International Conference on Renewable Energies and Power Quality (ICREPQ'13)
Bilbao (Spain), 20th to 22th March, 2013
Renewable Energy and Power Quality Journal (RE&PQJ)
ISSN 2172-038 X, No.11, March 2013

Integrated Gasification of Biomass Residues (IBGCC)

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Abstract. A comprehensive outline of a new approach in integrated gasification of biomass residues including the material flow management in urban areas being targeted on the generation of electricity and district heating is presented. The feedstock is derived from civilian material by fully automated collection, sorting and separation. Thereby an outward transfer of inerts is executed, such as minerals, metals, glass and electronic scrap as well as sorted plastics being object to recycling. Finally a ligno-cellulosic and a non-lignocellulosic fraction are gained. The former one is suitable for thermochemical conversion, the latter one for biological conversion into fuel gases which subsequently are oxidised completely at low air excess in a horizontally arranged cyclone combustion chamber. The heat recovered from the flue gases in the utility boiler is used to generate steam scooping in the supply of electricity and district heating. The basic design is scaled to an overall thermal capacity of 2-5 MW. This type is most capable of utilising renewable energy by converting the organic fractions of civilian material flows. The power plant is based on a reliable technology representing an on-site integrated biomass gasification combined cycle system including peripheral units specified for the treatment of complementary materials.

Key words

Power Plant, Co-Generation, Energy Efficiency

1. Urban Area Design

Urban area design globally has become a strongly technology orientated methodology. It connotes various conceptions of energy efficiency and rational energy use, applications of renewable energies and reusable materials, measures of local material flow management and achievements of advanced ecological and architectural works. These constructions are to be premised on a modern infrastructure both for inter- and intra-metropolitan purposes.

Paradigmatic implementations were already taken into consideration, e. g. in the Allende or Heidestrasse district in central Berlin in Germany and in the town of Fu Yang

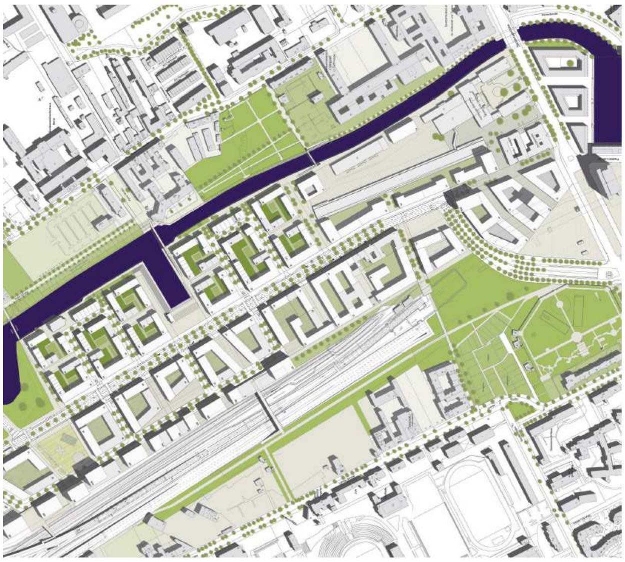

Fig. 1. Urban area to be reconstructed in the city of Berlin.

in East China, the former ones being re-designed areas and the latter one a so called drawing board city (Fig. 1). The size is approximately 0.4 - 4 square kilometre and ten to hundred thousand inhabitants. The principal characteristics include a central power plant, regional and local district networks for electricity supply, heating and cooling, photovoltaic and solar-thermal systems, low-emission techniques and the reuse of water [1].

2. On-site conversion process chain

Following these basic findings a technical concept including a reliable technology of an on-site conversion process chain has been exposed. It is based on the thermochemical and biological conversion of biomass residues derived from civilian material flows via integrated gasification and peripheral units specified for the treatment of complementary materials (Tab. I). The gasi-

