Reducing Ultra-Clean Transportation Fuel Costs with HyMelt[®] Hydrogen

Quarterly Report

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ABSTRACT

This report describes activities for the fourth quarter of work performed under this agreement. A second round of atmospheric testing was conducted as scheduled on September 2 through September 4, 2003. The test results demonstrated a much-improved rate of carbon dissolution with gas yields close to expectations. Additional atmospheric testing to demonstrate a commercially feasible feed and oxygen injection method is scheduled for the week of December 8, 2003.

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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 fourth 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 gasifier 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 task is being executed.

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 are currently designing and fabricating a commercially feasible tuyere for testing in December.

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. Execution of this task continues.

2.0 EXECUTIVE SUMMARY OF WORK DONE DURING THIS REPORTING PERIOD

Experimental testing of coal, petroleum coke and a heavy oil began on June 5 and continued through June 13. We believe that these tests represent the first instance of injection of these feeds into molten iron without the concurrent injection of substantial quantities of oxygen and other materials. The tests in June resulted in unacceptably low rates of carbon dissolution in the molten iron. Preliminary results from tests conducted in September indicate that much better carbon dissolution rates result from submerged injection. We have scheduled additional atmospheric testing using tuyeres for both oxygen injection and coal or coke injection to begin December 8, 2003. The December testing will operate in a commercially practical mode.

An economic evaluation by Kvaerner indicated that water gas shifting of carbon monoxide is prohibitively expensive at \$2.86 per kscf of incremental hydrogen produced over the fuel value of the feed carbon monoxide. HyMelt, unlike most other coal gasification processes, does not require water gas shifting to produce high purity hydrogen. Detailed flow sheets, equipment sizing, equipment cost, and preliminary operating cost estimates are presented in this report. Kvaerner obtained cost estimates from UOP for Polybed PSA hydrogen purification.

EnviRes and Siemens Westinghouse Power Corporation decided to evaluate catalytic burners for gas turbines using the carbon monoxide rich fuel gas from the HyMelt process. If performance similar to that already demonstrated with natural gas can be achieved with HyMelt fuel gas, we believe that post combustion abatement controls will not be required to meet currently envisioned new source performance standards for NO_x and CO emissions.

Brad Quinlan, auditor for the Defense Contract Audit Agency [DCCA] under contract by the U.S. Department of Energy, conducted a follow-up audit of the financial reporting and accounting system of EnviRes on July 9 & 10. An exit conference with Daniel French, EnviRes Controller, was conducted on July 10. On July 25 we received an electronic copy of the audit report concluding, "EnviRes' accounting system is adequate for accumulating costs under Government contracts".

3.0 Experimental

MEFOS Activities

As described in the previous quarterly report, testing using coal, coke and liquid petroleum injection were conducted from June 5 through June 13. Appendix I contains a detailed description of this work reported by MEFOS. MEFOS generated a large amount of data in this work. The data presented represent a summary of the data generated and still the data presentation takes tens of pages. The raw data from which MEFOS generated this summary can only be managed electronically.

The MEFOS report in Appendix I points out that some problems in sampling and analyzing streams occurred during the test program. Some of these problems included air infiltration into the process gas sample lines between the sample probe and the analytical equipment, calibration drift for the mass spectrometer, feed misidentification and other problems that were not clearly identified. Most of these problems can be corrected by standard data reconciliation techniques. Since the volume of data is great, data reconciliation represents a long and arduous task that would consume substantial resources and money. As we will describe later, the rate of carbon dissolution into the metal for the June test program was unacceptably low. Initial data analysis of work performed in early September indicate that we achieved acceptable carbon dissolution rates for at least some of the injection periods and that the quality of the gas analysis was better than that generated in June. We will, therefore, focus attention and resources on test periods that represent commercially attractive operating conditions. Our analysis of the June data will review the useful data generated with greater effort reserved for later work.

The MEFOS report in Appendix I describes the equipment, the materials used, the testing procedure and the heat notes in sufficient detail so that no further comment regarding them will be made. Additional comments on the results will be made in section 4.0 Discussion.

Preliminary analysis of the data generated June 5 to 13 indicated that carbon dissolution rates into the metal were unsatisfactory. MEFOS and EnviRes concluded that the problem was caused by problems associated with top entry lances. We further concluded that although significant improvements could be made to top entry lances and the way they are utilized, most of these improvements were not achievable within the financial and time constraints of this project. MEFOS suggested that we test tuyeres for coal and petroleum coke injection. The quickest, most cost effective, most likely to succeed approach was to use a side entry lance 10 cm from the bottom of the refractory lining. The initial tuyere to be tested was a single lanyard (one tube) design. Argon would transport the solid feed from the feed hopper to the tuyere. Figure 1 is a view of the universal converter with the lance installed. The single rubber hose

conveys the pneumatically transported particulate to the tuyere near the center of the figure. The stainless steel tubing connects a pressure gauge (to the top) allowing the inlet pressure to the tuyere to be monitored. The universal converter is tilted to the charging or tapping position in Figure 1. The hood that collects product gases and air for combustion appears at the very top of the figure. A connection for bottom stirring (not connected) appears at the lower left.

On Tuesday, September 2, 2003 we made several injection attempts with coal and petroleum coke. All attempts resulted in an occluded tuyere (the pressure drop across the tuyere was high and there was almost no flow). We observed that a solid accretion had formed on the inside wall of the universal converter at or near the location of the tuyere outlet. Figure 2 shows a dark formation near the tuyere outlet that appears to be a metal accretion.

We decided to use a slit tuyere in place of the single lanyard tuyere. Figure 3 shows an end view of the slit tuyere. A slit tuyere consists of two concentric pipes with the OD of the inner pipe only slightly smaller than the ID of the outer pipe. Such a design is much more resistant to metal intrusion into the annular space. We decided to inject air in the annular space and coal in the center pipe. The center pipe ID was 8.0 mm. We felt that the slightly exothermic effect of the small amount of injection air would retard or prevent accretion formation. MEFOS worked into the night to install the new tuyere. Figure 4 shows the installation of the slit tuyere in the universal converter. This view is similar to Figure 1. Note that there are two hoses. The original rubber hose still transports the solid feed. The second hose transports the air for the slit tuyere. We resumed testing on the morning of September 3. Little difficulty was encountered with coal or coke injections after installing the slit tuyere.

Figure 5 shows the temperature probe just after its removal from the universal converter. The outer wall of the temperature probe is approximately 8 mm of rolled cardboard. In the absence of oxygen, which is the case in the universal converter, the cardboard lasts for more than 30 seconds even when immersed in molten iron. This is longer than the insertion time of the probe. The temperature probe measures the temperature one time before it is discarded. MEFOS measured the metal temperature approximately once every 2 minutes during feed injection or oxygen injection and at least once, with a different probe, every time the universal converter was tilted.

Figure 6 shows the metal sample probe just after its removal from the universal converter. The sample probe also has a cardboard outer wall. The tip of the sample probe has a hollow ceramic cavity that allows metal to enter and freeze. The Tip is covered with a metal shroud that prevents slag from entering the cavity as the probe passes through the slag layer. The shroud melts in the molten iron. The probe can sample metal from 10 to 20 cm below the metal surface. MEFOS took metal samples using this method approximately once every 10 minutes. MEFOS also took metal samples with a different probe when the converter was tilted. The hopper and chute in the right center of both Figures 5 and 6 allows lime, scrap and fluxing agents to be added to the universal converter during operation.

Figure 1. Initial Tuyere Installation in the Universal Converter

Figure 2 Metal Accretion or Mushroom on Refractory at or near Tuyere outlet

Figure 3 Discharge End View of Slit Tuyere Before installation

Figure 4. Slit Tuyere Installed on the Universal Converter

Figure 5. Temperature Probe Removal During Decarburization for Universal Converter

Figure 6 Metal Sample Probe Removal During Decarburization

Kvaerner Activities

Kvaerner initiated simulation activities using Aspen Plus. The HyMelt reactor section process flow sheet appears in Appendix II page 2, the flow sheet for the amine system appears in Appendix II on AII page 15 stream flows for this flow sheet appear on AII page 14 and the flow sheet for the water gas shift appears in Appendix II on AII page 16 stream flows for this flow sheet appear on AII page 17 to 19. Kvaerner obtained cost estimates from Dow for the amine system and UOP for the PSA hydrogen purification system. This information is also given in Appendix II. Kvaerner estimated the differential cost for shifting nearly all of the carbon monoxide produced in a 450 t/d demonstration plant.

Siemens Westinghouse Power Corporation Activities

EnviRes, Siemens Westinghouse Power Corporation and some consultants of Siemens Westinghouse discussed the merits of diffusion and catalytic burners for gas turbines. We decided to evaluate a catalytic burner because it offers the potential of meeting future NO_x emission requirements without a selective catalytic reduction (SCR). Appendix III contains most of the information developed for this issue.

4.0 Results and Discussion

MEFOS Activities

For all injections performed in June, the methane content of the product gas was in the range of 5 to 10%. In some tests coke could be seen floating on the slag when the universal converter was tilted after injection. Dust samples contained as much as 90% carbon. Pages 49 to 51 of the MEFOS report show the carbon yield to metal for coal, petroleum coke and aromatic extract oil. Carbon yield to metal is calculated as the quotient of the change in the total mass of carbon dissolved in the metal divided by the total mass of carbon contained in the injectant for that period. The change in the total mass of carbon in the metal is calculated as the product of the mass of metal in the bath and the change in the weight fraction of carbon in the metal from the beginning to the end of the injection period. Since the yield is expressed as a percentage, the above quotient should be multiplied by 100%.

The maximum value for carbon yield to metal must always be less than 100% for several reasons. First, any oxygen contained in the feed will convert in near quantitative fashion to carbon monoxide. With Illinois #6 coal having 8.26% oxygen, the amount of carbon in the feed not reporting to the metal by this mechanism should be 7 to 10% of the feed carbon. If the coal moisture content increased during storage, this number will be higher. Similarly any methane formed will reduce the amount of carbon reporting to the metal from the feed although the thermodynamic amount of methane should always be less than 1% at these conditions. Second, any FeO present in either the metal or slag from decarburization will react with feed carbon to form carbon monoxide. In this case the value of carbon monoxide produced will have a maximum value near the beginning of the injection period and decrease as oxygen is consumed. Third, any slag reactions such as $\text{CaO} + \text{C} + \text{S} \rightarrow \text{CaS} + \text{CO}$ will consume carbon that would otherwise report to the metal. Slag reactions should consume very little carbon since the ratio of slag to metal is always small.

Top entry oxygen blowing typically created substantially more FeO in the slag than does tuyere injection of oxygen. Values of FeO in the slag are given in the MEFOS report in Appendix I. FeO in the slag after oxygen blowing typically ranged from 5 to 15%.

The carbon yield to metal for coal ranged from 59.6% to 13.7%, for petroleum coke the values ranged from 72.4 to 22.4% and for oil the values ranged from 33.4% to 11.4%. The oil injection differed significantly from the method of injection for coal and petroleum coke. The carbon yield to metal for petroleum coke and coal become nearly equal when the effect of oxygen contained in the coal is considered. For both petroleum coke and coal the carbon yield to metal decreased with increasing feed rate. The decrease in transport gas flow rate with increasing solid flow and thus the velocity of the gas particulate stream impinging on the slag/metal surface may explain at least in part the decrease of carbon to metal with feed rate.

MEFOS discusses many of the trends in product gas compositions. Several problems with sampling and analysis combined with injection problems, described earlier make detailed analysis of the gas compositions questionable without significant effort to correct for these problems. It is unclear whether the high COS values result from the high FeO levels in the slag. It is unclear whether oxygen in air leakage into the sample lines to various analyzers reacted with hydrogen and/or CO.

The results of mercury sampling and analysis show a wide range of mercury levels if the data are correct. We only sampled and analyzed the product gas for mercury three times during June testing.

The hydrogen-purging test for sulfur removal described on page 49 of the MEFOS report shows that much more sulfur disappeared from the metal and slag than could be accounted for by the amount of H₂S appearing in the product gas. Similar unexplained sulfur disappearance from the metal was always experienced in the early bench scale tests.

The vanadium tests show that vanadium has a partition coefficient that is highly dependent on the oxygen potential. These tests (page 35 and 43 of the MEFOS report) also show that vanadium in the slag can be reduced causing the vanadium to report back to the metal after it has been oxidized from the metal into the slag for vanadium levels of 0.6 to 0.8% in the metal.

Kvaerner Activities

Kvaerner completed an economic comparison of using the carbon monoxide rich stream for fuel vs. shifting the carbon monoxide rich stream to hydrogen. Results of this work are given in Appendix II. UOP estimated a cost of \$1.7 MM for a Polybed PSA system capable of producing 15.31 MMSCFD of product hydrogen. UOP estimated a cost of \$2.5 MM for a unit capable of producing 28.39 MMSCFD. Kvaerner obtained or determined detailed flow sheets, material balances, energy balances, equipment sizing and operating costs. Kvaerner obtained or determined similar information from Dow for an amine system to remove H₂S from the product hydrogen. As presented in Appendix II Kvaerner determined that the incremental cost over fuel value for upgrading the carbon monoxide rich HyMelt stream was \$2.86 per kSCF of hydrogen produced.

Siemens Westinghouse Power Corporation Activities

EnviRes and Siemens Westinghouse decided to model and test a catalytic burner instead of a diffusion burner for proposed gas turbines using the carbon monoxide rich stream as fuel. Most if not all combustion systems for IGCC turbines use diffusion burners to combust carbon monoxide rich fuel. These burners simply provide residence time and mixing for combustion to take place. Diffusion burners tend to produce NO_x levels of 25 ppmv when the flue gas is adjusted to a standard value for excess oxygen. Diffusion burners usually produce CO emissions in excess of 5 ppmv. It is likely that new source performance standards will require both NO_x and CO emissions to be below 3 ppmv for power plants by the time a commercial HyMelt plant is built. If both of these hypotheses are correct, combustion turbines (including those firing natural gas) will be required to have post combustion abatement controls for both NO_x and CO. While diffusion burners have not been specifically tested with a fuel that is representative of the carbon monoxide rich stream from HyMelt, we believe that the results would be very similar.

Siemens Westinghouse had a catalytic burner program under development before this project began. They have tested a prototype of their catalytic burner with natural gas at commercial conditions. In these test they found that NO_x and CO emissions could be kept under 2 ppmv under optimal operating conditions. If similar results can be obtained for the HyMelt carbon monoxide rich stream, gas turbines using catalytic burners may not require post combustion abatement controls for a HyMelt gasifier. This appears to us to be a strong incentive to pursue catalytic burners. If catalytic burners are not feasible for HyMelt carbon monoxide rich gas we can switch to diffusion burners with very little uncertainty.

5.0 Conclusions

All testing conducted from June 5 to 13 gave unacceptable carbon dissolution rates. At low feed rates both petroleum coke and coal resulted in approximately 70% of theoretical. At higher feed rates the rate of carbon dissolution dropped rapidly to near 20% of theoretical. Carbon dissolution rates for oil were even worse. Carbon dissolution rates could be improved with better injection lance design, but we feel that the probability of obtaining 98% of theoretical is unlikely with top entry lances.

Preliminary results based on visual observation and preliminary operating data indicate that submerged injection of coal and petroleum coke results in a much better carbon dissolution rate. The carbon dissolution rate also appears to be less dependent on coal or coke feed rate.

Hydrogen purging to remove sulfur does not appear to be attractive, however, during the testing much more sulfur disappeared than could be accounted for by H_2S appearing in the product gas. Further investigation of this phenomenon appears warranted.

Based on the economic analysis by Kvaerner, we believe that shifting carbon monoxide to hydrogen is not economically attractive at an incremental cost of \$2.86/kSCF above fuel value. We further conclude that gasification processes that must use water gas shift to produce hydrogen are at a disadvantage to processes that directly produce hydrogen.

