THREE-STAGE FURNACE FOR BIOMASS THERMAL TREATMENT

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Abstract

Currently, use of biomass energy potential accounts for less than 20 %, mainly because of the high energy costs. The reasons why the energy costs are high are that the energy transformation efficiency is low and the logistics costs are high. A systematic increase in the thermal processes for energy recovery from biomass has a great prospect. The conversion of biomass into energy is carried out by combustion or gas production through pyrolysis and gasification. In terms of energy and thermodynamic efficiency, the combined method consisting in the production of gas is most suitable. The combined method consists of pyrolysis, the primary combustion, gasification and secondary combustion. The optimal solution is achieved at the maximum calorific value of produced gas. The research of the proposed process was carried out by methods of physical and mathematical modelling. An economic efficiency of biomass energy use depends on the costs of biomass and its modification and it also depends on its thermal recovery efficiency. This paper compares three basic methods of heat generation from biomass: single-stage, two-stage and three-stage. The three-stage furnace designed and created by the results of modelling and experimental verification is presented. In the furnace is carried out high-temperature pyrolysis and generated separately pyrolysis and synthesis gas.

Keywords: Biomass, production of heat, three-stage furnace

Introduction

Biomass is currently the most important energy renewable source. One of the principal reasons for using a biomass as energy sources are its low price and environmental reasons. The conversion of biomass into energy is generally more expensive than energy produced from fossil fuels. Low efficiency of biomass energy is currently one of the major obstacles of its wider use due to logistical, technological and technical reasons.

An efficiency of energy use of biomass is a key factor limiting their wide use. It depends on the biomass costs and its processing method. There are two basic technologies for biomass processing:

- biochemical,
- thermal.

An advantage of thermal processing has resulted from an economic comparison of these technologies. Thermal biomass recovery includes heat and gas production.

The production of heat:

The production of heat is carried out by direct or indirect biomass combustion. Within direct combustion of biomass are burned all flammable components on the surface. Indirect biomass combustion consists of the gasification and subsequent combustion of generated gas.

The aim of the indirect combustion is to increase an efficiency of thermal processing of biomass. Energy optimality criterion of this process is the maximum of biomass energy transformed into heat. Thermodynamic criterion is the maximum temperature of the fresh flue gas. These criteria did not match any fundamental way of conversion. An external interconnection of the existing basic ways is not advantageous because this cases heat loss, thereby reducing the efficiency of the whole process. Therefore, most real processes are carried out in a single integrated device as a combination of the fundamental methods in a different configuration (Fig. 1). On Fig. 1c is an optimal configuration of the process of heat generation from biomass. During this process we can see that the process of pyrolysis and gasification process are parallel. Generated gases have a common secondary combustion

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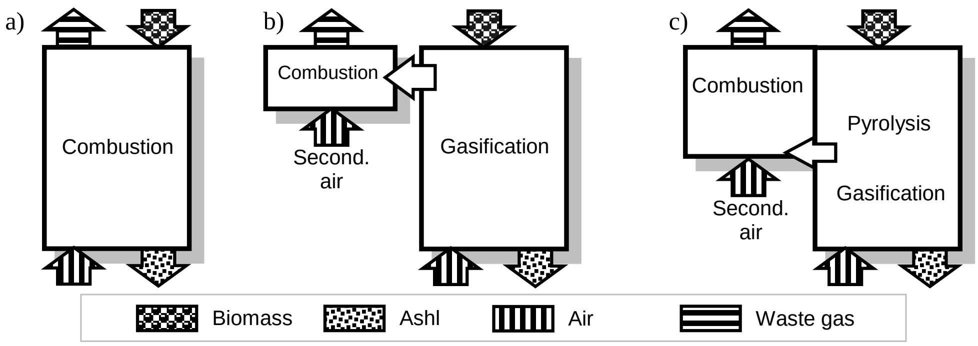

Fig. 1 Types of burning process: a) single-stage, b) two-stage, c) three-stage

Three-stage furnace

For the purpose of research and verification of the proposed process, the experimental device (Fig. 2) has been designed and created. The device consists of pyrolysis, gasification and combustion part. The pyrolysis and gasification parts are connected by material flow. Gases from the pyrolysis and gasification part pass into the combustion part. Pyrolysis process is carried out by heat from the flue gas. High temperature pyrolysis is effective because there is the highest degree of conversion and also high calorific value of gas. In addition, high temperature ensures that all pyrolysis products are in gaseous state and do not require any specific treatment.

