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New unit for clean energy production from contaminated biomass (1 to 3 MW_t) – examples of process design

Quido Smejkal[a], Marek Šarlej[b] and Petr Stehlík[c]
[a)] QUIDO-Engineering Berlin, Wassermannstr.52, 124 89 Berlin, Germany
Tel.: +49 306 097 5777, quido@quido-engineering.com
[b)] EVECO Brno, s.r.o., Foltýnova 17, CZ-635 00 Brno, Czech Republic
Tel./fax: +420 544 527 231, E-Mail: eveco@evecobrno.cz,
[c)] Brno University of Technology, Faculty of Mechanical Engineering,
Technicka 2896/2; CZ-616 69 Czech Republic; stehlik@fme.vutbr.cz

This article presents a new modern unit for energy production from contaminated biomass and/or alternative fuels, notable for its efficient integration of proven technological solutions into one unit. Its combustion chamber, heat utilisation system, flue gas cleaning system and flue gas heat utilisation are described in details. The technological unit provides high efficiency and low operating costs and therefore constitutes a highly competitive solution.

The focus of the process integration was given at the versatile utilisation of common waste raw materials. Not only wood chips or straw, but also contaminated waste material is of peculiar importance for new customers in this sector. Thus, the process parameters of the combustion unit as well as those of flue gas cleaning system were adjusted to different feedstock. The feedstock for our special system comprises for example raps oil rests, sunflower shells, oily waste from animal food manufacturing or wooden chips contaminated by animal excrements (i.e. from breeding branch - horses or dairy cattle). Another application can be found by the conversion of the rests from human doings. Thus, the baby nappies (from old and impuissant people inclusive) as well as waste from hospital and surgery establishments can be converted to the green energy.

1. Introduction

A new modern unit for energy production from contaminated biomass and/or alternative fuels was developed and designed with the aim to offer an efficient and environmental friendly solution for utilisation of contaminated bio-mass for energy generation [1]. The energy is produced by direct combustion with subsequent heat utilisation for heating, production of hot service water or for power production. The unit is therefore not only a "biomass boiler", but a highly efficient technological equipment allowing to treat contaminated biomass-based material in environmentally-friendly way and efficiently

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use maximum of energy, contained in the flue gas. The description of highly non-ideal combustion technology with respect to process and environmental control is the topic of presented contribution.

2. Description of the unit

The newly designed unit, shown in Fig. 1, is notable for its efficient integration of proven technological solutions and reflects present day's needs and the necessity to utilise waste biomass or biomass-based alternative fuels for the production of energy in ways regardful of the environment [2]. A significant advantage of this technology is the ability to utilise biomass contaminated e.g. by paints, varnishes, adhesives, sealants, oils, or biomass produced in bioremediation wetlands.

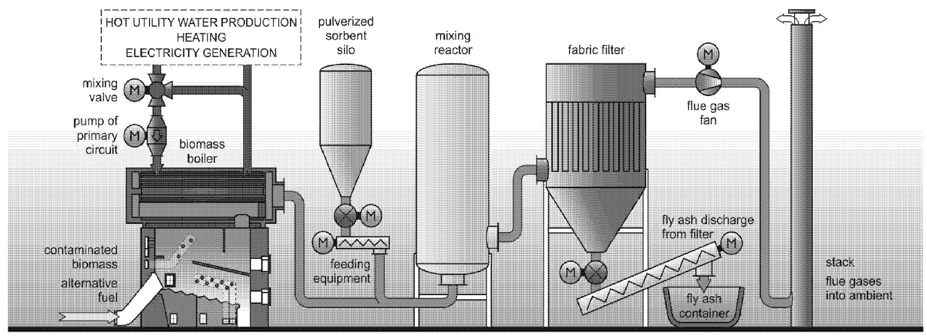

Figure 1: Technology overview

Schematic layout of the technology is provided in Figure 1 above. The unit consists of five basic operational systems:

1. storage, pre-drying and fuel conveying into the boiler
2. combustion chamber with an inclined hydraulic grate
3. flue gas heat utilisation
4. flue gas cleaning
5. residual flue gas heat utilisation

Conveying of fuel into the boiler is always customised for a specific type of biomass. In particular, the conveying system is robust hydraulic equipment, able to process occasional over-sized pieces of biomass and insensitive to the presence of small undesirable objects (e.g. stones). The system always requires a specific size of fuel lumps (maximum about 100 mm). When the available biomass is unsuitable for the conveying system, the unit may be additionally equipped with fuel pre-processing equipment (grinder, chipper, shredder, etc.). Additional pre-drying system may also be installed.

The fuel is fed into the boiler through a water-cooled upward channel, where it is pre-heated. From the channel, the fuel falls onto an inclined hydraulic grate with four combustion zones, flue gas recirculation and preheated combustion air inlet. Part of secondary combustion air is supplied into the primary combustion chamber directly above the grate. The rest is fed into the secondary combustion zone, ensuring complete combustion, as required by valid legislation for VOC and CO emissions.