Catalytic burners for gas turbines using HyMelt carbon monoxide rich fuel gas may not require post combustion abatement controls. If this possibility comes to fruition, it will produce a significant economic benefit for power generation.

6.0 References

No references were cited in this document.

7.0 PLAN FOR THE NEXT QUARTER

Additional atmospheric testing is scheduled for the second week of December 2003. The testing will last 3 days. Illinois #6 coal and petroleum coke will be the feeds to be tested using bottom tuyeres. The tuyeres used in this testing will simulate commercial operation. We have delayed final design and procurement of the vessel for super-atmospheric testing until completion of the December testing.

Kvaerner will continue evaluating amine systems and complete the carbon monoxide shift study. Kvaerner will begin atmospheric test data evaluation for commercial design studies.

EnviRes and Siemens Westinghouse have finalized all input parameters for a combustion testing and Siemens Westinghouse will begin combustion simulations in the upcoming quarter.

APPENDIX I
MEFOS DATA

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1 Introduction

The first test campaign in the development of the EnviRes HyMelt process has been performed at MEFOS. The tests have been made in the 6 ton universal converter equipped with facilities for injection of hydro-carbides and oxygen.

The technical objective was to make preliminary evaluation the process and functional test of the equipment and measuring systems.

The tests were made for:

- Solid feed injection for Illinois #6 (coal) and Pet-coke (coke)
- Liquid feed injection for 325 Aromatic extract (oil)
- Oxygen blowing
- Gas measurement
- Dust sampling
- Process control
- Process strategies

The campaign was carried out for six days in the period from June 5 to 13, 2003.

This document is a completion of collected data and a preliminary evaluation of the operational results and performance of process equipment and measuring systems.

2 Equipment

2.1 MEFOS standard equipment

2.1.1 Electric arc furnace

The electric arc furnace is a fully ceramic lined AC furnace suitable for melting 4 to 10 ton of steel or hot metal. In the project the furnace was used for production of high carbon iron melt in charges of 5 - 6 ton.

Technical data:

- Heat size 4 – 10 ton
- Trafo 4,9 MVA
- Shell diameter 2800 mm
- Diameter lined 2100 mm

2.1.2 Universal converter

The experiments were carried out in MEFOS universal converter. The converter has a nominal max capacity of 6 ton and can be altered into a variety of converter processes for metal refining. In the experiment the converter was used as a 5,5 ton, top blown vessel with bottom purging of inert gas.

Technical data:

Shell diameter 2000 mm

Diameter lined 1410 mm

Height lined 2893 mm

Lining

Far impregnated magnetite Radex ST

Two hoppers above the converter were erected for slag former and cooling scrap addition.

Totally four top lances was mounted:

- Oxygen lance for decarburisation
- Lance for solid injection alternatively lance for liquid injection
- Sub lance for metal sampling and temperature measurements
- Gas suction lance for sampling of process gas from converter gas atmosphere

In the converter bottom, on the half radius from the wall, a bottom tuyere was mounted for inert gas or hydrogen purging.

Figure – 1 MEFOS universal converter Hy-Melt, 5 ton, set up

The MEFOS venturie scrubber was used for gas treatment. Before gas cleaning the process gas has to be completely combusted by sufficient amount of air above the converter mouth.

Technical data, venturie scrubber:

Gas flow rate 21 000 m³n/h

Gas temperature inlet 650 °C

Pressure drop across venturie 500 – 1900 mm wq

2.1.3 Material injection system

For injection of coal and pet-coke a 3 m³ powder dispenser system was selected. The system has advantages in flexibility regarding blowing conditions and allows handling and charging of fine grained material from “big bags” by use of suction.

Technical data:

Dispenser volume 3 m³

Spec. transport gas ~0, 05 m³n/kg

Outlet diameter variable

Max pressure 10 bar

2.1.4 Measurements, sampling and automation

For process control a set of selected measurements were sampled and evaluated by an in-house system for converter automation that runs on a LabView platform. The system includes, data logging, standard closed loop regulation and modules for real time evaluation of fundamental process parameters.

Measurements:

Gas supply: range

Oxygen to lance, line C 0 – 20 m³n/min

Nitrogen bottom purging, line D 0 – 1 m³n/min

Nitrogen material transport 0 – 1 m³n/min (Operator notes)

Combusted gas

Flow rate, venturi 0 – 20000 m³n/h

Composition:

CO 0 – 5%

CO₂ 0 – 20%

O₂ 0 – 23%

SO₂ 0 – 0, 5%

Materials

Dispenser weight 0 – 3000kg

Bin weights

Cooling scrap	0 – 1000 kg
Lump lime	0 – 1000 kg
Oil feed	0 – 20 kg/min

Oxygen lance pos	mm above metal surface
Injection lance pos	mm above metal surface

Non-continuous measurements:

Metal temperature	0 – 1800 °C
Metal composition	
Process gas composition conventional	
CO	0 – 100%
CO ₂	0 – 20%
H ₂	0 – 20%
Process gas composition mass spectrometer MS 127	
H ₂	0 – 100%
Process gas composition mass spectrometer AIR SENSE 2000	
H ₂	0 – 100%
H ₂ S	0 – 2%
COS	0 – 100 ppm
CH ₄	0 – 4%

Special measurements and sampling not recorded on the process computer:

Metal weight, charging and tapping
Analysis of sampled metal and slag
Poured slag weights
Dust sampling in converter for composition analysis
Dust sampling in combusted gas for composition analysis and load
Manual additions of Al-bars, FeSi, FeV and FeS
Hydrogen gas for bottom purging

In blow metal sampling was made by use of a sub-lance system. Sampling during process stop in tilted converter was manually made. In both cases the samples were either analysed for carbon and sulphur by use of a Leco combustion analyser or sent to SSAB for spark emission spectrometry giving almost a complete analysis. All samples were stored for reference and further evaluations.

Slag sampling was manually made when the converter was tilted. All samples were stored and selected samples were analysed by X-ray at SSAB.

Dust sampling was made by two methods:

1. Process dust from the filter of the converter gas.
2. Iso-kinetic sampling of combusted dust from the duct.

Process parameters calculated on-line for supervising were:

1. Material injection flow rate
2. Gas flow rate, supply and combusted gas
3. Carbon balance for carburisation yield
4. Oxygen balance for oxygen yield during decarburisation
5. Carbon content in liquid metal

2.2 HyMelt equipment

2.2.1 Injection lance for coal and pet-coke

A water-cooled lance for solid material injection was designed and constructed.

Technical data:

Total length 4800 mm

Diameter 76 mm

Outlet nozzle diameter 7,0 mm, other dimensions were also tested

For transport of material from dispenser to the lance a flexible rubber hose was selected. The hose quality has reasonable abrasive wear resistance and can, with proper heat protections, be used in metallurgical environment.

2.2.2 Injection lance for oil feed

A water-cooled lance for oil injection was designed and constructed.

Technical data:

Total length 4800 mm

Diameter 76 mm

Outlet nozzle diameter 1,9 mm

Figure 2 – Water-cooled injection lances for solids and oil

2.2.3 Injection system for aromatic extract

A special designed oil injection system was set up for low viscosity oil. The demand for short transport distance of the oil called for special safety arrangements and it was found that the storage tank with heating and the pump were to be mounted in a steel container. The set-up gives sufficient safety for spitting and slag splashing that accidentally generates from oxygen converters.

Technical data:

Storage volume 3 m³

Max pressure 22 bar

Nominal oil feed rate 10 kg/minute

2.2.4 Lance for oxygen blowing

The oxygen lance was designed as a water cooled single Laval nozzle for BOF converters.

Technical data:

Total length 4800 mm

Diameter 76 mm

Nominal flow rate 10 m³n/min

Outlet nozzle diameter 15, 5 mm

Mach No 2

Figure 3 – Oxygen lance

2.2.5 Bottom purging tuyere

Top blown converters suffer from low metal stirring resulting in low mass transport rates which thereby sets a limit for material throughput. A simple and efficient solution is to install a gas purging element in the bottom of the converter. For the experiment a double eccentric pipe tuyere was selected for injection of nitrogen and hydrogen.

Technical data:

Length 700 mm
Outlet slit, diameters 17,40 – 17,95 mm
Nominal gas flow rate 0,5 m³n/minute

Figure 4 – Bottom tuyere

2.2.6 Gas and dust sampling lance for converter atmosphere

Process gas and dust was collected by a suction lance that could be lowered into the converter in parallel with the injection lance. The lance tip was made as an exchangeable ceramic probe of castable high alumina.

Technical data:

Length	3825
Diameter	76 mm

Figure 5 – Lance for gas sampling in converter

3 Material

3.1 Injectants

Materials used for the tests supplied by EnviRes.

3.1.1 Illinois #6

C	71, 14%
H	4, 91%
N	1, 48%
Cl	0, 13%
S	3, 48%
O	8, 26%

Ash	10, 81%
SiO ₂	50, 65%
Al ₂ O ₃	20, 15%
CaO	4, 01%
Fe ₂ O ₃	16, 25%

3.1.2 Pet-Coke

C	86, 3%
H	5, 0%
N	1, 0%
S	6, 5%

3.1.3 325 Aromatic extract

C	90, 31%
H	6, 99%
N	0, 24%
S	4, 09%

3.2 Additives

Locally supplied material

3.2.1 Lime mix

The slag former used was a pre mix of burned lime and burned dolomite in 9 to 1 ratio.

Lime

Fraction	3 – 14 mm
CaO	92, 5%
SiO ₂	1, 6%
MgO	1, 4%
LOI	2%
CO ₂	1, 5%

Dolomite

Fraction	10 – 40 mm
CaO	58%
SiO ₂	0, 25%
MgO	40%
CO ₂	0, 25%

3.2.2 Aluminium bars

Aluminium bars of ~5 kg were used as fuel additives for compensation of the heat balance. The addition was made before start of oxygen blowing.

Al	96, 57%
Si	0, 62%
Mg	1, 41%
Fe	0, 65%

3.2.3 Ferro silicon

Ferro silicon was used as fuel additives for compensation of the heat balance. The addition was made before start of oxygen blowing.

Si	92%
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3.2.4 Ferro sulphur

Ferro sulphur was used in the last heat S1787 in order to drastically increase operational sulphur level in slag and metal. The test included purging of hydrogen through bottom the tuyere.

S	29, 18%
P	0, 01%
C	0,047%

3.2.5 Ferro vanadium

In order to indicate the material balance for vanadium the concentration of vanadium was increased in the last heat S1787.

V	81, 88%
C	0,016%
S	0,023%
Si	1, 23%
Al	0, 46%
P	0,016%

4 Test procedure

4.1 Melting

Charging of pig iron was made the day before the test. The melting procedure followed standard routines for production of synthetic hot metal, ~4 % C and ~0, 2 % Si. Before tapping to a hot metal transfer ladle, the temperature was adjusted to ~1600 °C.

4.2 Decarburisation of hot metal

The converter operation started with oxygen blowing, 10 m³n/min, to ~1650 °C. During blowing, about 20 minutes, all silicon and some carbon from the metal were oxidised. To maintain a slag with reasonable fluid ability and melting temperature, the formed SiO₂ was neutralised by the double amount of lime mix. The lime mix consisted of 90% burned lime and 10% burned dolomite.

The oxygen lance and lime feed program was simplified to:

<i>Time</i>	<i>Operation</i>	<i>Lance position above metal surface</i>
0 min	Ignition	400 mm
1 min	Lime feed	800 mm
3 min		600 mm

During blowing the metal temperatures were measured and samplings were made approximately every second minute. The samples taken were analysed for C and S by use of a Leco analyser.

4.3 Carburisation H₂ production

The oxygen blowing was followed by carburisation and H₂ production. The operation was made by top lance injection, ~10 kg/min, at a distance of about 400 mm above the metal surface. Temperature measurements and sampling were made as for oxygen blowing. The operation was stopped when desired carbon content was achieved or if the metal temperature became too low.

During blowing a probe for gas sampling was lowered into the converter, 700 mm above metal surface. The sampled gas was analysed for CO, CO₂, H₂, H₂S, COS, and CH₄. Alternatively the sampled gas was collected in a liquid for later Hg analysis. A filter, placed back of the lance, was changed after each blowing period and the collected dust was saved for later analysis. Dust sampling was also made by isokinetic suction from combusted gas in the off gas duct.

After the injection period the converter was tilted and the slag and metal could be inspected and sampled. The metal samples were of spectrometer quality for full chemical determination. If necessary some slag was skimmed off.

4.4 De-carburisation CO production

The procedure for de-carburisation followed mainly the routines for classical BOF blowing. Compensation for heat losses were made by addition of additional fuel, aluminium bars and FeSi before blowing start. To maintain reasonable slag properties the formed Al₂O₃ and SiO₂ was compensated by lime mix.

The procedure was followed by a new injection period or by tapping in case of the last trial for the day.

4.5 Tapping

Before tapping the metal temperature was adjusted to about 120°C super heat. This was made by oxygen blowing in combination with scrap or aluminium addition. After slag skimming, tapping was made into a steel ladle or hot metal ladle and cast into sand beds. The following day slag and metal was separated and weights were recorded.

5 Heat notes

5.1 HyMelt 1

Un-alloyed pig iron was melted in the EAF, tapping and charging of 5500 kg of hot metal was made without only small disturbances.

Heat ID S1782

Coal was selected for injection.

Totally five period of injection were made and initial problems were detected on:

- Level control of the lances had a poor function because of mechanical interference between cooling rubber tubes and malfunction of chain for the oxygen lance
- Sub-lance system had to be tuned for dipping time and sampling level
- O₂ flow-rate control and routines for the MEFCON system had to be tuned
- The dust load indicated that the complete system for process gas had to be cleaned after each injection period.
- The temperature drop during injection was unexpected high about 10 °C
- Low temperature injection <1400°C gave “unreacted coke” on top of the slag

Tapping and casting could be made without any problems.

New routines for data collection and conducting the test must be made for the coming day.

5.2 HyMelt 2

Heat ID S1783

Operation could be performed under good control. Totally five periods of coal injection and one period of coke were made.

- The “unreacted coke” on top of the slag could almost be completely avoided by operation at higher temperatures, melt temperature was maintained above 1400°C.
- The poor heat balance was managed by aluminium addition and by avoiding tilting of the converter between oxygen blowing and injection.
- 4 periods of process gas sampling was possible.
 - 2 gas analysis coal injection
 - 1 Hg-sampling coal injection
 - 1 gas analyse coke injection
- From the start of gas suction the pressure drop increased giving a continuously increased amount of leakage air to the analysers.

- Sculling, narrowing the converter mouth gave some problems with lance movements
- The last injection was made with coke giving strong indications of an improved carbon yield and an improved heat balance.
- The feeding rate was reduced during coke injection. It was later found that some rubber material was blocking the outlet.

5.3 HyMelt 3

Heat ID S1784

Pet-coke was used for all injections periods. Totally five periods was made and gas suction of process gas was possible for all periods. An overall improved heat balance gave drastically reduced aluminium addition. This in combination with no ash in the material gave a low slag trough put and a stiff and dry slag. It was understood that the slag has been saturated with MgO from refractory wear during the day.

Moderate feed rate 10 kg/min gave in first two injection periods excellent result. Attempt to increase the rate up to 20 kg/min was only possible by reducing the carrying gas from 0,55 m³n/min to 0,35 m³n/min and by increasing the nozzle outlet diameter from 7,0 to 7,5 mm at ~12:00. Both these action caused a lower impulse of material jet to the bath. It was later found that coal was by mistake charged to the dispenser during the day.

- Large amount of coke was trapped in the slag giving flames spontaneously or when the slag was skimmed.
- The dry slag gave problems to measure in blow temperatures.
- The heat was tapped when water leakage occurred on the oxygen lance.
- Remaining problem with increased amount of leakage air during sampling of process gas. The analysed components must be corrected by use of an oxygen balance. Argon content is therefore included from this day in the database. Clogging is mainly caused by dust in the filter in top of the lance and in the ceramic head.
- The standard hydrogen analyser was closed before the start of the tests.
- Recalibration of MS hydrogen was made after that calibration gas of 100% responded only 85%. Can be seen in the data base.

