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Micro Gas Turbine Operation with Biomass Producer Gas

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MICRO GAS TURBINE OPERATION WITH BIOMASS PRODUCER GAS

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ABSTRACT: We report the performance of a micro gas turbine on biomass producer gas and mixtures of biomass producer gas with natural gas. The micro gas turbine delivers full power on gas mixtures with a heating value of at least 15 MJ/Nm^3. For gas of lower heating value, the maximum fuel gas flow limits the attainable power. The lower limit for stable operation is about 8 MJ/Nm^3. The gross efficiency of the micro gas turbine depends on output power but not on the gas heating value, within our measurement accuracy. Above 70% of full power, emissions of CO and NO are 40 and 10 times lower than those of a gas engine of similar size. At part load below 70% of full power, the micro gas turbine burner switches to a different operating mode which produces higher CO and NO levels, but still significantly below those of a gas engine.

Keywords: biomass conversion, emissions, gas turbines

1 INTRODUCTION

Gas engines are the common choice for co-generation of heat and power (CHP) from biogas or from gas produced by gasification of biomass ("producer gas"). Instead of gas engines, micro or mini gas turbines and fuel cells may be used. These alternatives promise a significant reduction of noxious emissions.

At present, that advantage is offset by lower electrical efficiency or higher costs. Market opportunities may arise if strict emission limits have to be obeyed or if cleaner flue gas has an economical value. That would be the case if flue gas could be used for CO_2 addition to greenhouses to enhance productivity.

ECN, Cogen Projects, HoSt and Pon Power have performed a study on the technical performance of a micro gas turbine operating on biomass producer gas and on the economical prospects of that concept for CHP. The study was partially funded by the Dutch organization SenterNovem.

Here, we present results from experiments with a Capstone micro gas turbine operating on biomass producer gas and mixtures of biomass producer gas with natural gas. A full report (in Dutch) can be obtained from the ECN website [1].

2 EXPERIMENTAL LAY-OUT

2.1 Gasification and gas cleaning

The installation used for the production of clean producer gas from biomass is essentially the same system as described in a contribution to a previous conference [2]. Since then, some modifications have been made to improve the performance. Results presented here were obtained in the course of a 700 hours duration test. Some results of that test are reported in a separate contribution to the present conference [3].

The atmospheric air-blown CFB gasifier operates at about 850°C to produce gas from clean wood pellets. The gas is cooled to 400°C before dust is removed by a cyclone. Tar is removed by the OLGA system developed by ECN and marketed by Dahlman [4]. A water scrubber removes NH_3 and reduces the water content to the water vapour pressure near the temperature of the surroundings.

Table 1 shows the average composition of the clean producer gas during the micro gas turbine tests. The gas has a net calorific value of 6 MJ/Nm^3.

Table I: Average composition of producer gas during micro gas turbine tests.

Component	Concentration [vol. %]	Component	Concentration [vol.%]
CO	17	C_2H_4	1.7
H_2	7	C_2H_2	0.2
CH_4	4	C_2H_6	0.1
N_2/Ar	53	C_6H_6	0.2
CO_2	15	C_7H_8	0.02
H_2O	1.8	tar	<0.002

2.2 Micro gas turbine

The Capstone micro gas turbine is a standard 30 kW_e version without modifications except for software settings altered to manage the lower calorific value of the gas. The required power output is entered manually. The software selects the corresponding operating conditions.

The Capstone micro gas turbine has originally been designed for natural gas. A special adapted version is available for operation on landfill gas or biogas with net heating values of about 20 MJ/Nm^3. A separate compressor is needed to compress gas to the required entrance pressure of about 4 bar.

In our tests, the micro gas turbine starts up on natural gas. When operating conditions are stable, we gradually replace natural gas by producer gas until the gas valve is fully opened or until operation becomes unstable. For measurements requiring prolonged operation, slightly more natural gas is added than the minimum needed. That way, the operating system retains a margin to counteract fluctuations in the heating value of producer gas.

The composition of producer gas and flue gas are monitored continuously and are recorded automatically each minute. Power output, engine speed, turbine entrance temperature and gas valve opening are read from the micro gas turbine console and recorded manually.

