Volker Aschmann, Rainer Kissel and Andreas Gronauer, Freising

Environmental Impact of Biogas Powered Combined Heating and Power Units (CHPU) in Practice

Six biogas powered CHPU's were tested at agricultural biogas plants. NO_x exhaust gas limits were usually exceeded under full-load operations. It was only possible to stay below those limits by lowering efficiency levels and simultaneously increasing the percentage of unburned carbon hydrogen (C_nH_m) in the exhaust gas. There was a direct relationship between the reduction of NO_x concentration and the level of carbon hydrogen exhaust. For climate-saving and at the same time efficient energetic utilization of biogas in combustion engines, further measures must taken to reduce the increased NO_x concentrations in the exhaust gas.

The amendment of the German Renewable Energy Sources Act (EEG) in 2004 brought about a significant increase in numbers of new biogas installations. At the same time, the prices for the construction of biogas plants rose considerably. Given these economical framework conditions, the actual electrical efficiency is a key factor for the profitability of a biogas plant. To achieve energy production from biogas in a sustainable and environmentally sound way, emissions of air pollutants need to be minimized, too.

Meanwhile, virtually all suppliers of CHPU guarantee that their engines meet limit values for NO_x according to the Technical Instructions on Air Quality Control (TA Luft). In practice, however, conditions for combustion are not always ideal. Servicing and adjustment of the engines are mostly performed to achieve maximum power output, sometimes without consideration of exhaust gas emissions.

Maintenance procedures for the investigated CHPU were very variable, reaching from maintenance only by the plant operator to a full service contract with guaranteed power output and operating time. The aim of this research was the analyses of power output and exhaust gas emissions of new stationary CHPU driven by biogas under real-world conditions, to derive measures for improvement.

Materials and Methods

Three pilot-injection engines (110 $kW_{el.}$, 250 $kW_{el.}$ and 265 $kW_{el.}$ nominal output) and three gas engines (190 $kW_{el.}$, 324 $kW_{el.}$ and 526 $kW_{el.}$ nominal output) were selected for the investigations. The following measurements were made to determine material and energy flows of the CHPU: volume, temperature, pressure, humidity and composition of the biogas in the supply pipe to the engine; volume of combustion air; amount of fuel oil if applicable; and electrical power output. Energy input into the engine was calculated as the sum of the heating values of the biogas under standard conditions and of the fuel oil. Electrical efficiency of the CHPU was determined according to the specifications given in DIN 3046-1 [1]. Combustion air flow was used to calculate the air-to-fuel ratio, λ.

In the exhaust gas, levels of NO_x, CO and hydrocarbons (C_nH_m) were measured. These values were used to analyze the influence of maintenance on meeting TA Luft limit values [2]. Total emissions of pollutants were calculated and compared to German grid emissions.

Table 1 gives an overview on the measuring equipment. The measurement setup on site is depicted in *Figure 1*, showing the impeller for measuring combustion air flow, the data logging unit connected to a laptop computer and the clamp-on ammeters for measuring electricity output. Not visible are the gas meter and the measuring instruments for exhaust gas analysis, located outside the machine room.

Table 1: Measuring equipment

Komponenten	Messgeräte	Einheiten
Gaszusammensetzung (CH_4, CO_2, O_2, H_2, H_2S)	AWITE	%, ppm
Gasdruck, -feuchte und -temperatur	Druck- u. Feuchtesensor, PT 100	mbar, %, °C
Luftvolumen	testovent 410, Messimpeller	m^3
Zündölverbrauch	Wägezelle	kg
Gesamtheit der Kohlenwasserstoffe	FID	mg/m^3
Abgaszusammensetzung (NO_x, CO, CO_2, O_2, Temperatur)	Testo 350	mg/m^3; %, °C
Strommenge	KBR Multimess	kWh
elektrischer Wirkungsgrad	Berechnung nach DIN 3046-1	%

Dipl.-Ing. (FH) Volker Aschmann and Dipl.-Ing. (FH) Rainer Kissel are staff members of the Institute for Agricultural Engineering, Farm Buildings and Environmental Engineering of the Bavarian State Research Centre for Agriculture, Am Staudengarten 3, D-85354 Freising; e-mail: *Volker.aschmann@LfL.bayern.de*
Dr. Andres Gronauer is deputy director of the Institute.