Flue gas from the secondary combustion zone goes into a three-pass heat exchanger, which is the primary heat utilisation device. This system comes in variations corresponding to standard heat utilisation approaches (heating + hot service water production in warm-water systems, technological hot water production in hot-water systems, steam production for technological applications, heat and power cogeneration).
From the heat exchanger, flue gas enters the dry cleaning system. This system is designed to secure compliance with valid emission regulations on acid gases, heavy metals and particulate matter. The system uses injection of suitable adsorbents that react with the fuel gas in the following contact reactor. Collection of particulates is provided by fabric filter. In exceptional cases of high concentration of nitrogen compounds in the biomass, NO_x removal system may be included. This part of the unit is always designed for the specific needs of every application, according to the specific fuel type, and is one of the main parts of know-how of the producer.
Part of flue gas after cleaning is fed by flue gas fan back into the primary combustion chamber. The remaining flue gas is further cooled in residual heat utilisation system. The main equipment is here a modular recuperative unit, in which flue gas preheats the combustion air. The last module of the recuperative unit may be designed as condensing, in which case the energy content of the biomass is used almost completely and thermal efficiency of the unit is very high.
The unit is fully automatic, does not require any permanent operating staff and is remarkable for its high user comfort. Operation control is possible through operator's PC. The system may further be equipped by remote monitoring or full remote control system through a web-based interface.
The above described unique integrated system provides high efficiency and low operating costs and therefore constitutes a highly competitive solution for the utilisation of contaminated biomass and other alternative fuels.

3. Results and discussion

3.1 Combustion chamber

The combustion chamber is equipped with a hydraulic grate and consists of a primary combustion zone and secondary combustion zone and within the technology represents the most important process part. The hydraulic grate is water-cooled and has two separate sections of primary air supply. Primary air distribution into these sections may be tuned for each specific type of biomass. Fuel properties also govern the amount of recirculated flue gas, which is brought under the grate together with primary air, as well as flow rate of secondary combustion air supplied directly into the combustion chamber (i.e. above the grate) and the temperature of preheated air (in the range from 80 to 130°C). During development of the unit, the locations and number of secondary air ports and flue gas recirculation have been optimised using CFD (Computational Fluid Dynamics) modelling [3]. An example of the CFD results is included in Figure 2. All these measures have a common target – to optimise the combustion process.
During grate combustion, fuel gradually moves through four zones, associated with specific processes occurring in the moving fuel bed. In the first zone, fuel is dried by the common action of high temperature and radiative heat flux. In the second zone fuel undergoes pyrolysis, which means that volatile fraction of combustible matter is

released and subsequently burns in the combustion chamber. Third zone is characterised by combustion of fixed carbon, bound in solid fuel residues. In the last zone, ash is cooled by primary combustion air supplied under the grate, which is followed by ash fall-out into ash pan.

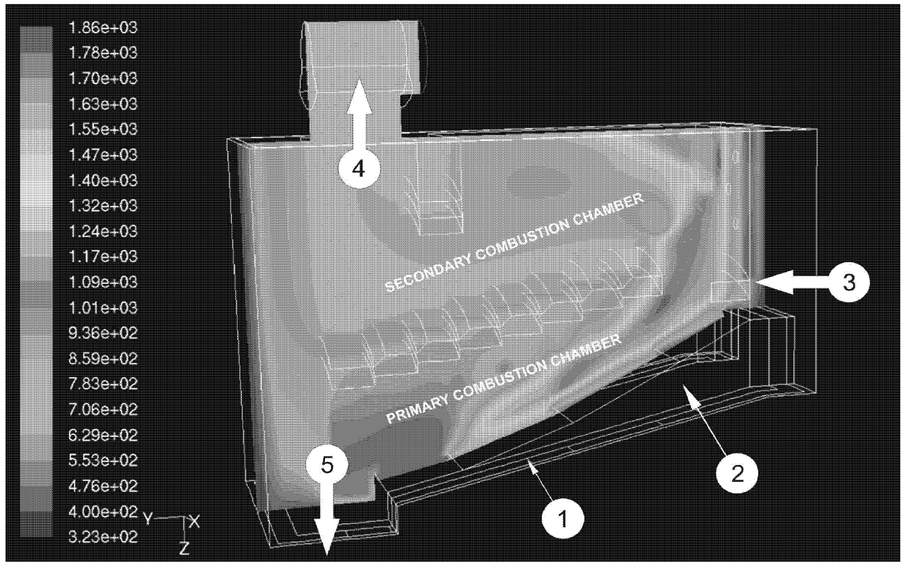

Fig. 2: *Temperature field in combustion chamber, predicted by CFD modelling [K]*
1 – Inclined grate, 2 – Layer of fuel, 3 – Fuel inlet to the grate,
4 – Flue gas outlet, 5 – Ash discharge

The amount of recirculated flue gas is between 10 and 35 % of flue gas leaving the combustion chamber. Recirculated flue gas enhances the pyrolysis process on the grate, while enabling lower excess air amount. Generally, lower excess air amount increases efficiency of the unit as a whole. The O_2 concentration however cannot be decreased arbitrarily – there must always be enough oxygen for complete combustion with low emissions. It is also necessary to avoid too high temperatures, which may cause ash slagging and fouling, as well as excessive heat loads to the refractories that could damage the combustion chamber. Flue gas recirculation offers a means of re-using oxygen contained in the flue gas and decreasing outlet oxygen concentration below 10 % vol., while securing suitable temperature levels in the combustion chamber. This was confirmed during combustion tests on the reference prototype when the oxygen concentration in flue gases was ranging from 7.5 to 9.5 vol. % at temperature from 800 to 870 °C in the combustion chamber.

