Вестник РУДН. Серия: Инженерные исследования
RUDN Journal of Engineering Research

2022;23(3):191–197

ISSN 2312-8143 (Print); ISSN 2312-8151 (Online)
journals.rudn.ru/engineering-researches

DOI 10.22363/2312-8143-2022-23-3-191-197
UDC 620.97

Research article / Научная статья

The relevance of using the renewable fuels for power grids

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Article history
Received: May 17, 2022
Revised: September 5, 2022
Accepted: September 10, 2022

Keywords:
cogeneration power plants, renewable fuels, firewood, characteristics, energy technology complex, steam piston machine

Abstract. The paper presents the analysis and efficiency of using the cogeneration power plants and alternative energy sources. The documents on the relevance of introducing the energy-efficient measures in the economies of various countries are given. The prospects of using the alternative and renewable fuels considering the effectiveness of their use in various power systems and grids are well substantiated. Such measures contribute, on the one hand, to saving the hydrocarbon fuels extracted from the ground and to extending their use, and, on the other hand, to the development and application of the alternative power grids with the use of the renewable fuels. Firewood can serve as such a fuel. The characteristics of the firewood in the corresponding tables are described. It provides the opportunity for evaluating the efficiency of the woodfired power plant depending on the type of the firewood and the territory of growing the firewood at the development stage. Moreover, the characteristics of the firewood make it possible to estimate its necessary amount and the territory for storing and harvesting. Based on the obtained data, the authors conclude that it is necessary to develop and establish the power plants based on the reciprocating steam engines for various small and medium-sized enterprises. Design proposals for the power plant based on the reciprocating steam engine are briefly present-ed and the economic effect of its use on site is estimated.

For citation
Razuvaev AV, Redko IYa, Krasnoludskiy NV, Kostin DA. The relevance of using the renewable fuels for power grids. *RUDN Journal of Engineering Research*. 2022;23(3):191–197. http://doi.org/10.22363/2312-8143-2022-23-3-191-197

Актуальность применения возобновляемых топлив в энергетических комплексах

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История статьи
Поступила в редакцию: 17 мая 2022 г.
Доработана: 5 сентября 2022 г.
Принята к публикации: 10 сентября 2022 г.

Аннотация. Представлен анализ и эффективность применения когенерационных энергоустановок и альтернативных источников электроэнергии. Отмечены документы по актуальности внедрения энергоэффективных мероприятий в экономики различных стран. Обоснована

Ключевые слова:
когенерационные энергоустановки, возобновляемые виды топлива, дрова, характеристики, энерготехнологический комплекс, паровая поршневая машина

перспективность применения альтернативных и возобновляемых видов топлива с учетом эффективности их применения в различных энергетических системах и комплексах. Такие мероприятия способствуют, с одной стороны, экономии добываемых в земле углеводородных топлив и продлению сроков их использования, а с другой стороны – развитию и применению альтернативных энерготехнологических комплексов с использованием в них возобновляемого топлива. Подобным топливом могут служить дрова. Приведены характеристики дров в соответствующих таблицах, что дает возможность уже на стадии проработки оценить эффективность применения энергокомплекса на дровах в зависимости от их сорта и территории его возрастания. Кроме того, характеристики дров позволят оценить необходимое их количество и территорию для складирования и заготовки. На основании полученных данных сделан вывод о необходимости разработки и создания энерготехнологических комплексов на базе паровых поршневых машин для различных малых и средних предприятий. Проектные предложения по энерготехнологическому комплексу на базе паровых поршневых машин представлены кратко, оценен экономический эффект по его применению на месте эксплуатации.

