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Practical experience of using a biogas-powered micro gas turbine

In an evaluation study of 2008 the operation of the Capstone micro gas turbine CR 65 in a biogas plant in Kupferzell proved to be low-maintenance and low-interference. The best electrical and thermal efficiency were achieved in full-load operation and amounted to 25.8 % and 60.8 % respectively. The gas concentrations measured in the exhaust gas were very low. The NO_x concentration was in all load levels below 6 mg/Nm³. The concentration of CO reached its minimum value of 21 mg/Nm³ in full-load operation. The operation of micro gas turbine in the most efficient and low emission full-load mode with coherent heat utilization is recommend.

Keywords
Biogas, micro gas turbine, energy efficiency

Abstract
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The energy efficiency of biogas utilisation can be increased through using the heat generated by the engine. This is why cogeneration applications such as with biogas-fuelled micro gas turbines are being increasingly applied for thermal utilisation in agricultural biogas plants. These offer a number of advantages compared with the internal combustion piston engines mainly used so far. For example more thermal efficiency is available for heating, absorption cooling machines or as process heat through the associated higher exhaust temperatures.

According to the amended 2009 Renewable Energy Act (EEG) a technology, an emission avoidance and – with an existing heating concept – a cogenerated heat utilisation bonus is ensured through the thermal utilisation of biogas in micro gas turbines.

Presented here are results from a practical investigation in 2008. The operational parameters of the Capstone CR 65 micro gas turbine were evaluated for assessment of performance capacity and energy efficiency. The ensuing data permitted determination of operational regimes that are practical from an economic and technical point of view. The CR 65 has in the meantime been replaced on the market by a micro gas turbine with an electrical output of 200 kW. According to manufacturer Capstone this machine achieves a notably higher electrical efficiency of up to 34%. These so-called CR 200 turbines were available by end of 2008 although no recording could be carried out with this machine in relation to the study presented here.

Material and methods

At the Karle biogas plant in Kupferzell two Capstone CR 65 micro gas turbines were powered by biogas from June 2007 to June 2009 as part of a Greenvironment GmbH pilot project. From January to end of November 2008 the State Institute for Agricultural Engineering and Bioenergy (Hohenheim University) recorded the operation of one of these turbines. The results presented here are analyses of this continuous recording operation.

Applied within the trial design was a specially developed gas preparation plant. The applied micro gas turbine was prepared by the manufacturer for operation with biogas fuel. It differed from a conventional 65 kW turbine through an adapted control valve, larger diameter feed pipes and special geometry of the burner. According to the manufacturer, the micro gas turbine is suitable for operation under a variety of work loads. Its electrical output under full load operation is 65 kW. For determining the optimum operational regime and its partial-load capacity a number of partial-load ranges from 30 to 65 kW were tested.

For determining energy flows, operation-relevant measurement parameters such as biogas volume flow, temperature, pressure and composition were recorded. These values were collected for the determination of the electrical and thermal performance as well as electrical and thermal efficiency in different partial load and full load operations. Thereby the electrical efficiency was calculated from the amount of current delivered and the energy contained in the biogas fuel. Among the emission values measured for the calculation of combus-

Table 1

Measured parameters and measuring equipment

Messparameter ***Measured parameters***	**Messgeräte** ***Measuring Instruments***	**Einheiten** ***Units***
Biogaszusammensetzung *Biogas composition*	Brenngas-Analysegerät SSM 6000 (pronova) *Analytical apparatus SSM 6000 (pronova)*	[%], [ppm]
Biogasvolumenstrom *Volumetric flow rate*	Messblende (McCrometer; Typ V-Cone) *Orifice flow meter (McCrometer; Typ V-Cone)*	[m^3/h]
Biogastemperatur *Biogas temperature*	Thermoelement Typ K (Testo 350 XL) *Thermal element type K (Testo 350 XL)*	[°C]
Biogasdruck *Biogas pressure*	Absolutdrucktransmitter *Pressure transmitter*	[mbar]
Wärmestrom *Heat flow*	Rechnerisch über die Abgaszusammensetzung und Abgastemperatur *Calculated on the basis of the exhaust gas composition and gas temperature*	[kW]
Elektrische Leistung *Electric power*	Zangenampermeter (Voltcraft, Typ AC-200) *Clamp-on ammeter (Voltcraft, Typ AC-200)*	[kW]
Abgaszusammensetzung *Exhaust gas composition*	Testo 350 XL *Testo 350 XL*	[%], [ppm]
Abgastemperatur *Exhaust gas temperature*	Testo 350 XL *Testo 350 XL*	[°C]

tion were the content of nitrogen oxide and carbon monoxide in the exhaust gas, as well as exhaust gas temperature. The influence of partial load operations on the emissions could then be determined from the recorded results. Additionally, exhaust gas values from the micro gas turbine could be compared with emissions from the biogas fuelled pilot injection gas engine and gas central heating plants **(table 1)**.

Results

The turbine was in operation for a total 355 hours during the trial period. The tested micro gas turbine is shown in **figure 1**. Its operation proved to be reliable and with low maintenance demand. Only air filter and ignition plugs were renewed after one and a half years of operation. Any down time was mainly from external factors e.g. peripheral problems from biogas compression or through the turbine not being used because no heat was required in the drying hall for the fermented substrate. Problems with biogas compression could be traced to the poor adjustability of the biogas compressor. Thus, minimum measured pressure during the total recording period was around 4 bar and maximum pressure approximately 10 bar. In that the turbine required a constant pressure of approx. 5 bar, the fluctuations had a negative effect on the operation and subsequently on the electrical efficiency.