5.4 HyMelt 4

Heat ID S1785

Pet-coke injection was made for 5 periods, gas analysis was possible for all. During the day the confusion between coal and pet-coke was detected.

A new slag was tested, the purpose was to achieve good fluid ability down to 1400°C. The slag was made of oxides from FeSi98 and aluminium bars fluxed with lime and dolomite mix. The result was acceptable and slag skimming could be made after the injections.

The injection nozzle was drilled to 8 mm to allow higher feeding rate up to 20 kg/min. However at this rate the transport gas had to be lowered to 0, 3 m³n/min giving a lower impulse from the gas/material jet into the melt. This was during the day compensated with higher gas flows 0, 7 m³n/min and a lower material flow rate.

The operational lance distance was measured with a steel bar placed on the material lance nozzle. The result confirmed calibration 400 mm indicated metal up to 280 mm. The difference is caused by unstable metal surface from bottom stirring.

Preliminary mass balance shows low carbon yield to the melt, the losses to combusted gas was typically 3 kg/min and coke in the slag was found in the same magnitude. High CH₄ % was also reported from process gas analysis.

Sculling on the oxygen lance was detected for the first time and had to be cleaned several times. It was also found that the nozzle of the material lance was clogged in home position during oxygen blowing. It was easily detected when carbon injection was started with the material plume in the slit between converter mouth and the hood. This small scull was removed before all tests except from the first injection which was operated with a poor plume.

The moderate carbon yield can be caused by:

- Particles not solute directly in the jet-metal interface will float up on slag surface giving only small possibilities to contact with metal. With a stiffer slag it is more likely that metal surface and coal particles in direct contact.
- Lower jet impulse from the larger nozzle diameter.

Later note: material confusion caused the main problems with C-yield.

5.5 HyMelt 5

Heat ID S1786

Injection of oil was made for the first 4 periods, the remaining day coal was injected for 3 periods. Oil seems to be a more difficult source than solids. Large amount of CO₂ was detected in the combusted gas indicating severe soot formation.

The coal tests showed similar results as previous heats, moderate carbon yield, tendency for build up of coal on top of slag and a weak heat balance. The lance was made with a 7 mm nozzle.

At 14:30 it was discovered that one of the coke bags was confused with coal. Until then coal has been injected as coke. This can explain the problems to repeat the good results achieved earlier with coke. Experiments made at HyMelt 4 must be rechecked.

Good gas suction of process gas for analyse. The last two periods was used for mercury sampling.

5.6 HyMelt 6

Heat ID S1787

Totally 6 injection periods with pet-coke were made at controlled conditions.

Tests at higher V and S levels.

Hydrogen purging at high sulphur level was performed

6 Result

The complete data base and the individual test periods have been distributed separately. Below is supplementary data presented as graphs. Detailed information on individual test periods can be found in Appendix 1.

6.1 Process gas analysis

In Appendix 2 is an overview of measured components in the process gas presented. Detailed graphs for individual injection periods are presented separately and comments made do also refer to those.

A general difficulty was clogging of the sampling probe giving an increased amount of leakage air in the gas sample during the measuring periods. For the evaluation the recorded values have been balanced by use of the measured oxygen for compensating the amount of air dilution

Isolated peak values are related to calibration and frequent peaks especially on CO are caused from partial combustion of sub-lance probes.

6.1.1 CO

The recordings show significant difference between the injectants.

- Coal gives stabile CO concentration in the range of 20 – 30%.
- Coke gives a decreasing CO concentration during injection starting around 20% down to 10%.
- Oil shows the same behaviour as coke but on a lower CO concentration down below 5%.

The measurements seem to mirror the oxygen content in the material and that we have to consider declining reduction of oxides in the slag during injection.

6.1.2 CO₂

It is not expected to have significant amount of CO₂ in the process gas. The presence can be due to leakage air into the converter atmosphere or to leakage in the sampled volume. The readings are generally below 5% and frequently below 1%.

6.1.3 H₂

The H₂ measurement has a long response time, up to 5 minutes when calibration with a fixed concentration and it is accordingly to be expected an increased reading during the injection period. Coal and coke generates a gas of 50% to 60% H₂, occasionally 10% higher or lower, while oil shows about 70% H₂.

6.1.4 CH₄

Coal and coke give gases of 5 to 7 % CH₄ while oil gives 8 to 12%.

The accuracy is not perfect since the component gives a stronger signal than recommended for optimal performance.

6.1.5 H₂S

The process gas has a content of 0,2 to 0,4 % H₂S independent of injectant. At higher sulphur level in metal the H₂S content in the gas is somewhat higher, 0,5%. (0,8 to 1,0 %S compared to normal level 0,1 to 0,3 %S)

It has not been shown that purging with H₂ will effect the H₂S concentration.

6.1.6 COS

The graphs shown in the Appendix 2 are based on the spectrometer data base, since the records in the Lab View system do not mach. Unexpected high values have been measured, frequently more than 500 ppm, more typical recordings are in the range 100 to 300 ppm.

The data base in the spectrometer operates with complete different format and it is preferred if all future measurements are transferred to the Lab View system.

6.1.7 O₂

No oxygen is expected to be in the gas, the presence is most likely due to leakage into the cooled gas sample.

6.2 Metal analysis

Below are the metal analysis presented for each element of interest. The analyses are generally believed to be good enough for the coming campaigns. However, the in-blow

samples of spectrometer quality are few and the sampling procedure must be improved. Carbon and sulphur were analysed on the Leco system which operates with samples of lower quality.

Complete analysis of metal and slag is shown in Appendix 3

6.2.1 Carbon

S1783

-AI p28 -

S1785 %C in metal

S1786 %C in metal

-AI p29 -

Figure 6 – C analysis in liquid metal HyMelt 2 to 6

6.2.2 Sulphur

-AI p30 -

-AI p31 -

Figure 7 – S analysis in liquid metal HyMelt 2 to 6

6.2.3 Vanadium

-AI p33 -

Figure 8 - V analysis in liquid metal HyMelt 2 to 6

6.3 Slag analysis

Slag samples are only possible to collect from tilted converter. The method can be used in coming campaigns.

6.3.1 Iron oxides

-AI p36 -

S1785 %Fetot in slag

S1786 %Fetot in slag

-AI p37 -

Figure 9 – Fe_{tot} in slag HyMelt 2 to 6

6.3.2 Sulphur

-AI p38 -

-AI p39 -

Figure 10 - S in slag HyMelt 2 to 6

6.3.3 Vanadium oxides

-AI p41 -

S1785 %V2O5 in slag

S1786 %V2O5 in slag

-AI p42 -

Figure 11 – V-oxides in slag HyMelt 2 to 6

6.3.4 Bas CaO/SiO_2

-AI p43 -

S1784 CaO/SiO2 in slag

S1785 CaO/SiO2 in slag

-AI p44 -

Figure 12 – CaO/SiO₂ ratio in slag HyMelt 2 to 6

6.4 Temperatures

The metal temperatures refer either from sub-lance measurements or manual lance measurements. The system and code for evaluation of the EMK must be improved in the Lab View system, presented values are manually evaluated.

-AI p46 -

-AI p47 -

Figure 13 – Temperature in liquid metal HyMelt 2 to 6

6.5 Carbon yield to metal

The carbon yield has been calculated for all injection periods. The calculation is based on the first and last metal analysis in the period and the injected amount of carbon during the time between sampling. Details are shown in Appendix 4.

The best results were archived for pet-coke at moderate feeding rate. A rather strong dependence between yield and feeding rate can be seen. The expected relation between nozzle diameter and yield can not be detected.

Figure 14 - C yield for coal injection

Figure 15 - C yield for coke injection

Figure 16 - C yield for coal/coke mix injection

-AI p50 -

Figure 17 - C yield for oil injection

6.6 Vanadium balance

During HyMelt 6, 80 kg ferro vanadium was added, equal to 65, 5 kg pure V. As can be seen in the table the vanadium is distributed between metal and slag. The concentration ratio is strongly depending on oxygen potential. The response in metal analysis after addition is higher than expected indicating some error in the background data for calculation.

Table 1 – Vanadium balance data

S1787

Time	Metal			Slag				Calculation	
	Weight kg	%C	%V	%Fe	%CaO	%SiO ₂	%V ₂ O ₅	CaO/SiO ₂	[V ₂ O ₅]/(V)
11:25	5376	1,06	0,051	6,06	37,82	21,09	0,15	1,79	2,94
12:12	5331	Addition of 80 kg FeV (81,88 %V)							
12:55	5207	2,98	1,573	18,65	9,67	24,32	0,89	0,40	0,57
13:44	5082	2,16	0,507	3,3	39,46	20,47	11,14	1,93	21,97
14:23	5082	2,27	0,744	4,09	36,24	26,72	6,00	1,36	8,06

6.7 Hydrogen purging

During HyMelt 6 hydrogen was purged trough the bottom tuyere for 17 minutes. The purpose was to investigate the possibility to remove S to the gas phase.

Before gas purging

Metal 0,8 % S

Slag 5,74 % S

After gas purging

Metal 0,60 % S

Slag 4,81 % S

About 12 kg sulphur has been removed from metal and slag. This corresponds to 44 % efficiency if creation of H₂S is assumed. However, this can not be confirmed by the gas analysing. Further studies must be made to fully understand the chemical mechanisms.

6.8 Dust analysis

6.8.1 Dust sampled from process gas

Dust from the ceramic filter have been analysed, the results are shown in Appendix 5.

Label “Prov K7” refers to coal injection

Label “Prov K21” refers to oil injection

Label “Prov K25” refers to coke injection

The lab has problem to determine carbon because of the small sample amount.

6.8.2 Dust sampled from combusted gas

Estimation by iso-kinetic sampling of the dust load has been made from the injection periods, Appendix 6. The results show a load less than 10 gram/m³ in dry gas in average.

Three samples have been analysed and the result are presented in Appendix 7.

Label “Prov 7” refers to coal injection

Label “Prov 21” refers to oil injection

Label “Prov 25” refers to coke injection

The lab has problem to determine carbon because of the small sample amount.

6.9 Mercury in process gas

Three samples for mercury determination in the process gas have been analysed, Appendix 8, The result differs very much in spite of that all three samples refers to coal injection. Obviously there are severe problems with the procedure and must be drastically improved. In future it will be necessary to have one dedicated suction line for the mercury sampling.

“Prov 1”, “Prov2” and “Prov 3” are sampled liquids while “Prov 0” is a reference on clean liquid.

6.10 Refractory wear

The converter lining was measured before and after the campaign. As can be seen in the table no severe wear has occurred. Typical erosion in the level of the slag can be seen.

Table 2 – Lining wear

Level	New lining		After HyMelt 6		Wear
	N/S	E/W	N/S	E/W	
Cone	1410	1410	1360	1420	-10
1500	1410	1410	1440	1440	15
1250	1410	1410	1460	1460	25
1000	1410	1410	1460	1460	25
750	1410	1410	1450	1460	23
500	1410	1410	1480	1470	33
250	1410	1410	1500	1460	35
0	1410	1410	1423	1413	4
Hight	2893		2990		97

The lining can stand a wear up to 150 mm and can consequently be used for further campaigns. Minor repair work will be necessary on local spots.

Date	Heat ID	Period ID	Hot metal kg	Al-Bar kg	FeSi kg	Line mix kg	Start O2 In min	Stop O2 In min	O2 In min	Duration minutes	Feed tonnes	In kg	Start In min	Stop In min	In kg	Duration minutes	Feed tonnes	Remarks	Sampling time converter ID	%C	%S	Seg ID	Temp C	Combedust start	Stop	g/min	Moist %	Hy-sampling ID	Start	Stop	
2003-06-08 HyMelt 2	1	3.1783	110	77		110	09:52	10:02	107	11	8.6	Coil	09:52	10:09	161	17	9.5	Late start logg 20 kg coal added	09:53	1	2.45	0.095		1385	5	09:56	10:16	3.60	2.59		
	2		150	77		150	10:26	10:37	105	11	9.5	Coil	10:37	10:58	185	21	8.8		11:01	8	2.61	0.078	8	1409	6	10:41	11:01	4.60	3.62		
	3		150	77		150	11:11	11:22	91	11	8.3	Coil	11:22	11:44	215	22	9.8		11:49		2.97	0.043	14	1407	7	11:23	11:49	1.70	1.99		
	4		150	77		150	12:33	12:44	109	11	9.9	Coil	12:45	13:00	145	15	9.7		13:04	16	2.57	0.090	16	1431	8	12:49	13:01	1.90	2.65		
	5		150	77		150	13:30	13:38	77	8	8.6	Coil	13:40	13:59	177	19	9.3			14:05	19	2.80	0.055	19	1415	9	13:51	14:01	2.20	6.09	1
	6		150	77		150	14:21	14:29	71	8	8.9	P-Coke	14:30	14:46	110	16	6.9	14:59 200 kg scrap, 15:08 200 kg scrap	14:55	22	3.46	0.034	22	1485	10	14:34	14:46	3.20	0.94		
	7		4800				14:58	15:12	124	13	9.5								15:17	23	0.99	0.150		1581							
2003-06-10 HyMelt 3	1	3.1784	85			85	09:44	10:00	160	16	10.0	P-Coke	10:00	10:23	192	23	8.3	Late start logg 38 kg coal added	09:40	1	3.67	0.044		1393	11	10:06	10:23	9.50	1.02		
	2		140	73		140	10:25	10:40	150	15	10.0	Mix	10:44	11:03	174	19	9.2		10:25	5	3.34	0.180		1393	12	10:48	11:03	8.60	2.27		
	3		150	77		150	11:25	11:34	87	9	9.7	Mix	11:40	11:51	139	11	12.6		11:03	8	2.48	0.310		1378	13	11:42	11:51	11.70	2.44		
	4		150	77		150	12:28	12:35	75	7	10.7	Mix	12:38	12:53	197	15	13.1	12:25 Lance nozzle 7.5 mm, 13:25 20 kg flux	12:00	10	1.59	0.200	10	1404	14	12:38	12:53	13.00	2.47		
	5						13:13	13:25	121	12	10.1	Mix	13:34	13:50	275	16	17.2		12:56	12	3.77	0.084	12	1419	15	13:35	13:51	21.20	1.35		
	6		4873	49			14:19	14:25	148	15	9.9								13:50	14	3.45	0.320	14	1324	15	13:35	13:51	21.20	1.35		
	7						14:10	14:25	148	15	9.9								14:30	15	3.34	0.320	15	1463							
2003-06-11 HyMelt 4	1	3.1785	120	35	35	150	09:18	09:33	148	15	9.9	Mix	09:35	09:45	133	10	13.3	09:00 Lance nozzle 6.0 mm	09:20	3.34	0.053		1332	16	09:04	09:05	13.30	2.72			
	2		35	35	35	150	10:07	10:21	140	14	10.0	Mix	10:25	10:39	210	14	15.0		09:51	3	2.62	0.185	3	1423	17	10:03	10:43	10.70	2.59		
	3		35	35	35	150	11:22	11:36	126	13	9.7	Mix	11:39	11:56	173	17	10.2		10:43	6	2.67	0.240	6	1432	18	11:04	11:56	7.20	2.49		
	4		35	35	35	150	12:42	12:53	114	11	10.4	Mix	12:57	13:12	151	15	10.1	Late start logg ad 10 min O2	12:01	9	2.75	0.230	9	1441	19	12:59	13:12	7.00	2.81		
	5		35	35	35	163	14:00	14:13	129	13	9.9	Mix	14:16	14:28	113	12	9.4		13:20	11	2.58	0.225	11	1464	20	14:17	14:29	12.80	2.38		
	6		4880																14:20	13	1.74	0.310		1518							
	7																		09:11	3.63	0.038		1343								
2003-06-12 HyMelt 5	1	3.1786	150	37	35	150	09:09	09:24	151	15	15.1	Oil	09:29	09:41	70	12	5.8		09:46	3	2.17	0.077	3	1465							
	2		37	35	35	150	10:09	10:19	93	10	9.3	Oil	10:28	10:48	55	20	2.8	Process stopped 10:38 - 10:42 cleaning of nozzle	10:24	4	1.52	0.063	4	1624							
	3		50	50	200	11:07	11:13	55	6	9.2	Oil	11:22	11:39	121	17	7.1		10:53						21	11:23	11:39	11.10	3.38			
	4		50	50	240	11:51	11:57	59	6	9.8	Coil	13:23	13:31	87	8	10.8		11:44	7	2.09	0.043		1434								
	5		50	50	1307	13:14	13:14	61	7	8.7	Coil	14:09	14:23	224	14	16.0	12:30 lateral lance nozzle 7 mm	12:02	6	1.56	0.086	6	1567								
	6		70	70	145	13:50	13:55	52	5	10.4	Coil	14:09	14:23	224	14	16.0		13:39	11	1.75	0.051	11	1471								
	7		35	35	165	14:40	14:51	107	11	9.7	Coil	15:03	15:18	205	15	13.7		14:29	13	2.76	0.052	13	1455								
2003-06-13 HyMelt 6	1	3.1787	120	25	25	100	09:13	09:27	134	14	9.6	Coil	09:32	09:44	110	12	9.2		15:23	15	2.56	0.110	15	1434							
	2		20	20	20	150	09:59	10:14	148	15	9.9	P-Coke	10:28	10:34	63	6	10.5	09:59 250 kg Fe-S	09:48	3	3.14	0.190	3	1482							
	3		45	45	175	11:12	11:18	59	6	9.8	P-Coke	11:28	11:34	64	6	10.7		10:41	4	1.36	0.130	5	1493								
	4		30	30	115	12:12	12:20	72	8	9.0	P-Coke	12:24	12:48	242	24	10.1	11:34 - 11:51 H2 70 m3/h	11:25	6	1.06	0.796	6	1651								
	5		75	75	1309	13:09	13:18	83	9	9.2	P-Coke	13:24	13:48	242	24	10.1	12:12 89 kg FeV	12:55	10	2.86	0.600	10	1457								
	6		20	20	75	13:51	13:59	75	8	8.4	P-Coke	13:29	13:38	93	9	10.3		13:44	12	2.16	0.800	12	1447								
	7																		14:23	14	2.27	0.850	14	1475							

