КОМБИНИРАНО ПРОИЗВОДСТВО НА ТОПЛИННА И ЕЛЕКТРИЧЕСКА ЕНЕРГИЯ, ПОСРЕДСТВОМ ГАЗИФИКАЦИЯ НА БИОМАСА С „ТОПЛИННИ ТРЪБИ - РЕФОРМЪР“

Илия Илиев, Ангел Териев, Веселка Камбурова

В настоящата работа се прави анализ на система за комбинирано производство на електрическа и топлинна енергия, чрез газификация на биомаса, посредством използването на система „топлинни тръби-реформър“. Специално внимание се отделя на процесите на производство на синтетичен газ в реформъра, неговото очистване и последващо изгаряне в когенерационна система. Направен е кратък финансов анализ по отношение на вложените инвестиции и генерираните печалби от едновременното производство на електрическа и топлинна енергия.

COMBINED HEAT AND POWER PRODUCTION THROUGH BIOMASS GASIFICATION WITH “HEATPIPE-REFORMER”

Iliya Iliev, Angel Terziev, Veselka Kamburova

The current report aims is to analyze the system for combined heat and power production through biomass gasification with “heatpipe-reformer” system. Special attention is paid on the process of synthetic gas production in the Reformer, its cleaning and further burning in the co-generation unit. A financial analysis is made regarding the investments and profits generated by the combined heat and power production.

INTRODUCTION

Combined heat and power process also known as cogeneration, is the simultaneous production of thermal and electric energy from a single fuel source (oil, gas, biomass, biogas, coal, etc.). Currently the CHP systems are affordable not only for commercial buildings but also for homeowners. The CHP engines producing electricity that can be internal combustion or Stirling engines. The micro-CHP installations applicable for residential buildings usually run on propane, natural gas, or even solar energy or biomass. The CHP systems offering combined heat and power have efficiency of approximately 90%.

Here is reviewed the CHP system by using biomass as a fuel source. The process of the syngas production is through biomass gasification accomplishing in the so called “Heatpipe-Reformer”. Currently such power plants produce up to 400kW electric energy and 630kW thermal energy. The calorific value of the syngas produced by the process of biomass gasification reaches up to 11 000 kJ/m3 or more than double the values of autothermal gasification process. The total efficiency of the power plant is 80%, as cold gas efficiency is in the amount of 70%, electrical efficiency is 30% and thermal efficiency is 50%.

GENERAL INFORMATION ABOUT CHP POWER PLANT

The biomass installation consists of one main building, the biomass storage and the steel container for the co-generator. The synthetic gas system contains three levels and has outer dimensions of (WxDxH) 9x9x12 m. The frame of the building is composed of pre-fabricated steel beams, which are assembled on site and is covered by a normal facade.

Scheme of the biomass installation is presented in Figure 1. The plant is comprised of three separated constructional units: the fuel storage, synthetic gas system and the combined heat and power plant.

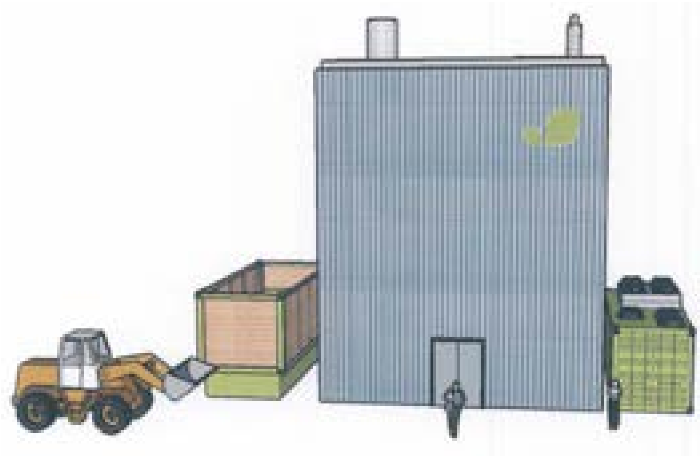

Figure 1 Principle work of the installation [1]

The CHP system goals are the production of electric energy for selling to the local electricity company, and the production of thermal energy for selling to a wood waste delivery company and greenhouses.

