Small-Scale Pellet Boiler with Thermoelectric Generator

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Abstract

Pellet boilers need auxiliary electrical power to provide CO_2-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 direct conversion of heat to electrical power. They have the advantage of a long maintenance-free durability and noiseless operation without moving parts or any working fluid. The useful heat remains almost the same and still can be used for heating. The challenge is the system integration and optimisation of TEGs in pellet burners. The consumption of electricity by the complete heating system is analysed and optimised in order to fulfil the purpose of independency. Grid independent operation is difficult to realise and optimise. In order to be successful it needs a simplified system. We do experiments with different arrangements of burners, heat exchangers and TEGs. We identified the important parameters to maximise the electricity produced. 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 novel kind of decentralised small-scale and micro-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. The advanced system also provides electricity for other electrical devices like radio, TV or light and is an additional benefit.

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

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 CO_2-balanced heat in a comfortable and environment-friendly way [2], [3]. 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.

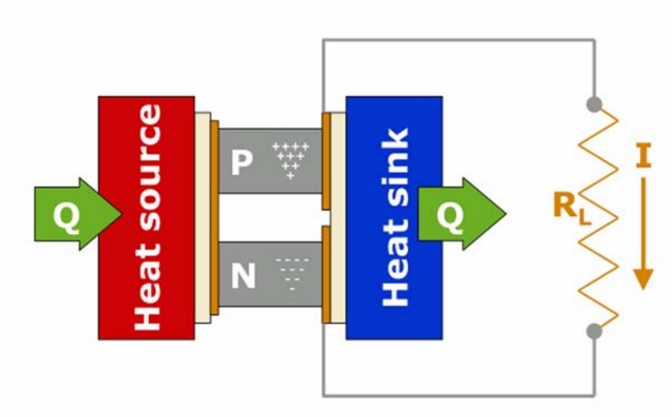
Usually the production of electricity with any fuel (fossil or renewable) in power plants is combined with production of heat. This heat is often not economically useable. On the other hand there is a tremendous amount of heat capacity all over the world which is nowadays only used for room heating or 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 [4]. So there is a high potential to safe resources if at least a part of this available heat could be refined into electricity. Another advantage of de-centralised energy generation is that there are no losses of electricity for transportation and distribution because it is produced where and when it is needed. There exist intensive activities to realize a micro-scale combined heat and power generation, e.g. using the Stirling technology [5] or externally heated micro-turbines [6]. Thermoelectric Generators are an alternative for special applications.

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.

Why Thermoelectric Generators?

For small-scale applications based on solid biomass we identified thermoelectric power generation as a promising technology because it allows a very simple assembly – simple at least for the end-user. Thermoelectric generators (TEGs) allow the direct conversion of heat to electrical power [7] (principle see figure 1).

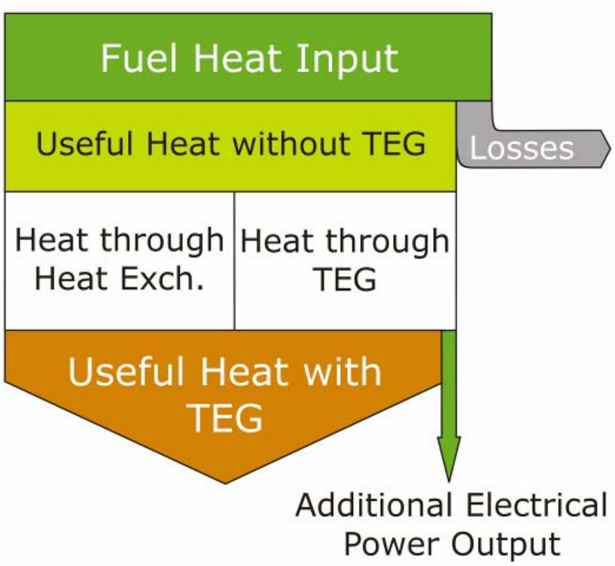
Figure 1: Principle of Thermoelectric Generation



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. No working fluids or moving parts are necessary, TEGs operate not only quiet but even soundless. One can expect maintenance-free long life durability. The user of such a system will notice nothing but increased comfort and security of supply. 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 [8]. This efficiency is only achievable as long as both temperatures and heat flows are sufficient, only the heat streaming through the TEG can be converted to electricity. 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.

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 remaining heat still can be used for heating (energy balance see figure 2). 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.

