Arbetsrapport SGC A32

Evaluation of CO_2-fertilization of a Greenhouse with Flue Gases from a Microturbine

Corfitz Norén
SVENSKT GASTEKNISKT CENTER AB

SGC:s FÖRORD

FUD-projekt inom Svenskt Gastekniskt Center AB avrapporteras normalt i rapporter som är fritt tillgängliga för envar intresserad.

SGC svarar för utgivningen av rapporterna medan uppdragstagarna för respektive projekt eller rapportförfattarna svarar för rapporternas innehåll. Den som utnyttjar eventuella beskrivningar, resultat e dyl i rapporterna gör detta helt på eget ansvar. Delar av rapport får återges med angivande av källan.

En förteckning över hittills utgivna SGC-rapporter finns på SGC´s hemsida www.sgc.se.

Svenskt Gastekniskt Center AB (SGC) är ett samarbetsorgan för företag verksamma inom energigasområdet. Dess främsta uppgift är att samordna och effektivisera intressenternas insatser inom områdena forskning, utveckling och demonstration (FUD). SGC har följande delägare: Svenska Gasföreningen, Sydgas AB, Sydkraft AB, Göteborg Energi AB, Lunds Energi AB och Öresundskraft AB.

Följande parter har gjort det möjligt att genomföra detta utvecklingsprojekt:

Turbec AB
Klitte & Lundh HB
Statens Energimyndighet

SVENSKT GASTEKNISKT CENTER AB

Johan Rietz

SAMMANFATTNING

Det är välkänt att CO_2-gödning av växter kan öka produktionen med 10-30 %. Vanligen köps CO_2 in på flaska eller tank, eller så leds avgaserna från en gaspanna eller gasmotor in i växthuset. Moderna mikroturbiner har låga emissionsnivåer och är därför väl lämpade för kombinerad kraftvärmeproduktion och CO_2-gödning. Anledningar att använda sig av CO_2-gödning som är baserad på mikroturbiner är:

- Lägre emissioner jämfört med en gasmotor av motsvarande storlek, framförallt av NO_x, CO och UHC.
- Inget behov av efterbehandling av avgaserna.
- Högt energiutnyttjande med samtidig produktion av kraft och värme och utnyttjande av restprodukten CO_2.

Föreliggande rapport beskriver och utvärderar den första installationen i Europa av mikroturbinbaserad CO_2-gödning i ett växthus. En Turbec T100 mikrogasturbin installerades hos gurkodlaren Klitte & Lundh HB utanför Helsingborg. Utförda mätningar visar att såväl de hygieniska gränsvärdena som de gränsvärden där plantorna riskerar ta skada, underskrids med bred marginal.

	Avgashalt (vid 15% O_2)	Växthusluftens halt
NO	12 ppm	100 ppb
NO_2	2 ppm	20 ppb
CO	ED	1 ppm
CO_2	1,5%	600-1200 ppm
UHC	ED	ED

ED = Ej detekterbart

SUMMARY

This report describes and evaluates the first European installation of a Turbec T100 microturbine for CHP and CO_2 fertilization in a greenhouse. The emissions from the turbine and the air quality inside the greenhouse are measured and evaluated.

The tested unit is well suited for CO_2 fertilization. From an energy efficiency point of view, CHP and CO_2 fertilization is highly efficient, as approximately 100% of the energy is utilized, the only significant loss is the power needed for the gas booster and ventilation losses.

The measurements show that the concentrations of potentially harmful components in the greenhouse are very low, even when the existing natural gas boiler also was supplying CO_2. The levels of NO, NO_2 and CO inside the greenhouse were well below the hygienic limits and well below the maximum allowable concentrations for the crops.

Component	Flue gas concentration (15% O_2)	Greenhouse air concentration
NO	12 ppm	100 ppb
NO_2	2 ppm	20 ppb
CO	ND	1 ppm
CO_2	1,5%	600-1200 ppm
UHC	ND	ND

ND = Non detectable

The main advantages of using microturbine based CO_2 fertilization are:

- Very efficient energy utilization, approximately 100% of the energy is utilized for heat and power production, and additionally, the CO_2 in the flue gases is used for fertilization.
- Compared to gas engine based CHP and CO_2 fertilization, microturbines offer considerably lower emissions of CO, hydrocarbons and NO_x and no flue gas cleaning is required.
- Compared to a gas boiler, a microturbine also produces electricity.