The annual consumption of wood waste material is 2 475t/yr. 15 % of the wood chips, or 0.371 t/yr, will fired to supply heat to the burning chamber, the rest will be consumed by the plant during the pyrolysis process.

The raw material is wood waste from the wood industry (branches, tree-tops, trunks, rind peelings and etc.) and wood pellets. The wood waste is delivered from the biomass storage to the heatpipe-reformer. In bottom of the heatpipe-reformer, the biomass is burned and in the top part, the biomass is heated for syngas production. Then the syngas is cooled with water before entering the cyclone filter. The cooled syngas passes through a cyclone filter where the hard particles like coke are separated from the gas. The water, heated and evaporated with the excess heat from the gas in the steam production system, is returned to the top part of the heatpipe-reformer as steam for improving the syngas's production environment. The exhaust gases from the burning process are filtered before being cooled. The hard particles, are separated from the syngas, are then returned for burning. The heat from the cooling syngas is then combined with the excess heat from the syngas to improve the conditions of the gasification process. After the hard particles are separated, the syngas undergoes chemical cleaning using bio-canola methyl ester (i.e., biodiesel) and the temperature of the gas is regulated to obtain the optimal temperature before entering the gas engine.

The waste products of the chemical cleaning are separated in a settling tank and the particulate residue is returned to the burning chamber, while the remaining ester is delivered to the rinse. The exhaust gases of the gas engine's burning chamber, after cooling, pass through a cyclone filter where the ashes are separated from the exhaust gases. After filtration the cleaned exhaust gases are mixed with the exhaust gases of the gas engine and the combined exhaust gases are released through the chimney.

THE PROCESS OF GASIFICATION AND CALCULATION OF ENERGY PRODUCTION

The biomass installation's heatpipe consumes 330 kg/hour wood waste (49.5 kg/hour for burning and 280.5 for syngas production) and generates approximately 250kg/h biogas. The efficiency of the gasifier is approximately 80%.The annual wood waste consumption of the gasifier is 2,104 t/yr. The components of the syngas are shown on Table 1.

The components of the syngas after the gasifier Table 1.

The gas components					
CO_2	CH_4	CO	H_2	H_2O	N_2
17%	12%	20%	37%	6%	8%

The cleaned syngas is burned in the gas engine, producing electricity and heat. The syngas fired in the gas engine is provided at a rate of 320 Nm^3/hour and it has caloricity 2,582 kcal/ Nm^3. The caloricity of the syngas is calculated by the methodology provided in [2], according Eq. 1. Result is presented in Table 2.

Content of gas fuel Table 2.

CH_4	C_2H_6	C_3H_8	C_4H_{10}	C_4H_{10}	C_5H_{12}	C_6H_{14}	Σ	Q^r_i
%	%	%	%	%	%	%	%	**kJ/m^3**
12							100.00	**10812**
CO_2	CO	H_2	O_2	N_2	H_2O	H_2S		Q^r_i
%	%	%	%	%	%	%		**kcal/m^3**
17	20	37	6	8		0		**2582**

$$Q_i^r = (0{,}108H_2 + 0{,}126CO + 234H_2S + 0{,}358CH_4 + \\ + 0{,}638C_2H_6 + 0{,}913C_3H_8 + 1{,}187C_4H_{10} + 1{,}461C_5H_{12}).1000,\ kJ/nm^3 \quad (1)$$

Heat pipes are sealed pipes filled with a working fluid. The working fluid – for example sodium or potassium – evaporates in the heating zone and condenses in the cooling zone of the heat pipe. The heat transfer coefficients in this process are considerably higher compared with pipes filled with flue gas so that the heat input is only limited by the (already very high) heat transfer from the pipe surface to the fluidized bed.