CO gas analysis

S1785 %CO

S1786 %CO

CO₂ gas analysis

S1785 %CO2

S1786 %CO2

H₂ gas analysis

CH₄ gas analysis

S1785 %CH4

S1786 %CH4

H₂S gas analysis

COS gas analysis

S1785 ppm COS

S1786 ppm COS

O₂ gas analysis

S1785 %O2

S1786 %O2

Metal		C	Si	Mn	P	S	Cr	Ni	Cu	V	Al	Mo	Ti
S1783	1	3,99	0,38	0,14	0,05	0,033	0,046	0,039	0,003	0,06	0,002	0,004	0,031
	3	2,89				0,028							
	4	1,53				0,032							
	5	2,45				0,09							
	6	2,31				0,039							
	7	1,5				0,06							
	8	2,61	0	0,12	0,055	0,078	0,048	0,04	0,009	0,071	0,009	0,004	0
	10	2,31				0,022							
	11	1,58				0,059							
	12	1,9				0,065							
	13	2,16				0,065							
	14	2,97				0,043							
	15	1,67				0,085							
	16	2,57	0	0,12	0,055	0,09	0,05	0,042	0,023	0,065	0,004	0,003	0
	17	1,54				0,094							
	18	2,35				0,09							
	19	2,8	0	0,12	0,054	0,055	0,05	0,042	0,03	0,062	0,007	0,003	0
	20	2,26				0,042							
	21	3,02				0,056							
	22	3,46	0	0,13	0,052	0,034	0,05	0,042	0,035	0,063	0,01	0,004	0
	23	0,99	0	0,09	0,042	0,15	0,069	0,08	0,035	0,013	0,055	0,012	0

Slag		Fe	CaO	SiO2	MnO	P2O5	S	Al2O3	MgO	Na2O	K2O	V2O5	TiO2	Cr2O3
S1783	8	1,38	45,97	13,51	0,56	0,04	0,94	30,91	9,99	0,03	0,03	0,34	0,73	0,03
	14	13,74	39,89	7,36	0,22	0,02	1,6	38,03	12,31	0,02	0,05	0,06	0,28	0,03
	16	4,29	43,65	6,05	0,49	0,03	1,04	41,5	10,32	0,02	0,02	0,25	0,22	0,03
	19	12,1	41,44	5,18	0,32	0,04	1,45	41,57	9,97	0,01	0,02	0,12	0,16	0,04
	22	7,19	43,07	3,45	0,21	0,02	1,91	43,06	10,18	0	0,01	0,05	0,1	0,03

Metal		C	Si	Mn	P	S	Cr	Ni	Cu	V	Al	Mo	Ti
S1784	1	3,87	0,3	0,07	0,05	0,044	0,045	0,042	0,002	0,061	0,027	0,003	0,012
	2	3,35				0,045							
	3	1,68				0,046							
	4	3,09				0,15							
	5	3,34	0	0,06	0,032	0,18	0,047	0,05	0,004	0,029	0,041	0,004	0
	6	0,98				0,2							
	7	2,06				0,29							
	8	2,46	0	0,07	0,041	0,31	0,051	0,051	0,003	0,016	0,017	0,003	0
	10	1,59	0,02	0,07	0,048	0,2	0,054	0,054	0,009	0,058	0,11	0,005	0
	11	1,99				0,085							
	12	3,77	0	0,09	0,046	0,084	0,058	0,054	0,017	0,074	0,032	0,005	0
	13	1,74	0	0,06	0,055	0,3	0,052	0,057	0,018	0,016	0,016	0,004	0
	14	3,45	0	0,06	0,048	0,32	0,054	0,055	0,016	0,061	0,132	0,004	0
	15	1,3	0	0,07	0,057	0,32	0,052	0,059	0,024	0,069	0,008	0,004	0

Slag		Fe	CaO	SiO2	MnO	P2O5	S	Al2O3	MgO	Na2O	K2O	V2O5	TiO2	Cr2O3
S1784	10	27,09	32,95	8,36	0,41	0,06	1,92	26,13	23,4	0,01	0,01	0,28	0,3	0,07
	12	24,27	34,66	4,35	0,18	0,02	3,36	36,58	17,6	0	0,01	0,07	0,15	0,05
	13	7,91	40,08	6,97	0,46	0,06	2,22	32,03	16,7	0	0,01	0,54	0,31	0,05
	14	33,28	30,41	4,65	0,28	0,04	2,53	32,42	19,45	0	0,01	0,18	0,14	0,08
	15	4,88	28,51	4,53	0,33	0,02	2,77	34,98	27,39	0,02	0	0,26	0,19	0,15

Metal		C	Si	Mn	P	S	Cr	Ni	Cu	V	Al	Mo	Ti
S1785	1	3,94				0,053							
	2	1,99				0,09							
	3	2,82	0	0,09	0,052	0,185	0,043	0,041	0,004	0,064	0,008	0	0
	5	1,91				0,093							
	6	2,67	0	0,09	0,054	0,24	0,044	0,042	0,007	0,08	0,006	0	0
	7	1,74				0,15							
	8	2,06				0,22							
	9	2,75	0	0,09	0,054	0,23	0,046	0,042	0,008	0,079	0	0	0
	10	1,58				0,21							
	11	2,58	0	0,08	0,057	0,22	0,047	0,042	0,013	0,085	0,015	0	0
	13	1,74	0,04	0,05	0,057	0,31	0,04	0,048	0,018	0,041	0,059	0	0

Slag		Fe	CaO	SiO2	MnO	P2O5	S	Al2O3	MgO	Na2O	K2O	V2O5	TiO2	Cr2O3
S1785	3	2	40,54	21,35	1,08	0,15	0,47	19,92	17,2	0,01	0,01	0,95	1,01	0,05
	6	1,89	36,64	21,87	0,47	0,02	0,82	19,77	24,65	0,02	0,01	0,21	0,42	0,04
	9	2,18	36,8	24,34	0,31	0,01	1,37	19,05	22,43	0,02	0,01	0,08	0,24	0,03
	11	2,34	36,28	24,36	0,28	0,01	1,29	18,39	23,69	0,02	0,02	0,09	0,17	0,03

Metal		C	Si	Mn	P	S	Cr	Ni	Cu	V	Al	Mo	Ti
S1786	1	3,93				0,038							
	2	2,04				0,046							
	3	2,17	0	0,08	0,056	0,077	0,04	0,039	0,003	0,054	0,018	0	0
	4	1,52	0,02	0,09	0,063	0,063	0,043	0,038	0,006	0,055	0,008	0	0
	5	1,8				0,079							
	6	1,38				0,022							
	7	2,09	0,6	0,1	0,063	0,043	0,039	0,041	0,01	0,057	0,03	0	0
	8	1,56	1,24	0,09	0,066	0,0086	0,039	0,041	0,012	0,054	0,173	0	0
	10	1,43	0,14	0,05	0,062	0,027	0,041	0,039	0,009	0,044	0,008	0	0
	11	1,75	0,12	0,06	0,064	0,061	0,041	0,04	0,009	0,019	0,003	0	0
	12	1,61				0,00028							
	13	2,76	0,21	0,06	0,057	0,092	0,039	0,039	0,013	0,052	0,038	0	0
	14	2,26	0,11	0,06	0,063	0,071	0,04	0,04	0,012	0,052	0,007	0	0
	15	2,56	0,11	0,06	0,053	0,11	0,041	0,04	0,011	0,051	0,026	0	0
	16	3,27	0,14	0,06	0,057	0,099	0,041	0,041	0,011	0,053	0,286	0	0
	17	4,01				0,12							
	18	1,77	0,13	0,05	0,046	0,018	0,026	0,024	0,008	0,041	0	0	0

Slag		Fe	CaO	SiO2	MnO	P2O5	S	Al2O3	MgO	Na2O	K2O	V2O5	TiO2	Cr2O3
S1786	3	7,18	42,6	31,91	1,98	0,29	0,13	4,41	8,79	0,03	0,05	1,17	1,27	0,1
	4	2,31	44,26	26,61	0,55	0,04	0,23	15,08	13,76	0,01	0,04	0,29	0,55	0,05
	5	2,98	42,15	26,86	0,45	0,06	0,34	14,66	17,43	0	0,02	0,25	0,52	0,05
	8	1,07	50,18	15,64	0,2	0,01	0,59	26,46	9,02	0	0,06	0,07	0,07	0,03
	10	3,11	34,68	33,36	0,83	0,01	0,06	15,69	16,53	0	0,03	0,27	0,1	0,05
	11	0,89	32,26	35,48	0,37	0,01	0,2	15,17	21,77	0,03	0,04	0,1	0,13	0,03
	14	1,17	37,67	24,2	0,18	0,01	0,75	20,85	20,25	0,02	0,04	0,05	0,09	0,03
	16	1,19	34,57	24,67	0,17	0,01	1,27	20,98	22,08	0,03	0,04	0,04	0,07	0,03
	18	7,27	31,62	26,04	0,12	0,01	2,25	18,49	24,3	0,02	0,01	0,03	0,06	0,04

Metal		C	Si	Mn	P	S	Cr	Ni	Cu	V	Al	Mo	Ti
S1787	1	3,99				0,05							
	2	2,18				0,067							
	3	3,14	0,39	0,09	0,053	0,15	0,046	0,042	0,003	0,066	0,331	0	0,002
	4	1,06	0	0,07	0,056	1,27	0,044	0,014	0,002	0,048	0,234	0	0
	5	1,36	0	0,06	0,055	1,31	0,044	0,04	0,003	0,046	0,333	0	0
	6	1,06	0,26	0,08	0,058	0,78	0,046	0,012	0,003	0,051	0,306	0	0
	7	1,71				0,74							
	8	1,69				0,72							
	9	1,52				0,79							
	10	2,98	0,03	0,09	0,055	0,6	0,041	0,043	0,007	1,573	0,299	0	0
	11	1,81				0,83							
	12	2,16	0	0,04	0,056	0,83	0,038	0,043	0,005	0,507	0,245	0	0
	13	1,43				0,85							
	14	2,87	0	0,04	0,054	0,85	0,041	0,043	0,006	0,744	0,257	0	0

Slag		Fe	CaO	SiO2	MnO	P2O5	S	Al2O3	MgO	Na2O	K2O	V2O5	TiO2	Cr2O3
S1787	3	1,85	48,71	32,69	1,24	0,12	0,24	5,92	9,46	0	0,03	0,53	1,12	0,04
	4	3,15	40,36	27,26	0,97	0,04	1,79	11,58	16,32	0,01	0,03	0,57	0,75	0,05
	5	2,72	39,14	26,66	1,06	0,05	1,97	11,48	18,51	0,01	0,02	0,63	0,74	0,06
	6	6,06	37,82	21,09	0,45	0,03	5,74	19,15	11,94	0	0,04	0,15	0,3	0,04
	10	18,65	29,67	24,32	0,38	0,02	4,81	17,52	17,24	0	0,01	0,89	0,16	0,06
	12	3,3	39,46	20,47	0,77	0,09	2,2	14,55	12,21	0	0	11,14	0,17	0,05
	14	4,09	36,24	26,72	0,56	0,03	2,07	16,31	13,77	0,02	0,01	6	0,21	0,06

