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Design and operation of a local cogeneration plant supplying a multi-family house (9,5 kW electrical / 35 kW thermic power) – a field report

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Abstract

In the paper at hand a small cogeneration plant that is suitable to supply heat and electric power to a three family house is presented. The plant is capable of delivering 9.5 kW electrical power to the mains and 30 kW thermal power used for heating the domestic hot water and the building respectively.
Woodchips, a renewable energy carrier, are used to power the plant, so it is CO_2 neutral.
Powering an internal combustion engine with wood gas made from woodchips has turned out to be the right technology for small cogeneration plants. Such units are not available from stock; hence a prototype has been constructed.
More than two years of operation experience with this prototype show the practicability of the system. The amount of maintenance work is acceptable and will be reduced in the future by optimization.
Measurements concerning the electrical as well as the thermal efficiency are presented. During these measurements further room for improvement has been discovered to maximise output power and to lower losses.
In summary it figured out that the plant operates reliable with acceptable amount of maintenance work. And, if we don't calculate the amount of development work for the prototype, it is profitable.

Key words

Energy efficiency, heat generation, cogeneration plant, exhaust gas after-treatment.

1. Introduction

The efficiency of power generation via caloric power plants can be increased by utilizing rejected heat. So in order to utilize the primary energy carrier more efficient, some existing district heating grids are fed from the rejected heat of large and medium scale caloric power plants.
This concept is not suitable for rural (sparsely populated) regions as the heat transport via district heating grids in this case is highly unprofitable. Secondary especially in agrarian regions most farmers are well provided with CO_2 neutral heating material from their forests (wood) or fields (e.g. straw) and therefore not interested in a comfortable but for them more expensive heating facility.
In order to reduce the costs for heating of a three family house (lived-in by my parents and brother), for the preparation of the domestic hot water and in order to generate electrical power a cogeneration plant named "Turdanitsch 2" has been planed and built up.
Building up as well as operation of the plant proof that the concept of combined heat and power generation is efficient even for small scale units.
At present no plants providing about 10kW electrical and 30kW thermal power are purchasable. Therefore a prototype had to be designed and built up. The concept of powering the plant by utilizing woodgas was chosen as the efficiency obtained with small units is higher than by using steam or ORC processes. The cogeneration plant was planed as an easily to be operated, low maintenance and reliable unit. This could be confirmed during the last two years since beginning of operation.

2. Description of the plant

Figure 1 shows the functional overview of the cogeneration plant “Turdanitsch 2”.

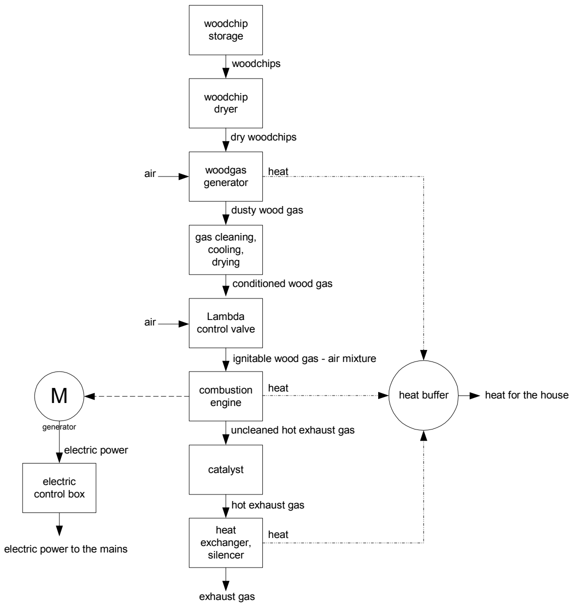

Fig. 1. Functional overview of the cogeneration plant

A. Gasification process of woodchips

Wood chips are used as energy carrier. These are small pieces of wood produced by shredding waste wood from thinning the forest or the sawmill industry. In the presented power plant, the wood chips are transported automatically from the storage room via the drying unit into the wood gas generator (gasifier). The dimensioning and construction of the gasifier was first taken from [1]. The gas quality of this design was insufficient and the amount of tar contented in the gas destroyed the internal combustion engine after few hours of operation. It turned out that reaction temperatures for gasification of woodchips had to be about 1400°C to generate tar-poor gas of satisfying quality. To achieve this, the whole gasifier had to be completely redesigned. (Theory of Gasification [2]). Reaction temperatures depend on the achieved gas flow rate. For the developed design it is essential to keep the gas flow and therewith the reaction temperature constant to achieve good gas quality. Therefore it is not possible to change the gas flow rate.
Furthermore it is not contemplated within this design to latch gas in a gas buffer, so the gas has to be consumed continuously by the internal combustion engine. That’s why the electrical and the thermal output power of this plant can not be adjusted easily.