The volatile combustible matter, released from fuel on the grate, must be completely oxidised (combusted) in the secondary combustion zone, which is equipped with an optimised air supply system. Geometry of this part of the combustion chamber is designed to ensure sufficient turbulence intensity and residence time under required temperature levels. This secures achieving VOC and CO emission levels below values required by legislative regulations.

3.2 Heat utilisation system

The heat contained in the flue gas stream may be utilised to generate various utilities like hot water, steam or electricity. Configuration of the heat utilisation system (the boiler's main heat exchanger and utility extraction system to individual consumers or networks) is governed by specific needs in each individual application. The technology is realised to produce either warm or hot water or medium-pressure steam. These utilities may serve for various purposes including heating, hot service water production, technological heating or other industrial process, or cogeneration of electricity.

Electricity production is implemented using a proven, simple and reliable solution based on "classical" Rankine water steam cycle with expansion on a small turbine, where steam, typically with pressure about 15 bar(g), expands on a pressure of about 1 bar (g). The decompressed steam from electricity production is then utilised in a heat exchanger, typically producing hot water for heating. During summer periods (when steam is not cooled by water used for heating), the technology typically wastes the superfluous heat in contact air coolers. In cases when the required target is maximum electricity production (without heating), it is possible to use a condensing turbine.

3.3 Flue gas cleaning system

Combustion of contaminated biomass produces flue gas, which may contain various harmful compounds as for example nitrogen oxides, carbon monoxide, volatile organic compounds, acid compounds (SO_2, HCl, HF), heavy metals and fine particulate matter (fly ash). Due to this fact, the unit must be equipped with appropriate flue gas cleaning equipment for collection of those polluting substances that may appear in each individual application (depending on fuel parameters). Formation of CO and volatile organic compounds is generally minimised by optimised design and operation of the combustion chamber, as these species are the products of incomplete combustion. Sufficiently high temperature in the combustion chamber, together with appropriate design of secondary air supply system and flue gas recycling ensure almost complete oxidation of these species. The products of this oxidation are water and carbon dioxide.

Sufficient contact time of flue gas with both agents is ensured by a specially designed rector, whereas the process continues also at the surface of filtration material in fabric filter, collecting both agents together with fly ash and products of neutralisation (salts).

Fabric filter extends the time during which flue gas is in direct contact with the adsorption agents and this way, it improves the efficiency of removing both acid compounds and heavy metals. For the filter fabric, it is important that operating temperature is maintained (depending on the specific fabric) in the range from 180 to 230°C, but does not exceed 240°C, otherwise the filter could be destroyed. Respecting this condition is ensured by proper design of the process and the whole unit.

3.4 Residual flue gas heat utilisation

Flue gas exits the cleaning section with a temperature around 220°C. Such temperature level is sufficient for combustion air preheating, which is a significant contribution to the efficiency of the whole unit. The air streams (primary and secondary) are preheated to temperature from around 80 to 130°C (the concrete level depends on prescribed stack temperature of flue gas). The process is performed in a modular recuperative unit, where material of the modules and outlet flue gas temperature of each module are chosen according to humidity and residual sulphur content in the flue gas (considering

the risk of H_2SO_4 condensation, which typically occurs in these applications below 120°C).
Maximum utilisation of heat contained in the biomass fuel is achieved with a condensing stage, included in the recuperative unit. The heat exchanger is in this case made of stainless steel, with vertical tubes in which flows the flue gas and on the outside is the heated medium. Condensate collected at the outlet is sprayed back into the flue gas at the inlet section of the heat exchanger, thus washing the flue gas side of heat exchanging surfaces and preventing fouling. The rate of condensation in flue gas depends on the type of heated medium. When the heated medium is cold water, then condensation is maximised.

4. Conclusions

A new modern unit for energy production from contaminated biomass and/or alternative fuels, notable for its efficient integration of proven technological solutions was presented. Focus was given on the most important part of the technology, on the combustion chamber of the boiler. Depending on the feed used, a complex description of the temperature profile along 3D boiler chamber was illustrated. Derived from the CFD calculation and optional experimental verification it can be withdrawn a necessity of in-depth and customer-tailored prediction of combustion behaviour of every type of contaminated biomass.
Described unique unit provides high efficiency and low operating costs and therefore constitutes a highly competitive solution for the utilisation of contaminated biomass and other alternative fuels.

5. Acknowledgement

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