Heat ID	HyMelt	Period	Injection period		Sample ID	Est. Metal	Injected C "As"		Start Comp	Stop Man	Stop Comp	Acc. C in WG "AE"		Injected	To metal		To WG	Rest		To metal	To WG		Rest	Remarc
			Start	Computer time			Stop	Start				%	Start		%	kg		%	kg		%	kg		
S1783	2	1	09:52	10:09	2.6	97.5	5500	10:00	09:56	1.53	10:13	10:09	2.45	151.1	187.3	94.9	50.6	36.2	8.1	53.3	38.1	8.5	Coal Injection	
S1783	2	2	10:37	10:58	0	127.7	5186	10:40	10:36	1.5	11:01	10:57	2.61	53.4	121.6	127.7	57.6	68.2	1.9	45.1	53.4	1.5	Coal Injection	
S1783	2	3	11:22	11:44	33.9	151.1	5029	11:32	11:28	1.58	11:49	11:45	2.97	70.0	123.9	117.2	69.9	53.9	-6.6	59.6	46.0	-5.6	Coal Injection	
S1783	2	4	12:45	13:00	0	99.3	4871	12:48	12:44	1.67	13:04	13:00	2.57	72.0	122.5	99.3	43.8	50.5	5.0	44.1	50.9	5.0	Coal Injection	
S1783	2	5	13:40	13:59	0	123.7	4714	13:43	13:39	1.54	14:05	14:01	2.80	44.9	106.0	123.7	59.4	61.1	3.2	48.0	49.4	2.6	Coal Injection	
S1783	2	6	14:30	14:46	7.68	64.9	4557	14:36	14:32	2.26	14:43	14:39	3.02	38.9	46.2	57.22	34.6	7.3	15.3	60.5	12.8	26.7	P-Coke Injection	
S1784	3	1	10:00	10:23	0	130.7	5700	10:04	10:00	1.68	10:25	10:21	3.34	128.3	155.8	130.7	94.6	27.5	8.6	72.4	21.0	6.6	P-Coke Injection	
S1784	3	2	10:44	11:03	0	130.3	5412	10:49	10:45	0.98	11:03	10:59	2.46	146.0	163.6	130.3	80.1	17.6	32.6	61.5	13.5	25.0	Mix Injection	
S1784	3	4	12:38	12:53	0	155.6	5149	12:40	12:36	1.99	12:56	12:52	3.77	41.8	70.3	155.6	91.7	28.5	35.4	58.9	18.3	22.8	Mix Injection	
S1784	3	5	13:34	13:50	0	237.9	5011	13:31	13:27	1.74	13:55	13:51	3.45	107.8	155.1	237.9	85.7	47.3	104.9	36.0	19.9	44.1	Mix Injection	
S1785	4	1	09:35	09:45	0	116.1	5700	09:38	09:34	1.99	09:51	09:47	2.82	117.2	139.3	116.1	47.3	22.1	46.7	40.7	19.0	40.2	Mix Injection	
S1785	4	2	10:25	10:39	0	177.3	5412	10:27	10:23	1.91	10:43	10:39	2.67	101.4	143.3	177.3	41.1	41.9	94.3	23.2	23.6	53.2	Mix Injection	
S1785	4	3	11:39	11:56	0	149.3	5268	11:38	11:34	1.74	12:01	11:57	2.75	69.8	128.8	149.3	53.2	59	37.1	35.6	39.5	24.8	Mix Injection	
S1785	4	4	12:57	13:12	0	130.8	5124	12:59	12:55	1.58	13:20	13:16	2.58	71.1	113.6	130.8	51.2	42.5	37.1	39.2	32.5	28.3	Mix Injection	
S1786	5	1	09:29	09:41	0	63	5520	09:28	09:24	2.04	09:46	09:42	2.17	107.3	147.9	63	7.2	40.6	15.2	11.4	64.4	24.2	Oil Injection	
S1786	5	2	10:28	10:48	0	49.4	5275	10:24	10:20	1.52	10:53	10:49	1.8	46.9	67	49.4	14.8	20.1	14.5	29.9	40.7	29.4	Oil Injection	
S1786	5	3	11:22	11:39	0	109.5	5153	11:17	11:13	1.38	11:44	11:40	2.09	9.6	59.9	109.5	36.6	50.3	22.6	33.4	45.9	20.7	Oil Injection, three feed rates	
S1786	5	5	13:23	13:31	0	72.8	4908	13:20	13:16	1.43	13:38	13:34	1.75	31.8	63	72.8	15.7	31.2	25.9	21.6	42.9	35.6	Coal Injection	
S1786	5	6	14:09	14:23	0	190	4785	14:03	13:59	1.61	14:29	14:25	2.76	14.1	74.1	190	55.0	60.0	75.0	29.0	31.6	39.5	Coal Injection	
S1786	5	7	15:03	15:18	0	176.1	4663	14:58	14:54	2.26	15:23	15:19	2.56	69.4	112.7	176.1	14.0	43.3	118.8	7.9	24.6	67.5	Coal Injection	
S1786	5	8	15:52	16:11	0	60.5	4540	15:48	15:44	3.27	16:05	16:01	4.01	59.6	77.2	60.5	33.6	17.6	9.3	55.5	29.1	15.4	Coal Injection	
S1787	6	1	09:32	09:44	0	91.7	5500	09:33	09:29	2.18	09:48	09:44	3.14	110.4	123.5	91.7	52.8	13.1	25.8	57.6	14.3	28.1	P-Coke Injection	
S1787	6	2	10:28	10:34	0	54.4	5501	10:20	10:16	1.06	10:41	10:37	1.36	120.6	129.3	54.4	16.5	8.7	29.2	30.3	16.0	53.7	P-Coke Injection	
S1787	6	3	11:28	11:34	0	55.9	5376	11:25	11:21	1.06	11:47	11:43	1.71	24.0	34.6	55.9	34.9	10.6	10.4	62.5	19.0	18.5	P-Coke Injection	
S1787	6	4	12:24	12:48	17.7	208	5331	12:31	12:27	1.52	12:55	12:51	2.98	31.1	84.9	190.3	77.8	53.8	58.7	40.9	28.3	30.8	P-Coke Injection	
S1787	6	5	13:29	13:38	0	81.3	5207	13:30	13:26	1.81	13:44	13:40	2.16	66.8	95.1	81.3	18.2	28.3	34.8	22.4	34.8	42.8	P-Coke Injection	
S1787	6	6	14:04	14:18	0	129	5082	14:03	13:59	1.43	14:23	14:19	2.87	45.7	99.5	129	73.2	53.8	2.0	56.7	41.7	1.6	P-Coke Injection	

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Registrerad: 2003-06-26
Analyserad: 2003-07-14
Utfärdad: 2003-07-14

MEFOS
L-E From

Box 812
971 25 Luleå

Analyspaket: **MG2-N**

Provnummer: U10097099-00
Beteckning 1: Prov K7
Beteckning 2:

Analys	Resultat	Mätosäk. Enhet	Metod	Analys	Resultat	Mätosäk. Enhet	Metod
SiO ₂ *	0,882	%	ICP-AES	S *	1060	mg/kg	ICP-AES
Al ₂ O ₃ *	0,182	%	ICP-AES	Sc *	<2	mg/kg	ICP-AES
CaO *	0,312	%	ICP-AES	Sn *	<30	mg/kg	ICP-AES
Fe ₂ O ₃ *	2,42	%	ICP-AES	Sr *	5,77	mg/kg	ICP-AES
K ₂ O *	0,235	%	ICP-AES	V *	30,9	mg/kg	ICP-AES
MgO *	0,0700	%	ICP-AES	W *	<80	mg/kg	ICP-AES
MnO *	0,195	%	ICP-AES	Y *	<3	mg/kg	ICP-AES
Na ₂ O *	0,118	%	ICP-AES	Zn *	585	mg/kg	ICP-AES
P ₂ O ₅ *	0,0095	%	ICP-AES	Zr *	3,23	mg/kg	ICP-AES
TiO ₂ *	0,0045	%	ICP-AES				
Summa *	4,4	%	Man.Inm.				
As *	<7	mg/kg	ICP-QMS				
Ba *	151	mg/kg	ICP-AES				
Be *	<0,8	mg/kg	ICP-AES				
Cd *	<0,7	mg/kg	ICP-QMS				
Co *	4,85	mg/kg	ICP-QMS				
Cr *	62,1	mg/kg	ICP-AES				
Cu *	30,4	mg/kg	ICP-QMS				
Hg *	<0,5	mg/kg	AFS				
La *	<8	mg/kg	ICP-AES				
Mo *	9,70	mg/kg	ICP-AES				
Nb *	<8	mg/kg	ICP-AES				
Ni *	60,9	mg/kg	ICP-AES				
Pb *	109	mg/kg	ICP-QMS				

Vid analys av As, Cd, Cu, Co, Hg, Ni, Pb, Sb, Se och S gäller: Upplösning har skett enligt ASTM D3683 (modifierad). För övriga grundämnen har upplösning skett enligt ASTM D3682 (LiBO₂ – smälta).

Vid analys av B har upplösning skett i mikrovågsugn med HNO₃.

Analys har skett enligt EPA –metoder (modifierade) 200.7 (ICP-AES) och 200.8 (ICP-QMS).

Parametrar märkta med * indikerar ej ackrediterade analyser.

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Siv Andersson
Kemist

RAPPORT

L0306060

Sidan 2 av 3

Er Order Id:
Registerad: 2003-06-26
Analyserad: 2003-07-14
Utfärdad: 2003-07-14

MEFOS
L-E From
Box 812
971 25 Luleå

Analyspaket: **MG2-N**

Provnummer: U10097100-00
Beteckning 1: Prov K21
Beteckning 2:

Analys	Resultat	Mätosäk. Enhet	Metod	Analys	Resultat	Mätosäk. Enhet	Metod
SiO ₂ *	21,4	%	ICP-AES	S *	545	mg/kg	ICP-AES
Al ₂ O ₃ *	1,76	%	ICP-AES	Sc *	<10	mg/kg	ICP-AES
CaO *	1,09	%	ICP-AES	Sn *	<200	mg/kg	ICP-AES
Fe ₂ O ₃ *	0,980	%	ICP-AES	Sr *	63,4	mg/kg	ICP-AES
K ₂ O *	0,879	%	ICP-AES	V *	20,5	mg/kg	ICP-AES
MgO *	0,348	%	ICP-AES	W *	<500	mg/kg	ICP-AES
MnO *	<0,03	%	ICP-AES	Y *	<20	mg/kg	ICP-AES
Na ₂ O *	1,16	%	ICP-AES	Zn *	463	mg/kg	ICP-AES
P ₂ O ₅ *	0,0319	%	ICP-AES	Zr *	44,0	mg/kg	ICP-AES
TiO ₂ *	0,0462	%	ICP-AES				
Summa *	27,7	%	Man.Inm.				
As *	<7	mg/kg	ICP-QMS				
Ba *	2740	mg/kg	ICP-AES				
Be *	<5	mg/kg	ICP-AES				
Cd *	<0,7	mg/kg	ICP-QMS				
Co *	0,929	mg/kg	ICP-QMS				
Cr *	<100	mg/kg	ICP-AES				
Cu *	<7	mg/kg	ICP-QMS				
Hg *	<0,6	mg/kg	AFS				
La *	<50	mg/kg	ICP-AES				
Mo *	<50	mg/kg	ICP-AES				
Nb *	<50	mg/kg	ICP-AES				
Ni *	<6	mg/kg	ICP-QMS				
Pb *	35,0	mg/kg	ICP-QMS				

Vid analys av As, Cd, Cu, Co, Hg, Ni, Pb, Sb, Se och S gäller: Upplösning har skett enligt ASTM D3683 (modifierad). För övriga grundämnen har upplösning skett enligt ASTM D3682 (LiBO₂ – smälta).

Vid analys av B har upplösning skett i mikrovågsgugn med HNO₃.

Analys har skett enligt EPA –metoder (modifierade) 200.7 (ICP-AES) och 200.8 (ICP-QMS).

Parametrar märkta med * indikerar ej ackrediterade analyser.

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RAPPORT

L0306060

Sidan 3 av 3

Er Order Id:
Registrerad: 2003-06-26
Analyserad: 2003-07-14
Utfärdad: 2003-07-14

MEFOS
L-E From

Box 812
971 25 Luleå

Analyspaket: **MG2-N**

Provnummer:	U10097101-00
Beteckning 1:	Prov K25
Beteckning 2:	

Analys	Resultat	Mätosäk. Enhet	Metod	Analys	Resultat	Mätosäk. Enhet	Metod
SiO ₂ *	0,849	%	ICP-AES	S *	4020	mg/kg	ICP-AES
Al ₂ O ₃ *	0,308	%	ICP-AES	Sc *	<1	mg/kg	ICP-AES
CaO *	0,129	%	ICP-AES	Sn *	<20	mg/kg	ICP-AES
Fe ₂ O ₃ *	0,987	%	ICP-AES	Sr *	8,03	mg/kg	ICP-AES
K ₂ O *	0,0974	%	ICP-AES	V *	283	mg/kg	ICP-AES
MgO *	0,0398	%	ICP-AES	W *	<60	mg/kg	ICP-AES
MnO *	0,0167	%	ICP-AES	Y *	<2	mg/kg	ICP-AES
Na ₂ O *	0,0926	%	ICP-AES	Zn *	44,2	mg/kg	ICP-AES
P ₂ O ₅ *	0,0081	%	ICP-AES	Zr *	2,54	mg/kg	ICP-AES
TiO ₂ *	0,0090	%	ICP-AES				
Summa *	2,5	%	Man.lnm.				
As *	5,46	mg/kg	ICP-QMS				
Ba *	105	mg/kg	ICP-AES				
Be *	<0,6	mg/kg	ICP-AES				
Cd *	<0,4	mg/kg	ICP-QMS				
Co *	2,63	mg/kg	ICP-QMS				
Cr *	12,7	mg/kg	ICP-AES				
Cu *	4,72	mg/kg	ICP-QMS				
Hg *	<0,3	mg/kg	AFS				
La *	7,51	mg/kg	ICP-AES				
Mo *	<6	mg/kg	ICP-AES				
Nb *	<6	mg/kg	ICP-AES				
Ni *	43,2	mg/kg	ICP-AES				
Pb *	8,10	mg/kg	ICP-QMS				

Vid analys av As, Cd, Cu, Co, Hg, Ni, Pb, Sb, Se och S gäller: Upplösning har skett enligt ASTM D3683 (modifierad). För övriga grundämnen har upplösning skett enligt ASTM D3682 (LiBO₂ – smälta) .

Vid analys av B har upplösning skett i mikrovågsugn med HNO₃.

Analys har skett enligt EPA –metoder (modifierade) 200.7 (ICP-AES) och 200.8 (ICP-QMS).

Parametrar märkta med * indikerar ej ackrediterade analyser.

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Kemist

DUST SAMPLES-Preliminary

2003-06-18

Sample No	Sampling place	Date	Starttime hhmm	Stoptime hhmm	Meas.Time min	Dust content g/m3n dry gas	Moisture %
1	Before wet venturie, off gas	2003-06-05	11,41	11,55	14,00	9,80	2,04
2	Before wet venturie, off gas	2003-06-05	12,38	12,47	9,00	2,40	3,40
3	Before wet venturie, off gas	2003-06-05	14,03	14,29	26,00	3,60	1,22
4	Before wet venturie, off gas	2003-06-05	14,53	15,10	17,00	2,90	2,82
5	Before wet venturie, off gas	2003-06-06	9,56	10,16	20,00	3,60	2,59
6	Before wet venturie, off gas	2003-06-06	10,41	11,01	20,00	4,60	3,62
7	Before wet venturie, off gas	2003-06-06	11,23	11,49	26,00	1,70	1,99
8	Before wet venturie, off gas	2003-06-06	12,49	13,01	12,00	1,90	2,65
9	Before wet venturie, off gas	2003-06-06	13,51	14,01	10,00	2,20	6,09
10	Before wet venturie, off gas	2003-06-06	14,34	14,48	14,00	3,20	0,94
11	Before wet venturie, off gas	2003-06-10	10,06	10,23	17,00	9,90	1,02
12	Before wet venturie, off gas	2003-06-10	10,48	11,03	15,00	8,60	2,27
13	Before wet venturie, off gas	2003-06-10	11,42	11,51	9,00	11,70	2,44
14	Before wet venturie, off gas	2003-06-10	12,38	12,53	15,00	13,00	2,47
15	Before wet venturie, off gas	2003-06-10	13,35	13,51	16,00	21,20	1,35
16	Before wet venturie, off gas	2003-06-11	9,40	9,50	10,00	13,30	2,72
17	Before wet venturie, off gas	2003-06-11	10,30	10,43	13,00	10,70	2,59
18	Before wet venturie, off gas	2003-06-11	11,40	11,56	16,00	7,20	2,49
19	Before wet venturie, off gas	2003-06-11	12,59	13,12	13,00	7,00	2,91
20	Before wet venturie, off gas	2003-06-11	14,17	14,29	12,00	12,80	2,38
21	Before wet venturie, off gas	2003-06-12	11,23	11,39	16,00	11,10	3,38
22	Before wet venturie, off gas	2003-06-12	13,28	13,36	8,00	2,80	3,50
23	Before wet venturie, off gas	2003-06-12	14,14	14,29	15,00	11,60	2,53
24	Before wet venturie, off gas	2003-06-12	15,56	16,16	20,00	14,60	1,87
25	Before wet venturie, off gas	2003-06-13	9,26	9,48	22,00	6,30	3,34
26	Before wet venturie, off gas	2003-06-13	10,33	10,39	6,00	8,10	4,81
27	Before wet venturie, off gas	2003-06-13	11,33	11,56	23,00	0,70	1,56
28	Before wet venturie, off gas	2003-06-13	12,29	12,53	24,00	9,20	2,72
29	Before wet venturie, off gas	2003-06-13	13,34	13,44	10,00	10,80	3,17
30	Before wet venturie, off gas	2003-06-13	14,09	14,23	14,00	12,40	1,67

