creating a better place

Environment Agency

Mr Finnin
Vaporo Tech Limited
Innovation Works
National Technology Park
Limerick
Republic of Ireland.

Our ref:
Your ref:

Date: 22nd March 2012

Dear Mr Finnin,

Thank you for your submission reference SOL12IIVTO1, December 2011 and subsequent supporting information regarding production of a synthetic gas from the pyrolysis of "BioFibre" as a substitute for natural gas. We note that "BioFibre" is derived from municipal, commercial and industrial waste which has undergone a heat treatment and separation process to produce a biomass predominantly comprising cellulose fibre.

Ultimately, whether or not your proposed product has ceased to be waste is a matter for the courts. However, we have considered whether your proposed waste derived product has achieved end of waste within the meaning of Article 3(1) and 6 of the Waste Framework Directive (EC/2008/98). Our view draws on the principles established in the case law on definition of waste, emanating both from the European Court of Justice and England and Wales. The principles established in the 2007 Court of Appeal judgment in OSS Group Ltd vs Environment Agency are particularly relevant to waste derived fuels. We consider all end of waste submissions received by us on a case by case basis having regard to the current law.

**1. Is it a distinct and marketable product?**
The synthetic gas is produced from the pyrolysis of BioFibre derived from mixed wastes. The synthetic gas is equivalent to natural gas and can be used as a direct replacement.

**2. Can it be used in exactly the same way as an ordinary fuel?**
The synthetic gas is further cleaned before final use to remove any volatilised metals, particulates and acid gases. The final synthetic gas can be used in the same way as natural gas.

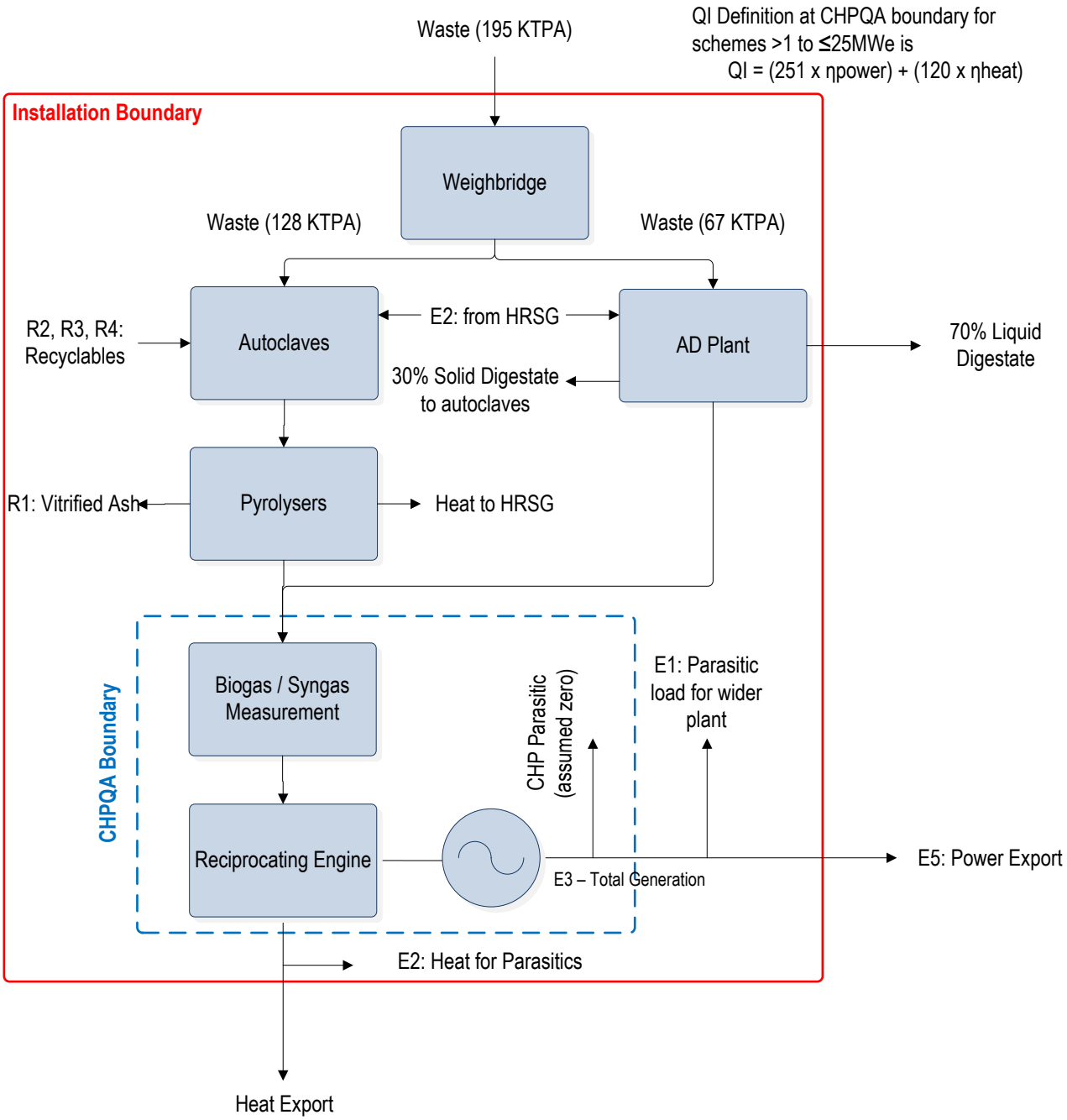
**3. Can it be used with no worse environmental effects than a comparative fuel?**
You have provided a specification for your synthetic gas which shows that it can be used in the same way as natural gas with no worse environmental effects.

Based on the information provided, our view is that your submission meets the 'End of Waste' test for the reasons set out in the numbered paragraphs above. Please be aware that our decision is only relevant to your specific submission and that any failure to meet the prescribed technical specification you have supplied will be regarded as waste, unless you can show otherwise. You will need to ensure you have the necessary quality assured processes and testing regimes in place to attain this specification. Again, as discussed with you, the synthetic gas must be tested to demonstrate compliance with the specification before being used or marketed as fuel.

We want to make it easier for our customers to use waste derived products without the need for regulatory control where the waste material used has achieved end of waste status. Our aim is to remove any unnecessary regulatory burden on business whilst at the same time, ensuring the environment is appropriately protected.

Yours sincerely

Pandora Rene
Waste Recovery Team Leader
Tel: 07879 430366


Waste (195 KTPA)
QI Definition at CHPQA boundary for schemes >1 to ≤25MWe is
QI = (251 x ηpower) + (120 x ηheat)
Installation Boundary
Weighbridge
Waste (128 KTPA)
Waste (67 KTPA)
R2, R3, R4: Recyclables
Autoclaves
E2: from HRSG
AD Plant
70% Liquid Digestate
30% Solid Digestate to autoclaves
R1: Vitrified Ash
Pyrolysers
Heat to HRSG
CHPQA Boundary
Biogas / Syngas Measurement
CHP Parasitic (assumed zero)
E1: Parasitic load for wider plant
Reciprocating Engine
E3 – Total Generation
E5: Power Export
E2: Heat for Parasitics
Heat Export

| | | |
|---|---|---|
| Total Waste Processed: | | 195,000 TPA (assume 128KTPA / 67 KTPA) |
| E1: | Electrical Energy required to operate the plant PA: | 9230 MWh |
| E2: | Thermal Energy required to operate the plant PA: | 161,500 MWh |
| E3: | Total Electrical Energy generated PA: | 150,000 MWh |
| E4: | Total Thermal Energy generated PA: | 276,923 MWh |
| E5: | Electrical Energy for export PA: | 140,769 MWh |
| E6: | Thermal Energy for export PA: | 115,384 MWh |
| | Syngas Values: | 116,230,000 Cu.m @ 4.7kW |
| | | 549,538 MWh |
| R1: | Total Inert material for reuse: | 12,099 TPA |
| R2 | Total Tonnage of ferrous metal recycled: | 11,792 TPA |
| R3: | Total Tonnage of non-ferrous metals recycled: | 3,368 TPA |
| R4: | Total Tonnage of plastics recycled: | 26,593 TPA |

CHPQA Plant Efficiency: $\frac{\text{Total Exportable Energy (MWh)}}{\text{Total Thermal Energy Syngas}}$

CHPQA Plant Efficiency: $\frac{[E6 - (E2+E3)]}{E6}$

CHPQA Plant Efficiency: 56.68% Assuming that no heat is exported from the boundary of the Installation

Fact Sheet

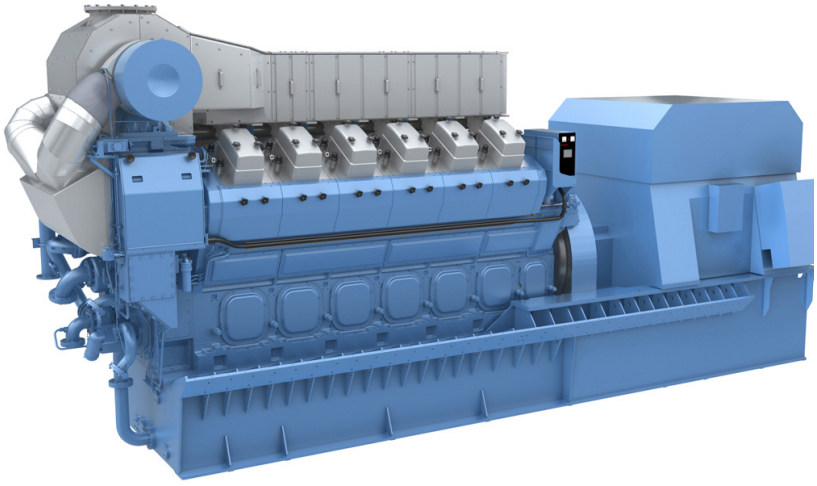
Rolls-Royce

# Rolls-Royce diesel and gas engines

Bergen B35:40V auxiliary lean-burn gas engine, Marine

## Features

- The widest power range in the 720 – 750 rpm class
- Compact and powerful
- Exceptionally low emissions of Nox and CO2
- Low energy consumption
- Service friendly
- Variable Turbo Geometry
  - Optimum response at all engine load points
- Super silent resilient mounting
- Stable frequency



## Choose Rolls-Royce engines for cost-effective operation.

For more than sixty years of operation, we have produced four stroke medium speed engines for marine propulsion, marine auxiliary and power generation to customers world wide.

## Technical data for the Rolls-Royce B-engine with 720/750 rpm - auxiliary type engine

| Engine type | | B35:40V12AG | B35:40V16AG |
|---|---|---|---|
| Number of cylinders | | 12 | 16 |
| Engine speed | r/min | 720/750 | 720/750 |
| Mean piston speed | m/s | 9.6/10 | 9.6/10 |
| Max.cont rating | kW | 5040/5250 | 6750/7000 |
| Max.cont rating altern, (h=0.96) | kW | 4890/5090 | 6520/6790 |
| Max.cont rating altern, (Cosf=0.8) | kVA | 6110/6360 | 8150/8490 |
| Mean effective pressure (BMEP) | bar | 18.2 | 18.2 |
| Specific energy consumption | kJ/kWh | 7550/7550 | 7550/7550 |
| Specific lubricating oil consumption | g/kWh | 0.4 | 0.4 |
| Cooling water temp. engine outlet | °C | 90 | 90 |

### Heavy fuel operation

- All technical data is valid at 100% load, including two engine driven pumps (lub oil and jacket water pump)
- Engine power definition and fuel gas consumption are according to ISO 3046-1 (ICFN)

### Waste heat recovery

- Fuel gas consumption is applicable for ambient temperature range 5 - 40°C
- Reference fuel is natural gas with a lower heating value of 36 MJ/nm3
- Minimum fuel gas pressure to the gas regulating module: 3.3 bar/g
- Due to continuous development, some data may change

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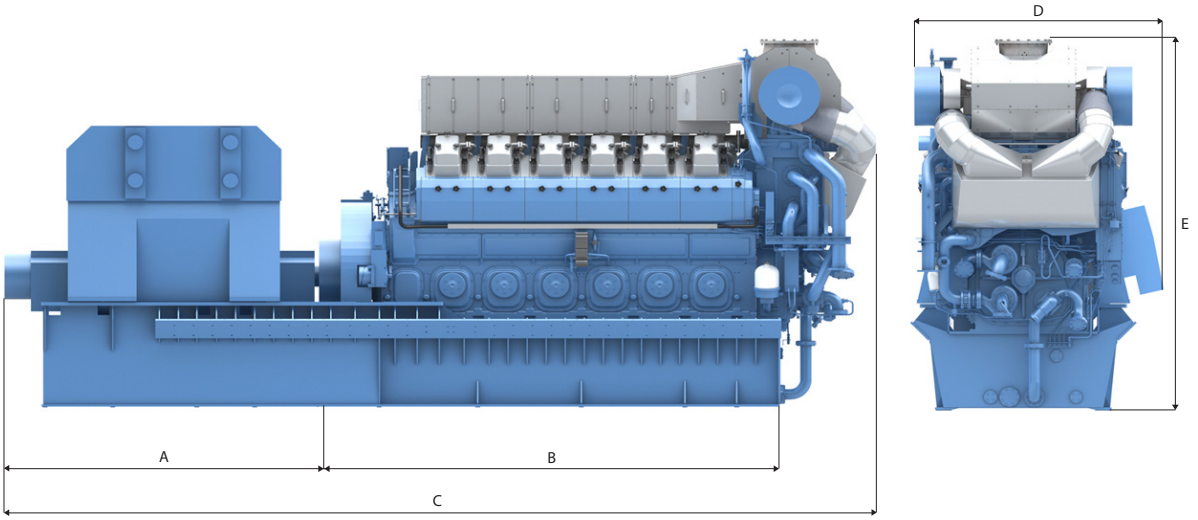
# Fact Sheet




## Principal dimensions

Cylinder dia. 250 mm. Piston stroke 300 mm.

All dimensions in mm.

| | | | | | | Weights dry |
|---|---|---|---|---|---|---|
| **Engine type** | **A** | **B** | **C** | **D** | **E** | **Engine** |
| B35:40V12AG | 3948 | 6366 | 10306 | 2712 | 4620 | 88050 kg |
| B35:40V16AG | 3561 | 7947 | 11507 | 3306 | 4587 | 105580 kg |

## NB

Figures A and C depends on type of alternator.
This is also applicable for total weight.



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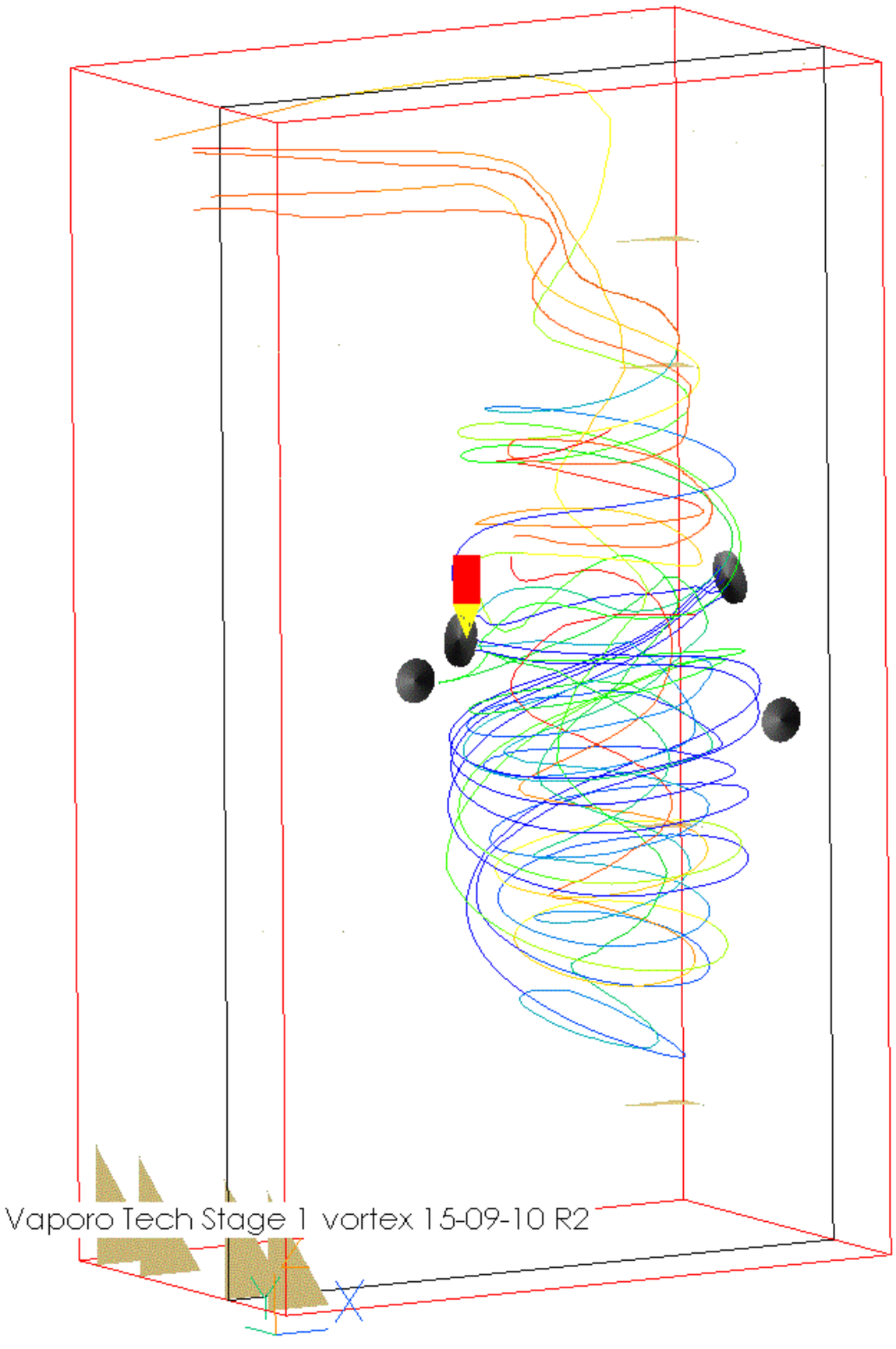
Engines - Bergen
P.O. Box 924, N-5808 Bergen, Norway
Tel: +47 815 20 070 Fax: +47 55 53 61 04
E-mail: engines.bergen@rolls-royce.com
www.rolls-royce.com

Flight time (s)

2.500000
2.343750
2.187500
2.031250
1.875000
1.718750
1.562500
1.406250
1.250000
1.093750
0.937500
0.781250
0.625000
0.468750
0.312500
0.156250
0.000000



Probe value
45.96875

Vaporo Tech Stage 1 vortex 15-09-10 R2

TRES

2.500000
2.343750
2.187500
2.031250
1.875000
1.718750
1.562500
1.406250
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1.093750
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0.781250
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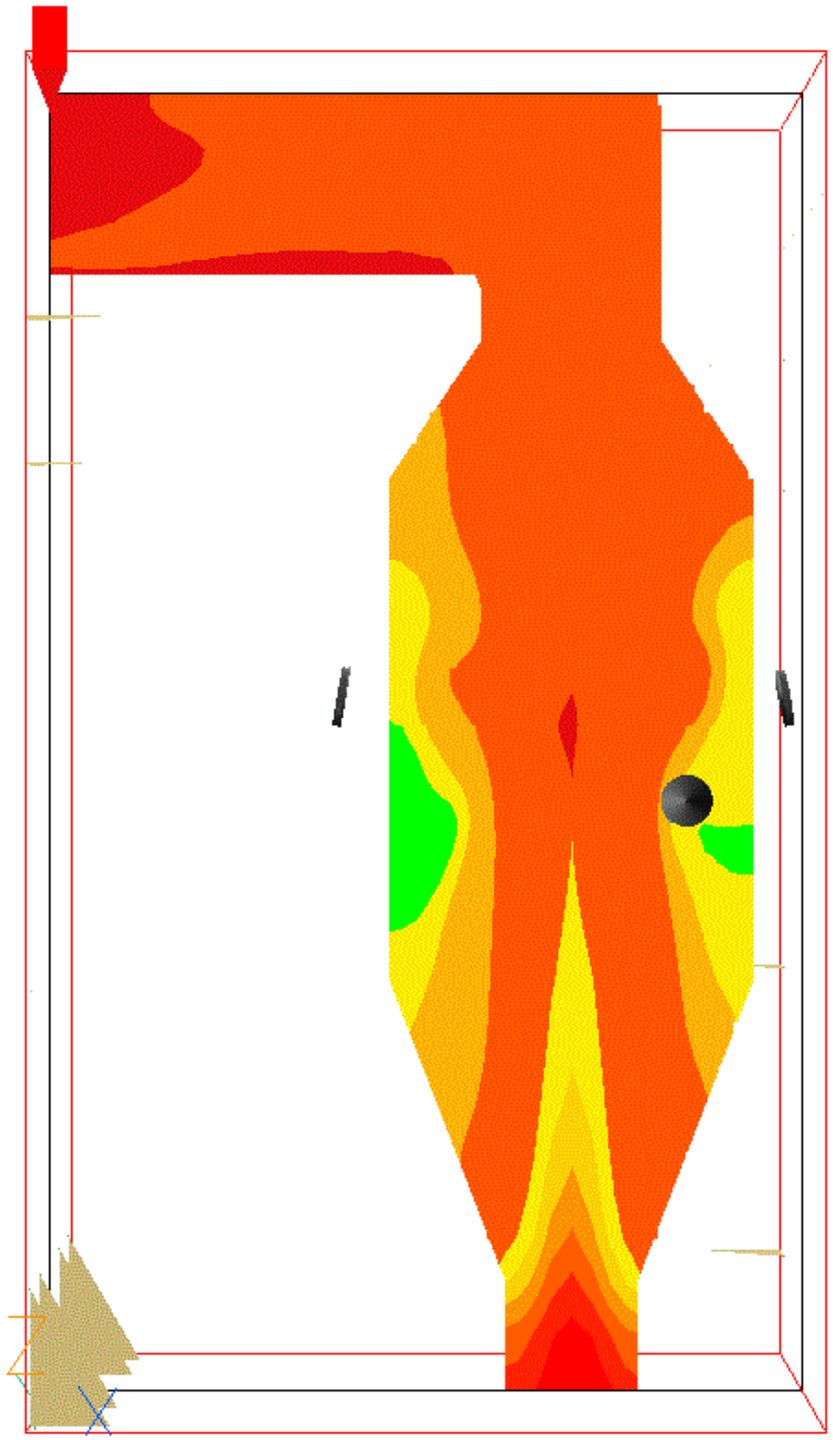
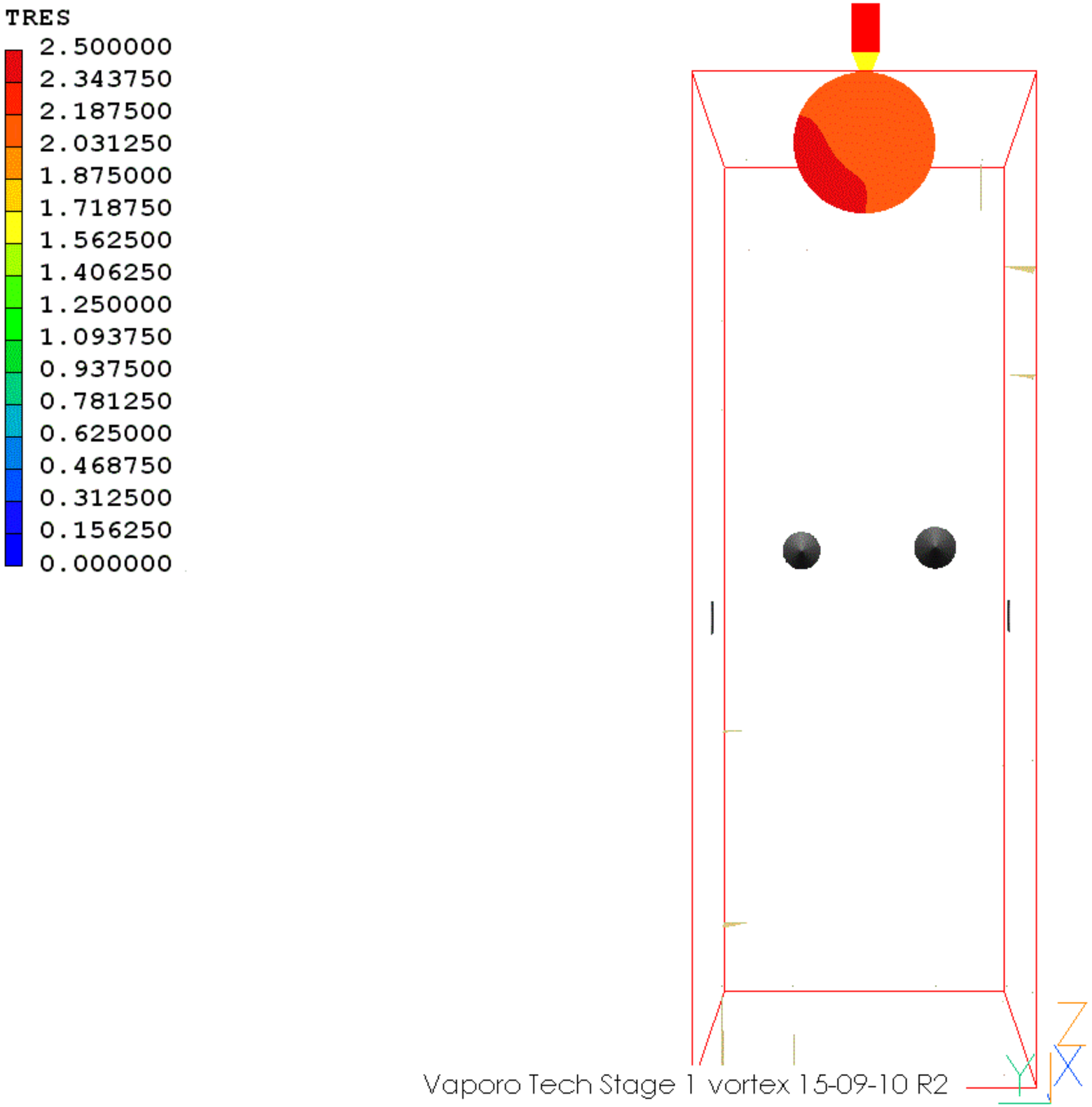


Average value
2.031250

Vaporo Tech Stage 1 vortex 15-09-10 R2


TRES
2.500000
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0.937500
0.781250
0.625000
0.468750
0.312500
0.156250
0.000000
Vaporo Tech Stage 1 vortex 15-09-10 R2

| Pyrolysis Synthesis Gas Specification – Vaporo Tech Ltd | | | | |
|---|---|---|---|---|
| **Relevant parameter** | **Units** | **Typical UK natural Gas Composition** | **Syn Gas Spec (% unless stated)** | **Comments** |
| **Major Elements** | | | | |
| Hydrogen ($H_2$)† | % vol / vol | <0.1 mol% | 5.80 – 18.15 | Converted to water during combustion |
| Oxygen ($O_2$) † | % vol / vol | 0-0.2% | 0.24 – 1.53 | Low levels of Oxygen will have little effect on combustion. |
| Nitrogen ($N_2$) † | % vol / vol | 0-5% | 2.00 – 9.00 | None |
| Carbon Monoxide (CO) | % vol / vol | No Limits Stated | 18.00 – 42.00 | Will be converted to $CO_2$ during combustion |
| Methane ($CH_4$) † | % vol / vol | 70-90% | 10.10 – 21.51 | Will be converted to $CO_2$ during combustion |
| Carbon Dioxide ($CO_2$) † | % vol / vol | 0-8% | 15.60 – 48.00 | Unaffected during combustion |
| Ethene‡ | % vol / vol | No Limits Stated | 2.80 – 6.40 | Converted to $CO_2$ and water during combustion |
| Ethane ($C_2H_6$) ‡ | % vol / vol | 0-20% | 1.71 – 5.04 | Converted to $CO_2$ and water during combustion |
| Propene ($C_3H_6$) ‡ | % vol / vol | No Limits Stated | 0.50 – 5.30 | Converted to $CO_2$ and water during combustion |
| Propane ($C_3H_8$) ‡ | % vol / vol | No Limits Stated | 0.07 – 1.79 | Converted to $CO_2$ and water during combustion |
| $C_4$ - Butane (n-$C_4H_{10}$) ‡ | % vol / vol | No Limits Stated | 0.14 – 0.93 | Converted to $CO_2$ and water during combustion |
| $C_5$ – Pentane (n-$C_5H_{12}$) ‡ | % vol / vol | No Limits Stated | 0.06 – 0.27 | Converted to $CO_2$ and water during combustion |
| **Sulphur containing compounds** | | | | |
| Total Sulphur† | $mg/m^3$ | 0 - 50$mg/m^3$ | < 30 $mg/m^3$ | Removed during gas scrubbing |
| Hydrogen Sulphide ($H_2S$) | $mg/m^3$ | 0 - 5$mg/m^3$ | < 5$mg/m^3$ | Removed during gas scrubbing. Very odorous |
| **Inorganic gases** | | | | |
| Ammonia | $mg/m^3$ | 20 $mg/m^3$ | <20 $mg/m^3$ | None present in synthesis gas - removed by gas cleaning stages |
| Hydrogen Chloride | $mg/m^3$ | 1.5 $mg/m^3$ | < 1.5 $mg/m^3$ | As above |
| Hydrogen Fluoride | $mg/m^3$ | 5 $mg/m^3$ | < 5 $mg/m^3$ | As above |
| **Rare gases (A, He, Ne, Xe)** | % vol / vol | Trace | < LOD 0.05 $mg/m^3$ | None present in synthesis gas |
| **Halogenated Hydrocarbons** | | | | |
| Total Halogenated Hydrocarbons | $mg/m^3$ | 1.5 $mg/m^3$ | < 1.5$mg/m^3$ | None present in synthesis gas – removed by gas scrubbing stages |
| **Aromatic Hydrocarbons** | | | | |
| Xylenes (all isomers) | $mg/m^3$ | 100 $mg/m^3$ | < 100 $mg/m^3$ | None present in the synthesis gas, cracked during pyrolysis |
| **Metals** | | | | |
| All Heavy Metals | mg/kg | Trace | < LOD | None expected - all metals retained in Char |
| Gross Calorific Value | | 36.9 – 42.3 $MJ/m^3$ | 14.73 – 22.73 $MJ/m^3$ | Approximately half that of natural gas |

***** Denotes figures quoted directly from EA Biomethane Protocol

† Denotes figures quoted directly from UK Gas Safety Regulations / National Grid Gas Entry Standard

‡ Denotes figures quoted directly from analysis

Johnson Matthey

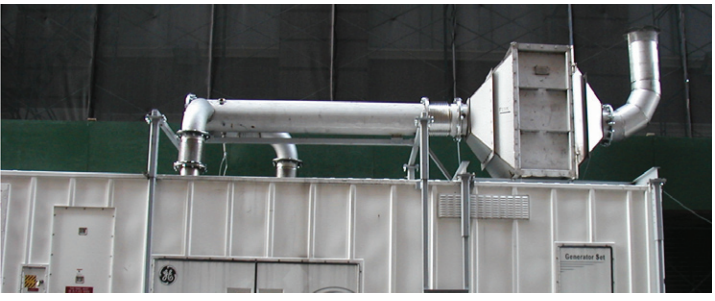
JOHNSON MATTHEY STATIONARY EMISSIONS CONTROL

*Selective Catalytic Reduction*

# SCR

STATIONARY EMISSIONS CONTROL

## *Maximum NOx Control for Stationary Diesel and Gas Engines*



## Leading the Industry in Innovation, Emissions Solutions and Experience

When it comes to effective, efficient and high-performance NOx control for stationary diesel and gas engines, it's not enough to just be good. You want—and need—the best Selective Catalytic Reduction (SCR) solution…from the leader in catalyst technology—Johnson Matthey.