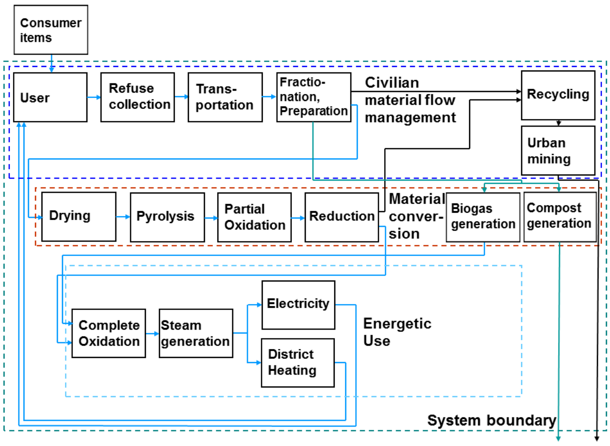

Fig. 2. Material flow management.

fication processes are proportionated to a thermal capacity of 2-5 MW, and therefore being of remarkably lesser throughput than even the solid municipal waste gasification processes reviewed recently [2]. In the context of innovative urban design concepts the specific type of energy conversion system is re-designed and custom-engineered in order to be most compact featuring a Rankine cycle, consequently [3]. Thermochemical conversion processes are assessed to be an important element of elaborated and integrated material flow management, which generates a remarkable surplus in material and energy efficiency by electricity and heat supply based on a lower demand in fuel and money compared to combustion or alternative routes [4].

3. Systems technology

Reffering to this basic scenario the integrated biomass gasification combined cycle system is constituted by the material flow management including recycling and urban mining, the material conversion as well as the energy conversion and the networking sub-systems (Fig. 2). To a large degree the energy supply is basicly designed as an internal semi-closed loop sub-system, except additional replenishments by imports from the exterior or exports to the public grid, and consumer items represent the significant input of the system.
A comprehensive study of the present situation was carried out which showed that two thirds of the annual mass flow consists of biomass residues. Reffering to investigations of the corresponding situation in Asia even larger fractions of biomass residues can be found [5].

Table I. – Fractionation of civilian material

CIVILIAN MATERIAL FLOW PER CAPITA	
Type	Mass Flow
$kg \cdot a^{-1}$	
Domestic waste	170
Bulky refuse	30
Valuable Material	143
Unspecified waste	2
Organic waste	110
Greencut	410
Total biomass residues	520

A. Material Flow Management

The material flow management follows the principles of a fully automated waste collection (AWCS) and sorting system (AWSS) with a hermitically sealed transportation tube system and interlocks either on the sides of the user, the material and energy conversion system and the suplementary units.
In order to get the biomass residues as stable and ash-free as possible three major fractions have to be processed: Inerts, non-linocellulosic organics and lignocellulosic organics. The first ones including minerals, metals, glas and electronic scrap. The second one, being the major proportion in tropic and subtropic regions, needs biological processing with the aim of generating biogas from the wet sub-fraction and compost using the dry parts. In particular the fermentation path to generate biogas and the rotting processes to gain compost are useful in rural areas due to the large mass fractions and the high temperature and humidity.
According to the state of the art the remaining ligno-cellulosic fractions of organics are conditioned for the thermochemical material conversion processes. In some cases it would be preferable to manage an average grain size of 5 centimetre, but briquetting has not necessaringly to be practised because there are cold binderless rolling techniques, too.

B. Material and Energy Conversion System

The technology of integrated biomass gasification combined cycle represents an innovative approach to a non-centralised strategy of material flow management and energy supply adopted to an urban situation.
At present the work is concentrated on a prototypic configuration with a thermal capacity of 2 to 5 MW. There are three companies and three test facilities involved carrying out experimental investigations, numerical calculations and constructive work. In this context profound expertise exist concerning components as well as complete material and energy conversion systems for several types of biomass with ash fractions up to 5 Mas.-% and even larger thermal capacities.
Both the thermochemical and biological gasification sub-system consist of a pair of reactors being very robust under parametric fluctuations of the fuel, which is fed in generally from above via buffer storage with charging screw, while the generated gas leaves the reactors at the top.
Each of the thermochemical reactors has a hexagonal cross section and consists of six tube panels with a likewise water cooled lid and a water cooled grate integrated into the feed water system of the boiler. From the constructional side of view it is the simplest variant of a polygon of high order in similarity of a perfect cylinder [6]. The drying zone is in the upper part of the gasifier, where steam accumulates in the gas, volatile salts and oxides, too. Due to pyrolysis processes mainly the volatiles are separated from the remaining solid fuel and converted into highly calorific compounds. In the lower third of the vessel the reduction reactions take place, wherefor the Boudouard- and the Water Gas-Reaction are the significant conversion processes to generate the synthesis