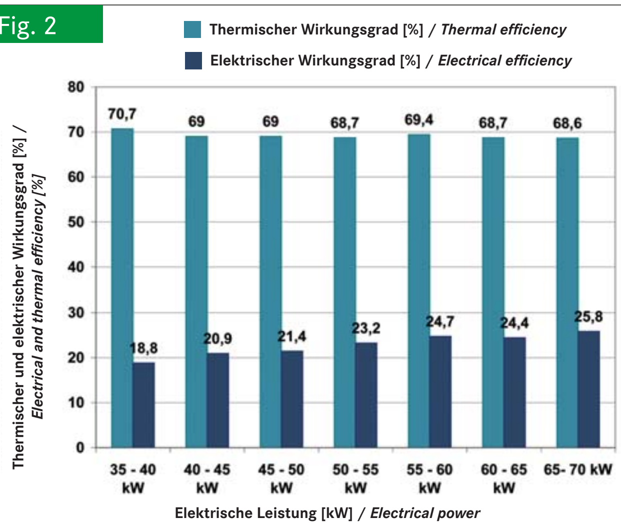
An overview of the calculated electrical and thermal efficiency at the different loadings is given in **figure 2**. At full load electrical efficiency was highest at 25.8% with the thermal efficiency thereby 68.6%.

Electrical efficiency increased with the rise in performance demand and at 55 kW was in the region of 24.7 to 25.8%. Thermal efficiency reacted in exactly the opposite way. At 70.7% it was high during lower performance demand and fell by 2.1% to 68.6% under full load. Through direct application of emitted heat for drying of fermented substrate, a carrier medium was not required for heat transfer from the exhaust. Thus there were no additional losses through a heat exchanger and this direct use of heat meant that thermal efficiency was therefore very high. So that performance could be compared with other plant models, the effect of the thermal energy in an exemplary

Fig. 1

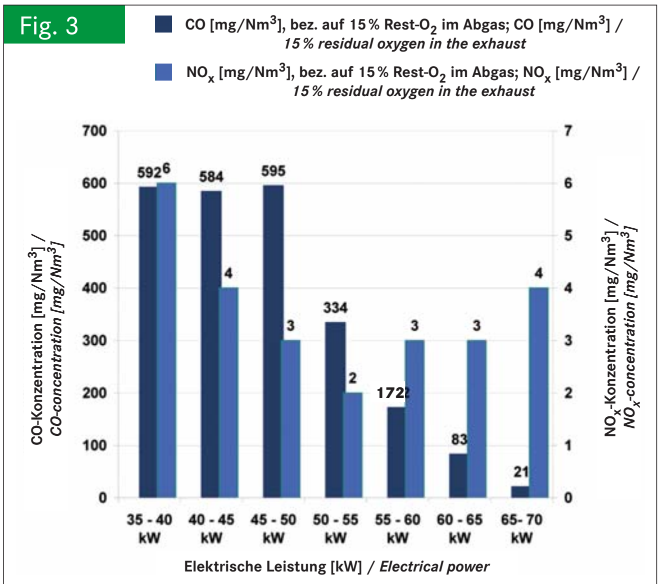
Microgasturbine Capstone CR 65. Photo: Bekker

Fig. 2



Electrical and thermal efficiency of the microgasturbine depending on the load level without tacking into account energy consumption of the gas processing

Fig. 3



CO- and NO_x-Concentrations in the exhaust gas of the investigated load levels

heat exchanger with 70 °C return temperature was calculated. Through the lower temperature difference between exhaust gas and secondary heat carrier the level of transferred heat decreased and the thermal efficiency reduced to between 50 and 55%.

In comparison with those of conventional central heating plants (BHKW) the measured exhaust gas concentrations were very low. **Figure 3** gives an overview of the measured CO and NO_x concentrations in the investigated performance levels. A detailed presentation of the measured exhaust concentrations during the investigation was published in the conclusive report for the BWPLUS Research Project [1].

In total the NO_x concentration was low under partial load as well as full load operation at under 6 mg/Nm³. The CO concentration reduced as electrical current production was increased and reached, under full load operation, a very low value of 21 mg/Nm³. In the low partial load area between 35 and 50 kW electrical power, notably higher values of carbon monoxide of from 334 to 592 mg/Nm³ were recorded.

The SO_2 concentration in the exhaust gas was relatively high at around 50–130 mg/Nm³. This is related to the higher H_2S content in biogas because large amounts of sulphur-containing substrate such as salad leftovers were fermented in the biogas plant. The increased SO_2 values did not affect turbine performance negatively. An important advantage in the operation of the micro gas turbine is that, because no lubrication oil is present, it is not affected by high hydrogen sulphide content in the gas fuel. With conventional gas-Otto BHKW the motor oil is normally to be changed every 600 hours. Because micro gas turbines, contrary to conventional internal combustion engines, do not feature cooling systems all the heat produced is conducted via the exhaust gases. This results in high exhaust gas temperatures with the trial exhaust gases recorded at 238–293 °C. Among other possibilities, high temperature processes can be carried out by the resultant low pollutant potential and high temperature exhaust gases.

Conclusions

This investigation proved the practical suitability of the Capstone CR 65 micro gas turbine fuelled by biogas. When calculating the complete plant concept it is important to take into account and, where required, optimise the energy required for the processing of biogas, e.g. compression and dewatering. Because there's now a micro gas turbine on the market with 200 kW which, according to manufacturer information, also has high electrical efficiency, the future offers completely new perspectives for application of micro gas turbines in biogas plants.

Literature

[1] Thomas, B.; A. Wyndorps, M. Bekker, H. Oechsner und T. Kelm: Gekoppelte Produktion von Kraft und Wärme aus Bio-, Klär- und Deponiegas in kleinen, dezentralen Stirling-Motor-Blockheizkraftwerken. Abschlussbericht zum BWPLUS-Forschungsprojekt, Förderkennzeichen BWK 25008–25010, 2009

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