L0306059

Sidan 1 av 3

Er Order Id:
Registrerad: 2003-06-26
Analyserad: 2003-07-14
Utfärdad: 2003-07-25

MEFOS
L-E From

Box 812
971 25 Luleå

Analyspaket: **MG2-N**

Provnummer:	U10097096-00
Beteckning 1:	Prov 7
Beteckning 2:	

Analys	Resultat	Mätosäk.	Enhet	Metod	Analys	Resultat	Mätosäk.	Enhet	Metod
SiO ₂ *	9,64		%	ICP-AES	S *	7250		mg/kg	ICP-AES
Al ₂ O ₃ *	4,28		%	ICP-AES	Sc *	3,71		mg/kg	ICP-AES
CaO *	4,97		%	ICP-AES	Sn *	<20		mg/kg	ICP-AES
Fe ₂ O ₃ *	10,3		%	ICP-AES	Sr *	59,3		mg/kg	ICP-AES
K ₂ O *	1,84		%	ICP-AES	V *	131		mg/kg	ICP-AES
MgO *	0,728		%	ICP-AES	W *	<60		mg/kg	ICP-AES
MnO *	0,276		%	ICP-AES	Y *	8,12		mg/kg	ICP-AES
Na ₂ O *	0,798		%	ICP-AES	Zn *	2130		mg/kg	ICP-AES
P ₂ O ₅ *	0,0417		%	ICP-AES	Zr *	25,9		mg/kg	ICP-AES
TiO ₂ *	0,136		%	ICP-AES					
Summa *	33,0		%	Man.Inm.					
As *	12,3		mg/kg	ICP-QMS					
Ba *	76,5		mg/kg	ICP-AES					
Be *	1,40		mg/kg	ICP-AES					
Cd *	7,69		mg/kg	ICP-QMS					
Co *	19,0		mg/kg	ICP-QMS					
Cr *	90,8		mg/kg	ICP-AES					
Cu *	55,1		mg/kg	ICP-AES					
Hg *	0,618	0,128	mg/kg	AFS					
La *	10,0		mg/kg	ICP-AES					
Mo *	7,56		mg/kg	ICP-AES					
Nb *	<6		mg/kg	ICP-AES					
Ni *	61,6		mg/kg	ICP-AES					
Pb *	154		mg/kg	ICP-QMS					

Vid analys av As, Cd, Cu, Co, Hg, Ni, Pb, Sb, Se och S gäller: Upplösning har skett enligt ASTM D3683 (modifierad). För övriga grundämnen har upplösning skett enligt ASTM D3682 (LiBO₂ – smälta).

Vid analys av B har upplösning skett i mikrovågsugn med HNO₃.

Analys har skett enligt EPA –metoder (modifierade) 200.7 (ICP-AES) och 200.8 (ICP-QMS).

U10097096-00: -97101 Förlite material för C-analys

Parametrar märkta med * indikerar ej ackrediterade analyser.

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Dan Krekula
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L0306059

Sidan 2 av 3

Er Order Id:
Registrerad: 2003-06-26
Analyserad: 2003-07-14
Utfärdad: 2003-07-25

MEFOS
L-E From

Box 812
971 25 Luleå

Analyspaket: **MG2-N**

Provnummer:	U10097097-00
Beteckning 1:	Prov 21
Beteckning 2:	

Analys	Resultat	Mätosäk.	Enhet	Metod	Analys	Resultat	Mätosäk.	Enhet	Metod
SiO ₂ *	0,881		%	ICP-AES	S *	1740		mg/kg	ICP-AES
Al ₂ O ₃ *	0,280		%	ICP-AES	Se *	<1		mg/kg	ICP-AES
CaO *	30,5		%	ICP-AES	Sn *	<20		mg/kg	ICP-AES
Fe ₂ O ₃ *	15,4		%	ICP-AES	Sr *	99,4		mg/kg	ICP-AES
K ₂ O *	0,119		%	ICP-AES	V *	93,9		mg/kg	ICP-AES
MgO *	0,907		%	ICP-AES	W *	<60		mg/kg	ICP-AES
MnO *	0,265		%	ICP-AES	Y *	3,82		mg/kg	ICP-AES
Na ₂ O *	0,0561		%	ICP-AES	Zn *	798		mg/kg	ICP-AES
P ₂ O ₅ *	0,0183		%	ICP-AES	Zr *	2,70		mg/kg	ICP-AES
TiO ₂ *	0,0062		%	ICP-AES					
Summa *	48,4		%	Man.Inm.					
As *	2,65		mg/kg	ICP-QMS					
Ba *	6,58		mg/kg	ICP-AES					
Be *	<0,6		mg/kg	ICP-AES					
Cd *	0,386		mg/kg	ICP-QMS					
Co *	9,25		mg/kg	ICP-QMS					
Cr *	46,9		mg/kg	ICP-AES					
Cu *	9,16		mg/kg	ICP-QMS					
Hg *	<0,1		mg/kg	AFS					
La *	<6		mg/kg	ICP-AES					
Mo *	<6		mg/kg	ICP-AES					
Nb *	<6		mg/kg	ICP-AES					
Ni *	24,7		mg/kg	ICP-AES					
Pb *	59,8		mg/kg	ICP-QMS					

Vid analys av As, Cd, Cu, Co, Hg, Ni, Pb, Sb, Se och S gällar: Upplösning har skett enligt ASTM D3683 (modifierad). För övriga grundämnen har upplösning skett enligt ASTM D3682 (LiBO₂ – smälta).

Vid analys av B har upplösning skett i mikrovågsugn med HNO₃.

Analys har skett enligt EPA –metoder (modifierade) 200.7 (ICP-AES) och 200.8 (ICP-QMS).

U10097096-00: -97101 Förlite material för C-analys

Parametrar märkta med * indikerar ej akkrediterade analyser.

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Dan Krekula
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L0306059

Sidan 3 av 3

Er Order Id:
Registrerad: 2003-06-26
Analyserad: 2003-07-14
Utfärdad: 2003-07-25

MEFOS
L-E From

Box 812
971 25 Luleå

Analyspaket: **MG2-N**

Provnummer:	U10097098-00
Beteckning 1:	Prov 25
Beteckning 2:	

Analys	Resultat	Mätosäk.	Enhet	Metod	Analys	Resultat	Mätosäk.	Enhet	Metod
SiO ₂ *	1,16		%	ICP-AES	S *	4230		mg/kg	ICP-AES
Al ₂ O ₃ *	0,353		%	ICP-AES	Sc *	<1		mg/kg	ICP-AES
CaO *	33,7		%	ICP-AES	Sn *	<20		mg/kg	ICP-AES
Fe ₂ O ₃ *	16,8		%	ICP-AES	Sr *	113		mg/kg	ICP-AES
K ₂ O *	0,0969		%	ICP-AES	V *	240		mg/kg	ICP-AES
MgO *	0,896		%	ICP-AES	W *	<60		mg/kg	ICP-AES
MnO *	0,0906		%	ICP-AES	Y *	4,42		mg/kg	ICP-AES
Na ₂ O *	0,0557		%	ICP-AES	Zn *	316		mg/kg	ICP-AES
P ₂ O ₅ *	0,0234		%	ICP-AES	Zr *	5,28		mg/kg	ICP-AES
TiO ₂ *	0,0049		%	ICP-AES					
Summa *	53,2		%	Man.Inm.					
As *	11,4		mg/kg	ICP-QMS					
Ba *	28,6		mg/kg	ICP-AES					
Be *	<0,6		mg/kg	ICP-AES					
Cd *	0,644		mg/kg	ICP-QMS					
Co *	21,8		mg/kg	ICP-AES					
Cr *	22,8		mg/kg	ICP-AES					
Cu *	18,0		mg/kg	ICP-QMS					
Hg *	<0,2		mg/kg	AFS					
La *	<6		mg/kg	ICP-AES					
Mo *	<6		mg/kg	ICP-AES					
Nb *	<6		mg/kg	ICP-AES					
Ni *	136		mg/kg	ICP-AES					
Pb *	16,6		mg/kg	ICP-QMS					

Vid analys av As, Cd, Cu, Co, Hg, Ni, Pb, Sb, Se och S gäller: Upplösning har skett enligt ASTM D3683 (modifierad). För övriga grundämnen har upplösning skett enligt ASTM D3682 (LiBO₂ – smälta) .

Vid analys av B har upplösning skett i mikrovågsugn med HNO₃.

Analys har skett enligt EPA –metoder (modifierade) 200.7 (ICP-AES) och 200.8 (ICP-QMS).

U10097096-00: -97101 Förlite material för C-analys

Parametrar märkta med * indikerar ej ackrediterade analyser.

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Signatur

Dan Krekula
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RAPPORT

L0305883

Sidan 1 av 2

Er Order Id: MEFOS
Registrerad: 2003-06-19 L-E From
Analyserad: 2003-07-01
Utfärdad: 2003-07-25 Box 812
971 25 Luleå

Analyspaket: **V3A-N**

Provnummer:	U10096343-00	U10096344-00
Beteckning 1:	Prov 0	Prov 1
Beteckning 2:		

Analys	Resultat	Mätosäk.	Enhet	Metod	Analys	Resultat	Mätosäk.	Enhet	Metod
Volym *	130		ml	Man.Inm.	Volym *	206		ml	Man.Inm.
Hg *	<0,02		µg/l	AFS	Hg *	253		µg/l	AFS

Analys av absorptionslösning.

Analys har skett enligt EPA-metoder (modifierade) 200.7 (ICP-AES) och 200.8 (ICP-SMS).

Parametrar märkta med * indikerar ej ackrediterade analyser.

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Signatur

Emma Engström
Kemist

RAPPORT

L0305883

Sidan 2 av 2

Er Order Id: MEFOS
Registrerad: 2003-06-19 L-E From
Analyserad: 2003-07-01
Utfärdad: 2003-07-25 Box 812
971 25 Luleå

Analyspaket: **V3A-N**

Provnummer:	U10096345-00	U10096346-00
Beteckning 1:	Prov 2	Prov 3
Beteckning 2:		

Analys	Resultat	Mätosäk.	Enhet	Metod	Analys	Resultat	Mätosäk.	Enhet	Metod
Volym *	177		ml	Man.Inm.	Volym *	86		ml	Man.Inm.
Hg *	0,456		µg/l	AFS	Hg *	0,0431		µg/l	AFS

Analys av absorptionslösning.

Analys har skett enligt EPA-metoder (modifierade) 200.7 (ICP-AES) och 200.8 (ICP-SMS).

Parametrar märkta med * indikerar ej ackrediterade analyser.

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Aurorum 10
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Signatur

Emma Engström
Kemist

Appendix II

Kvaerner Process Flow, Hydrogen Purification, Amine and CO-Water Gas Shift Studies

REV	DATE	BY	CHKD	DESCRIPTION	APPROV

These drawings are the property of ENVIRES LLC. If they are used for any purpose other than that for which they were prepared, the user assumes all liability for the consequences. The user agrees to indemnify and hold ENVIRES LLC harmless from and for all claims, damages, costs and expenses, including attorney's fees, arising out of or from the use of these drawings in any manner not intended by ENVIRES LLC.

The Hymelt Process
WATER GAS SHIFT OPTION
PROCESS FLOW DIAGRAM
HYMELT REACTOR

FOR: PROJECT NO.	CLIENT #1
SCALE: 1" = 10' - 0"	CLIENT #2
DATE: 10/1/2010	SCALE: 1" = 10' - 0"
BY: J. K. KREMER	SCALE: 1" = 10' - 0"
CHKD: J. K. KREMER	SCALE: 1" = 10' - 0"
DATE: 10/1/2010	SCALE: 1" = 10' - 0"

DISCIPLINE	DESIGNER	CHECKER	SCALE	DATE	FILE NAME	DRAWING NO.	REV

CONST. NO.	CONST. DATE	CONST. BY	CONST. CHKD.	CONST. DATE	CONST. BY	CONST. CHKD.

CONST. NO.	CONST. DATE	CONST. BY	CONST. CHKD.	CONST. DATE	CONST. BY	CONST. CHKD.

CONST. NO.	CONST. DATE	CONST. BY	CONST. CHKD.	CONST. DATE	CONST. BY	CONST. CHKD.

CONST. NO.	CONST. DATE	CONST. BY	CONST. CHKD.	CONST. DATE	CONST. BY	CONST. CHKD.

July 9, 2003

Email: mike.friedrich@akerkvaerner.com

Mr. Mike Friedrich
Aker Kvaerner
1200 Penn Avenue
Pittsburgh, PA 15222

SUBJECT: UOP Polybed PSA Unit
Envires, Kentucky
UOP Proposal P3H038 Rev. 4

Dear Mike,

In reply to your request, two budgetary designs and price estimates are provided for a UOP Polybed PSA Unit that produces a hydrogen product for the Hymelt Process.

Case 1 produces 15.31 MMSCFD of product hydrogen and Case 2 produces 28.39 MMSCFD of product hydrogen.

If there are any questions, please contact me at 713-744-2863 or email: Eugene.kuchta@uop.com.

Sincerely,

Eugene Kuchta

Process Technology & Equipment

EAK:rk

UOP POLYBED™PSA UNIT

for

Kvaerner

Envires / Hymelt Process

Project No: P3H038

July 9, 2003

Case 1 : 15.31 MM SCFD Product

		<u>Feed</u>	<u>Product</u>	<u>Tail Gas</u>
Flowrate,	MM SCFD	19.08	15.31	3.76
	lb-mol/hr	2,095	1,681	413
Pressure,	psig	500	490	5 (Ex ST)
Temperature,	°F	120	130	110
	°C	49	54	43
Composition, mol%				
Hydrogen		93.24	99.9	66.15
Nitrogen		1.13	Balance	5.32
Carbon Monoxide		3.69	10 ppmv	18.70
Carbon Dioxide		0.01	--	0.05
Methane		0.86	Balance	4.36
Acetylene		0.01	--	0.05
Water		0.01	--	0.05

Hydrogen Sulfide	1.00	--
Hydrogen Cyanide	0.05	--

5.07

0.25

Design Hydrogen Recovery: 86%

PSA Price ($\pm$ 20% FCA USA. Shop): \$1,700,000 USD

PSA Approximate Plot Size: 50 ft. x 30 ft.

PSA Utilities:

Instrument Air 1,400 SCFH @ 85 psig

Electric Power 5.0 kW @ 120 VAC, 1 ph, 60 Hz

Nitrogen (Startup only)

Leak Test 120,000 SCF @ 500 psig

Purge 60,000 SCF @ 85 psig

UOP POLYBED™PSA UNIT

for

Kvaerner

Envires / Hymelt Process

Project No: P3H038

July 9, 2003

Case 2 : 28.39 MM SCFD Product

		<u>Feed</u>	<u>Product</u>	<u>Tail Gas</u>
Flowrate,	MM SCFD	46.19	28.39	17.80
	lb-mol/hr	5,072	3,118	1,954
Pressure,	psig	491	481	5 (Ex ST)
Temperature,	°F	120	130	110
	°C	49	54	43
Composition, mol%				
	Hydrogen	71.40	99.9	25.94
	Nitrogen	0.60	Balance	1.40
	Carbon Monoxide	5.20	10 ppmv	13.49
	Carbon Dioxide	21.70	--	56.31
	Methane	0.40	Balance	1.04
	Water	0.20	--	0.52

Hydrogen Sulfide	0.40	--	1.04
Hydrogen Cyanide	0.10	--	0.26

Design Hydrogen Recovery: 86%

PSA Price ($\pm$ 20% FCA USA Shop): \$2,500,000 USD

PSA Approximate Plot Size: 70 ft. x 40 ft.