3 RESULTS

3.1 Output power

Full nominal output power can be delivered if the net heating value of the mixture of biomass producer gas and natural gas is at least 15 MJ/Nm^3. At the limit value, about twice as much fuel gas mixture is fed as for operation on Groningen natural gas. The contribution of biomass producer gas is two thirds by volume, but only one thirds on energy basis.

Further increase of the fuel gas flow would require hardware modifications to allow full power operation at even lower heating values. Instead, we tried to determine the inherent lower limit for operation at reduced power demand. In that case, less fuel is required, or an equal volume of lower heating value gas.

Figure 1 shows the result of our experiments. The spread between measurements reflect different gas valve operating margins kept during short and long duration experiments. It proved possible to operate the Capstone micro gas turbine on pure biomass producer gas of 6 MJ/Nm^3. However, because of the limited fuel gas flow, the actual maximum power output on pure biomass producer gas is only 20% of the nominal maximum power.

Although we managed to perform measurements during operation of the micro gas turbine on pure biomass producer gas with a heating value of 6 MJ/Nm^3, the combustion stability proved insufficient for operation over periods longer than one hour. Addition of a small amount of natural gas to obtain a gas mixture with a heating value of 8 MJ/Nm^3 solved the instability problem. Hence, we expect the Capstone micro gas turbine would operate reliably on biomass producer gas of slightly higher heating value, as produced e.g. by a Silva Gas or FICFB gasifier.

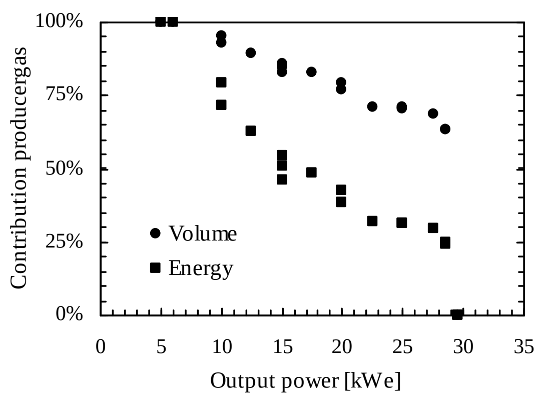

Figure 1: Contribution of biomass producer gas, by volume and energy, to total micro gas turbine fuel input as function of output power.

3.2 Efficiency

We have performed global measurements of the electrical efficiency by dividing the electrical power output, as indicated by the micro gas turbine operating system, by the total heat input, as derived from the measured gas flow and composition. It should be noted, that the results shown in Figure 2 have not been obtained according to standard procedures but are for comparison only. Power use by the gas compressor has not been taken into account. Compression of natural gas reduces the system efficiency by about 1%. That figure may double if producer gas of 15 MJ/Nm^3 is used, i.e. at the limit value for which full power can be obtained without modifications to the micro gas turbine.

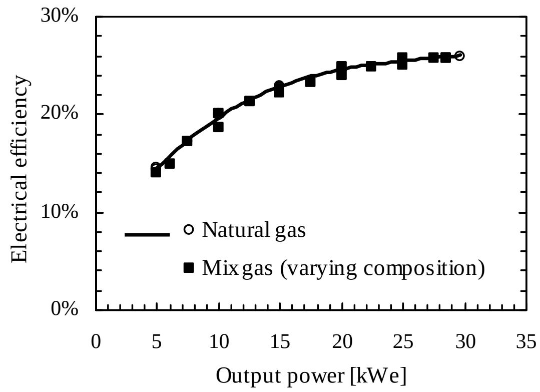

Figure 2: Gross electrical efficiency of micro gas turbine as function of output power for operation on biomass producer gas mixed with natural gas and on natural gas.

Within the accuracy of our measurements, the gross electrical efficiency (i.e. excluding gas compression) does not change when producer gas substitutes natural gas.

We did notice that the micro gas turbine operating system compensates the larger fuel gas flow by a reduction of the air flow. The turbine could deliver the same amount of mechanical power, while less would be needed for air compression. This would leave room for more electrical power production and increase the efficiency.

On the other hand, the smaller air volume would not be able to recuperate the same amount of heat from the flue gases. That would reduce the efficiency. Apparently, these and possible other effects which could increase or reduce the efficiency cancel each other or are just too small to be noticeable in our results.

