Research of technologies of local fuel and energy resources using for distributed power generation

O M Larina, 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: george.sytchev@gmail.com

Abstract. Development of methods of energy self-sufficiency is a priority for present power generation sector advancing. For our country, it is of particular importance. Approximately 70% of the territory of the Russian Federation (with a population of about 20 million people) are located outside centralized energy supply systems. Capacity of existing centralized energy systems is not enough for many regions of the country. At the same time, in the existing economic conditions, distributed power generation turns out to be more advantageous from an economic point of view in relation to centralized power generation. The production of energy without imported organic fuels implies local fuel and energy resources using, such as peat, wood, agricultural, household and other types of waste. Energy utilization of various types of waste, which are also local fuel and energy resources, will reduce the negative impact on the natural balance of accumulated environmental damage.

1. Introduction
A promising direction for the development of distributed power generation is using of local fuel and energy resources, in particular, biomass. As it is well known, the Russian Federation occupies a leading place in reserves of peat and wood. Approximately 37% of the world peat reserves and about 25% of the wood resources are concentrated here [1]. Millions of tons of sewage sludge have been accumulated in the country, for storage of which huge areas are being allocated. According to the existing estimates, about 15–18 million tons of chicken litter is formed annually at poultry farms. There are also big problems with the disposal of cattle manure. From an economic point of view, the manure using in the form of fertilizers is less profitable compared to chemical fertilizers. Effective integrated biomass utilization technologies (including various types of waste) do not currently exist. In this paper, results of research of methods of organic waste energy utilization with subsequent production of various fuel and energy resources: synthesis gas, conditioned solid hydrocarbon fuel, and carbon composite.

2. Technology of biomass conversion into gaseous fuel
From the efficiency point of view, the most preferable is the energy utilization of biomass waste various types, at which the conversion of the raw material into energy gas suitable for further use in power generating units is carried out. In the current context of distributed power generation, preference is often given to gas piston power plants rather than gas turbines, because of their economically viable use in small-scale enterprises (up to 3 MW) [2]. Currently, the development
of technologies that allows to obtain electricity using biomass as an energy fuel is at the level of pilot and research facilities. From the literature [3], it follows that the existing technologies for the conversion of biomass into energy gas are not able to solve the whole range of tasks aimed at using such a gaseous product as an independent fuel for the generation of electrical energy. In the JIHT RAS, studies are being carried out on a pilot plant, carrying out the process of two-stage thermochemical pyrolytic conversion (first stage is pyrolysis and the second one is volatile compound thermal cracking) of the raw material into a high-calorific energy gas, suitable for use as an independent fuel for gas piston unit (GPU) [4]. The coefficient of energy conversion of the initial solid fuel into gaseous one (as the ratio of their heating values) in the proposed by the JIHT RAS technology is in the range of 0.75–0.8. It should be noted that the processing of 1 kg of raw materials (for example, wood waste) allows to obtain up to 1.4 m$^3$ of energy gas with a heating value of about 12.5 MJ/m$^3$.

Based on the technology proposed at the JIHT RAS, the conversion of such specific raw materials as sewage sludge (from Podolsk treatment plant) was successfully implemented. The results of the studies of gas production are shown in figures 1 and 2.

Figure 1 presents data on the dynamics of the yield of the components of the gas mixture with pyrolysis temperature increasing in the pyrolysis reactor. It should be noted that the main components of the mixture described above are carbon monoxide and hydrogen. In the case of traditional pyrolysis (one-stage pyrolysis), the final gaseous product is significantly diluted with carbon dioxide and methane.

From the data presented in figure 2, it also follows that the specific volume yield of the gas fraction in the implementation of the technology proposed by the JIHT RAS is sequence higher than the technology of traditional pyrolysis.