Keywords

Exhaust gas, emissions, biogas, CHPU, electrical efficiency

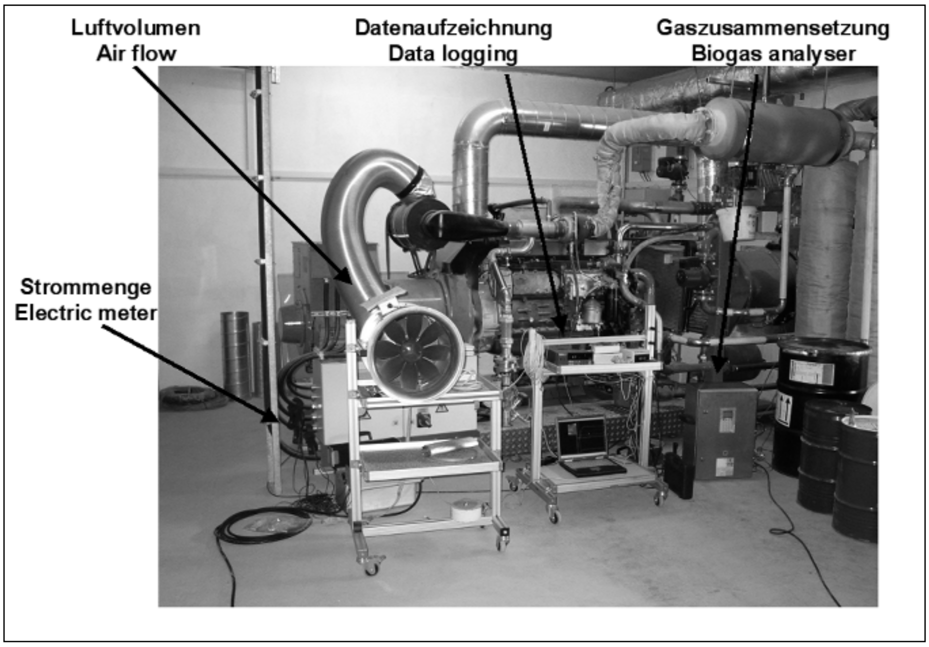

Fig. 1: Measuring setup on site

Results

Influence of Maintenance
Power output, electrical efficiency and exhaust gas emissions of CHPU are influenced by a number of factors. On the one hand, engine components are subject to aging. Amongst other things, this includes motor oil, spark plugs, valves, air-, oil- and gas filters, and piston rings. All of these parts can be replaced to extend engine lifespan. Intervals for replacing these components are normally specified by the manufacturer but may be significantly shorter in case of corrosive constituents in the biogas (particularly H_2S in conjunction with moisture). Unless they are subject to a service contract, these maintenance procedures are the main responsibility of the plant operator.

On the other hand, power output, electrical efficiency and also the level of exhaust gas emissions are affected by the adjustment of the engine. Normally, servicing and adjustment of the CHPU are performed by the supplier's servicing staff or another company, authorized by the plant owner. Frequently, plant operators do engine maintenance and adjustment on their own, either because the manufacturer does not offer these services or simply to save costs.

The individual CHPU were investigated at full load. It was found that, normally, full-load NO_x levels exceeded the limit value during measurements taken prior to servicing (v.). The manufacturers were informed about this and were asked to control exhaust gas emissions during the next servicing. After this, the CHPU were again measured at full load.

Figure 2 summarizes mean NO_x concentrations in the exhaust gas from all CHPU investigated. In part, NO_x levels were significantly above the respective limit value. Particularly, the 190 $kW_{el.}$ gas engine exhibited extremely high NO_x levels during all measurements. This CHPU was maintained exclusively by the plant operator and adjusted only with respect to power output. Engine adjustment in consideration of exhaust gas emissions was never done.

In *Figure 2*, the measurements marked with circles were picked to further illustrate the results since in these cases, engine adjustment yielded a reduction of NO_x levels under the respective limit value. After servicing by the manufacturer, five out of six CHPU exhibited NOx concentrations in the exhaust gas below the limit (only the 190 $kW_{el.}$ gas engine still produced high NO_x emissions). However, due to the higher air-to-fuel ratio and, consequently, the lower heating value of the fuel mixture, the concentrations of hydrocarbons in the exhaust gas were increased. At the same time, a lower electrical efficiency was determined for the CHPU with 110 $kW_{el.}$, 250 $kW_{el.}$, 324 $kW_{el.}$ and 526 $kW_{el.}$ nominal power output (*Fig. 3*). For the 265 $kW_{el.}$ dual-fuel engine, NO_x levels were already significantly below the limit value. Therefore, this engine could be adjusted with respect to maximum power output which yielded a higher electrical efficiency. As for the 190 $kW_{el.}$ gas engine, NO_x concentrations in the exhaust gas were decreased but still at a very high level. In this case, the electrical efficiency was higher after maintenance while the power output remained at the same level (*Fig. 3*).