B. Gas conditioning

The gas emerging from the wood gas generator still has a temperature of about 800°C and is loaded with soot particles. A heat exchanger from a central-heating boiler is used to cool the gas down to about 150°C to raise the gas density. The emitted heat energy is given to the domestic heating water. The gas then passes a cyclone and an electrostatic filter system to separate soot particles. A second wet cooling system cools down the gas to about 60°C to let water vapour condensate. The moisture contended in the gas is then intercepted in a demister.
Now the clean and dry gas is mixed with the right amount of air to achieve an ignitable mixture. The necessary amount of oxygen is determined by a lambda feedback control.

C. Internal combustion engine

The ignitable air gas mixture is then fed to a standard combustion engine which has been dismounted from a motorcar. The engine is a Otto gasoline engine with six cylinders and two valve technology.
For wood gas combustion the ignition timing has been adjusted and spark plugs with low heat rating have been installed, because wood gas burns slower and “colder” than gasoline.
Under standard working conditions the engine makes about 1500-1600 revolutions per minute. This is just a little bit above idle speed, which reduces oscillation losses and permits good combustion of the slow-burning wood gas. Another effort of this slow speed is that wear out of the engine is slow. The disadvantage is, that an engine, designed for gasoline, producing 139 horsepower at 4000 revolutions per minute, powered with wood gas at about 1500 revolutions per minute, brings only 15 horsepower to the shaft, but this continuously.
The combustion engine powers an induction generator which is connected to the three phase mains power. The rejected heat of the combustion engine’s cooling water is fed via heat exchanger to the heating water.
To ignite the wood gas generator the combustion engine is bypassed with a fan. This electric fan stets the whole system under vacuum and allows fast start-up of the gas generator. After about 2 to 5 minutes the wood gas is combustible. The engine is started by the original 12 Volt electric starter motor powered by an automotive battery.

D. Exhaust gas treatment

The hot combustion gas from the internal combustion engine passes the lambda probe and is after treated in a standard three-way catalytic converter in order to reduce the anyway low CO and HC percentage. A heat exchanging device extracts further useable warmth from the combustion gas and feeds the central heating. After this treatment the utmost temperature of the combustion gas is about 60 degree Celsius. The subsequent muffler reduces the acoustic emission to a scarcely audible measure.

E. Generator

An induction machine with 1500 revolutions per minute idle speed (4 poles) has been chosen as generator. Compared to a synchronous generator, one big advantage of an induction generator is that switching the generator to the mains is much more easily. Neither rotor speed nor polar wheel angle has to be controlled very accurately. A second advantage is that no excitation device has to be provided.

The induction machine used is designed to be run as a motor and features a nominal voltage of 420V. As the mains voltage is only 400V, the machine's magnetization state and the magnetizing current are not too high. This is essential for low iron and copper losses in generating mode.
By now the frequency of the ignition pulses of the combustion engine is measured to calculate the generator rotor speed. If, during start-up of the combustion engine, the rotor speed reaches 1500 revolutions per minute, the induction machine is switched to the mains.
In a second stage of expansion a rotor speed measurement unit is designed that allows to measure the speed from the voltage induced into the stator windings by residual magnetism. With this the switching of the generator to the mains can be carried out more smoothly.
The excess electric energy produced during operation of the plant is applied to the public mains. Parallel main operation is carried out.
In order to reduce the reactive power that has to be provided by the public mains, capacitors are switched in parallel to the induction machine after connecting the machine to the mains.

F. Heat Treatment

The rejected heat of the wood gas generator, the combustion engine's cooling water and the heat of the exhaust gases are fed via heat exchangers to the heating water.
Power modulation is not advisable due to the underlying concept, so an buffer storage of 4m³ heating water is used to meet the different heat quantity requirements of the house.
For efficient use of the produced thermal energy, the plant has to be operated in a heat led mode.
If heat requirements can not be covered by the heat stored in the buffer, the plant has to be started.
During operation the rejected heat of the plant heats the house and the domestic hot water. The excess heat which cannot be used during operation is stored in the heat buffer. If heat consumption of the house is too low and the heating water storage buffer is hot enough, the combustion engine cannot be cooled down any more. The temperature of the engine rises, and if it comes above 95°C the plant shuts down automatically.
During standstill of the plant the house is heated using the previously heated up buffer storage. In this case no electrical power is generated. As there is no electric energy storage system implemented, it is necessary that during standstill of the plant the electric power company provides the necessary electric energy for the house. This applies for the whole non-heating period during summer too.

