ABSTRACT: Pellet burners need auxiliary electrical power to provide CO₂-balanced heat in a comfortable and environment-friendly way. The idea is to produce this and some extra electricity within the furnace in order to save resources and to gain operation reliability and independency. Thermoelectric generators (TEGs) allow the direct conversion of heat to electrical power to a certain extent. They have the advantages of a maintenance-free long life and soundless operation without moving parts or any working fluid. A novel kind of decentralised small-scale biomass-based combined heat and power generation will be developed. The basic system allows grid-independent operation of automatically running biomass furnaces including fuel delivery from storage and circulating the cooling respectively heating water or air. The advanced system also provides electricity for network supply or for other electrical devices and is an additional benefit.

Keywords: combined heat and power generation (CHP), de-centralised energy generation, stand-alone systems, pilot plant, solid biofuels

1 INTRODUCTION

The European Union demands an increased utilisation of biomass as energy source in order to reduce the emission of green house gases and the import of non-renewable energy sources [1]. In the last years small-scale pellet boilers and pellet stoves broke through in many European countries. They provide CO₂-balanced heat in a comfortable and environment-friendly way [2]. For operation they need some auxiliary electrical power. The idea is to produce this and some extra electricity within the system in order to gain operation reliability and independency and to save resources.

Usually the production of electricity with any fuel (fossil or renewable) in power plants is combined with production of heat. This heat is often not economically useable. On the other hand there is a tremendous amount of heat capacity all over the world which is nowadays only used for room heating or supply of hot water in small scale systems (e.g. in Austria about 50-70 PJ firewood and wood chips for private consumers each year [3]). So there is a high potential to safe resources if at least a part of this available energy could be refined into electricity.

Another advantage of de-centralised energy generation is that there are no losses of electricity for transportation and distribution if it is produced where it is needed.

Modern heating installations do not work without electricity. The idea of this project is to make automatically driven heat-production possible even if there is an electrical power outage or in remote areas without an electricity network. The first case is emergency operation, the second one grid independent operation. In order to be successful it needs an optimised and simplified system. Any surplus of produced electricity can either be used immediately for other purposes than heating or fed into network respectively stored for later use.

The idea to produce at least some electricity with available heat is charming. As it is technical feasible there should be reasonable and intensive research and development on this promising future technology. Without optimisation it is at present not economic and for now it is not sure whether it will ever be.

2 APPROACH

2.1 Why Thermoelectric Generators

Thermoelectric generators (TEGs) allow the direct conversion of heat to electrical power to a certain extent [4] (principle see figure 1). The TEG receives heat at high temperature and delivers heat at a lower temperature while generating electricity. TEGs can be interpreted as intelligent heat exchangers which refine some of the exchanged heat into electricity.

Figure 1: Principle of Thermoelectric Generation

One has to be aware of the properties of TEGs to apply them in the best way. The higher the temperature difference between heat source and heat sink is, the higher are efficiency and power output. But the TEG has to be protected carefully against overheating. Otherwise it will be damaged or even destroyed. So the challenge is to reach high, but not too high, and very constant temperatures on the hot side of the TEG for constant high electrical power output. State of the art materials can convert a maximum of 5-6 % of the useful heat into electricity, new materials promise 10 % and more [5]. This efficiency is only achievable as long as both temperatures and heat flows are sufficient. If the temperature difference is half as much, both the
efficiency and the heat flow are also halved and therefore the electrical power is only one fourth. Therefore the production of electricity strongly correlates with the production of heat. Until now TEGs were only used for certain niche applications especially due to their relatively high prize. New applications with higher quantities will follow in reduced costs.

TEGs have a great potential, in particular for small scale applications, because of their advantages, as follows:

- direct conversion of heat into electricity
- long life cycle
- maintenance-free
- operation without moving parts
- not only quiet but even soundless
- no working fluid required
- the remaining heat not converted to electricity still can be used for heating (energy balance see figure 2)

![figure 2](Image)

**Figure 2:** Energy Balance of a Pellets Boiler with TEG

The total efficiency of the furnace is the same with or without TEG. The difference is that a part of the provided energy is converted to electricity.

The electrical efficiency of the system depends on two main factors: On the one hand the efficiency of the TEGs – hence the efficiency of thermoelectric materials – is important. On the other hand the amount and the temperature level of heat which can be conducted through the TEG determine the possible electrical power output.

2.2 Electrical Power Balance

The over all-consumption of electricity of the complete heating-system is analysed and optimised in order to fulfil the purpose of independency (see figure 3 for electrical demand of different existing pellet boilers with different heat capacity). Grid-independent operation includes fuel delivery from storage and circulating heating water or air.

The time-dependent factors for the consumption and production of electric power are considered. Especially critical times are in spring and autumn, when there are many ignitions and only partial load operation. Measures have to be taken to provide enough electric power for all periods. The dimensioning and assembly of the TEG have to be done in such a way that a maximum for the production of electricity is gained at partial load, since it is the most frequent mode over the heating period.