The heatpipe-reformer technology is based on the allothermal steam production process. The heat supply (the burning chamber) and the endothermic steam production are separated. Both reactors are fluidized beds, which enhances the optimized setting of the process parameters. The burning chamber is fluidized with sand and air and the reformer with sand and steam. The heat from the burning chamber is transported into the reformer in the heat pipes. The transport of the heat via the heat pipes is performed by evaporation and condensation of the work medium in the closed-off pipes of the heat pipes. In this way, high specific thermal power can be transported under low temperature differences.

The burning chamber is located below the reformer and the combustion process accomplishes in a low under-pressure media created via a draught ventilator. An adjustable conveyor system for dosing the wood chips is used for supplying the burning chamber with fuel. The temperature in the burning chamber can be adjusted by the amount of fuel and the amount of combustion air provided. The generated hot materials are then used for producing heat in order to reduce heat losses from the burning chamber. Intermediate products (residual coke, slurry) are used for starting-up the process. These intermediate products originate in the synthetic gas filter (residual coke) and the rinser, and they are added to the burning chamber for refiring. In Figure 2 is presented the heatpipe-reformer with the accomplishing processes.

In the reformer system the production of syngas and the endothermal reforming is performed in pressurized environment. Therefore, the conveyor systems for the bedding material and the fuel have pressure locks. The fuel is entered into the reformer from the top. The fluidized beds are kept in suspension and sand is used as a heat carrier.

The steam required for reforming is produced in the steam production system via the heat exchanger. It is operated in a natural cycle. The main sources of heat are the two main gas streams: flue gas and syngas. The process steam is generated in the steam drum. Excess steam is cooled with water from the heat transfer system, which transfers energy during the process.

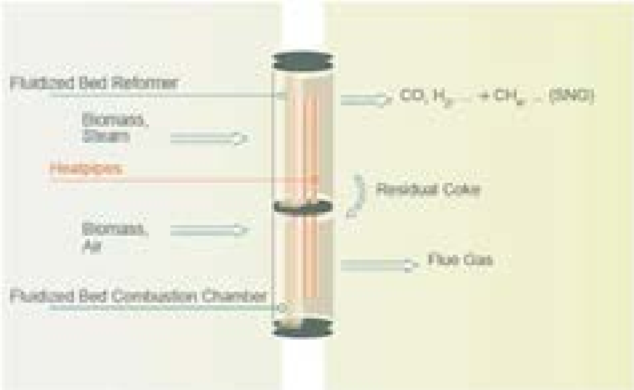

Figure 2 Picture of heatpipe-reformer [1]

The flue gas is lead through a heat exchanger in the steam production system. Thereafter, the cooled flue gas is cleaned, in addition to the connected cyclone, via dust filter for ash particles. A conveyor system transports the ash to an ash container. The filtered flue gas is lead into the smokestack with a suction draught.

A flare is required for starting and stopping the plant when the gas engine is not in operation. As soon as the syngas is continuously produced, the gas engine is operated and flaring ceases. When the plant stops, this process is reversed. The gas engine is turned off and the flares burn off the gas until the gas production is ceases in the heatpipe-reformer.

The cooled gas, which contains particles, flows into a synthetic gas filter in which sand and particles are separated. The dry filtration on the cooled, particle-laden synthetic gas occurs above the dew point of tar at 300°C. Bedding materials from the fluidization beds, coke from thermo-chemical biomass, are separated. The regeneration of the filter cartridges is done using inert gas pulses in the reverse direction of the synthetic gas flow. This process is time-controlled or triggered by increased differential pressure in the cartridges. Via a particle and sand conveyor the filtered material, residual coke and sand, is transported into the burning chamber.

