Challenges and opportunities of torrefaction technology

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Challenges and opportunities of torrefaction technology

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Abstract. Since the active exploitation and usage of classical non-renewable energy resources the most promising direction is the development of technologies of heat and electricity production from renewable sources—biomass. This is important in terms of reducing the harmful man-made influence of fuel-and-energy sector on the ecological balance. One of the most important aims when using biomass is its pre-treatment. The paper describes the fuel preliminary preparation for combustion with such technological process as torrefaction. Torrefaction allows bringing the biomass fuel as close as it possible to fossil coals for the main thermotechnical parameters. During torrefaction moisture is removed from initial material and the partial thermal decomposition of its components appears. The final torrefied product can be recommended for utilization in existing coal-fired boilers without their major reconstruction. Thus torrefaction technology enables the partial or complete replacement of fossil coal. At JIHT RAS, a torrefaction pilot plant is developed. As heat transfer medium the gas-piston engine exhaust gases were used. Results of researching and proposals for further development are showed in this paper.

1. Introduction
The biofuel usage is regarded as one of the main directions in modernization of the existing energy system in the world. Utilization of raw unprocessed biomass in power plants is inefficient. The reason for this is the fact, that the raw biomass fuel has a low combustion heat, additional requirements for storage and transportation (because of its hygroscopicity, etc). Application properties improving of fuels from biomass (wood, peat, straw, chicken litter) is ensured by torrefaction technology. Torrefaction is the low-temperature pyrolysis, which is held in a non-oxidizing environment at temperatures of 200–300 °C. During torrefaction biomass fuel becomes hydrophobic, i.e. loses the ability to actively absorb water during storage, the weight is reduced by 20–25% while combustion heat increasing is about 25–30%.

Torrefaction seen as a promising technology of qualified biomass fuel production for energy purposes.

The main advantage of the torrefaction process is that obtained (in the form of pellets or chips) torrefied product on the main thermotechnical characteristics is similar to coal, and can be used to coal replacement in different energy units. According to the content of harmful components and, above all, sulfur and heavy metals, from the total ash content and etc., torrefied product is preferable than modern energy coal.
Figure 1. Temperature change curves (1, 2, 3) and the mass change curves (4, 5, 6) during torrefaction process for different modes: 1, 4—270 °C; 2, 5—250 °C; 3, 6—230 °C.

Figure 2. The thermal decomposition of the main wood components depending on the process temperature [1].

2. JIHT RAS experience and ongoing investigations

Of all wood fuels torrefied product has the highest weight and volumetric combustion heat, and requires the least energy consumption for grinding of feeding it into the furnace of coal-fired boiler (co-firing with energy coal). For power plant is very important to keep fuel with high thermotechnical characteristics for a long time. It would allow to create the necessary reserve resources for uninterrupted supply of consumers. From this point of view torrefied fuel has a distinct advantage because of its degradation rate is infinitesimal when compared with other types of wood fuel. The graph in figure 1 shows a typical torrefaction process of wood raw material for the three operating conditions (230, 250 and 270 °C).

With temperature increasing, the thermal decomposition process captures first the cellulose and then the lignin. Typically, at the completion point of the wood is decomposed over half hemicellulose content, 20% of cellulose and 10–15% of lignin. Experimental data analysis shows the following generalized picture of the thermal decomposition of the main components of wood during torrefaction progress (figure 2).
Figure 3 shows shear photographs of initial and torrefied wood samples. As seen from the photographs, torrefied product has a homogenous dense porous structure [2]. This fact causes primarily, the increased hydrophobic properties.

In today’s Russia the proposed technology of torrefied pellet production, in addition to the above, receives additional incentives for development by the following factors:

- in the presence in country of a unique volume sources of wood raw material having a low, and in some cases a negative value;
- a huge variety of regions with different natural and economic conditions, many of which are traditional fossil fuels, especially coal, are becoming too expensive because of long transportation lines and fragmentation of local energy systems.

In these conditions the production from local raw material qualified fuel suitable for storage and transportation at a reasonable distance, can effectively solve the problem of the local power supply. This is especially important if the proposed technology of producing such fuel is cheap enough and allows to organize the production, entirely relying on the resources of the local industry and the workforce of medium and low qualifications.

2.1. The JIHT RAS existing torrefaction plant

The Joint Institute for High Temperatures of the Russian Academy of Sciences proposed a new scheme of industrial torrefaction plant (figure 4). The working volume of the reactor is divided into four zones: a drying zone, a preheating zone, torrefaction zone and a cooling zone. Through all this zones the feedstock (wood pellets) passes successively process.