1 BACKGROUND

It is well documented that CO_2 fertilization in greenhouses increases the growth rate with approximately 15-30%. Outside air contains approximately 350 ppm CO_2 but by increasing the rate up to 700-1 200 ppm, a significant growth increase has been observed in numerous studies. If no additional CO_2 is supplied, the level inside the greenhouse can drop below the outdoor air level because of the CO_2 consumption of the crops and this causes a lower growth rate. CO_2 can be supplied to the greenhouse in different ways:

- CO_2 from a tank or bottle, which is the most expensive method.
- CO_2 from a conventional gas burner either fitted inside the greenhouse (CO_2 generator) or from a central heating boiler where hot water also is produced.
- The flue gases from a conventional gas engine can be lead to the greenhouse by a pipe system. The gas engine is also used for cogeneration. Flue gas cleaning and high dilution of the flue gases will be necessary.
- During recent years, the development of small gas turbines (microturbines) with low emissions and high efficiency has enabled microturbine based CO_2 fertilization. Gas turbines have considerably lower NO_x, CO and UHC emissions compared to modern gas engines and are therefore highly suitable for CO_2 fertilization.

1.1 SCOPE

The scope of this report is to describe and evaluate the first European installation of a Turbec T100 microturbine for CHP and CO_2 fertilization of a greenhouse. The emissions from the turbine and the air quality inside the greenhouse are measured and evaluated.

1.2 LIMITATIONS

Only the emissions from the turbine and the air quality inside the greenhouse are measured and evaluated. The energy performance (efficiency) of the unit is not considered.

2 Description of the site and the T100 unit

2.1 KLITTE & LUNDH HB

Klitte & Lundh HB is situated ten kilometres east of Helsingborg in the south of Sweden. Klitte & Lundh grows cucumbers: Frillestads Gurka®. The total area of the greenhouses is 23 000 m^2, whereof the T100 supplies CO_2 to 10 700 m^2. Klitte & Lundh produces 4 000 000 cucumbers (1 500 000 kg) annually, corresponding to 5% of the total annual Swedish cucumber production. Heat and CO_2 is also supplied from natural gas fired boilers. At full load, the T100 produces 6.3 g CO_2/m^2. During cultivations season, more than 20 g CO_2/m^2 is required on sunny days, and additional CO_2 will be supplied from the existing boiler. A hot water accumulator allows the boiler and T100 to be run continuously and the CO_2 production is optimised without having to waste heat.

A number of studies have shown growth increase in cucumber cultivations when additional CO_2 is supplied. When raising the CO_2 level to 700 ppm, up to 30% faster growth, earlier and higher yield has been observed, especially during summer with high sun intensities and high CO_2 absorption. These studies have also shown that cucumbers should not be exposed to CO_2 levels exceeding 1500 ppm and that there is little production gains to be made by increasing the CO_2 level above 1200 ppm. During early spring, the crops are very sensitive to the CO_2 levels and high exposure must be avoided. Lars Klitte's own experience is a growth increase by approximately 20% compared to when no additional CO_2 was supplied [1].

Figure 2-1 Lars Klitte speaks about cucumber cultivation during the official start-up of the microturbine.

The T100 unit will during spring 2002 be modified for black start/island operation, i.e. the unit can be started and operated without any external power supply in case of a total blackout. Therefore the unit will also be used as emergency backup for the electricity and heat supply. Reliable power is of extreme importance in this case, as it is estimated that the crops only will survive for two hours without water during summer [2].

2.1.1 Site description

The unit was installed in an existing boiler room next to a natural gas fired boiler, Figure 2-2 shows a sketch of the site.

