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Novel type of technology for biomass utilization

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This paper deals with utilizing biomass as a fuel in utility systems supplying heat covering demand in units of MW. Utility systems of small industrial plants or systems covering heat demand of blocks of flats or groups of buildings (small district heating systems, shopping centres) can be considered as typical representatives. Systems like these are mostly based on using fossil fuel which is not always utilized in an effective way, i.e. only for heat production (heat only boilers).

As a consequence of effort to substitute fossil fuels by renewable energy sources, a range of technologies based on biomass as a fuel has been developed during recent period. Small boilers for heating individual houses, as well as highly sophisticated systems covering demand of extensive networks have been operated.

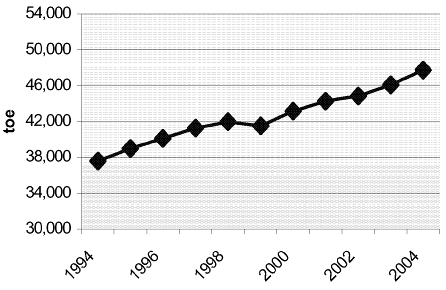
Several issues based on the facts given below are discussed in the paper. It is necessary to take into account that biomass represents a local source of energy. Therefore the longer the distance for transport, the lower the contribution from both environmental and economic points of view. Hand in hand with increasing price of natural gas this fact represents a logical reason for development of biomass boilers with medium duties. On the other hand it is necessary to provide investors with long-term profitable solutions to ensure support of more extensive biomass utilization. Principles of this approach based on made-to-measure solutions can be formulated as follows:

- Optimum choice of the boiler and its duty following the real demand of consumers, safety of energy supply and investigating all the possibilities to extend time of operation are necessary for design of an overall system.
- Flexibility in connection with the local biomass market and thus an ability to minimize the operational cost for biomass supply.
- High efficiency of a biomass unit with a wide range of operational regimes guarantees reduction of costs for energy generation.

To be able to meet the principles stated above it is necessary to have a technically feasible and cost-effective solution representing a driving force for development of units with medium energy output. This approach is analyzed in the paper and illustrated through practical examples.

1. Introduction

Although the efficiency of energy conversion from its primary sources to the useful forms is improving, the energy consumption is quickly increasing at the same time. Utilizing fossil fuels in order to meet rising demands has negative effects on the environment. Carbon dioxide concentration in the ambient contributes to the greenhouse effects and consequently to the global warming. In the past decade a number of technologies utilizing energy from biomass have been developed in order to be able to substitute fossil fuels with renewable sources [1]. Utilizing renewable sources of energy, especially biomass is one of the priorities of the EU energy policy. Biomass can be considered as a local energy source with ecological and regional contributions [2].
The amount of biomass used for energy production in the EU rises every year by about 2% to 3% (see Fig. 1). It is expected that in the future the growth will be much higher.



toe – Tonne of oil equivalent

Fig. 1 *Biomass utilization in EU* [3]

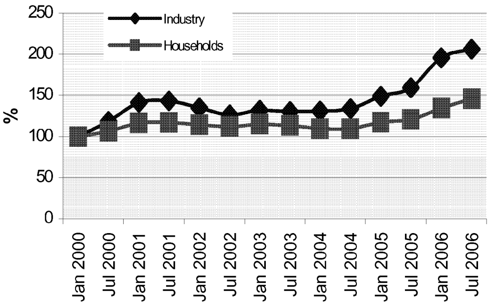


Fig. 2 *Trend in EU 15 gas prices [3]*

The following Table 1 provides an estimate of the potential of biomass development in the EU up to 2030.

Table 1 *Estimated development of biomass potential in EU 25 in Mtoe* [4].

Biomass source	**Biomass potential**		
	2010	**2020**	**2030**
Forestry residues	43	39 - 45	39 - 72
Organic waste from wood processing, agricultural production and food industry	100	100	102
Energy crops	43 - 46	76 - 94	102 - 147
Total	**186 - 189**	**215 - 239**	**243 - 316**

2. Optimal selection of biomass boiler capacity

In comparison to commonly used boiler types, biomass boilers have a different construction. Compared to gas boilers with the same capacity they are bigger and their dynamic characteristics is not as good. For these reasons it is advised to operate these boilers in a stable mode without sudden variations. This is possible, when biomass boiler covers only base demand. In this case the boiler is operated in a long-term steady state and produces majority of the overall heat. Energy peaks are covered by auxiliary (back-up) gas-fired boiler, which only operates during periods of time with increased heat consumption (e.g. peak load periods, winter months). Such a system may be referred to as multifuel system. In multifuel energy production plant the designed biomass boiler capacity is very important. It directly affects the economy (finding optimum trade-off between investment and fuel costs), efficiency as well as emissions.. An annual heat demand curve, current fuel prices (Fig. 2) as well as a number of other factors are considered in the procedure. The methodology of integration of biomass boilers into a large energy production system was described in [5].