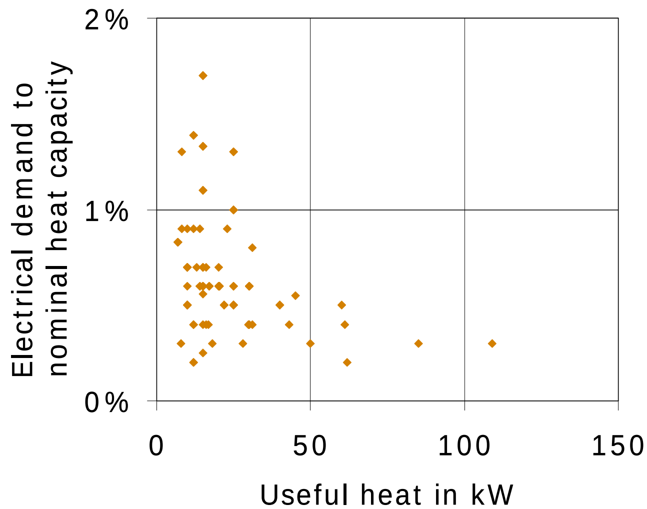
Figure 2: Energy Balance of a Pellets Boiler with TEG



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 (e. g. see figure 3 for the 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. Critical periods are in spring and autumn, when there are many ignitions and most time partial load operation which follows in smaller amounts of produced electricity. 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. Only some days a year the full heat capacity of the boiler is needed.

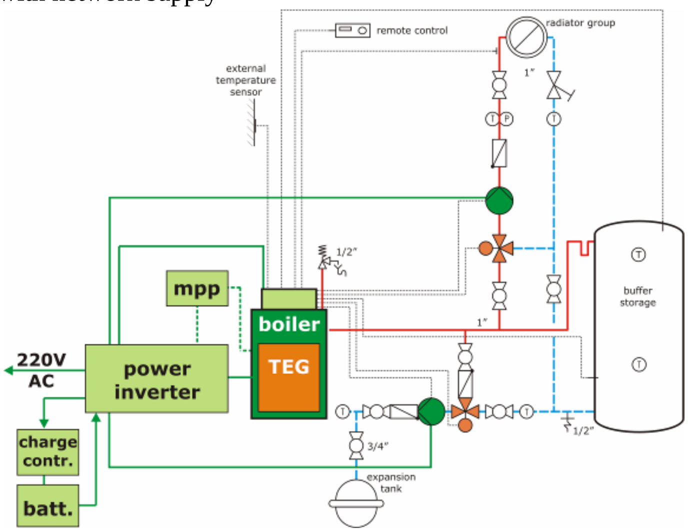
Figure 3: Electrical Demand for different Pellet Boilers at Full Load (data: FJ-BLT)



The electrical demand of pellet boilers can be reduced by modified control and new electrical equipment. Also efficient DC-Technologies are necessary. One has to reconsider the technical demands of furnaces and meet these demands with as little electricity as possible. Optimising the electrical power demand of any pellet-boiler is an additional benefit for the environment-friendly operation also without TEG. 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).

Finally the costs for both the TEGs and the new electrical components have to be considered and optimised due to the requirements of different systems. Calculations resulted in the potential of a 40 kW boiler to produce about 1000 kWh electrical power per year, which is in the range of typical photovoltaic systems. This amount is more than the demand of the whole heating system. Very important is the fact that the electricity is produced at times when there is a high demand of electricity in the net.

Figure 4: Scheme for Electrical Power Balance of a System with network supply

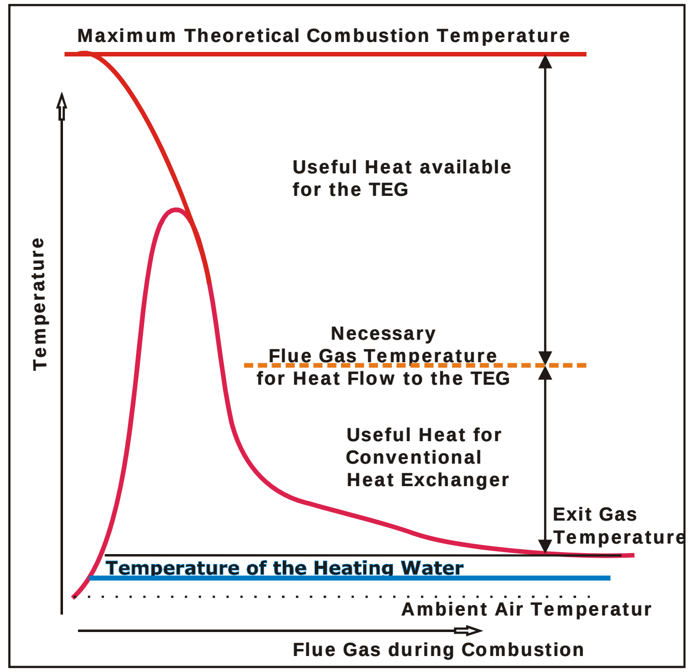


Experiments

To optimise the system we deal with both the burner as well as the TEG-configuration. Experiments with different configurations of burners, heat exchangers and TEGs are performed to understand the basics and principles of this combination of technologies. The properties of both the furnaces as well the TEGs have to be considered to develop an optimised system. Detailed analysis will show where and how it is possible to make the best efforts. Some matters of fact won't be changed, e.g. the available temperatures in pellets boilers or the theoretical maximum efficiencies of thermoelectric materials. But many parameters can and have to be adjusted to optimise the systems overall performance. 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.