PSA Utilities:

Instrument Air 3,400 SCFH @ 85 psig

Electric Power 5.0 kW @ 120 VAC, 1 ph, 60 Hz

Nitrogen (Startup only)

Leak Test 360,000 SCF @ 491 psig

Purge 180,000 SCF @ 85 psig

UOP POLYBED™PSA UNIT

for

Kvaerner

Envires / Hymelt Process

Project No: P3H038

July 9, 2003

UOP Scope of Supply includes

Adsorber Vessels

Off-Gas Drum(s)

Valve and Piping Skid

Initial Adsorbent Charge

Engineering

Control Panel with CRT

Relief Valves for Adsorber Vessels and Off-Gas Drum

Block Valves

Interconnecting Piping from Adsorber Vessels to Skid

Customer Scope of Supply includes

but is not limited to

Foundation including Anchor Bolts

Installation of All UOP Supplied Equipment

Piping from Valve and Piping Skid to Off-Gas Drum

Adsorbent Loading Under UOP Supervision

Performance Test

Piping To/From PSA Battery Limits

Wiring between Skid and Control Cabinet/CRT

Supply of Utilities

Leak and Pressure Test of the PSA Unit

Design and Supply of Peripheral Controls

- Product Back Pressure Control Valve
- Feed KO Drum
- Feed Flow Control
- Block Valves on All Piping To/From Unit
- Feed and Tail Gas Vent
- Tail Gas Flow/Pressure Control

Analyzer

Finish Paint

Notes:

1. The price is quoted exclusive of taxes, crating, insurance, or freight costs, and is based upon UOP standard fabrication and third quarter, 2003, costs.
2. The typical U.S. installation cost for Polybed™ PSA Units similar to the proposed system has been approximately 15% of UOP's quoted purchase price.

SPECIALTY ALKANOLAMINES

Gas Treating Products

Products, Technology and Service from Dow

AkerKvaerner PSA TGU

Contents:	Page Number
Simulation Summary	1
Feed and product Quality	
Treated Gas Conditions	
Solvent	
Solution Conditions	
Regenerator Conditions	
Exchanger Data	
Major Equipment Summary	2
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Regenerator	
Reboiler	
Lean/Rich Exchanger	
Lean Solvent Cooler	
Reflux Condenser	
Stream Summary	3
Process Flow Diagram	4

SPECIALTY ALKANOLAMINES

AkerKvaerner PSA TGU

Absorber Feed Gas Conditions

Gas Flow Rate: 22.09 MM SCFD
Pressure: 5.00 Psig
Temperature: 110.0 Deg F

Composition

	<u>Feed</u>		<u>Product</u>	
	<u>Mol %</u>	<u>LB MOL/HR</u>	<u>Mol%</u>	<u>LB MOL/HR</u>
H2S	0.86%	20.98	0.00%	0.02
CO2	65.29%	1,583.19	60.56%	1,424.87
H2	20.10%	487.47	20.72%	487.44
CO	11.40%	276.52	11.75%	276.50
N2	1.02%	24.69	1.05%	24.69
CH4	0.75%	18.09	0.77%	18.09
C2H6	0.02%	0.58	0.02%	0.58
C3H8	0.05%	1.16	0.05%	1.16
H2O	0.51%	12.32	5.08%	119.47
UCARSOL	0.00%	0.00	0.00%	0.00
TOTAL	100.00%	2,425.00	100.00%	2,352.82

Treated Gas Conditions

GAS FLOW RATE: 21.43 MM SCFD
H2S 10 PPMV
CO2 63.8 %(V/V) DRY
CO2 Slippage 90.0 %

Solvent

Name UCARSOL HS 103
Lean Solvent Flow 560.0 GPM
Amine Strength 50.00 %(W/W)
Internals - Number of Contact Trays 10 TRAYS

Solution Conditions

Lean Solvent Temperature 100.0 Deg F
Lean Loading 0.005 Mol/Mol
Rich Loading 0.159 Mol/Mol

Regenerator Conditions:

Tower Internals - Number of Trays 20 TRAYS
Rich Amine Feed Temp 213.3 Deg F
Reboiler Press 13.0 Psig
Reflux Flow 31.8 GPM

Exchanger Data:

Lean Cooler Duty 13.681 MM BTU/HR
Lean - Rich Exch'r 27.269 MM BTU/HR
Reflux Cond'r Duty 17.221 MM BTU/HR
Reboiler Duty 32.619 MMBTU/HR

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AkerKvaerner PSA TGU**Major Equipment Summary****Absorber**

Absorber Internals	10 TRAYS
Absorber Diameter	7.6 FT
Lean Loading	0.005 Mol/Mol
Rich CO ₂ Loading	0.141 Mol/Mol
Rich H ₂ S Loading	0.019 Mol/Mol
Atmospheric Pressure	14.7 Psia

Treated Gas H ₂ S	10.0 PPMV
Treated Gas CO ₂	63.8 %(V/V) DRY

Regenerator

Regenerator Internals	20 TRAYS
Regenerator Diameter	6.3 FT
O/H Reflux Ratio	5.00 Mol H ₂ O/Mol AG
Regenerator Heat to Acid Gas Ratio	181.954 M BTU/Mol Acid Gas
Steam to Feed Ratio	1.077 LB/GAL

Reboiler

Heat Duty	32.619 MMBTU/HR	U	145.0 BTU/HR-FT ² -DEGF
Steam Rate	35.8 M LB/HR	LMTD	41.8 Deg F
Reboiler Temperature	253.3 Deg F	Fn	1.00
Reboiler Steam Pressure	50.0 Psig	Area	5,384 SQFT

Lean/Rich Exchanger

Heat Duty	27.269 MM BTU/HR	U	120 BTU/HR-FT ² -DEGF
Rich Inlet Temp	110.0 Deg F	LMTD	41.6 Deg F
Rich Outlet Temp	213.3 Deg F	Fn	0.80
Lean Inlet Temp	253.3 Deg F	Area	6,836 SQFT
Lean Outlet Temp	153.1 Deg F		

Lean Solvent Cooler

Type	AIR	U	90 BTU/HR-FT ² -DEGF
Heat Duty	13.681 MM BTU/HR	LMTD	15.4 Deg F
Lean Inlet Temp	153.1 Deg F	Fn	0.80
Lean Outlet Temp	100.0 Deg F	Area	12,309 SQFT

Reflux Condenser

Type	AIR	U	64 BTU/HR-FT ² -DEGF
Heat Duty	17.221 MM BTU/HR	LMTD	49.7 Deg F
Inlet Temp	231.6 Deg F	Fn	0.80
Outlet Temp	120.0 Deg F	Area	6,759 SQFT
Reflux Flow Rate	31.8 GPM		

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AkerKvaerner PSA TGU

Stream Summary			Feed Gas 1	Product Gas 2	Lean UCARSOL 3	Cool Rich UCARSOL 4	Hot Rich UCARSOL 5	Hot Lean UCARSOL 6	Warm Lean UCARSOL 7	Stripper Overhead 8	Reflux Liquid 9
Temperature		Deg F	110.0	100.0	100.0	110.0	213.3	253.3	153.1	231.6	120.0
Pressure		Psig	5.0	4.0	4.0	5.0	.0	13.0			11.0
Gas Flow		MM SCFD	22.1	21.4						9.80	
Liquid Flow		GPM			560.0	573.2	-	594.4	570.4		31.8
Lean Solution Density		LB/GAL			8.8	8.7	8.4	8.3	8.6		8.7
Lean Solution Viscosity		cP			5.35			0.96	2.25		
Lean Solution Specific Heat		BTU/LB-F			0.858			0.956	0.889		
Lean Solution Surface Tension		DYNE/CM			38.8			30.3	35.9		
Lean Solution Thermal Conductivity		BTU/HR-FT-F			0.27			0.328	0.298		
H2S		LB MOL/HR	20.98	0.02	0.68	21.63	21.63	0.68	0.68	20.95	
CO2		LB MOL/HR	1,583.19	1,424.87	5.13	163.45	163.45	5.13	5.13	158.32	
H2		LB MOL/HR	487.47	487.44		0.03	0.03			0.03	
CO		LB MOL/HR	276.52	276.50		0.02	0.02			0.02	
N2		LB MOL/HR	24.69	24.69		0.00	0.00			0.00	
CH4		LB MOL/HR	18.09	18.09		0.00	0.00			0.00	
C2H6		LB MOL/HR	0.58	0.58		0.00	0.00			0.00	
C3H8		LB MOL/HR	1.16	1.16		0.00	0.00			0.00	
H2O		LB MOL/HR	12.32	119.47	8,184.32	8,077.67	8,077.67	8,184.82	8,184.82	896.36	883.17
UCARSOL HS		LB MOL/HR		0.003	1,161.02	1,161.02	1,161.02	1,161.02	1,161.02	0.379	0.379
TOTAL		LB MOL/HR	2,425.00	2,352.82	9,351.64	9,423.82	9,423.82	9,351.64	9,351.64	1,076.07	883.55
TOTAL		LB/HR	80,391.4	74,640.1	295,147.8	300,899.1	300,899.1	295,147.8	295,147.8	23,830.3	15,958.5
M/H A.G.		LB MOL/HR	1,604.16	1,424.89	5.81	185.08	185.08	5.81	5.81	179.27	

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C99168

Stream Number	2-1	2-2	2-3	2-4	2-5	2-6	2-7	2-8	2-9	2-10	2-11	2-12	2-13			H2
Description	COFEED	HTRIN1	COFEED2	WGOUT	WHBIN	WGWHB OUT	FLASHIN	FLASHOUT	FLOCOND	WGSOUT	REC	PSAPROD	TAILGAS	Convey. H2		PRODUCT
Temperature F	350	192.4	600	842.5	694.9	390.3	120	120	120	119.9	126.1	130	110	130		130
Pressure psia	500	500	497	496	493	490	487	486	486	485	475	475	19.7	475		475
Vapor Frac	1	1	1	1	1	1	0.646	1	0	1	1	1	1	1		1
Mole Flow lbmol/hr	1816.315	5537.209	10912.55	10912.55	10912.55	10912.55	10912.553	7045.592	3866.961	3324.701	3720.891	2994.447	2424.883	1400		1594.447
Mass Flow lb/hr	51524.224	139485.15	236323.5	236323.5	236323.5	236323.5	236323.49	166555.9	69767.546	78595.05	87960.9	6038.129	80368.87	2823.019		3215.111
Volume Flow cuft/hr	32111.641	77404.455	245686	307933	273443.6	197321.5	89632.643	88311.34	1503.461	41755.83	45844.97	40665.93	750683.8	19012.626		21653.31
Enthalpy MMBtu/hr	-91.849	-402.652	-921.167	-921.125	-936.191	-966.694	-1065.708	-588.848	-476.859	-277.868	-310.803	1.136	-282.267	0.531		0.60505
Mole Flow lbmol/hr																
CO	1702.668	1925.713	1925.713	422.348	422.348	422.348	422.348	422.347	0.001	199.299	223.048	0.028	276.508	0.013		0.015
H2	25.356	1736.241	1736.241	3239.606	3239.606	3239.606	3239.594	3239.594	0.012	1528.712	1710.882	2994.375	487.456	1399.966		1594.409
H2O	3.051	16.546	5391.891	3888.525	3888.525	3888.525	3888.525	25.552	3862.973	12.058	13.495	0	12.325	0		0
CH4	0.163	0.346	0.346	0.346	0.346	0.346	0.346	0.346	0	0.163	0.183	0.018	18.098	0.008		0.01
C2H2	0.272	0.577	0.577	0.577	0.577	0.577	0.577	0.577	0	0.272	0.305	0	0.584	0		0
N2	1.108	2.348	2.348	2.348	2.348	2.348	2.348	2.348	0	1.108	1.24	0.025	24.673	0.012		0.013
CO2	83.55	1855.13	1855.13	3358.495	3358.495	3358.495	3358.495	3354.521	3.974	1582.944	1771.577	0	1583.099	0		0
H2S	0.031	0.065	0.065	0.065	0.065	0.065	0.065	0.064	0.001	0.03	0.034	0.002	20.974	0.001		0.001
COS	0.114	0.242	0.242	0.242	0.242	0.242	0.242	0.242	0	0.114	0.128	0	0.12	0		0
HCN	0	0	0	0	0	0	0	0	0	0	0	0	1.043	0		0
HG	0	0	0	0	0	0	0	0	0	0	0	0	0.001	0		0
*** VAPOR PHASE ***																
Enthalpy Btu/lb	-1782.636	-2886.704	-3897.905	-3897.728	-3961.479	-4090.553	-3535.439	-3535.439	-3535.439	-3535.446	-3533.423	188.158	-3512.138	188.158		188.158
Heat Cap Btu/lb-R	0.261	0.327	0.415	0.436	0.429	0.421	0.36	0.36	0.36	0.36	0.361	3.448	0.254	3.448		3.448
Conductivity Btu-ft/hr-sqf	0.022	0.035	0.041	0.065	0.058	0.042	0.039	0.039	0.039	0.039	0.039	0.112	0.021	0.112		0.112
Density lb/cuft	1.605	1.802	0.962	0.767	0.864	1.198	1.89	1.886	0.112	1.882	1.919	0.148	0.107	0.148		0.148
Viscosity cP	0.024	0.019	0.024	0.029	0.027	0.02	0.017	0.017	0.017	0.017	0.017	0.01	0.016	0.01		0.01
WSTDIMX @ 60 F. MMcut/day	16.543	50.432	99.389	99.389	99.389	99.389	99.389	64.170		30.281	33.889	27.273	22.085	12.751		14.522
*** LIQUID PHASE ***																
Enthalpy Btu/lb							-6834.935		-6834.971							
Heat Cap Btu/lb-R							1.146		1.146							
Conductivity Btu-ft/hr-sqf							0.335		0.335							
Density lb/cuft							46.404		46.405							
Viscosity cP							0.564		0.564							
Surface Ten dyne/cm							68.034		68.036							
Flowrate gpm																

Balance14Jul03.xls

C99168

PRELIMINARY MATERIAL BALANCE - Water Gas Shift Option

Stream Number	2-14	2-15	2-16	2-17 *	1-20	2-18	2-19	2-20	2-21	2-22	2-23	2-24	2-25	2-26	2-27	2-28
Description	CLEAN TAIL GAS	CLAUS FEED	BOILER FLUE	SULFUR PRODUCT	H ₂ FEED	CITY WATER	STRIPPED COND	DEMIN MAKE-UP	DEMIN TO RX GAS TRAIN BOILERS	DEMIN TO WGS BOILERS	MED PRES BFW	WATER GAS SHIFT WHB BFW	WATER GAS SHIFT WHB BDOWN	MED PRES BDOWN	DEMIN PLANT WASTE	STEAM COND RETURN
Temperature F	100	120	465		120	60	212	100	100	100	250	250	308	474	100	298
Pressure psia	18.7	24.7	14.7		500	90	15	65	65	65	715	215	75	535	65	65
Vapor Frac	1	1	1		1	0	0	0	0	0	0	0	0	0	0	0
Mole Flow lbmol/hr	2352.714	192.502	6520		2094.63	2006.97	4219.37	6164.08	856.73	5187.01	6097.81	1772.97	17.76	120.34	62.26	1985.57
Mass Flow lb/hr	74618	7919	204170	670	7811.948	36155	76012	111046	15434	93444	109852	31940	320	2168	1122	35770
Volume Flow cuft/hr					26584.86											
Enthalpy MMBtu/hr					-3.749											
Mole Flow lbmol/hr																
CO	276.489	0.019			77.237											
H ₂	487.427	0.029			1953.119											
H ₂ O	119.470	13.190	928.77		0.268	2006.97	4219.37	6164.08	856.73	5187.01	6097.81	1772.97	17.76	120.34	62.26	1985.57
CH ₄	18.098	0.000			17.953											
C ₂ H ₂	0.584	0.000			0.312											
N ₂	24.673	0.000	3505.48		23.59											
CO ₂	1424.789	158.310	1872.48		0.155											
H ₂ S	0.021	20.953	802.22 ppmv		20.946											
COS	0.120	0.000			0.006											
HCN	1.043	0.000			1.043											
HG	0.001	0.000			0.001											
*** VAPOR PHASE ***																
Enthalpy Btu/lb					-479.868											
Heat Cap Btu/lb-R					1.877											
Conductivity Btu-ft/hr-sqft					0.099											
Density lb/cuft					0.294											
Viscosity cP					0.011											
WVSTDMX @ 60 F. MMbtu/day	21.428	1.753	59.383		19.077											
*** LIQUID PHASE ***																
Enthalpy Btu/lb																
Heat Cap Btu/lb-R																
Conductivity Btu-ft/hr-sqft																
Density lb/cuft																
Viscosity cP																
Surface Ten dyne/cm																
Flowrate gpm						72.3	158.6	223.5	31.1	188.1	233.2	67.8	0.8	4.9	2.3	80.3