No other company offers the engineering experience and innovation, corporate longevity, reputation, financial resources and superior customer service. We have provided emissions solutions to control air pollution for over 40 years. At Johnson Matthey, our principal R&D, engineering, manufacturing and technical support are based in the U.S.

What's more, Johnson Matthey's Stationary Emissions Control (SEC) group has been installing SCR systems on stationary diesel and gas engines since 1993. We design and supply catalysts and catalytic systems for controlling NOx, CO, HC, VOC, HAPs and PM.

## Engineered to Be the Best

Johnson Matthey's SCR technology delivers an economical—and extraordinarily effective—solution that has achieved an impressive 15,000-plus hours of operation before any routine maintenance is required. Incorporating the highest quality components, the JM SCR System is designed to last, and is the most reliable technology available today. It will meet the most stringent air emissions standards and is the most reliable and durable emissions control solution you can buy for your lean burn engine application, including:

- Emergency Backup Power
- Prime Power
- Cogeneration
- Pumping
- Gas Compression

Designed for flexibility and adaptability, the Johnson Matthey SCR System offers three NOx control options:

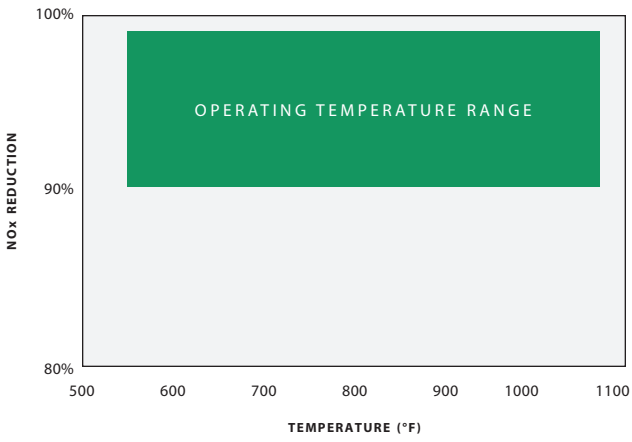
- Load-based curve
- Closed-loop feedback
- Load-based curve with NOx trim

Using urea (or aqueous ammonia), Johnson Matthey's SCR systems achieve NOx reductions of 90%+ for diesel or gas engines. Urea serves as the ideal reducing agent since it can be shipped and stored easily and is colorless, odorless, nontoxic and bio-friendly.

At Johnson Matthey, when we say that our SCR system is engineered to be the best, we back it up with services to prove it. We provide turnkey project engineering—from design and engineering to installation and commissioning. No matter how complex the project is, our engineers are up to the challenge.

*An installed SCR system.*

***NOx Reduction vs. Temperature*** *(large operating temperature range, 550°F–1070°F)*




**At higher temperature the catalyst formulation is adjusted for:**

- Stronger $NH_3$ adsorption
- Lower $NH_3$ oxidation rate
- Higher DeNOx rate
- Lower sintering rate

**Catalyst supported on:**

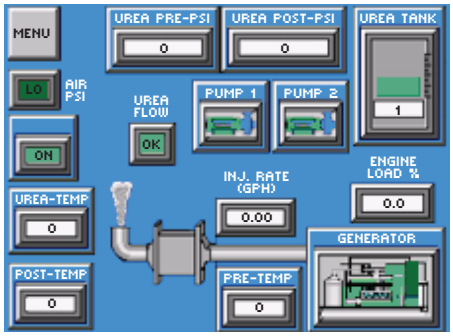
- Metal monolith
- Extruded ceramic monolith
- Various cell densities

**Building on Experience…**
**Built for Performance**

Our experienced engineers will help you select the best NOx Control option to meet your requirements. Since every Johnson Matthey SCR System is built on cutting-edge technology, your SCR System can be customized to ensure the most effective and efficient performance while allowing for easy upgrades if conditions should change in the future.

The standard SCR System includes SCR catalyst, durable housing, mixing duct, injection system components and control panel or an optional fully-integrated skid-mount package. The skid-mount option includes a converter, injection system components, electronic controls, urea day tank, compressor and freeze protection. In addition, the skid is assembled at the Johnson Matthey plant and is delivered ready for installation, minimizing installation labor and time. The JM catalyst housing is much more compact than others in the marketplace. So, while the Johnson Matthey SCR catalyst packs maximum punch in performance, its smaller size makes it much easier to install, especially in tight spaces.

At the heart of the SCR System is a PC-based control system that is exceptional for its performance, construction and versatility. With no moving parts, the risk of a breakdown is minimal. The software logic in the Johnson Matthey SCR system is the most efficient self- diagnostic software available. It continuously monitors process parameters such as urea flow, pressure, temperature and performance with the optional NOx analyzer. If a problem is diagnosed, the software is designed to make adjustments, fix the problem and safeguards against urea plugging. Upgrades are done simply by modifying the software, which means quick and easy compliance with new EPA, ARB or local air agency requirements.

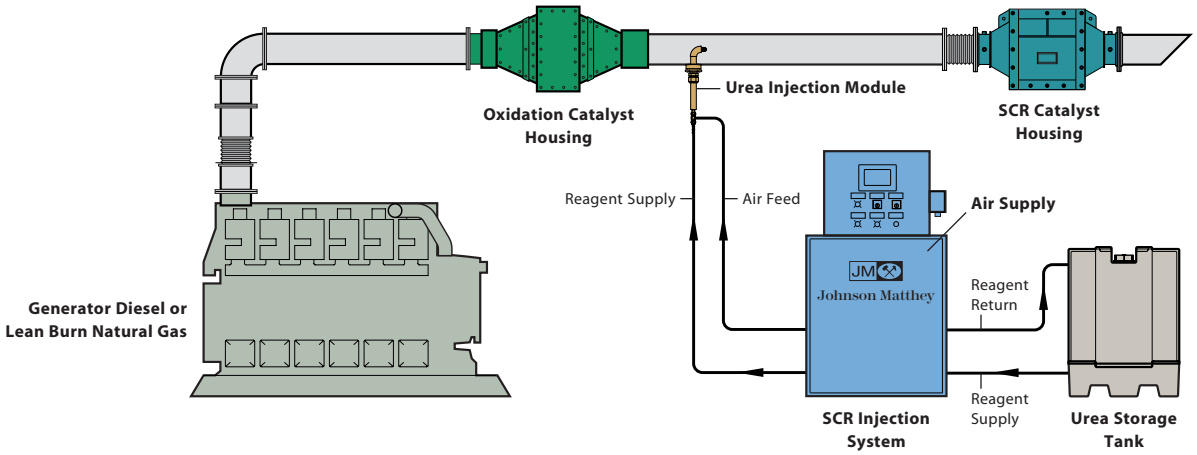



*Urea injection control panel touch screen.*

***Highlights of the Johnson Matthey SCR Control System***

- Urea or ammonia compatible
- Reagent injection based on Load Tracking or Continuous Emissions Monitoring (CEM) feedback control
- Intel-based processor
- Touch-screen operator interface panel–for programming and monitoring with instant feedback
- Modem and SCADA capability for remote monitoring, upgrades or diagnostics
- Ethernet and other network communication protocols (available)
- Stainless steel modular watertight enclosure
- UL Listed Ⓤ Open Industrial Control Panel No. BJ-661076

***Typical Oxidation Catalyst and SCR System Flow Diagram***



***Urea Injection Nozzle***

The Johnson Matthey urea injection nozzle is designed and built for accurate, plug-free performance and reliability. The self-checking nozzle delivers injection control of either urea or aqueous ammonia, with the following benefits:

- Air atomizer injection
- Controlled droplet size for good distribution and optimal NOx reduction
- Self-cleaning (air/water purge) nozzle to prevent deposit buildup
- Insulation around air pipe to prevent urea crystallization
- Injection module complete with connection fittings
- Injection rate control bias
- Redundant delivery pump included
- Reagent day tank level monitoring and control
- Minimal field terminations required which reduces installation costs significantly

## A More Advanced Injection Nozzle

One of the superior features of this nozzle is its ability to be quickly disconnected for change-out or for routine cleaning. Unlike other urea injectors, which require the nozzle to be unbolted, the Johnson Matthey unit simplifies routine maintenance and saves time.

## Flexibility to Meet All of Your Emissions Control Needs

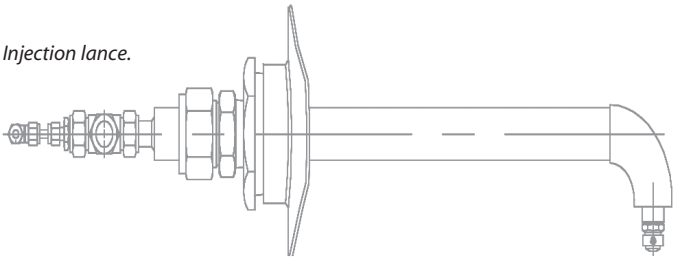
The SCR System can be combined with an Oxidation catalyst to oxidize HC, CO, VOC and HAPs for all lean burn diesel or gas engines…reducing emissions to meet the most stringent regulations. If you need to reduce particulate matter (PM) as well as HC and CO in a stationary diesel engine—at a consistent rate of 90%+ —the SCR System can be combined with Johnson Matthey's patented Continuously Regenerating Technology (CRT®) particulate filter system. This level of design flexibility makes the Johnson Matthey SCR System ideal for retrofit or for new lean burn engines.

*Additional options for the SCR System include:*

- Reagent freeze protection devices and programming
- Catalyst differential pressure monitoring
- Downstream SCR catalyst temperature monitoring
- Ability to monitor and transfer reagent from bulk storage tank to the day tank

SCR

*Injection lance.*



Johnson Matthey
Stationary Emissions Control

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**www.jmsec.com**

Find a contact near you by visiting www.ge.com/water and clicking on “Contact Us”.

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imagination at work

Bulletin 1053EN Sep-08

GE Water & Process Technologies

# Packaged plants for water and wastewater treatment


a product of
ecomagination℠

# ZeeWeed* packaged plants provide large-scale performance in a compact pre-assembled system

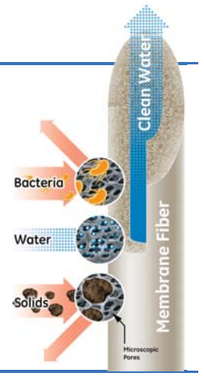
Incorporating a simple and expandable building-block design, GE packaged plants can be quickly set up in virtually any location and feature scalable treatment capacity that can be increased as demand grows. These highly automated, plug-and-play UF systems outperform conventional treatment alternatives in all categories, offering superior treated water quality that meets or exceeds regulatory requirements, reduced operating costs, smaller plant footprints, and highly reliable performance—at a price that is comparable to conventional systems.

**Pre-assembled and factory tested systems offer:**

- Reduced on-site construction costs with less interconnecting requirements;
- Quick delivery with complete engineering package already completed;
- Cost-effective solutions for virtually all water and wastewater treatment applications;
- Comprehensive cleaning capability for peak system performance;

### How membranes work

Membranes are based on filtration methods found throughout nature. ZeeWeed membranes are hollow polymer fibers with billions of microscopic pores on the surface. The pores are much smaller in size than common contaminants, bacteria and viruses. This physical barrier only allows clean water to pass through while rejecting impurities—guaranteeing an exceptional water quality and clarity on a continuous basis. Application of pressure outside or a slight vacuum inside is all that is required to draw water into the membrane and filter out impurities.




- Simple and highly automated operation and in-situ membrane cleaning;
- Modular building-block design;
- Simplified start up with minimal installation time;
- Compact footprint with flexible layout options;
- Greenfield or retrofit solutions.

Municipal Drinking Water
Township of Tay, ON - 70,000 gpd (265 m³/d) ADF‡
Z-BOX M

Municipal Wastewater Treatment
Huntsville, TN - 300,000 gpd (1,136 m³/d) ADF‡
Packaged Equipment Skids Z-MOD L

Decentralized Treatment
Office Park, Oakville, ON - 17,500 gpd (66 m³/d) ADF‡
Z-MOD S

‡ Average Daily Flow

## Water Treatment & Tertiary Systems

### Z-BOX S

up to 400,000 gpd (1,514 m³/d)

- Fully integrated process and control components
- Less than 6-foot (1.8-meter) tall system readily fits into any building
- Side-loading membrane door for easy access

### Z-BOX M

up to 350,000 gpd (1,325 m³/d)

- Equipped with rugged reinforced membranes to withstand the harshest environments and the most difficult-to-treat water sources
- Fully-integrated, skid-mounted system

### Z-BOX L

up to 3.25 MGD (12,300 m³/d)

- Easily fits beneath a 9-foot (2.7-meter) ceiling
- Side loading membrane door for easy access

### Z-PAK

up to 720,000 gpd (2,725 m³/d)

- ZeeWeed fiber in a pressurized module
- Fully integrated skid-mounted system with compact footprint

### Typical Treated Water Results

| | |
|---|---|
| Turbidity | < 0.1 NTU |
| Bacteria | > 4-log removal |
| *Giardia* | > 4-log removal |
| *Cryptosporidium* | > 4-log removal |
| Virus - ZeeWeed 500 | > 2.0-log removal |
| Virus - ZeeWeed 1000/1500 | > 3.5-log removal |
| Iron | < 0.05 mg/L§ |
| Manganese | < 0.02 mg/L§ |
| TSS | < 1 mg/L |
| TOC | 50 - 90% removal§† |
| Arsenic | < 5 µg/L |
| Color | < 5 PCU§† |

§ pre-treatment required
† dependent on raw water quality

* Average Daily Flow

## Wastewater Treatment Systems

### Z-MOD S

up to 80,000 gpd (303 m³/d)‡

- Fully integrated wastewater treatment plant
- Can be buried or installed above ground (smaller flows available for below ground systems)
- Complete plug-and-play design with all components in a single tank
- Can operate at MLSS concentrations between 3,000 and 15,000 mg/L

### Z-MOD M

up to 110,000 gpd (416 m³/d)‡

- Fully integrated skid-mounted system
- Can operate at MLSS concentrations between 3,000 and 15,000 mg/L

### Z-MOD L

up to 1 MGD (3,785 m³/d)‡

- Containerized or skid-mounted components
- Dual-train systems
- Can operate at MLSS concentrations between 3,000 and 15,000 mg/L

### Z-MOD X

up to 4.0 MGD (15,142 m³/d)‡

- Equipment skid comes complete with permeate pump, process blower, RAS pump, PLC, MCC, piping and wiring
- Can operate at MLSS concentrations between 3,000 and 15,000 mg/L

### Achievable MBR Effluent

| | |
|---|---|
| Turbidity | < 0.1 NTU |
| $BOD_5$ | < 2 mg/L |
| TSS | < 1 mg/L |
| $NH_3$-N | < 0.5 mg/L |
| Total Nitrogen | < 3 mg/L†† |
| Total Phosphorous | < 0.05 mg/L†† |
| Fecal Coliform | < 2.2 CFU/100 ml§§ |
| SDI | < 2 |

†† with appropriate biological design and/or chemical addition
§§ after disinfection




# END OF WASTE APPLICATION
# Synthesis Gas

## Vaporo Tech Ltd

Prepared by:
**Sol Environment Ltd**

Date:
**December 2011**

Project or Issue Number:
**SOL1211VT01**

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| VERSION CONTROL RECORD | | | |
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| **Contract/Proposal Number:** | | SOL1211VT_01 | |
| **Authors Name:** | | Steve Butler | |
| **Signature:** | |  | |
| **Issue** | Description of Status | **Date** | **Reviewer Initials** |
| 1 | Final Issue to EA for determination | 22nd December 2011 | SMB |
| 2 | Revised gas Specification following EA consultation | 3rd February 2012 | SMB |

# CONTENTS



## ANNEXES

# EXECUTIVE SUMMARY

This application is on the behalf of Vaporo Tech for an end of waste determination 'opinion' to be sought from the Environment Agency in relation to the synthesis gas produced by their proprietary pyrolysation technology.

Vaporo Tech has developed an advanced conversion technology based on existing pyrolysis technology, designed to generate clean synthesis gas from biomass materials. Vaporo Techs specific application for this technology is for the pyrolysation and generation of synthesis gas from their 'BioFibe' material, which is a high purity waste derived biomass predominantly comprising cellulose fibre, produced by Vaporo Techs proprietary autoclave waste treatment technology.

Vaporo Tech's autoclave technology has been specifically designed to produce a clean, contaminant free, stable biomass that is suitable for pyrolysis. The biomass is predominantly chemically composed of cellulose material which unlike other biomass products is free of lignin and other naturally occurring tar producing materials. The synthesis gas produced by the 'BioFibe' is devoid of tars and other impurities and requires little in the way of clean up before being used as an industrial gas.

Vaporo Techs intended use for their processing plant is to generate a synthesis fuel gas that can be used in gas engines and generation sets for the purposes of generating clean renewable energy. The gas quality and GCV meets the requirements of Ofgem Synthesis Gas requirements and will enable the plant to qualify under the Renewables Obligation Order 2009.

All gas being produced by the plant can be used directly as part of a close coupled CHP scheme or be exported to a neighbouring third party for similar use.

There are a number of gas engines on the market that have been specifically designed to operate using industrial gases with similar (and significantly worse) properties. These engines produce electrical power at a comparable output with a comparable level of emissions (NOx and CO) when compared with the combustion of Natural Gas used in similar applications.

The pyrolysis plant and the gas produced is all subject to a very detailed monitoring regime that will ensure that a quality specification is met at all times. In the event that the gas or the upstream production plant cannot meet the quality specification, the production of synthesis gas will cease and any residual quantities flared.

Vaporo Tech's technology when operated as described in this application, successfully converts the waste derived biomass material into a distinct and marketable product. The synthesis gas can be combusted conventionally in a number of commercially available gas engine types in the same manner as mains supplied gas. The combustion of synthesis gas is no more polluting than the combustion of mains gas in similar applications.

Based on the above it is therefore the consideration of Vaporo Tech that the synthesis gas produced by their pyrolysis plant, when operated as described above, meets the published definition of 'End of Waste'.

# 1. BACKGROUND INFORMATION

This Section provides general information on the applicant, including contact details, permitted activities and the proposed waste types that are to be processed.

| Table 1A – General Information | |
|---|---|
| Organisation Name | Vaporo Tech Ltd |
| Address | Vaporo Tech Limited.<br>InnovationWorks, National Technology Park,<br>Limerick, Republic of Ireland. |
| E-mail | ger@vaporotech.com |
| Company Registration | NI602769 |
| Telephone Number | +00353 61 503050 |

| Table 1B – Activities | |
|---|---|
| Permit Reference Number | N/A |

**Over view Description of permitted activities**

Vaporo Tech Ltd are the supplier and designers of proprietary waste pyrolisation and energy generation equipment that utilises pyrolisation technology coupled with upstream autoclaves and fuel conditioning plant. The purposes of the upstream processes is to specifically manufacture / condition clean biomass material suitable for pyrolysis.

Vaporo Tech Ltd are supplying plant and equipment to a number of operators in both the UK and overseas who are intending to construct and operate Permitted Waste to Energy Installations. The first UK site is to be operated at the site of Crapper & Sons Landfill in Wooton Bassett Wiltshire under an Joint Venture with the Landfill Operator and Vaporo Tech Ltd. Permit discussions relating to this application have been held with the EA's Bridgewater office, permitting team.

The proposed installation and the technologies associated with its operation fall under the definitions of a Co-Incineration Plant under the definitions provided by Schedule 1, Section 5.1 of the Environmental Permitting Regulations 2010 where, namely;

*Co-Incineration Plant means any stationary technical unit whose main purposes is the generation of energy or production of material products, and*

a) *Wastes are used as a regular or additional fuel; or*
b) *In which waste is thermally treated for the purposes of disposal.*

The proprietary pyrolyser technology utilised by Vaporo Tech is uses a design that utilises the generated solid (char) fraction of the pyrolisation process as a fuel to generate heat for the pyrolyser retort. All synthesis gas (*the 'product' and subject of this application*) generated by the retort is processed through a gas scrubbing and cleaning line to remove all solid, liquid and acid contaminants. The resulting synthesis gas is then suitable for use directly as either a fuel to generate electrical power (through the use of a gas engine generator set) or to provide heat.

A simplified process description has been included within Section 2 of this application document.

## Table 1C – Incoming Waste Information

The pyrolysis plant will be operated using clean (non hazardous) BioFibe as the only feedstock. The BioFibe will be manufactured and supplied by Vaporo Tech's proprietary plant and pre-treated to meet a specific fuel supply specification.

Nominally the fuel will be prepared to comply with the following outline requirements:

- Free of plastic contaminants
- Free of metal contaminants
- Free of glass contaminants
- Free from oils, solvents and volatile materials
- Dried to approx 8% moisture

Although the original source materials used to produce the BioFibe are non hazardous mixed source wastes, the resultant material has been proven to be clean stable biomass. All BioFibe produced by the autoclave systems are subject to batch testing, inspection and periodic analysis to confirm that the above specification is being met.

All materials accepted and processed by Vaporo Tech will be subjected to stringent waste acceptance criteria in accordance with the site environmental management plan and associated procedures (see Table 2C);

- EM-E01 Waste Pre-Acceptance;
- EM-E02 Waste Acceptance; and
- EM-E03 Waste Rejection.

Waste Acceptance documents are attached to the Appendix 2 of this application.

***Waste Type 1 – Biofibe***

| | |
|---|---|
| **EWC Code:** | 19-12-10 Combustable Waste (Refuse Derived Fuels) |

**Description:**

All wastes processed by the site will be clean waste derived BioFibe which has been processed through Vaporo Techs proprietary waste treatment plant. All BioFibe materials will be free of hazardous materials, plastic and metal contamination, dry and shredded to meet quality specification prior to pyrolysis

**Figure 2**:Biofibe (RDF) clean biomass feedstock prior to compaction

**Figure 3:** A compacted BioFibe 'log' prior to pyrolysation (note that this material has been subject to significant testing and proven to contain very low levels of inorganic material or contaminants.)

# 2. END OF WASTE JUSTIFICATION

This Section provides a justification for the proposed fuels in order to satisfy the end of waste criteria, in particular how the material meets the criteria set out by the OSS Court of Appeal Judgement (summarised in Box A and Box B below).

**Box A – Complying with the Court of Appeal Judgement**

(a) the waste has been converted into a distinct and marketable product

*Provide full details of the processing to which it has been subjected and the way in which it is marketable e.g.*

- *what makes the processed fuel distinct from the original waste?*
- *what is the intended market for the processed fuel?*

(b) the processed substance can be used in exactly the same way as an ordinary fuel

*Which virgin fuel will the waste derived fuel replace? Will the replacement be 100%. If not, why? Specify the virgin fuel comparator and the applications that product will be used in*

(c) with no worse environmental effects

*Identify any parameters unique to your waste derived fuel that would not be found in your comparator fuel.*

*Provide the specification that every batch of fuel will comply with along with your sampling and analytical methods and a specification of the virgin comparator against which a comparison can be drawn. Your sampling and analytical methods should be UKAS accredited where possible. If not, you should provide evidence that your chosen method has been validated.*

**Box B – How will the waste derived fuel meet the required specification?**

Provide details of your waste acceptance procedures, quality assurance procedures, sampling and analytical methods (including limits of detection) that ensure your waste derived product will consistently meet the specifications you have identified above.

How will batches be dealt with if they fail the specification?

In order to demonstrate compliance with the Court of Appeal Judgement, the following Section provides the following information (in accordance with the End of Waste Submission Template (Fuels) provided by the Environment Agency);

- A Non-Technical Summary and process description of the operations by which the waste will be converted into a distinct and marketable product is provided in Table 2A;
- Description of applications in which the waste-derived fuel can be used is provided Table 2B;
- Provision of validated specifications of both the waste-derived fuel and a comparator fuel (natural gas and/or non waste derived biogas), in order to demonstrate the compostional similarities (including fuel and environmental parameters) between the two fuels is provided in Table 2C;
- Disclosure of sampling / analytical methods used for the fuel comparison is provided in both Table 2C and within the annexes;
- Comparison of pollution produced per unit of heat generated by burning each fuel is provided in Table 2D; and
- Provision of Waste Acceptance Procedures to be utilised during site operation (including Waste Rejection) is included within Table 2E.

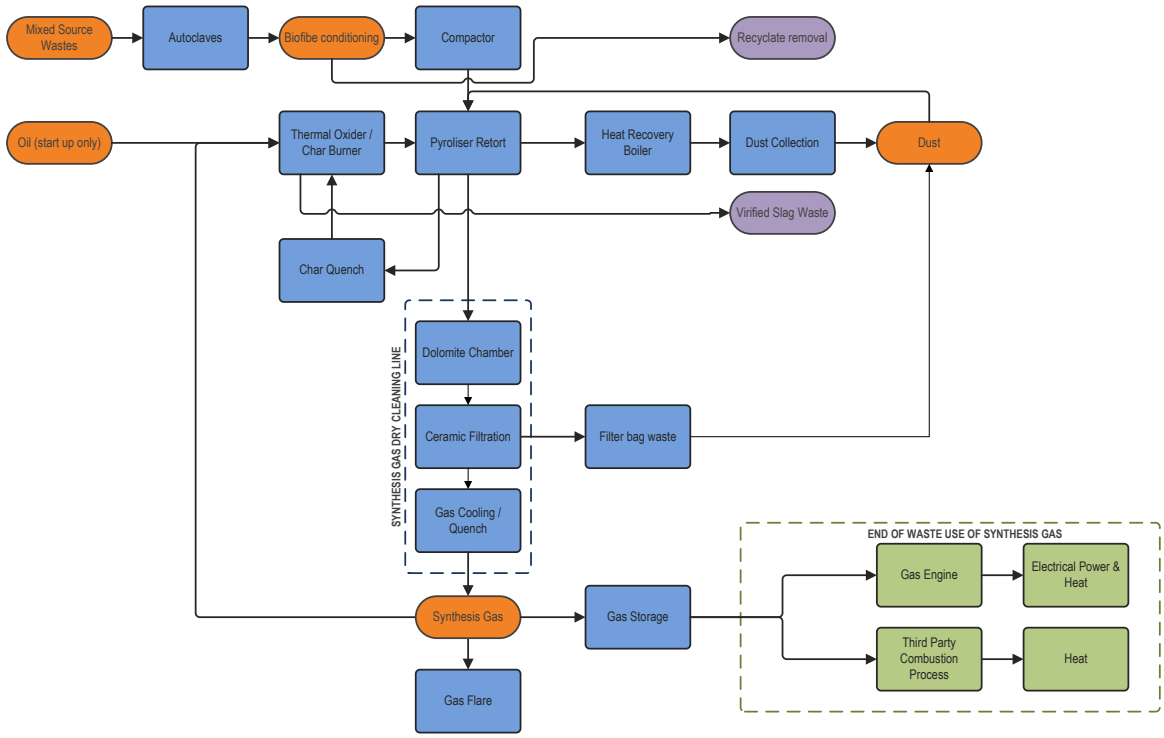
## Table 2A – Process Overview

| Process Name | Vaporo Tech Biomass Advanced Conversion / Pyrolysis |
|---|---|

### Process Overview / Justification

Vaporo Tech have developed a unique waste processing facility that utilises 'Advanced Pyrolysis'[1] process which can be used for the production of synthesis gas from their proprietary biomass feedstock materials.

The technology produces a high quality synthesis gas which can be utilised in a multitude of combustion applications which can be either directly or indirectly coupled for the generation of either onsite or offsite heat or electrical power.




Vaporo Tech will be using Advanced Pyrolysis technology as part of a waste to energy scheme, for the purposes of processing their proprietary BioFibe biomass feed stocks. The synthesis gas produced by the scheme will then be either used directly, or exported to neighbouring industrial facilities under a formal fuel supply agreement.

The production of synthesis gas from BioFibe provides a sustainable alternative to mains supplied gas. The synthesis gas is a flammable mixture of carbon monoxide (CO), carbon dioxide ($CO_2$), hydrogen ($H_2$), methane ($CH_4$) and other short chain hydrocarbon gases. This mixture is sometimes referred to as producer gas or town gas.

[1] "Advanced Pyrolysis" means electricity generated from a liquid or gaseous fuel which is produced from waste or biomass by means of pyrolysis, and (a) in the case of a gaseous fuel, has a gross calorific value when measured at 25 degrees Celsius and 0.1 megapascals at the inlet to the generating station of at least 4 mega joules per metre cubed. (Source Ofgem)

The cleanliness specification of the synthesis gas compares favourably when compared to those prescribed and defined by the UK Gas Safety (Management) Regulations and the EASEE European Gas Quality Specification document CBP 2005-001/02. (CBP 2005-001/02 specification provided – see Table 2C). Comparison has also been made against the quality specifications derived as part of the Environment Agency's Biomethane Injection Technical Advisory Group.

This comparison approach has been previously used by Sol Environment Ltd and agreed by the EA as an appropriate methodology.

Furthermore, due to the absence of contaminant materials and lignin within the BioFibe, the synthesis gas produced by Vaporo Tech's process, does not contain any tars or pyrolysis oils, typical of wood based biomass materials. As such, the BioFibe represents a much cleaner waste derived feedstock than other 'similar' biomass materials.

The use and combustion of the renewable/waste derived synthesis gas will also have a significantly lower intrinsic environmental impact than regular mains supplied gas, as it is both regarded as a renewable[2] (i.e. non fossil fuel) source and will lead to a reduction in the generation of methane that would otherwise arise from the land filling of such materials.

The pyrolysis process itself produces very little waste as the majority of the by-products (such as chars, water and heat) are re-introduced and used by the process.

Significant product testing has occurred (validated by MCERTS approved contractors), demonstrating the properties of all associated products and by-products arising from the process have been carried out. Using the analysis results a specification has been derived for the fuel. It is clear from the analysis that has been carried out on both the gas and the other by-products generated by the process, that the all contaminants potentially present within the source feed stocks are removed from the gas stream and retained within the liquid and solid waste products produced by the plant.