Для цитирования
Разуваева А.В., Редько И.Я., Краснолудский Н.В., Костин Д.А. Актуальность применения возобновляемых топлив в энергетических комплексах // Вестник Российского университета дружбы народов. Серия: Инженерные исследования. 2022. Т. 23. № 3. С. 191–197. http://doi.org/10.22363/2312-8143-2022-23-3-191-197

Introduction

Nowadays the shortage of energy carriers in Europe indicates that studies in this regard are relevant. On the one hand, the energy resources are saved, on the other, various types of fuels instead of hydrocarbons extracted from the bowels of the earth, are used. The problem of the fuel economy can be solved on the basis of applying the cogeneration system used at various facilities requiring the energy resources, such as electricity and heat.

The document,[1] which states that "the potential of using cogeneration as an energy saving measure is not fully used in the Commonwealth today, is devoted to the issues of cogeneration and its effective application. The promotion of high-efficiency cogeneration based on the demand for useful heat is a priority for the Commonwealth, given the savings of the primary energy sources, the prevention of distribution losses and the reduction of harmful emissions (greenhouse gases) into the atmosphere." Moreover, the efficient use of the energy produced by cogeneration can also contribute to the continuity of energy supply and has a positive impact on the development of competition in the European Union and member states. Therefore, it is necessary to take measures to ensure the best use of the potential within the domestic energy market. Besides, it seems interesting, relevant, and appropriate to use the relevant provisions contained in Directive 2003/54/EC and Directive 2001/77/EC of the European Parliament and of the Council of 27 September 2001 on the promotion of electricity generated from the renewable energy sources.

In this case, the issue of using the energy generated from the renewable energy sources is noteworthy. This contributes to the development of the general-purpose heat and power plants based on the reciprocating steam engines [1].

The given plant is powered by steam generated by using the renewable fuels which include firewood from various types of trees, pellets, manure and some other fuels, including gas generator gas. Gas generator gas production technology is also relevant since various types of fuels and materials can be used to produce gas.

1. The relevance of using the renewable fuels

Russian Energy Strategy paper[2] states that "the growth rate of the global primary energy consumption contained in ES-2035 is expected to be 1.2% per year" and further the paper states that "the emergence of new producers, the growing importance of unconventional hydrocarbon resources

[1] Directive 2004/8/EC of the European Parliament and of the Council of 11 February 2004 on the promotion of cogeneration based on a useful heat demand in the internal energy market and amending Directive 92/42/EEC. Available from: https://base.garant.ru

[2] Energy Strategy of Russia for the period till 2035, main provisions (as amended on 07.02.2014).

and the accelerated development of the renewable energy sources lead to the tougher competition in the global energy markets. When studying the prospects for external demand for Russian energy resources formulated in ES-2035, the analysis results of energy strategies of the largest consumers and producers of energy resources aimed at the energy self-sufficiency are also taken into account." This confirms the relevance of considering and applying unconventional energy resources and accelerated development of renewable energy sources. Such fuels include firewood of different types, pellets, and a number of others.

It is worth considering the parameters of such fuels which include not only energy parameters, e.g., the fuel calorific value, but also the weight and size values. These data should facilitate their application at the specific facilities of power plants.

Such power plants have been previously considered in paper, where the concept [2; 3] of their development has been proposed. Paper describes the energy complex calculated depending on its purpose. Simultaneously, it is necessary to analyse its parameters as the entire energy technology complex, thereby defining its performance specifications. Furthermore, the parameters of the reciprocating steam engine, such as the pressure and temperature of steam, its flow rate and rotor speed are defined.

The horizontal arrangement of the machine, namely double expansion compound steam engine is the most appropriate. The estimating calculations of the main values have been presented. The diameter of the high-pressure cylinder is 310 mm, the diameter of the low-pressure cylinder is 460 mm, while the steam pressure required for the operation is 1.2 MPa (12 kg/cm^2) with a temperature of 573 K (300 °C), its consumption is 1887 kg/hour, the number of revolutions is 2.66 s-1 (160 rpm) [3].

A steam engine rotates a generator through a manual transmission to generate the electric current. The generator BG-160M-4 by the Baranchinsky Electromechanical Plant was selected from a catalogue. The specifications of the generator are as follows: the rated power is 160 kW, the rated rotor speed is 25 s-1 (1500 rpm), the stator current is 289 A, the efficiency is 91.6%, the transmission ratio is 9.4.

