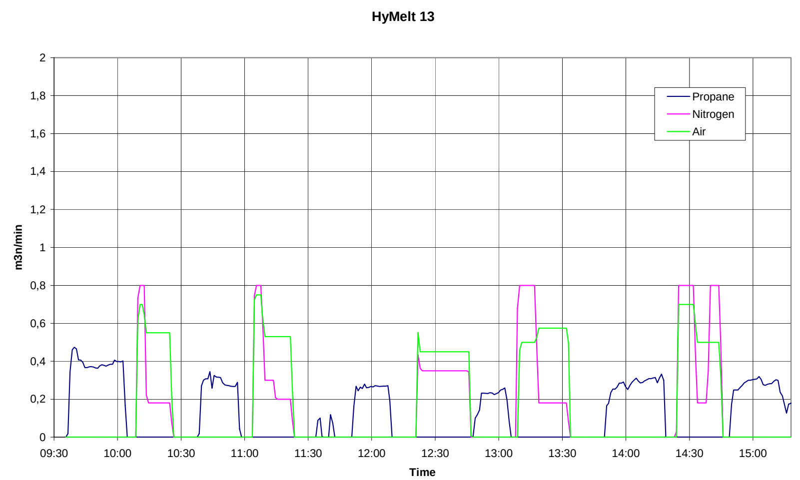
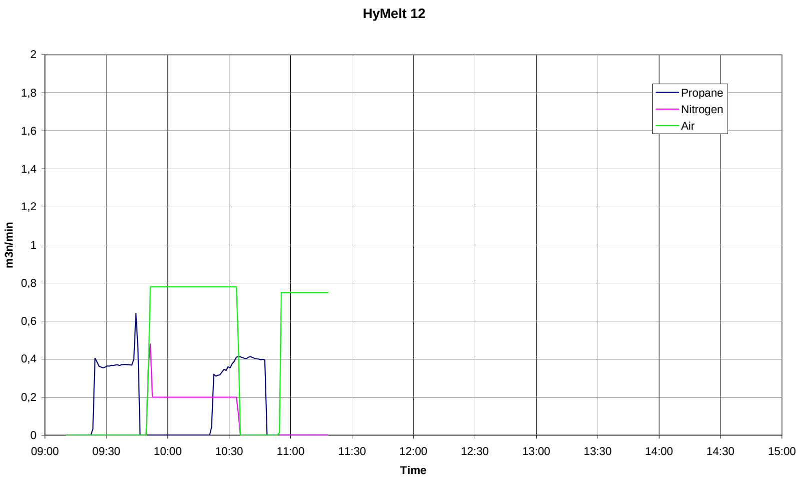


Figure 3 – Feed of material and O_2 flow rate HyMelt 11-14







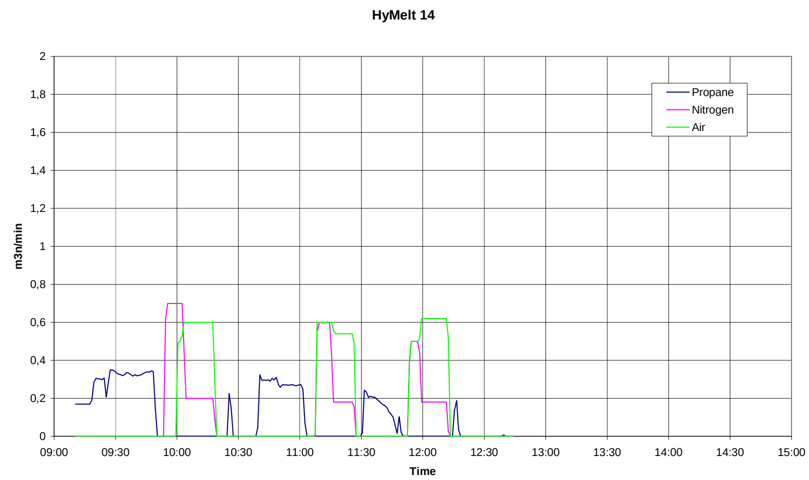


Figure 4 – Injected nitrogen, propane and air HyMelt 11-14

5.2 Metal

5.2.1 Metal temperature

The metal temperature was a primary controlled parameter and mainly kept between 1350 to 1650^{o}C. Oxygen blowing for decarburization was made until the desired temperature was achieved and injection was considered possible above 1350^{o}C. Lowest recommended operational temperature can however be discussed since it seems to be a relation between gas composition and metal temperature.

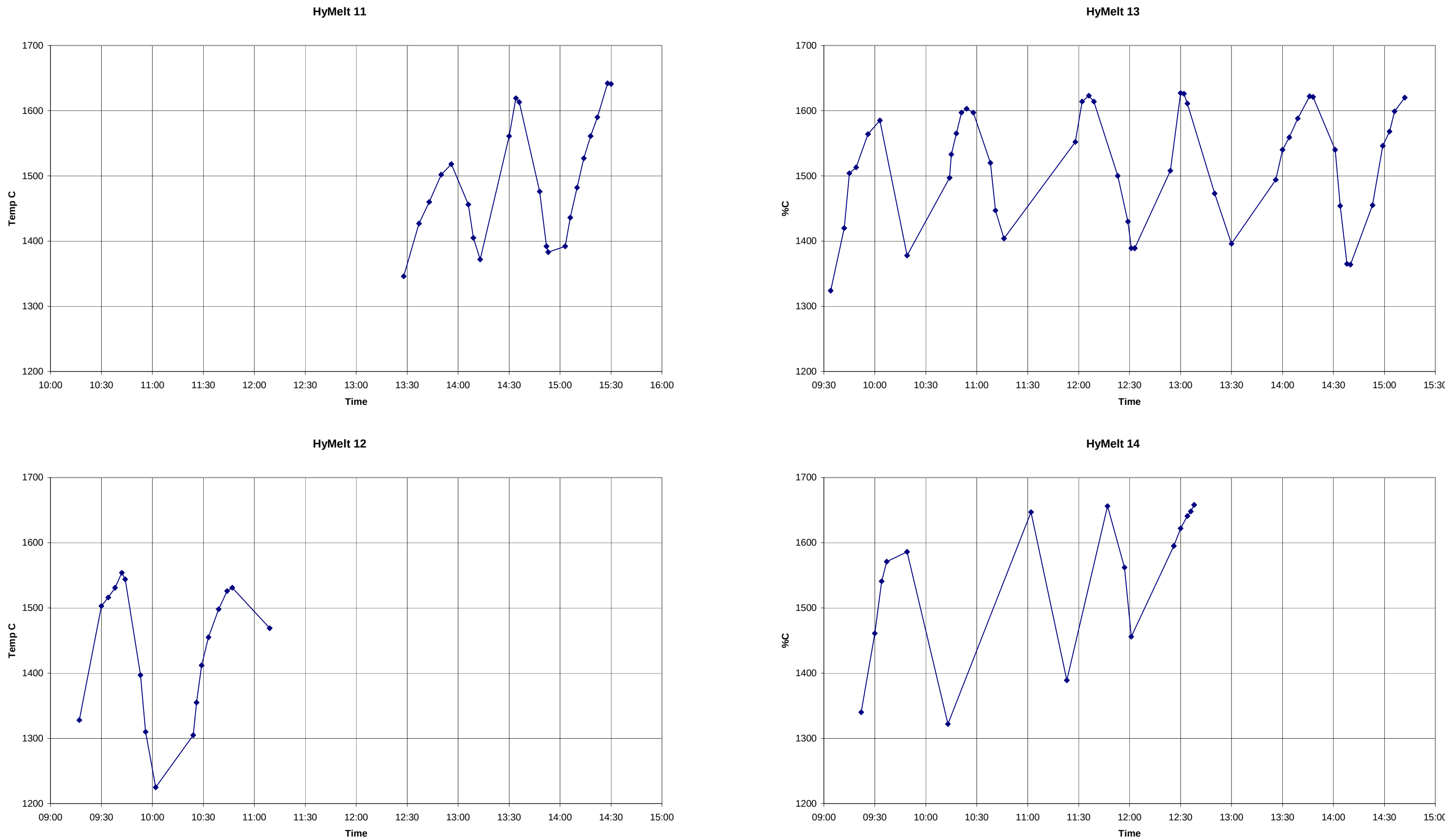


Figure 5 – Melt temperatures HyMelt 11-14

5.2.2 Metal %C

The carbon content was varied between 1 and 4,5 %. The lower limit is a consequence of the relation to oxides in the slag and the upper limit is set by the temperature and available energy for solution of carbon.

