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Torrefaction. Prospects and Application

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Replacing of fossil fuels to biomass, including partial replacement (achieved with co-firing of coal and biomass) is one of the priority problems of modern power producing. In addition to the energy aspects, this is important in terms of reducing harmful man-made impact of fuel and energy sector on the ecological situation. This report presents the results of researches carried out at the Joint Institute for High Temperatures of the Russian Academy of Sciences (JIHT RAS) to develop optimal directions to replace coal in power plants by biomass (wood chips, pellets, torrefied fuel). In JIHT RAS the new scheme of industrial torrefaction technology is proposed. Economic preferences of this scheme are provided by heating of the feedstock by exhaust gases from gas piston power plant. In this case the cogeneration scheme is implemented. The implementation of the scheme demanded working out of operating parameters of the power plant at the stoichiometric ratio of fuel-air mixture. The oxygen content in exhaust gases in this case does not exceed 0.2 % by volume. JIHT RAS technology allows for the main heat engineering parameters of pellets to bring them to coal as much as possible. The torrefaction temperature is determined not only by a variety of properties of raw material, but also by required properties of the final product. Torrefaction advantages are high fuel heating value, high bulk density, low humidity, no tendency to rot and decay, the minimum fire and explosion hazard. Torrefied fuel can almost completely replace coal without major rework of the existing fuel systems. Under the same conditions untreated chips and pellets can replace only 8 – 15 % of the coal.

1. Introduction

Russian Federation is the leading country of forest resources. In Russia concentrated 22 % of the world's forests and 40 % of world reserves of peat. As renewable sources, wood and peat can have the prospect to use as fuel for power generation. The amount of wood waste from wood-processing enterprises is 300 million m^3 per year. At the same time, there is another problem - the utilization of offal timber.

Forest sanitation is necessary to remove sick or damaged trees from the forest to prevent the spread of epidemic. So in recent years outbreak of bark beetle in the Moscow region has become a threat to the entire forest area. In this connection in 2016 to eliminate the further spread of this insect is necessary to cut down 32.4 thousand hectares of forest. Since this offal timber cannot be used in the construction or furniture, so it can be recycled as fuel. This amount of wood in terms of fuel corresponding to 1.5 million toe or 15 – 20 % of the annual cost of fuel for heating in Moscow and Moscow region (Zaichenko, 2015). The development of efficient, cost-effective methods of recycling waste wood and offal timber to produce a conditioned fuel is a very critical task.

Now in Russia, as well as the world's electricity is generated mainly (70 %) in thermal power plants using fossil fuels: gas and coal (40 %). Replacing of fossil fuels to biomass, including partial replacement (achieved with co-firing of coal and biomass) is one of the priority problems of modern power producing. In addition to the energy aspects this is important in terms of reducing harmful technogenic influence of fuel and energy sector on the ecological situation.

In the world practice use several methods of co-firing of coal and biomass. The simplest way is to mix the coal and biomass fuel in stock and burning of this mixture in coal-fired boiler. The disadvantage of this method is the possibility to use only a small (5 %) proportion of the biomass. Where separate input of coal and biomass to the boiler capital costs increase about twice, but the proportion of the biomass can be increased to 50 % (Ryabov, 2005).

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The most interesting and promising is a modern solid fuel obtained by grinding and pelletizing of wood - wood pellets. Pellets have higher density and heating value as compared with the original wood chips or sawdust. Production of wood pellets in the world has reached several million tons per year and continues to increase. According to Rosstat, in 2014 the production of fuel wood pellets in Russia amounted to 888,000 tons that makes only 3 % of world production. At the same time, the volume of Russian exports of pellets totalled 879,000 tons worth 126 million US dollars (Rosstat, 2015). These data suggest that for Russia the cost of transportation and storage are key cost components for the production of fuel pellets.
With all positive qualities of granular fuel, it has a significant drawback: the high absorbability. This leads to higher requirements for the storage and transport (restriction interaction with air and moist environment).

2. Torrefaction

One way to improve the thermal and mechanical characteristics of biomass and pellets is using of low-temperature pyrolysis technology (torrefaction) (Bergman, 2005). The biomass is heated in an oxygen-free environment at temperatures of 200 - 300 °C with following holding at fixed temperature. As a result of torrefaction biomass develops improved hydrophobic properties and higher than that of the original biomass, heating value (~ 20 – 30 %). Such companies as TopellEnergy (Netherlands), Thermya (France), Atmosclear (United Kingdom), IntegroEarthFuels (USA) are worth to be mentioned in the field of torrefaction (Kleinschmidt, 2011). Despite the increasing interest in the development process and the creation of torrefaction plants nowadays, most of the projects are just pilot samples. Absence of significant progress in this direction is due primarily to the low energy process efficiency and, consequently, low economic performance of technology.

