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The electrical efficiency of biogas-driven combined heat and power plants

Over a period of up to six years, nine combined heat-and-power units (CHPU) running on biogas were measured for electrical efficiency. The electrical capacity of these units ranged from 30 to 526 kW. From the first to the last measurement, the electrical efficiency of the systems decreased significantly. In the case of the oldest CHPUs the decrease reached almost 5 percentage points. This effect of ageing could be counteracted by systematic and consistent maintenance.

Keywords
Biogas, CHPU, lifetime, maintenance, electrical efficiency

Abstract
Landtechnik 67 (2012), no. 2, pp. 118–121, 3 figures, 2 tables, 2 references

For analyzing the profitability of biogas operations, the actual electrical efficiency of the combined heat-and-power unit is a very important factor. Usually, due to a lack of real-world data, manufacturer's specifications are used for this purpose. However, these specifications are determined under test-stand conditions and thus not representative of actual operating conditions on site. Therefore, smaller or larger adjustments are made to these values without individual verification. In reality, CHPU electrical efficiency and its development over engine life time is influenced by several factors. At the Institute of Agricultural Engineering and Animal Husbandry of the Bavarian State Research Center for Agriculture (LfL), the development of electrical efficiency of different CHPUs was analyzed on site over a time period of up to six years.

Materials and Methods

To determine material and energy flows into and out of the CHPU, the following measurements were taken: Volume, temperature, pressure, humidity and composition of the biogas supplied to the engine; volume of combustion air; fuel oil supply; and electrical power output. Energy input was calculated as the sum of the calorific value of the normalized biogas flow and fuel oil supply if applicable. Given the electricity output of the generator, CHPU electrical efficiency was calculated according to DIN 3046-1 [1].

From a four-hour continuous measurement, the mean value of electrical efficiency was calculated based on mean hourly values. To determine average electrical efficiency over the whole observation period, all measurements were plotted on a time axis at a resolution of 1,000 operating hours (o.h.). Missing values were interpolated on a linear basis.

Concentrations of nitrous oxides (NO_x), carbon monoxide (CO) and hydrocarbons (C_nH_m) were measured in the exhaust gas, in order to assess the influence of engine maintenance on exhaust emissions and compliance with the limit values of TA-Luft (Technical Instructions on Air Quality Control) [2].

Results

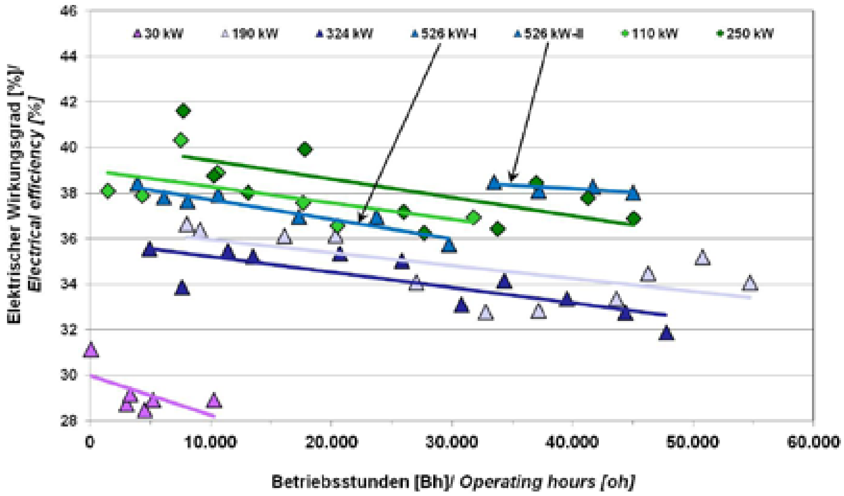
Influence of operating time

As can be seen from **Figure 1**, electrical efficiencies showed a decreasing trend with increasing operating times. This was true for all CHPUs that were observed over a longer period of time. In the case of the 526 kW_{el} gas engine (see 526 kW-I and 526 kW-II, **Figure 1**), electrical efficiency was back to its initial value after a general overhaul (see also 'Influence of maintenance').

The total decrease in engine efficiency over the entire observation period was calculated as the difference between the results of the first and last measurements (**Table 1**). This was only done for those CHPUs that were observed for a longer period of time. **Table 1** shows the decrease in electrical efficiency together with the respective observation period for six CHPUs. For the remaining units the observation periods were too short to yield reliable results. Due to its relatively short lifetime, the 30 kW_{el} gas engine was still included in this analysis.