Detailed analysis and the derived synthesis gas specification has been appended to this application as Annex A and summarised in Table 2A.

The critical elements of the technology are as follows;

- BioFibe conditioning and separation plant
- Fuel Feed & Compaction System
- Retort & Synthesis gas Generation
- Char Recovery & Delivery System
- Gas Cleaning & Conditioning
- Thermal Oxidiser / Secondary Converter

A summary of the process is detailed within the Non Technical Summary below.

2 The quality of the synthesis gas meets the definition of a renewable (i.e. non fossil fuel derived) fuel as defined by the Renewables Obligations Order and associated regulations

**Non-Technical Summary**

The pyrolysis aspect of the Vaporo Tech process shall take BioFibe material (a clean processed biomass RDF derived fibre material) in accordance with quality control procedures (See EM-E01 – EM-E03), within a pyrolysis plant with an approximated throughput of approximately 4 tonnes per hour. Additional plants, each with a similar throughput will be used in parallel to achieve greater plant capacity if required.

All materials being processed by the pyrolyser will be pre-conditioned and processed such that it meets the acceptance criteria for the pyrolisation plant. Vaporo Techs by advanced thermal treatment (ATT) processing requires the BioFibe feedstock, to have a specified moisture content typically 8% ± 2.5%.

The conditioning of the Biofibe is achieved by a comprehensive upstream fuel conditioning system comprising;

- Autoclaving; to achieve full breakdown of biomass from MSW waste source:
- Separation; to remove all plastics, metals, glass contaminants;
- Drying; to achieve the correct moisture content (8%)

The key aspects of the pyrolysis plant are described below:

**Fuel Feed and Compaction System**

The fuel feed system is a key process to ensure the removal of oxygen/air in the input feedstock of the retort. The compaction of the feed stock by compression screw is key for the removal any intrinsic air, thus excluding oxygen. Excluding oxygen prevents combustion of the fuel and ensures that no dioxins can be formed. By increasing the piston loading speed increased gas and char production is achieved.

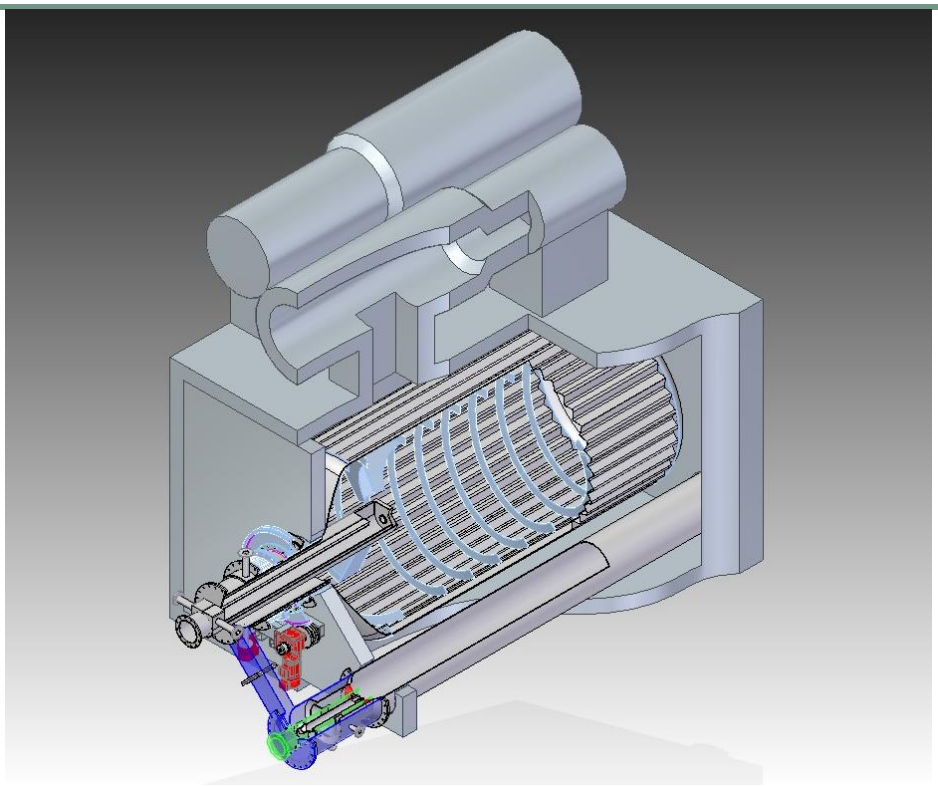
**Retort & Synthesis gas Generation**

BioFibe is prepared to the required fuel specification and then fed through the compaction system into the rotary pyrolysis chamber. The chamber is kept as an oxygen free environment through the use of nitrogen purging, adequate sealing and through a specific control philosophy. The sealing of the screw compactor mechanism has been designed to eliminate air ingress through the in feed mechanism.

At the core of the advanced thermal treatment process is a rotating retort which operates at approximately 700$^{o}$C.

All BioFibe material within the retort is thermally decomposed 'cracked' into a carbon monoxide, carbon dioxide, methane and hydrogen synthesis gas stream, which forms the main **product** of the pyrolyser.

Within the tube retort is a specific vane design that progressively advances the feedstock in an auger fashion alongside the inside of the chamber. This ensures maximum fuel residence time, uniform constant heat exposure and minimal shell stress while the fuel is converted into two products: 1) a synthesis gas and, 2) char (charcoal) at an optimum rate.



The synthesis gas releases any gaseous contaminant compounds (chlorine, sulphur etc) with a volatilisation temperature below 700ºC. All gases exit the pyrolysis chamber to undergo condition and quenching prior to storage and use for combustion or the generation of electricity.

The lack of oxygen prevents combustion and thus prevents the formation of dioxins and furans. The synthesis gas will have very low levels of oxygen (typically less than 0.5%). Tedlar bag analysis of the fuel trials is provided in Annex A.

The control of temperature and retention times within the oxygen free retort controls the quality of gas being generated and therefore the cracking of the hydrocarbons. The gas is subsequently conditioned to remove all acid compounds and filtered to remove all solid phase contaminants prior to onsite utilization or export to third parties.

The synthesis gas produced in the pyrolysis chamber is a mixture of light gases, heavier gases and condensable organics. The light gases, which comprise the main fraction, include hydrogen, carbon monoxide, carbon dioxide, methane and ethane and similar short chain hydrocarbons.

The retort is heated from hot exhaust gases produced by a thermal oxidiser which is fired using the chars generated by the pyrolysis process. The hot gases are exhausted from the oxidizer at approximately 1200°C, and are used to heat the externally surfaces of the retort.

The hot exhaust gases from retort heating process (at approx. 700°C) are utilized in a heat recovery boiler to generate hot water or steam, or which can be use for drying the incoming BioFibe.

**Char Recovery and Delivery System**

The char produced by the retort consists of carbon and ash, commonly called charcoal. Any inert material that may be embedded in the fuel will also remain with the char. The char is extracted from the retort by a scroll whilst maintaining gas seals and process conditions.

Char is pulverised injected it into the thermal oxidiser / charcoal burner system and subsequently burned. The heat generated in the thermal oxidiser (secondary converter) is conveyed to the external surfaces of the retort.

When analysed, the BioFibe pyrolysis char comprises carbon contents typically 66%wt with a very high carbon/hydrogen ratio. This indicates that the carbon is a highly coked species.

**Photo 4:** Example Char residue

The gas product from pyrolysis retort when processing BioFibe is essentially clean. Unlike other biomass mass materials (especially wood based biomass) very little, if any, pyrolysis oils and tars are produced. Due to the upstream conditioning of the BioFibe, no plastics, volatiles or oils are present within the feedstock. As such, little in the way of further contaminant removal is required.

The clean up stages utilised by Vaporo Tech are as follow:

- Passing through a Dolomite Chamber (essentially a packed reactor filled with an alkaline reagent to neutralise any acid containing compounds);
- Ceramic Filtration – to remove any fine particulate / solid phase contaminants;
- Gas cooling / Quenching

All gas produced by the pyrolysis plant has been design to meet with the stringent requirements of the Gas Engines (end users) of the fuel.

Gas contaminants in the synthesis gas are mostly solid phase or mildly acid compounds which are easily removed through the conventional gas cleaning technologies. Accordingly, the resultant gas is clean and suitable for use within a range of industrial uses.

More specifically, due to the cleanliness of the gas, it can be reliably produced in accordance to a specification that is suitable for combustion with commercial CHP gas engines.

Dry Gas Cleaning Plant:
Due to the low levels of tar production in gas generated from Biofibe (cellulose fibre) the use of dolomite as the primary cleaning catalyst provides a number of advantages over water based scrubbing. Calcinated dolomite is a very effective catalyst for decomposition of tar and its benefit consists also in its being relatively inexpensive and available. Dolomite is calcium magnesium mineral, its chemical formula is $CaMg(CO_3)_2$.

At elevated temperatures, calcination occurs, i.e. carbonates are converted to oxides and this is accompanied by subsequent release of $CO_2$. The course of calcination depends on temperature, particle size, dolomite composition, speed of heating, and surrounding atmosphere, particularly partial pressure of $CO_2$. Calcinated dolomite shows high activity in decomposition of tars, particularly at temperatures above 850°C.

The maintenance of the dolomite catalyst at elevated temperature removes any deposited soot and ash from the reaction vessel. On exiting the dolomite reactor the gas is passed through a ceramic filter bank and then cooled prior to storage and use in the gas engines

The cooling plant is a standard air blast chiller unit that is designed to cool the gas from around 350$^{o}$C to 60$^{o}$C. Any moisture in the gas will be condensed and removed.

**Thermal Oxidiser**
The carbon and ash produced by the pyrolysis process is used as the primary fuel source for the process. The carbon has been proven to be free from hydrocarbon, chlorines, sulphurs and contaminants and produces temperatures in excess of 1150ºC for greater than 2 seconds residence time. The carbon is an excellent fuel source and is a very stable product delivering consistent and uniform heat to the primary pyrolytic chamber.[3]

The thermal oxidiser in the Vaporo Tech plant is in a horizontal configuration to minimise overhead height / space.

The char is combusted to generate the temperature that is used to heat the outside of the pyrolysis chamber. The hot gases generated by the burner are forced into a cyclonic downward action causing the heavy ash to melt to form a vitrified slag.

The process generates no ash apart from a vitrified slag which has been WAC tested and proven to be an inert, vitrified, non-leaching material.

Some key design and safety features of the thermal oxidiser include;

3 During start up the burners utilise LPG or gas oil, and then transfer to charcoal firing once the process becomes self-sustaining. Pressure, temperature and oxygen levels are continuously monitored to ensure satisfactory control is achieved.

- Minimum temperature in thermal oxidiser set at 900°C based on the char having less than 1% halogenated organic substances.
- Temperature measurements at exit of the thermal oxidiser, surface temperature of the retort and at inlet to heat recovery system.
- Computational Flow Dynamics (CFD) modelling and design calculations confirm 2 seconds residence time for the system as required per Article 6.1, paragraph two of the Waste Incineration Directive (2000/76/EC).
- Airflow to the char burners is monitored by thermal dispersion mass flow meters.
- Pressure monitored in thermal oxidiser chamber.

## Table 2B - Specification of applications in which the synthesis gas can be used in

The pyrolysis plant design used by Vaporo Tech has been optimised to operate in conjunction with Vaporo Tech's proprietary BioFibe feedstock material. The system was developed specifically to convert biomass feedstocks into a clean-burning synthesis gas that can be combusted in reciprocating gas engines for electricity production, steam generation or the production of hot water.

Vaporo Tech's pyrolysis system offers gas cleanliness, gas yields and gas quality at rates which suggests that this form of thermal treatment, once correctly operated and combined with adequate pre-treatment and engine type, can surpass all other forms of commercial thermal processing for achieving best available technology (BAT).

The gas produced from the pyrolysis system is suitable for use on many engine ranges which convert the chemical energy in the product gas into electrical energy, while waste heat produced by the engine is used for district heating or drying purposes. This allows for efficiency levels that were previously impossible with biomass energy generation including waste to energy.

The electrical efficiency of the plant as a whole is very attractive and overall efficiency (electrical and thermal) even reaches values comparable to CHP systems. A typical installation will meet the Industrial Emissions Directive (2010 75 EU) standard and operates without producing effluent.

Vaporo Techs gas results when processing BioFibe, relative to reported data in scientific literature on biomass or MSW are impressive. The Gross Calorific Values are typically 20 $MJ/Nm^3$ (+/- 20%) and is more than twice what is commonly recorded for similar thermal conversion technologies.

The gas is free of contaminants and compares well with the required cleanliness specifications of the UK Gas Supply Regulations and the EASEE European Gas Quality Specification document CBP 2005-001/02.

This gas can be used in a multitude of industrial applications the most applicable being electrical generation using gas engines. There are a number of plant manufacturers who manufacture gas engines capable of being operated on synthesis gas, all of which have been proven to be able to operate with lower CV fuels than natural gas.

The specific specifications of these engines are provided in Appendix B. Vaporo Tech have had written confirmation from a proposed engine supplier that the specific composition of the synthesis gas is suitable for use in Vaporo Tech's application.

Gas engines that operate on synthesis gas are available from:

- GE Jenbacher
- MWM Deutz
- Rolls Royce

Manufacturers letters of confirmation that these engines can operate using this syngas are provided within the Annexes.

| Table 2C – Fuel Parameters | |
|---|---|
| **Product** | Synthesis Gas (Waste (BioFibe) - derived) |
| **Comparator Fuel** | Mains (natural) Gas |
| **Relevant Specification** | The majority of natural gases are mixtures of saturated hydrocarbons where methane prevails; they come from underground accumulations of gases alone or gases associated with oil. There are thus as many compositions of natural gases as exploited hydrocarbon layers. Apart from the methane which is the prevailing element, the crude natural gas usually contains decreasing volumetric percentages of ethane, propane, butane, pentane, etc.<br><br>The ultimate analysis of a natural gas thus includes/understands the molar fraction of hydrocarbons in $CH_4$, $C_2H_6$, $C_3H_8$, $C_4H_{10}$ and the remainder of heavier hydrocarbons is generally indicated under the term $C_5$+. Table 1 gives typical compositions. Apart from these hydrocarbons, one often finds one or more minor elements, or impurities, quoted hereafter:<br><br>• Nitrogen $N_2$: it has as a disadvantage its inert character which decreases the commercial value of gas,<br>• Carbon dioxide $CO_2$: it is harmful by its corrosive properties,<br>• Hydrogen sulphide $H_2S$: it is harmful by its corrosive properties,<br>• Helium $He$: it can be developed commercially,<br>• Water $H_2O$: the natural gas of a layer is generally saturated with steam.<br><br>The typical characteristics of natural gas in term of composition and physical properties and combustion features are presented in the table below. These figures are developed from a sample of group of 10 fuel gases and averaged (Saikaly et al., 2008). |

**Table 2Ca**

| Fuel | $CH_4$ | $C_2H_6$ | $C_3H_8$ | $C_4H_{10}$ | $C_5H_{12}$ | $N_2$ | $CO_2$ | MN |
|---|---|---|---|---|---|---|---|---|
| **Ave** | 88.85 | 4.68 | 2.64 | 0.3 | 0.06 | 2.99 | 0.39 | 78.19 |

The synthesis gas exhibit very similar components to natural albeit with lower % concentrations of hydrocarbons and higher % concentrations inert nitrogen and hydrogen, oxygen, nitrogen and carbon monoxide and oxides. As such, methane, $C_2$, $C_3$ and $C_4$ hydrocarbon gases constitute approximately 30% of the gas content when compared with the ~90% methane content of natural gas. Accordingly the GCV figures are also proportionally lower.

Although the presence of greater % hydrogen, oxygen, nitrogen and carbon monoxide and dioxide has no direct impact on the pollutants released during combustion, their presence does reduce the gross calorific value of the synthesis gas.

In the UK there are two types of quality specifications for gas, those set out in the Gas Safety (Management) Regulations[4], which relate to the supply of domestic gas, and those which relate to specific commercial and industrial contracts which will be plant / contract specific and will relate specifically to the requirements of an end user.

The GS(M)R has been used by the Environment Agency TAG as a means of reference for the Biomethane Injection Protocol Project.

The GS(M)R does however provide a set of requirements in relation to the following pollutant parameters:

**Table 2Cb – Domestic Gas Quality Parameters**

| Parameter | Purpose | Specification | Relevance |
|---|---|---|---|
| Hydrogen Sulphide levels | Toxic Pollutant | < 5 mg/m$^3$ | Relevant to industrial gases |
| Total Sulphur | Acid gas forming compound | < 50 mg/m$^3$ | Relevant to industrial gases |
| Impurities | Water, glycol, amines, methanol, oils, salts chlorides, sand, dirt, carbon | No limits provided, specification only states *'shall not interfere with integrity of with pipes or appliances'* | Not relevant to industrial gas |

In order to determine other potential contaminants that are present within mains supplied natural gas a number of sources have been consulted, including the National Grid Energy Balance and Tracking Teams and the Environment Agency.

It has been concluded by the Environment Agency (Waste Protocols and TAG Teams) that there are no reliable sources of information of trace gases from natural gas to make a comparison. As such, when deriving a comparison standard for the bio-methane to grid inject project the Environment Agency concentrated on a risk assessment approach and considered the impacts of the trace gases on people and the environment from their use.

The EA risk assessment methodology originally developed from the French Avis de l Afsset, from which a database of trace gas analysis for both landfill gases and biogases from AD plant has been developed. This includes detail of around 250 gases. For each of the trace gases, a concentration has been identified and a health criteria value established and a risk assessment carried out considering the critical pathway. In this instance the pathway was the use of the gas

4 The GS(M)R is not concerned with safe combustion at industrial sites as industrial burners and equipment can be adjusted to accommodate the gas received.

in a gas cooker within a small kitchen. Although this pathway is unlikely ever to manifest itself with the synthesis gas associated with this application, the use of this risk methodology to establish a specification for the synthesis gas guarantees that no hazardous effects / impacts will arise from the combustion of the synthesis gas. The long term and short term concentrations were calculated and compared to the relevant health criteria value.

It has been determined by the Environment Agency that the majority of the gases considered posed no risk to human health or the environment. However for the following gases we identified a risk that needs to be managed and hence specification limits derived.

**Halogenated hydrocarbons:** (including 1,2-dichloroethane, vinyl chloride, tetrachloroethene, 1,1,2-tricholoroethane, chlorobenezene, dichloromethane, tetrachloroethane, and trichloroethene). This showed a high risk of impact at the concentration within the gas however an assessment considering the limit set within the network entry agreement demonstrated that these gases at this concentration did not pose an unacceptable risk.

For a range of other gases we determined an acceptable concentration using the risk assessment.

Annex C provides the Risk Assessment Concentration Derived by the EA as part of the TAG Biomethane injection project.

The syngas specification is also provided within Annex C.

## Fuel Parameters

**Table 2Cc: Waste-Derived Synthesis Gas Comparison**

| Relevant parameter | Units | Typical UK natural Gas Composition | Syn Gas Spec (% unless stated) | Comments |
|---|---|---|---|---|
| Hydrogen ($H_2$) | % vol / vol | <0.1 mol% | 5.80 – 18.15 | Converted to water during combustion |
| Oxygen ($O_2$) | % vol / vol | 0-0.2% | 0.24 – 1.53 | Low levels of Oxygen will have little effect on combustion. |
| Nitrogen ($N_2$) | % vol / vol | 0-5% | 2.00 - 9.00 | None |
| Carbon Monoxide (CO) | % vol / vol | No Limits Stated | 18.00 – 42.00 | Will be converted to $CO_2$ during combustion |
| Methane ($CH_4$) | % vol / vol | 70-90% | 10.10 – 21.51 | Will be converted to $CO_2$ during combustion |
| Carbon Dioxide ($CO_2$) | % vol / vol | 0-8% | 15.60 – 48.00 | Unaffected during combustion |
| Ethene | % vol / vol | No Limits Stated | 2.80 – 6.40 | Converted to $CO_2$ and water during combustion |
| Ethane ($C_2H_6$) | % vol / vol | 0-20% | 1.71 – 5.04 | Converted to $CO_2$ and water during combustion |
| Propene ($C_3H_6$) | % vol / vol | No Limits Stated | 0.50 – 5.30 | Converted to $CO_2$ and water during combustion |
| Propane ($C_3H_8$) | % vol / vol | No Limits Stated | 0.07 - 1.79 | Converted to $CO_2$ and water during combustion |
| $C_4$ - Butane (n-$C_4H_{10}$) | % vol / vol | No Limits Stated | 0.14 – 0.93 | Converted to $CO_2$ and water during combustion |
| $C_5$ - Pentane (n-$C_5H_{12}$) | % vol / vol | No Limits Stated | 0.06 – 0.27 | Converted to $CO_2$ and water during combustion |
| Sulphur | % vol / vol | <50mg/m$^3$ | 0.00 – 0.02 | Removed during gas scrubbing |
| Hydrogen Sulphide ($H_2S$) and other reduced sulphur compounds | % vol / vol | 0-5% | 0.00 – 0.02 | Removed during gas scrubbing. Very odorous |
| Acid Gases | mg/kg | Trace | < LOD 2mg/kg | None present in synthesis gas |
| Rare gases (A, He, Ne, Xe) | % vol / vol | Trace | 0.00 – 0.05 | None present in synthesis gas |
| Halogenated Hydrocarbons5 | | | | |
| 1,2 Dichloroethane | mg/m$^3$ | <8.15E+02 | <8.15E+02 | None present in synthesis gas – removed by gas scrubbing stages |
| Vinyl chloride | mg/m$^3$ | <2.16E+03 | <2.16E+03 | None present in synthesis gas – removed by gas scrubbing stages |

5 Reference figures taken from EA 'safe levels for biomethane injection', provided by Steve Storey

| | | | | |
|---|---|---|---|---|
| Tetrachloroethene | mg/m$^3$ | <9.32E+03 | <9.32E+03 | None present in synthesis gas – removed by gas scrubbing stages |
| 1,1,2, Trichloroethane | mg/m$^3$ | <2.33E+00 | <2.33E+00 | None present in synthesis gas – removed by gas scrubbing stages |
| Chlorobenzene | mg/m$^3$ | <8.18E+04 | <8.18E+04 | None present in synthesis gas – removed by gas scrubbing stages |
| Dichloromethane | mg/m$^3$ | <3.49E+03 | <3.49E+03 | None present in synthesis gas – removed by gas scrubbing stages |
| Tetrachloroethane | mg/m$^3$ | <0.00E+00 | <0.00E+00 | None present in synthesis gas – removed by gas scrubbing stages |
| Trichloroethene | mg/m$^3$ | <1.16E+03 | <1.16E+03 | None present in synthesis gas – removed by gas scrubbing stages |
| PAH's (nathphalene) | mg/m$^3$ | <9.32E+03 | <9.32E+03 | None present in synthesis gas –removed by gas cleaning stages |
| Metals (see list below) | | | | |
| Arsenic | mg/kg | Trace | < LOD 2mg/kg | None expected - all metals retained in Char |
| Beryllium | mg/kg | Trace | < LOD 0.5 mg/kg | None expected - all metals retained in Char |
| Cadmium | mg/kg | Trace | < LOD 0.5 mg/kg | None expected – all metals retained in Char |
| Hexavalent Chromium | mg/kg | Trace | < LOD 2 mg/kg | None expected – all metals retained in Char |
| Lead | mg/kg | Trace | <LOD 0.5 mg/kg | None expected – all metals retained in Char |
| Mercury | mg/kg | Trace | <LOD 0.12 mg/kg | None expected – all metals retained in Char |
| Chlorinated Hydrocarbons | % vol /vol | Trace | <LOD 1ug/m$^3$ | None present in synthesis gas |
| Ammonia | mg/m$^3$ | <2.91E+03 | <2.91E+03 | None present in synthesis gas - removed by gas cleaning stages |
| Gross Calorific Value | | 52.9 MJ/m$^3$ | 14.73 – 22.73 MJ/m$^3$ | |
| | | 100% | 100% | |

Based on the gas specification above, when compared with the allowable UK and EU specifications and the Risk Assessed Limits of the EA biogas injection protocols of mains pressure gas, the combustion of synthesis gas will not lead to the releases of any greater level of pollutants than the combustion of mains gas.

Combustion of synthesis gas, in general, produces lower emissions for heat and power generation than conventional liquid and solid fuels. The composition of the synthesis gas strongly influences the level of emissions. Hydrogen and carbon monoxide in synthesis gases results in elevated combustion temperature that facilitates the thermal formation of NO and $NO_2$. In contrast, higher temperatures promote complete combustion and reduce the emission of organic volatiles, which are formed mainly from minor fractions of hydrocarbons in synthesis gases.

Particulate matter, metallic compounds and other undesired pollutants are **not present in the synthesis gas** as they are all removed by the gas clean up stages. The table included in Annex C provides a summary of all of the potential pollutant materials and their environmental fate. The purpose of this table is to demonstrate the mechanisms and key control parameters by which all pollutants / contaminant materials are removed from the synthesis gas.

Third party gas analysis has been carried out by MCERTS approved laboratories TES Bretby and is provided within Annex A. This analysis provides the makeup of synthesis gas demonstrates that the gas is free of contaminants and hydrogen sulphide.

In summary:

- The upstream BioFibe conditioning processes effectively removes all potentially contaminative materials, such that oils, Volatile organics, plastics and metals are not present within the source feedstocks.
- Any acid containing compounds are removed through the reaction within the dolomite chamber an
- Any compounds that have a melting point below 350$^{o}$C are removed through the filtration of the gas in the gas clean up train.
- There are no tars or oils generated by the pyrolysis of biofibe due to the lack of lignin in the fibre feedstock.
- All materials that remain solid at 700$^{o}$C and below are removed in the char and then encapsulated in the vitrified ash;
- All carbon material is retained in the pyrolyser ash and burnt within charcoal burner systems.

Therefore cleaned synthesis gas when combusted within a gas engine will produce emissions similar with natural gas.

## Monitoring / Sampling Summary

The generation of clean synthesis gas is a function of the upstream BioFibe conditioning processes (autoclave processing, contaminant removal & recyclate separation, drying), pyrolyser controls and gas cleaning plant.

The operation of the entire plant and ancillaries will by default create a clean synthesis gas. Therefore in order to ensure that gas cleanliness is assured, a very high level of process control and monitoring is required.

All gas produced by the pyrolyser will be continuously monitored for volume, temperature and GCV prior to combustion. Any changes in the gas composition will be monitored and controlled in accordance with the process logic of the SCADA systems.

The table below provides an outline of the key process control and monitoring equipment that provides all the necessary process parameters to ensure good quality gas is produced. In the event that these control measures fail or exceed the required operational parameters, the plant will be shut down and the synthesis gas released to the emergency flare.

This table only details the key control parameters related to gas generation.

All of the system parameters are controlled using a SCADA instrumentation and control system. All pressure, flow and temperature instrumentation senses and controls continuously and in real time.

**Table 2Cd – Synthesis gas Quality Control and Monitoring Measures**

| Parameter | Purpose | Control Philosophy | Mitigation |
|---|---|---|---|
| Fuel Supply Quality | To control the quality of all fuel supplied to the plant | All feed stocks will be manufactured by the Vaporo Tech's proprietary autoclave plant and preparation/conditioning plant. All BioFibe will be manufactured in accordance to an internal Quality Specification that ensures cleanliness and moisture content. | All fuel will be inspected and batch tested for compliance to specification in accordance to Quality Standards.<br><br>All non compliance feedstock will be rejected in accordance to procedure and reprocessed until it conforms to Quality Standards. |

| | | | |
|---|---|---|---|
| | | Each batch of fuel will be inspected upon arrival in accordance to Site acceptance procedures. | |
| Fuel feed rate | Accurate control of the fuel feed rate will ensure a consistent gas generation rate. | Inlet feed rate interlocked and controlled with:<br>• Retort pressure<br>• Gas outlet flow rate<br>• Gas temperature | The inlet feed rate is controlled and monitored on a continuous basis and is adjusted in accordance to the retort pressure and outlet gas flow rate.<br>Plant will modulate automatically, alarm and enter a controlled shut down if control set-points are not maintained. All gas will be flared. |
| Retort temperature | Accurate and steady state retort temperature is a fundamental requirement for synthesis gas quality. If the temp exceeds the 700°C set point, gasification of certain metals may occur. | Temperature is monitored in the retort through a pyrometer. Temperature is also monitored at the muffle, to the heat recovery system and in the flue gas lines from the thermal oxidiser. The temperature control function, together with fuel type helps to create the optimum gas composition to give the highest calorific value MJ/m³. Temperature is delivered to the pyrolyser chamber from the thermal oxidiser at a flow, pressure and temperature. Oxygen levels are also monitored at the flue exit from the pyrolyser as it enters the boiler (heat recovery system). | The pyrolyser combustion systems are controlled and monitored on a continuous basis and adjusted in real time.<br><br>If the retort does not reach, or exceeds temperature the plant will alarm and enter a controlled shutdown. All gas will be flared. |
| Retort Atmosphere | The atmosphere within the retort is a key parameter for the formation of synthesis gas. The presence of oxygen can lead to the formation of dioxins and combustion products. | Synthesis gas is generated by applying a temperature of approximately 700°C ± 50°C to a feed material with moisture content of 8% ± 2.5% in the presence of an oxygen-depleted environment. The pressure in the chamber is kept positive to the outside atmosphere through the addition of $N_2$ and specific gas pressure control parameters. | The retort pressure is continuously monitored as part of the SCADA control system.<br><br>The SCADA controls will automatically modulate and control within the set point parameters.<br>Operation of the plant outside of these parameters will alarm the plant and enter a controlled shutdown. All gas will be flared. |
| Gas booster pressure | The gas booster fan draws synthesis gas from the retort through the gas clean up systems and | The gas booster pressure is continuously monitored and interlocked to only operate when the gas | The gas booster system is interlocked with the gas scrubber systems. |

| | | | |
|---|---|---|---|
| | directs it to the gas engines or flare. The pressure of this system is key control requirement | scrubbing systems are operational.<br>The fan is controlled on pressure and is set to match the rate of generation of gas within the retort | The system will not draw gas from the retort if the cleaning plant systems fail or do not operate correctly.<br>In the case of the fan failure no gas will be drawn from the retort and the plant will enter a controlled shut down.<br>In the case of a filter plant, the fans will shut down and discharge to flare. |
| Dry Gas Cleaning Operation | The dry gas cleaning plant operation is a key parameter for the cleanliness of the synthesis gas. | The dry gas cleaning train is monitored continuously for gas flow rate, filter plant differential pressure, gas inlet and outlet temperature. | The gas clean up plant is interlocked to all of the key plant operations. In the event of a plant failure, the retort and all associated ancillary plant will enter a controlled shut down sequence. All gas will be flared. |
| Gas Quality | The steady temperature, flow rate and GCV of the gas are essential for safe and consistent operation of the process plant. | All gas being produced by the pyrolyser will be continuously monitored to ensure that the GCV, temperature and volume meets with the engine and plant performance requirements. | The monitoring equipment will operate continuously and provide feedback into the control plant. The failure of the plant to produce consistent gas will result in a controlled shutdown. |
| Engine management system (close coupled CHP plant only) | The gas engines will provide continuous feedback into the performance of the engines. | In the event that the engines reduce in power or that the required set point parameters are not met the plant will not operate.<br>All gas will be routed to flare. | The engine management system will operate continuously and provide feedback into the control systems as required. |

The above control philosophy will ensure that the synthesis gas produced by the plant is free of solid and gaseous contaminants.