Pellet burners reach high combustion temperatures up to 1200 °C (see also figure 5, the maximum theoretical combustion temperature without heat extraction is 1400-1600°C, depending on the excess air, the calorific value and the water content of the fuel). 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. The heat transfer from the flue gas to the water in conventional pellet boilers is easier due to lower surface temperatures resulting in higher temperature differences. The heat exchanger for the TEG has to be constructed clever in order to reach very high heat transfer rates and high surface temperatures.

Figure 5: Schematic Progression of Theoretical and Practical Flue Gas Temperatures during Combustion



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 6). The advantage of this test is that it was easy to realise with immediately available components.

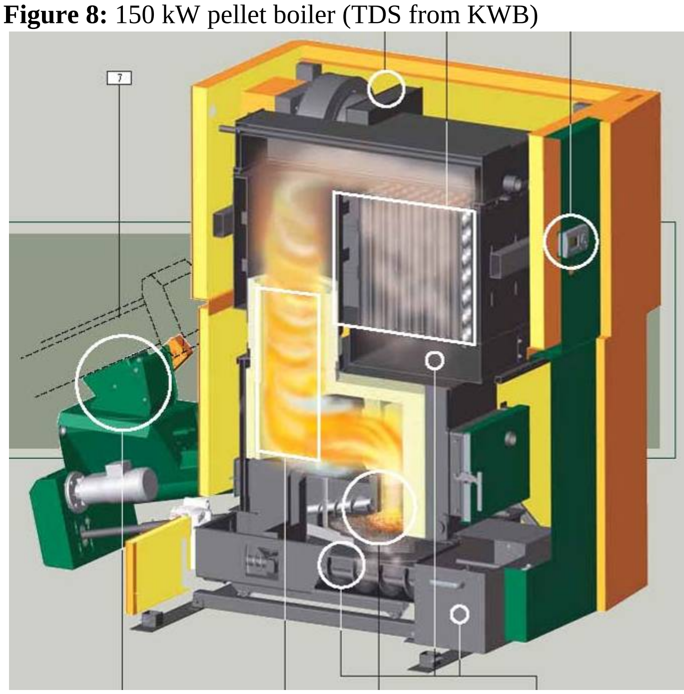
Figure 6: Combined Pellet Boiler/Stove with TEG-Prototype (located around flame in the combustion chamber)

To increase the heat transfer from the flue gas to the TEG another TEG-prototype with heat pipes was tested (see figure 7). But the high heat uptake of the heat pipes is difficult to control, one of them exploded during the experiments. Another serious problem is the fouling of the heat pipes due to the relatively low surface temperatures.

Figure 7: TEG-Prototype with Heat Pipes (bottom)

Based on these first tests a whole prototype system in the range of 15 kW thermal power with already adapted both TEG and boiler will be built up in order to validate the expected system efficiencies and expected amount of electricity. Further experiments will be done with a boiler delivering 100-150 kW heat (next generation up to 300 kW, see figure 8).

Figure 8: 150 kW pellet boiler (TDS from KWB)



Conclusions

A novel kind of decentralised small-scale and micro-scale biomass-based combined heat and power generation will be developed. Thermoelectric Power Generation is predestined for small-scale applications and there is a high amount of heat available for cogeneration. 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.

The challenge is the system integration and optimisation of TEGs in pellet burners. Several different configurations will be analysed and evaluated in experiments. 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 user of such a system should notice nothing but increased comfort and security of supply. Micro-scale CHP has to run automatically. The main task of the boiler is still to provide heat. A Simplified and optimised system has to be developed to be competitive. To make the scientific challenge both technical and economic successful it needs an optimised implementation of the intelligent heat exchanger.

The possible Network supply occurs in times when there is a high demand. Pellets boilers with TEGs deliver electricity at peak load of the electric network. Electrical devices with temporal as well as local close demands are light, ventilation and heat distribution. Grid independent and emergency operation are beneficial in remote areas respectively in the case of electrical power outage, which appeared more and more often the last years also in many European countries. TEGs in pellets boilers promise more operation reliability and independency.

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. The potential of this technology strongly correlates with the efficiency and costs of thermoelectric materials. 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 (TEC COM GmbH, Halle, Germany) and thermoelectric materials (German Aerospace Center, Institute of Materials Research, Köln, Germany).

Acknowledgements

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