For the CHPUs that were investigated over time periods of 10,200 o.h. (30 kW_{el} gas engine) to 46,700 o.h. (190 kW_{el} gas engine), the decrease in electrical efficiency ranged from 0.4 percentage points (526 kW_{el} gas engine) to 4.7 percentage points (250 kW_{el} pilot-injection engine). The low value of 0.4 percentage points for the 526 kW_{el} gas engine is due to the effect of a general overhaul after 33,000 o.h. Without this

Fig. 1



Course of the electrical efficiency of different CHPU

measure, the decrease in electrical efficiency of this engine would have reached more than 2.7 percentage points (see **Figure 1**).

Manufacturers do not specify the electrical efficiency of their CHPUs relating to a certain time period but based on a measurement taken in a test stand according to DIN 3046-1. This allows for a tolerance in fuel consumption of up to 5 % which leads to a higher value of electrical efficiency. The differences between our values for average electrical efficiency on site and manufacturers' specifications are more or less pronounced (**Table 2**). For the various CHPUs, this difference ranges from 1.9 percentage points for the 110 kW_{el} pilot-injection engine on the one end, to 5.0 percentage points for the 250 kW_{el} pilot injection engine on the other end. Typically, the difference varies from 2.9 to 3.8 percentage points. Most of the CHPUs are still operating, so the decrease in electrical efficiency over the whole engine lifetime can only be specified for the 324 kW_{el} gas engine with 3.5 % and the 110 kW_{el} pilot-injection engine with 1.9 %, which were replaced by new units (**Table 2**).

Generally, electrical efficiency increases with higher engine power as can be seen from manufacturers' specifications plotted in **Figure 2**. Our average values show the same trend, yet at a lower level. For the gas engines, the average difference between specified and measured efficiency is 3.3 percentage points, while for the pilot-injection engines it is 3.0 percentage points. For the pilot-injection engines, the trend curve of the measured efficiency values deviates from that of the specified values. Reasons for this are that only a few measurements were available for small pilot-injection engines (40 and 75 kW_{el}) and that these engines were adjusted by the manufacturer prior to measurements. In addition, the decrease in electrical efficiency of the 250 kW_{el} pilot-injection engine was relatively high (**Figure 2**).

Influence of maintenance

Starting in 2006, the observation period for the 526 kW_{el} gas engine spanned almost six years (**Figure 3**). This CHPU was operated under a service contract that included maintenance and

Table 1

Decrease of electrical efficiency during the measuring period

BHKW *CHPU*	El. Wirkungsgrad 1. Messung [%] *El. efficiency 1st measurement [%]*	El. Wirkungsgrad letzte Messung [%] *El. efficiency last measurement [%]*	Beobachtungszeitraum [Bh] *Observation period [oh]*	Abnahme des el. Wirkungsgrades [%-Punkte] *Decrease of el. efficiency [%-points]*	Durchschnittliche Abnahme des el. Wirkungsgrades [% / 10 000 Bh] *Average decrease of el. efficiency [% / 10 000 oh]*
30 kW GO	31,2	28,9	10 200	-2,3	-2,2
190 kW GO	36,7	34,1	46 715	-2,6	-0,4
324 kW GO	35,6	31,9	42 840	-3,7	-0,7
526 kW GO	38,4	38,0	41 105	-0,4	-0,1
110 kW ZS	38,1	36,9	30 340	-1,2	-0,3
250 kW ZS	41,6	36,9	37 365	-4,7	-0,9

Table 2

Difference between the measured electrical efficiency and manufacturer's specifications

BHKW *CHPU*	Betriebsstundenzahl [Bh] *Operation hours [oh]*	Durchschnittlicher el. Wirkungsgrad [%] *Average of el. efficiency [%]*	Herstellerangaben [%] *Manufactrer´s specification [%]*	Differenz [%] *Difference [%]*
30 kW GO	10 250	29,2	k. A	k. A
100 kW GO	57 350	35,1	38,0	2,9
190 kW GO	54 700	34,6	38,4	3,8
324 kW GO	47 750	34,2	37,7	3,5
526 kW GO	45 050	37,4	40,4	3,0
40 kW ZS	30 500	34,9	37,0	2,1
75 kW ZS	12 700	37,0	40,0	3,0
110 kW ZS	33 000	37,8	39,7	1,9
250 kW ZS	45 050	38,0	43,0	5,0

repair by the manufacturer. A general overhaul was performed after 33,000 o. h. as mentioned above.