The entire plant has been subject to a HAZOP study and appropriate controls and mitigation applied accordingly. As such there are a number of key duty and standby components to ensure that plant stability is maintained. For example:

- Critical Hydraulic pumps
- Cooling Fans
- Gas cleaning filters etc.

Furthermore, all BioFibe is manufactured to a stringent quality standard in order to ensure the composition of the final product is not compromised. The plant will only pyrolyse

BioFibe (as detailed in Table A1)

### Gas sampling

Under the amended Renewables Obligation Order 2009, generating stations using gasification or pyrolysis to produce a gaseous fuel are obliged to measure the gross calorific value of this fuel so that Ofgem can place generation from a gasification / pyrolysis station within the appropriate band in a given month. This requirement is set out in Schedule 2.1 Part 1 of the Order.

In accordance with this requirement, all synthesis gas being produced by the plant will be subject to continuous measurement and analysis. The analysers used by the plant will comprise high speed process gas analyser for monitoring and control of Calorific value, Wobbe Index, Specific gravity and the Air/Fuel ratio of process gas.

This analyser will feed back directly into the SCADA control system and be used to control a number of the key input parameters of the plant (i.e. retort speed, fuel feed rate etc).

In addition the synthesis gas produced by the plant will be subject to periodic compliance sampling to double check and verify the online analysers and to confirm other gas quality aspects (gas chemical analysis etc).

In addition, the gas engines that will be used for downstream electrical generation will all be fitted as standard with engine management systems that will as standard modulate in accordance to any variations in gas parameters. The gas engines will typically control by continuously monitoring gas CO levels, gas pressure, flow rate and temperature.

The gas engines will be interlocked to the pyrolyser control system to ensure that any significant fluctuations in gas quality outside of the stated specification leads to a controlled shut down of the system.

## Table 2D – Comparison of Pollution & Emissions

Engine performance specification sheets to demonstrate the gas engine emission performance are provided below and included within Annex B. These specifications have been provided by the engine manufacturer and relate to the same engine model operated on synthesis gas and natural gas respectively:

**Table 2Da: Engine performance data**

| | Natural Gas | | Synthesis Gas | | Comment |
|---|---|---|---|---|---|
| Electrical Power Output | 3333kWe | | 2630Kwe | | Natural Gas generation provides greater electrical output but also greater fuel / air requirements |
| Generation efficiency | 43.5% | | 41.4% | | |
| Exhaust Mass Flow (wet) | 17,220 kg/hr | 5.17 kg/kWe | 14,212 kg/hr | 5.4 kg/kWe | Similar to +/- 5% |
| $NO_X$ emissions (@5%$O_2$) | 500 mg/Nm$^3$ | 1.854 g/s<br>(6.674 kg/hr)<br>2.00 kg/MWh | 500 mg/Nm$^3$ | 1.53 g/s (5.508kg/hr)<br>2.09 kg/MWh | The mass releases of NOx per MWh are very similar +/-5% |
| CO (@5%$O_2$) | <1200 mg/Nm$^3$ | 4.449 g/s (16.016kg/hr)<br>4.81 kg/MWh | <1000 mg/Nm$^3$ | 3.06 g/s (11.016kg/hr)<br>4.19 kg/MWh | The mass releases of CO per MWh when operating on Synthesis gas is approximately 13% cleaner assuming 1200mg/Nm$^3$<br><br>The mass releases of CO are approximately similar if lower (1000mg/Nm$^3$) emissions rate. |
| SOx (assuming max 5%) | <50mg/Nm$^3$ | 0.02g/s<br>(0.072kg/hr)<br>0.02kg/MWh | None | <0.0002<br>(<0.0007kg/hr)<br>0.0002kg/MWh | The specification relating to sulphur reduced compounds indicated that syngas will contain approx 1/100 of the maximum allowable hydrogen sulphide concentrations. |

Figures provided by MWM

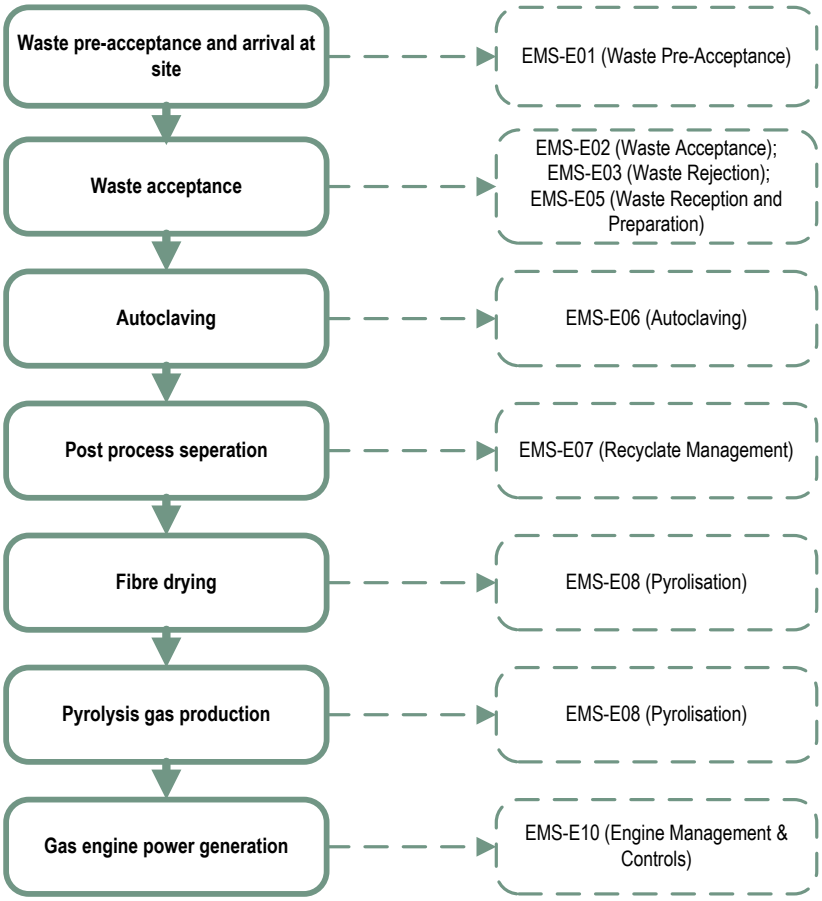
## Table 2E - Site Operation Procedures

In order to ensure operational control and subsequent product quality is maintained, all sites that Vaporo Tech operate will adopt a working plan (in accordance with Environmental Permitting requirements), comprising a number of core procedures that correspond to specific process stages (including waste acceptance and monitoring).

All feed stocks provided to the site will be in accordance to an agreed specification and be accepted in accordance with site acceptance and rejection procedures.

In addition to the working plan, detailed operation and maintenance manuals (as well as training) will be provided for all operators and technicians working for the process plant.

A summary map of the site working plan is provided below;



# 3. SUMMARY

Vaporo Tech has developed an advanced conversion technology that has been designed to generate clean synthesis gas from a proprietary processed RDF derived biomass fibre called BioFibe. Vaporo Tech's application of the technology in conjunction with upstream autoclaving and biomass conditioning, creates a fundamentally clean gas product with an intrinsically low contaminant content.

The entire upstream fuel conditioning and pyrolysis plant has been designed to generate a synthesis fuel gas that can be used in gas engines and generation sets for the purposes of generating clean renewable energy. The gas quality and GCV meets the requirements of Ofgem Synthesis Gas requirements and will enable the plant to qualify under the Renewables Obligation Order 2009.

All gas being produced by the plant can be used directly as part of a close coupled CHP scheme or be exported to a neighbouring third party for similar use.

There are a number of gas engines on the market that have been specifically designed to operate using industrial gases with similar (and significantly worse) properties. These engines produce electrical power at a comparable output with a comparable level of emissions (NOx and CO) when compared with the combustion of Natural Gas.

The pyrolysis plant and the gas produced is all subject to a very detailed monitoring regime that will ensure that a quality specification is met at all times. In the event that the gas or the upstream production plant cannot meet the quality specification, the production of synthesis gas will cease and any residual quantities flared.

Vaporo Techs advanced pyrolisation technology when operated as described in this application, successfully converts the waste material into a distinct and marketable product. The synthesis gas can be combusted conventionally in a number of commercially available gas engine types in the same manner as mains supplied gas. The combustion of synthesis gas is no more polluting than the combustion of mains gas in similar applications.

Based on the above it is therefore the consideration of Vaporo Tech that the synthesis gas produced by their pyrolysis plant, when operated as described above, meets the published definition of 'End of Waste'.

# ANNEX A – Third Party Sampling / Analysis

- Synthesis Gas
- Char and Vitrified Slag Analysis
- Pyrolyser Emissions

# Annex A1 – Example Syn Gas Analysis

# TEST REPORT

1513

**Customer:** OMC Engineering, Ballysimon Road, Limerick, Ireland
On behalf of Vaporotech

Date analysed: 7 July 2010
Date received: 5 July 2010
Date sampled: 2 July 2010
**Report №** 41078

| SAMPLE REF | Analysis % v/v | | | | | |
|---|---|---|---|---|---|---|
| | $CO_2$ | $O_2$ | $CO^{\dagger}$ | $N_2$ | $H_2{}^{\dagger}$ | $H_2S$* |
| Sample 5<br>BioFibe, Vaporotech | 21.0 | 1.53 | 18 | 9 | 6.1 | 0.0090 |
| **Method of Analysis** | 1 | 2 | 1 | 4 | 4 | 5 |

* Not UKAS Accredited
**x** Insufficient Sample possible leak on bag
† Out of UKAS Range

| | | | | |
|---|---|---|---|---|
| Method of Analysis: | 1 | Infra Red | 3 | G.C. with F.I.D. |
| | 2 | Paramagnetic | 4 | G.C. with T.C.D. |

Analyst: I Thornewill

| **Customer Analytical Requirements** | | **Authorised by:** |
|---|---|---|
| $CO_2$, $CH_4$, $O_2$, CO, $N_2$, $H_2$, $H_2S$, $C_2H_4$, $C_2H_6$, $C_3H_6$, $C_3H_8$, n-$C_4H_{10}$, i-$C_4H_{10}$, n-$C_5H_{12}$, i-$C_5H_{12}$ | By Letter | I Thornewill |

Authorised by:
Issue Date: 09 July 2010

B Royals, Head of Gas Monitoring
Direct Dial: 01 283 554435





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Registration Numbers FS75748, EMS 511803

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Registered office: ESG House, Bretby Business Park, Ashby Road, Burton on Trent DE15 0YZ Registered in England no. 2880501
www.esg.co.uk

# TEST REPORT

1513

**Customer:** OMC Engineering, Ballysimon Road, Limerick, Ireland
On behalf of Vaporotech

Date analysed: 7 July 2010 Date received: 5 July 2010

Date sampled: 2 July 2010 **Report №** 41078

| SAMPLE REF | Analysis % v/v | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $CH_4$ | $C_2H_4$* | $C_2H_6$ | $C_3H_6$* | $C_3H_8$ | n-$C_4H_{10}$ | i-$C_4H_{10}$* | n-$C_5H_{12}$ | i-$C_5H_{12}$* | c.v. Net $MJm^{-3}$ | c.v. Gross $MJm^{-3}$ |
| Sample (5) BioFibe, Vaporotech | 19.3 | 6.18 | 3.56 | 2.15 | 0.26 | <0.02 | 0.63 | 0.03 | 0.07 | 18.78 | 20.45 |
| **Method of Analysis** | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | - | - |

* Not UKAS Accredited
**x** Insufficient Sample possible leak on bag
† Out of UKAS Range

| | | | | | |
|---|---|---|---|---|---|
| Method of Analysis: | 1 | Infra Red | 3 | G.C. with F.I.D. | |
| | 2 | Paramagnetic | 4 | G.C. with T.C.D. | |
| | | | | | Analyst: I Thornewill |

| **Customer Analytical Requirements** | | **Authorised by:** |
|---|---|---|
| $CO_2$, $CH_4$, $O_2$, CO, $N_2$, $H_2$, $H_2S$, $C_2H_4$, $C_2H_6$, $C_3H_6$, $C_3H_8$, n-$C_4H_{10}$, i-$C_4H_{10}$, n-$C_5H_{12}$, i-$C_5H_{12}$ | By Letter | I Thornewill |

Authorised by: Issue Date: 09 July 2010

B Royals. Head of Gas Monitoring
Direct Dial: 01 283 554435


**End of Report**

TES Bretby accepts no responsibility for the collection of any of the samples referred to in this report

TES Bretby, P.O. Box 100, Burton-upon-Trent, DE15 0XD Telephone: 01283 554400 Fax: 01283 554422
Registration Numbers FS75748, EMS 511803

TES Bretby

# TEST REPORT

UKAS TESTING 1513

Date analysed: 17 March 2010 Date received: 17 March 2010

**Report №** 40563

| SAMPLE REFRENCE | Analysis % v/v | | | | | | | | | | | | | | | Calorific Value $MJ.m^{-3}$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $CO_2$ | $O_2$ | CO† | $N_2$ | *$H_2$ | $CH_4$ | $C_2H_6$ | $C_3H_8$ | n-$C_4H_{10}$ | n-$C_5H_{12}$ | *$C_2H_4$ | *$C_3H_6$ | *i-$C_4H_{10}$ | *i-$C_5H_{12}$ | *$H_2S$ | Net | Gross |
| Autoclave Biofuel @ 702°C | 25.0 | 0.42 | 22 | 1 | 22 | 15.8 | 1.47 | 0.10 | <0.02 | <0.02 | 6.75 | 1.12 | 0.38 | 0.09 | 0.0365 | 16.44 | 17.92 |
| Autoclave Biofuel @ 707°C | 25.0 | 0.47 | 21 | 1 | 25 | 14.8 | 1.26 | 0.09 | <0.02 | <0.02 | 6.23 | 0.98 | 0.35 | 0.09 | 0.0352 | 15.71 | 17.17 |
| | | | | | | | | | | | | | | | | | |
| **Method of Analysis** | 1 | 2 | 1 | 4 | 4 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | - | - |

Method of Analysis:
1 Infra Red
2 Paramagnetic
3 G.C. – F.I.D.
4. G.C. – T.C.D.
5. G.C. – F.P.D. (Not UKAS Accredited)
* Not UKAS Accredited
† CO Results >10% are outside our UKAS Scope

Analyst: I Thornewill

| Customer Analytical Requirements: | By Letter | Authorised by: |
|---|---|---|
| $CO_2$, $O_2$, CO, $N_2$, $H_2$, $CH_4$, $C_2H_6$, $C_3H_8$, $C_4H_{10}$, $C_5H_{12}$, $C_2H_4$, $C_3H_8$, $C_4H_{10}$, $C_5H_{12}$, $H_2S$ | | I Thornewill |

Authorised by:

I Thornewill, Senior Analyst
Direct Dial: 01 283 554461

Issue Date: 22 March 2010

**Page:** 1 of 1
End of Report

TES Bretby accepts no responsibility for the collection of any of the samples referred to in this report.

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BSI Registration Nos: FS 75748, EMS 511803

# Annex A2 – Sample Char and Slag Analysis

**ITS Testing Services (UK) Ltd**
Sunbury Technology Centre
Unit 'A' Shears Way
Brooklands Close
Sunbury-on-Thames
Middlesex TW16 7EE
Tel : 01932 73 2100
Fax : 01932 73 2113

| | | |
|---|---|---|
| To: Vaporo Tech Limited | **Report:** | RT/ELE/6807V3 |
| | **Date:** | 09/03/2010 |
| | Order No. | 018 |
| | Quote No. | QT/SUN/10/B44V2 |
| | Total Cost for Analysis | £1575 |

# Chemical characterization of carbon chars (ITS ref. 177512-15;17) and vitrified slag samples (ITS ref. 177511;16;18-19)

## Introduction.

A total of nine samples were submitted for chemical characterization (5 carbon chars and 4 vitrified slags) and were described as follows:

(i) Carbon chars

ITS ref. 177512 Sample AC
ITS ref. 177517 Sample BC
ITS ref. 177513 Sample CC
ITS ref. 177515 Sample DC
ITS ref. 177514 Sample DC2

(ii) Vitrified slags

ITS ref. 177518 Sample AS
ITS ref. 177519 Sample BS
ITS ref. 177511 Sample CS
ITS ref. 177516 Sample DS

## Experimental.

Initially, both sets of samples were ground to fine powders after residual metal fragments etc were removed where necessary. High temperature combustion systems were used to determine the amounts of carbon, hydrogen, nitrogen and sulfur present in each case using replicate analyses. The mean results are given below in Table 1.

The two sets of samples were also scanned for other elements (elements with atomic weights of sodium and above) using a wave-length dispersive x-ray fluorescence spectrometer (WDXRF) as pressed pellets. All the samples have been run under the same operating conditions for comparative purposes. The software on the instrument uses correction factors to take into account matrix effects etc so the values are classed as 'semi-quantitative'. The lighter elements such as aluminium and silicon are most affected by these effects and thus their results have a wider uncertainty factor. The metals are reported as the elements themselves rather than their oxides, having been corrected for the amounts of carbon present. The XRF scans are shown below in Tables 2 and 3.

## Results and Discussion of Results. ¥

| **Table 1 CHNS** | | | | | |
|---|---|---|---|---|---|
| | | | | | |
| Sample ref.no. | Sample | Carbon | Hydrogen | Nitrogen | Sulfur |
| ITS | | %wt | %wt | %wt | %wt |
| | | | | | |
| 177512 | AC | 57.8 | 1.0 | 0.4 | 0.25 |
| 177517 | BC | 66.0 | 1.6 | 1.1 | 0.25 |
| 177513 | CC | 33.3 | 0.9 | 0.5 | 0.51 |
| 177515 | DC | 60.0 | 0.6 | 0.7 | 1.0 |
| 177514 | DC2 | 11.8 | 0.5 | 0.2 | 0.24 |
| | | | | | |
| 177518 | AS | 0.03 | <0.1 | <0.05 | <0.01 |
| 177519 | BS | 0.03 | <0.1 | <0.05 | <0.01 |
| 177511 | CS | <0.02 | 0.2 | <0.05 | <0.01 |
| 177516 | DS | 0.09 | 0.3 | <0.05 | <0.01 |
| | | | | | |

From Table 1, it can be seen that the carbon chars (samples AC to DC) have carbon contents in the range from approximately 33%wt to 66%wt. Since the carbon analysis is designed to give a total figure, combustion conditions are sufficiently severe to decompose carbon from organic species, carbonates and highly coked species. In the case of the hydrogen content value, this would include both the contribution from organic species and trace moisture. Though the samples were not dried (to avoid any potential loss of volatile organic species), the nature of the powders suggested that if water was present it would have been at very low levels. This being the case, the very high carbon/hydrogen ratio indicates that the carbon is the form of highly coked species. Sample DC2 has a lower carbon content at 11.8% by weight. In respect of the other two elements monitored ie nitrogen and sulfur, it would be surmised that any organic species or thermally unstable compounds containing these elements would have been broken down in the carbon charring process. Thus, it would be expected that the remaining nitrogen- and sulfur- containing compounds would be in the form of heat stable entities such as sulfates etc.

The vitrified slags (samples AS to DS) show very low levels of carbon (below 0.1%wt) as was found for the previous slag sample analysed (Report no. RT/ELE/5216). Similarly the values are very low for hydrogen, nitrogen and sulfur; in most cases below the detection limits of the instruments.





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## (i) Carbon chars.

| Table 2 XRF Scan | | | | | |
|---|---|---|---|---|---|
| | | | | | |
| Sample ref.no. | 177512 | 177517 | 177513 | 177515 | 177514 |
| ITS | | | | | |
| | AC | BC | CC | DC | DC2 |
| **Element** | | | | | |
| %wt | | | | | |
| Na | 1.5 | 0.20 | ND | 0.30 | 0.81 |
| Mg | 0.40 | 0.16 | ND | 0.47 | 0.30 |
| Al | 1.4 | 0.92 | 2.0 | 0.54 | 2.8 |
| Si | 4.4 | 2.4 | 12.3 | 3.00 | 15.5 |
| P | 0.37 | 0.21 | 0.35 | 0.32 | 0.34 |
| Cl | 0.71 | 1.3 | 0.98 | 0.68 | 0.96 |
| K | 0.64 | 0.60 | 0.31 | 0.23 | 0.90 |
| Ca | 4.8 | 5.4 | 6.9 | 11.0 | 7.3 |
| Ti | 1.1 | 1.5 | 0.6 | 0.31 | 0.41 |
| Cr | 0.08 | 0.08 | ND | ND | ND |
| Mn | 0.08 | ND | ND | ND | ND |
| Fe | 4.7 | 2.6 | 5.0 | 3.0 | 7.3 |
| Cu | 0.08 | 0.07 | 0.28 | 0.10 | ND |
| Zn | 1.1 | 0.24 | 1.8 | 2.1 | 1.5 |
| Br | 0.02 | 0.05 | ND | ND | ND |
| Sr | 0.02 | 0.02 | 0.02 | 0.03 | 0.03 |
| Zr | 0.02 | 0.01 | ND | ND | 0.02 |
| Ba | ND | ND | 0.27 | 0.12 | ND |

**ND = Not detected**

## (ii) Vitrified slags

| Table 3 XRF Scan | | | | |
|---|---|---|---|---|
| | | | | |
| Sample ref.no. | 177518 | 177519 | 177511 | 177516 |
| ITS | | | | |
| | AS | BS | CS | DS |
| **Element** | | | | |
| %wt | | | | |
| Na | 2.3 | 0.81 | 1.5 | ND |
| Mg | 1.1 | 0.36 | 0.54 | ND |
| Al | 5.4 | 4.4 | 3.8 | 2.6 |
| Si | 13.4 | 14.6 | 8.0 | 6.4 |
| P | 0.37 | 0.34 | 0.16 | 0.07 |





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| | | | | |
|---|---|---|---|---|
| Cl | ND | ND | ND | ND |
| K | 0.70 | 0.69 | 0.30 | 0.19 |
| Ca | 18.4 | 17.3 | 8.3 | 4.0 |
| Ti | 1.2 | 1.1 | 0.71 | 0.29 |
| Cr | ND | ND | 0.25 | 0.18 |
| Mn | 0.14 | 0.13 | 0.18 | 0.11 |
| Fe | 3.1 | 3.0 | 22.5 | 19.7 |
| Cu | 0.47 | 0.45 | 0.45 | 0.31 |
| Zn | 0.04 | 0.06 | 0.22 | 0.32 |
| Br | ND | ND | ND | ND |
| Sr | 0.07 | 0.07 | 0.04 | 0.03 |
| Zr | 0.07 | 0.07 | 0.04 | 0.03 |
| Ba | 0.18 | 0.19 | 0.30 | 0.28 |

**ND = Not detected**

The XRF scan data is given above in Tables 2 and 3. As mentioned in the experimental section, the propriety software has been used to provide a semi-quantitative estimate of the elements present. (If fully quantitative data is required, matrix matched powder standards would need to be prepared for the elements detected. This would require a considerable effort in term of time and cost.) The figures are presented as the element concentrations rather than as pseudo oxides. For the vitrified slags, the evidence is that they are essentially in-organic as was seen for the previous sample (RT/ELE/5216) and thus most likely to be made up of mixed silicates. These chemical entities, having already undergone extensive heat treatment, would be considered 'inert' materials.

Analysis has been carried out on samples as received, independent of sampling procedure, using the latest versions of all test methods.

Samples will be disposed of after 1 month unless alternative arrangements have been made in agreement with the customer.

¥ Opinions and interpretations expressed herein are outside the scope of UKAS accreditation.

**Methods:**
1) 1)MT/ELE/13 Determination of Carbon, hydrogen & nitrogen using an elemental analyser.
2)MT/MCR/10 Determination of Sulphur by Eltra Analyser. (Not UKAS accredited).

Reported By:_____
Dr. John A. Price
Team Leader – Senior Technical consultants

Checked By:_____
Carol Elkins
Deputy Laboratory Manager





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# Annex A3 – Pyroliser Air Emissions Sampling

# AIR & EMISSIONS TESTING GROUP

Great Western One
Bristol Street
Swindon
SN1 5ET
Tel: 01793 714 714
Fax: 01793 714 715

**Your contacts at Scientifics:**

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Senior Team Leader
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Technical Manager
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## Stack Emissions Testing Report

**Operator / Company**
VAPORO TECH

**Site:**
Stratford, London

**Release Point:**
Gasifier - Material B

**Sampling Date/s:**
27th November 2009

**Job Number:**
LSW 02520

| | |
|---|---|
| Report Date:<br>Version: | 5th January 2010<br>1 |
| Report By:<br>MCERTS Number:<br>MCERTS Level:<br>Technical Endorsements: | Matt Webster<br>MM 07 816<br>MCERTS Level 2 - Team Leader<br>1 & 4 |
| Report Approved By:<br>MCERTS Number:<br>Business Title:<br>Technical Endorsements:<br>Signature: | David May<br>MM 07 862<br>MCERTS Level 2 - Team Leader<br>1 & 4 |

UKAS TESTING 1015

mCERTS THE ENVIRONMENT AGENCY'S MONITORING CERTIFICATION SCHEME

# CONTENTS

# EXECUTIVE SUMMARY

## Stack Emissions Monitoring Objectives

FIRST POWER LTD operates a gasification process at Stratford, London

Scientifics Limited were commissioned by FIRST POWER LTD to carry out stack emissions monitoring to determine the release of prescribed pollutants from the following Plant under fuel trial operating conditions.

**Plant**

Gasifier

**Operator**

FIRST POWER LTD
Shakespeare House
Wyke Road
Stratford
London
E3 2PL

**Stack Emissions Monitoring**

Scientifics Limited - Swindon Laboratory
Great Western One
Bristol Street
Swindon
SN1 5ET
UKAS and MCERTS Accreditation Number: 1015

# EXECUTIVE SUMMARY

## Emissions Summary

| Parameter | Units | Result | Uncertainty +/- | Limit |
|---|---|---|---|---|
| Volatile Organic Compounds | $mg/m^3$ | ND | - | - |
| Volatile Organic Compounds Emission Rate | g/hr | - | - | - |
| Oxides of Nitrogen (as NO2) | $mg/m^3$ | 164.7 | 20.06 | - |
| Oxides of Nitrogen (as NO2) Emission Rate | g/hr | - | - | - |
| Sulphur Dioxide | $mg/m^3$ | 4.9 | 4.77 | - |
| Sulphur Dioxide Emission Rate | g/hr | - | - | - |
| Carbon Monoxide | $mg/m^3$ | 2.69 | 2.14 | - |
| Carbon Monoxide Emission Rate | g/hr | - | - | - |
| Oxygen | % v/v | 13.2 | 0.4 | - |
| Moisture | % | 4.5 | 0.71 | - |
| Stack Gas Temperature | $^oC$ | - | - | - |
| Stack Gas Velocity | m/s | - | - | - |
| Gas Volumetric Flow Rate (Actual) | $m^3/hr$ | - | - | - |
| Gas Volumetric Flow Rate (STP, Wet) | $m^3/hr$ | - | - | - |
| Gas Volumetric Flow Rate (STP, Dry) | $m^3/hr$ | - | - | - |
| Gas Volumetric Flow Rate (@ref conditions) | $m^3/hr$ | - | - | - |

where ND = None Detected

Reference conditions are 273K, 101.3kPa, dry gas, 11% Oxygen.

# EXECUTIVE SUMMARY

## Monitoring Times

| Parameter | Sampling Date | Sampling Times | Sampling Duration |
|---|---|---|---|
| Volatile Organic Compounds Run 1 | 27 November 2009 | 11:20 - 11:34 | 14 minutes |
| Combustion Gases | 27 November 2009 | 11:20 - 11:34 | 14 minutes |

# EXECUTIVE SUMMARY

## Process Details

| Parameter | Process Details |
|---|---|
| Process Status | Fuel Trial |
| Percentage of capacity or Tonnes / Hour | N/A |
| Continuous or Batch Process | Batch |
| Feedstock (if applicable) | N/A |
| Abatement System | - |
| Abatement System Running Status | - |
| Fuel | Material B |
| Plume Appearance | Not Visible from Sampling Location |

# EXECUTIVE SUMMARY

## Monitoring Methods

The selection of standard methods employed by Scientifics is determined, wherever possible by the hierarchy of method selection outlined in Environment Agency Technical Guidance Document (Monitoring) M2. i.e. CEN, ISO, BS, US EPA etc.