An analysis of the obtained results for sewage sludge processing indicates an increasing in the heating value up to 11.4 MJ/m$^3$ and the specific volume gas yield up to 1.4 m$^3$/kg when
Figure 2. A comparative analysis of the specific volumetric yield of a gas product during the implementation of traditional pyrolysis technologies and the technologies proposed by the JIHT RAS.

using the two-stage thermochemical conversion technology (for traditional pyrolysis this values are 11.03 MJ/m$^3$ and 0.14 m$^3$/kg correspondingly).

On small power plants as the source of heat and electric power production unit can potentially be used in gas piston power stations. In the context of ongoing research at the JIHT RAS, the development of operational parameters was carried out at the GPU shown in figure 3.

The main goal of researches of the JIHT RAS in the field of GPU is to test the operating parameters and refine the design of the engines for the highly efficient use of gaseous products of the two-stage thermochemical conversion as the main fuel. The solution of a range of tasks related to the difficulties of implementing the two-stage conversion process together with the subsequent supply of energy gas as fuel to a gas piston engine will allow the implementation of integrated approaches to energy-efficient utilization of local fuel energy resources from biomass, as well as biomass waste: forestry and timber harvesting waste, agro-industry waste, etc. The wide promotion of distributed power generation plants will significantly increase the power loading and energy security of the regions of decentralized energy supply.

3. Increasing of consumer properties of solid fuel from biomass by torrefaction

The main criterion that is capable of ensuring the high competitiveness of fuel local types in the modern fuel and energy market is the high consumer and thermotechnical characteristics of biomass as a fuel. Currently, the most popular type of fuel from biomass is pellets. The main disadvantage of such fuel product is its high hygroscopicity, which places a number of severe limitations on the conditions of transportation and storage of pellets, which practically exclude their contact with the environment. Nonadherence of the requirements described above leads to a significant increase in the moisture content of the fuel (up to its destruction), as well as to decreasing of its heating value, which together makes the fuel unsuitable for further using. One of the most effective methods for improving the consumer properties of newly created
Figure 3. The GPU at the JIHT RAS experimental stand.

fuel after granulation of biomass is torrefaction technology. Torrefaction is a preliminary heat treatment of solid hydrocarbon fuel carrying out in an oxygen-free environment at temperatures in the range of 200–300 °C. This technology allows not only removing moisture from the initial material, but also due to the partial decomposition of the main components of the organic part of the processed raw materials to improve the hydrophobic properties of the final product. It should be noted that the final product, torrefied biomass, has up to 30% higher specific heating value in comparison with the raw pellets [5]. Torrefaction, along with other ways to improve the consumer properties of granulated biomass, is the most high-tech and efficient technology for the preparation of solid fuels. In addition to the high thermal characteristics of torrefied biomass, an important factor is the possibility of creating significant strategic reserves of such a local fuel resource.

Despite the fact that the technology is currently in trend and is being investigated throughout, it is necessary to take into account the fact that there are no industrial torrefaction technologies in the world. The most significant range of problems when working with large volumes of processed raw materials is associated with the presence of the so-called “exothermic effect”, appeared in the process of the raw materials heating to temperatures in the range of 250–280 °C [6]. Occurrence of exothermic effect is connected with the thermal destruction of one of the three main components of plant origin biomass—hemicellulose [7]. The inclusion of the exothermic effect neutralization stage into the torrefaction process may entail costs that will
not be compensated by the advantages that the torrefied product achieved. The torrefaction process organization, which implements the concept of partial exothermic heat utilization, has been created and tested at the JIHT RAS. The combustion products of a gas piston power plant using natural gas as a fuel were used as an inert environment supplier in this scheme. The investigation results confirmed the possibility of significant reducing of fuel consumption in comparison with the “classical” organization of the process, including the stage of exothermic process cooling. The nominal productivity of the plant was 30 kg/h by feedstock, and due to partial use of the internal heat of the processed raw materials, productivity of up to 100 kg/h was achieved. General view of the biomass torrefaction plant is presented in figure 4.

Using of technical solutions obtained at the JIHT RAS can later positively influence the industrial development and implementation of the torrefaction process. It should be noted that,
according to the main thermal characteristics, torrefied biomass approaches modern energy coals. The industrial implementation of torrefaction technology will ensure the provision of local solid fuel to various small and distributed power plants.