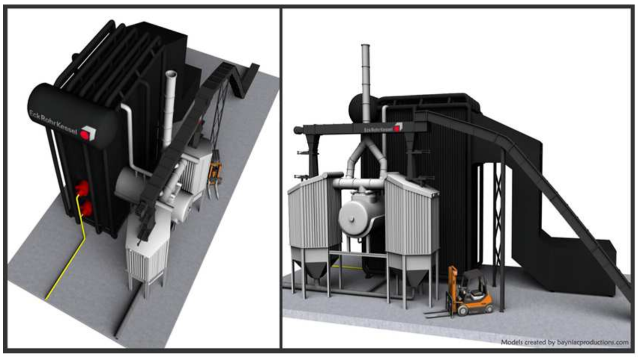

Fig. 3. 3D-Model of twin gasifier, combustor and boiler.

Gas all in all following complex kinetics. All these coupled reactions are driven by the enthalpy of the exothermic, substoichiometric oxidation reaction of the solid fuel at the bottom of the gasifier.
Regarding the reactor walls a definite spiral surface structure was developed and installed by which the boundary near disturbances in the particle distribution could almost perfectly be avoided. This truly newest innovation of definite spiral surface structures on the inner walls effectuates a significantly higher heat transfer coefficient between the bulk fuel grains and the reactor vessel. Thereby not only the velocity of the gasification agent air became 35 % greater at constant volume flow, but also the lower heating value of the product gas was increased by 25 %, implicating that the whole gasification process is shifted advantageously towards a more beneficial state of equilibrium. Table II shows in the first and the third columns the corresponding values using a model fuel of wood spheres and of untreated residues in the second and forth column.

Table II. – Thermochemical Gas Quality

LOWER HEATING VALUE			
$H_{u,WGP}$	$H_{u,RGP}$	$H_{u,WGS}$	$H_{u,RGS}$
$MJ \cdot m_N^{-3}$			
2.2	1.83	2.71	2.21
Plain Walls		Structured Walls	

The connection between the gasifiers and the cyclone combustion chamber located downstreams directly above the reactors consists of two short tube pipes with a large cross section. The combustor has a cylindrical design, horizontally arranged, with water cooled walls and ceramic protection coating. The water circulation is integrated with the boiler operating either as an evaporator or a preheater. The synthesis gas enters tangentially at low temperatures via ring nozzles and forms a rotating gas body, effecting the separation of larger particles towards the wall, which are then retained by a concentric ring. By doing so and keeping the air excess low, minimum temperatures of 1000°C and sufficient long residence times are achieved.
At Present the main task is focussed on the re-engineering, calculation and construction of the product gas combustor. Therefore a physical concept of the flow regime was formulated which was used to outline a new construction suitable for the combustion of gaseous fuel. Based on these considerations a geometric design including fluid mass flow was developed, optimised and meshed using ICEM-

Fig. 4. 2.2 Mio. optimised meshing of the combustor (ICEM).