The tables below summarise the monitoring methods, techniques and technical procedures employed, and details any deviations from the aforementioned hierarchy:

**Sampling Methods with Subsequent Analysis**

| Species | Standard Method | Scientifics Technical Procedure | UKAS Lab Number | MCERTS Accredited Method | Limit of Detection (LOD) | MU of Method +/- % | MU +/- % |
|---|---|---|---|---|---|---|---|
| - | - | - | - | - | - | - | - |

**On-Site Testing**

| Species | Standard Method | Scientifics Technical Procedure | UKAS Lab Number | MCERTS Accredited Method | Limit of Detection (LOD) | MU of Method +/- % | MU +/- % |
|---|---|---|---|---|---|---|---|
| VOCs | BS EN 13526 | AE 056 | 1015 | Yes | 0.4 mg/m³ | 20% | N/A |
| $NO_X$ | BS EN 14792 | AE 008 / AE 015 | 1015 | Yes | 0.2 mg/m³ | 25% | 12.2% |
| $SO_2$ | M21 | AE 008 / AE 015 | 1015 | Yes | 0.2 mg/m³ | 25% | 97.3% |
| CO | BS EN 15058 | AE 007 / AE 015 | 1015 | Yes | 0.2 mg/m³ | 25% | 79.3% |
| $O_2$ | BS EN 14789 | AE 007 / 015 | 1015 | Yes | 0.01% | 10% | 3.25% |
| $H_2O$ | BS EN 14790 | AE 004 | 1015 | Yes | 0.0031 % | 10% | 15.9% |

# EXECUTIVE SUMMARY

## Analytical Methods

The following tables list the analytical methods employed together with the custody and archiving details:

**Sampling Methods with Subsequent Analysis**

| Species | Analytical Technique | Analytical Procedure | UKAS Lab Number | UKAS Accredited Analysis | Laboratory | Sample Archive Location | Archive Period |
|---|---|---|---|---|---|---|---|
| - | - | - | - | - | - | - | - |

**On-Site Testing**

| Species | Analytical Technique | Analytical Procedure | UKAS Lab Number | MCERTS Accredited Analysis | Laboratory | Sample Archive Location | Span Gas |
|---|---|---|---|---|---|---|---|
| VOCs | Flame Ionisation Detection | AE 056 | 1015 | Yes | Swindon | N/A | 8.17 ppm |
| $NO_X$ | Chemiluminsence | AE 008 / AE 015 | 1015 | Yes | Swindon | N/A | 83.1 ppm |
| $SO_2$ | Non Dispersive Infra Red | AE 008 / AE 015 | 1015 | Yes | Swindon | N/A | 153 ppm |
| CO | Non Dispersive Infra Red | AE 007 / AE 015 | 1015 | Yes | Swindon | N/A | 152.5 ppm |
| $O_2$ | Zirconia Cell | AE 007 / 015 | 1015 | Yes | Swindon | N/A | 20.95 % |
| $H_2O$ | Gravimetric | AE 004 | 1015 | Yes | Swindon | N/A | N/A |

# EXECUTIVE SUMMARY

## Sampling Location

| Sampling Plane Validation Criteria | Value | Units | Requirement | Compliance | Method |
|---|---|---|---|---|---|
| Lowest Differential Pressure | - | Pa | >= 5 Pa | - | All |
| Lowest Gas Velocity | - | m/s | - | - | - |
| Highest Gas Velocity | - | m/s | - | - | - |
| Ratio of Above | - | : 1 | < 3 : 1 | - | All |
| Mean Velocity | - | m/s | - | - | - |
| Angle of flow with regard to duct axis | - | ° | < 15° | - | All |
| No local negative flow | - | - | - | - | All |
| Highly homogeneous flow stream / gas velocity | - | - | - | - | ISO 10396 |

**Duct Characteristics**

| | Value | Units |
|---|---|---|
| Type | Circular | - |
| Depth | - | m |
| Width | - | m |
| Area | - | $m^2$ |
| Port Depth | 30 | mm |

**Sampling Lines & Sample Points**

| | Isokinetic (CEN Methods) | Isokinetic (ISO Methods) | Non-Iso & Gases |
|---|---|---|---|
| Sample Port Size | - | - | 1" Screw |
| Number Used | - | - | 1 |
| Orientation | - | - | Horizontal |
| Number Points / Line | - | - | 1 |
| Filtration | - | - | Out Stack |

**Sampling Platform**

| General Platform Information | |
|---|---|
| Permanent / Temporary Platform | Ground |
| Inside / Outside | Inside |

| M1 Platform requirements | |
|---|---|
| Minimum Platform Area 5 $m^2$ | Yes |
| Platform has 2 levels of handrails (approximately 0.5 m & 1.0 m high) | N/A |
| Platform has vertical base boards (approximately 0.25 m high) | N/A |
| Platform has removable chains / self closing gates at the top of ladders | N/A |
| Handrail / obstructions do not hamper insertion of sampling equipment | Yes |
| Depth of Platform = Minimum of 2m or Probe Length + 1m | Yes |

**Sampling Location / Platform Improvement Recommendations**

The sampling location meets all the requirements as specified in EA Guidance Note M1.

# EXECUTIVE SUMMARY

## Sampling & Analytical Method Deviations

**Sample Port**

Due to the fact the Sample Port was extremely narrow a Preliminary Flow Traverse could not be performed.

APPENDICES

## CONTENTS

APPENDICES

## STACK EMISSIONS MONITORING TEAM

| | |
|---|---|
| Team Leader | Matt Webster<br>MCERTS Level 2, Technical Endorsements 1 & 4<br>MM 07 816 |
| Technician | John Stevens<br>MCERTS Level 1<br>MM 07 840 |

## VOLATILE ORGANIC COMPOUNDS SUMMARY

| Test | Sampling Times | Concentration mg/m³ | LOD mg/m³ | Limit mg/m³ | Emission Rate g/hr |
|---|---|---|---|---|---|
| Run 1 | 11:20 - 11:34<br>27 November 2009 | ND | 0.40 | - | - |

Reference conditions are 273K, 101.3kPa, dry gas, 11% Oxygen.

### INSTRUMENTAL SPAN & ZERO CHECKS

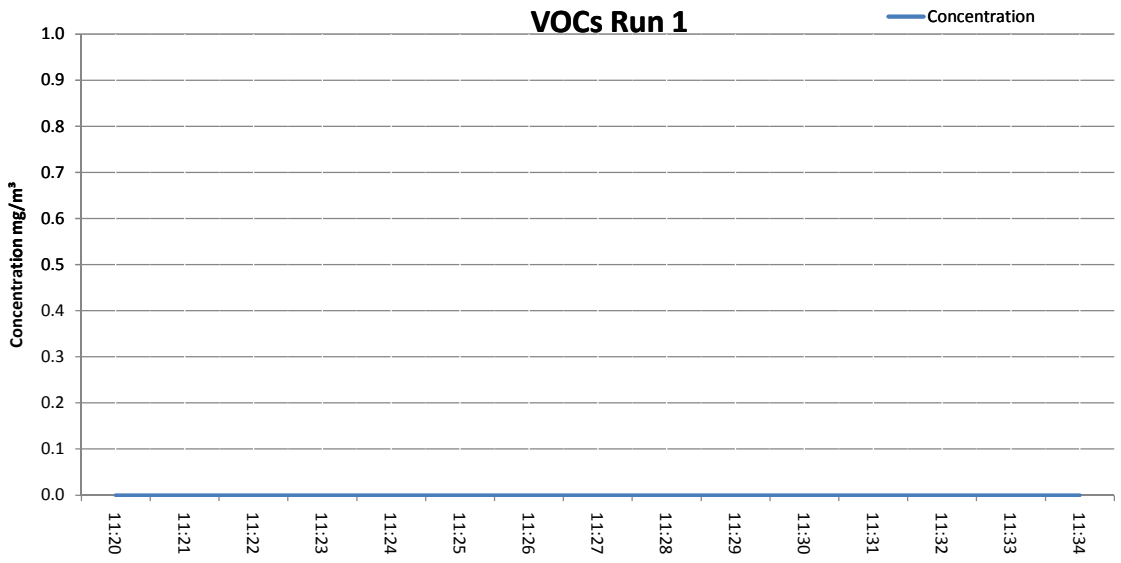
PRE-SAMPLING CALIBRATION CHECKS RUN 1

| Gas | Cylinder Ref No | Gas Conc (ppm) | Start Time | End Time | Range | Instrument Zero Reading | Instrument Span Reading | Span down line reading |
|---|---|---|---|---|---|---|---|---|
| Propane | LSW 048 | 8.17 | 09:40 | 10:03 | 10 | 0.536 | 8.416 | 8.684 |

POST-SAMPLING CALIBRATION CHECKS RUN 1

| Gas | Start Time | End Time | Instrument Zero Reading | Zero Drift (%) | Instrument Span Reading | Span Drift (%) | Span down line reading | Zero Drift ppm |
|---|---|---|---|---|---|---|---|---|
| Propane | 13:25 | 13:30 | 0.408 | -1.28 | 8.399 | -4.25 | 8.428 | 0.128 |

## VOLATILE ORGANIC COMPOUNDS EMISSIONS CHART




Reference conditions are 273K, 101.3kPa, dry gas, 11% Oxygen.

## COMBUSTION GASES SUMMARY

| Test | Sampling Times | Concentration mg/m³ | LOD mg/m³ | Limit mg/m³ | Emission Rate g/hr |
|---|---|---|---|---|---|
| NOx | 11:20 - 11:34 27-November-2009 | 164.75 | 0.21 | - | - |
| $SO_2$ | 11:20 - 11:34 27-November-2009 | 4.91 | 0.62 | - | - |
| CO | 11:20 - 11:34 27-November-2009 | 2.69 | 0.35 | - | - |

| Test | Sampling Times | Concentration mg/m³ | LOD mg/m³ | Limit mg/m³ | Emission Rate g/hr |
|---|---|---|---|---|---|
| $O_2$ | 11:20 - 11:34 27-November-2009 | 13.23 | 0.003 | - | - |

Reference conditions are 273K, 101.3kPa, dry gas, 11% Oxygen.

### PRE-SAMPLING CALIBRATION DATA

| | |
|---|---|
| Date | 27th November 2009 |
| Start Time | 09:25 |
| End Time | 10:27 |

| | |
|---|---|
| Cooler Temp. (℃) | 1.8 |

(should be < 4℃)

| Gas | Range (ppm) | Zero Reading at analyser | Span Reading at analyser | Zero Check at analyser | Zero Check down line | Span Check down line | Response Time (Secs) | Leak Rate % |
|---|---|---|---|---|---|---|---|---|
| NO | 100 | 0 | 83.1 | 0.1 | 0.3 | 84.2 | 7 | 1.31 |
| SO2 | 200 | 0 | 153 | 1.2 | 1.7 | 152 | 199 | -0.66 |
| CO | 200 | 0 | 152.5 | 0.4 | 0.7 | 152.1 | 21 | -0.26 |
| O2 | 25 | 0 | 20.93 | -0.03 | 0.09 | 20.93 | 112 | 0.00 |

### POST-SAMPLING CALIBRATION DATA

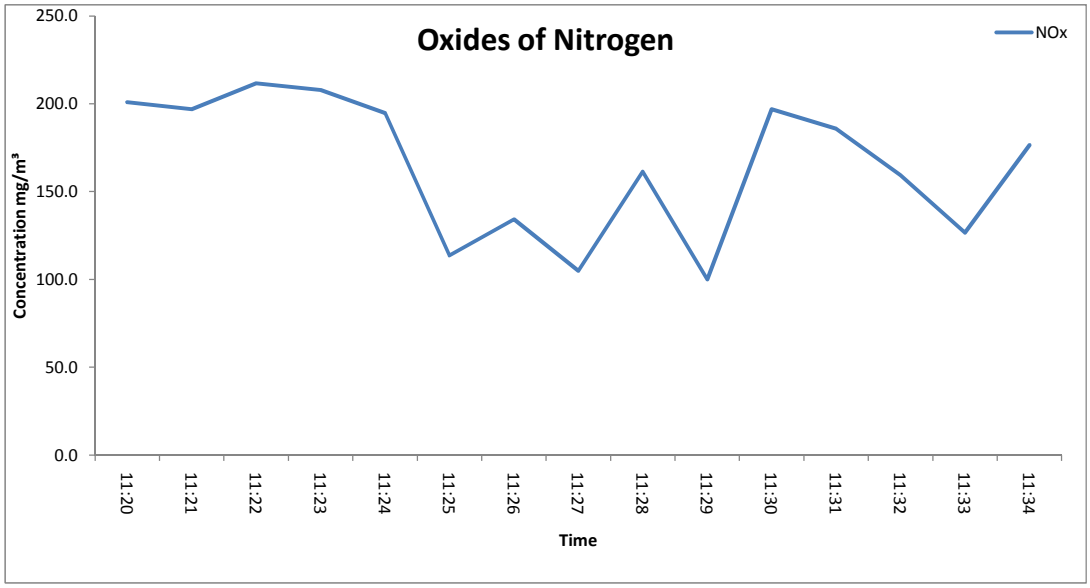
| | |
|---|---|
| Date | 27th November 2009 |
| Start Time | 13:20 |
| End Time | 13:40 |

| | |
|---|---|
| Cooler Temp. (℃) | 1.8 |

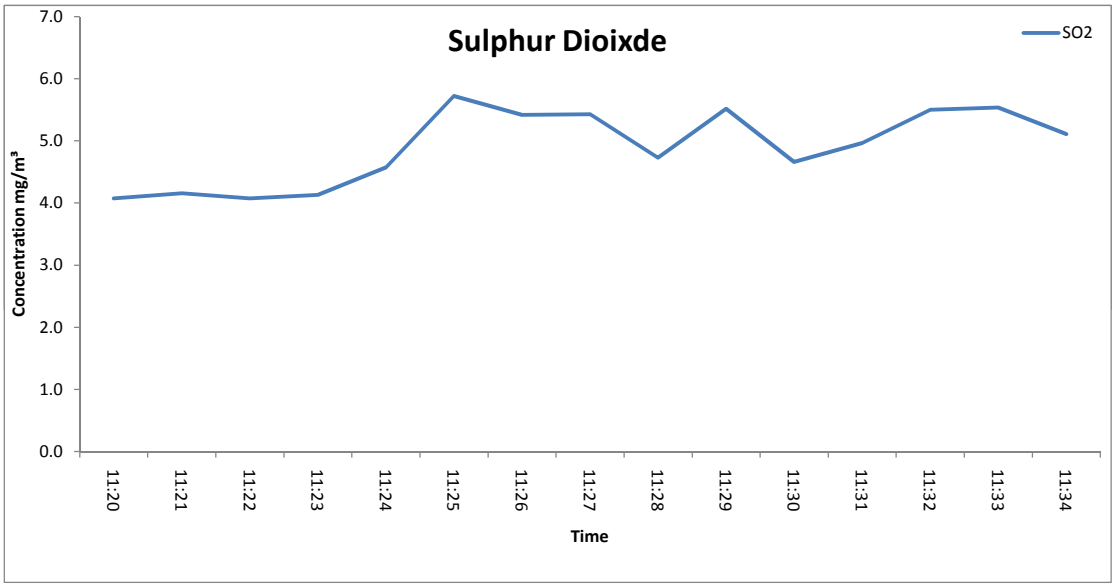
(should be < 4℃)

| Gas | Zero Check down line | Span Check down line | Zero Drift (%) | Span Drift (%) |
|---|---|---|---|---|
| NO | 0.8 | 83.1 | 0.50 | 0.00 |
| SO2 | 1.6 | 153 | -0.05 | 0.00 |
| CO | 0 | 152.5 | -0.35 | 0.00 |
| O2 | 0.14 | 20.91 | 0.20 | -0.16 |

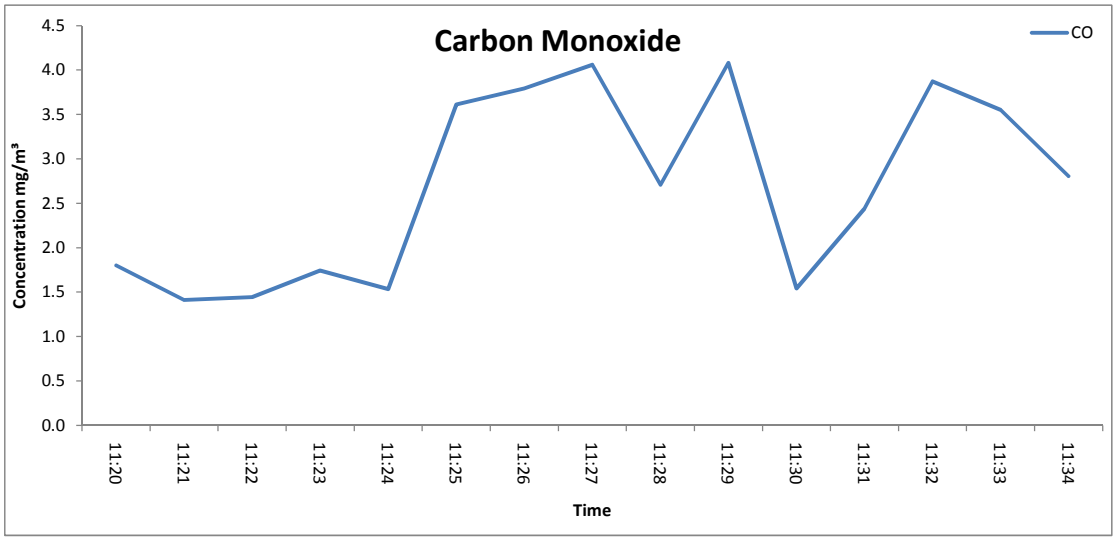
## OXIDES OF NITROGEN (as $NO_2$) EMISSIONS CHART



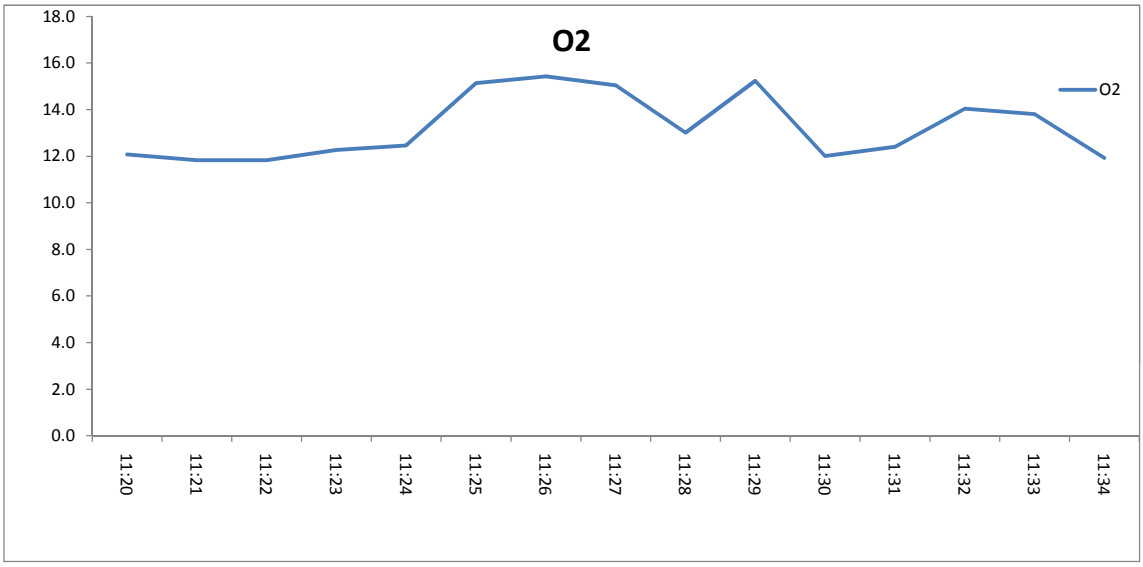

## SULPHUR DIOXIDE EMISSIONS CHART



## CARBON MONOXIDE EMISSIONS CHART




## OXYGEN EMISSIONS CHART



## DAILY OXYGEN SUMMARY

| Sampling Times | Concentration % | LOD % |
|---|---|---|
| 11:20 - 11:34 27th November 2009 | 13.23 | 0.01 |

PRE SAMPLING CALBRATION DATA

| Date | Time of Analyser | Range (%) | Zero Reading at analyser | Span Reading at analyser | Zero Check at analyser | Zero Check down line | Span Check down line | Leak Rate % |
|---|---|---|---|---|---|---|---|---|
| 27th November 2009 | 09:25 - 10:27 | 25 | 0 | 20.93 | 0.03 | 0.09 | 20.93 | 0.43 |

POST SAMPLING CALBRATION DATA

| Date | Time of Analyser | Zero Check down line | Span Check down line | Zero Drift (%) | Span Drift (%) |
|---|---|---|---|---|---|
| 27th November 2009 | 13:20 - 13:40 | 0.14 | 20.91 | 0.24 | -0.10 |

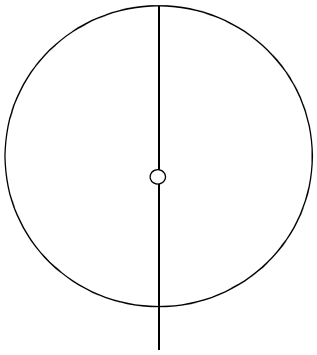
# STACK DIAGRAM

| | Value | Units |
|---|---|---|
| Stack Depth | - | m |
| Stack Width | - | m |
| Area | - | $m^2$ |

**Non-Isokinetic Sampling**

| Sampling Point | Distance (% of Depth) | Distance into Stack | Units |
|---|---|---|---|
| A | 40 | - | m |

**Analysers**



Sampling Line

APPENDIX 3 - Calibrateable Equipment Checklist & Calibration Gases

## CALIBRATEABLE EQUIPMENT CHECKLIST

| Extractive Sampling | | Instrumental Analyser/s | | Miscellaneous | |
|---|---|---|---|---|---|
| **Equipment** | **Equipment I.D.** | **Equipment** | **Equipment I.D.** | **Equipment** | **Equipment I.D.** |
| Control Box DGM | - | Horiba PG-250 Analyser | LSW 21-07 | Laboratory Balance | - |
| Box Thermocouples | - | JCT JCC P-1 Cooler | LSW Green | Tape Measure | - |
| Meter In Thermocouple | - | MAK 10 Cooler | - | Stopwatch | - |
| Meter Out Thermocouple | - | FT-IR | - | Protractor | - |
| Control Box Timer | - | FT-IR Oven Box | - | Barometer | - |
| Umbilical | - | Bernath 3006 FID | - | Digital Micromanometer | - |
| Oven Box | - | Signal 3030 FID | - | Digital Temperature Meter | - |
| Probe | - | Servomex | - | Stack Thermocouple | - |
| Probe Thermocouple | - | JCT Heated Head Filter | - | Mass Flow Controller | - |
| Probe | - | Thermo FID | LSW 21-08 | Mass Flow Control Box | - |
| Probe Thermocouple | - | Stackmaster | - | 1m Heated Line (1) | - |
| S-Pitot | - | FTIR Heater Box for Heated Line | - | 1m Heated Line (2) | - |
| L-Pitot | - | | - | 1m Heated Line (3) | - |
| Site Balance | - | | - | 5m Heated Line (1) | - |
| Last Impinger Arm | - | | - | 10m Heated Line (1) | - |
| Dioxins Cond. Thermocouple | - | | - | 10m Heated Line (2) | - |
| Callipers | - | | - | 15m Heated Line (1) | LSW 18-08 |
| Small DGM | - | | - | 20m Heated Line (1) | - |
| Heater Controller | - | | - | 20m Heated Line (2) | - |

NOTE: If the equipment I.D is represented by a dash (-), then this piece of equipment has not been used for this test.

## CALIBRATION GASES

| Gas | Cylinder I.D. Number | Supplier | ppm | % | Analytical Tolerance +/- % |
|---|---|---|---|---|---|
| Oxygen | Ambient | Fresh Air | - | 20.95 | - |
| Propane | LSW 048 | Cryoservice | 8.17 | - | 2 |
| Carbon Monoxide | LSW 089 | Cryoservice | 152.5 | - | 2 |
| Nitric Oxide | LSW 078 | Cryoservice | 83.1 | - | 2 |
| Sulphur Dioxide | LSW 096 | Cryoservice | 153 | - | 2 |

## MEASUREMENT UNCERTAINTY BUDGET - MOISTURE

| Run | Sampled | Sampled Gas | Sampled Gas | Sampled Gas | Oxygen | Leak |
|---|---|---|---|---|---|---|
| | $m^3$ | K | kPa | % by volume | % by volume | % |
| **MU required** | **≤ 2%** | **≤ 2%** | **≤ 1%** | **≤ 1%** | **≤ 10%** | **≤ 2%** |
| Run 1 | 0.000 | 2 | 1 | 1 | 0.1 | - |
| as a % | 0.20 | 0.73 | 0.99 | 1.00 | 0.76 | 0.00 |
| **compliant?** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |

| Run | Volume (STP) | Mass Gained | O2 Correction | Leak | Uncollected Mass | Combined uncertainty |
|---|---|---|---|---|---|---|
| | $m^3$ | mg | - | $mg/m^3$ | mg | |
| Run 1 | 0.0 | 1500.0 | 1.29 | 0.0 | 57.7 | - |
| MU as % v/v | 0.08 | 0.31 | 0.28 | 0.00 | 0.18 | **0.46** |
| MU as % | 1.6 | 6.7 | 1.29 | 0.0 | 3.8 | - |

| | | | | |
|---|---|---|---|---|
| **R1 - Uncertainty expressed at a 95% confidence level (where k = 2)** | **0.92** | **% v/v** | **15.93** | **%** |

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APPENDIX 4 - Measurement Uncertainty Budget Calculations

**MEASUREMENT UNCERTAINTY BUDGET - VOLATILE ORGANIC COMPOUNDS RUN 1**

| | | |
|---|---|---|
| Measured Concentration | ND | $mg/m^3$ |
| Limit | - | $mg/m^3$ |
| Calibration Gas Concentration | 13.072 | $mg/m^3$ |
| Range | 16 | $mg/m^3$ |

| Performance characteristics | Value | Units | specification | MU Met? |
|---|---|---|---|---|
| Response time | 30 | seconds | <180 | Yes |
| Logger sampling interval | 60 | seconds | - | - |
| Measurement period | 14 | minutes | - | - |
| Number of readings in measurement | 14 | - | - | - |
| Repeatability at zero | 0.25 | % full scale | <1 % range | No |
| Repeatability at span level | 0.15 | % full scale | <2 % range | Yes |
| Deviation from linearity | 0.70 | % of value | <2 % range | No |
| Zero drift | -1.28 | % full scale | <2% range / 24hr | Yes |
| Span drift | -4.25 | % full scale | <2% range/24hr | Yes |
| volume or pressure flow dependence | 0.02 | % of full scale/3 kPa | <2 % / 3 kPa | Yes |
| atmospheric pressure dependence | 0.80 | % of full scale/2 kPa | <3% / 2 kPa | Yes |
| ambient temperature dependence | 0.01 | % full scale/10K | <3% range / 10 K | Yes |
| dependence on voltage | 0.10 | % full scale/10V | < 0.1%vol /10 volt | Yes |
| losses in the line (leak) | 3.09 | % of value | < 2% of span gas value | No |
| Uncertainty of calibration gas | 2.0 | % of value | < 2% of value | Yes |

| Performance characteristic | Uncertainty | Value of uncertainty quantity |
|---|---|---|
| Standard deviation of repeatability at zero | ur0 | 0.04 |
| Standard deviation of repeatability at span level | urs | 0.04 |
| Lack of fit | ufit | 0.06 |
| Drift | u0dr | N/A |
| volume or pressure flow dependence | uspres | 0.00 |
| atmopsheric pressure dependence | uapres | 0.00 |
| ambient temperature dependence | utemp | 0.00 |
| Dependence on voltage | uvolt | 0.01 |
| losses in the line (leak) | uleak | N/A |
| Uncertainty of calibration gas | ucalib | N/A |
| Uncertainty in factor | uf | N/A |

| | | |
|---|---|---|
| Measurement uncertainty Measured Concentration | ND | $mg/m^3$ |
| Combined uncertainty | - | $mg/m^3$ |
| Expanded uncertainty | - | $mg/m^3$ |

| | | |
|---|---|---|
| **Expanded uncertainty expressed with a level of confidence of 95%** | **-** | **% ELV** |
| | | |
| **Expanded uncertainty expressed with a level of confidence of 95%** | **-** | **$mg/m^3$** |
| | | |
| **Expanded uncertainty expressed with a level of confidence of 95%** | **-** | **% value** |

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APPENDIX 4 - Measurement Uncertainty Budget Calculations

**MEASUREMENT UNCERTAINTY BUDGET - OXIDES OF NITROGEN**

| | | |
|---|---|---|
| Limit value | - | $mg/m^3$ |
| Measured concentration | 164.7 | $mg/m^3$ |
| Cal gas conc | 170.355 | $mg/m^3$ |
| Full Scale | 205 | $mg/m^3$ |

| Performance characteristics | Value | Units | specification | MU Met? |
|---|---|---|---|---|
| Response time | 7 | seconds | 180 | Yes |
| Logger sampling interval | 60 | seconds | - | - |
| Measurement period | 14 | minutes | - | - |
| Number of readings in measurement | 14 | - | - | - |
| Repeatability at zero | 0.25 | % full scale | <1 % range | Yes |
| Repeatability at span level | 0.15 | % full scale | <2 % range | Yes |
| Deviation from linearity | 0.7 | % of value | <2 % range | Yes |
| Zero drift | 0.5 | % full scale | <2% range / 24hr | Yes |
| Span drift | 0 | % full scale | <2% range/24hr | Yes |
| volume or pressure flow dependence | 0.02 | % of full scale/3 kPa | <2 % / 3 kPa | Yes |
| atmospheric pressure dependence | 0.8 | % of full scale/2 kPa | <3% / 2 kPa | Yes |
| ambient temperature dependence | 0.01 | % full scale/10K | <3% range / 10 K | Yes |
| dependence on voltage | 0.1 | % full scale/10V | < 0.1%vol /10 volt | Yes |
| losses in the line (leak) | 1.31 | % of value | < 2% of value | Yes |
| Uncertainty of calibration gas | 2 | % of value | < 2% of value | Yes |

| Performance characteristic | Uncertainty | Value of uncertainty quantity |
|---|---|---|
| Standard deviation of repeatability at zero | ur0 | 0.04 |
| Standard deviation of repeatability at span level | urs | 0.04 |
| Lack of fit | ufit | 0.83 |
| Drift | u0dr | 0.29 |
| volume or pressure flow dependence | uspres | 0.00 |
| atmopsheric pressure dependence | uapres | 0.05 |
| ambient temperature dependence | utemp | 0.00 |
| Dependence on voltage | uvolt | 0.18 |
| losses in the line (leak) | uleak | 1.24 |
| Uncertainty of calibration gas | ucalib | 1.90 |
| Uncertainty in factor | uf | 9.73 |

| | | |
|---|---|---|
| Measurement uncertainty (Concentration Measured) | 164.75 | $mg/m^3$ |
| Combined uncertainty | 10.03 | $mg/m^3$ |
| Expanded uncertainty | 20.06 | $mg/m^3$ |

| | | |
|---|---|---|
| **Expanded uncertainty expressed with a level of confidence of 95%** | **-** | **% ELV** |
| **Expanded uncertainty expressed with a level of confidence of 95%** | **20.06** | **$mg/m^3$** |
| **Expanded uncertainty expressed with a level of confidence of 95%** | **12.18** | **% value** |

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APPENDIX 4 - Measurement Uncertainty Budget Calculations