3. Operation flexibility

The basic condition for efficient biomass exploitation, either provided from forestry, wood processing or fast-growing energy crops, is that it has to be combusted close to the place of its origin. Long distance transport considerably increases the fuel costs and also reduces positive environmental impact. From the investors point of view, feasible payback period can be reached only in the case of accessibility of low-cost biomass in the locality. It is always important to carry out a through analysis of biomass potential for the given area. This problem is further explored by various European projects [6]. Presently, the majority of operated biomass boilers are adapted only for one type of fuel, primarily due to various operational reasons [7]. Considering that the situation on the local biomass market can change quickly, up-to-date units, which take into account present trends, have to be able to process wide range of biomass-based fuels. This can guarantee independence of the plant on one type of fuel only and thus allows finding optimal operation in the case of increased fuel prices in the future.

4. Features guaranteeing high efficiency

It is a general fact that reducing concentration of oxygen in flue gas leaving the boiler has a positive effect on the overall efficiency of the system. Fig. 3 shows results of heat and mass balance calculations for varying oxygen content in flue gas and various fuels (from wet wood chips or saw dust with lower heating value of about 8.2 MJ/kg, to extremely dry wood processing industry waste with lower heating value of about 18.9 MJ/kg). Combustion air was considered to be not-preheated and temperature of flue gas at boiler output was set to 180 °C. By reducing the concentration of oxygen the efficiency of the boiler will be increased, but the concentration of O_2 cannot be chosen arbitrarily. It is necessary to provide sufficient excess oxygen to secure the conditions for complete combustion resulting in low emissions.

On the other hand extreme temperatures in the combustion chamber can be expected when processing extremely dry fuels or specific types of phytomass (e.g. straw). To avoid operational problems connected with agglomeration of ashes on the grate and fouling on the chamber walls or excessive thermal loading of the refractories, it is necessary to cool the combustion chamber by an increased input of cold combustion air. The significant raise in the boiler efficiency as a result of combustion of calorific fuel (see the trend in Fig. 3 for fixed 0_2 concentrations) is practically unattainable because of higher air excess ratio and subsequently higher oxygen content in the flue gas.

One of the features applied in up-to-date mid-sized units, which allow the performance with high thermal efficiency during combustion of different types of biomass and phytomass fuels in one unit, is recirculation of a significant amount of flue gas back to the combustion chamber. The most important results from a number of balance calculations are shown in Fig. 4. Flue gas recirculation can maintain pre-selected concentration of oxygen in flue gas even if fuel with higher calorific content is combusted whilst retaining acceptable temperature in the chamber. The chamber space is cooled by the recycled flue gas instead of additional combustion air. Oxygen contained in flue gas is reused. The input of combustion air then can be reduced, which has positive effect on boiler efficiency (Fig. 3). For a required temperature in the combustion chamber the optimum recycled flue gas amount depends especially on the target oxygen concentration (see Fig. 4). The curves in Fig. 4 were calculated for a secondary chamber temperature of 900 °C. The temperature of the combustion air was assumed 25°C or alternatively the air was preheated to 150 °C. It is evident that the lower the concentration of oxygen is required, the more flue gas is recycled. Using similar graphs based on balance calculations, other relationships and operation recommendations can be identified.

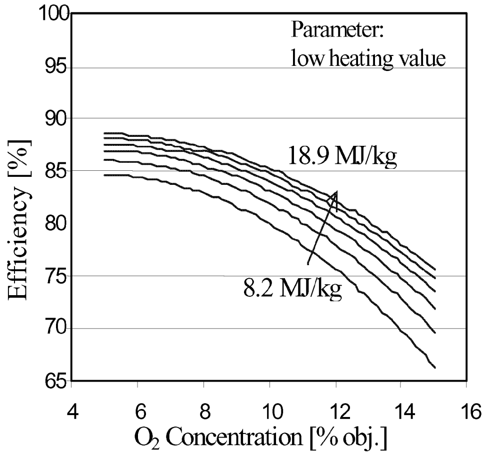


Fig. 3 *Relation between thermal efficiency and the concentration of O_2 in flue gas at the boiler outlet*

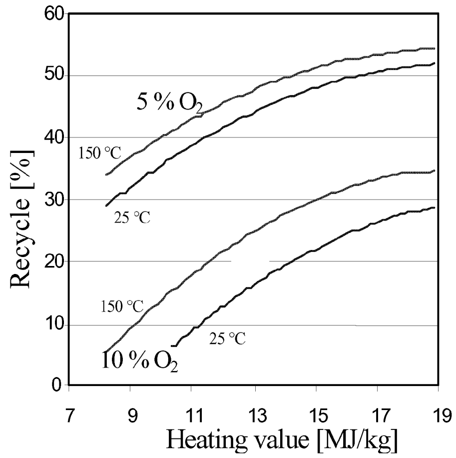


Fig. 4 *The recycled amount of flue gas selection chart*

5. Prototype of technology for utilization of various types of biomass

Regarding the above stated facts it can be concluded that in the future can be expected increased demand for up-to-date biomass boilers of medium capacity (i.e. units with an output of about 1 to 3 MW). Characteristic features in the development of such units are as follows:

- An effort to integrate field proven features of presently used technologies into the new unit. This includes measures contributing to high performance and operation flexibility (e.g. flue gas recirculation or air preheating).