2.1 Unit for torrefaction

At JIHT RAS proposed new scheme of industrial heating technology, including gas piston engine (GPE) (Figure 1) (Kosov, 2014). The greatest economic benefit of the scheme provided by heating of the feedstock with exhaust gases of the engine, and heat from the heat exchanger in which the cooled combustion products is directed to the needs of the consumer.
Initial material (pellets) is loaded the feed hopper and subsequently pass three reactor zones: pre-treatment zone, torrefaction zone and a cooling zone. Hold-up time in each zone is determined by the specified characteristics of torrefied pellets (rate of weight loss).
Part of the exhaust gases from GPE passes through the gas-water heat exchanger (HE1) and sent to the cooling zone. The exhaust gases after cooling zone are mixed with hot gas. The mixing ratio is regulated so that the temperature at the entrance to the reaction zone maintained at set point. Further, the gases are consistently move through torrefaction and pre-treatment zone, and then enter the gas-water heat exchanger (HE2) and disposal unit.

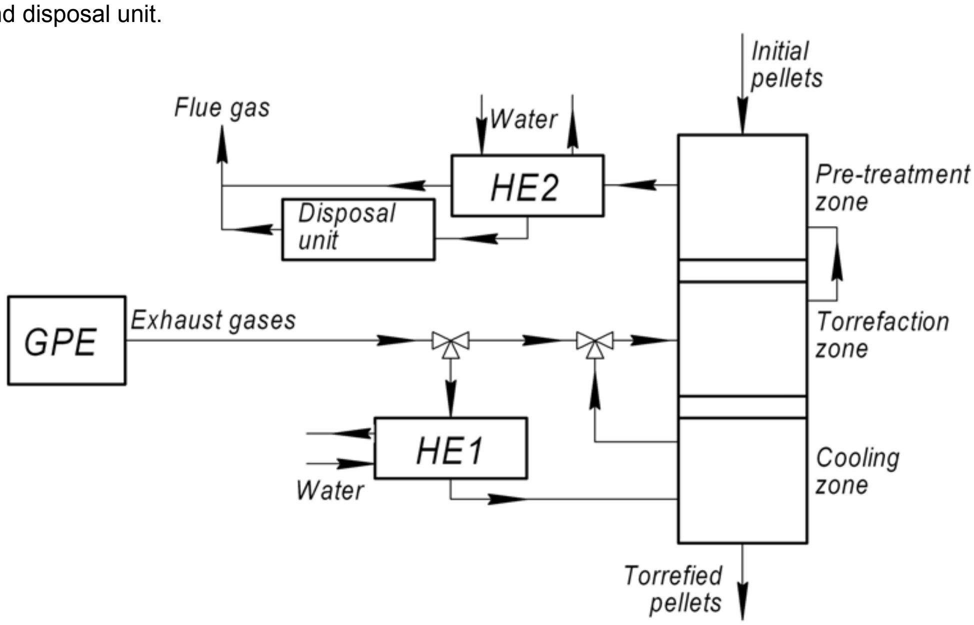

Figure 1: Block diagram of torrefaction unit.

JIHT RAS technology allows bringing the main heat engineering parameters of pellets to coal as much as possible. The torrefaction temperature is determined not only by a variety of properties of raw material, but also by required properties of the final product.

2.2 Using of exhaust from GPE

The use of exhaust gas as exchange gas is a promising solution and enables to heat biomass directly. The implementation of the scheme demanded working out of operating parameters of the power plant at the stoichiometric ratio of fuel-air mixture. The oxygen content in exhaust gases in this case is not exceed 0.2 % by volume.

As seen from the Figure 2 with a coefficient of excess air (α) is close to 1 the generating efficiency of engine (η_e) is 5 - 6% lower than the maximum, respectively, loss of power in this mode is 5 - 6%.

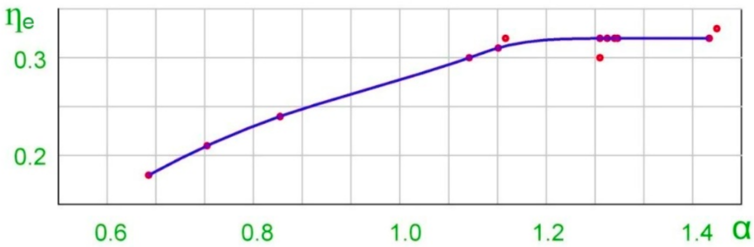

Figure 2: Changes in the efficiency of GPE, depending on the excess air ratio.

In this scheme, reduction in the efficiency of power generation part of the combustion is compensated by using of extra energy in heating process. Consequently, the overall fuel efficiency increases.