Generally, the investigations show that engine adjustment in consideration of TA-Luft limit values for the exhaust gas significantly affects combustion performance, power output and electrical efficiency. A conflict exists between the aims of maximizing power output and efficiency during the generation of electricity from biogas on the one hand, and minimizing emissions of air pollutants on the other hand.

Environmental impacts
To achieve a sustainable and environmentally sound production of electricity, the individual processes have to be assessed with respect to their contribution to global warming. Absolute emissions of pollutants of the individual CHPU were calculated from exhaust

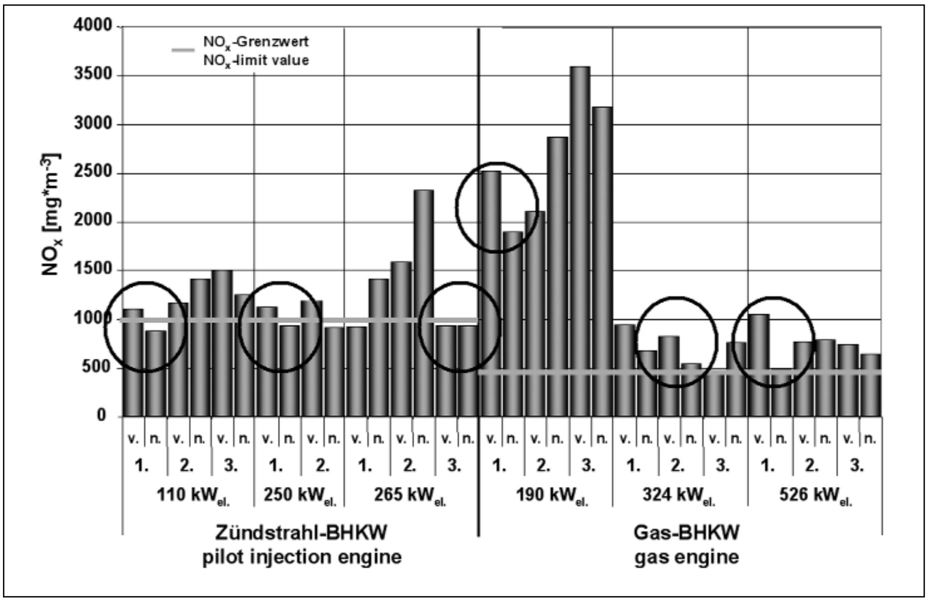

Fig. 2: Exhaust gas emissions of biogas powered gas engines before maintenance (v.) and after maintenance (n.)

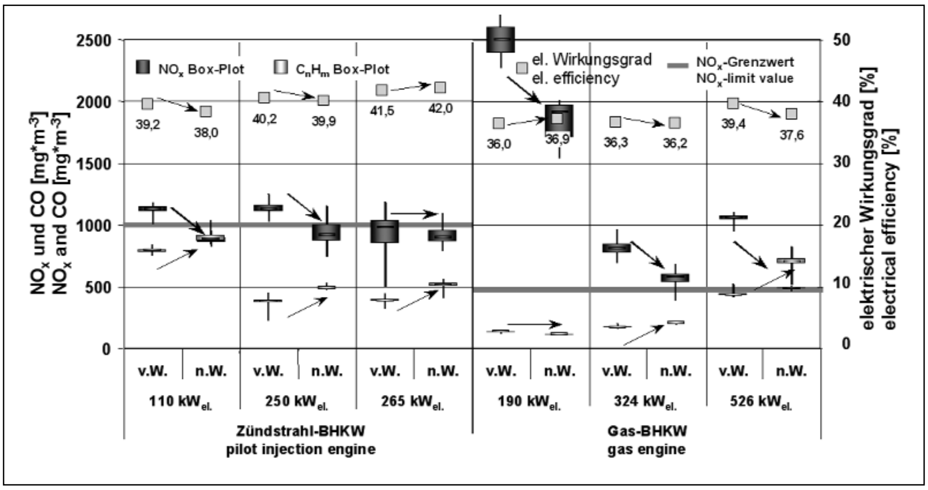

Fig. 3: Exhaust gas emissions and electrical efficiency of biogas powered pilot injection gas engines depending on maintenance

gas flows. To compare electricity production from renewable and conventional resources, emissions were converted to CO_2-equivalents per kWh electrical energy produced. NO_x emissions which unlike methane are not directly adding to global warming but to acidification and eutrophication, and which contribute to the formation of ground-level ozone, were converted to SO_2-equivalents.