According to the preliminary design study of the reciprocating steam engine, its dimensions are 4500×4200×1000 mm, and necessary auxiliary power equipment and components are selected from the commercially available ones. A typical scheme of the power plant is shown in Figure 1.

Besides, the economic efficiency of its application has been analysed and shown. When calculating the economic efficiency of the power plant aimed at increasing the validity of the results obtained, the most common option was adopted as a fuel – maple firewood with a calorific value of 1600 kcal/dm^3 and a specific gravity of 0.65 kg/dm^3.

When determining the cost of the power plant, we used the publicly available data, while the cost of the reciprocating steam engine was defined based on the expert knowledge by comparing it with the cost of producing the equipment similar in design. Moreover, we took into consideration the cost of the equipment installation and commissioning. The total amount of capital expenditures was about 16 million rubles.

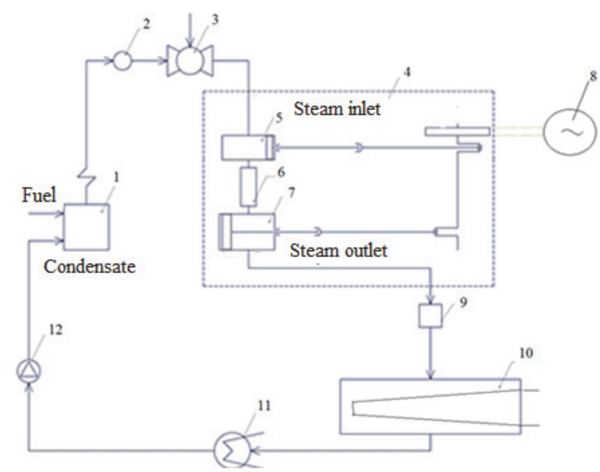

Figure 1. A typical scheme of a power plant:
1 – a steam boiler; *2* – a steam flow meter;
3 – a steam pressure regulator; *4* – a piston steam engine;
5 – a high-pressure cylinder; *6* – a receiver; *7* – a low pressure cylinder;
8 – a generator; *9* – an oil separator; *10* – a consumer heating system;
11 – a condenser; *12* – a condensate pump

The cost-effectiveness analysis was carried out for a period of one month. From the condition of the need to ensure the superheated steam consumption of 1600 kg/h at the boiler efficiency of 88%, the required amount of heat was defined as the sum of the heat for heating water to the boiling point, the heat required for vaporization and the heat for overheating the steam to the required temperature. The final value for ensuring the piston steam engine operation under the design parameters was 1.195 Gcal/hour or 860.4 Gcal/month, which corresponds to the current district heating tariff of 1.376.640 rubles per month.

The current costs of obtaining the same amount of thermal energy during the power plant operation have been estimated by the object of expenditures: the cost of firewood, the cost of the water system condensate flow, the stuffing costs, the maintenance costs, the costs of electricity for own needs (for the water circulation pump operation, for the power supply of the control and lightning system). Besides, we took into account the costs of maintenance consumables and the costs of the required amount of fuel (firewood).

The total cost of operating expenditures was about 656 thousand rubles per month, which gives an economic benefit of about 720 thousand rubles. The payback period of the plant is approximately 1.9 years.

The proposed calculation is estimates, and the economic benefit of the presented plant in every particular case will depend on the performance specifications [4; 5] of the facility and its configuration. More detailed information about this is given in [6–8], while in Russian scientific and technical literature [9].

2. Some types of alternative fuels and their parameters

Some types of alternative fuels include firewood and their wastes. These include twigs, bark, off-cuts (wood processing wastes), as well as pellets based on production wastes and sawdust. Pellet fuels have quite good parameters, including transportation and different types of packaging.