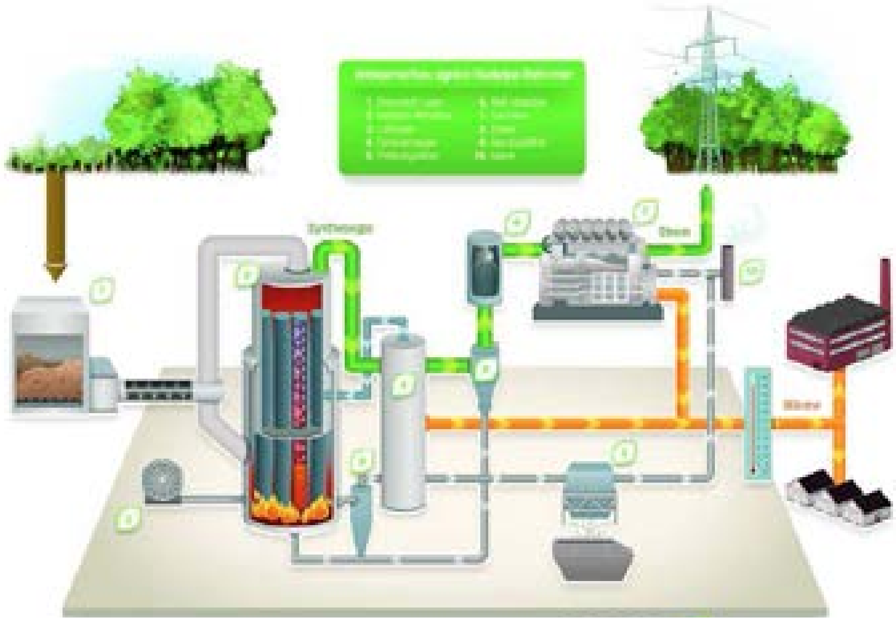

Figure 3 Picture of the entire power plant – CHP unit and peatpipe-reformer [1]

The rinser, which is equipped with a quencher, reduces the impurities of the syngas and regulates the temperature of the gas entering the gas engine. The impurities are dissolved in bio-canola methyl ester (i.e., biodiesel). The methyl ester is then directed into a settling tank, in which the methyl ester and water phases separate. The central layer, the so-called slurry, is sucked off and transported into the burning chamber. The pure methyl ester is redirected into the cleaning process. The cleaned and pressurized synthetic gas leaves the rinser at a defined exit temperature and is transported into the gas engine.

The motors' manufacturer is 2G Energietechnik and the generator is an Agnion 412SG. The efficiency of the gas generator is 42%.

The thermal balance for complete biomass installation is presented in Figure 4.

During the biogas production process, the installation consumes the electrical energy for own needs. The total installed capacity of the electrical devices is 150 kW. The power factor of the loads is approximately 37%. The annual internal electricity consumption for the plant's equipment is 412.5 MWh/year. This includes the auxiliary equipment serving the installation (feeders, water pumps supply and etc.).

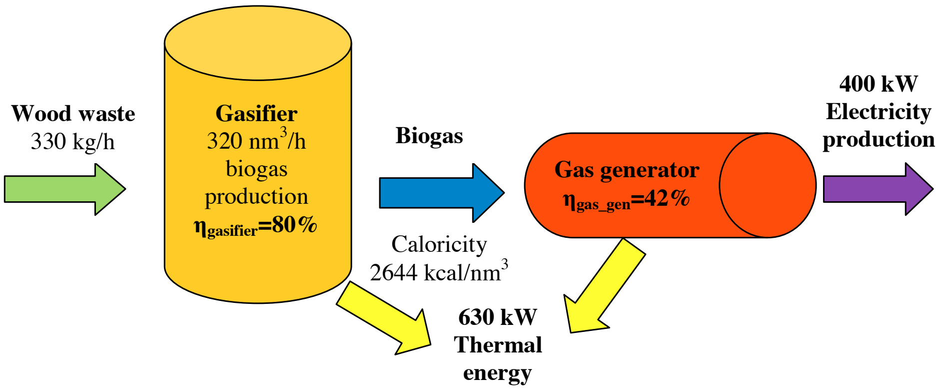

Figure 4 Thermal balances of the biomass installation [4]

FINANCIAL ANALYSIS

Below is provided the short financial analysis, concerning the project investments, cash flow generated by the power plant during the period of operation and operational and maintenance costs.

The allocation of sold heat production, electricity production, electricity own needs, wood consumption and O&M cost savings in Figure 5.