Figure 4 shows amounts of CO_2-equivalents resulting from methane slippage due to incomplete combustion and amounts of SO_2-equivalents due to NO_x emissions, both with respect to 1 kWh electrical energy produced. The values of CO2-equivalent emissions due to methane losses of 5 to 70 $g \bullet kWh^{-1}_{prod.}$ are significantly below the respective German grid emissions of 624 $g \bullet kWh^{-1}_{prod.}$. However, one has to keep in mind that these emissions are only a small part of the emissions that occur along the whole biogas process chain from the production of the input materials to the application of the digestate to agricultural land. Still it is clear that CO_2-equivalent emissions from combustion of biogas cannot to be neglected.

Due to the NO_x level in the exhaust gas, the production of electricity from biogas produces significantly higher SO_2 equivalent emissions than the average current grid emissions of 723 $mg \bullet kWh^{-1}_{prod.}$. NO_x are produced at high combustion temperature and due to the lower quality of biogas compared to natural gas (higher levels of CO_2, H_2S, NH_3). While for almost all CHPU these emissions were reduced by servicing, methane losses were increased consequently (*Fig. 4*).

Conclusions

Efficiency and environmental impacts of biogas driven CHPU are directly linked. Engine adjustment only to achieve maximum power output and profit will always affect the environment. Therefore, the control of the respective emission limit values during servicing and adjustment should be part of standard procedures to achieve efficient and environmentally sound electricity production from biogas.

For most plant owners, the earnings from electricity production are given top priority. However, the value of electrical efficiency specified by the manufacturer is hardly to be achieved over the whole engine lifetime and is very much dependent on the state of maintenance. For appropriate dimensioning and reliable operation of a CHPU, data on the average electrical efficiency over the whole lifetime are required.

Acknowledgment

This work was financed by the Bavarian State Ministry for Environment, Health and Consumer Protection from the EU Fund for Regional Development (EFRE) and supervised by the Bavarian State Agency for Environment (LfU).

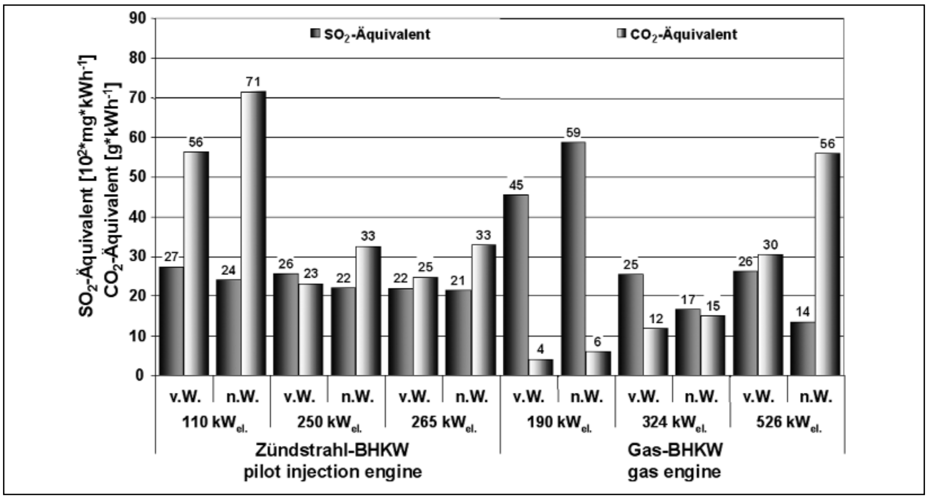

Fig. 4: Emissions of CO_2- and SO_2-equivalents from the CHPU as investigated

Literature

[1] Deutsche Norm DIN ISO 3046-1 : Hubkolben-Verbrennungsmotoren-Anforderungen, Teil 1; Deutsches Institut für Normung e.V., 4. Ausgabe, Beuth-Verlag, Berlin, 1995

[2] Erste Allgemeine Verwaltungsvorschrift zum Bundes-Immissionsschutzgesetz : (Technische Anleitung zur Reinhaltung der Luft – TA-Luft) (GMBl. Nr. 25-29/2002 – 29 S. 511) in der Fassung vom 24. Juli 2002