Firewood is one of the most traditional and ancient sources of thermal energy.[3] According to their characteristics, firewood is one of the most unstable fuels, but it is a renewable source of thermal energy which is the main advantage.

Firewood is recorded according to the following parameters: on the one hand by weight (kilograms and tons), and by volume (cubic meters) on the other [10].

A composition of wood fuel is almost the same for any type and is as follows: up to 60% of cellulose, from 7 to 8% of accompanying hydrocarbons, up to 30% lignin and the rest is from 1 to 3% of minerals. The firewood quantity mass measuring is rarely used, if it is convenient, e.g., when transporting firewood by car. The weight of the car is calculated before and after the firewood delivery to the place of consumption. This measuring also simplifies the calculation of the calorific value of the supplied amount of firewood.

However, the most common way of measuring the amount of firewood is volumetric, which is simple and fast. The results of measurements by such a parameter are easy to check and control. Besides, there are appropriate methods for various types of storage, size of logs, etc.

We should first consider the characteristics and parameters of such type of alternative fuel as firewood. It is necessary to point out their difference in one of the main characteristics, namely the calorific value. In this case, the volumetric and mass calorific values of various firewood are distinguished. Table 1 shows the examples of these values.

Table 1

The volumetric calorific value of firewood

No	Wood species	Volumetric specific calorific value of firewood, kcal/dm^3	
1	Birch	1389–2240	The first group includes birch, beech, ash, hornbeam, elm, field elm, maple, oak, larch
2	Beech	1258–2133	
3	Ash	1403–2194	
4	Hornbeam	1654–2148	
5	Elm	(analogue is field elm)	
6	Field elm	1282–2341	
7	Maple	1503–2277	
8	Oak	1538–2429	
9	Larch	1084–2207	
10	Pine	1282–2130	The second group includes pine and alder
11	Alder	1122–1744	
12	Spruce	1068–1974	The third group includes spruce, cedar, fir, aspen, linden, poplar, willow
13	Cedar	1312–2237	
14	Fir	(analogue is spruce)	
15	Aspen	1002–1729	
16	Linden	1046–1775	
17	Poplar	839–1370	
18	Willow	1128–1840	

The presented characteristics[4] make it possible to calculate the required volume or weight of the firewood for a certain time of operation or for the processing period by the amount of heat received.

Table 2 provides the firewood characteristics of different varieties of trees, which allow us to obtain the necessary heat data from a specific volume of firewood.

The volumetric calorific value of firewood for the same type of firewood may differ depending on

[3] Wood heating. Available from: http://tehnopost.kiev.ua/drova/13-teplotvornost-drevesiny.html (accessed: 22.02.2022).

[4] Wood heating. Available from: http://tehnopost.kiev.ua/drova/13-teplotvornost-drevesiny.html (accessed: 22.02.2022).

the region of growth. This is due to the soil water saturation in the area. This factor must be taken into account when harvesting the firewood, i.e., the drier the firewood, the higher the reward, or if the firewood harvesting is carried out in a more arid region, the profit is also bigger. Although this difference is not great, only 2–5%, but at larger volumes it can affect the economic indicators in general in terms of the harvest volume.[5]

On this basis and from Table 3, it is necessary to take into account the specific weight of firewood depending on moisture.