One of the most promising (from an ecological point of view) applications of torrefaction technology can be the processing of various types of waste, e.g., chicken litter. Taking into account the capacity of modern poultry farms, it becomes obvious that it is impossible to completely process such waste into high-quality fertilizers due to the economic unjustified nature of this type of production. As in the case of small energy plants, the torrefaction technology can also be used in poultry farms, transferring them to partial own energy supplying using local fuel, and also solve the environmental problem associated with the need of such waste large-scale dumping.

4. Technology for the production of pure carbon materials by joint thermal processing of wood waste and hydrocarbon gas (natural and associated oil gases)

The developed technology is based on new ideas about the joint thermal processing of natural and associated gases and plant origin carbon-containing materials (e.g., wood) [8]. Wood, on average, up to 50 wt % consists of carbon. The developed technology allows producing a composite material that consists of wood carbon and carbon of natural or associated oil gas.

The technology consists of two stages [8, 9]: the first stage is for carbonization of granular biomass and follow activation by activating gases to increase the pore surface of granules per volume and the second stage is for the original “packing” of pore by carbon of dissociated hydrocarbons.

At the first stage of developed technology thermal structure of charcoal are formed. At the second stage thermal decomposition of natural gas is carried out in this porous matrix bed. As a result of the experiments, carbon-carbon composite (97–98 wt % carbon) was obtained. It was possible to obtain such a composite with high purity and density above 1000 kg/m³. About 90 vol % of gaseous reaction products is hydrogen. A photograph of samples of such composite carbon material is shown in figure 5 [9].

Figure 5. Photograph of carbon composite.
The carbon materials produced by the developed technology can be used as high-calorific fuel for power plants, and also, as a raw material, in various industrial technologies. One of the possible ways of use of produced materials can be the metallurgical production. According to the available data, the unbalanced demand of the metallurgical industry of only Western Europe in pure carbon materials of similar quality amounts to about 8–20 million tons [9]. This technology could be considered as one of the possible ways for processing of associated oil, as well as natural gases with low reservoir pressure directly at the fields, subject to the availability of biomass.

5. Conclusion
The article demonstrates a number of approaches that in the long run make it possible to abandon the use of fossil fuels. The transition to renewable (local) fuel and energy resources will reduce the ecological load on the environment. On the basis of the JIHT RAS approaches it was shown, that such technologies implementation could solve a number of problems associated with decentralized electricity and heat supply in the regions (for example, interruptions in fuel supply and, as a consequence, with energy supply).

References
[1] Zaichenko V M and Chernyavskiy A A 2016 Prom. Energ. 2–8
[2] Zaichenko V M, Tsoy A D and Shterenberg V Ya 2008 Distributed Energy Production (Moscow: Bookos)
[3] Zaichenko V M, Kachalov V V, Lavrenov V A, Lishchiner I I and Malova O V 2016 Ekol. Prom-st. Ross. 20 4–9
[4] Lavrenov V A, Larina O M, Sinelshchikov V A and Sytchev G A 2016 High Temp. 54 892–8
[5] Kosov V V, Sinelshchikov V A, Sytchev G A and Zaichenko V M 2014 High Temp. 52 907–12
[6] Cavagnol S, Roesler J F, Sanz E, Nastoll W, Lu P and Perre P 2015 Can. J. Chem. Eng. 93 331–9
[7] Faleeva J M, Sinelshchikov V A, Sytchev G A and Zaichenko V M 2018 J. Phys.: Conf. Ser. 946 012033
[8] Zaichenko V M, Bessmertnykh A V and Maikov I L 2012 Biomass as a Renewable Source of Energy and Carbon Materials (Germany: Lambert Academic Publishing)
[9] Bessmertnykh A V, Zaichenko V M and Maikov I L 2014 Tepl. Protsessy Tekh. 3 110–4