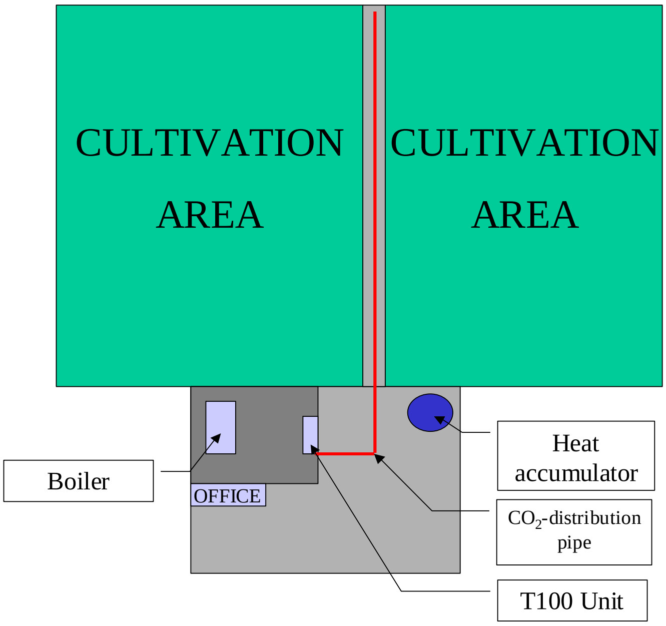

Figure 2-2 Sketch of the site.

A new CO_2 distribution system for the flue gases from the turbine was installed. The CO_2 distribution system is a standard system for greenhouses made of PVC. As PVC cannot withstand temperatures higher than 57°C, a secondary heat exchanger was installed which ensures that the flue gas temperature is kept below 57°C.

For next cultivation season, hoses made of polyethylene (PE) will be fitted to the exhaust from the PVC pipes to further increase the distribution of the flue gases among the crops. Currently, 16 fans fitted in the roof of the greenhouse increase the circulation of the air inside the greenhouse.

Figure 2-3. 16 fans fitted in the roof increase the air circulation inside the greenhouse.

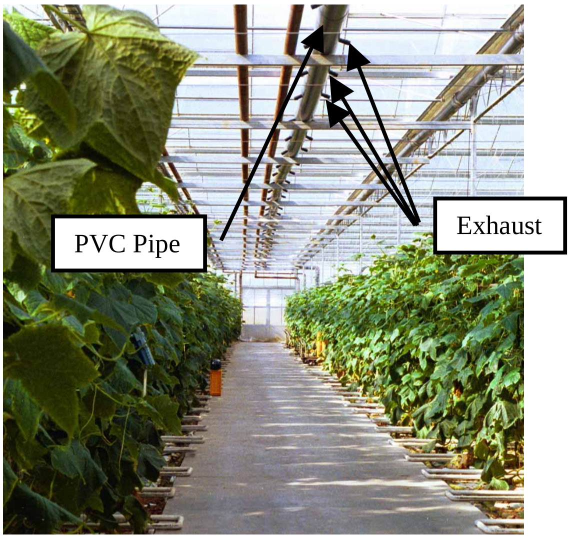

Figure 2-4. The PVC pipe was fitted in the roof of the greenhouse.

2.1.2 Safety precautions

In case of faulty operation, resulting in incomplete combustion, CO_2 and NO_x levels will likely remain approximately the same compared to normal operation. Though, CO and UHC levels, whereof ethylene, C_2H_4, if of particular danger to the crops, will likely rise dramatically. The greenhouse is fitted with a Sercom CO-detector that continuously monitors the CO content of the flue gases and shuts down the T100 unit in case of CO levels exceeding 25 ppm. CO_2 levels inside the greenhouse if also continuously monitored and the CO_2 fertilization is aborted when CO_2 levels exceed 1200 ppm.

When CO_2 is needed in the greenhouse, the computerized control system turns the T100 unit to 100% load to ensure that emission levels are kept as low as possible. When CO_2 isn’t needed, the control system maintains the electricity production at a level that corresponds to the electricity consumption of the site and the flue gases are released through a chimney.

2.2 THE T100 UNIT

The T100 microturbine is a CHP (Combined Heat and Power) unit. The unit produces electricity and heat, fuelled by natural gas. The microturbine is designed for indoor installation and takes air from an outdoor intake. The unit is divided into the following main parts:

- Gas turbine engine
- Electrical generator
- Electrical system
- Exhaust gas heat exchanger
- Supervision and control system
- Gas booster (external)

The unit at Klitte & Lundh HB is shown in Figure 2-5.