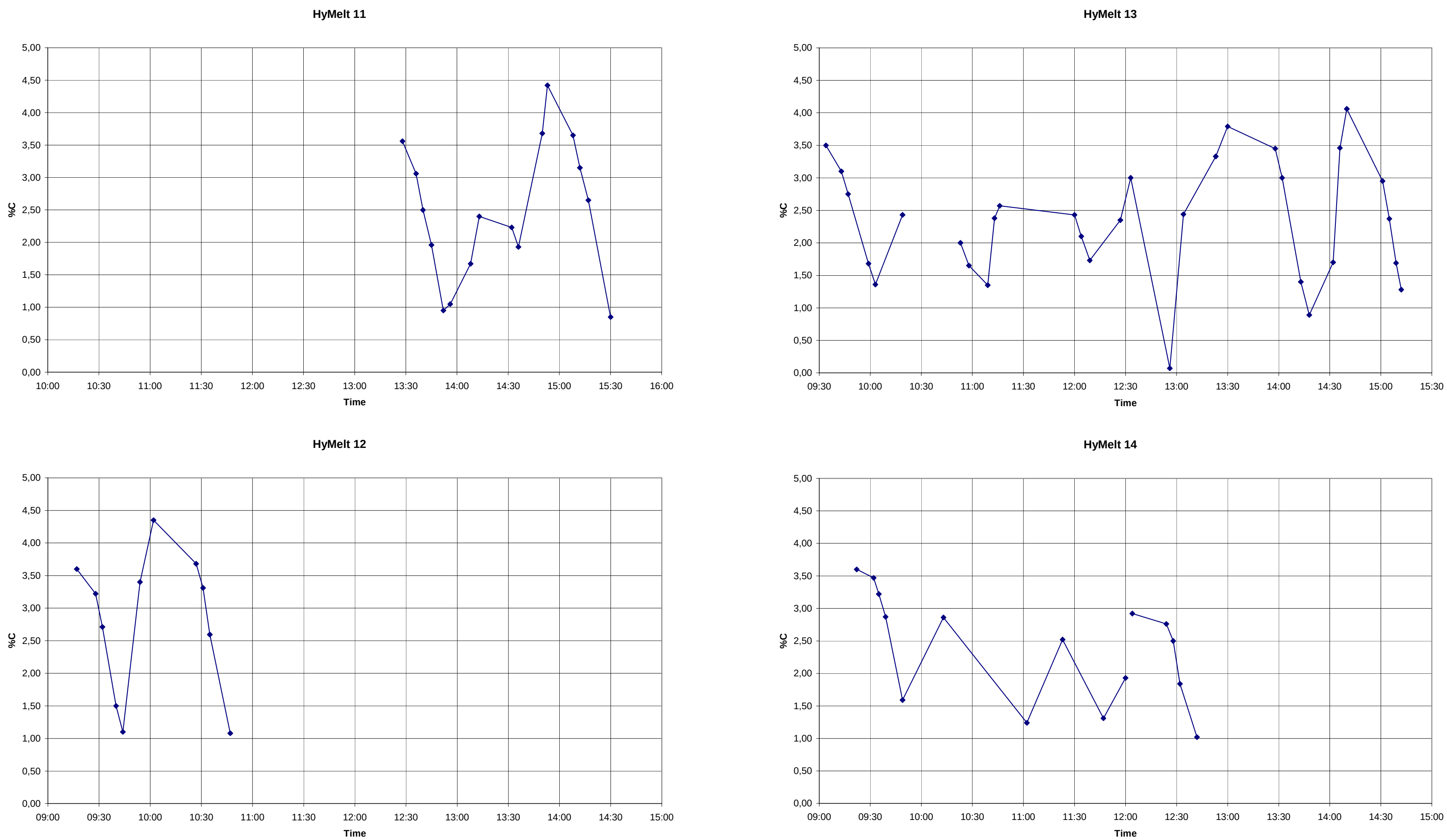
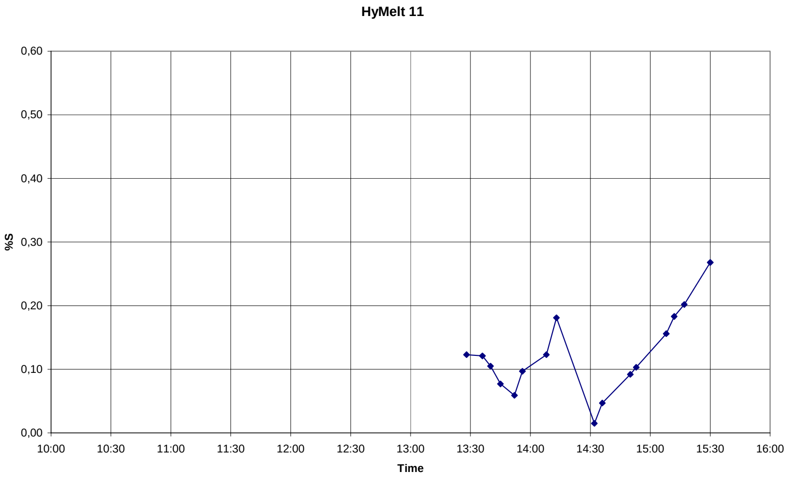
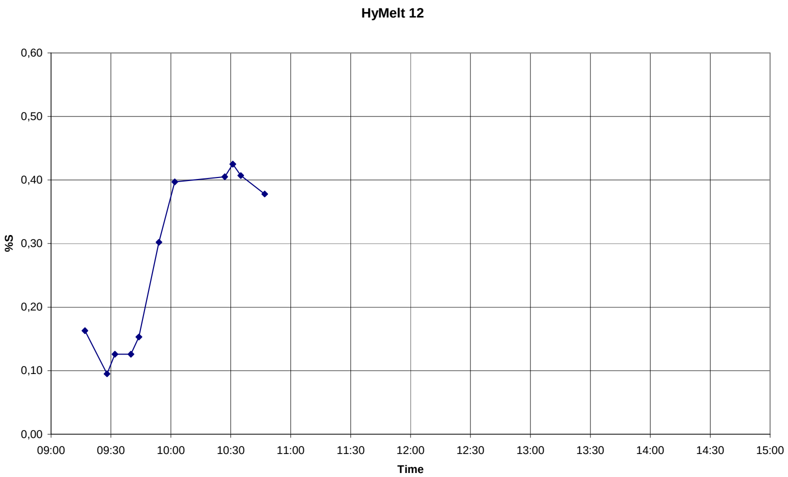


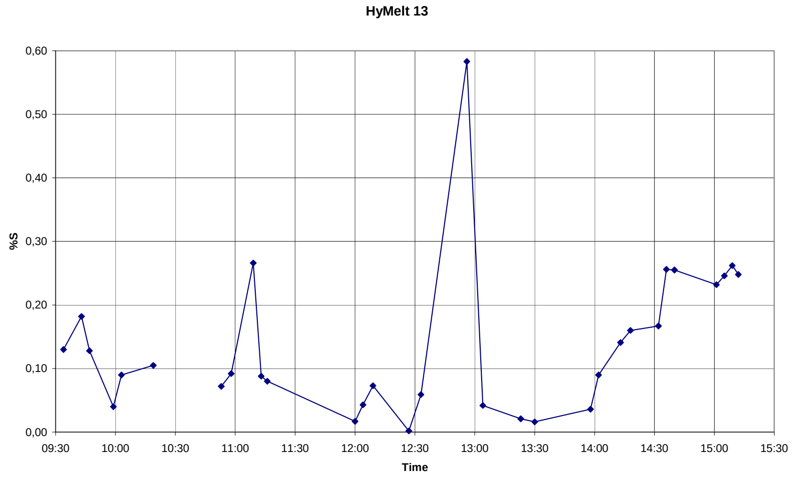
Figure 6 – Carbon content HyMelt 11-14

5.2.3 Metal %S

Sulphur is an element of great importance in metallurgy and has consequently been studied for several reasons. The distribution between slag and metal is well known and has a strong relation to CaO/SiO_2-ratio and the oxygen potential, i.e. Fe_{tot}. and % C. A fundamental aspect in the HyMelt process is the variation of the carbon content in the metal and it is expected that the sulphur content in the metal will vary accordingly.







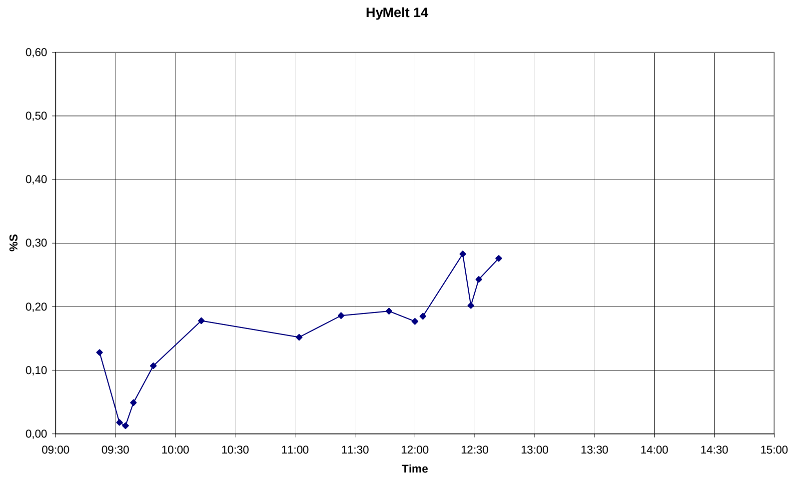


Figure 7 – Sulphur content HyMelt 11-14

5.3 Slag

5.3.1 Slag % Fe_{tot}

There are at least two good reasons to keep Fe_{tot} as low as possible in the slag:

1. Fe_{tot} is for HyMelt conditions a description of the FeO content in the slag and will at higher levels influence the time between start of material injection and the point where gas of good quality can be produced.

2. Fe_{tot} does also directly influence the solidification temperature of the slag and thereby the refractory wear

Bottom blowing promotes lower Fe_{tot} at comparable carbon contents and compared to previous top blown campaigns. The most reliable samples are shown in HyMelt 13 and 14.