**MEASUREMENT UNCERTAINTY BUDGET - SULPHUR DIOXIDE**

| | | |
|---|---|---|
| Limit value | - | $mg/m^3$ |
| Measured concentration | 4.9 | $mg/m^3$ |
| Cal gas conc | 434.52 | $mg/m^3$ |
| Full Scale | 572 | $mg/m^3$ |

| Performance characteristics | Value | Units | specification | MU Met? |
|---|---|---|---|---|
| Response time | 199 | seconds | 180 | No |
| Logger sampling interval | 60 | seconds | - | - |
| Measurement period | 14 | minutes | - | - |
| Number of readings in measurement | 14 | - | - | - |
| Repeatability at zero | 0.25 | % full scale | <1 % range | Yes |
| Repeatability at span level | 0.15 | % full scale | <2 % range | Yes |
| Deviation from linearity | 0.7 | % of value | <2 % range | Yes |
| Zero drift | -0.05 | % full scale | <2% range / 24hr | Yes |
| Span drift | 0.00 | % full scale | <2% range/24hr | Yes |
| volume or pressure flow dependence | 0.02 | % of full scale/3 kPa | <2 % / 3 kPa | Yes |
| atmospheric pressure dependence | 0.8 | % of full scale/2 kPa | <3% / 2 kPa | Yes |
| ambient temperature dependence | 0.01 | % full scale/10K | <3% range / 10 K | Yes |
| dependence on voltage | 0.1 | % full scale/10V | < 0.1%vol /10 volt | Yes |
| losses in the line (leak) | -0.66 | % of value | < 2% of value | Yes |
| Uncertainty of calibration gas | 2 | % of value | < 2% of value | Yes |

| Performance characteristic | Uncertainty | Value of uncertainty quantity |
|---|---|---|
| Standard deviation of repeatability at zero | ur0 | 0.040 |
| Standard deviation of repeatability at span level | urs | 0.04 |
| Lack of fit | ufit | 2.31 |
| Drift | u0dr | -0.03 |
| volume or pressure flow dependence | uspres | 0.00 |
| atmopsheric pressure dependence | uapres | 0.14 |
| ambient temperature dependence | utemp | 0.00 |
| Dependence on voltage | uvolt | 0.49 |
| losses in the line (leak) | uleak | -0.02 |
| Uncertainty of calibration gas | ucalib | 0.06 |
| Uncertainty in factor | uf | 0.29 |

| | | |
|---|---|---|
| Measurement uncertainty (Concentration Measured) | 4.9 | $mg/m^3$ |
| Combined uncertainty | 2.39 | $mg/m^3$ |
| Expanded uncertainty | 4.8 | $mg/m^3$ |

| | | |
|---|---|---|
| **Expanded uncertainty expressed with a level of confidence of 95%** | **-** | **% ELV** |
| | | |
| **Expanded uncertainty expressed with a level of confidence of 95%** | **4.77** | **$mg/m^3$** |
| | | |
| **Expanded uncertainty expressed with a level of confidence of 95%** | **97.31** | **% value** |

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APPENDIX 4 - Measurement Uncertainty Budget Calculations

**MEASUREMENT UNCERTAINTY BUDGET - CARBON MONOXIDE**

| | | |
|---|---|---|
| Limit value | - | $mg/m^3$ |
| Measured concentration | 2.7 | $mg/m^3$ |
| Cal gas conc | 190.625 | $mg/m^3$ |
| Full Scale | 250 | $mg/m^3$ |

| Performance characteristics | Value | Units | specification | MU Met? |
|---|---|---|---|---|
| Response time | 21 | seconds | 180 | Yes |
| Logger sampling interval | 60 | seconds | - | - |
| Measurement period | 14 | minutes | - | - |
| Number of readings in measurement | 14 | - | - | - |
| Repeatability at zero | 0.25 | % full scale | <1 % range | Yes |
| Repeatability at span level | 0.15 | % full scale | <2 % range | Yes |
| Deviation from linearity | 0.7 | % of value | <2 % range | Yes |
| Zero drift | -0.35 | % full scale | <2% range / 24hr | Yes |
| Span drift | 0 | % full scale | <2% range/24hr | Yes |
| volume or pressure flow dependence | 0.02 | % of full scale/3 kPa | <2 % / 3 kPa | Yes |
| atmospheric pressure dependence | 0.80 | % of full scale/2 kPa | <3% / 2 kPa | Yes |
| ambient temperature dependence | 0.01 | % full scale/10K | <3% range / 10 K | Yes |
| dependence on voltage | 0.10 | % full scale/10V | < 0.1%vol /10 volt | Yes |
| losses in the line (leak) | -0.26 | % of value | < 2% of value | Yes |
| Uncertainty of calibration gas | 2 | % of value | < 2% of value | Yes |

| Performance characteristic | Uncertainty | Value of uncertainty quantity |
|---|---|---|
| Standard deviation of repeatability at zero | ur0 | 0.04 |
| Standard deviation of repeatability at span level | urs | 0.04 |
| Lack of fit | ufit | 1.01 |
| Drift | u0dr | -0.20 |
| volume or pressure flow dependence | uspres | 0.00 |
| atmopsheric pressure dependence | uapres | 0.06 |
| ambient temperature dependence | utemp | 0.00 |
| Dependence on voltage | uvolt | 0.22 |
| losses in the line (leak) | uleak | 0.00 |
| Uncertainty of calibration gas | ucalib | 0.03 |
| Uncertainty in factor | uf | 0.16 |

| | | |
|---|---|---|
| Measurement uncertainty (Concentration Measured) | 2.7 | $mg/m^3$ |
| Combined uncertainty | 1.1 | $mg/m^3$ |
| Expanded uncertainty | 2.1 | $mg/m^3$ |

| | | |
|---|---|---|
| **Expanded uncertainty expressed with a level of confidence of 95%** | **-** | **% ELV** |
| **Expanded uncertainty expressed with a level of confidence of 95%** | **2.14** | **$mg/m^3$** |
| **Expanded uncertainty expressed with a level of confidence of 95%** | **79.29** | **% value** |

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APPENDIX 4 - Measurement Uncertainty Budget Calculations

**MEASUREMENT UNCERTAINTY BUDGET - OXYGEN**

| | | |
|---|---|---|
| Reference | 11 | %vol |
| Measured concentration | 13.23 | %vol |
| Calibration gas | 20.95 | %vol |
| Full Scale | 25 | %vol |

| Performance characteristics | Value | Units | specification | MU Met? |
|---|---|---|---|---|
| Response time | 112 | seconds | < 200 s | Yes |
| Logger sampling interval | 60 | seconds | - | - |
| Measurement period | 14 | minutes | - | - |
| Number of readings in measurement | 14 | - | - | - |
| Repeatability at zero | 0.015 | % by volume | <0.2 % range | Yes |
| Repeatability at span level | 0.014 | % by volume | <0.4 % range | Yes |
| Deviation from linearity | 0.13 | % vol | <0.3 % volume | Yes |
| Zero drift (during measurement period) | 0.20 | % vol at zero level | <2% of volume / 24hr | Yes |
| Span drift (during measurement period) | -0.16 | % vol at span level | <2% volume/24hr | Yes |
| volume or pressure flow dependence | 0.02 | % of fs / 10l/h | <1% range | Yes |
| atmospheric pressure dependence | 0.80 | % of fs/kPa | < 1.5 % range | Yes |
| ambient temperature dependence | 0.01 | % by volume /10K | <0.3% volume 10 K | Yes |
| Combined interference | 0.14 | % range | <2% range | Yes |
| Dependence on voltage | 0.10 | % by volume /10V | < 0.1%vol /10 volt | Yes |
| Losses in the line (leak) | 0.00 | % of value | < 2% of value | Yes |
| Uncertainty of calibration gas | 2.00 | % of value | < 2% of value | Yes |

| Performance characteristic | Uncertainty | Value of uncertainty quantity |
|---|---|---|
| Standard deviation of repeatability at zero | ur0 | - |
| Standard deviation of repeatability at span level | urs | 0.0037 |
| Lack of fit | ufit | 0.0751 |
| Drift | u0dr | 0.0571 |
| volume or pressure flow dependence | uspres | 0.00003 |
| atmospheric pressure dependence | uapres | 0.0122 |
| ambient temperature dependence | utemp | 0.0005 |
| Combined interference (from mcerts) | - | 0.0808 |
| dependence on voltage | uvolt | 0.0862 |
| losses in the line (leak) | uleak | 0.0000 |
| Uncertainty of calibration gas | ucalib | 0.1528 |

| | | |
|---|---|---|
| Measurement uncertainty (Concentration Measured) | 13.23 | %vol |
| Combined uncertainty | 0.22 | %vol |
| % of value | 1.63 | % |

| | | |
|---|---|---|
| **Expanded uncertainty expressed with a level of confidence of 95%** | **3.25** | **% of value** |

| | | |
|---|---|---|
| **Expanded uncertainty expressed with a level of confidence of 95%** | **0.431** | **% vol** |

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APPENDIX 4 - Measurement Uncertainty Budget Calculations

**MEASUREMENT UNCERTAINTY BUDGET - OXYGEN**

DAY 1 - 27th November 2009

| | | |
|---|---|---|
| Reference | 11 | %vol |
| Measured concentration | 13.23 | %vol |
| Calibration gas | 20.93 | %vol |
| Full Scale | 25 | %vol |

| Performance characteristics | Value | Units | specification | MU Met? |
|---|---|---|---|---|
| Response time | 112 | seconds | < 200 s | Yes |
| Logger sampling interval | 1 | seconds | - | - |
| Measurement period | 14 | minutes | - | - |
| Number of readings in measurement | 840 | - | - | - |
| Repeatability at zero | 0.015 | % by volume | <0.2 % range | Yes |
| Repeatability at span level | 0.014 | % by volume | <0.4 % range | Yes |
| Deviation from linearity | 0.13 | % vol | <0.3 % volume | Yes |
| Zero drift (during measurement period) | 0.24 | % vol at zero level | <2% of volume / 24hr | Yes |
| Span drift (during measurement period) | -0.10 | % vol at span level | <2% volume/24hr | Yes |
| volume or pressure flow dependence | 0.02 | % of fs / 10l/h | <1% range | Yes |
| atmospheric pressure dependence | 0.8 | % of fs/kPa | < 1.5 % range | Yes |
| ambient temperature dependence | 0.01 | % by volume /10K | <0.3% volume 10 K | Yes |
| Combined interference | 0.14 | % range | <2% range | Yes |
| Dependence on voltage | 0.1 | % by volume /10V | < 0.1%vol /10 volt | Yes |
| Losses in the line (leak) | 0.43 | % of value | < 2% of value | Yes |
| Uncertainty of calibration gas | 2 | % of value | < 2% of value | Yes |

| Performance characteristic | Uncertainty | Value of uncertainty quantity |
|---|---|---|
| Standard deviation of repeatability at zero | ur0 | - |
| Standard deviation of repeatability at span level | urs | 0.000 |
| Lack of fit | ufit | 0.075 |
| Drift | u0dr | 0.103 |
| volume or pressure flow dependence | uspres | 0.001 |
| atmospheric pressure dependence | uapres | 0.115 |
| ambient temperature dependence | utemp | 0.003 |
| Combined interference (from mcerts) | - | 0.020 |
| dependence on voltage | uvolt | 0.029 |
| losses in the line (leak) | uleak | 0.033 |
| Uncertainty of calibration gas | ucalib | 0.153 |

| | | |
|---|---|---|
| Measurement uncertainty (Concentration Measured) | 13.23 | %vol |
| Combined uncertainty | 0.24 | %vol |
| % of value | 0.02 | % |

| | | |
|---|---|---|
| **Expanded uncertainty expressed with a level of confidence of 95%** | **0.04** | **% of value** |

| | | |
|---|---|---|
| **Expanded uncertainty expressed with a level of confidence of 95%** | **0.27** | **% vol** |

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# ANNEX B: Gas Engine Confirmation and performance specifications

www.mwm.net

# TCG 2032

3333 – 4300 $kW_{el}$ at 1000 $min^{-1}$ (50 Hz)

MWM

Energy. Efficiency. Environment.

# Technical data 50 Hz – Natural gas applications

$NO_x$ <= 500 mg /$m_n^3$ [1]

Minimum methane number MN 70
dry exhaust manifolds

| Engine type | | | TCG 2032 V12 | TCG 2032 V16 |
|---|---|---|---|---|
| Engine power [2] | | kW | 3404 | 4390 |
| Speed | | $min^{-1}$ | 1000 | 1000 |
| Mean effective pressure | | bar | 20.0 | 19.4 |
| Exhaust temperature | approx. | °C | 440 | 436 |
| Exhaust mass flow wet | approx. | kg/h | 17220 | 22217 |
| Combustion air mass flow [2] | approx. | kg/h | 16655 | 21488 |
| Combustion air temperature for engine with air preheater minimum/design | | °C | 10/25 | 10/25 |
| Ventilation air flow [3] | approx. | kg/h | 90126 | 114305 |

| Engine parameters | | | | |
|---|---|---|---|---|
| Bore/stroke | | mm | 260/320 | 260/320 |
| Displacement | | $dm^3$ | 203.9 | 271.8 |
| Compression ratio | | | 12.0 : 1 | 12.0 : 1 |
| Mean piston speed | | m/s | 10.7 | 10.7 |
| Lube oil flow rate | | $m^3/h$ | 110 | 125 |
| Lube oil content [4] | | $dm^3$ | 1750 | 2200 |
| Lube oil temperature engine inlet | | °C | 80 | 80 |
| Typical mean lube oil consumption [5] | | g/kWh | 0.3 | 0.3 |

| Generator | | | | |
|---|---|---|---|---|
| Efficiency [6] | | % | 97.9 | 97.95 |

| Energy balance | | | | |
|---|---|---|---|---|
| Electrical power [6] | | kW | 3333 | 4300 |
| Jacket water heat | ± 8 % | kW | 1140 | 1538 |
| Intercooler LT heat [7] | ± 8 % | kW | 300 | 326 |
| Exhaust cooled to 120 °C | ± 8 % | kW | 1804 | 2240 |
| Lube oil heat | ± 8 % | kW | 397 | 543 |
| Engine radiation heat | | kW | 175 | 220 |
| Generator radiation heat | | kW | 71 | 90 |
| Fuel consumption [8] | + 5 % | kW | 7657 | 9891 |
| Specific fuel consumption [8] | + 5 % | kWh/kWh | 2.25 | 2.25 |
| Electrical efficiency | | % | 43.5 | 43.5 |
| Thermal efficiency | | % | 43.6 | 43.7 |
| Total efficiency | | % | 87.1 | 87.2 |

| System parameters | | TCG 2032 V12 | TCG 2032 V16 |
|---|---|---|---|
| Engine jacket water flow rate min./max. | $m^3/h$ | 79/100 | 105/130 |
| Engine $K_{VS}$-value [9] | $m^3/h$ | 89 | 93 |
| Intercooler coolant flow rate | $m^3/h$ | 55 | 65 |
| Intercooler $K_{VS}$-value [9] | $m^3/h$ | 57 | 57 |
| Engine jacket water volume | $dm^3$ | 430 | 570 |
| Intercooler coolant volume | $dm^3$ | 51 | 51 |
| Engine jacket water temperature max. [10] | °C | 78/90 | 78/90 |
| – with glycol [10] | °C | (78/90) | (78/90) |
| Intercooler coolant temperature [10] | °C | 40/44.8 | 40/44.4 |
| Exhaust backpressure min./max. | mbar | 30/50 | 30/50 |
| Maximum pressure loss in front of air cleaner | mbar | 5 | 5 |
| Gas flow pressure, fixed between [11] | mbar | 50...300 | 50...300 |
| Air bottle, volume/pressure | $dm^3$/bar | 2000/30 | 2000/30 |

| Dimensions 50 Hz Genset | | | |
|---|---|---|---|
| Length | mm | 7800 | 8900 |
| Width | mm | 2700 | 2750 |
| Height | mm | 3700 | 3800 |
| Dry weight genset | kg | 44500 | 49000 |

| Noise emissions* 50 Hz<br>Noise frequency band | Hz | 63 | 125 | 250 | 500 | 1000 | 2000 | 4000 | 8000 |
|---|---|---|---|---|---|---|---|---|---|
| **Engine type TCG 2032 V12** | | | | | | | | | |
| Exhaust noise 125 dB (A) | dB (lin) | 127 | 128 | 125 | 123 | 118 | 116 | 114 | 105 |
| Air-borne noise 105 dB (A) | dB (lin) | 99 | 97 | 101 | 98 | 96 | 97 | 100 | 94 |
| **Engine type TCG 2032 V16** | | | | | | | | | |
| Exhaust noise 123 dB (A) | dB (lin) | 131 | 124 | 122 | 121 | 117 | 115 | 113 | 109 |
| Air-borne noise 109 dB (A) | dB (lin) | 99 | 109 | 104 | 101 | 99 | 99 | 104 | 101 |

Exhaust noise at 1 m, ∢ 45°, ± 2.5 dB (A)

Air-borne noise at 1 m from the side, ± 1 dB (A)

*Values apply to natural gas applications, measured as noise pressure level.

1) Exhaust emissions with oxidizing catalyst:
$NO_X$ < 0.50 g $NO_2/m_n^3$ dry exhaust gas at 5 % $O_2$
CO < 0.3 g $CO/m_n^3$ dry exhaust gas at 5 % $O_2$
2) Engine power ratings and combustion air volume flows acc. to ISO 3046/1
3) Intake air flow at delta T = 15 K including combustion air
4) Without pipes and heat exchangers
5) This values are the mean lube oil consumption between maintenance steps which include an E 60 service. Also the procedures defined in the TPI 1111-E-06-02 and the Technical Circular TR 0199-99-2105 are to be carefully followed.
6) At 50 Hz, U = 11 kV, power factor = 1
7) At 40 °C water inlet
8) With a tolerance of + 5 %
9) The $K_{VS}$-value is the parameter for the pressure loss in the cooling system (= flowrate for 1 bar pressure loss)
10) Inlet/outlet
11) Consider TR 0199-99-3017

Data for special gas and dual gas operation on request.

The values given in this data sheet are for information purposes only and not binding.
The information given in the offer is decisive.

# Your benefits

- Extremely low operating costs thanks to high efficiency and excellent specific fuel and oil consumption figures.
- Innovative repair concept with easily exchangeable cylinder unit with cylinder head, piston, connecting rod, liner enhances ease of service.
- The extremely slim engine with compact dimensions, low noise emissions and excellent smooth-running characteristics guarantee minimized installation costs.
- The combination of high power and low weight provides an exceptional power-to-weight ratio. Precise governing and control of the combustion process ensures a very high level of speed stability.
- Exhaust emission levels which comply with the most stringent European standards and represent the best available control technology world-wide.

# Characteristics

- State-of-the-art four-stroke Otto gas engines of V-configuration.
- Single cylinder heads with four-valve technology.
- Nonwearing high-voltage ignition system.
- Turbocharging and two-stage intercooling .
- Pearl® exhaust system located in V-space (Pulse Energy Advanced Recovery Line).
- TEM EVOLUTION SYSTEM (Total Electronic Management) for control of gas combustion as well as for monitoring and control of engine generator set with optional integration of peripheral and auxiliary equipment.

Version 05/09/E

**MWM Group**
Mail: info@mwm.net
Web: www.mwm.net

# DEUTZ POWER SYSTEMS

## Project : EDINA UK / Scarborough Power

DEUTZ-Order number : 820 746

### Technical data

| | | | |
|---|---|---|---|
| Power : 2.700 kW mech. | | Fuel gas : Natural gas [1] | |
| Speed : 1.000 rpm | | Methane number MN : >= 80 | |
| Speed governor : TEM EVO | | Emission NOx : <= 500 mg/Nm³ at 5%O2 | |
| Related to : TG 632-3-194 | | Emission CO : <= 1.000 mg/Nm³ at 5%$O_2$ without catalyst | |
| ATL-Specification : 1228 2817 | | Altitude of installation: 100 m | |
| Starter motor : air | | Relative air Humidity: 60% | |
| Genset drawing no. : 1246 6800 UA | | P&I number : 1245 6595 UA | |

| **Engine type** | | | **TCG 2032 V12** | | |
|---|---|---|---|---|---|
| Number of cylinder / configuration | | | 12 / V | | |
| Bore / stroke | | mm | 260,0 / 320,0 | | |
| Displacement | | dm³ | 203,9 | | |
| Compression ratio | | | 12,0 : 1 | | |
| Mean piston speed | | m / s | 10,7 | | |
| Lube oil content engine | | dm³ | 1.750 | | |
| Typical mean lube oil consumption at full load | approx. | g / kWh | 0,30 | | |
| Lube oil flow rate | | m³/h | 110 | | |
| Lube oil temperature engine in / out | | °C | 80,0 / 85,5 | | |
| Engine jacket water content / Kvs value | | dm³ / m³/h | 430,0 / 89 | | |
| Engine jacket water temperature in / out | | °C | 76,0 / 86,3 | water with 35% glycol | |
| Engine jacket water flow rate / pressure loss | | m³/h / bar | 87,6 / 0,97 | | |
| Intercooler coolant content engine / Kvs value | | dm³ / m³/h | 51,0 / 57 | | |
| Intercooler coolant temperature in / out | | °C | 40,0 / 43,7 | water with 35% glycol | |
| Intercooler coolant flow rate / pressure loss | | m³/h / bar | 55,0 / 0,93 | | |

| **Generator** | | | | |
|---|---|---|---|---|
| Generator brand / type | | AvK 150 DIG m/6 | | |
| Weight alternator | | kg | 13.800 | |
| Voltage / frequency [2] | | V / Hz | 11.000 / 50 | |
| Generator efficiency (with power factor = 1) | | % | 97,4 | 95,5 |
| Maximum operation temperature | | °C | 40 | |

| **Load** | | **%** | **100** | **50** |
|---|---|---|---|---|
| Engine power according ISO 3046/1 | | kW | 2.700 | 1.350 |
| Mean effective pressure | | bar | 15,9 | 7,9 |
| Combustion air mass flow - ISO 3046/1 | approx. | kg / h | 13.742 | 7.271 |
| Exhaust mass flow wet | approx. | kg / h | 14.212 | 7.524 |
| Exhaust temperature | approx. | °C | 470 | 514 |
| Exhaust temperature maximum at part load | approx. | °C | | 550 |

| **Energy balance** (tolerance for heat rejection ± 8%) | | | | |
|---|---|---|---|---|
| Electrical power (with power factor = 1) | | kWel | 2.630 | 1.289 |
| Jacket water heat | | kW | 943 | 386 |
| Lube oil heat | | kW | 313 | 227 |
| Intercooler LT heat with coolant temperature | 40 °C | kW | 213 | 109 |
| Exhaust heat total | | kW | 1.920 | 1.125 |
| Engine radiation heat | | kW | 185 | 174 |
| Genset radiation heat | | kW | 255 | 235 |
| Fuel consumption [3] | | kW | 6.360 | 3.416 |
| Electrical efficiency | | % | 41,4 | 37,7 |

| **System parameters** | | | | |
|---|---|---|---|---|
| Min. ventilation air flow for genset [4] ΔT = 15 K | approx. | kg/h | 74.685 | (including combustion air) |
| Min. ventilation air flow for auxiliaries and heat recovery unit [4] | | kg/h | 7.796 | |
| Room temperature minimum / maximum at ventilation outlet | | °C | 10 / 50 | |
| Maximum room over- and underpressure | | mbar | 0,5 / -0,1 | |
| Combustion air temp. (before the air preheater) minimum / design | | °C | 5 / 35 | |
| Maximum pressure loss infront of air combustion cleaner | | mbar | 5 | |
| Exhaust backpressure minimum / maximum | | mbar | 35 / 50 | |
| Gas flow pressure [1] | | mbar | 3.000 | |
| Air bottle, volume / pressure | | dm³ / bar | 2.000 / 30 | |
| Dry weight engine | | kg | 19.700 | |
| Full weight genset | | kg | 42.800 | |

**Noise emissions (at 1m)**

| Frequency band | | Hz | 63 | 125 | 250 | 500 | 1000 | 2000 | 4000 | 8000 |
|---|---|---|---|---|---|---|---|---|---|---|
| Exhaust noise [5] | 125 dB(A) ± 2,5 | dB(lin) | 126 | 127 | 124 | 122 | 117 | 115 | 113 | 104 |
| Air-borne noise [6] | 104 dB(A) ± 1,0 | dB(lin) | 98 | 96 | 100 | 97 | 95 | 96 | 99 | 93 |

1) According TR 0199-99-3017
2) Extended voltage range +/-10% / range acc. to EN 600034-1, zone B
3) Tolerance +/- 5 %, Based on special conditions at site, after 500 operation hours at full load, average across all engines
4) Please consider chapter 5 of "Layout of Power plants" for your calculation
5) Exhaust noise at 1m, 45°
6) Air-borne noise at 1m from site

Specialists in Power Generation
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**e-mail**: alan-smyth@edina.ie
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Mr Sean O'Grady
Thurles
Co. Tipperary

**ATTENTION**: Sean O'Grady

Ref: QT 9080 GSAS

14th July 2010

## Ref: Fuel Gas Suitability

Dear Sean,

I acknowledge receipt of your test report from Environmental Scientifics Group, reference number 41078. I understand that this sample was obtained by processing Autoclave MSW waste using your treatment system.

After consideration of all the information available to us at this time I can confirm that this gas has all of the necessary constituents, in suitable quantities to be used as a fuel gas for our MWM 2032 V16 Syn Gas engines.

Performance shall be in line with the datasheets previously supplied and subsequent correspondence.

I can confirm compliance with MWM TR 0199-99-3017/4 and appendix concerning Syngas.

Regards,

**Alan Smyth**
***Project Manager***

# ANNEX C: Syngas Specification & Comparator Gas RA

| Table 2Cc: Waste-Derived Synthesis Gas Comparison | | | | |
|---|---|---|---|---|
| **Relevant parameter** | **Units** | **Typical UK natural Gas Composition** | **Syn Gas Spec (% unless stated)** | **Comments** |
| Hydrogen ($H_2$) | % vol / vol | <0.1 mol% | 5.80 – 18.15 | Converted to water during combustion |
| Oxygen ($O_2$) | % vol / vol | 0-0.2% | 0.24 – 1.53 | Low levels of Oxygen will have little effect on combustion. |
| Nitrogen ($N_2$) | % vol / vol | 0-5% | 2.00 - 9.00 | None |
| Carbon Monoxide (CO) | % vol / vol | No Limits Stated | 18.00 – 42.00 | Will be converted to $CO_2$ during combustion |
| Methane ($CH_4$) | % vol / vol | 70-90% | 10.10 – 21.51 | Will be converted to $CO_2$ during combustion |
| Carbon Dioxide ($CO_2$) | % vol / vol | 0-8% | 15.60 – 48.00 | Unaffected during combustion |
| Ethene | % vol / vol | No Limits Stated | 2.80 – 6.40 | Converted to $CO_2$ and water during combustion |
| Ethane ($C_2H_6$) | % vol / vol | 0-20% | 1.71 – 5.04 | Converted to $CO_2$ and water during combustion |
| Propene ($C_3H_6$) | % vol / vol | No Limits Stated | 0.50 – 5.30 | Converted to $CO_2$ and water during combustion |
| Propane ($C_3H_8$) | % vol / vol | No Limits Stated | 0.07 - 1.79 | Converted to $CO_2$ and water during combustion |
| $C_4$ - Butane (n-$C_4H_{10}$) | % vol / vol | No Limits Stated | 0.14 – 0.93 | Converted to $CO_2$ and water during combustion |
| $C_5$ - Pentane (n-$C_5H_{12}$) | % vol / vol | No Limits Stated | 0.06 – 0.27 | Converted to $CO_2$ and water during combustion |
| Sulphur | % vol / vol | <50mg/m$^3$ | 0.00 – 0.02 | Removed during gas scrubbing |
| Hydrogen Sulphide ($H_2S$) and other reduced sulphur compounds | % vol / vol | 0-5% | 0.00 – 0.02 | Removed during gas scrubbing. Very odorous |
| Acid Gases | mg/kg | Trace | < LOD 2mg/kg | None present in synthesis gas |
| Rare gases (A, He, Ne, Xe) | % vol / vol | Trace | 0.00 – 0.05 | None present in synthesis gas |
| Halogenated Hydrocarbons[1] | | | | |
| 1,2 Dichloroethane | mg/m$^3$ | <8.15E+02 | <8.15E+02 | None present in synthesis gas – removed by gas scrubbing stages |
| Vinyl chloride | mg/m$^3$ | <2.16E+03 | <2.16E+03 | None present in synthesis gas – removed by gas scrubbing stages |
| Tetrachloroethene | mg/m$^3$ | <9.32E+03 | <9.32E+03 | None present in synthesis gas – removed by gas scrubbing stages |
| 1,1,2, Trichloroethane | mg/m$^3$ | <2.33E+00 | <2.33E+00 | None present in synthesis gas – removed by gas scrubbing stages |
| Chlorobenzene | mg/m$^3$ | <8.18E+04 | <8.18E+04 | None present in synthesis gas – removed by gas scrubbing stages |
| Dichloromethane | mg/m$^3$ | <3.49E+03 | <3.49E+03 | None present in synthesis gas – removed by gas scrubbing stages |
| Tetrachloroethane | mg/m$^3$ | <0.00E+00 | <0.00E+00 | None present in synthesis gas – removed by gas scrubbing stages |
| Trichloroethene | mg/m$^3$ | <1.16E+03 | <1.16E+03 | None present in synthesis gas – removed by gas scrubbing stages |