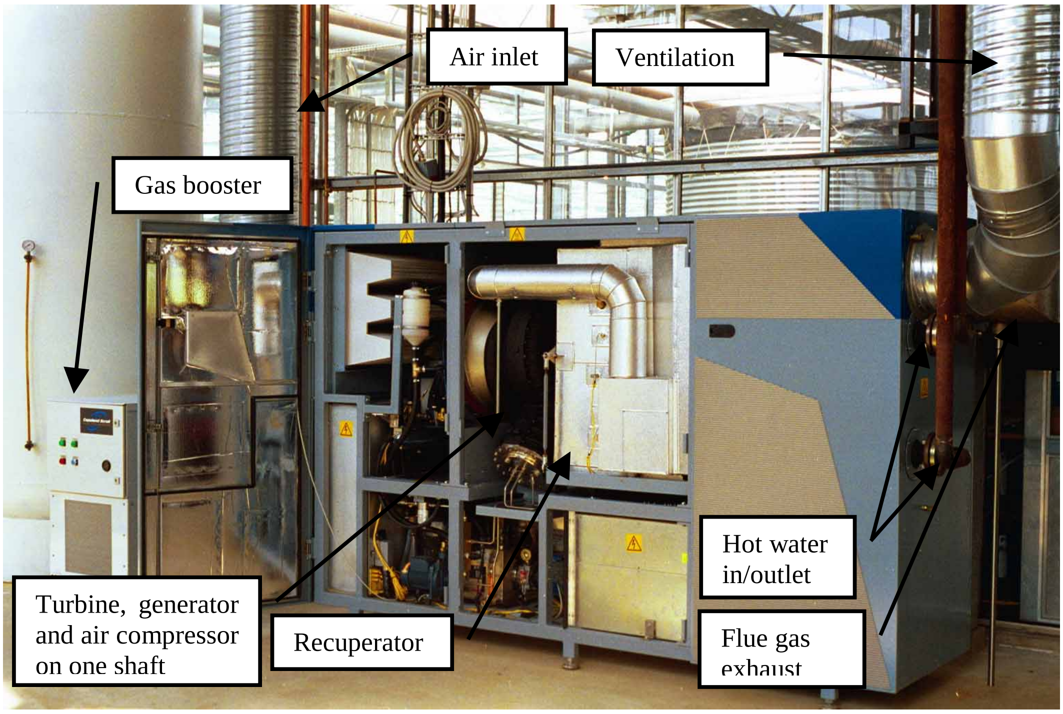

Figure 2-5.The Turbec T100 microturbine at Klitte & Lundh HB.

2.2.1 Technical data of the T100 [3]

Size

Width: 840 mm (33.1")
Height: 1 920 mm (75.6")
Length: 2 900 mm (114.2")
Weight: 2 000 kg (4 410 lbs)

Fuel: Natural gas LHV 30-50 MJ/kg (25-42 MJ/Nm^3). LPG, methanol and LCV gas options are under development.

Combustor: Lean pre-mix

Electrical generator: High-Speed Generator (HSG), 70 000 rpm. Power is converted to a suitable frequency (i.e. 50/60 Hz) in a power converter and no gearbox is required. When starting the turbine, the electric system is used in reverse.

Required gas pressure: 6-9.5 bars (a)

Gas booster: Copeland scroll compressor, variable volume flow 0-40 m^3/h

Performance

Net electrical output: 100 kW$_e$[*]
Net electrical efficiency: 30%[*]
Net total efficiency: 80%
Fuel consumption: 333 kW
Net thermal output: 167 kW at 70/50°C hot water outlet/inlet. (The installation at Klitte & Lundh is equipped with a secondary heat exchanger and delivers 180 kW of hot water see section 2.1.1.)
Exhaust gas flow: 0.79 kg/s
Noise level: 70 dB at 1 meter

Emissions (at 15% O_2 and 100% load)

NO_x: < 15 ppm
CO: < 15 ppm
UHC: < 10 ppm
CO_2[**]: ≈ 1.5 % (approximately 68 kg CO_2/hour)

Compared to conventional gas burners, the flue gases from the microturbine are highly diluted due to the high amount of excess air ($\lambda \approx 8$) in the combustion chamber. Thus, there is no need to further dilute the flue gases before feeding the flue gases into the cultivation area.