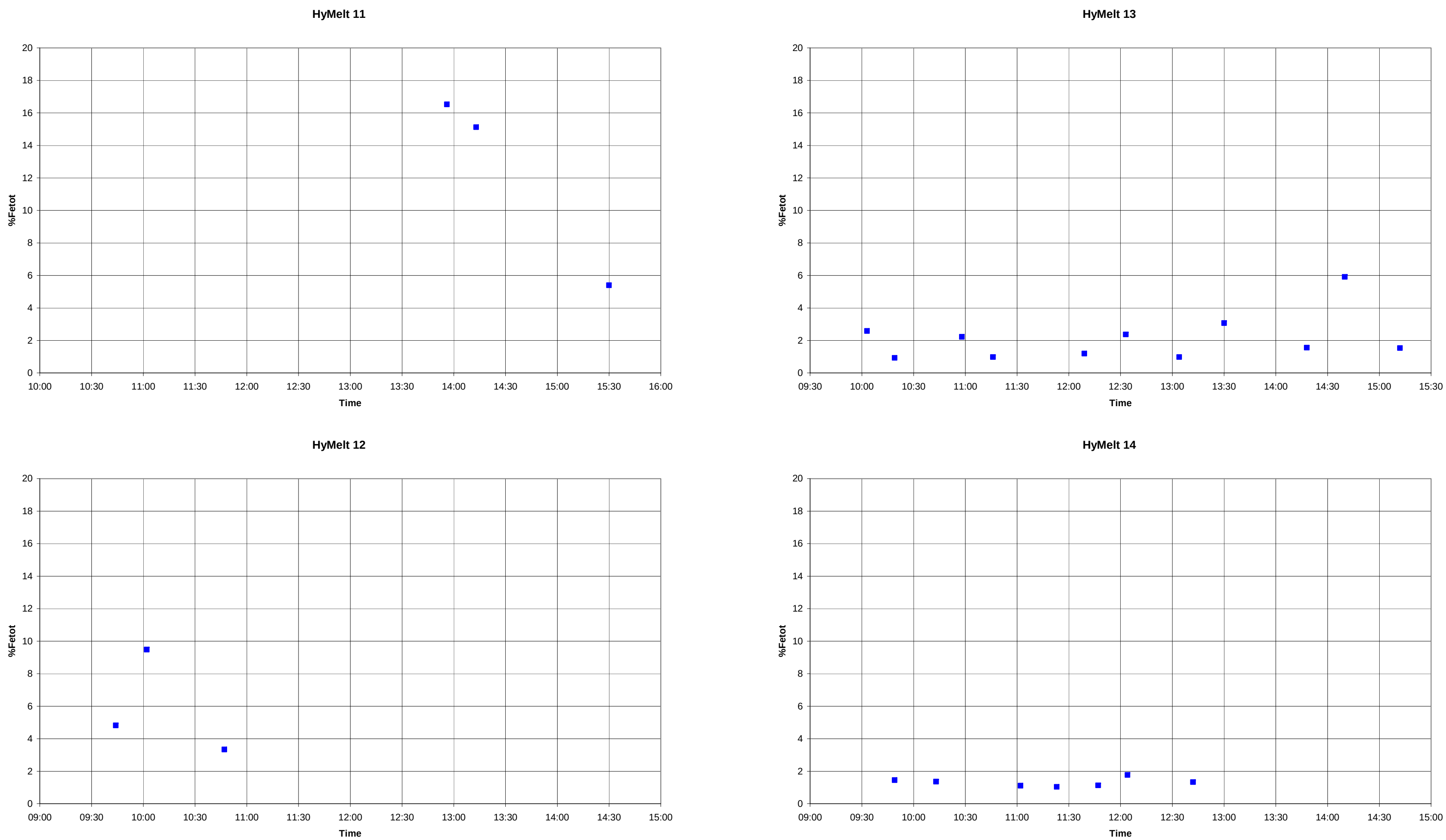


Figure 8 – Fe_{tot} HyMelt 11-14

5.3.2 Slag $\%CaO/\%SiO_2$

The % CaO/ % SiO_2-ratio is a simplified indication of solidification temperature and sulphur capacity of the slag. The optimal ratio for the HyMelt has so far not been investigated but it is likely that improved performances can be achieved at levels higher than 2.

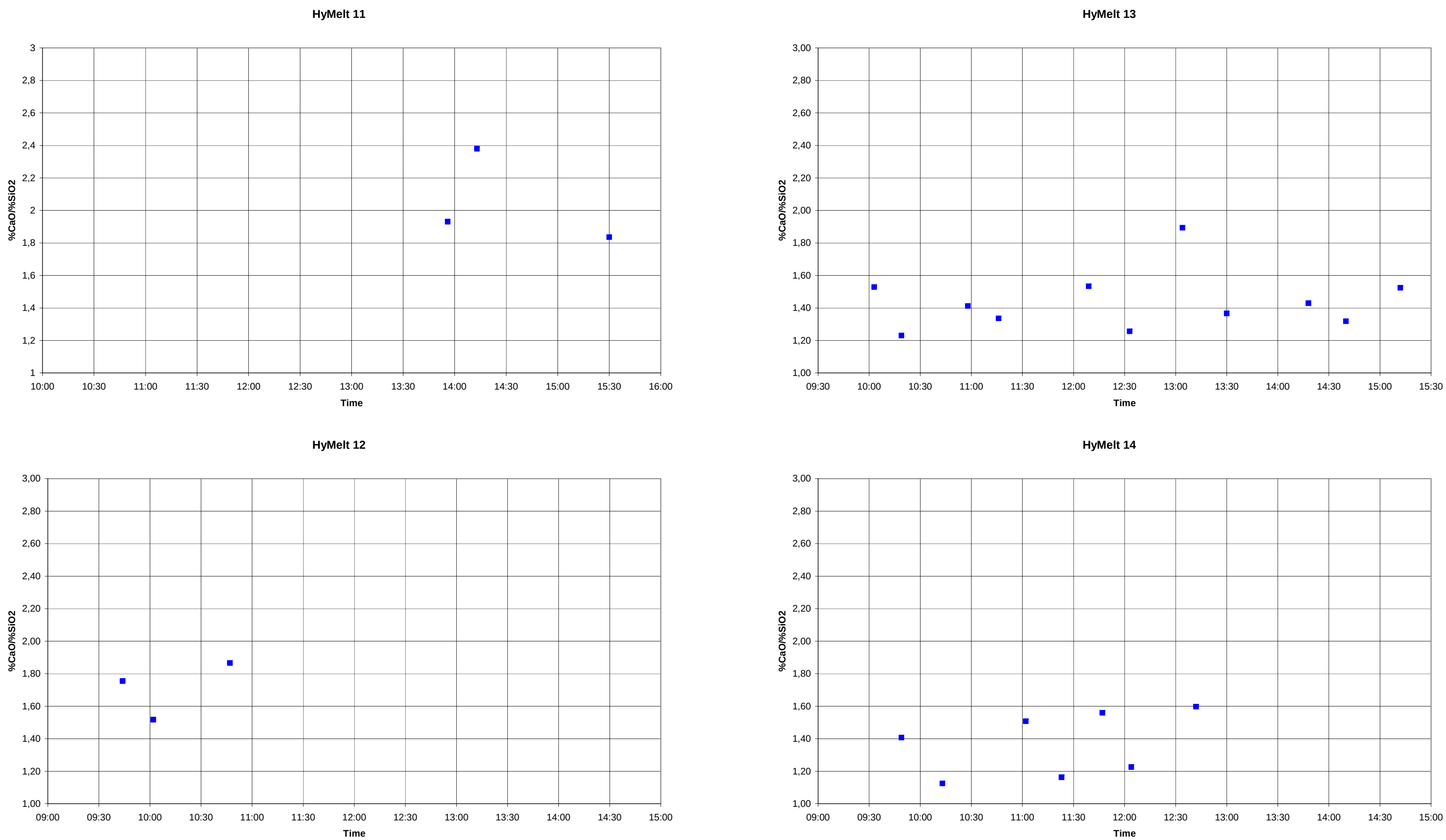


Figure 9 – % CaO/% SiO_2 HyMelt 11-14

5.3.3 Slag % S

The concentration of sulphur in the slag is a mirror of the concentration in the metal. Saturation is expected at levels somewhere above 3 % and has not been achieved in any of the heats since the concentration is increasing during the entire campaign.

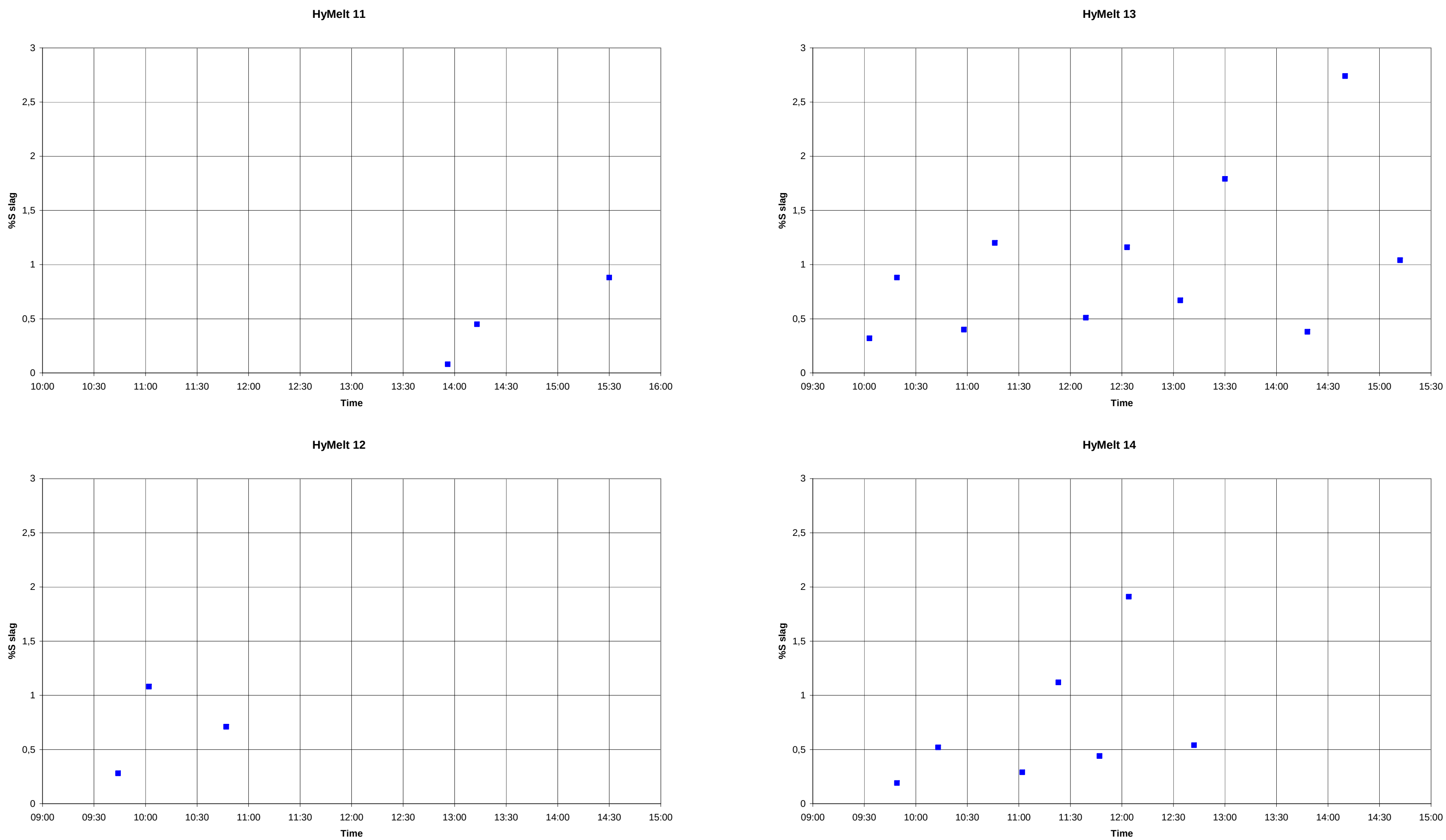


Figure 10 – % S slag HyMelt 11-14

5.4 Generated gas

For reference the gas composition are shown as in the previous reports and obtained analysis confirm mainly the earlier reported composition.

The sampling system was improved after HyMelt 11 and the leakage of air was decreased.

H_2 Up to 60 %.

CO 15 – 30 % Lower for coke and higher for coal.

CO_2 0,5 – 5 % CH_4 typically below 1%

C_2H_2 50 – 200 ppm, significantly lower than HyMelt II 1000 ppm

H_2S 200 ppm

COS 10 – 60 ppm, significantly lower than HyMelt II 50 – 200 ppm

C_2S 10 – 20 ppm

HCN 10 – 30 ppm

O_2 <2 %

N_2 Unstable instrument function

Ar No significance for the experimental set up

In addition to gas generated at coal and coke feeding some periods with oxygen blowing were analysed in this campaign.