3. Operation experiences

By now the plant has reached over 3500 operating hours. The plant is only in operation during winter, when heat is required.
During winter 2006-2007 and 2007-2008 no major faults occurred.
The first and only bigger breakdown occurred in December 2008. At about 3000 hours of operation the timing belt of the internal combustion engine ripped off during operation. This caused extensive damage of the engine. The engine was then replaced with a new used-one of the same type within one day. The reason of the breakdown was caused by insufficient service of the engine and not by wood gas operation.
Normal operation of the cogeneration plant is quite simple and done by laities. The work is reduced to about 15 minutes of preparation per start-up, and about 10 minutes for the starting procedure itself. If the plant is in operation, no further attendance is required. The plant stops and shuts down automatically when enough heat is generated or if faults occur.
One operation period takes about 2 to 4 days, depending on the amount of needed heat.
The preparation for start-up consists of cleaning up the gas filter system and the ashtray of the wood gas generator, and visually checking the whole system. The amount of work will be reduced to about 1-2 minutes by improvement of the gas filter system.
By now an automatically start up procedure, which could allow fully automated operation is not planned.
Figure 2 shows the plant at the development status of January 2008.

Fig. 2. The plant at January 2008.

4. Efficiency analysis

Efficiency analysis has been started recently. For this purpose several additional energy-counters have been installed. The measurements are still in progress. Table I shows average efficiency data that has been determined by now.
The biggest inaccuracy with efficiency analysis is to determine the consumed energy of the plant. By now only the volume of the consumed woodchips is measured, with only rare information about the packing density. To weigh the consumed woodchips would be more precisely, but is not possible by now. The energy content of the consumed woodchips can not be determined exactly too. The moisture and the ligneous crop of the woodchips give only a weak hint to the energy content of the wood. Packing density, moisture

content and ligneous crop are not homogenous, so just average values can be taken.

TABLE I. – Efficiency analysis result

Consumed woodchips per hour	0.06483	loose m³/h
Woodchip moisture after dryer	18.26	%
Overall el. power dissipation	6.48	kW/h
Dissipated useful heat	26.55	kW/h
Electrical efficiency	13,32	%
Thermal efficiency	54,52	%
Overall efficiency	67,84	%

5. Efficiency improvement

Several Experiments show that output power and efficiency could be increased by optimising the gas conditioning process. Cleaning the gas with lower flow losses could improve the filling of the cylinders of the combustion engine, which would result in higher power output. Better cooling of the gas will increase the gas density, which will improve performance too.
Modifying the compression rate of the combustion engine or turbo charging of the engine are further perspectives [3] to increase output power.
Another possibility of improvement is to optimize the exhaust gas heat exchangers, which will result in higher thermal power output.
At the electric part of the plant it turned out that during operation the plant consumes about 1200Wh per hour itself. Most of this power is used for transportation of the Woodchips, for electronics, water pumps and fans. There are few possibilities to improve the transportation of the woodchips at the prototype plant due to the spacious situation. But if the plant would be produced in series, the transportation process could be optimised. Electronics have to be checked for further improvement possibilities, some power supplies could be replaced by more efficient ones. Three water pumps are in use, even these pumps could be replaced by more efficient ones.

6. Government aid and basic financial conditions

Whereas the building up of commercially available biomass heating systems is funded no government aid is available in case of self-construction prototypes.
The whole project as well as the research and development work carried out (the application of a patent is under examination) are financed privately.
The electric power is payed according to the austrian law concerning green electricity [5]. The fees are 0,12 €/kWh when using saw mill residue as a heating material and 0,16 €/kWh when using wood chips from small trees as a heating material. The fee does not depend on time of day or season. Hence on an average 1400€ are earned per year, the consumption of wood chips is about 90m³.
The energy produced equals the one of 8000 liters heating oil. As wood is carbon neutral, an amount of 23 t of carbon dioxide is saved.
Building up of the plant started in January 2005, during summer 2006 the plant was switched to the mains for extensive test runs after considerable tests carried out by the local energy supply company (Kelag).

7. Further Information

Questions concerning the presented cogeneration plant "Turdanitsch 2" may be addressed to:

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8. Conclusion

During winter 2006-2007 and 2007-2008 the cogeneration plant was under operation without major faults [5]. One bigger breakdown occurred in December 2008, due to service faults. In the meantime about 3500 hours of operation are reached.
The amount of maintenance is about 15 minutes per operating period. The operating period lasts about 2-4 days a week depending on the weather. The ease of servicing is still to be improved.
Even though the cogeneration plant "Turdanitsch 2" is just a prototype which works not yet at maximum possible efficiency, it could be shown that the concept of combined heat and power generation is efficient even for small scale units fed from biomass. The high market price for wood chips makes the mere generation of electrical power from biomass unprofitable. The break even point can only be reached when utilizing the rejected heat for heating purposes.
For rural regions with high potential of waste wood the presented technique could be an option, at raising energy prices, to increase the income for the population. In countries like austria where the majority of electric energy is produced by hydropower plants, wood gas cogeneration plants could support the hydropower plants in winter, when heat is needed and the water levels of the rivers are low.

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