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Energy efficiency analysis of reactor for torrefaction of biomass with direct heating

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Abstract. Paper presents energy analysis of reactor for torrefaction with direct heating of granulated biomass by exhaust gases. Various schemes of gas flow through the reactor zones are presented. Performed is a comparative evaluation of the specific energy consumption for the considered schemes. It has been shown that one of the most expensive processes of torrefaction technology is recycling of pyrolysis gases.

1. Introduction

Torrefied process is realized with slow heating of biomass in oxygen-free environment to temperature of 200–300 °C. As a result specific heat value of biofuel increases and its hydrophobicity significantly decreases [1]. The heating value of torrefied biofuel is close to the heating value of fossil coal that makes it possible to use it in coal boilers. Wastes of wood and timber production, agricultural wastes (straw, husks, shells) and domestic wastes can be used as a feedstock. Comparative data on the heating value of different solid fuels are shown in table 1 [2].

Torrefied biofuel from local resources is promising for the partial or complete replacement of coal in the boilers, due to the exclusion of costs of coal delivery from the place of its production to consumer. Moreover, high hydrophobic properties of torrefied fuel provides long-term storage.

Today there are many types of torrefaction reactors. The most common are screw and rotaty drum reactor, fluidized and moving bed reactor. Also as promising types considered reactor with superheated steam with supercritical parameters as heat–trasfer fluid and reactor with microwave heating. Research works in the field of torrefaction are carried out in several European countries and in the United States. Among the companies involved in this problem can be distinguished Topell Energy (Netherlands), 4Energy Invest (Belgia), Thermya (France), Rotaware (Great Britain), Integro Earth Fuels (USA) [2]. Despite the increasing interest in the development process and the creation of torrefaction plants nowadays, most of the projects are just pilot samples. However, in a number of projects large volumes of torrefied pellet production (more than 1.5 Mt per year) are declared. Table 2 shows an overview and a qualitative assessment of the different torrefaction technologies [3].

The productivity of different types of torrefaction reactors are often limited by the low intensity of heat and mass transfer processes, which determine the intensity of pyrolysis process. The most efficient in terms of heat transfer are directly gas heated reactors and fluidized bed reactors.


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Table 1. Calorific value of different solid fuels, MJ/kg.

Wood chips	Wood pellets	Torrefied pellets	Coal
9–12	15–16	20–24	23–28

Table 2. Comparative characteristics of the main types of reactors.

Criteria	Screw reactor	Rotary drum reactor	Fluidized bed reactor	Moving bed reactor
Process and optimum temperature control	++	++	±	+
Mixing of fuel	±	++	++	±
Proven technology	++	++	+	+
Tar formation and handling	−	±	±	+
Quality of product	±	++	±	+
Capability of processing low density biomass	±	−	±	+
Total working hour	+	++	±	+
Potential for up scaling	−−	±	++	++
Total dimension of equipment	±	±	++	+
Current total capacity	−	−	++	+
Conversion costs	−	−−	+	++

++ technology is very good
+ technology is good
± technology is medium
− technology is bad
−− technology is very bad

2. Compare energy efficiency torrefaction reactors with direct heating of biomass

From the viewpoint of energy input the torrefaction process can be divided into four stages:

- drying of feedstock–heating to 170 °C with removal of water;
- torrefaction–heating and holding at a temperature of 200–300 °C (depending on the type of raw materials and end product requirements);
- cooling of the finished product in an oxygen free environment to 100–150 °C;
- utilization of pyrolysis gases.

Below 170 °C flue gases are substantially free of harmful impurities and can be discharged into the atmosphere. During torrefaction at temperatures above 170 °C the release of harmful substances occurs in the gas phase: acetic and formic acid, furfural, methanol, carbon monoxide [4]. For the removal of these substances a disposal unit, in which their thermal decomposition at a temperature of about 1000 °C take place, is required.

Schematic diagram of installation for torrefaction of granular biomass with direct heating by hot raw gas (exhaust gases) is shown in figure 1. The reactor is a sealed cylindrical tank. The tightness of the reactor is provided by two rotary lock (1) at the inlet and outlet of the reactor.