PRELIMINARY MATERIAL BALANCE - Water Gas Shift Option

[illegible]

Water Gas Shift Equipment List
C99268
EnviRes LLC HyMelt Process

Equipment Number	Quantity	Operating/S tandby	Description	Capacity/Size	Motor Hp operating/ connected
14202	1	1/0	Sulfur Storage Pit	10,000 gallon	
31201	1	1/0	WGS Heat Exchanger	15.1 MM Btu/h; Shell: 0.5 Mo; Tube: 316 SS	
31202	1	1/0	Start-up Heater	5 MM Btu/h; Shell: CS; Tube: CS	
31203	1	1/0	WGS Cooler	99.0 MM Btu/h; Shell&Tube: 316 SS	
32105	1	1/0	Condensate Stripper	3 ft dia. X 20' T/T; 10' packed section; Shell SS	
34201	1	1/0	City Water Storage Tank	400,000 gallons, CS	
35201	2	1/1	WGS Filter	2 ft dia. X 10 ft high, 500 psig, 120 F	
35202	1	1/0	Water Gas Shift Reactor	10 ft dia x 20 ft high, 1.0 Cr, 0.5 Mo	
35204	1	1/0	WGS Cooler Flash Drum	9 ft.x 18 ft high	
35205	1	1/0	Blowdown Flash Drum	1.5 ft.dia X 3 ft. high	
35212	1	1/0	WGS Reactor Catalyst	1050 ft3 each reactor bed	
40201	1	1/0	H2 Purification System	28 million SCFD H2 Product	
40202	1	1/0	Amine Scrubbing System	22 MM SCFD feed	
40202.01	1	1/0	Absorber	7.6 ft dia. X 35' T/T; 10 SS trays; Shell CS	
40202.02	1	1/0	Regenerator	6.5 ft dia. X 55' T/T; 20 SS trays; Shell CS	
40202.03	1	1/0	Lean/ Rich Exchanger	27.3 MM Btu/hr; Plate&Frame: 316 SS	
40202.04	1	1/0	Lean Solvent Cooler	13.7 MM Btu/h; Plate&Frame: 316 SS	
40202.05	1	1/0	Reflux Condenser	17.2 MM Btu/h; Tubes: 316SS; Shell: CS	
40202.06	1	1/0	Reboiler	32.6 MM Btu/h; Tubes: SS; Shell: CS	
40202.07	1	1/0	Reflux Drum	3 ft dia. X 6' T/T; SS	
40202.08	1	1/0	Activated Carbon Bed	8 ft dia. X 14' T/T; CS; 530 cu ft activated carbon	
40202.09	1	1/0	Rich Solution Filter	650 gpm; 50 micron; 8" line	
40202.10	1	1/0	Activated Carbon Inlet Guard Bed	200 gpm; 10 micron; 4" line	
40202.11	1	1/0	Activated Carbon Outlet Guard Bed	200 gpm; 10 micron; 4" line	
40202.12	2	1/1	Lean Solvent Pump	700 gpm @ 50 psi; Shaft: SS	40 / 80
40202.13	2	1/1	Rich Solvent Pump	650 gpm @ 50 psi; Shaft: SS	30 / 60
40202.14	2	1/1	Reflux Pump	40 gpm @ 100 ft TDH ; SS	2 / 4
40202.15	2	1/1	Make-up Pump	150 gpm @ 100 ft TDH	7.5 / 15
40202.16	1	1/0	Amine Storage Tank	20,000 gal; underground	
40203	1	1/0	Claus Sulfur Recovery Plant	8 tons/day skid mounted	
40203.01	1	1/0	Claus Plant Incinerator	Operation at 1000 F w/ recuperator; 0.83 MM Btu/h fuel	
40205	1	1/0	CO Power Generation Plant	Not included in this option as produce 14.5 MM SCFD Hydrogen (9.5 MM SCFD more than base case)	
41201	2	1/1	WH Boiler Feedwater Pump	80 gpm x 200 psi TDH	20 / 40
41203	2	1/1	City Water Pump	300 gpm x 100 ft. TDH	15 / 30
41204	2	1/1	MP BFW Pump	250 gpm x 700 psi TDH	150 / 300
41205	2	1/1	Sulfur Storage Pump	100 gpm x 30 psi TDH	5 / 10
41501	2	1/1	Cooling Tower Pump	13,000 gpm x 50 psi TDH	500 / 1000
42201	1	1/0	Water Gas Shift Recycle Compressor	800 acfm x 25 psi pressure rise, 500 psig discharge	150 / 150
44201	1	1/0	WGS Waste Heat Boiler	31,600 lbs/hr (60 psig)	
44202	1	1/0	Medium/ Low Pressure Boiler	97,000 lbs/hr (505 psig/700 F) & 7,300 lbs/hr (60 psig)	75 / 75
44301	1	1/0	Cooling Tower	Est. one 75 Hp comb air fan 130 MM Btu/hr; 13,000 gpm circulation Est. three fans @ 125 Hp ea.	375 / 375
47202	1	1/0	Deaerator Chemical Treatment System	Est. two 1/2 Hp metering pumps	0.5 / 1
47203	1	1/0	Boiler Chemical Treatment System	Est. two 1/2 Hp metering pumps	0.5 / 1
47204	1	1/0	Water Treatment System	250 gpm demin plant w/ inlet filter, regeneration Est. two 15 Hp demin pumps, two 20 Hp blowers; two 15 Hp pumps for regen,etc.	35 / 100
47501	1	1/0	Deaerator	350 gpm; Storage Section - 6.5 ft dia. X 21 ft T/T	

Water Gas Shift Equipment List
C99268
EnviRes LLC HyMelt Process

Project Direct Cost Comparison to Base Case

Equipment, Material Costs & Field labor			
Areas	Base Case	WGS Cost	WGS Delta
Feed Prep			\$0
Reactor Area			\$0
WGS Area	----	3113700	\$3,113,700
Hydrogen Purification	1998200	2961400	\$963,200
Amine Scrubbing	1593000	2371500	\$778,500
Claus Plant	2888500	3247000	\$358,500
Steam Generation			\$3,511,700
Power Generation		----	\$0
Utilities			\$2,800,000
			\$11,525,600

Results:

- 1.) WGS option ---> \$22,083,050 Project Total
Produce 9.5 MM SCFD more of hydrogen than base.

- 2.) Base Power Options (from CO)
 - Simple Cycle: Generate 17.8 MW for \$15,200,000
 - Combined Cyc: Generate 27 MW for \$30,600,000

Water Gas Shift Equipment List
C99268
EnviRes LLC HyMelt Process

Preliminary Economics of Water Gas Shift Option (Differential to Base Case)

Capital Cost Multiplier	1
Basis:	
Avg. On-stream Factor	90%
Amortization Parameters	
Annual Interest Rate	10%
Payoff Period	20 years

Labor Rates (all-up):

Engineering	80 \$/hr
Field Labor	70 \$/hr
Constr. Mgt	85 \$/hr

Estimated Differential Capital Costs:

Major Equipment Cost	6,206,000
Installed Equipment Cost	5,319,800
Direct Totals	11,525,800
Constr Equip & Indirects	\$2,305,160
Constr. Mgt. Staff Supv	\$794,100
Freight	\$366,520
Taxes & Permits	\$504,830
Engineering	\$2,545,600
Other Project Costs (Ovhd & GA)	\$1,342,339
Contingency	\$3,420,768
Indirect Totals	\$11,279,317
Total Capital Cost	\$22,805,117

Field Hrs	49300
% Directs	20%
% Field Hrs	18.95%
% Directs	3.18%
% Directs	4.38%
Manhours	31820
% Above Indirects	20.60%
% Total	15.00%

9342

Differential Operating & Maintenance Costs, \$ per year:

Natural Gas @ \$ / MM Btu	5	\$2,135,250
Electricity @ cents / kwh	0.04	\$443,081
Cooling Water Chem @ cents/kgal	0.02	\$122,990
BFW Chem @ cents/kgal	0.08	\$12,488
LP Stm (from Reactor) @ \$ / k lb	0	\$0
Operation/ Maint @ \$ / manhr	50000	\$150,000
Insur & Taxes @ 1% Capital/yr		\$228,051
O & M Mgt Fees		\$400,000
Spare Parts @ 5% Major Equip/yr		\$310,300
Total O & M Cost		\$3,802,161
Amortization Cost @ % capital/ yr	11.75	\$2,678,680
Total Yearly Costs		6,480,841

MM SCFD	1.3	Btu/SCF	1000
kwh	1405		
gpm	13000		
gpm	330		
lb/hr consumed	14300		
No. of addnl	3		

Differential Sales, \$ per year:

CO Fuel Lost @ \$ / MM Btu	2.5	-\$4,142,960
PSA TailGas Fuel Lost @ \$ / MM Btu	1.5	-\$648,459
Total Sales		-\$4,791,419

MM SCFD	-16.54	Btu/SCF	305
MM SCFD	-3.76	Btu/SCF	350

Net Hydrogen Production Cost, \$ per year \$11,272,260

Net Hydrogen Production Cost, \$ per k scf \$ 2.86

MM SCFD	12
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Appencix III
Siemens Westinghouse Power Corporation

Selection issues for the DF-42 and catalytic burners are compared in Table AIII 1.

Table A III 1
Candidate Burner Comparison

	DF-42	Catalytic
Technical Areas		
Commercial fleet	(+) Many running units	(-) None running
Proven on CO/H ₂ fuel?	(-) No	(-) No
NOx control	(-) Burner designed for 42 ppm with diesel fuel (DF). May get 25 ppm with syngas. Needs steam or water injection, plus SCR	(+) Lowest NOx emission. Catalytic burner has tested capability to achieve around 2 ppm NOx without SCR (but not with this fuel). SCR may not be needed.
Dual-fuel capability (natural gas and high-CO syngas)	(+) Dual-fuel capable	(-) Dual-fuel capability may be complicated.
Programmatic Areas		
Technology advancement	(-) Mainly adaptation of an existing design	(+) Development of new type of burner
Scalability	(-) ~1/250 scale testing	(+) ~full-scale testing
Burner geometry model	(-) Model needed	(+)STC has model
Transition geometry model	(-) Model needed	(-)Model needed
Kinetics model	All by CS&E	Catalytic partial reactions by STC, downstream combustion by CS&E
Test burner design	(-) Design needed	(+) Design complete
Test burner fabrication	(-) Hardware needed	(?) Hardware may be needed
Commercial Areas		
GT (w/burner) capital cost	(+) Slightly less?	(-) Slightly more?
SCR capital cost	(-) SCR needed	(?) SCR may not be needed
SCR operating cost	(-) SCR needed	(+) less than for DF-42, maybe zero.
Development needed	(+) Basic burner is developed, may need modification	(-) Burner development needed
Commercial Availability	(+) Sooner	(-) Later

EnviRes High-CO Gas Turbine Study Specification

This document describes the key parameters that form the boundary conditions, for the conceptual design of a gas turbine operating with HyMelt off-gas. This is intended to be a working document that can be updated throughout the project by Siemens Westinghouse.

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7 Revisions

Rev.	Date	Description of Change
A	22 Oct 03	Original Issue

8 Syngas Composition

The composition, temperature, and pressure of HyMelt syngas from Illinois #6 Coal are shown in Table 2. The syngas from petroleum coke will be virtually identical to that from coal. The contaminants listed in Table 2 are all expected to be less than 1 ppmv.

Table A III 2
Illinois #6 Coal Syngas Composition

Composition

CH ₄	0.07	%(vol)
CO	75.72	%(vol)
CO ₂	3.92	%(vol)
COS [1]	-	%(vol)
H ₂	19.96	%(vol)
H ₂ O	0.30	%(vol)
H ₂ S [1]	-	%(vol)
N ₂	0.03	%(vol)
Total	100.00	%(vol)

Properties

Temperature	160 or lower °F	71 or lower °C
Pressure	365 to 415 psia	25 to 29 bar
HHV	309 Btu/scf	12.16 MJ/Nm ³
HHV	4,995 Btu/lb	11.61 MJ/kg
LHV	298 Btu/scf	11.76 MJ/Nm ³
LHV	4,832 Btu/lb	11.23 MJ/kg

Contaminants

Barium (Ba)	ppm(w)
Calcium (Ca)	ppm(w)
Chlorides (Cl)	ppm(w)
Copper (Cu)	ppm(w)
Iron (Fe)	ppm(w)
Lead (Pb)	ppm(w)
Magnesium (Mg)	ppm(w)
Manganese (Mn)	ppm(w)
Nickel (Ni) [1]	ppm(w)
Phosphorus (P) [1]	ppm(w)
Potassium (K)	ppm(w)
Silica (SiO ₂)	ppm(w)
Silicon (Si)	ppm(w)
Sodium (Na)	ppm(w)
Vanadium (V)	ppm(w)
Zinc (Zn)	ppm(w)
Other trace metals	ppm(w)

[1] These constituents may be harmful to catalysts.

9 Gas Turbine Size

The original proposal assumed that the HyMelt® process module would produce about 1157 million Btu/hr of CO-rich gas, which was slightly less than the fuel requirements of a W501D5A gas turbine. The actual gasification module may produce more gas, which would match the fuel requirements of a larger turbine or turbines.

Table 3 lists the approximate syngas consumption of the three W-class gas turbines in 1x1 and 2x1 combined cycle arrangements. More detailed calculations performed during the project will determine the actual syngas requirements.

Table A III 3
Estimated Gas Turbine Syngas Consumption

Combined Cycle Plant Designation	Gas fuel, Million Btu/h	Syngas, Million scf/h[1]	Gas Turbine Power, MW	Combined Cycle Power, MW
1x1.W501D5A	1,169	3.9	121	173
1x1.W501FD	1,726	5.8	190	283
1x1.W501G	2,146	7.2	253	365
2x1.W501D5A	2,338	7.8	241	346
2x1.W501FD	3,452	11.6	379	567
2x1.W501G	4,292	14.4	506	730

[1] Estimated consumption of syngas with an LHV of 298 Btu/scf.

10 Use of Natural Gas

Natural gas is the preferred fuel for start-up and, if necessary during shutdown.

11 Emission Limits

The two tentative plant sites are

- A. East St. Louis, Illinois
- B. Decatur, Illinois

In the absence of specific information about emission limits at these sites, the values of 2 ppmv for both CO and NO_x seem to be the best choice. In the near future, stack emissions are projected to be as low as 2 ppmv NO_x and 2 ppmv CO when corrected to 0% moisture and 15% oxygen. These projections are based on (1) current limits in California, Massachusetts, New York, and New Hampshire of 2.5 to 3.5 ppmv NO_x, and (2) the current best available emission control technology (BACT) can achieve 2-3 ppmv for both NO_x and CO. These limits are not expected to be relaxed during the next 15 years.

If the gas turbine exhaust contains NO_x and CO emissions higher than the target levels, some exhaust gas treatment, such as selective catalytic reduction, will have to be added.