CO, CO_2 and H_2 shows expected values but for several periods CH_4 C_2S C_2H_2 etc. are present and for others not. For the moment no definitive explanation can be given. A likely explanation could be remaining contamination in the sampling system or remaining coal/coke in the slag.

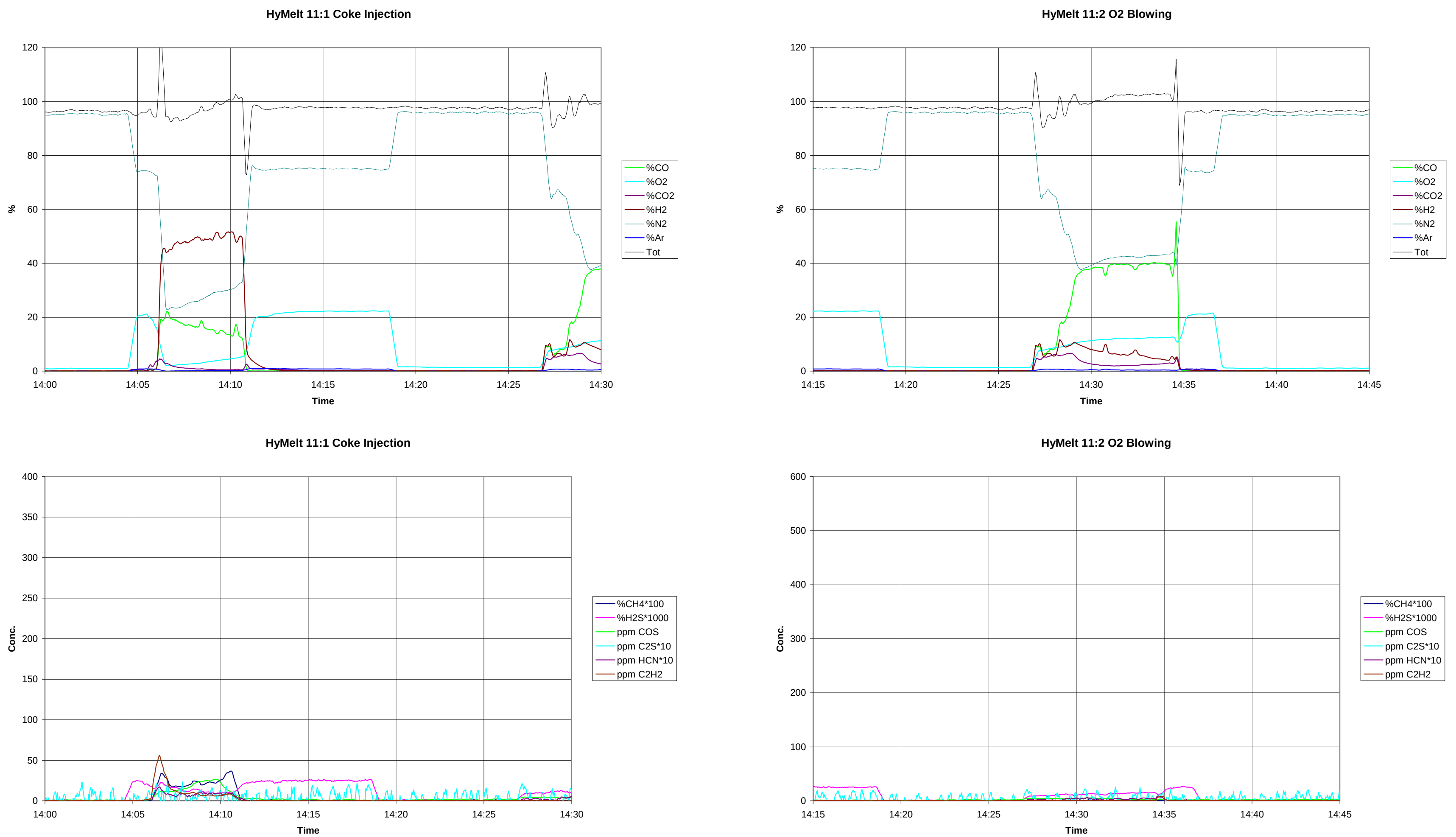


Figure 11 – Process gas HyMelt 11

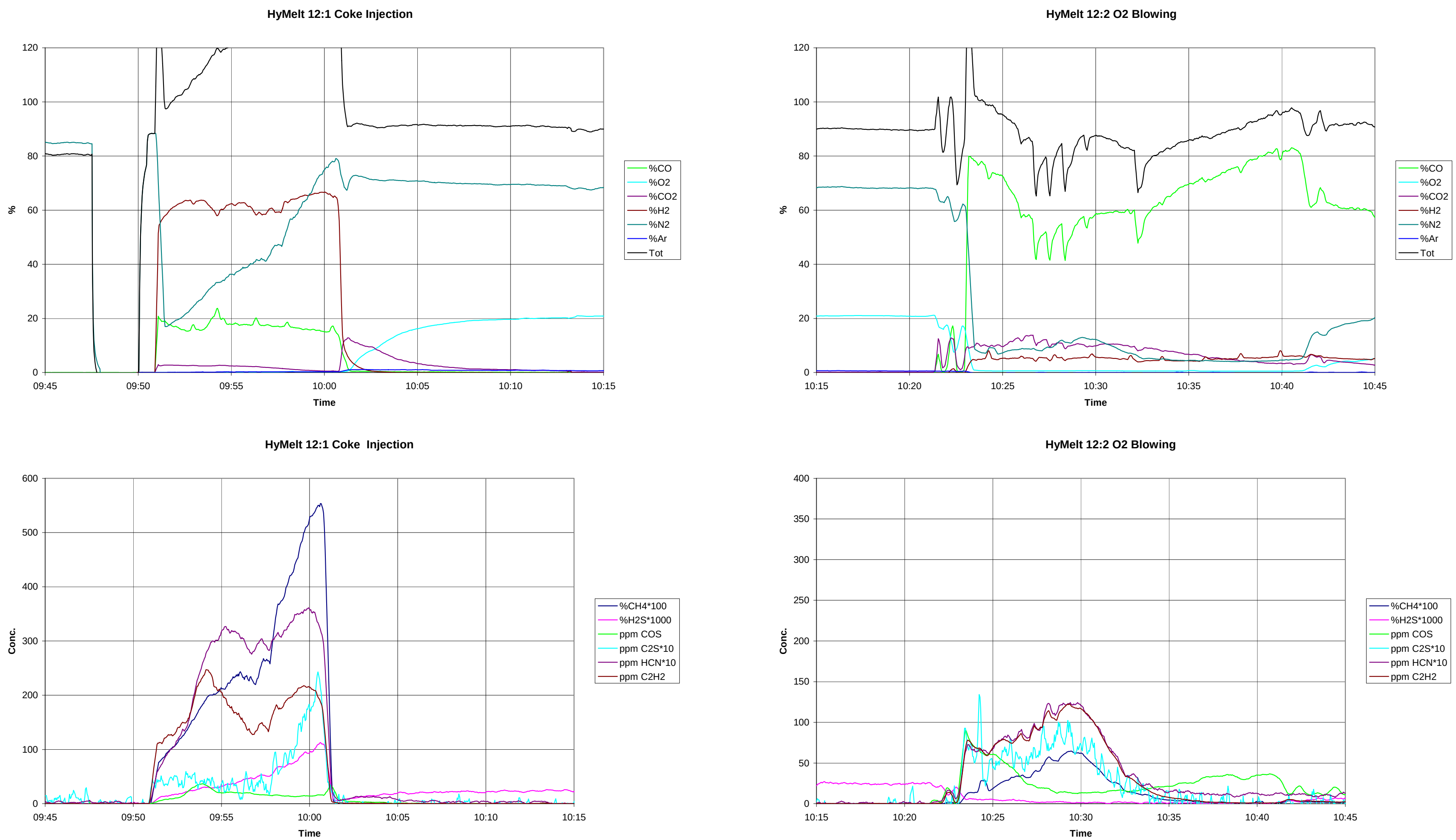


Figure 12 – Process gas HyMelt 12

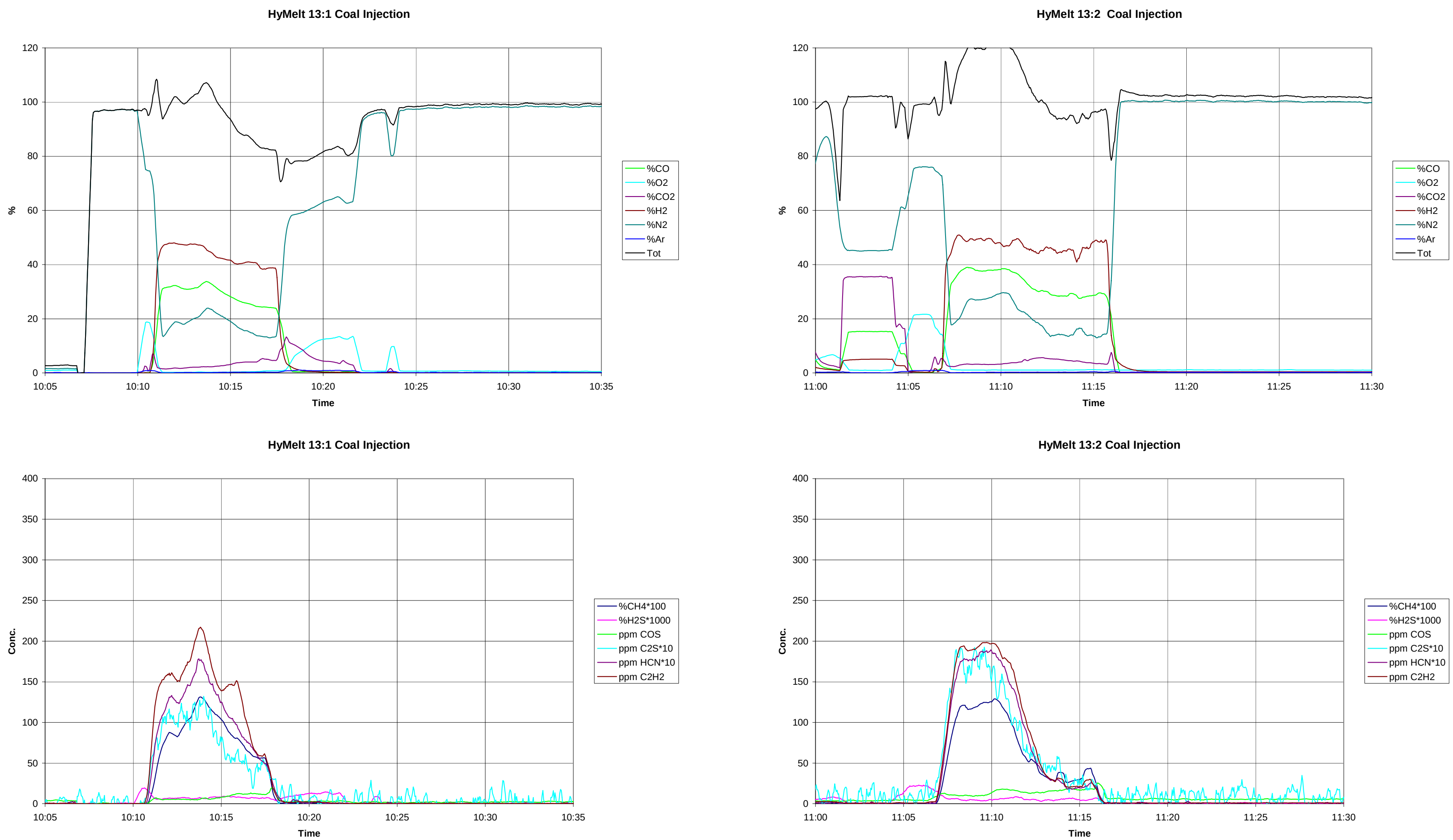


Figure 13 – Process gas HyMelt 13

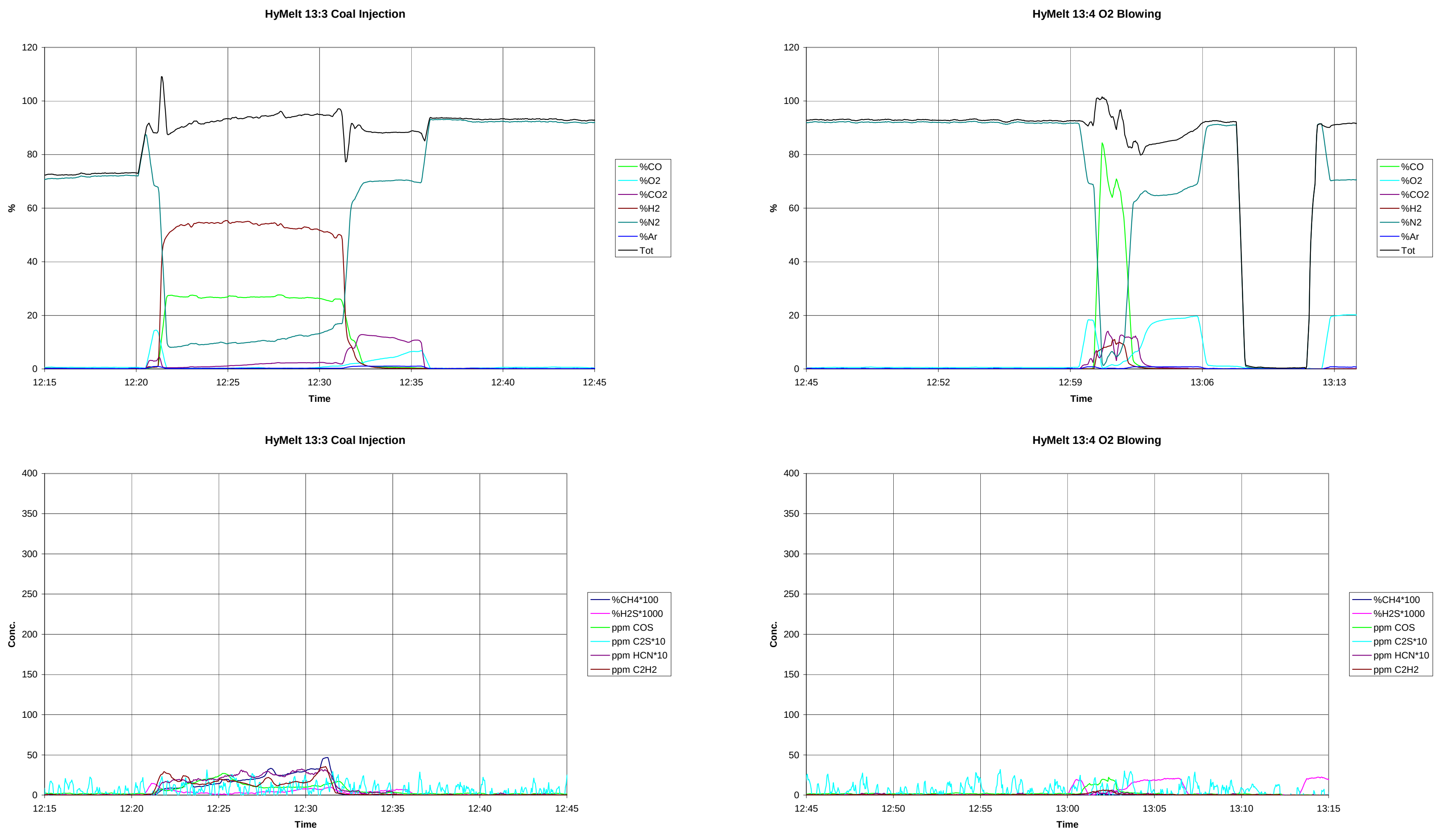


Figure 14 – Process gas HyMelt 13

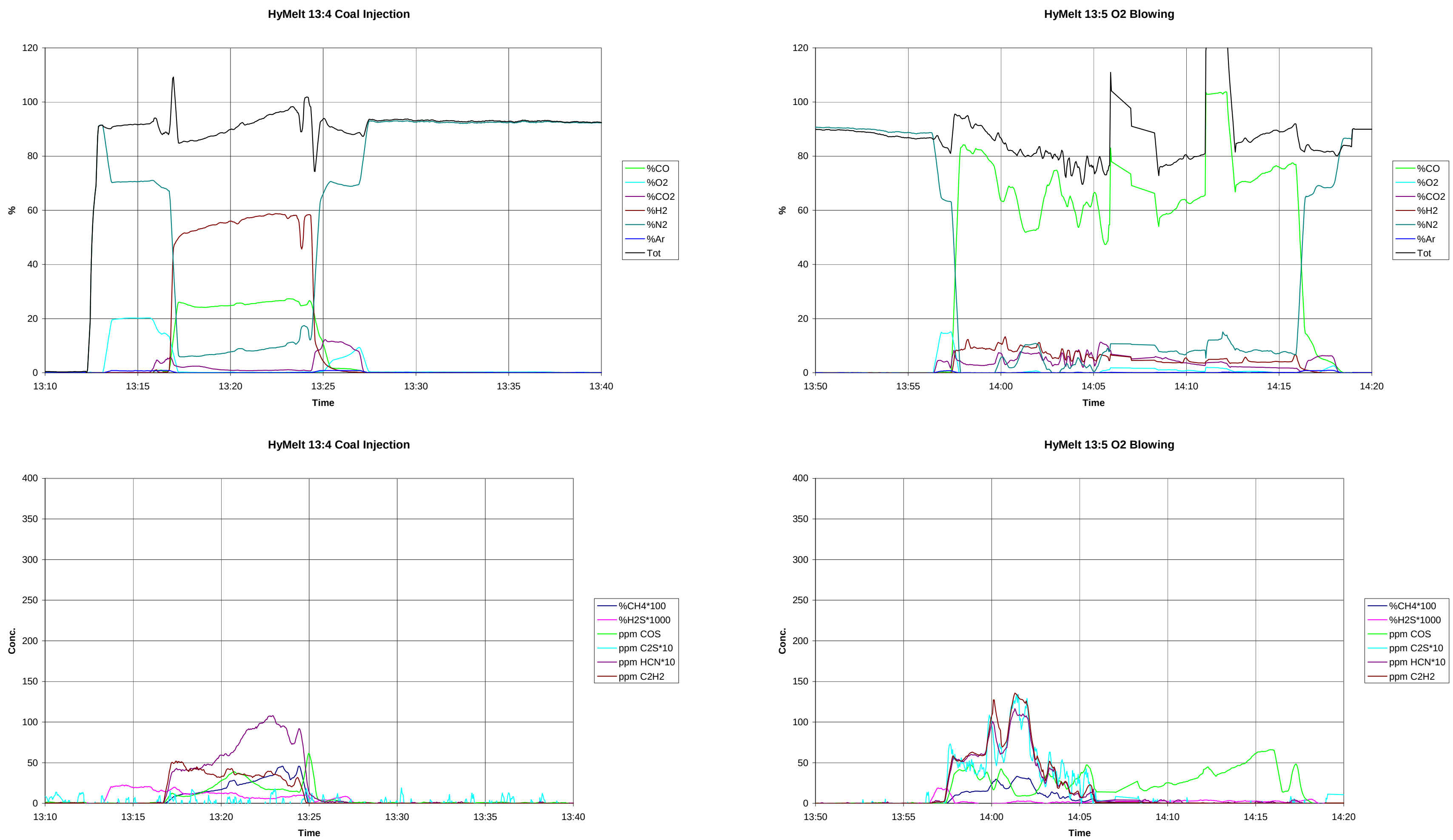


Figure 15 – Process gas HyMelt 13