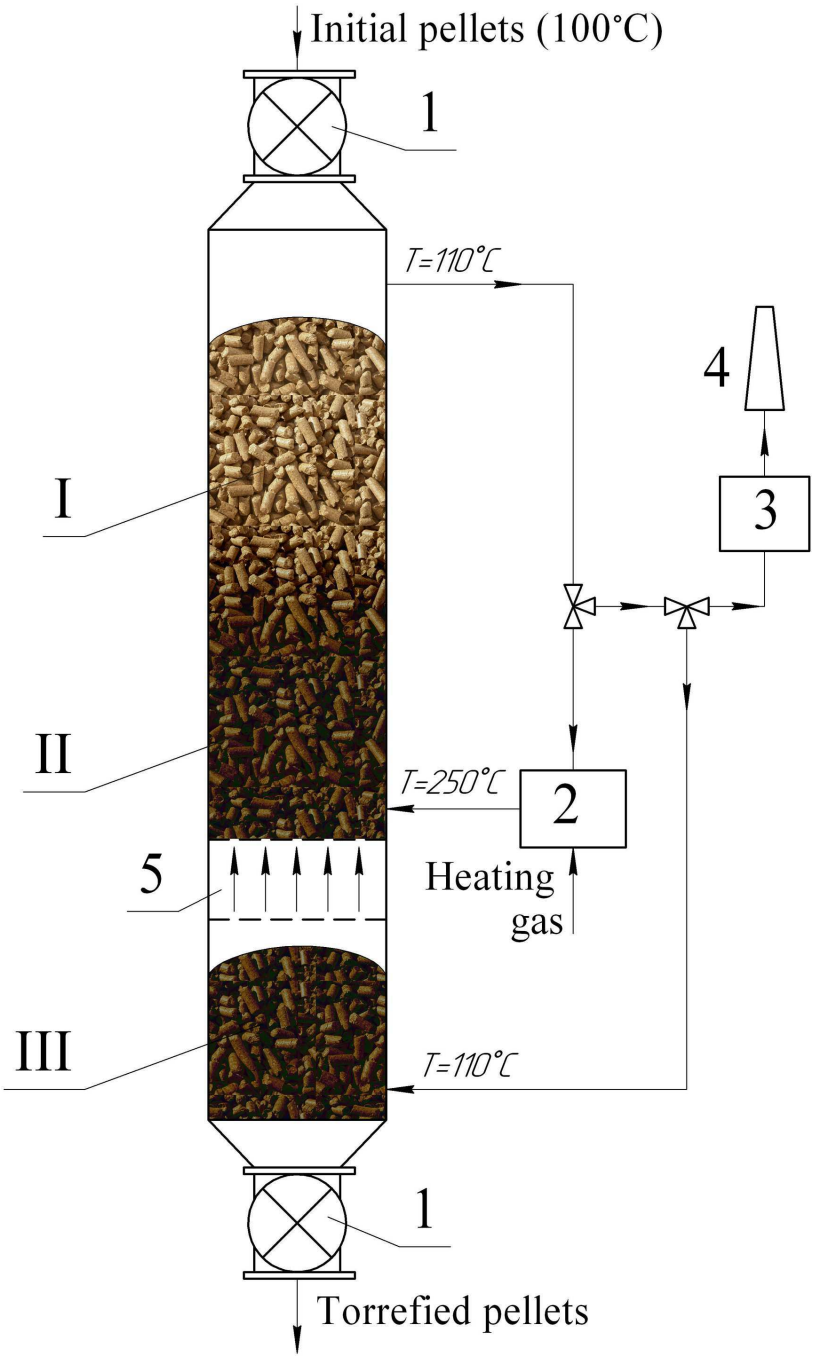


Figure 1. Schematic diagram of installation for torrefaction.

Pellets heated to 100 °C (pellets temperature after press granulator) enter the reactor through the rotary lock (1). Reactor is divided into two zones by gas-permeable shutter (5). The upper zone is drying section (I), torrefaction section (II). After end of the heating process torrefied pellets enter the bottom of the reactor–a cooling zone (III).

The installation scheme implements recycling of pyrolysis gases. Gases from the drying section (I) at a temperature of approximately 110 °C enter the cooling section (III). Thereafter,

through the shutter (5), they enter torrefaction section, where they are mixed with the main flow of heat transfer agent from the mixing unit (2). Finished torrefied pellets in cooling zone give off heat to the gas flow, and they are cooled to a temperature at which there is no ignition in contact with air during the discharge of pellets through the rotary lock (1). In addition, this scheme allows removing harmful impurities from the gas phase by condensing them on the surface of the finished pellets.