Maintenance and lifetime

Expected lifetime of main components is:

Gas turbine engine: > 60 000 hrs
Recuperator: > 60 000 hrs
Combustor: > 30 000 hrs

The scheduled preventive maintenance is divided into:

	Interval (hrs)	Outage (hrs)
Inspection	6 000	24
Overhaul	30 000	48

2.2.2 Maximum allowable component concentrations in greenhouses

As can be seen in Table 2-1 and Table 2-2, it is the maximum acceptable component concentrations with regards of the crops that will set the limit of all components except CO. All critical limit values are marked in red.

Table 2-1. Hygienic limit values (if the source is flue gases) [4].

Component	Limit ppm	Limit mg/m^3
CO	20	25
NO	25 (50[*])	30 (60[*])
NO_2	1	2
Ethylene	250 (1 000[*])	330 (1 200[*])
CO_2	5 000 (10 000[*])	9 000 (18 000[*])

[*] Recommended maximum 15-minute exposure

---

[*] Guaranteed data at LHV = 39 000 kJ/Nm^3 and ISO conditions
[**] Theoretical CO_2 level in the flue gases, not corrected to 15% O_2.

Table 2-2. Maximally acceptable component concentrations for plants [5,8,6].

Component	Short-time exposure (ppm)	Long-time exposure (ppm)
CO	2 000-2 400	n.a.
NO	1.0	0.25
NO_2	0.6	0.1
Ethylene	0.05	0.008
CO_2	1 500	≈1 200

2.3 ECONOMICAL REPORT

The installation of the unit is a co-operation between DESS, Turbec AB, Klitte & Lundh HB and Öresundskraft AB. The total cost for the installed unit (including unit and modification of unit, modification of the electrical system, computerized control system, CO_2 distribution system and all plumbing) was 148 000 Euro, equalling a specific cost of 1 480 Euro/kW. This is a high specific cost but the unit at Klitte & Lundh is a pilot installation and the future installed cost of a CHP unit including CO_2 fertilization is expected to be around 100-110 000 Euro.

3 Results

3.1 GASUNIE MEASUREMENTS

Table 3-1 Emissions of hydrocarbons from a Turbec T100 measured by Gasunie [7].

Component	Power output					
	100 kW_e	90 kW_e	80 kW_e	70 kW_e	60 kW_e	50 kW_e
	ppm	ppm	ppm	ppm	ppm	ppm
Methane (CH_4)	ND	ND	ND	ND	13.80	208.3
Etheen (C_2H_4)	ND	ND	ND	ND	0.93	11.98
Ethyn (C_2H_2)	ND	ND	ND	ND	0.05	0.26
Ethane (C_2H_6)	ND	ND	ND	ND	0.17	4.87
Propeen (C_3H_6)	ND	ND	ND	ND	ND	0.18
Propane (C_3H_8)	ND	ND	ND	ND	ND	0.09

ND = Non-detectable

As can be seen from Table 3-1, the emissions of hydrocarbons are below the lowest detection limit (0.03 ppm) at all power outputs above 60 kW_e. Methane and ethylene emissions rise considerably when operating at loads below 60%, which must be avoided when using the T100 for CO_2 fertilization. As a safety precaution, the T100 is only operated at 100% load when used for CO_2 fertilization.

3.2 IVL MEASUREMENTS OF GREENHOUSE AIR QUALITY

In 1991 Swedish Environmental Research Institute (IVL) drew up a measurement programme to monitor the work environment in connection with the combustion of natural gas for CO_2 fertilization in greenhouses [8]. The basic contents of this programme are described in sections 3.2.1 and 3.2.2.

3.2.1 Level 1 measurements

CO and CO_2 should always be measured and initially also NO_2. If the NO_2 levels do not exceed 25% of the limit value, there is no need for further measurements of NO_2. According to the programme, NO_2 should be measured during a full day with personal carried equipment but due to the poor precision of the personal carried equipment, it was decided to use a precision instrument instead.