In the gasification part the solid residue of pyrolysis is processed. The gasification intensity depends on the amount of primary air. Increased air flow causes an increase in the gasification at the expense of pyrolysis. This reduces the thermodynamic efficiency of the process. Therefore device parameters should be proposed so that the pyrolysis yield is close to the maximum value which depends on the biomass chemical composition.

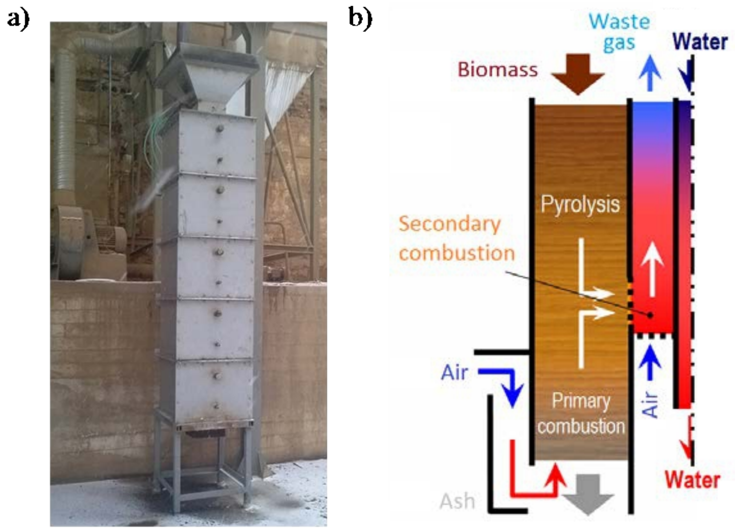

Fig. 2 Three-stage furnace: a) experimental furnace, b) functional scheme

Formation of a mathematical model:

The mathematical model is used to simulate the processes of thermal processing of biomass. It is used for designing processes and renewable energy facilities and their operation and optimization. The model includes the following processes:

- heating processes,
- drying processes,
- pyrolysis processes,
- gasification processes,
- combustion processes.

The method of elementary balances (Fig. 3) has been used for simulation processes. Using this method, the furnace is decomposed into zones, layers and elements. The individual elements comprise the following processes:

- evaporation and condensation
- pyrolysis

$C + 2H_2 \rightarrow CH_4$

$2C + 2H_2 \rightarrow C_2H_4$

- gasification

$C + CO_2 \rightarrow 2CO$

- formation of water-gas

$H_2O + C \rightarrow CO + H_2$

- combustion of carbon

$C + O_2 \rightarrow CO_2$

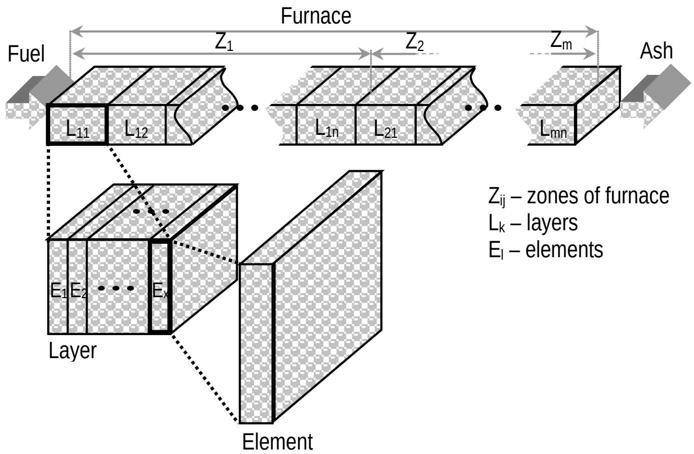

Fig. 3 Furnace decomposition

The proposed three-stage model of the furnace (Fig. 4) consists of pyrolysis, gasification and combustion part.