It was also studied the influence of the oxygen concentration in the exhaust gases to the operation mode of torrefaction reactor (Figure 3). In conducting research for the purpose of the temperature reading chromel-alumel thermocouples were used. Thermocouple T1 indicates the temperature of the exhaust gases before entering the torrefaction zone. Thermocouple T2 and T3 are installed in series in a layer of pellets on flue gas path. T4 installed at the outlet of torrefaction zone. When the concentration of oxygen in the combustion products of up to 2 %, which corresponds to α = 1.1, slow growth temperature of heating pellets (curves T3 and T4). When α = 1.3 (O_2=5 %) due to exothermic reactions, there is a sharp uncontrolled growth of temperature leading to emergency operation of the reactor.

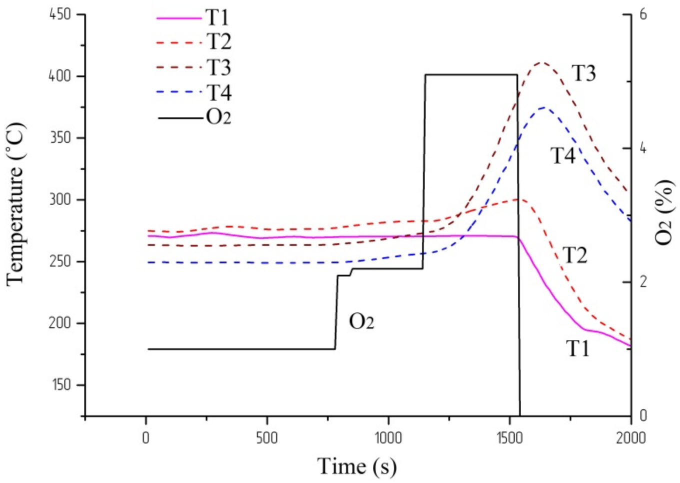

Figure 3: Effect of oxygen concentration in the exhaust gases on the temperature regime in reactor for torrefaction.

Modes of operation of GPE when the excess air ratio of more than 1.1 (> 2% O2) can lead to emergency operation of the reactor.

3. Comparison of fuels characteristics

The untreated wood chips is hydrophilic product that require compliance with strict conditions of storage and transportation, otherwise its usage for energy purposes becomes less efficient. Raw wood chips humidity can reach up to 50 %. For wood chips heating value is one grade less, than for coal. In case of low density co-firing of coal and wood chips can be realized only by redesigned boiler plants.

Wood pellets have a higher density and specific heating value than wood chips. The main problem with this kind of fuel consists in its high hygroscopicity. Pellets actively absorb moisture and when the humidity reaches 22-26% they lose their shape and crumble. Partial replacement of coal by pellets is possible under maintenance requirements for their storage.

During torrefaction not only feedstock drying occurs, but also the thermal degradation of hemicellulose (part of biomass) is carried out. Specific heating value of torrefied fuel is 20 – 30 % higher than the original, and has increased hydrophobic properties. Volumetric combustion energy density of torrefied fuel is close to coal.

The literature provides data on the dependence of fuels heating value from its humidity. Summary diagram is shown in Figure 4. It is clear that the point of view of heat engineering torrefied pellets as close as possible to coal.

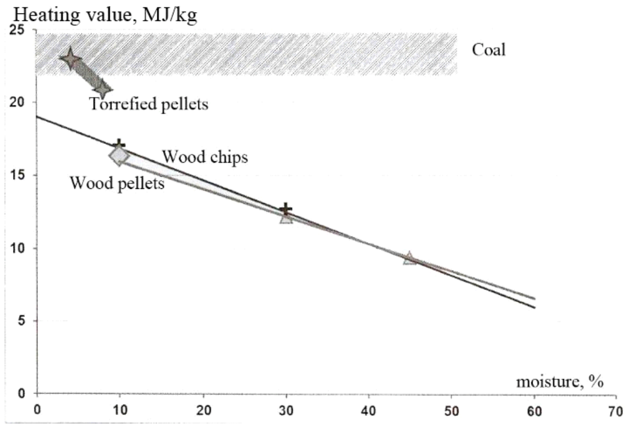

Figure 4: Relation between heating value and moisture content for different fuels.

Figure 5 presents data on the rate of mass loss as function of temperature (so-called DTG curves) for wood chips, wood pellets, torrefied pellets and coal. At this paper pellets were torrefied at temperature of 270 □C. For this purpose, the thermogravimetric analyser SDT Q600 was used.