[1] Reference figures taken from EA 'safe levels for biomethane injection', provided by Steve Storey

| Table 2Cc: Waste-Derived Synthesis Gas Comparison | | | | |
|---|---|---|---|---|
| **Relevant parameter** | **Units** | **Typical UK natural Gas Composition** | **Syn Gas Spec (% unless stated)** | **Comments** |
| PAH's (nathphalene) | $mg/m^3$ | <9.32E+03 | <9.32E+03 | None present in synthesis gas –removed by gas cleaning stages |
| Metals (see list below) | | | | |
| Arsenic | mg/kg | Trace | < LOD 2mg/kg | None expected - all metals retained in Char |
| Beryllium | mg/kg | Trace | < LOD 0.5 mg/kg | None expected - all metals retained in Char |
| Cadmium | mg/kg | Trace | < LOD 0.5 mg/kg | None expected – all metals retained in Char |
| Hexavalent Chromium | mg/kg | Trace | < LOD 2 mg/kg | None expected – all metals retained in Char |
| Lead | mg/kg | Trace | <LOD 0.5 mg/kg | None expected – all metals retained in Char |
| Mercury | mg/kg | Trace | <LOD 0.12 mg/kg | None expected – all metals retained in Char |
| Chlorinated Hydrocarbons | % vol /vol | Trace | <LOD $1ug/m^3$ | None present in synthesis gas |
| Ammonia | $mg/m^3$ | <2.91E+03 | <2.91E+03 | None present in synthesis gas - removed by gas cleaning stages |
| Gross Calorific Value | | 52.9 $MJ/m^3$ | 14.73 – 22.73 $MJ/m^3$ | |
| | | 100% | 100% | |

| Trace Gas | Acceptable Concentration | | | |
|---|---|---|---|---|
| | **Instantaneous ($mg/m^3$)** | **Ratio** | **Long term ($mg/m^3$)** | **Ratio** |
| **Raw Biomethane** | | | | |
| *Halogenated hydrocarbons* | | | | |
| 1,2 Dichloroethane | 8.15E+02 | 4.48E-01 | 4.41E+01 | 2.42E-02 |
| Vinyl chloride | 2.16E+03 | 2.95E+00 | 1.22E+02 | 1.68E-01 |
| Tetrachloroethene | 9.32E+03 | 1.21E+00 | 3.06E+04 | 3.97E+00 |
| 1,1,2, Trichloroethane | 2.33E+00 | 2.33E-01 | 2.45E+01 | 2.45E+00 |
| Chlorobenzene | 8.18E+04 | 2.73E+01 | 1.59E+04 | 5.30E+00 |
| Dichloromethane | 3.49E+03 | 2.29E+00 | 5.51E+04 | 3.61E+01 |
| Tetrachloroethane | 0.00E+00 | 0.00E+00 | 6.45E+02 | 1.29E+01 |
| Trichloroethene | 1.16E+03 | 1.32E+01 | 2.82E+03 | 3.20E+01 |
| *Aromatics* | | | | |
| Benzene | 2.42E+02 | 3.32E+00 | 3.92E+02 | 5.37E+00 |
| Toluene | 9.32E+03 | 7.45E+00 | 8.27E+03 | 6.61E+00 |
| Xylenes | 7.71E+04 | 1.25E+00 | 6.99E+03 | 1.13E-01 |
| Naphthalene | 9.32E+03 | 5.48E+02 | 9.54E+01 | 5.61E+00 |
| *Reduced sulphur compounds* | | | | |
| Hydrogen sulphide | 1.75E+02 | 3.01E-01 | 4.77E+03 | 8.22E+00 |
| Dimethyl sulphide | 0.00E+00 | 0.00E+00 | 1.59E+02 | 6.54E+00 |
| Dimethyl disulphide | 0.00E+00 | 0.00E+00 | 1.59E+02 | 1.32E+01 |
| Carbon disulphide | 1.16E+02 | 6.85E-01 | 3.18E+03 | 1.87E+01 |
| *Other* | | | | |
| Arsenic | 0.00E+00 | 0.00E+00 | 7.34E-01 | 1.71E+00 |
| Ammonia | 2.91E+03 | 1.37E-01 | 5.72E+03 | 2.69E-01 |
| | **Short term ($mg/m^3$)** | **Ratio** | **Long term ($mg/m^3$)** | **Ratio** |
| **Combustion Gas** | | | | |
| $SO_2$ | 3.82E+01 | 3.82E-01 | 2.63E+01 | 2.64E-01 |
| *Acid Gases* | | | | |
| HCl | 8.18E+01 | 9.62E-02 | 0.00E+00 | 0.00E+00 |
| HF | 1.74E+01 | 2.37E-02 | 3.37E+00 | 4.58E-03 |
| *Aromatics* | | | | |
| Benzene | 2.27E+01 | 6.74E+02 | 2.18E+00 | 6.47E+01 |
| Toluene | 8.72E+02 | 1.60E+04 | 5.48E+01 | 1.01E+03 |
| *Polycyclic aromatic hydrocarbons (PAHs)* | | | | |
| Naphthalene | 8.72E+02 | 8.87E+04 | 6.32E-01 | 6.42E+01 |
| Acenaphthylene | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Acenaphthene | 0.00E+00 | 0.00E+00 | 4.42E+01 | 1.48E+06 |
| Fluorene | 0.00E+00 | 0.00E+00 | 2.95E+01 | 6.57E+05 |
| Phenanthrene | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Anthracene | 0.00E+00 | 0.00E+00 | 2.21E+02 | 5.75E+06 |
| Fluoranthene | 0.00E+00 | 0.00E+00 | 9.27E+00 | 1.93E+05 |
| Pyrene | 0.00E+00 | 0.00E+00 | 2.21E+01 | 2.76E+05 |
| Benzo-a-anthracene | 0.00E+00 | 0.00E+00 | 1.70E-03 | 5.90E+01 |
| Chrysene | 0.00E+00 | 0.00E+00 | 5.67E-03 | 1.97E+02 |
| Benzo-b-fluoranthene | 0.00E+00 | 0.00E+00 | 1.70E-03 | 5.90E+01 |
| Benzo-k-fluoranthene | 0.00E+00 | 0.00E+00 | 1.70E-03 | 5.90E+01 |
| Benzo-a-pyrene | 0.00E+00 | 0.00E+00 | 1.70E-04 | 8.85E+00 |
| Dibenzo-ah-anthracene | 0.00E+00 | 0.00E+00 | 8.90E-05 | 4.63E+00 |
| Benzo-ghi-perylene | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |

| | | | | |
|---|---|---|---|---|
| Indeno-123-cd-pyrene | 0.00E+00 | 0.00E+00 | 2.13E-03 | 7.37E+01 |
| *Metals* | | | | |
| Cd | 0.00E+00 | 0.00E+00 | 1.05E-03 | 5.98E-02 |
| As | 0.00E+00 | 0.00E+00 | 4.08E-03 | 1.27E+00 |
| Se | 0.00E+00 | 0.00E+00 | 4.21E+00 | 1.10E+04 |
| Cu | 6.54E+00 | 4.81E+02 | 4.21E-01 | 3.09E+01 |
| Co | 6.54E-01 | 4.86E+02 | 6.80E-02 | 5.05E+01 |
| Cr | 1.64E+01 | 7.29E+02 | 5.27E-04 | 2.35E-02 |
| CrVI | 0.00E+00 | 0.00E+00 | 1.36E-04 | 6.07E-03 |
| Mn | 1.64E+02 | 2.69E+04 | 3.16E-02 | 5.19E+00 |
| Ni | 0.00E+00 | 0.00E+00 | 1.36E-02 | 4.04E-01 |
| Pb | 0.00E+00 | 0.00E+00 | 5.27E-02 | 7.15E+00 |
| V | 1.09E-01 | 2.96E+00 | 2.11E-01 | 5.72E+00 |
| Hg | 8.18E-01 | 1.96E+02 | 4.21E-02 | 1.01E+01 |
| Ba | 5.45E-01 | 7.74E+00 | 1.05E-01 | 1.49E+00 |
| Zn | 1.09E+02 | 2.35E+02 | 1.05E+01 | 2.27E+01 |
| *Chlorinated hydrocarbons* | | | | |
| 1,2 Dichloroethylene | 0.00E+00 | 0.00E+00 | 1.26E+01 | 6.74E+01 |
| 1,1 Dichloroethylene | 0.00E+00 | 0.00E+00 | 8.42E+01 | 4.49E+02 |
| Trichloroethylene | 1.09E+02 | 5.82E+02 | 1.56E+01 | 8.34E+01 |
| Tetrachloroethylene | 8.72E+02 | 4.65E+03 | 1.70E+02 | 9.07E+02 |
| 1,1,1 Trichloroethane | 2.42E+04 | 1.29E+05 | 4.42E+02 | 2.36E+03 |
| 1,1 Dichloroethane | 1.80E+04 | 9.60E+04 | 8.68E+02 | 4.63E+03 |
| 1,2 Dichloroethane | 7.63E+01 | 4.07E+02 | 2.45E-01 | 1.31E+00 |
| Chlorobenzene | 7.66E+03 | 4.08E+04 | 1.05E+02 | 5.62E+02 |
| Dichlorobenzene | 0.00E+00 | 0.00E+00 | 2.11E+02 | 1.12E+03 |
| 1,2 Dichlorobenzene | 2.18E+02 | 1.16E+03 | 2.11E+02 | 1.12E+03 |
| 1,3 Dichlorobenzene | 0.00E+00 | 0.00E+00 | 2.11E+02 | 1.12E+03 |
| 1,4 Dichlorobenzene | 3.34E+03 | 1.78E+04 | 2.11E+02 | 1.12E+03 |
| 1,2,4 Trichlorobenzene | 2.49E+02 | 1.33E+03 | 1.60E+01 | 8.54E+01 |

# ANNEX D: Contaminant Fate

| Component | Qty in Feedstock | Primary Action | Secondary Action | Environmental Fate | Quantity in Syn Gas | Quantity in Pyrolyser Exhaust[6] | Quantity in Slag[7] | Quantity in Gas train abatement plant[8] |
|---|---|---|---|---|---|---|---|---|
| Moisture (%) | 5 | All water content flashes to steam in retort.<br><br>% will react with Carbon to produce Hydrogen and Carbon monoxide | Water Vapour absorbed in dry gas treatment plant.<br><br>CO and $H_2$ in gaseous form remain in Synthesis gas | CO and $H_2$ combusted to form $CO_2$ and $H_2O$ in engine | ~18% $H_2$<br>~30% CO | - | - | - |
| Ash content (%) | 18 | Stays in Char | Melts but does not boil off in Secondary Convertor | Forms a vitrified slag. All solid materials (i.e. in solid phase at 700°C) retained in char | - | Nil – all removed by ceramic filtration | 540 kg/hr per pyrolisation unit | - |
| Sulphur (%) | ~ 0.9 | Boils and forms a gas phase within the retort | Stripped from gas stream in dry gas treatment plant (alkali reagent) prior to filtration. | Acid gas neutralised by dry gas treatment plant | < 0.001% | - | - | <1kg neutralised in dolomite tower |
| Chlorine (%) | 0 | Not present in feedstock, stripped out in pre stage conditioning | None | Acid gas neutralised by water /steam treatment plant | - | - | - | - |
| Arsenic (mg/kg) | ~ 0.2 | Boils and forms a gas phase metal within the retort | Boils of to gaseous form in Secondary Converter | Reformed to micro solid as cooled in HRSG. 99.9% will be collected in Ceramic filters | - | - | - | Trace – removed in dolomite tower |
| Cadmium (mg/kg) | ~ 1 | Remain solid phase and retained within char | Boils of to gaseous form in Secondary Converter | Reformed to micro solid as cooled in HRSG. 99.9% will be collected in Ceramic filters | - | 0.00666 mg/$Nm^3$ | - | Trace – removed in dolomite tower |
| Fluorine (%) | 0.01 | Forms a gas in retort | Neutralised in dry gas clean up train (Absorbed by Dolomite Tower). | Water neutralised by ph correction | - | - | - | - |
| Chromium (mg/kg) | ~32 | Remain solid phase and retained within char | Remains in solid phase and retained in char | Encapsulated in vitrified slag | - | - | < 2000 mg/hr | Trace – removed in dolomite tower |

6 Refer to Exhaust emissions data (Catalyst Environmental Ltd 2011) Annex A
7 Refer to Vitrified Ash analysis (Catalyst Environmental Ltd 2011) Annex A
8 Refer to Effluent analysis (Catalyst Environmental Ltd 2011) Annex A

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Copper (mg/kg) | ~ 26 | Remain solid phase and retained within char | Remains in solid phase and retained in char | Encapsulated in vitrified slag | - | - | < 2000 mg/hr | Trace – removed in dolomite tower |
| Lead (mg/kg) | ~ 38 | Melts to liquid phase but retained in Char | Remains in solid phase and retained in char | Encapsulated in vitrified slag | - | - | < 4000 mg/hr | Trace – removed in dolomite tower |
| Mercury (mg/kg) | ~ 0.18 | Boils and forms a gas phase metal within the retort | Reformed to solid on quench | Settles as a sludge at bottom of oils separation tank | - | - | - | Trace – removed in dolomite tower |
| Nickel (mg/kg) | 7 | Remain solid phase and retained within char | Remains in solid phase and retained in char | Encapsulated in vitrified slag | - | - | < 2000 mg/hr | Trace – removed in dolomite tower |
| Magnesium (mg/kg) | - | - | - | - | - | - | - | Trace – removed in dolomite tower |
| Manganese Mn (mg/kg) | ~ 37 | Remain solid phase and retained within char | Remains in solid phase and retained in char | Encapsulated in vitrified slag | - | - | < 2000 mg/hr | Trace – removed in dolomite tower |
| Vanadium (mg/kg) | ~ 1.9 | Remain solid phase and retained within char | Remains in solid phase and retained in char | Encapsulated in vitrified slag | - | - | < 2000 mg/hr | Trace – removed in dolomite tower |
| Zinc (mg/kg) | ~105 | Remain solid phase and retained within char | Boils of to gaseous form in Secondary Converter | Reformed to micro solid as cooled in HRSG. May be collected in ceramic filters | - | 1.03030303 mg/Nm3 | | Trace – removed in dolomite tower |
| Titanium (mg/kg) | 10 | Remain solid phase and retained within char | Boils of to gaseous form in Secondary Converter | Encapsulated in vitrified slag | - | - | < 1500 mg/hr | Trace – removed in dolomite tower |
| Thallium (mg/kg) | < 0.05 | Boils and forms a gas phase metal within the retort | Remains in solid phase and retained in char | Encapsulated in vitrified slag | - | - | < 1500 mg/hr | Trace – removed in dolomite tower |
| Beryllium (mg/kg) | < 0.05 | Remain solid phase and retained within char | Remains in solid phase and retained in char | Encapsulated in vitrified slag | - | - | < 500 mg/hr | Trace – removed in dolomite tower |
| Tin (mg/kg) | - | Remain solid phase and retained within char | Remains in solid phase and retained in char | Encapsulated in vitrified slag | - | - | < 3000 mg/hr | Trace – removed in dolomite tower |
| Tellurium | - | Remain solid phase and | Boils of to gaseous | Reformed to micro solid as | - | - | | Trace – removed in dolomite |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| (mg/kg) | | retained within char | form in Secondary Converter | cooled in HRSG | | | - | tower |
| Selenium (mg/kg) | - | If present, it would boil and forms a gas phase metal within the retort | Would return to solid form in Dolomite tower, captured in filtration plant | Retained within gas train bag house | - | - | - | Trace – removed in dolomite tower |
| Antimony (mg/kg) | ~ 4 | Remains solid phase and retained within char | Remains in solid phase and retained in char | Encapsulated in vitrified slag | - | - | < 1000 mg/hr | Trace – removed in dolomite tower |
| Cobalt (mg/kg) | - | Remain solid phase and retained within char | Remains in solid phase and retained in char | Encapsulated in Vitrified slag | - | - | - | Trace – removed in dolomite tower |


# Mechanical Separation Solutions from GEA Westfalia Separator

engineering for a better world

GEA Mechanical Equipment

The know-how for over 3000 processes and procedures makes GEA Westfalia Separator Group an approved partner.

We provide solutions for the food industry, chemistry, pharmaceuticals, biotechnology, energy, shipping and environmental technology.

# Contents

# Our Answer to the Global Challenges: Liquids to Value

GEA Westfalia Separator Group is the leading company in the world in the field of mechanical separation. With the efficient processing of liquids and liquid mixtures, this technology ensures considerable added value: more quality of life for mankind. More sustainability for the earth. And more efficiency for your company.

The global population is expanding rapidly. Almost seven billion people nowadays have to be supplied with water, energy, food and medical products. At the same time, the requirements for sustainable management are becoming more and more stringent. Only efficient handling of valuable resources will ensure our quality of life without endangering the fundamental basis of future generations. Healthy growth – this is the objective of mechanical separation of GEA Westfalia Separator Group.

Since 1893, we have been building centrifuges used for separating liquids and liquid mixtures. Whether separators or decanters: the process lines of GEA Westfalia Separator Group combine high separating efficiencies, clarifying efficiencies and throughput capacities with maximum savings in terms of energy, water, production and disposal costs.

Based on the experience gained with more than 3000 process applications and a procedure for rapidly translating innovations into marketable processes, we provide profitable answers to some of the most urgent questions of our time. Liquids to Value. This message has made us one of the leading companies in the world in the field of mechanical separation.

# *Liquids to Value*

# GEA Mechanical Equipment – Pooled Competence for Flowing Processes

Within the GEA Group, GEA Westfalia Separator Group is allocated to the segment GEA Mechanical Equipment. It pools and coordinates the services of leading specialists in the treatment of liquid substances. Cooperation in the worldwide network releases synergies and promotes the identification of customized high-end solutions for complex tasks.

The GEA Mechanical Equipment segment combines GEA Westfalia Separator Group as well as other companies in the GEA Group which handle and process liquids. In addition to mechanical separation, this includes products such as homogenizers, pumps, valves and tank cleaning systems. The close combination of these companies in the worldwide network offers a direct practical benefit to customers.

The integration in a segment permits coordinated research and development. The continuous know-how transfer and joint innovation competition encourages the optimization of technologies and the development of new markets.

Synergies are utilized in order to enable the services of all affiliated companies to be adapted even better to individual customer wishes.

Liquids to Value is the promise of success of GEA Mechanical Equipment. Suitably qualified employees, a high quality level, decades of know-how and far-reaching knowledge of the market always guarantee the best solution for a wide range of requirements. Our handling of liquids forms the basis for considerable added value. At the same time, we also enable production costs to be reduced and the strain on the environment to be reduced noticeably and in a sustainable manner.

**The Business Units**


GEA Mechanical Separation
(GEA Westfalia Separator Group, Oelde, Germany)


GEA Homogenizers
(GEA Niro Soavi, Parma, Italy)


GEA Flow Components
(GEA Tuchenhagen, Büchen, Germany)

stand for the GEA Mechanical Equipment segment. The market of liquid-processing components receives very broad regional as well as application-related cover as a result of a global network of sales and service branches.

# Our Organization is Optimum. For You.

We want to make everything as simple as possible for you. This is shown by the organization of our business lines already. Flat hierarchies, practical structures and easy-to-understand designations are designed to promote proximity to our customers.

**Engineering made in Germany**

The strategy headquarters of GEA Westfalia Separator Group is based in Oelde. From here, we provide you with engineering made in Germany – with a strong focus on innovation and maximum quality awareness. The company is organized in business areas and subordinate business lines. The system for allocating powers to the various business areas consistently reflects practical realities. This is also reflected in the easy-to-understand names of these areas.

**Business Area Sales**

The Business Area Sales supports you with competence and experience in all phases of the preparation and realization of your investment decision. Backed up by the comprehensive specialist expertise of the business lines, customized centrifuges and process lines are available for a broad application spectrum.

Our process-oriented business lines are dedicated primarily to complex processes. Our specialists plan and realize procedures and processes for the most stringent separating requirements.

Such applications are covered by the business lines:

- Beverage Technology
- Dairy Technology
- Renewable Resources
- Chemical / Pharmaceutical Technology

Our system-oriented business lines are primarily involved with the purification and treatment of large volume streams. They supply high-performance machines, systems and modules that are seamlessly integrated in your operations.

These duties are covered by the business lines:

- Marine
- Energy
- Oil & Gas
- Environmental Technology

**Business Area Service**

The Business Area Service combines all services of the company under a single roof. Worldwide, customers benefit from a tightly-knit network, rapid response times and high flexibility. The proactive service concept Westfalia Separator® **capital**care ensures that the specialist knowledge of the manufacturer is available on a round-the-clock basis.

**Business Area Production**

This business area is responsible for all worldwide production activities for separators and decanters. The Oelde headquarters and also all other production facilities are certified according to DIN EN ISO 9001:2008 and DIN EN ISO 14001:2004.

**More than 50 sales and service companies worldwide**

The international network of GEA Westfalia Separator Group comprises more than 50 sales and service companies. They offer excellent customer support around the globe, ranging from advice right through to ensuring the permanent availability of specified machine capacities.

# Excellent Engineering for Future-Proof Separation Technology Systems

Speed to market – under this premise, we concentrate our experience on one objective: strengthening the value added chains of our customers with no time delay. Complete solutions from a single source minimize the time required for process integration and strengthen investment security.

The speed of implementation of new process and system developments in line with market requirements is a significant feature of GEA Westfalia Separator Group solutions. This is made possible by comprehensive experience and process knowledge.

GEA Westfalia Separator Group realizes process solutions from one supplier – with no interface problems. Technological know-how and comprehensive understanding of processes enable us to reliably solve critical issues even at the plant planning stage. As such, we can harmoniously align all process and system units to each other, from the multi-cyclone for precleaning to classic separation solutions with separators or decanters.

Complete solutions from one supplier eliminate time delays and expensive coordination processes right from the start. Instead, they ensure constant high performance in terms of flow rate and separation efficiency – at minimal expense. This excellent process economy secures your investment decisions in the long term.

**Highly productive process lines from a single source:**

- Competence and clear responsibility
- Reliable communication
- Reliable planning
- Optimum plant and process configuration without barriers
- High level of functionality and investment reliability

# Separators and Decanters from GEA Westfalia Separator

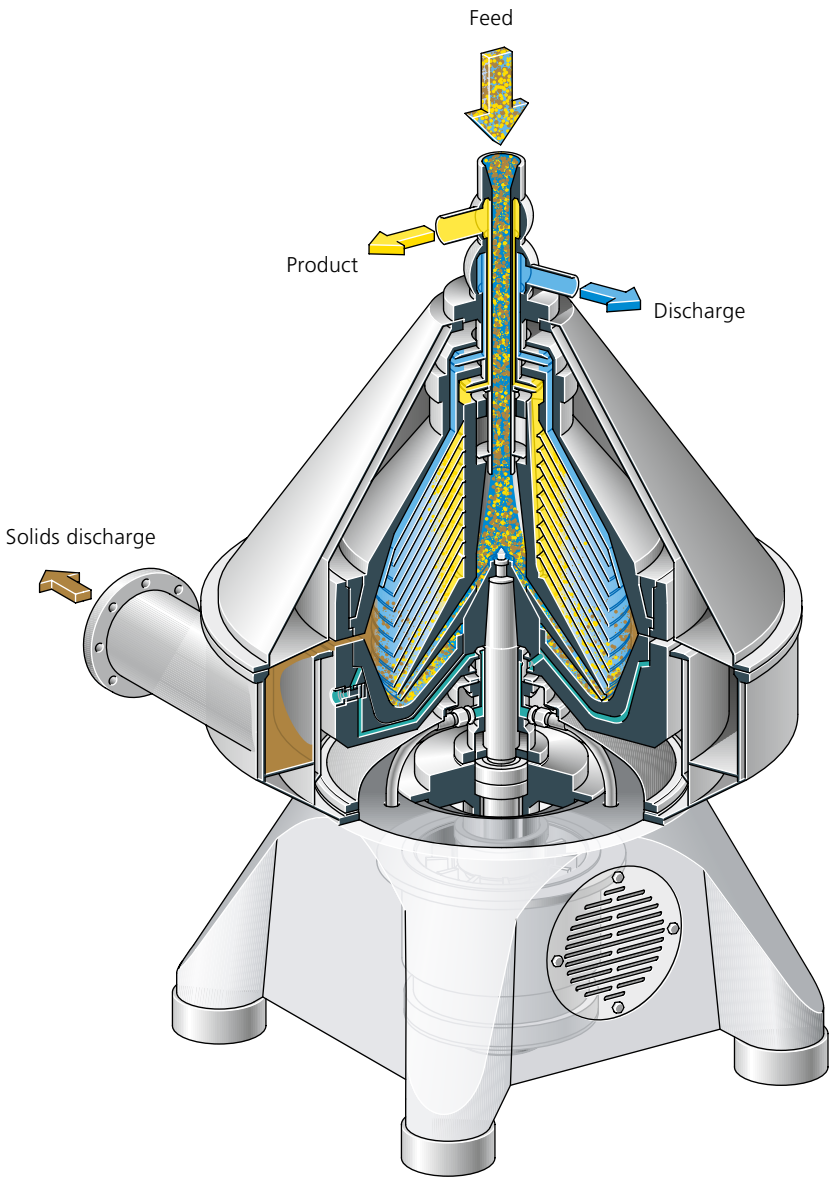
**Separating and clarifying liquids**

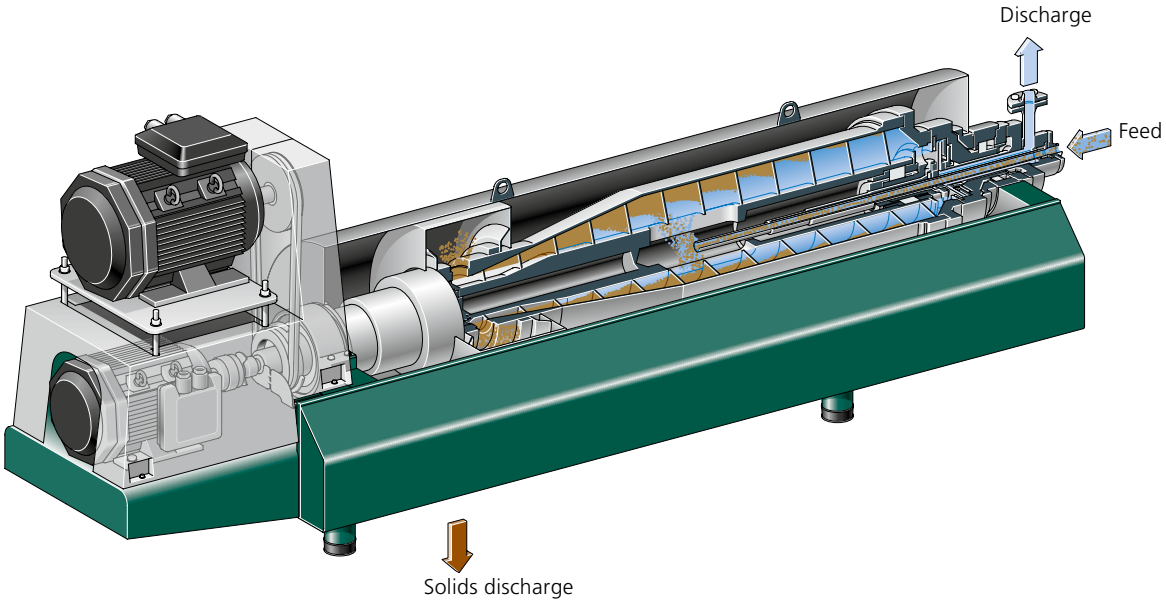
Our separators are designed especially for liquid-based applications. Using centrifugal force, they separate substances and solids from liquids. They are equally as effective at separating liquid mixtures at the same time as removing solids.

The fields of application range from separating processes in the chemical and pharmaceutical industries through oil and fat recovery to the production of dairy products, beer, wine, fruit and vegetable juices, as well as the processing of mineral oil and mineral oil products.

**Separator designs:**

- Solid-wall separators for the separation of liquids
- Chamber separators, also in coolable design, for example for the fractionation of human blood plasma
- Self-cleaning disk separators for clarification and separating processes
- Nozzle separators for the concentration and washing of suspensions






**Separating solids and clarifying liquids**
In solid-based applications, our decanters ensure optimum separation efficiency, particularly in the case of suspensions with a very high proportion of solids. They are also used for the extraction of constituents from liquids and for concentrating, dewatering and classifying solids.

Application areas include the cleaning of wash water and the treatment of fruit and vegetables in the food industry, the recovery of animal and plant oils and fats, the production of herbal medicines, copper extraction, chemical extraction in the paper industry, the treatment of waste oil for power generation, waste water treatment in waste water treatment plants, and use on oil platforms for the extraction of crude oil.

**Decanter designs:**
- Clarifying decanter for clarifying liquids
- Dewatering decanter for maximum concentration of solids
- Concentrating decanter for the concentration of solids
- Separating decanter for the separation of liquid mixtures and the simultaneous separation of solids
- Classifying decanters for the extraction of different solid fractions
- Extraction decanters for the extraction of reusable materials

# As Simple as Possible, a

## Innovations from GEA Westfalia Separator set

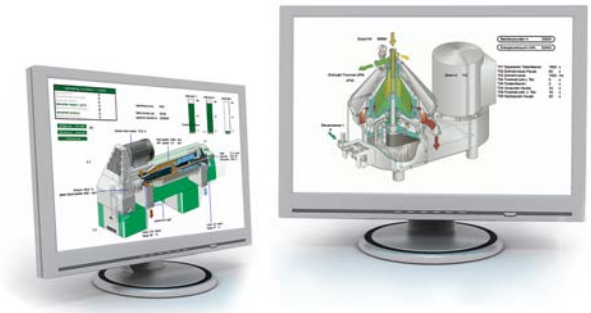
Westfalia Separator®
**vinex**

Westfalia Separator® **vinex**: this process uses a continuous separation process to extract the juice from grapes. High juice yield and outstanding quality properties increase the profits of the producers.

Westfalia Separator®
**directdrive**

Westfalia Separator® **direct**drive: separators use the power transmission with almost no loss of efficiency and the result is good: minimized energy consumption, lower wear and maintenance costs, plus a reduced space requirement.

Westfalia Separator®
**we**watch®



Westfalia Separator® we**watch**®**:** the condition monitoring of separators and decanters, which can be used to evaluate the relevant parameters online or offline, brings transparency and reliability to the production process.

**PRO**FI

**PRO**FI: the innovative beer filtration with the intelligent combination of a high-performance centrifuge and membrane filtration improves clarification and eliminates the need for kieselguhr handling.

# s Complex as Necessary

## the standard for efficiency around the world


Westfalia Separator® **seaprotect**solutions: bilgewater and oil sludge are treated with the greatest efficiency in separation. The result is that IMO-compliant clear water with < 15 ppm can be discharged back into the sea.


Westfalia Separator® **unitrol**plus: monitors and controls automatic separators for the treatment of fuel and lube oil. Concepts for the unmanned machine room are monitored reliably.


Westfalia Separator® **vari**pond®: identifies the automatic regulation of decanter pond depths, e. g. for waste water treatment. Even with a fluctuating feed concentration, a constant discharge concentration is regulated.


Westfalia Separator® capital**care**: these tailor-made products offer the benefit from the service competence of the technology leader throughout the entire life cycle of the centrifugal technology from GEA Westfalia Separator Group.

# BUSINESS A

# REA SALES

# Business Line Beverage Technology

Beer, wine, fruit and vegetable juices, coffee, tea, soy drinks… the demands made by our customers with respect to quality and variety are increasing with the international growth in the beverage markets.

In production, slim, fluent processes and high yield from the raw materials used are gaining as much in importance as the conservation of the environment and resources. The efficient separators, decanters, filtration systems and process lines from GEA Westfalia Separator Group are completely compliant with these demands. They achieve first class product results, allow product differentiation in line with market requirements, and minimize environment-related material flows as well as the consumption of water, natural ingredients and energy. Examples of this include the following process innovations, with which GEA Westfalia Separator Group sustainably strengthens the competitiveness of its customers:

**PROFI**

Combines the specific advantages of centrifugal separation technology and membrane filtration in the production of beer. This eliminates the need to use kieselguhr. The beer filtration is continuous – with maximum yield and simple changing of types. With this new process, breweries are able to ensure high beer quality and efficient processing with the maximum possible conservation of the environment.

**Westfalia Separator® vinex**

Facilitates continuous, gentle and rapid juice extraction from the grapes in wine production by means of decanters. With the Westfalia Separator® **vinex** process, wineries achieve constant high quality with a significantly greater yield from the grapes and reduced mash standing times.

**Westfalia Separator® frupex®**

Replaces the pressing process previously used in the production of fruit juice by the use of a complete processing line of separators and decanters. This means that producers are able to handle all sorts of fruit and vegetables even in small batches, with good results: sparing use of raw materials, significant increases in yield and consistently high juice quality.

**Maximum extract yield with instant coffee and tea**

Ensures an efficient process, in which GEA Westfalia Separator Group uses specially designed separators and decanters in the areas of flavour separation (de-oiling), clarification, extraction from solids and process water treatment.