![figure 3](Image)

**Figure 3:** Electrical Demand for different Pellet Boilers at Full Load (data: FJ-BLT)

The electrical demand of pellet boilers can be reduced by modified control and new electrical equipment. One has to reconsider the technical demands of furnaces and meet these demands with as little electricity as possible.

Different concepts with different electrical devices and working data for different purposes of the system are being developed, e.g. AC and DC solutions with different voltages, grid independent operation or network supply, systems for different power ranges (e.g. see figure 4).

![figure 4](Image)

**Figure 4:** Scheme for Electrical Power Balance

Finally the costs for the TEGs and for the electrical components have to be considered and optimised due to the requirements of different systems.

2.3 Experiments

To optimise the system we deal with the burner as well as with the TEG-configuration. Experiments with different configurations of burners, heat exchangers and TEGs are performed to understand the basics and principles of this technology.

Pellet boilers reach high combustion temperatures up to 1200 °C. Nowadays this available heat at high temperatures is only used at relatively low temperatures; either with heating water in boilers or with air in stoves or with both in combined furnaces. So there is a great loss of available exergy. Of course the heat transfer from the flue gas to the water is easier to lower water
temperatures resulting in higher temperature differences. The heat exchanger has to be constructed clever in order to reach very high heat transfer rates.

In order to understand both the operation of TEGs themselves and the interaction with furnaces experiments with different prototypes are done. E.g. the operation of a usually gas-flame driven TEG was tested in a combined pellet boiler/stove. The TEG is located in the combustion chamber around the flame and is cooled with the circulating water (see figure 5). The advantage of this test is that it was easy to realise with immediately available compounds.

![Figure 5: Combined Pellet Boiler/Stove with TEG-Prototype (located around flame in the combustion chamber)](image)

To increase the heat transfer from the flue gas to the TEG another TEG-prototype with heat pipes was tested (see figure 6). The challenge is the system integration and optimisation of TEGs in pellet burners. The different heat flows through the TEG and the furnace are analysed in order to assess the heat transfer. There are several problems to solve, concerning e.g. heat transfer, fouling of heat exchanger or deterioration of TEGs. Several different configurations will be analysed and evaluated in experiments.

![Figure 6: TEG-Prototype with Heat Pipes (bottom)](image)

The main aims are an optimisation of the heat transfer and of the electrical power output for different configurations. Experience is gained about different thermo-electrical materials with different necessary temperatures and heat flows. Either the efficiency or the power output can be maximised.

Long term experiments are necessary to judge about different configurations (TEGs, heat exchanger, furnaces and the whole system); to gain practical knowledge and to build up an adapted and new constructed prototype-system. The heat transfer rate, the risk of overheating, the tendency of fouling, problems with streaming flue gas (e.g. erosion or dead space) as well as stable and complete combustion have to be examined. The efficiency of TEGs and the whole systems will be tested and optimised; different concepts will be compared.

Based on these first tests a whole prototype system with already adapted both TEGs and boilers will be built up in order to validate the expected system efficiencies and expected amount of electricity. Based on these first tests a prototype system (with specially adapted TEGs and boilers) will be built up to validate the expected system efficiencies and the expected amount of produced electricity. The grid independent operation and/or emergency operation will be tested (simulation of electrical power outage).

Several different aspects have to be considered. Therefore we are collaborating not only with leading producers of pellet boilers but also experienced producers of TEGs, of thermoelectric materials, of electrical components and if necessary other producers of new materials.

3 RESULTS

In first experiments a prototype TEG was operating at best efficiency but moderate power. The potential of this technology strongly correlates with the efficiency and costs of thermoelectric materials. Optimised integration will result in additional benefits and saved resources.

A high heat transfer rate has to be realised with a low pressure drop of the flue gas. Fouling and deterioration of both the heat exchangers and TEGs have to be minimised. This is a reason why it is best to use pellets for combustion in burners with TEGs. The good and constant fuel composition of pellets promises good and constant combustion conditions and therefore a maximum of produced electricity.

The important parameters to maximise the amount of produced electricity were identified. We have knowledge and ideas about constructions and solutions to optimise prototypes and pilot series in order to evaluate the technical and economical potential of this technology.

TEGs in pellet boilers are not only an additional component; a new system of TEG with furnace has to be developed. The generation of heat should not be affected; it is still the main requirement of the pellet boiler. The user of such a system should notice nothing but increased comfort and security of supply.

4 CONCLUSIONS

A novel kind of decentralised small-scale biomass-based combined heat and power generation will be developed. The basic system allows grid-independent operation of automatically running biomass furnaces including fuel delivery from storage and circulation of the heating water. The advanced system will also provide electricity for network supply or other electrical devices as an additional benefit.
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6 REFERENCES