3.3 Emissions

Figure 3 shows the measured NO concentration in dry flue gas produced by the micro gas turbine. The composition of mix gas varies with output power as shown in Figure 1. The NO concentration increases with output power until 20 kW$_e$. Above that value, the Capstone combustion system switches to a different operating mode that produces significantly less thermal NO.

Combustion of natural gas produces more thermal NO than combustion of biomass producer gas because of the higher flame temperature. That explains the lower NO concentration for operation on mix gas until 20 kW$_e$. Above 20 kW$_e$ combustion of residual NH_3 in mix gas produces sufficient NO to raise the concentration in case of mix gas above the level of thermal NO from natural gas.

Figure 4 shows the measured CO concentration in dry flue gas produced by the micro gas turbine. At low output power, operation on mix gas results in higher CO levels. The difference can be ascribed to incomplete combustion at the lower flame temperature derived from the NO results. Alternatively, the difference may indicate that 0.4% of the producer gas CO content passes the combustion zone unaffected. Above 20 kW_e the CO emission in case of mix gas drops to the value observed for natural gas. Apparently, the high power operating mode of the combustor results in full conversion of CO into CO_2.

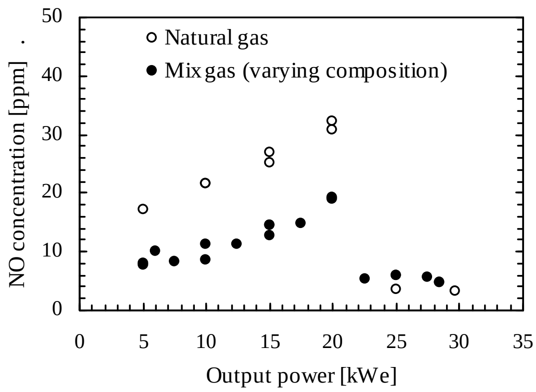

Figure 3: NO concentration in dry flue gas of micro gas turbine as function of output power for operation on biomass producer gas mixed with natural gas and on natural gas.

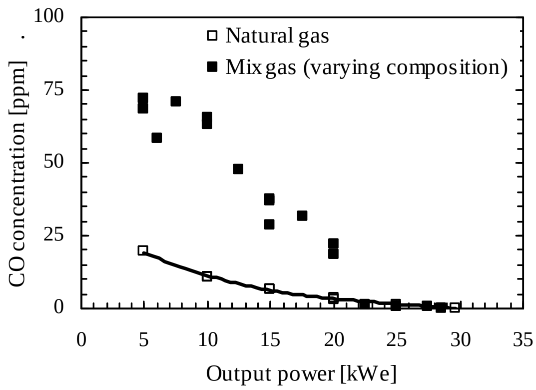

Figure 4: CO concentration in dry flue gas of micro gas turbine as function of output power for operation on biomass producer gas mixed with natural gas and on natural gas.

For comparison of NO and CO emissions reported here with figures from gas engines, it should be realised that flue gas of the micro gas turbine is highly diluted with air to an O_2 concentration of about 18%. Correction to a standard value of 6% O_2 would increase the reported NO and CO concentrations by a factor 5. Still, at high power output the CO and NO concentrations are lower by a factor 40 and 10 respectively than our measured values for a gas engine of similar power using the same biomass producer gas [5].

3 CONCLUSIONS

The standard Capstone micro gas turbine operates remarkably well on mixtures of biomass producer gas and natural gas. Even without modifications it is able to deliver full power provided the heating value is at least 15 MJ/Nm^3. Our results at reduced power show, it would suffice to enable a larger fuel gas flow to make the micro gas turbine deliver full power on producer gas from indirect gasifiers, like the Silva gas concept and the FICFB gasifier developed by the Technical University of Wien.

A reduction of the gas heating value has a negligible effect on the gross efficiency of the Capstone micro gas turbine. The net efficiency may decrease by about 1% because of the higher power demand for compression of the larger gas volume required for the same heat input.

At full power emissions of CO and NO are very low, both for natural gas and biomass producer gas. When compared to a gas engine of similar size, the micro gas turbine produces 40 times less CO and 10 times less NO. At part load below 70% of maximum power, the micro gas turbine burner switches to a different operating mode which produces more CO and NO, but emissions remain far below those of a gas engine.

4 REFERENCES

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5 ACKNOWLEDGEMENT

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