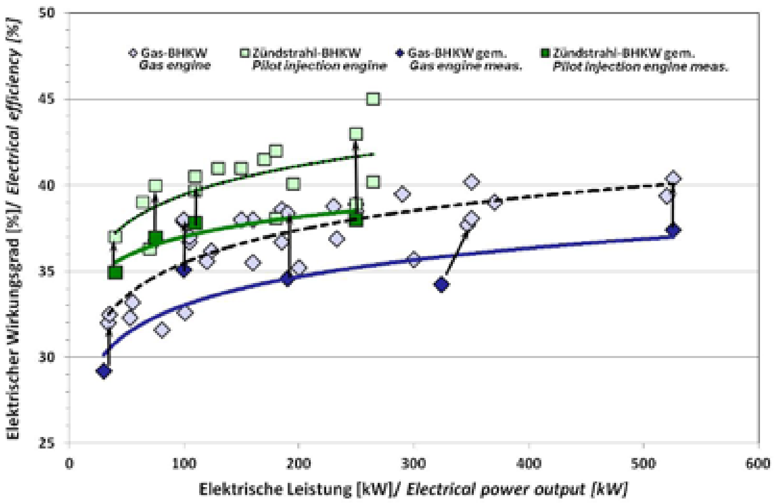
The electrical efficiency of this engine measured on site decreased from more than 38 % during the first measurement to below 36 % during the last measurement before the overhaul in 2009. After the general overhaul, the electrical efficiency was back to its initial value. Apparently, sound maintenance can thus enhance the development of CHPU electrical efficiency over lifetime. Compared to other CHPUs with similar observation periods, this unit exhibited the smallest decrease in electrical efficiency. Another CHPU that had been maintained by the owner of the biogas plant did not show an increase of electrical efficiency after a general overhaul, while exhaust emissions were significantly reduced.

With values above 1,000 mg • m^{-3}, the concentrations of hydrocarbons in the exhaust gas of the 526 kW_{el} gas engine were quite high (**Figure 3**). This engine is operated with high compression, similar to a pilot-injection engine, resulting in an improved electrical efficiency but also higher hydrocarbon emissions. Also, it can be seen that C_nH_m concentrations in the exhaust gas increased over time due to engine wear. Here, the general overhaul also had a positive impact. From measurement 09-I on, the CHPU was equipped with an oxidation catalytic converter which reduced CO emissions, significantly (**Figure 3**).

Conclusions

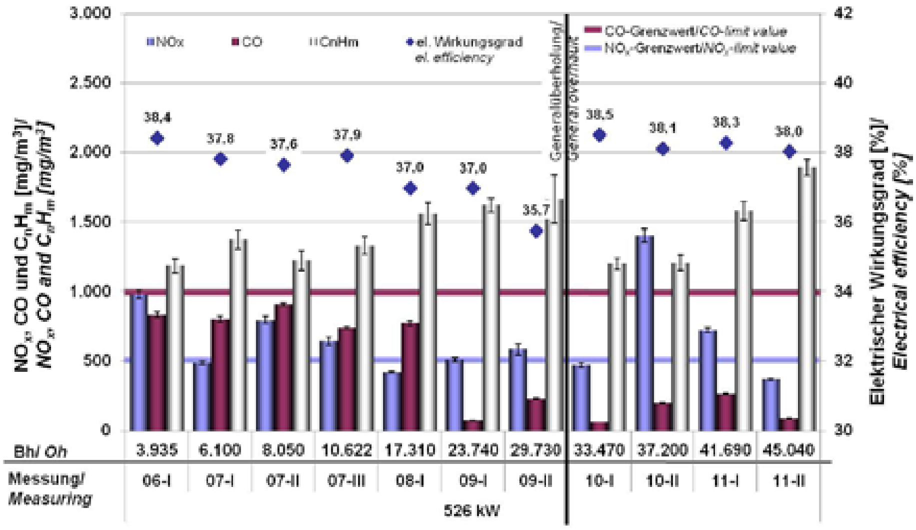
During the lifetime of a CHPU, the electrical efficiency decreases to a lesser or greater extent, depending on several factors. Thorough maintenance including a general overhaul can have a positive impact on the development of electrical efficiency. We observed best results if maintenance and overhaul were carried out by the manufacturer. To be on the safe side for profitability analysis, a deduction of 3 percentage points should be made from the electrical efficiency specified by the manufacturer.

Fig. 2



Comparison of the measured electrical efficiency (average) and the manufacturer's specifications

Fig. 3



Influence of a general overhaul on exhaust emission and electrical efficiency

Literature

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Acknowledgements

The work was funded by the Bavarian State Ministry of Food, Agriculture and Forestry.