Heating of heat transfer agent (circulating combustion gases) to an operating temperature of 250–300 °C can be performed by burning of natural gas (or other type of fuels, including pellets). This also can be achieved by using exhaust gases of gas piston engine (GPE) [5, 6]. In disposal unit (3) decomposition of pyrolysis gas components is occured, after which the waste gases emitted into the atmosphere (4).

A special feature of the scheme is recycling of polluted by pyrolysis products heating agent, which reduces the concentration of harmful substances due to deposition of condensable components on the surface of the cooled pellets. This deposition will no longer be dangerous for the environment because pellets will be subsequently combusted at a high temperature. Furthermore, the concentration of combustible components of pyrolysis in the flue gas increases due to recirculation. A boiler can be used as the flue gas disposal unit. Exhaust gases enter the boiler's furnace and its thermal energy is used for the needs of district heating.

The implementation of considered scheme leads to considerable energy consumption associated with heating large amount of gases emitted into the atmosphere to the temperature of harmful impurities decomposition (900–1000 °C). Power consumption can be significantly reduced if torrefaction reactor is divided into three sections: the drying, torrefaction and cooling sections, wherein the torrefaction section must be isolated from other sections.

Scheme of sectioned installation is shown in figure 2. In this scheme, the volume of the reactor is divided into three sections: drying section (I), torrefaction section (II) and cooling section (III) with a dual circuit for gas heating agent. In each circuit a mixing unit (2) is installed, which maintains the necessary operating temperature of heating agent. Exhaust gases from the torrefaction circuit pass through the disposal unit (3). In scheme considered disposal unit is a boiler, in which a mixture of combustion products and pyrolysis gases is heated to a temperature of thermal decomposition of harmful substances and then ejected into the atmosphere (4).

In the second circuit heat agent has a temperature not higher than 170 °C. Therefore, gases being emitted during drying (mainly water vapor) may be released to the atmosphere. Results of comparison of the two schemes' of torrefaction energy efficiency are presented in table 3.

In table 3 C—pellet heat capacity (2.24 kJ/(kgK)); ΔT—pellet temperature change: ΔT_{I}—drying zone, ΔT_{II}—torrefaction zone, ΔT_{III}—cooling zone; β—initial moisture content of raw materials (15%); r—evaporation heat (2.26 MJ/kg); ε—weight loss of pellets (15%), E_a—activation energy of the reaction of the hemicellulose decomposition (180–230 kJ/mole) [7], M—molar mass of hemicellulose (0.162 kg/mole); C_{cp}—heat capacity of combustion gases (1.1 kJ/(kgK)); γ—amount of pyrolysis gases ($\gamma \approx \varepsilon$); ΔT_{hg}—temperature pressure of the heating gas, T_{d}—temperature of thermal decomposition of harmful substances; T_{v}—temperature of gases at inlet of disposal unit.

The advantage provided by three-section scheme is minimum energy and, accordingly, operating costs. However, compared with the scheme shown in figure 1, it is more complicated: three separate sections and special high-temperature gateway connecting sections. All this leads to increased capital costs and made installation more expensive.

Furthermore, at a fixed gas supply (e.g., GPE of a given power) the separation of gas flow decreases productivity of technology. For numeric evaluation of heat exchange effectiveness and reactor productivity was used module for calculating the reactor of torrefaction from software package ETCC v.01 (Energy Technological Cogeneration Complex) [8].