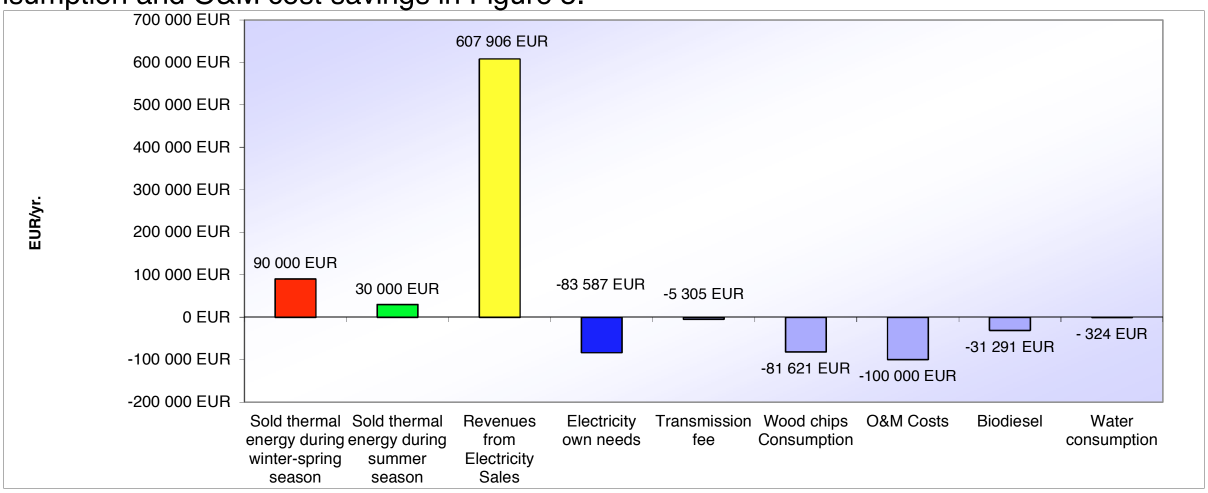

Figure 5 Allocation of sold heat production, electricity production, electricity own needs, wood consumption and O&M cost savings

The revenues from the purchase electricity produced by the power plant according the prices announced in the Resolution No Ц-018/28.06.2012 [3] of State Energy and Water Regulatory Commission.

The approximate base project costs are presented in Table 3

Base project costs Table 3.

(EUR)		Design	Equipment	Construction Works	Total Investment	Total Project Cost
ECO 1	Implementation of renewable project producing heat and electricity from waste wood	167,000	2,666,000	72,000	2,905,000	**2,905,000**

The investments for the implementation of such systems are in the amount of 2 820 EUR/kW installed capacity.

The financial indicators are presented in Table 4. The internal rate of return (IRR) of the project is 12.19% which is higher than 10%. The Net Present Value is positive, and it is in the amount of 422 552 EUR. These two items make the project attractive from a financial perspective.

Basic financial indicators of the project Table 4.

	IRR %	NPV EUR	Payback Period Years
Base Case	**12.19%**	**422 552**	**7.17**

CONCLUSIONS

1. Here is presented and discussed the modern system for the combined heat and power energy production by gasification of biomass with heatpipe-reformer system. The heat needed for the gasification of biomass is obtained by the heatpipe. The special liquid in the heatpipe is heated through direct burning of the biomass in the bottom of the Reformer body;
2. The caloricity of the generated syngas is twice than the gas obtained by the standard gasification process;
3. Higher efficiency of the CHP plant (30% electrical and 50% thermal efficiency) leads to higher energy production and significant incomes from the purchase of the produced electricity;
4. The presented power plant is compact and has low operation and maintenance costs;

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1. Assoc. Prof. Iliya Iliev, Ph.D, Ruse University "Angel Kantchev" iiliev@enconservices.com; +359 887 306 898;
2. Assoc. Prof. Angel Terziev, Ph. D – Technical University of Sofia, aterziev@tu-sofia.bg; +359 885 955 183;
3. Assoc. Prof. Veselka Kamburova, Ph. D, Ruse University "Angel Kantchev", vkambourova@enconservices.com; +359 885 955 347