3.2.2 Level 2 measurements

Measurements according to level 2 should only be carried out during special circumstances. In addition to the level 1 programme, formaldehyde and bensopyrene should also be measured. As the measurements according to level 1 were sufficient in this case (the highest measured NO_2 level was 1/20th of limit value), no further measurements were carried out.

3.2.3 Measurement results

The measurements were carried out by IVL (Swedish Environmental Research Institute) on the 11th (day 1) and 12th (day 2) of October 2001. Measurements were started at 11.00 on day 1 and stopped at 16.00 on day 2. In order to resemble "real" operating conditions (i.e. "worst-case" conditions), the existing boiler was also running and provided CO_2 to the greenhouse. Due to a minor problem with the heating control system for the greenhouse, the T100 could not be run continuously until at 14.00 on day 1. Due to major electrical grid interference on the night between day 1 and 2, some problems occurred and measurements could not be started until 12.20. Unfortunately, all data logged during the late afternoon and night of day 1 was lost.

Both days were very well suited for measurements since the sun radiation was very high, and thus, the demand for CO_2 was also high. Figure 3-1 and Figure 3-2 shows he measured values of CO_2, CO, NO, NO_2 and NO_x during the two days. No smoking or operation of forklifts occurred during the measurements.

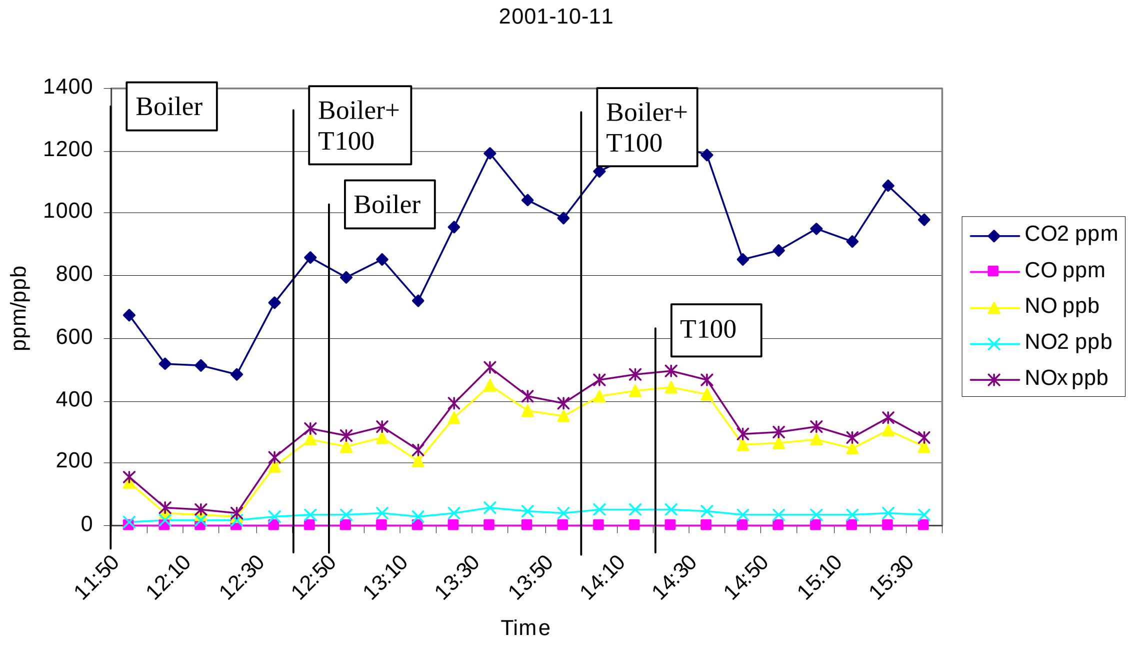

Figure 3-1 Measurements on day 1.