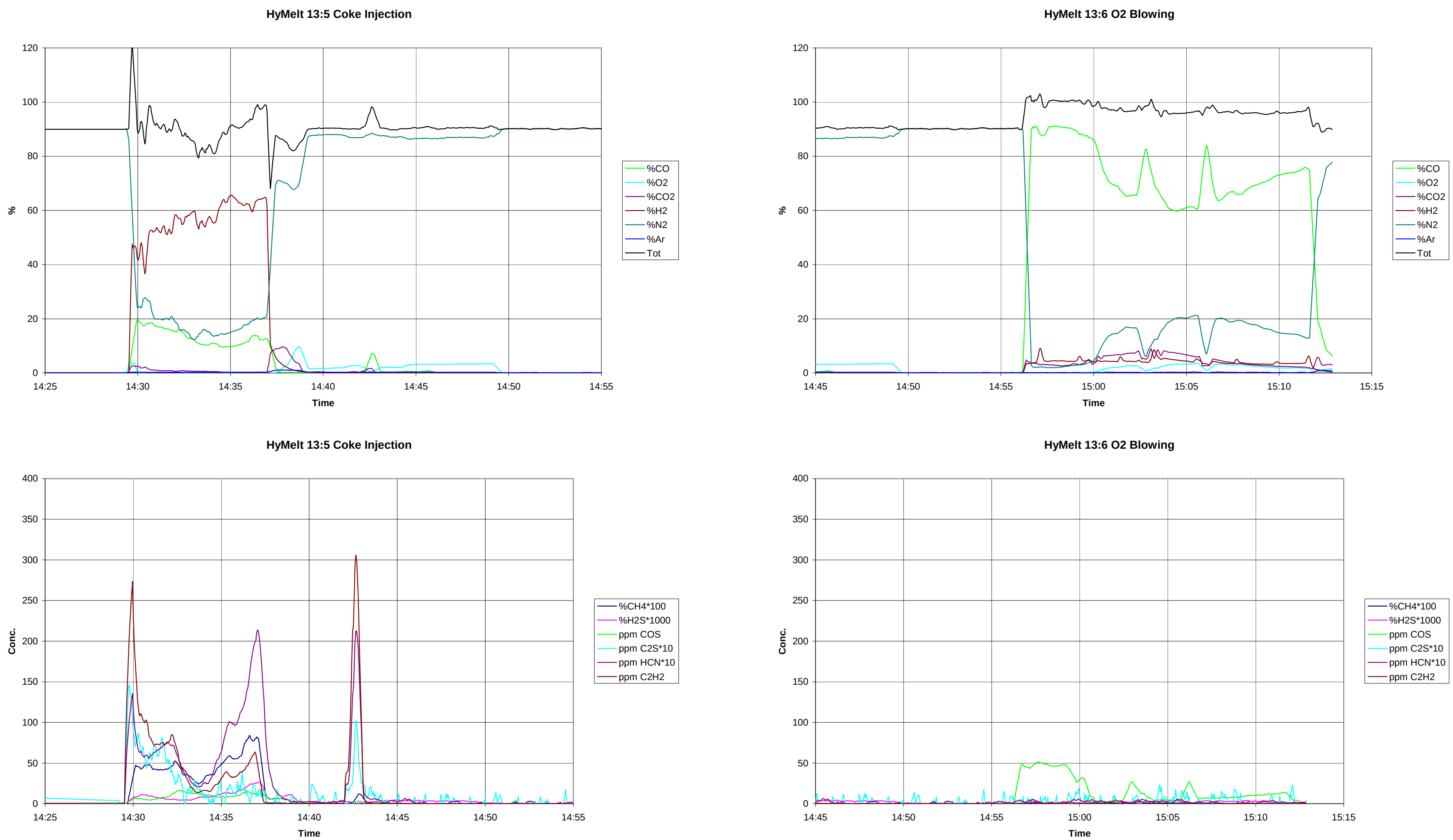


Figure 16 – Process gas HyMelt 13

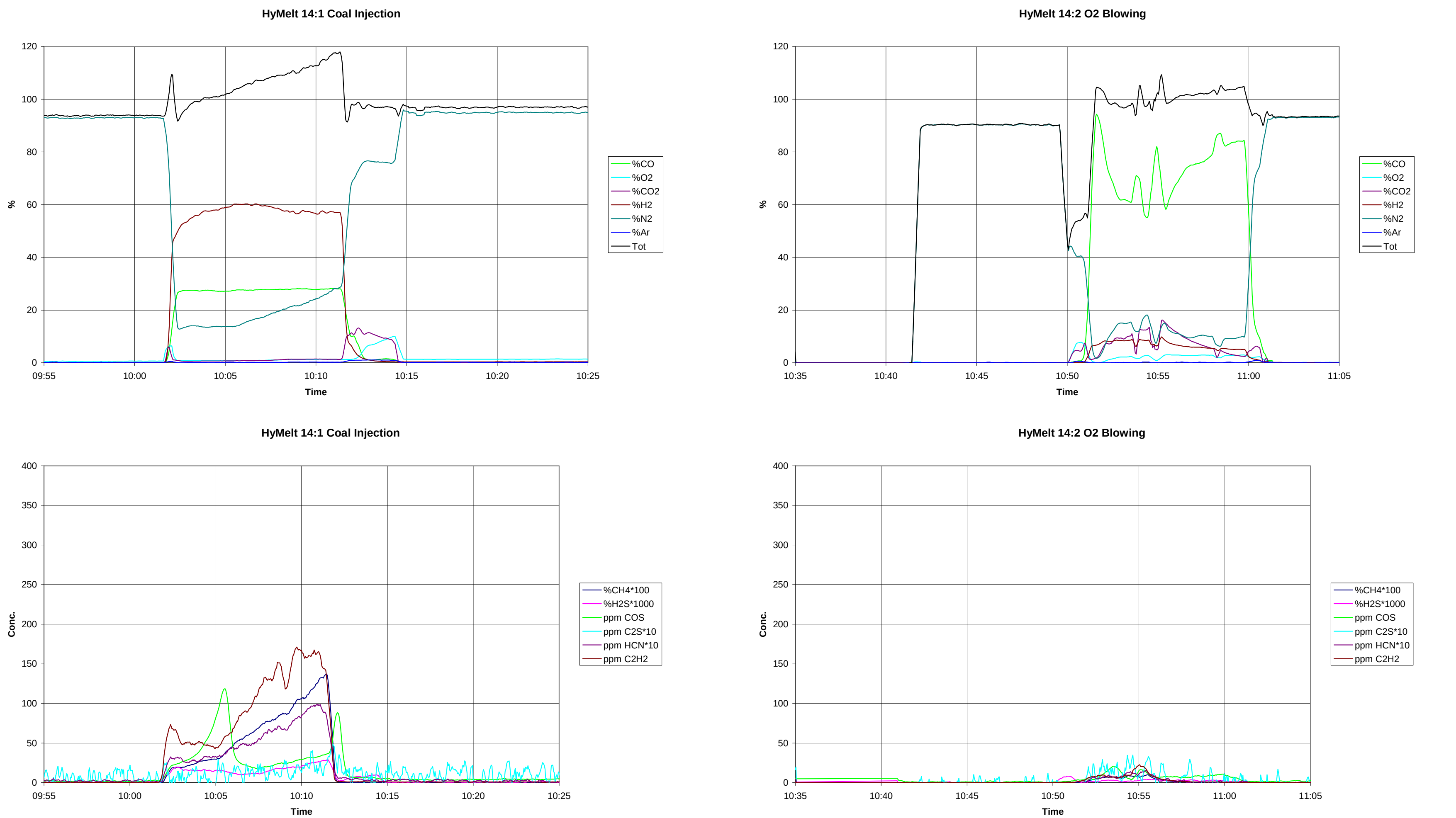


Figure 17 – Process gas HyMelt 14

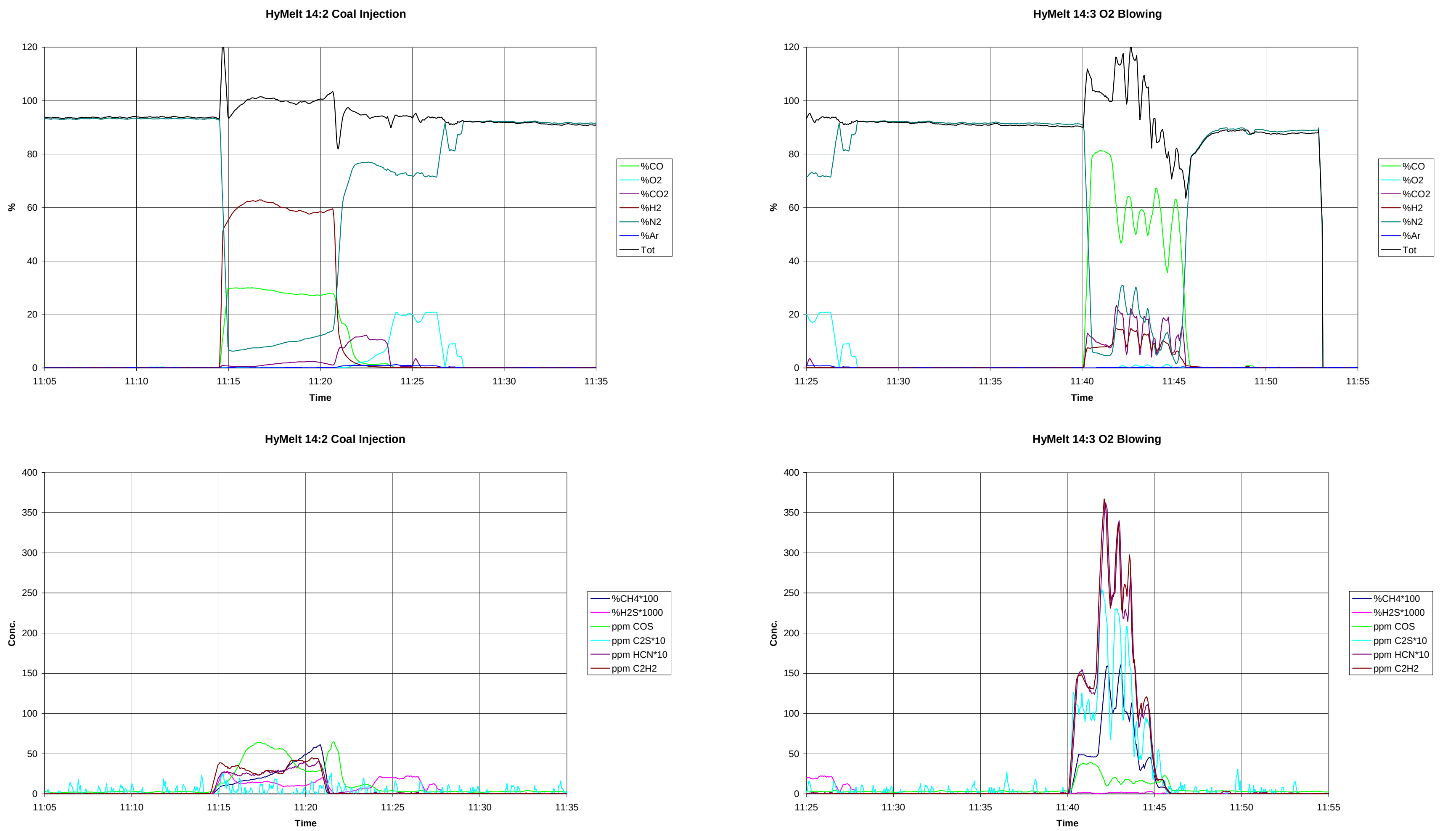


Figure 18 – Process gas HyMelt 14

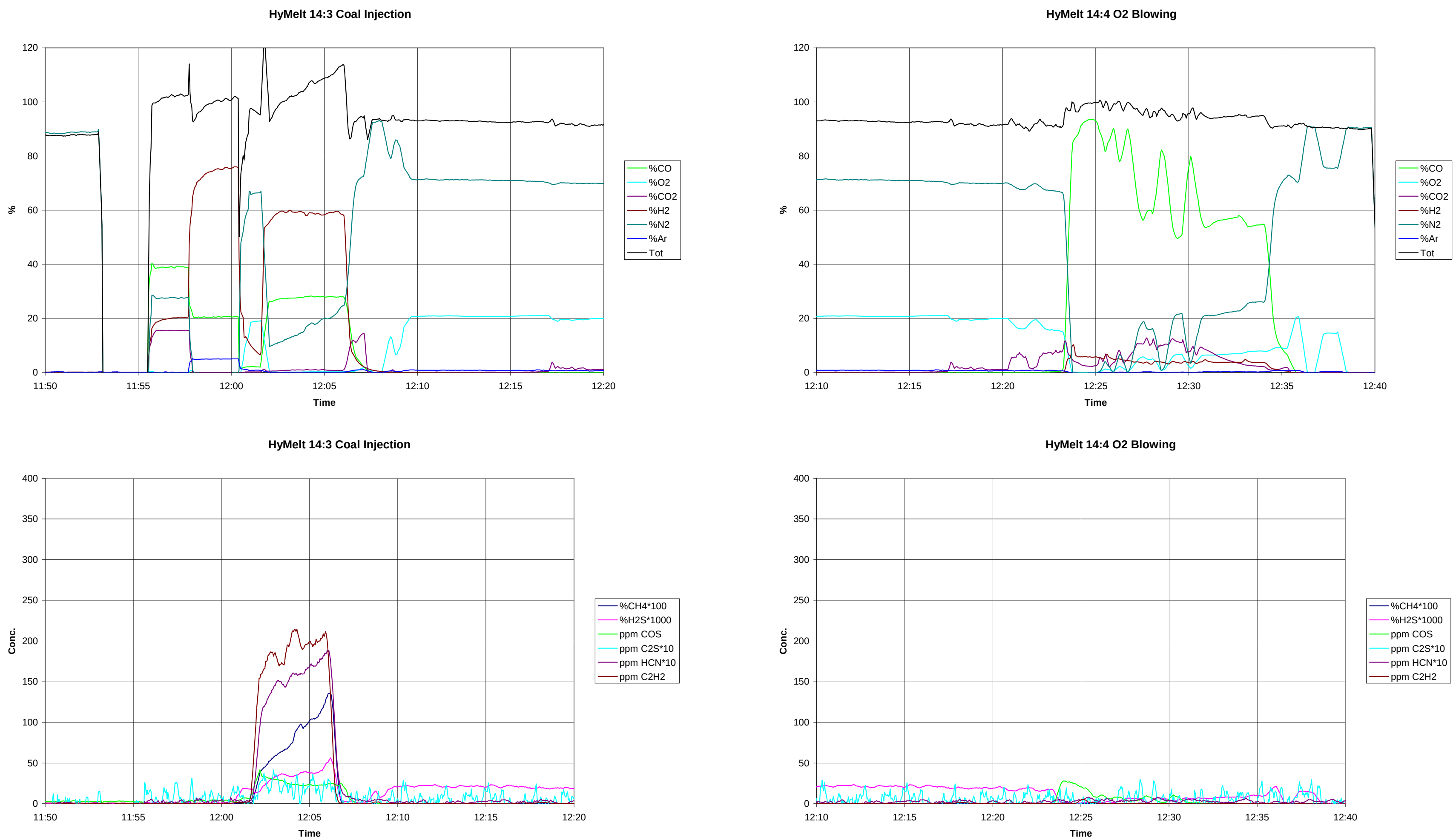


Figure 19 – Process gas HyMelt 14

5.5 Dust

The dedicated dust sampling probe for larger amounts of material for analysis was clogged and destroyed during period 13:1. The following samples were collected from the gas probe filter, as in previous campaigns.

Sample ID	HyMelt period	Process step	%C	Method	Note
1	11,1	Coke	82,6	Dust probe	
2	11,2	Coke	88,6	Dust probe	
3	12,1	Coke	91,5	Dust probe	