- The possibility to combust various types of biomass from saw dust and wood chips to fast-growing energy crops (e.g. amaranth). Naturally all types of fuel cannot be processed in one unit. Especially straw fuels require a different boiler construction [8].

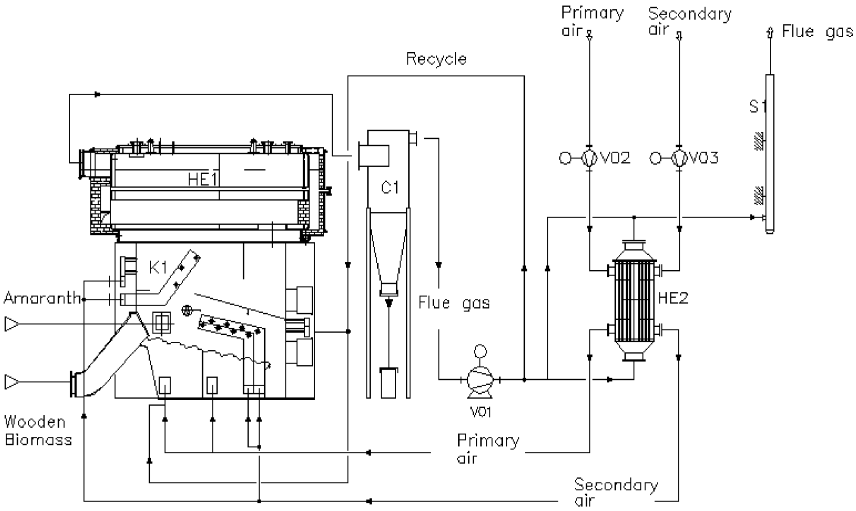


***Fig. 5** Simplified flowsheet of an up-to-date unit*

A flow sheet of an up-to-date unit and 3D model of its prototype are shown in Fig. 5 and Fig. 6.

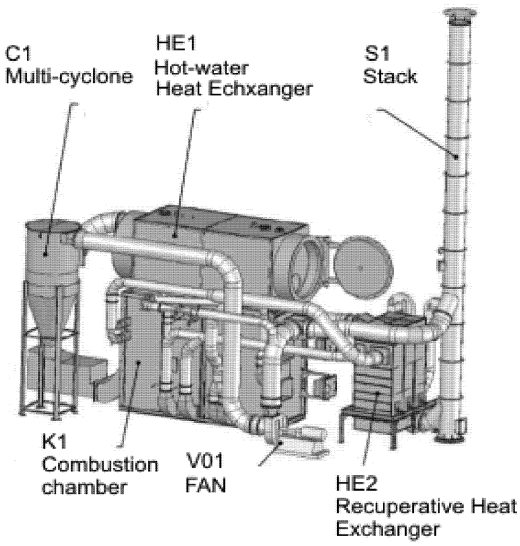


***Fig. 6** Prototype of technology for utilization of energy in various types of biomass*

The fuel feeding system consists of two separate paths for wooden biomass and for phytomass. The combustion process takes place on an inclined hydraulic grate and is completed in the secondary chamber (K1). The products of combustion then flow through heat transfer tube bundle in the heat exchange section of the boiler (HE1). The fly ash contained in the gas is removed in the multi-cyclone (C1). Induced draft fan is situated downstream the multi-cyclone (V01) and it is the only driving equipment of the flue gas stream from the combustion chamber to the stack (S1). Controlled amount of flue gas is extracted in the splitter situated downstream of the fan. Using this recycled stream, part of the flue gas is brought back to the combustion chamber. The rest of flue gas continues to special recuperative heat exchanger "flue gas – air" (HE2), where its sensitive heat is used for preheating of primary and secondary combustion air. The aim is to cool down the flue gas as much as possible and thus eliminate the stack losses. On the other hand excessive fouling caused by tarry compounds condensation has to be avoided. Flue gas cooled in the exchanger than goes to the stack (S1).

6. Discussion and conclusion

The main trends and problems linked to the utilization of energy contained in biomass by combustion in boilers with medium capacity were analysed in this paper. An example of up-to-date technology was used to describe the measures, which can enhance the efficiency and flexibility of operation. The flue gas recirculation was mentioned in more detail. Its significance has been evaluated on the basis of a number of balance calculations. The most important results of the calculations were demonstrated and discussed. Results of simulations (parameters of the main process streams) were used for a prototype design. The validity of the created and applied simulation model will be experimentally verified during operating measurements on a real unit.

7. References

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