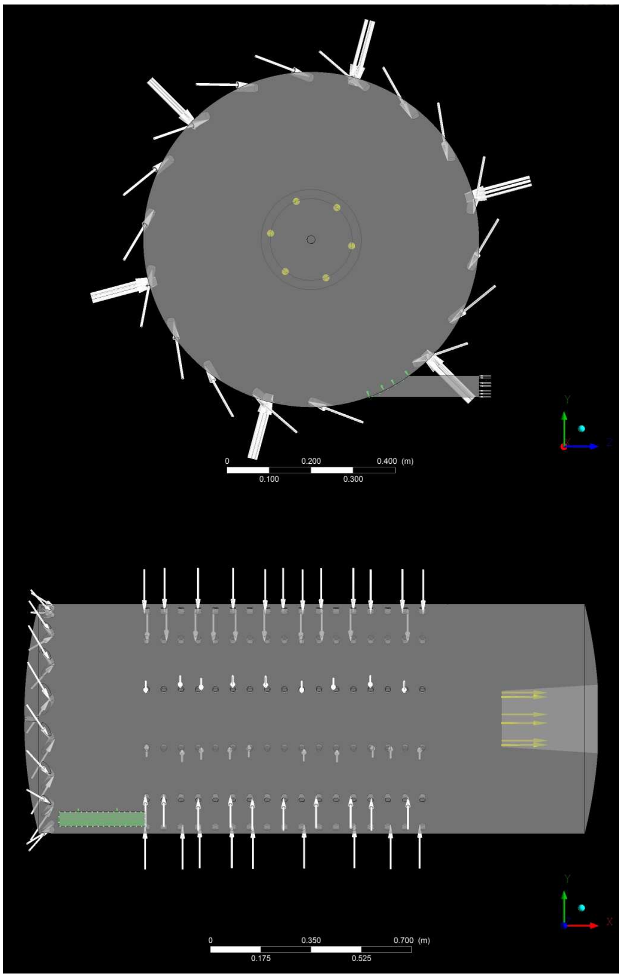

Fig. 5. Boundary Conditions of numerical calculations (CFD).

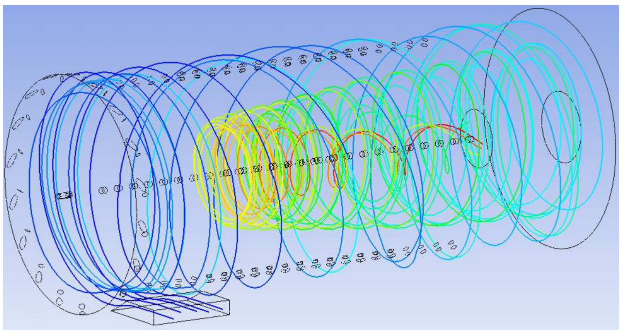

Fig. 6. Resulting streamlines calculated numerically (CFD).

Software (Fig. 4). Finite Volume Method and the 2.2 Mio. cells were used to carry out virtual experiments with systematically varied parameters by numerical calculations. The requirements include the definitions of the necessary boundary conditions at the surface as well as the in- and outflows of the model (Fig. 5). For example

the results of one virtual experiment out of a couple of others indicate a double reversed fluid flow starting from the gas inlet with nearly constantly decreasing circulation radius until it leaves the chamber through the flue gas outlet (Fig. 6). Methodically the calculations were executed using a turbulent k-ω-SST sheer stress model.
In the case presented here the combustor is integrated on the gas side with a three passed corner tube boiler and superheater, consisting of a radiation chamber and convective heating surfaces in the second and third draft. The steam supplied propels a so called pre-designed rotational working machine generating electricity with remarkably increased electric efficiency compared to a conventional system.

4. Conclusion

The presented concept of a local energy plant corresponds perfecty with the polygeneration of biogas and the requirements of the technologically orientated construction or re-construction of urban areas wourld-wide.
The particular type of a two-stage integrated biomass gasification combined cycle system being part of a material flow management process chain for provides a remarkably higher efficiency and reliability than conventional combustion plants.
The systems is based on a Rankine cycle with thermal capacities of 2 to 5 MW in conformance with the standards of best available technology (BAT). Moreover synergetic impacts of an innovative surface structure technique result in intensified heat and mass transfer, whereby an increase of exchange process intensity, demonstrated by the improvement of the synthesis gas quality by 25 %, and a reduction of deposit formation are achievable. Although the absolute lower heating value of synthesis gas from biomass residues indicates a lean gas, it can easily be upgraded by mixing it with methane rich biogas, anyway.
Moreover investigations of the life cycle costs showed clearly, that this kind of renewable energy plant could add significant contribution margins allocated to the overhead expenses which have to be payed by the public in general.
Assuming a averadge lifetime of 25 years the corresponding reduction in Global Warming Potential amounts 200.000 t CO_2-equivalents, if the quantity of energy has to be supplied by the consumption of conventional sources. Finally we conclude, that the demonstrated integrated biomass gasification combined cycle system coordinated with the co-generation of biogas and a material flow management is a challenging option, paticularly regarding combined thermochemical and biological conversion of biomass residues gaining a gaseous fuel to run a Rankine cycle. This will significantly contribute to solving the most important tasks of strengthening the highly efficient use of renewable energies and climate change precaution.

Acknowledgement

The Federal Ministry of Economics and Technology for grants by the Central Innovation Programme SME.

Federal Ministry of Economics and Technology BUSINESS. GROWTH. PROSPERITY.

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