4	13,1	Coal	97,2	Dust probe	Clogging of probe during sampling
5	13,3	O2		Gas probe	Small amount of sample
6	13,3	Coal	97,1	Gas probe	
7	13,4	O2		Gas probe	Small amount of sample
8	13,4	Coal	99,3	Gas probe	
9	13,5	O2		Gas probe	Small amount of sample
10	13,5	Coke	78,1	Gas probe	Small amount of sample
11	13,6	O2	2,3	Gas probe	Small amount of sample
12	14,1	Coal	95,5	Gas probe	
13	14,2	O2		Gas probe	Small amount of sample
14	14,2	Coal	96,9	Gas probe	
15	14,3	O2		Gas probe	Small amount of sample
16	14,4	Coal	98,3	Gas probe	Small amount of sample
17	14,4	O2	2,5	Gas probe	Small amount of sample

Figure 20 – Dust samples

It is significant that the carbon content is higher in the dust than in the feed.

5.6 Carbon balances

The new set up for injection gives significantly better function at higher feeding rates for both coke and coal feeding. This is demonstrated below by calculation of the carbon transferred from powder to metal. The results are compared with the results obtained in previous campaigns.

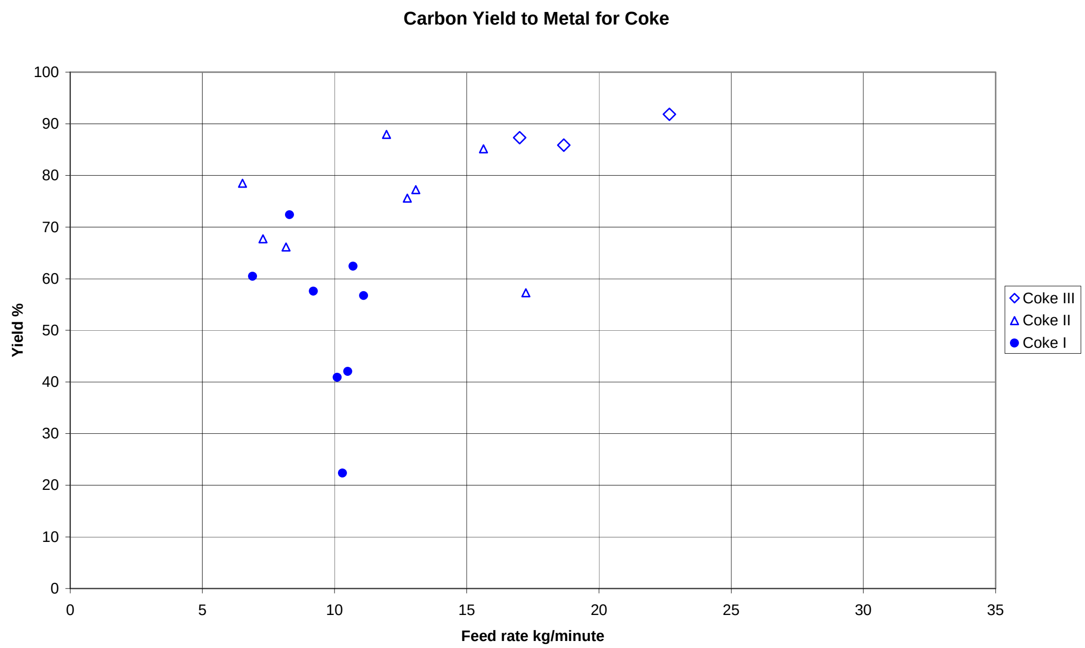


Figure 21 – Carbon yield to metal coke feed Campaign I to III

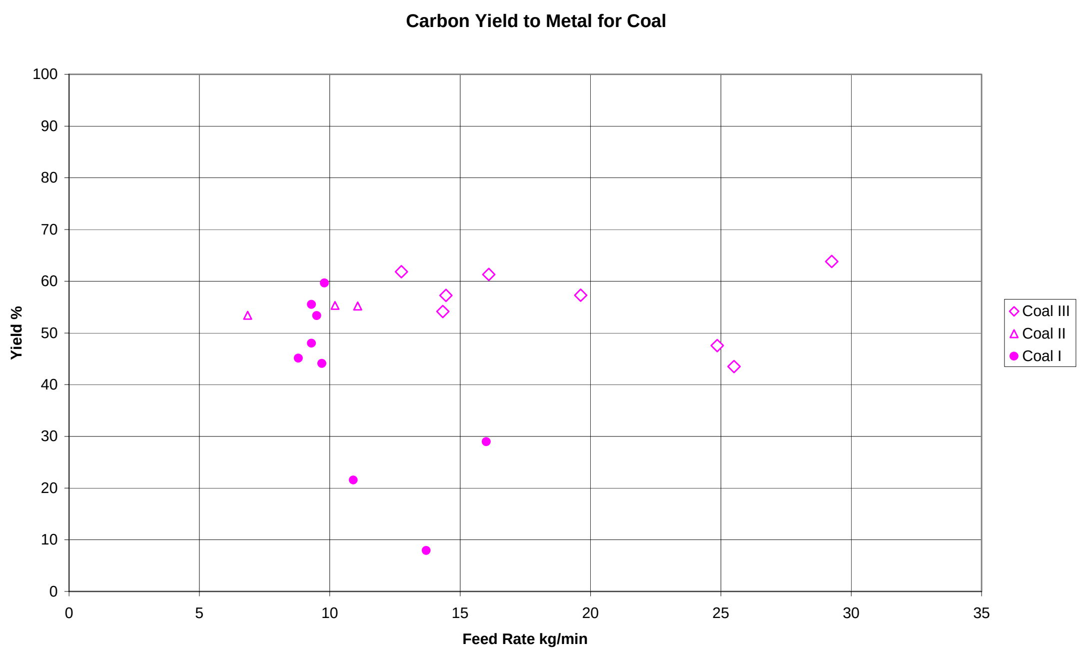


Figure 22 – Carbon yield to metal coal feed Campaign I to III

6 Discussion

6.1 Coal and coke injection

The expected gas composition and carbon yield can be estimated by a simple mass balance for coke and coal injection