Fig. 4 Mathematical model structure

Calibration of the mathematical model

To calibrate the mathematical model were used the results of experiments on an experimental device. The "steady state" based on average temperatures for an individual segment along the height of the device (Fig. 5) has been chosen.

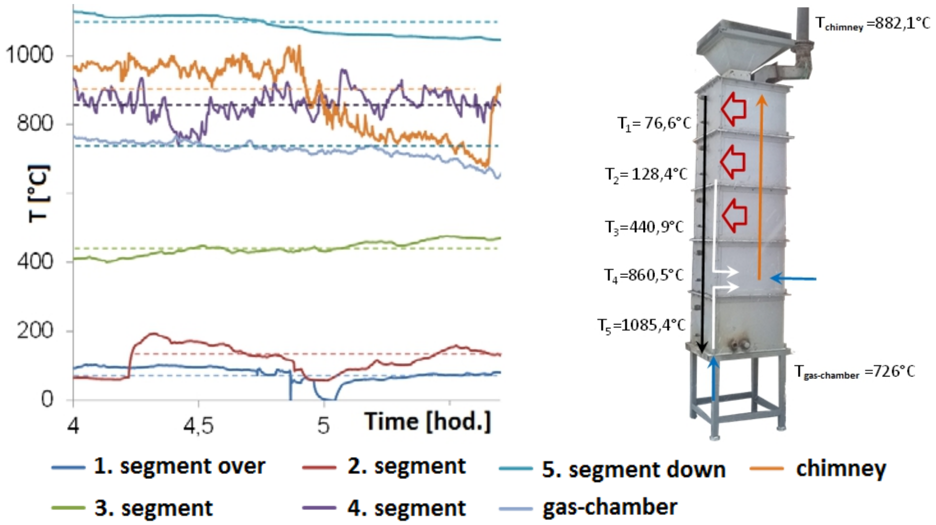

Fig. 5 „Steady state" to calibrate a mathematical model

The results of temperatures measurement and percentages content of the individual material components are shown in Fig. 6.

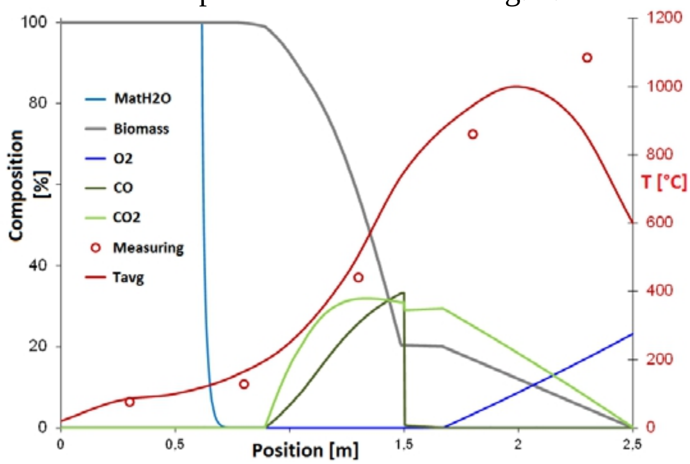

Fig. 6 Calibrated mathematical model

Simulation results

Two selected alternatives were simulated with the calibrated mathematical model. The amount of injected secondary air has been changed. The first alternative was intended for the production of heat in the form of hot waste gas (Fig. 7).