The highest economic effect of the scheme is provided by the heating of the feedstock with gas piston power plant combustion gases.

Within this technology the cogeneration scheme of fuel usage is implemented. In this case the fuel is presented by natural gas. Gas piston power plant operating on natural gas, generate electricity and combustion gases heat is used to warm up the biomass. For biomass heating not all of the exhaust products volume is consumed. Decomposition of cellulose and lignin and the subsequent pitches polymerization reaction all are exothermic processes. They are often leads to an uncontrolled increase of torrefaction reactor temperature [3]. In this case, the excess heat can be removed from the working space by increasing the volume of combustion products flow through the torrefaction reactor [4].

Figure 3. Shear photographs of initial (left) and torrefied at 270 °C (right) of wood pellets.
The implementation of the scheme demanded working out of operating parameters of the gas piston power plant at the stoichiometric ratio of fuel–oxidizer. The oxygen content in the combustion products must not exceed 0.2% by volume.

2.2. The direction for future investigations

The main problem and obstacle in the way to the widespread introduction of torrefaction plants is a question of recycling torrefaction gaseous products whose emissions into the atmosphere is not valid for the sanitary norms. At JIHT RAS is proposed a solution of this problem with using of an additional boiler in a line. Schematic diagram of such plant is shown in figure 5.

Gas-vapor torrefaction products (GTP) exiting the torrefaction reactor are transported and dumped in the various points of the gas path of typical boiler. The dumping is organized that on the one hand, it is useful to use the heat content of the combustible components of the process and on the other—to minimize the reduction in boiler efficiency due to discharge a large amount of additional gases.

Preliminary analysis of the typical boiler working conditions provided with co-firing of primary solid fuel and GTP shows that major violations of its efficiency causes an additional gas stream discharged through the burner directly into the furnace. Organization of gas reset into the cross-section of convection shaft leaving can be easily solved by slight modifications of the boiler unit, which have practically no effect on its performance. This fact was the main argument in favor of torrefaction reactor volume separation into several areas with their own independent supply and output of GTP in different points of the gas path of the boiler.

Figure 4. Biomass torrefaction plant.
Figure 5. Schematic diagram of torrefaction reactor with exhaust heat using of gas piston power plant.

Figure 6. Comparison of the cost of production and delivery of initial and torrefied pellets [5].
3. Economic analysis of the torrefied fuel production process

For the production of energy sum of all costs up to the time of fuel combustion is crucial. In particular, it is interesting option when the manufacturer and the consumer are separated by great distances, and for the delivery the marine and road transport are used. Figure 6 is a line-item comparison of all expenses—from raw material to final fuel supply to the boiler, made to compare the economic efficiency of using as a fuel initial and torrefied pellets.

The analysis shows that even though the production process torrefied pellets significantly more expensive than conventional wood (almost 30%), the aggregate savings in the rest of the cost components makes more profitable the energy production on the basis of torrefied pellets. The main contribution is a reduction in transport costs and a decreasing in costs of preparing the fuel before combustion in a power plant. In absolute values torrefied pellets production process, on average, more expensive than conventional process for wood pellets to 1.4 $/GJ (about 30 $/ton). However, taking into account all the costs in the energy production process difference changes the sign and the use of conventional energy producers of pellets costs 35 $/t higher than torrefied ones. It should be noted, that in this case we use literature data when comparing economic parameters.

4. Conclusion

Torrefaction process is the most technologically advanced of all modern methods of preparing wood fuel for burning. For this reason torrefied products are the most expensive type of wood fuel. Torrefied fuel in all major indicators is superior to alternative fuel wood. In all listed indicators torrefied wood is close to fossil coal, and in some ways surpasses it:

- lower moisture and ash content;
- absence of harmful impurities, especially sulfur;
- reduced total ecological impact on the environment.

In economic indicators torrefied product can compete with other types of wood fuel for transportation over long distances. In these conditions the profit from reducing the cost of transport and intermediate storage and also cheaper preparation for burning in power boiler can recover the increased cost of torrefied product and can bring economic benefits.

An important torrefaction advantage is the ease of its usage in typical coal-fired boilers. In comparison with other types of wood fuel an additional load on the system of preparation and the fuel supply is reduced by several times, allowing to replace a significant portion of the coal stream (and in some cases the entire flow) by torrefied product practically without fuel system remaking.

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