2001-10-12

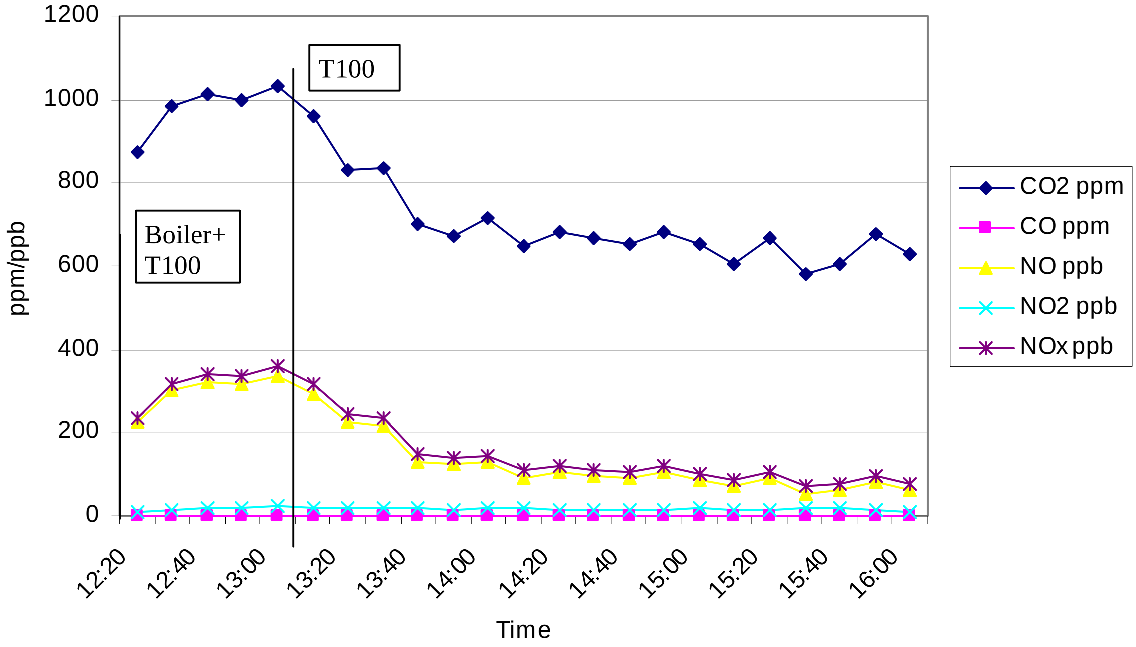

Figure 3-2 Measurements on day 2.

NO and NO_2 levels are very low when only the T100 is running, NO_x levels are well below 100 ppm. Most of the NO_x is NO and the NO_2 levels are approximately 10% of the NO levels. During the afternoon of Day 2, NO_2 measured below 20 ppb (including “background NO_2”). Since the nighttime measurements were lost, the true levels of ”background NO_2” are unknown but in Helsingborg (10 km to the east), the annual average NO_2 content in the air is 12 ppb [9]. The conclusion is that the NO_2 content in the air is almost unaffected by the microturbine CO_2 fertilization. This was further verified by the emission measurements that did not detect any NO_2 during full load operation. As can be seen from day 2 measurements, the T100 alone cannot maintain more than 600-700 ppm of CO_2 in the greenhouse. Three air samples were taken in tedlar bags and no hydrocarbons could be detected.

Table 3-2 Summary of IVL measurements.

	CO_2 (ppm)	CO (ppm)	NO (ppb)	NO_2 (ppb)	NO_x (ppb)
Day 1, average	875	0,3	225	10	235
Day 2, average	755	0,1	157	17	174
Day 2, T100 only	677	0,1	107	16	123

3.3 SYCON EMISSION MEASUREMENTS

Emissions measurements were carried out by Sycon AB on the 20th of March 2002, Table 3-3 shows the results.

Table 3-3 Results of Sycon measurements at 100% load, dry flue gases.

Load	O_2 (%)	CO_2 (%)	CO (ppm)	NO (ppm)	NO_2 (ppm)	UHC (ppm)
100%	18,4 (measured values)	1,5	ND	5	1	ND
100%	15 (corrected values)	-	ND	12	2	ND
75%	18,7 (measured values)	1,3	250	5	2	27
75%	15 (corrected values)	-	666	13	5	71
50%	19,1 (measured values)	1,1	449	5	2	85
50%	15 (corrected values)	-	1446	16	6	272

ND = Non-detectable

At full load, no CO or UHC could be detected which indicates a highly efficient combustion. This is of extreme importance when using the flue gases for fertilization. NO_x emissions are below the guaranteed 15 ppm. At lower loads, CO and UHC emissions begin to rise, which is typical for gas turbines where the combustion chamber is optimised for full load operation. NO_x levels also rise slightly. Table 3-4 shows the calculated emissions at full load when converted into g/MJ fuel input.