Table 2

The specific calorific value of wood fuel for different types of wood

No	Wood species	Absolute (higher) calorific value of wood fuel, kcal/kg	Net (lower) mass calorific value of wood fuel, kcal/kg	Net (lower) volumetric calorific value of wood fuel, kcal/dm^3	Wood density, kg/dm^3	Maximum wood density, kg/dm^3
1	Oak	4753	4000	3240	0.810	0.690–1.03
2	Ash	--||--	--||--	3000	0.750	0.520–0.95
3	Rowan	--||--	--||--	2920	0.730	0.690–0.89
4	Apple tree	--||--	--||--	2880	0.720	0.660–0.84
5	Beech	--||--	--||--	2720	0.680	0.620–0.82
6	Acacia	--||--	--||--	2680	0.670	0.580–0.85
7	Field elm	--||--	--||--	2640	0.660	0.560–0.82
8	Larch	--||--	--||--	2640	0.660	0.470–0.56
9	Maple	--||--	--||--	2600	0.650	0.470–0.56
10	Birch	--||--	--||--	2600	0.650	0.510–0.77
11	Pear	--||--	--||--	2600	0.650	0.610–0.73
12	Chestnut	--||--	--||--	2600	0.650	0.600–0.72
13	Cedar	--||--	--||--	2280	0.570	0.560–0.58
14	Pine	--||--	--||--	2080	0.520	0.310–0.76
15	Linden	--||--	--||--	2040	0.510	0.440–0.80
16	Alder	--||--	--||--	2000	0.500	0.470–0.58
17	Aspen	--||--	--||--	1880	0.470	0.460–0.55
18	Willow	--||--	--||--	1840	0.460	0.490–0.59
19	Spruce	--||--	--||--	1800	0.450	0.370–0.75
20	Pussy willow	--||--	--||--	1800	0.450	0.420–0.50
21	Hazelnut tree	--||--	--||--	1720	0.430	0.420–0.45
22	Fir	--||--	--||--	1640	0.410	0.350–0.60
23	Bamboo	--||--	--||--	1600	0.400	0.395–0.405
24	Poplar	--||--	--||--	1600	0.400	0.390–0.59

Table 3

The specific weight of firewood, kg/m^3, depending on the tree species and moisture percentage

No	Wood species	Moisture percentage, %										
		Fresh	100	80	70	60	50	40	30	25	20	15
1	Larch	940	1100	990	930	880	820	770	710	700	690	670
2	Poplar	700	760	690	650	610	570	540	500	480	470	460
3	Beech	960	1110	1000	950	890	830	780	720	710	690	680
4	Field elm	940	1100	1100	930	880	820	770	710	690	680	660
5	Oak	990	1160	1160	990	930	870	820	760	740	720	700
6	Hornbeam	1060	1330	1330	1130	1000	990	930	860	840	830	810
7	European spruce	740	750	750	640	600	560	520	490	470	460	450
8	Walnut tree	910	1000	1000	850	800	750	700	650	630	610	600
9	Linden	760	830	830	710	660	620	580	540	540	530	500
10	Bustard acacia	1030	1330	1330	1190	1060	990	930	860	840	830	810
11	Alder	810	880	880	750	700	660	620	570	560	540	530
12	Maple	870	1160	1160	990	930	870	820	760	740	720	700
13	European ash	960	1150	1150	930	920	860	800	740	730	710	690
14	Siberian fir	680	630	630	540	510	470	440	410	400	390	380
15	Common pine	820	850	850	720	680	640	590	550	540	520	510
16	Caucasian fir	720	730	730	620	580	550	510	480	460	450	440
17	Siberian pine	760	730	730	620	580	550	510	480	460	450	440
18	Birch	870	1050	1050	890	840	790	730	680	670	650	640
19	Aspen	760	830	830	710	660	620	580	540	530	510	500

[5] Wood heating. Available from: http://tehnopost.kiev.ua/drova/13-teplotvornost-drevesiny.html (accessed: 22.02.2022); In the field of biomass processing. Available from: http://www.bm-biomass.com

