Oxygen influence on the process of low-temperature pyrolysis of biomass

A L Shevchenko, A E Petrov, G A Sytchev and V M Zaichenko
Joint Institute for High Temperatures of the Russian Academy of Sciences, Izhorskaya 13 Bldg 2, Moscow 125412, Russia
E-mail: s1246626@yandex.ru

Abstract. The installation for studying the processes of low-temperature pyrolysis of biomass was created in JIHT RAS. A feature of the installation is heated biomass through the exhaust gas of the internal combustion engine (mini-power stations) through the solid granules, the dried biomass (pellets). A series of experiments was conducted to study the effect of oxygen on the process of torrefaction on the installation. The oxygen content in the combustion products varied from 0.8 to 2% in the course of the experiments. Studies have shown that a slight increase in oxygen content increases the rate of heating of the processed raw materials.

1. Introduction
Improvement of solid biofuel consumer properties (reduction of hygroscopicity limit, increasing of the combustion heat value) can be achieved during torrefaction process (low-temperature pyrolysis) [1]. Torrefaction consists in raw material heating up to temperatures of 250–270 °C in inert atmosphere with following holding. Notwithstanding the simplicity of such solution, nowadays there are no on-stream industrial plants producing high-quality torrefied biofuel. One of main disadvantages of torrefaction technology consists in its low energy efficiency—spent resources are paying off with produced high-quality torrefied biofuels. An energy-efficient torrefaction unit was created in JIHT RAS with using of exothermic effect heat and gas-piston power unit (GPU) exhaust gas as coolant. The paper presents studies of the effect of oxygen concentration in the GPU exhaust gases on torrefaction process.

2. Experimental equipment
At JIHT RAS, there are provided exploratory in the field of processes of the low-temperature pyrolysis of biomass. The experimental torrefaction plant [2] was specially created. A feature of this plant is initial biomass processing in internal combustion engine exhaust gas flow GPU. The experimental plant includes feeding unit where pre-drying and pre-warming of the raw biomass occurs with help of blast-engine, torrefaction section, the blend section (where the preparation of the heat transfer agent occurs, which consists in mixing of hot gases from GPU and cold gases after heat exchanger). During the experiment torrefaction temperature value in the blend section can be set by varying hot and cold gas proportion and the temperature, pressure and gas composition at several points of plant can be checked.
3. Research results
An important attribute of the torrefaction process is the absence of oxygen in reactor hot face. However, a number of studies [3, 4] on the effect of oxygen concentration in the torrefaction reactor area on whole process showed that O\textsubscript{2} complete absence is not necessary. Oxygen moderate concentration in the heat transfer agent can even conduct the torrefaction process. Set of experiments was carried out a series using this plant to study the effect of oxygen presence on the torrefaction process. In the course of experiments, the oxygen content in the combustion products were varied from 0.8 to 2.0 vol % (engine stability condition) due to a change in the enrichment of the engine feeding mixture. Figure 1 shows torrefaction section temperature distribution changing for engine run-up modes with oxygen content in the combustion gases of 0.8, 1.2 and 2.0 vol %.

It should be mentioned that, with input temperature of 220 °C, the effect of oxygen on the pyrolysis process is inconspicuous. With heating gas temperature growing up to 275 °C, in processed biomass there are initiated intense exothermic reactions that leads to a fast heating of the processed raw material. With oxygen concentration growing the more intensive exothermic reaction inner heat release and higher biomass heating rate occurs. After fast temperature rise (due to the avalanche of exothermic reaction execution) an exponential drooping occurs, associated with a concentration decreasing of the reacting components that could initiate self-heating process.

At 1.2 and 2.0 vol % oxygen concentration, the temperature rises above 300 °C, which is not desirable from the point of view of torrefaction operating mode. This mode is accompanied by a significant mass loss (50–60%) of initial raw material. However, the objective of the present research was to demonstrate oxygen concentration effect upon the process without restriction of the exothermic reaction. Studies have shown that external oxygen influences on exothermic reaction behavior due to additional oxidation processes taking place on raw material surface.
Thus the effect of oxygen is not observed at a temperature below the temperature of the onset of exothermic reaction. It should be noted that at temperatures below the exothermic reaction onset temperature oxygen effect is not observed.

After torrefaction processed pellets are discharged to the cooling section. In this section, the torrefied pellets temperature is reduced in flow of gases from heat exchanger. Thus, self-heating process of treated biomass can be suppressed. After all, cooled pellets are unloaded into the hopper. Moreover, due to more intensive biomass heating, the torrefaction time can be reduced and, thus, the productivity of the plant can be increased. Figure 2 shows biomass heating rate changing as a function of the oxygen concentration.

It can be observed almost linear dependence of the heating rate on the oxygen concentration in the combustion products, and an increase of oxygen content by 1 vol % leads to proportional heating rate increasing and, correspondingly, twofold increasing exothermic reaction energy.

4. Conclusion
Conducted studies have shown that a rather small oxygen concentration in the combustion gases can significantly increase the exothermic reaction energy value during biomass torrefaction and, thereby, increasing of process energy efficiency.

References
[1] Basu P 2013 Biomass Gasification, Pyrolysis and Torrefaction. Practical Design and Theory (Academic Press)
[2] Zaichenko V M, Larina O M, Markov A V and Morozov A V 2017 Equipment for biomass thermal conversion Patent RU175131U1
[3] Vassilev S V, Baxter D, Andersen L K, Vassileva C G and Morgan T J 2012 Fuel 94 1–33
[4] Vassilev S V, Baxter D, Andersen L K, Vassileva C G and Morgan T J 2011 Biomass Bioenergy 35 171–8