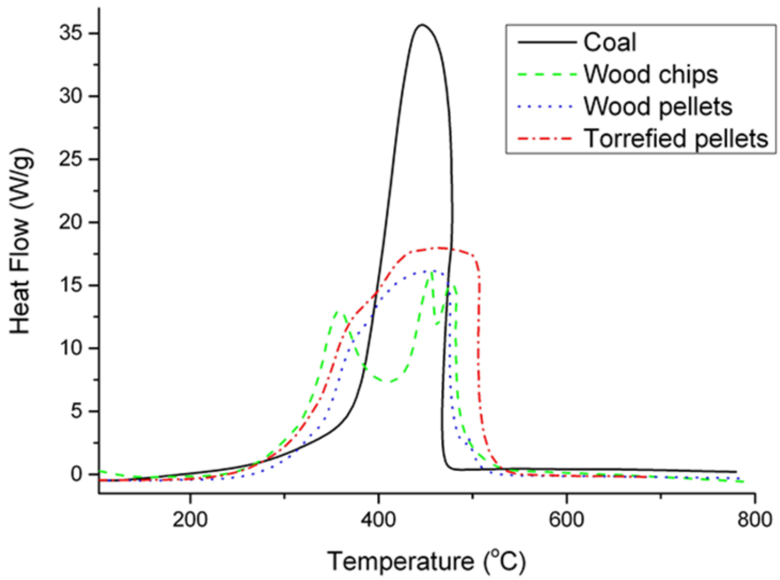

Figure 5: Dependence rate of weight loss of torrefied pellets from temperature for wood chips, wood pellets, torrefied pellets and coal.

As can be seen from Figure 4, area under the curve of heat flow (heat of combustion) for torrefied pellets is greater than for the untreated pellets. The heating value of torrefied pellets are much closer to coal, than for the untreated pellets. Thus, the change-over to the torrefied fuel will not reduce the thermal power of boilers.
Before the fuel inlet supplying (wood) into the furnace of a coal boiler must be pre-milled. This is required even in the case of separate feeding of coal and biomass. This indicator determines the amount of energy wood in the process of its co-firing with coal. All types of raw wood require more than the original coal electricity consumption for grinding. By using the technology of torrefaction achieves energy savings in comparison with the refining costs initial grinding wood.
The figure 6 shows the results of studies conducted by a group of organizations in Europe and the United States, shows the specific power consumption for grinding of different types of fuel (Dutta, 2012)..

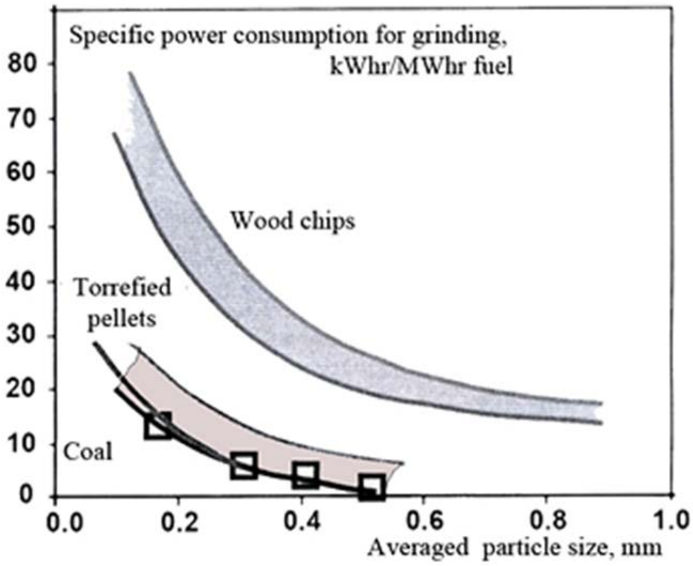

Figure 6: Specific power consumption for grinding of different types of fuel.

The data shows that for torrefied pellets specific electricity consumption is almost equal to the grinding power consumption for grinding of coal in a typical system of coal preparation.

4. Conclusions

Torrefaction advantages are high fuel combustion heat, high bulk density, low humidity, no tendency to rot, decay, the minimum fire and explosion hazard. Torrefied fuel can almost completely replace coal without major rework of the existing fuel systems. Under the same conditions untreated chips and pellets can replace only 8-15% of the coal.
The torrefied pellets can be an alternative to low-grade brown coals (39 % solid fuel in Russia). This coal is supplied to consumers at a price of 70 $/t. When heating value of such coal 14 MJ/kg purchase price is 5 $/GJ. This means that when using torrefied pellets with a heating value 22 MJ/kg purchase price will be 3 $/GJ.
This work is important not only for Russia but for the entire world. So for the European Union it is extremely important to recognize the replacement of fossil fuels, solid biofuels or co-firing, the further improvement of biofuels (pelletizing, briquetting) and increased use of wood and other wastes. At the same time agriculture was seen as a key sector in achieving the goals related to renewable energy resources.
Therefore, it was recommended that member states give a high priority to renewable energy projects in rural areas:
• to support the use of biofuels in the framework of rural development programs;
• to support the regions participating in the financing of innovation, demonstration and application projects, such as joint development of heat and electricity based on solar and wind energy and biomass.

Acknowledgments

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