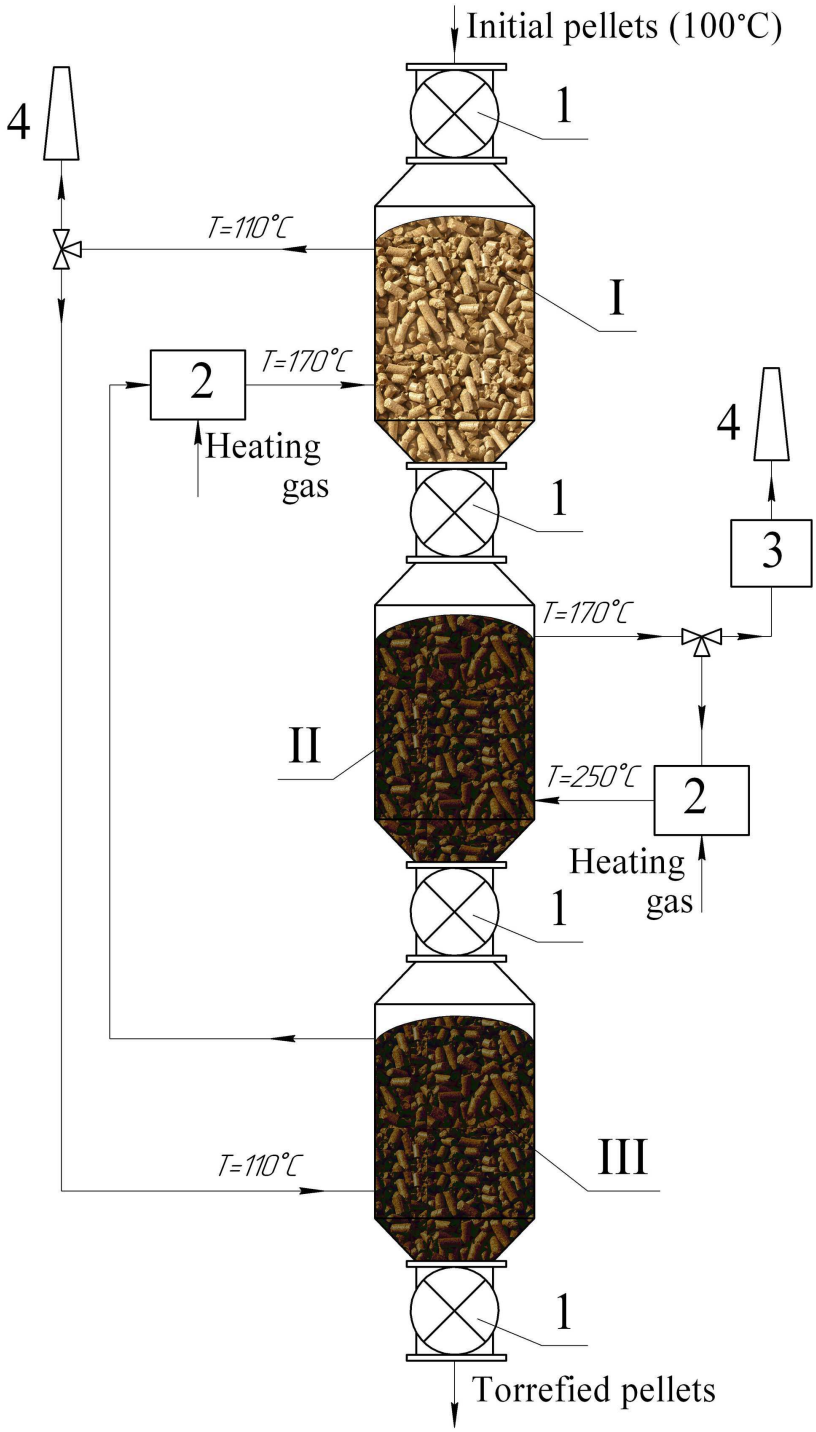


Figure 2. Schematic diagram of installation with three-section reactor of torrefaction.

The initial temperature of pellets in torrefaction zone was 200 °C, total flow of combustion gases was 0.198 kg/s, which corresponds to the power of GPE 155 kW. The residence time of the pellets in torrefaction section in all modes corresponded to weight loss of pellets 13%, equivalent to an increase calorific value to 13%.

Table 3. Comparison of the energy consumption of the two schemes of torrefaction.