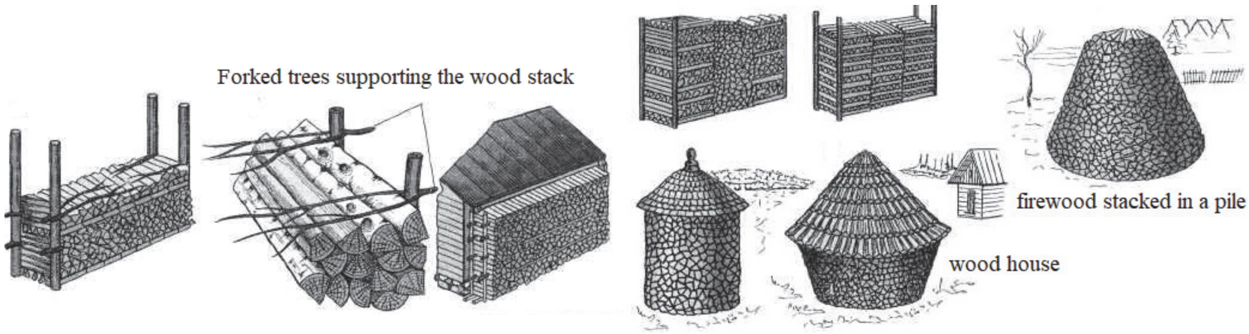

Figure 2. Methods of stacking the firewood

In addition to these data, the ways of storing the firewood for various places of consumption are interesting and presented in Figure 2.

Sawdust as a waste product of woodworking operations is also a fuel, but with worse combustion and storage properties. Nevertheless, sawdust is a good material for pellet production. Sawdust characteristics are presented in Table 4.

Table 4

Weight of the landed dry sawdust depending on the tree species

No	Wood species	Bulk density, kg/m^3	Weight of 1 cube of sawdust, kg
1	Acacia	215	182–225
2	Ash	210	146–266
3	Beech	190	174–230
4	Hornbeam	213	207–223
5	Oak	227	193–288
6	Larch	186	151–186
7	Birch	182	143–216
8	Pine	146	87–213
9	Chestnut	182	168–202
10	Pear	188	164–199

Pellets can be considered as a type of renewable fuel. They are made from compacted sawdust, wastes from wood products, as well as other types and varieties of energy material (production wastes – seed and nuts husk, buckwheat hulls, sunflower husk, tree bark, some types of manure, etc.). The advantages of this type of fuel include the fact that the basis for its production are various renewable combustible materials.[6]

The production itself is uncomplicated and therefore the cost is very competitive in this sector. The shape of the pellets is close to cylindrical with the height of 5–15 mm and the diameter of 6–8 mm. At the same time, the thermal energy during combustion is about 17.216 kJ/kg and depends on the feedstock used, the ash content is no more than 5%. The density of pellets is 1200–1400 kg/m^3, and the bulk density of pellets for storage and transportation is 650 kg/m^3. We should mention one more significant advantage, namely the transportation in pellet bags of small weight from 10 to 15 kg and of large weight from 500 to 1200 kg.

Besides, an auger feeds pellets for boiler equipment, which makes it possible to automate the heat production in the boiler, maintaining the necessary parameters of water or steam.

3. Results and discussion

The presented materials provide a justification for the effective and expedient application of the fuel in the form of firewood. Moreover, this type of fuel is renewable due to planting seedlings to compensate felled trees.

The given parameters of different types of trees make it possible to carry out calculations on their application onsite and to evaluate the effectiveness in specific conditions taking into consideration their transportation and storage.

In addition, the main parameters and characteristics of pellets deserving a special attention as a renewable and efficient fuel for the operation of cogeneration plants based on steam piston engines have been presented [11].

Conclusion

It should be noted that it is necessary to develop and effectively use the general-purpose heat and power plants based on the reciprocating steam engines using the renewable fuels in the form of vari-

[6] Warmth in the house. Pellet Production. Available from: https://vse-otoplenie.ru/proizvodstvo-pellet-svojstva-toplivnyh-granul-osobennosti-processa-izgotovlenia-primenaemye-ustanovki (accessed: 22.02.2022).

ous types of firewood and pellets. It would save the limited reserves of hydrocarbon fuel and extend its use in the existing power plants, as well as establish the isolated power plants with low power systems and units.

Finally, further investigation is required regarding the possibility of using other types of alternative and renewable fuels considering the efficiency in various power systems and plants.

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