With the simplest integration into existing production lines, producers achieve a high yield from the raw materials used and first class results in the quality of their instant coffees and teas.

**Examples of application areas include the production and extraction of:**

- Beer
- Wine, sparkling wine and champagne
- Citrus juice
- Premium juice from fruits, berries, vegetables and herbs
- Exotic juices
- Base materials for soft drinks
- Essential oils
- Coffee
- Tea
- Soy drinks
- Cereal drinks
- Phytochemicals from natural raw materials

With the mechanical separation technology from GEA Westfalia Separator Group, beverage manufacturers are able to achieve a decisive competitive advantage.


Westfalia Separator®
directdrive

# Business Line Dairy Technology

Milk is one of the most important and versatile foodstuffs in the world. Consumers no longer expect only naturalness and freshness in milk products; they now also increasingly demand variety of flavor as well as maximum functionality.

In cooperation with our company, dairies benefit from over a century of successful experience in all areas of milk processing. Tailored to the sometimes extreme differences in preferences of the international milk market, GEA Westfalia Separator Group has developed a series of forward-looking processes.

**Westfalia Separator® directdrive**

With this innovation, the company has achieved a major advance in terms of separator technology. Westfalia Separator® **direct**drive is the first separator with an integrated direct drive to be used for removing bacteria from milk. This new drive considerably boosts the efficiency. The result: lower energy costs, lower infrastructure costs and leaner processes. In conjunction with the proactive services of Westfalia Separator® **direct**care, the dairy industry benefits from higher availability with full budget certainty.

**Westfalia Separator® hy**vol**® pro**plus

Westfalia Separator® hy**vol**® **pro**plus characterizes the new generation of separators which combines the excellent performance features of the Westfalia Separator® hy**vol**® with the Westfalia Separator® **pro**plus systems. The features are a considerable increase in protein yield and a significant cost reduction. The results that can be expected right from the start include rapid amortization and greater profit from the raw milk used, over the entire lifetime.

**Westfalia Separator® pro**cool

This process advances dairies in the area of cold milk skimming. The innovative Westfalia Separator® **pro**cool process maintains optimum product quality and provides high microbiological safety for cold milk separation.

The focus of this process is on energy saving, lower operating costs, and higher protein quality. The separators used for this stand out for performance and skimming efficiency, which are currently rivalled by no other cold milk skimming machine.

**Complete system solutions**

In addition to supplying individual separators and decanters for integration into existing plants, GEA Westfalia Separator Group also implements complete process lines for the production of various milk products, e. g. for the production of quark and soft cheese.

**Example of application areas include:**

- Skimming of milk and whey
- Clarification of milk and whey
- Bacteria removal from milk and whey
- Concentration of cream

**Production and extraction of:**

- Casein
- Cheese fines
- Quark
- Soft cheese
- Lactose
- Whey protein
- Phospholipids
- Butter
- Butter oil
- Calcium phosphate

# Business Line Renewable Resources

Conservation of resources and sustainability both play a key role in the future provision of basic supplies. Pioneers and researchers focusing on solutions with renewable resources will find us to be a technically accomplished and committed partner.

Renewable raw materials offer many opportunities for securing food for the people as well as substituting fossil-based raw materials and thus introducing completely new products and industrial processes. Efficient handling of natural resources is the order of the day. With the concentration of our know-how in the Business Line Renewable Resources, we give these requirements a platform for forward-looking solutions.

The Business Line Renewable Resources remains your market aide for tried and tested processes, e. g. in the extraction of cooking oil and starch, at the same time as forming a centre of competence for new, innovative ideas and visions – particularly in the development and exploitation of renewable energy sources. We support the forward-thinkers of our time by providing the latest process technology, from laboratory testing to industrial implementation.

BUSINESS LINE RENEWABLE RESOURCES:

# Tradition and Innovation

The Business Line Renewable Resources is the competence and development center for new visions and future markets. At the same time, we remain your market aide for tried and tested processes, with core competences in the following areas:

**Starch and protein**

International demand for custom-made starch products and high purity proteins is constantly increasing. Centrifugal separation technology is a key technology with considerable potential for improving products and production processes in the extraction of reusable plant materials.

Examples of application areas of our centrifuges and process lines:

- Corn starch and corn gluten
- Wheat starch (A and B starch), wheat gluten, pentosans and protein coagulate
- Tapioca / manioc starch
- Potato starch, pulp, gratings and protein
- Rice starch
- Pea starch
- Proteins (e. g. from soy), protein concentrate, protein isolate

**Biofuels and the fermentation industry**

The Business Line Renewable Resources supports the production of high-quality biodiesel from sustainable raw materials by way of implementing complete process lines and optimizes the extraction of bioethanol with separators and decanters constructed especially for the stringent demands in these processes.

Solutions of the Business Line Renewable Resources for the production of biodiesel:

- Complete process lines with the Connemann – ADM System CD process
- Glycerine cleaning, separation of glycerine and catalyst from biodiesel, separation of salts from glycerine, and for separation of fatty acids and glycerine

Application areas of our separators and decanters in the production of bioethanol:

- Dry milling process
- Wet milling process
- Extraction of ethanol from molasses
- Extraction of ethanol from biomasses, e. g. such as yeast or cellulose

Examples of application areas of our centrifuges and process lines in the modern fermentation industry:

- Processing of bioproducts such as molasses, stillage, vinasse, sugar juice
- Processing of extra-cellular products such as amino acids, acetic acid, L-Lysine, monosodium glutamate, threonines, tryptophan, citric acid
- Processing of fermentation products such as algae, baker's yeast, single-cell proteins, fodder yeast
- Processing of intra-cellular products such as yeast extract, ribonucleic acid

**Oils and fats**

Highly reliable, energy-saving and extremely productive in the smallest of spaces – separators and decanters from the Business Line Renewable Resources recover oils and fats in any quality required.

Our separation technology systems and plants are used both for the extraction of raw oils and fats and in the refining of oils for press oil clarification, de-gumming, neutralization, washing, wax removal, fractionation and splitting soapstock. Here, examples of applications include:

- Extraction of olive oil, avocado oil, nut oils, cocoa butter, jojoba, linseed and others
- Extraction of animal fats, blood meal and plasma, gelatine and others from meat by-products
- Extraction of fish meal, fish and liver oil, protein hydrolysates and surimi
- Processing of flotation sludges in the fish and meat industry
- Cleaning of frying and cooking fats
- Refining raw oils to cooking oils, e.g. such as soy oil, rapeseed oil, palm oil, sunflower oil, cotton-seed oil, corn oil

# Business Line Chemical / Pharmaceutical Technology

The preservation of fragile cell cultures, processing with the highest CIP and SIP requirements, comprehensive safety e. g. in the handling of concentrated acid compounds or explosive mixtures – the separation technology solutions of the Business Line Chemical / Pharmaceutical Technology represent engineering at the highest level.

The centrifuges that we develop specifically for these industries are compliant with exceptionally high standards in the areas of safety, hygiene and product quality. Examples of these include:

- Steam-sterilizable separators – which work extremely sparingly with the product using their hydrohermetic feeds – are produced entirely in GMP design and reliably eliminate the risk of product contamination by the sterilizability of all plant components (including separators)
- Separators in various corrosion-resistant special materials for use in the chemical industry. Here, one particular speciality of GEA Westfalia Separator Group is the lining of solid-wall bowls e. g. with Incoloy 825 or titanium palladium. The result for our customers: manageable investment costs at the same time as a high degree of reliability and performance from the separators used
- Classifying decanters for use in the area of mineral processing, with special drive systems for high torques
- Gastight decanters compliant with ATEX regulations, designed for systems with excess pressure and with electrical components that are especially suitable for operation in explosion-hazarded zones

In this business line, we combine the complex safety requirements of chemistry, pharmaceuticals and biotechnology with high separation performances and a significant reduction in the operating costs of separation technology plants in the following applications:

**Organic, inorganic and petrochemicals:**

- Aldehydes, alcohols
- Aluminum hydroxide
- Barium sulphate
- Recovery of alkali salts (boiler ash)
- Cellulose and derivatives
- Printing colours, ink
- Paints, lacquers, resins
- Gum arabic
- Catalyst separation (as well as liquid gas)
- Cosmetic and hygiene products

- Lyes
- Phosphors
- Solvent recovery / clarification
- Nitration of aromatic compounds
- Nylon, caprolactam
- Petrochemical additives
- Pesticides
- Peroxides
- Phosphoric acid
- Polyacetates
- Polyethylene
- Acids (inorganic and organic)
- Terephtalic acid
- Viscose, cellulose acetate
- Xanthan

**Pharmaceutical biotechnology**

- Human vaccines and veterinary vaccines
- Insulin from biomass
- Enzymes
- Starter cultures (bacteria cultures)
- Human blood proteins
- Synthetic pharmaceutical products
- Animal cell cultures

**Extraction**

- Essential oils
- Alkaloids
- Antibiotics
- Aromatic substances
- Fragrances
- Medicinal teas
- Organ extracts
- Pectins
- Herbal medicines
- Statins
- Steroids, hormones
- Vitamins
- Polycarbonate

**Mineral processing**

- Industrial minerals
  - Calcium carbonate
  - Kaolin
  - Bentonites
  - Titanium dioxides
- Metal ores
  - Copper
  - Nickel
  - Zinc
  - Cobalt

# Business Line Marine

The greater the reliability, economy, cleanness and strength of the drive and supply systems, the quicker, more efficient, safer and more environmentally friendly the ship. The separators and the cooling and supply systems from the Business Line Marine give equal consideration to the economic challenges of maritime logistics and the increasingly stringent regulations for the protection of the sea as well as progress in shipbuilding technology.

The system solutions of this business line reliably ensure high performance and economical operation of diesel engines, increasing their life expectancy even under extreme conditions. Examples of this include:

- Westfalia Separator® **eagle**class: with their high g-force, these separators set the new standard around the world for the treatment of fuel and lube oils for maritime use. They are designed for unmonitored continuous operation and comply with all the regulations of the classification societies.
- Westfalia Separator® **d**type separators cost-effectively treat bilgewater and sludges containing oil, under the brand of Westfalia Separator® **seaprotect**solutions, and are fully compliant with the IMO and USCG requirements.
- Westfalia Separator® **Bilge**Master® **clean**design systems for processing bilgewater. Capacities of up to 4000 l per hour can be reduced to achieve a residual oil content of < 5 ppm. All requirements relating to environmental protection are also satisfied in particularly sensitive marine areas.
- Modular compact units consist of a base module, which is additionally completely pre-assembled with the required units. Such compact units can be easily installed in the shipyard, as plug and play devices. Alternatively, the Westfalia Separator® centri**packs** concept offers the option of combining all of the required separators in a single unit and delivering this to the shipyard piped and pre-fitted with all control modules, where it can be quickly installed.
- Westfalia Separator® **ViscoBooster**Units for the treatment of heavy fuel oil for marine engines. These adjust the viscosity, temperature and pressure to be optimal for the requirements of the engine manufacturer.
- Fresh water generators from GEA Westfalia Separator Group continuously extract drinking water from seawater and eliminate the need for fresh water supply tanks.
- Performance-enhancing retrofit units are easy to install and used to replace existing processes with the more efficient centrifugal separation technology, to extend performance limits, to increase capacities, to automate processes, and to reduce service and maintenance costs.

From the perspective of GEA Westfalia Separator Group, all options are available for the marine area, from individual components to complete system solutions. The concept is set up for our customers in such a way that the interfaces and planning expenditure are reduced and substantial savings can be achieved in terms of weight and space requirement.

The outstanding separation efficiency of the high-performance Westfalia Separator® **eagle**class centrifuges sustainably optimizes the reliable operation of turbines and diesel engines in power stations.

# Business Line Energy

Reliable, economical and resource-saving energy supply ensures quality of life and economic growth. It is largely based on fault-free, efficient and clean systems working in all load ranges. With the work-related treatment and maintenance of fuel oils, lube oils and combustible fuels for turbines and diesel engine power plants, the Business Line Energy makes a decisive contribution to future-proof energy supply.

The concept of our treatment plants is precision work, which we adjust to the nature of the respective fuels and oils used. Here – in addition to demand-based dimensioning – the design is influenced by aspects including viscosity, density and level of contamination.

As such, trace elements, which cause corrosion damage at high exhaust gas temperatures, are separated e. g. from the combustible fuels by our separators. The reliable desalination of fuel oil and the separation of solids by our separators reduce corrosion problems to the minimum level that is technically practical and ensure fault-free operation of these plants.

Water, wear and other impurities may have a considerable effect on performance, e. g. in the case of steam turbines. In severe cases, unplanned stoppages or complete failures threaten consequences that can quickly become “unaffordable”. Here too, our treatment systems ensure continuous reliability and constant high performance.

This applies equally for self-cleaning separators in continuous operation and for ready-to-connect treatment systems with a high level of automation in any performance class.

In order to replace existing systems, extend performance boundaries, automate processes and – at the same time – reduce maintenance and service costs, the Business Line Energy supplies retrofit units, which are easy to install and facilitate considerable increases in treatment efficiency.

**Our separators and system solutions for the energy industry carry out:**

- The treatment and maintenance of combustible fuels for diesel and gas turbines
- The treatment and maintenance of lubricating oils
- The treatment of oil, water and solid mixtures
- The treatment of waste water containing oil

# Business Line Oil & Gas

The high-speed centrifuges of the Business Line Oil & Gas are used in the exploration, production and processing of oil and gas. Efficiency, safety and environmental protection in a wide range of extremely specialized applications mean that these are first-choice developments. The processing of the industrial liquids is a further area of application. The centrifuges from GEA Westfalia Separator Group make a contribution towards considerably reducing operating costs and the consumption of resources.

Our new generation of separators and decanters carries out continuous liquid-liquid-solid separation in many different application areas, reliably meeting the decisive parameters of the oil, gas and metal industries:

- Safety for people and the environment
- Continuous availability of constant high performance even under extreme usage conditions
- Weight and space-saving structures and process efficiency

With their modular structure based on the plug and play principle, being simple to operate and extremely easy to maintain, the centrifuges safely and economically manage even large volume flows.

We support extreme operating conditions, for example with the use of highly corrosion-resistant materials and technical solutions that are compliant with applications which require gastight and explosion-proof designs.

**Aligned to your ambient and application conditions on site, our centrifuges ensure optimum processes and process results in the following application areas:**

- Treatment of drilling fluids
- Separation of oil from “produced water” and “drain water”
- Dewatering of crude oil, also heavy crude oil
- Cleaning and treatment of fuel, lubricating and hydraulic oil
- Separation of cat fines from residual oil
- Cleaning of “slop oil” and oil pits
- Monoethylene glycol clarification

**Save process media – protect the environment**

Our separators and decanters can also be profitably used for processing industrial fluids. They extend the operating life of the fluids by a factor of between four and five; they reduce the wear of the production systems and reduce disposal costs.

**Fields of application for industrial fluids:**

- Maintenance of cooling lubricants, clarifying liquids, fountain solutions and process liquids
- Clarifying and dewatering of lube oil, hydraulic oil and diesel oil
- Treatment of waste oil, used emulsion, MARPOL oil and water-containing oil

The market launch of the Westfalia Separator® **eagle**class separators provides new options for increased flow rates with minimum weight and space requirements.

# Business Line Environmental Technology

Whether they are used for generating drinking water or treating process water or effluents: the system solutions of the Business Line Environmental Technology set worldwide standards for economy, efficiency and sustainable environmental protection. Companies and municipal institutions are able to considerably reduce their operating costs and consumption of resources.

It is not only oil deposits but also global reserves of fresh water that are limited. The focus is increasingly on the economical use of water and particularly on more efficient ways of extracting drinking water. Installation operators have to face the challenge of carrying out these and other tasks such as the treatment of sewage sludge or process water with minimum costs. For these challenges, the Business Line Environmental Technology provides answers which are convincing from the economic as well as ecological points of view.

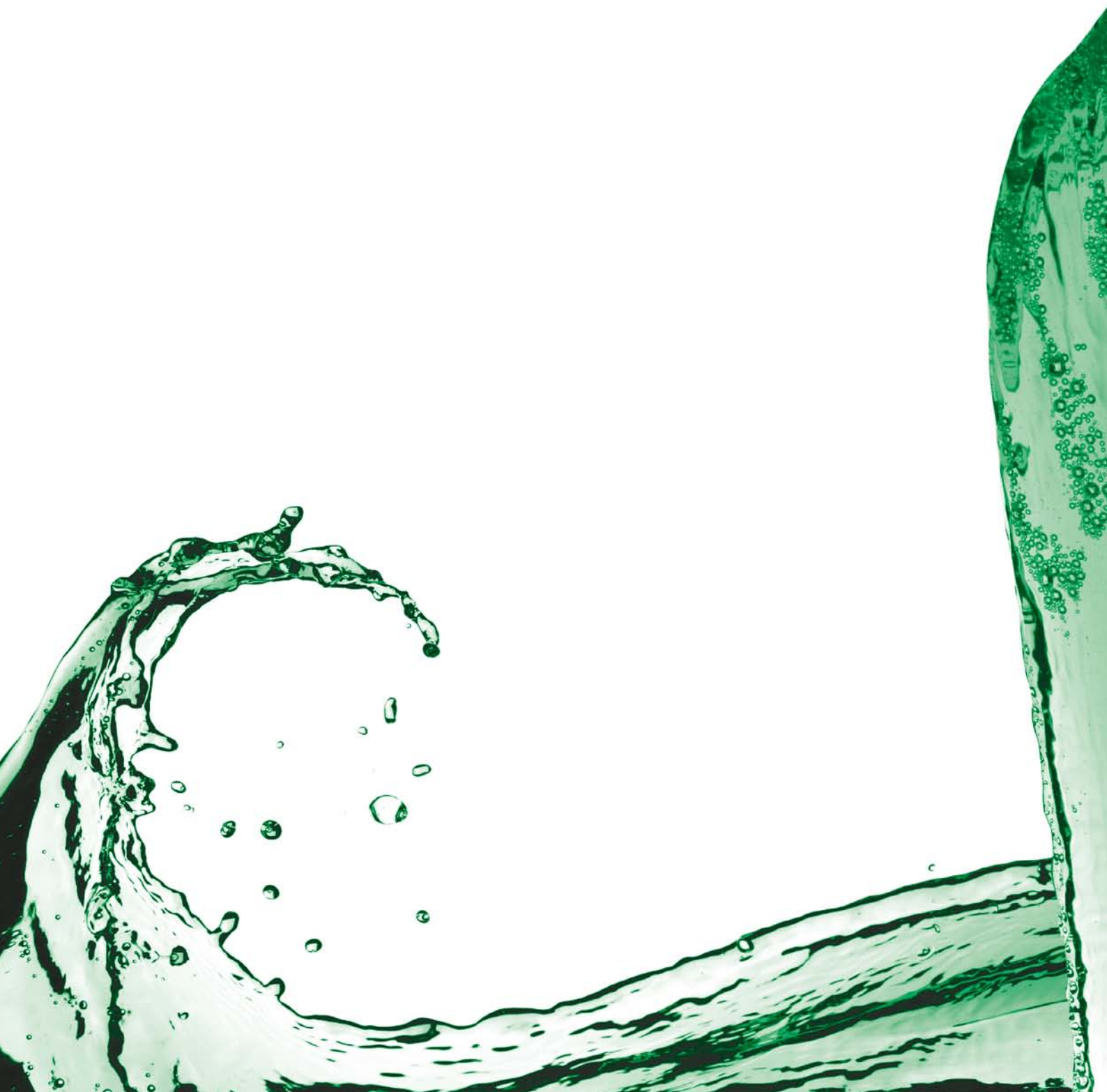
For many years, GEA Westfalia Separator Group has been developing successful solutions for the sustainable use of precious resources: over 3500 stationary and mobile plants improve drinking water and waste water treatment around the world. The mechanical separation technology that has the highest flow rates with the lowest energy consumption and low-maintenance operation stands out particularly in the dewatering and thickening of sewage sludge. The figures are self-explanatory: decanters from GEA Westfalia Separator Group for instance thicken sewage sludge in such a way that the volume of surplus activated sludge which is produced is reduced by up to 90 percent.

These parameters mean that the technology is compliant with the restrictive cost management both in industry and in municipal waste water treatment plants.

**Versatile application:**

- Treatment of process water
- Dewatering of sewage sludge
- Thickening of sewage sludge
- Treatment of drinking water
- Treatment of municipal and industrial waste water
- Recovery of reusable materials from production flows and sewage sludge
- Stationary or mobile solutions

# BUSINESS AR



# EA SERVICE


Only by using the modularly structured original service from GEA Westfalia Separator Group is it possible to avoid the risk of jeopardizing the investment in the product and process quality – and therefore the success of the entire project – with unqualified servicing.

# Westfalia Separator® capital**care** – Original Manufacturer Service

Westfalia Separator® capital**care** – the service for process applications. There is only one way to ensure the unique service level of our separation technology systems over the entire life cycle: service from the manufacturer.

You expect the highest separation technology performance for the best possible results in production. Machines from GEA Westfalia Separator Group are among the best in the world, regularly setting new standards in terms of flow volume and separation efficiency.

The excellence of the machine is complemented by the comprehensive know-how of the specialists in separation technology processes. We are happy to pass on this knowledge to our customers and support them in the aim of establishing optimum production processes.

**Best machines need the best service**
In order to achieve the performance level, we have combined the best experts and production technologies with decades of know-how. So that our machines and process components continue to provide maximum performance even after many years, we provide our knowledge to you through coordinated services.

Here, we keep in mind that our customers plan their repair and maintenance budgets to be as efficient as possible. Customized service level agreements offer numerous options here. These may be agreements for basic services, although premium contracts are also available, which can be defined with specified services for the framework of a budget.

**Reliability for processes and investments**
Only with detailed knowledge of the modern centrifuges and process lines from GEA Westfalia Separator Group and with original spare parts is it possible to provide the reliability that the equipment will accurately complete its separation technology tasks with all of the specific performance parameters, hour by hour and day by day.

**All of the major services are provided for you – within a manageable budget:**

- Field service
- Original spare parts
- Repair
- Condition monitoring
- Training
- Service level agreements are adjusted precisely to the requirements of customers' production processes

# Customized Service Packages – 24/7 – Around the World

Westfalia Separator® capital**care**: with customized service packages, the 24/7 manufacturer's service concept for system applications ensures the outstanding performance of our separation technology machines and systems. If necessary, our service technicians can be on site straight away – all over the world.

The reliable availability of maximum system performance is a prerequisite for the highest level of process efficiency. The machines must run at a constant level of effectiveness, around the clock. Our preventive services and measures are designed to comprehensively secure this performance and availability and to avoid unplanned stoppage times.

Here, we keep in mind that our customers plan their repair and maintenance budgets to be as efficient as possible. Customized service level agreements offer numerous options here. These may be agreements for basic services, although premium contracts are also available, which can be defined with specified services for the framework of a budget.

**Proactive services for constant process efficiency**
Our most important services for individual alignment to your plant technology and your budget framework:

- Field service
- Original spare parts
- Repair
- Training
- Service level agreements are adjusted precisely to the requirements of application conditions

**Support points around the world – 24/7 service on site**
Our proactive services are run from many centers in strategically important ports, for example in Hamburg, Singapore, Tianjin and Dubai. With numerous authorized workshops and service stations around the world, we are never far away, so we can be there when you need us.

# BUSINESS AREA

# PRODUCTION

# Centre of Competence in Oelde Assures First-Class Quality Worldwide

Managed by the Centre of Competence in Oelde, the Business Area Production has established worldwide production capacities in order to ensure that products are manufactured efficiently and in close proximity to customers.

Automated production processes and computer-based production technologies ensure that our production enjoys a sound economic and ecological base. Very short production times also provide our customers with clear advantages in terms of time; this is reflected particularly in product development and the development of new markets.

**Location investments around the globe**

In order to further optimize our delivery capability and product quality, we continuously invest in buildings, installations and in the ideas of our employees. This improves our infrastructures for production, assembly and final testing.

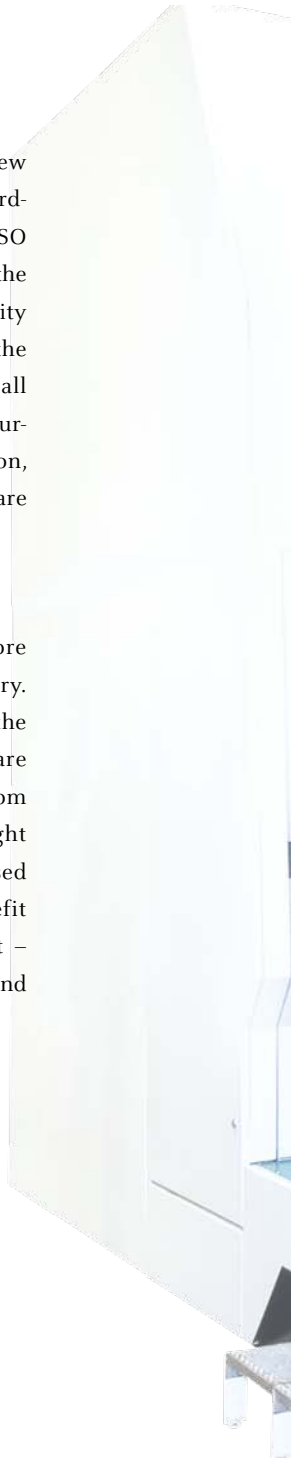
Specialization is the key to success. In Oelde, Germany, our centre of competence for mechanical separation as well as in the production locations in Niederahr (Germany), Château-Thierry (France), WuQing (China) and Bengaluru (India), we have the most modern production facilities in the world. With these production facilities, we provide effective support to our customers in the markets of today and tomorrow.

**Quality management at global level**

GEA Westfalia Separator Group is one of the few companies in the world which are certified in accordance with DIN EN ISO 9001:2008 and DIN EN ISO 14001:2004 in all production facilities throughout the globe. Compliance with extremely stringent quality requirements at our company is assured with the latest measuring technology and test bays in all production phases. By means of good manufacturing practice and complete quality documentation, we ensure that all of our quality commitments are implemented in reality.

**Westfalia Separator® lifecycle**benefit®

Our quality commitment comprises much more than error-free production and punctual delivery. All performance criteria are harmonized with the aim of maximizing the holistic benefit, and are optimized throughout the entire life cycle. From planning, installation and commissioning right through to upgrade and return concepts for used machines. This makes sure our customers benefit from maximum performance at minimum cost – throughout the entire life cycle of the machines and systems.




With the know-how and original spare parts from the manufacturer, authorized workshops ensure reliable availability.



Quality with a system: GEA Westfalia Separator Group is internationally certified in accordance with DIN EN ISO 9001:2008 and DIN EN ISO 14001:2004.

# Technology Centre for Process Engineering: Greater Security in the Investment Decision

From initial laboratory tests through pilot phases to the large-scale industrial plant, we develop optimally designed process integration in cooperation with our customers. This is based on our broad portfolio of separation technology systems and decades of experience in analysis, advising and construction. From this, our customers gain sound decision-making support and security in investment and production planning.

When selecting the right separation technology solution, not only are customers advised well by our process engineering centre, they also receive active support. This is based on investigations of the original / sample to be produced or processed in large-scale series and on customer specifications with respect to working temperature, flow capacity, degree of clarification or separation etc. After thorough analysis of all the data, the team from the application-specific laboratory recommends which machine type and which model will be best suited to the task. The results report and the documentation provide the greatest possible security for the investment decision.

**Sound support for new development and scale-up**

We provide intensive support right from the start for companies entering into new territory by planning the development of new types of products for production processes. Even for small volume units, we are able to design our separation technology systems exactly and to integrate them easily into the research work and product development of the customer.

Thus, in cooperation with the engineers from the respective business line, it is possible to clarify even before product development whether the planned quality parameters for new formulations are also achievable in the industrial application – and at which performance dimensions our separation technology solutions meet the set requirements 1:1. From this, our customers know the size to expect the investment to come to, even at the initial stage.

**One-off training field for performance tests**
Other indications can be gained from test trials on original products at 20 to 2000 litres. The central process engineering test bay keeps numerous machines and systems for various performance tests under conditions that closely resemble practical application.

**Basic scientific research**
In cooperation with various colleges, we acquire the basic scientific knowledge to enable us to integrate new technical processing solutions into the production processes of our customers.

Which way is right depends on the task. The objective is always to support customers in the selection of their centrifuges and to place their investment decisions on a secure footing.

# Engineering Made in Oelde – Plant and Control from a Single Source

The two essential elements for solving a technical process task are the plant and the control. However, it is only by their individual coordination and combination that they unite to form a useful unit – and thus an efficient technical processing plant.

GEA Westfalia Separator Group sees every plant as a whole, to set it up for the highest level of efficiency from the start. Customer requests, quality requirements and the relevant regulations are taken into consideration here. The package units and process lines developed in this way produce immediate added value.

**Service and added value:**
**what we supply to you**

The general trend is going in the direction of modules and package structures – because this provides numerous benefits; the Business Area Production takes full advantage of this trend in the interests of its customers, by breaking down larger process lines where possible into sensible modules.

The advantages are obvious: one package unit describes a clearly defined scope, both in terms of function and in terms of mechanics and technical control. Thanks to clear interfaces, the alignment work is reduced. This enables the Business Area Production to boost efficiency in all areas.

All modules are manufactured under optimum conditions by the Business Area Production: the components are assembled on a frame, the pipes fully installed, all electrical and pneumatic connections fitted, checking carried out, and qualification and acceptance are completed if desired.

Here, the individually aligned control is also of particular significance, as without it, even the most efficient machine or plant cannot operate to its full potential. The modules are then integrated into the ongoing production process at the minimum possible expense.

For this reason, system solutions of GEA Westfalia Separator Group are packages which relieve our customers of the need to worry – because they extend their value added chain without interrupting it.

**Your advantages at a glance:**

- Individual complete development
- Highest standards with innovative technologies
- No interface problems, no time delay
- Perfect system alignment and control
- Very easy operation
- One system partner for the entire process

# Sales, Engineering and Service Worldwide – We are Here, Where You Need Us

For us, proximity to the market is more than a catchphrase; it is the fundamental requirement for added value from partnerships and it secures the long-term success of our customers.

GEA Westfalia Separator Group is present all over the world, with more than 50 sales and service companies and over 20 authorized workshops. As such, original spare parts from the technology leader are always quickly on site. Naturally, our experts are also there for you when you need us.

Use the advantage of knowledge from the technology leader in mechanical separation technology to fulfill your requirements for production and process solutions. The result is clear: Liquids to Value!

*We live our values.*

Excellence • Passion • Integrity • Responsibility • GEA-versity

GEA Group is a global engineering company with multi-billion euro sales and operations in more than 50 countries. Founded in 1881, the company is one of the largest providers of innovative equipment and process technology. GEA Group is listed in the STOXX® Europe 600 Index.


**GEA Mechanical Equipment**

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