Energy input	Scheme with one section	Scheme with three sections
q_1, kJ/kg	470	470
q_2, kJ/kg	150	150
q_3, kJ/kg	150	150
q_4, kJ/kg	220	220
m_2, kg/kg	$1.5^{\dagger}$	$0.85^{\ddagger}$
q_5, kJ/kg	1700	900
q_{total}, kJ/kg	2250	1450

$q_1 = C\Delta T_{\text{I}} + \beta r$ is for drying (heating to 170 °C and dehumidification)
$q_2 = C\Delta T_{\text{II}}(1-\beta)$ is for heating in torrefaction zone to 250 °C
$q_3 = (1-\beta)\varepsilon E_a/M$is for torrefaction
$q_4 = C \times \Delta T_{\text{III}}(1-\beta)(1-\varepsilon)$ is for cooling of pellets
m_2 is for specific mass of the exhaust gas containing harmful substances
$^{\dagger}m_2 = (q_1+q_2+q_3-q_4)/(C_{\text{cp}}\Delta T_{\text{hg}}) + \gamma + \beta$
$^{\ddagger}m_2 = (q_2+q_3)/(C_{\text{cp}}\Delta T_{\text{hg}}) + \gamma$
$q_5 = m_2 C_{\text{cp}}(T_{\text{d}} - T_{\text{v}})$ is for disposal of waste gases (flaring—the heating of the entire volume of the exhaust gases m_2 to the temperature of thermal decomposition of harmful substances)
$q_{\text{total}} = q_1 + q_2 + q_3 - q_4 + q_5$

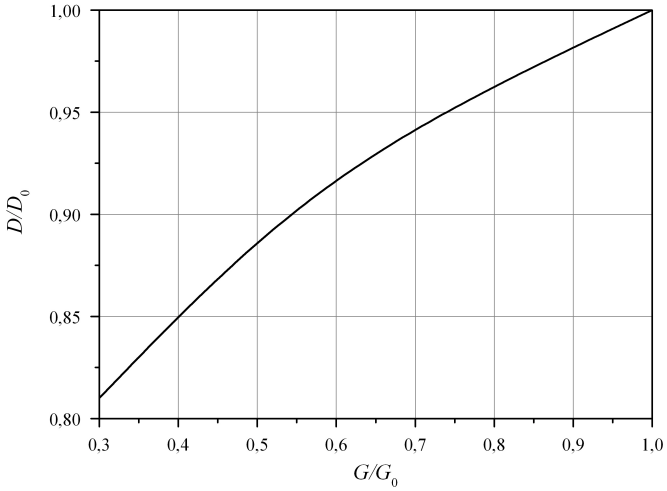


Figure 3. Dependence of relative productivity of torrefaction section from the proportion of the total flow of heating gas.

Dependence of relative productivity of torrefaction section of reactor (D/D_0) from the proportion of the total flow of heating gas (G/G_0), passing through torrefaction section is shown in figure 3.

The graph shows that the effective solution of ecology problems leads to a significant decrease in the reactor productivity. However, combining multiple technologies into a single energy technological complex (gas-piston cogeneration power plant, torrefaction reactor, boiler) by obtaining extra market product (heat) could be economically and energetically advantageous solution.

In any case, the target product must be determined (most often it is the electricity) and other products (torrefied pellets and heat) will be a by-product, which, if there is demand, will significantly reduce the cost of electricity.

3. Conclusion

The analysis shows that due to the separation of torrefaction reactor to zones (preheating and drying, torrefaction, cooling) and the use of schemes with recycling of heating gas allows reducing energy consumption for solving waste pyrolysis gas problems. This significantly decreases the productivity of reactor. However, the inclusion of boiler in the scheme of energy-technological complex makes the total economic effect significant due to the maximum utilization of the heat content of the primary fuel (natural gas).

Acknowledgments

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References

[1] Bergman P C A and Kiel J H A 2005 *ECN [Rep.]*
[2] Kleinschmidt C P 2011 *Proc. Cent. Eur. Biomass Conf.*
[3] Deutmeyer M, Bradley D, Hektor B, Hess R, Tumuluru J S, Nikolaisen L and Wild M 2012 *IEA Bioenergy Task 40* **2** 48
[4] Kiel J H A, Zwart R W R and Verhoeff F 2012 *ECN [Rep.]*
[5] Zaichenko V M, Kosov V F, Kuzmina J S, Markov A V and Morozov A V 2013 *Energy technology complexes with torrefaction reactor for pellets* (Patent RU 136801)
[6] Kuzmina J S, Kosov V F, Director L B and Zaichenko V M 2016 *Ind. Power* **2** 58–62
[7] Maryandyshev P A, Chernov A A and Lubov V K 2015 *Bull. North. Fed. Univ., Sci.* **2**
[8] Director L B 2015 *Program for calculation and optimization of energy-technological complex characteristics* (Certificate of official registration of computer program system 2015660172)