To process

Coal	20 kg/min		
C	71,14 w%	14,23 kg/min	1,186 kmol/min
H	4,91 w%	0,98 kg/min	0,982 kmol/min
O	8,26 w%	1,65 kg/min	0,103 kmol/min
N	1,48 w%	0,30 kg/min	0,021 kmol/min
Air	0,5 m3n/min		
O2	21 v%	0,11 m3n/min	0,005 kmol/min
N2	79 v%	0,40 m3n/min	0,018 kmol/min
Nitrogen	0,2 m3n/min		
N2	100 v%	0,20 m3n/min	0,009 kmol/min

To process

C			1,186 kmol/min
H			0,982 kmol/min
O			0,113 kmol/min
N			0,074 kmol/min

Out of process

Proc. Gas	16,6 m3n/min		
H2	79,8 v%	13,29 m3n/min	0,593 kmol/min
CO	15,2 v%	2,52 m3n/min	0,113 kmol/min
N2	5,0 v%	0,83 m3n/min	0,037 kmol/min

To melt

C Yield	90,5 %	12,88 kg/min	1,073 kmol/min

Figure 23 – Estimation of ideal coal feed mass balance

To process

Coke	20 kg/min		
C	86,3 w%	17,26 kg/min	1,438 kmol/min
H	5 w%	1,00 kg/min	1,000 kmol/min
O	0 w%	0,00 kg/min	0,000 kmol/min
N	1 w%	0,20 kg/min	0,014 kmol/min
Air	0,5 m3n/min		
O2	21 v%	0,11 m3n/min	0,005 kmol/min
N2	79 v%	0,40 m3n/min	0,018 kmol/min
Nitrogen	0,2 m3n/min		
N2	100 v%	0,20 m3n/min	0,009 kmol/min

To process

C			1,438 kmol/min
H			1,000 kmol/min
O			0,009 kmol/min
N			0,067 kmol/min

Out of process

Proc. Gas	17,1 m3n/min		
H2	94,4 v%	16,12 m3n/min	0,719 kmol/min
CO	1,2 v%	0,21 m3n/min	0,009 kmol/min
N2	4,4 v%	0,76 m3n/min	0,034 kmol/min

To melt

C Yield	99,3 %	17,15 kg/min	1,429 kmol/min

Figure 24 – Estimation of ideal coke feed mass balance

In both cases, it is obvious from the process gas analysis that the air flow rate has to be increased considering not only pressurised air but also leakage air. The leakage air can be due to leakage directly into the converter or into the gas sampling system.

In the figures below the total amount of air is set to 5 m^{3}n/min and the results are somewhat closer to achieved results.

To process

Coal	20 kg/min		
C	71,14 w%	14,23 kg/min	1,186 kmol/min
H	4,91 w%	0,98 kg/min	0,982 kmol/min
O	8,26 w%	1,65 kg/min	0,103 kmol/min
N	1,48 w%	0,30 kg/min	0,021 kmol/min
Air	5 m3n/min		
O2	21 v%	1,05 m3n/min	0,047 kmol/min
N2	79 v%	3,95 m3n/min	0,176 kmol/min
Nitrogen	0,2 m3n/min		
N2	100 v%	0,20 m3n/min	0,009 kmol/min

To process

C			1,186 kmol/min
H			0,982 kmol/min
O			0,197 kmol/min
N			0,391 kmol/min

Out of process

Proc. Gas	22,1 m3n/min		
H2	60,2 v%	13,29 m3n/min	0,593 kmol/min
CO	20,0 v%	4,41 m3n/min	0,197 kmol/min
N2	19,9 v%	4,39 m3n/min	0,196 kmol/min

To dust

C	7,0 %	1,00 kg/min	

To melt

C Yield	61,9 %	8,81 kg/min	

Figure 25 – Estimation of coal feed mass balance compensated for leakage air

To process

Coke	20 kg/min		
C	86,3 w%	17,26 kg/min	1,438 kmol/min
H	5 w%	1,00 kg/min	1,000 kmol/min
O	0 w%	0,00 kg/min	0,000 kmol/min
N	1 w%	0,20 kg/min	0,014 kmol/min
Air	5 m3n/min		
O2	21 v%	1,05 m3n/min	0,047 kmol/min
N2	79 v%	3,95 m3n/min	0,176 kmol/min
Nitrogen	0,2 m3n/min		
N2	100 v%	0,20 m3n/min	0,009 kmol/min

To process

C			1,438 kmol/min
H			1,000 kmol/min
O			0,094 kmol/min
N			0,385 kmol/min

Out of process

Proc. Gas	22,5 m3n/min		
H2	71,5 v%	16,12 m3n/min	0,719 kmol/min
CO	9,3 v%	2,10 m3n/min	0,094 kmol/min
N2	19,1 v%	4,31 m3n/min	0,192 kmol/min

To dust

C	0,0 %	0,00 kg/min	

To melt

C Yield	87,8 %	15,16 kg/min	

Figure 26 – Estimation of coke feed mass balance compensated for leakage air

6.2 Oxygen blowing

Similar calculations can be made for O_2 blowing periods and also in this case better agreement can be achieved if leakage air is considered.

To process

Propane	0,4 m3n/min		0,018 kmol/min
C	3 kmol/kmol		0,054 kmol/min
H	8 kmol/kmol		0,143 kmol/min
Air	0 m3n/min		
O2	21 v%	0,00 m3n/min	0,000 kmol/min
N2	79 v%	0,00 m3n/min	0,000 kmol/min
Oxygen	6,5 m3n/min		
O2	100 %	6,50 m3n/min	0,290 kmol/min

To process

C			0,054 kmol/min
H			0,143 kmol/min
O			0,580 kmol/min
N			0,000 kmol/min

Out of process

Proc. Gas	13,6 m3n/min		
H2	4,4 v%	0,60 m3n/min	0,027 kmol/min
CO2	0,0 v%	0,00 m3n/min	0,000 kmol/min
CO	95,6 v%	13,00 m3n/min	0,580 kmol/min
N2	0,0 v%	0,00 m3n/min	0,000 kmol/min

Figure 27 – Estimation of ideal gas composition at oxygen blowing

To process

Propane	0,4 m3n/min		0,018 kmol/min
C	3 kmol/kmol		0,054 kmol/min
H	8 kmol/kmol		0,143 kmol/min
Air	5 m3n/min		
O2	21 v%	1,05 m3n/min	0,047 kmol/min
N2	79 v%	3,95 m3n/min	0,176 kmol/min
Oxygen	6,5 m3n/min		
O2	100 %	6,50 m3n/min	0,290 kmol/min

To process

C			0,054 kmol/min
H			0,143 kmol/min
O			0,674 kmol/min
N			0,176 kmol/min

Out of process

Proc. Gas	16,6 m3n/min		
H2	3,6 v%	0,60 m3n/min	0,027 kmol/min
CO2	6,3 v%	1,05 m3n/min	0,047 kmol/min
CO	78,2 v%	13,00 m3n/min	0,580 kmol/min
N2	11,9 v%	1,98 m3n/min	0,088 kmol/min

Figure 28 – Estimation of gas composition at oxygen blowing compensated for leakage air

6.3 Slag % Fe_{tot} in relation to metal % C

The bottom blown converter has as expected a stable and lower content of Fe_{tot} in the slag. The divergent values are more likely as a result of poor samples than a realistic description of the slag. If the carbon content in the metal can be kept higher than 1 % the % Fe_{tot} can be expected to be lower than 5 %.

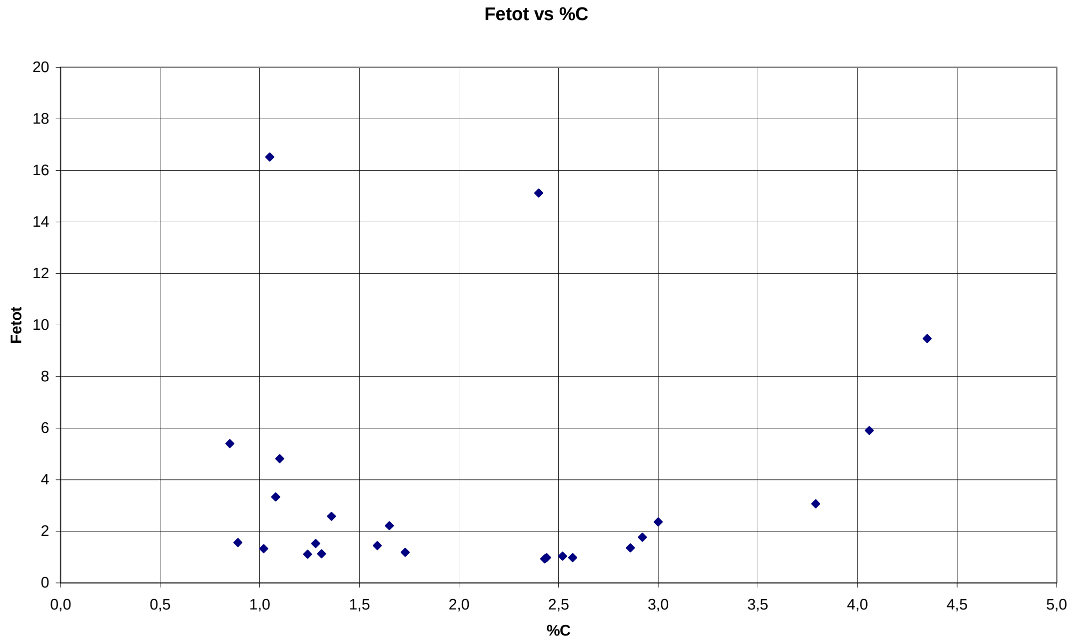


Figure 29 – Fe_{tot} as function of % C

6.4 Process control

Bottom material injection and bottom oxygen blowing simplify the operation and improves process performances. Some of the most obvious observations are:

- No lance sculling and no oxygen lance maintenance
- More stabile operation with less slag foaming and slopping
- Reduced oxygen level in the slag at the end of oxygen blowing improves the gas quality in the beginning of coal/coke injection.
- Improved material conversion gives higher possible gas production

The operation can probably be further improved by a more sophisticated process strategy. The result shows less hydrocarbons in the beginning of the injection period indicating a dependency between transformation capacity and metal temperature or/and carbon level. It is likely that the feeding rate can be optimised for each minute during injection, starting at a higher input successively reduced. Possible input parameter can be CH_4 of the process gas.

Compared to experiences from simultaneous coal/oxygen injection the possible feed rate in HyMelt is surprisingly high. The amount of gas in the process can be of greater importance than what earlier have been understood. It is of great interest to investigate how much a lower carrier gas to material ratio effects the transformation capacity.