Table 3-4 Calculated emissions (g/MJ, mg/MJ fuel input) at 100% load.

CO_2 (g/MJ)	CO (mg/MJ)	NO (mg/MJ)	NO_2 (mg/MJ)	UHC (mg/MJ)
57	0	12	4	0

4 Conclusions

The T100 is well suited for CO_2 fertilization. From an energy efficiency point of view, CHP and CO_2 fertilization is highly efficient, as approximately 100% of the energy is utilized, the only significant loss is the power required for the gas booster and ventilation losses.

The measurements verify that the concentrations of potentially harmful components in the greenhouse are very low, even when the existing natural gas boiler also was supplying CO_2. The levels of UHC, CO NO, NO_2 and CO_2 inside the greenhouse were well below hygienic limits and well below values that could affect the plants in a negative way.

Based on measurements from Gasunie and Sycon, the turbine should not be operated below 70-75% load when used for CO_2 fertilization. To ensure that emission levels are kept as low as possible, the T100 currently only operates on 100% load when CO_2 is supplied to the greenhouse.

Microturbines are still a very new technology area and some minor problems have occurred during the first months of operation, mainly problems with the supervision & control system and integration with the existing heating system.

From an economical point of view, the current natural gas and electricity prices in Sweden are not favourable for this kind of installation. Currently, no electricity is sold to the grid but this can of course be changed if electricity prices continue to rise. The main advantages of microturbine based CO_2-fertilization are:

- Very efficient energy utilization, approximately 100% of the energy is utilized for heat and power production, and additionally, the CO_2 in the flue gases is used for fertilization.
- Compared to gas engine based CHP and CO_2 fertilization, a microturbine offers considerably lower emissions of CO, UHC and NO_x and no expensive flue gas cleaning is required.
- Compared to a gas boiler, a microturbine also produces electricity.

5 Further information

Anyone interested in further information or a site visit can contact:

Svenskt Gastekniskt Center AB
Corfitz Norén
SE-205 09 Malmö
Sweden
Phone: +46 40 24 43 10
Fax: +46 40 24 43 14
E-mail: info@sgc.se
www.sgc.se

Turbec AB
Johan Hall
Regnvattengatan 1
SE-200 21 Malmö
Sweden
Phone: +46 40 680 00 00
Fax: +46 40 680 00 01
www.turbec.com

Klitte & Lundh HB
Norra Vallåkravägen 781
SE-260 34 Mörarp
Sweden
Phone: +46 42 790 88

Öresundskraft AB
Box 642
SE-251 06 Helsingborg
Sweden
Phone: +46 42 490 31 00
Fax: +46 40 42 490 31 30
E-mail: info@oresundskraft.se
www.oresundskraft.se

6 References

1. Personal communication with Lars Klitte, Klitte & Lundh HB, 2001-09-20.
2. Personal communication with Lars Klitte, Klitte & Lundh HB, 2001-10-11.
3. Turbec AB, T100 CHP datasheet ver. 4. www.turbec.com
4. Hygieniska gränsvärden och åtgärder mot luftföroreningar. Arbetarskydds-styrelsens föreskrifter om hygieniska gränsvärden och åtgärder mot luftföroreningar samt allmänna råd om tillämpningen av föreskrifterna, AFS 2000:3.
5. J. Klimstra, Exhaust Treatment for CO_2 Fertilization with Reciprocating Gas Engines. 1998 International Gas Research Conference, 8-11 November, San Diego, Kalifornien, USA.
6. Personal Communication with Wageningen University and Research Centre Plant Research International BV 2002-02-07.
7. Turbec AB, internal material.
8. Stig-Arne Molén, Koldioxidgödsling i växthus med hjälp av naturgas, handbok och tillämpningsexempel. SGC rapport 026, Malmö, augusti 1992.
9. http://www.helsingborg.nu/luft/

SGC Svenskt Gastekniskt Center AB

SE-205 09 MALMÖ • TEL 040-24 43 10 • FAX 040-24 43 14
Hemsida www.sgc.se • epost info@sgc.se