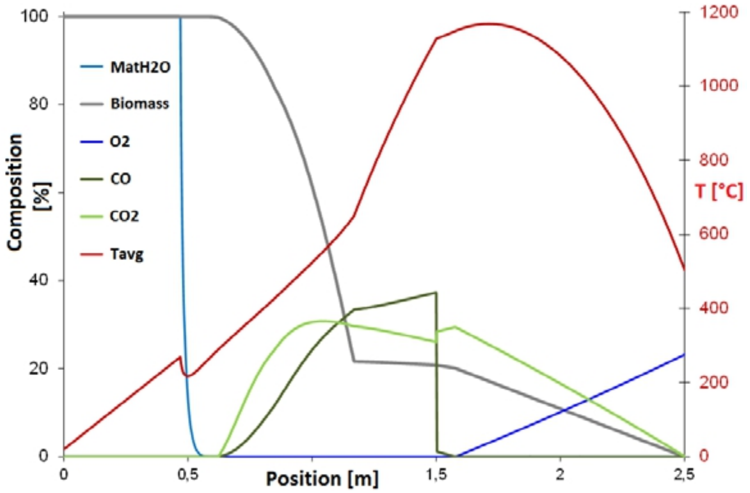

Fig. 7 Result of the simulation for alternative 1 – waste gas production

The second alternative is intended for the process adjustment to allow gas production of "Syngas" (Fig. 8).

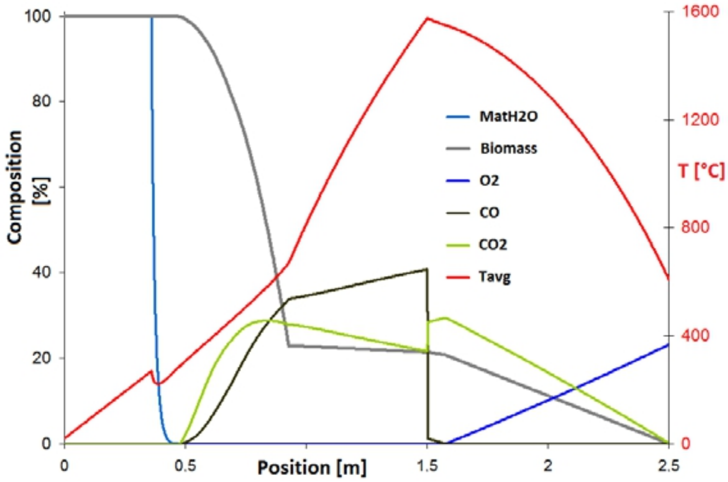

Fig. 8 Results of the simulations for alternative 2 – production of „Syngas“

The comparison of the output parameters of two simulated parameters and reference calibrated state is shown in Table 1.

Table 1 Comparison of alternatives

Alternative	H_{min}	Humidity	Prim. air	Secon. air	T_{gas} Out	V_{gas} Out	Fuel value	$Q_{phys.}$	$Q_{chem.}$	Q_{total}	
	kg/h	%	m^3/h	m^3/h	°C	m^3/h	MJ/m^3	MJ/h	J/h	MJ/h	MJ/s=MW
Reference state calibrated model	70	10	90	400	904	525	0	569,5	0	569,52	0,16
Alternative 1	400	10	500	2200	1098	2901	0	3822	0	3822	1,06
Alternative 2	400	10	500	0	941	753	4,6	850	3463,8	4314	1,20

Conclusion

Based on the analysis of the combustion process, pyrolysis and gasification, a combined method of biomass thermal recovery which is able to achieve energy and thermo dynamical optimal solution has been designed and used. Achieving energy and thermodynamic efficiency of the process allows increasing the economic efficiency of energy recovery from biomass and thereby promoting its wider use.

The pilot three-stage furnace, which is currently under construction, has been designed by simulation results of combustion process, pyrolysis and gasification as well as performing experiments on an experimental device.

The three-stage furnace operates at a higher temperature creating the possibility to burn municipal waste. The concept of the furnace crates the solution for heat and gas production. The produced gas is suitable for cogeneration unit from which the waste heat can be used directly in the process of biomass recovery (drying).

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