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EXPERIMENTAL STUDY OF ECOLOGICAL INDICES OF 40 KW GAS-GENERATOR HOT-WATER BOILER

The results of experimental research of ecological indices of gas-generator hot-water boiler, operating on the wood, have been analyzed. Ecological indices of boiler operation were compared with the existing standards. Recommendations, aimed at improvement of boiler design are given.

Key words: gas-generator boiler, ecological indices, nitrogen oxide, carbonic oxide.

Introduction. Problem set-up

Annual rise in prices for energy resources leads to the necessity of using renewable sources of energy. One of the most promising types of renewable sources of energy for Ukraine is biomass: farm waste, woodwork and timber industry waste, wood. According to [1], total potential resources of wood waste, including bark in forestry and woodwork branches of industry makes up 3743 thousand m³, that is equivalent to 984 thousand tons of equivalent fuel per year. Burning of biomass, according to [2] is the greatest source of atmospheric pollution. For efficient combustion of low grade types of fuel a number of measures has been developed [3].

The most promising method of thermal energy generation from wood and its waste is thermochemical gasification of fuel with further reburning of the produced gas. Boilers, operating on this principle, are called gas-generator boilers. This is rather new type of boilers on the market of heating equipment. Such method of burning enables to increase considerably heat efficiency and controllability of the equipment and reach high ecological parameters. In national literature publications regarding the study of ecological and power characteristics of such boilers can hardly be found, that is why, the subject of the paper is topical.

The aim of the given paper is the analysis of ecological indices of 40kW gas-generator hot-water boiler for further introduction of such equipment in heat supply systems of buildings.

Structural characteristics of the boiler

Gas-generator hot-water boiler was designed by engineer Dovgal A. N. Adjustment tests of the boiler were carried out in the shop of manufacturing enterprise. The furnace of the boiler is double, made of steel and ceramics. Nozzle for gasification is located between loading chamber and secondary combustion space. Holes for auxiliary air supply, which is heated in loading chamber are located in the nozzle. Secondary combustion space is surrounded by water jacket and inside provided with ceramic insulation material. Combustion products are eliminated by means of exhaust fan. Regulation of the amount of air, supplied to the boiler is also performed by means of fan. The boiler is equipped with the facilities of automatic control of the indices. Convective part of the boiler consists of 30 tubes of 58/51 diameter, the length is 0.57 m. Load of the boiler is 40 kW. Diagram of the experimental installation is shown in Fig. 1.

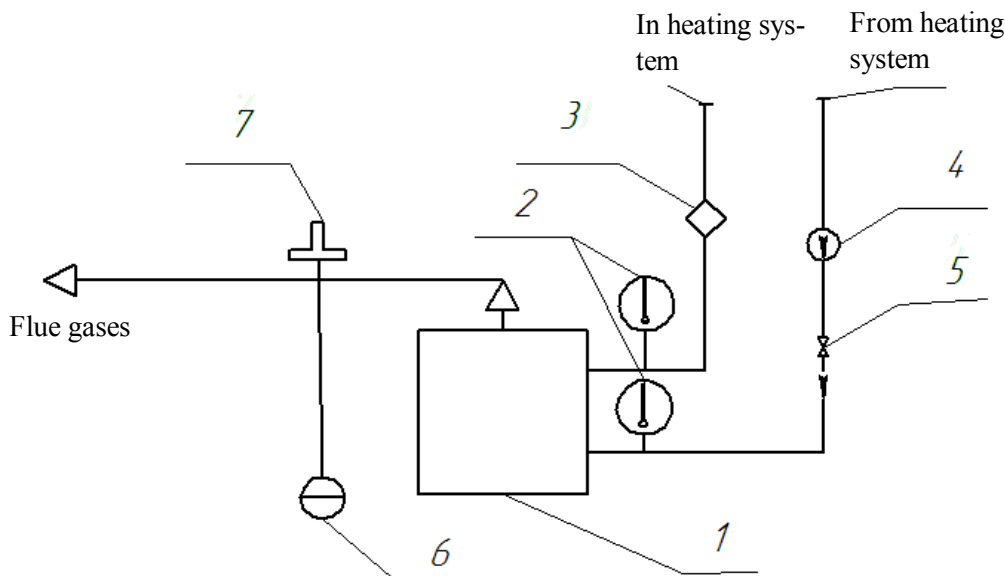


Fig. 1. Diagram of experimental installation: 1 – boiler; 2 – thermometers; 3 – heat meter; 4 – pump of heating system; 5 – cock; 6 – gas analyzer; 7 – sampler of combustion products

Results of research

Sampling of combustion products was carried out in the chimney at the outlet of the boiler by means of gas analyzer OKCH5M-5. The following parameters were measured during the experiment: temperature of flue gases; content of oxygen in flue gases; content of CO, NO, NO₂, NO_x in stack gases; temperature mode of the water; weight of the loaded fuel. Wood, containing not less than 30% of moisture, was burnt in the boiler. Temperature mode of water is 70/50 °C. Efficiency factor of the boiler is within the limits 82.5 – 84%. Fuel consumption was within the limits 18.8 – 19.5 kg / hr.

Table 1

Results of experimental studies

Temperature of flue gases, °C		197.7	190.3	193	187	196.7	192.9
Content of oxygen in stack gases, %		8.1	8.2	9.3	9.6	10.5	9.1
Water temperature mode $t_{\text{run}}/t_{\text{cir}}, ^\circ\text{C}$		70/50	70/50	70/50	70/50	70/50	70/50
Content of CO in stack gases, mg/m ³	1	3751.66	4368.75	3128.34	1947.5	3710	3381.2
	2	6115.21	7164.75	5599.73	3583.4	7420	5951
	3	4389.44	5111.44	5111.44	2570.7	5268.2	4490.2
	4	3199	3754.5	2940.6	1879	3886.6	3124
Content of NO in stack gases, mg/m ³	1	247.9	262.64	235.84	244.78	252.82	248.8
	2	404.08	430.73	422.15	450.4	505.64	437.89

Continuation of the Table 1

	3	290.04	307.29	307.29	323.11	359	317.35
Content of NO ₂ in stack gases, mg/m ³	1	8.88	17.08	15.03	11.62	16.4	13.8
Content of NO ₂ in stack gases, mg/m ³	2	14.47	28.01	26.9	21.38	32.8	24.29
	3	10.39	19.98	19.98	15.34	23.29	17.8
Content of NO _x in stack gases, mg/m ³	1	388.13	418.88	375.83	386.08	403.17	394.42
	2	632.65	686.96	672.74	710.39	806.34	694.18
	3	454.11	490.09	490.09	509.63	572.5	503.28

Note. 1 – data, obtained as a result of the experiment; 2 – experimental data, given in $\alpha = 1$; 3 – experimental data are reduced to the content of oxygen in combustion products 6%; 4 – experimental data, reduced by the authors of the paper to the content of oxygen in combustion products 10%.

Analysis of the results obtained

As it is mentioned in [2], burning of fuel is characterized by the complexity of processes and their dependence on numerous factors, that are difficult to control by technological means. As a result, emission indices may differ, depending on the type of biomass, its state before burning, method of burning, thermal capacity of the power installation, aerodynamics and mixing in the furnace, character of heat transfer in the furnace, realization of primary and secondary measures, aimed at reduction of harmful substances emission. In small capacity installations simple technologies with minimum level of burning process automation are used.

In gas generator boilers principle of two-stage combustion is used, it enables to reduce the emission of harmful substance. For boilers, operating on solid fuel, national standards regulate only CO emissions [4]. While burning anthracite, admissible content of CO is 10000 $\mu\text{g}/\text{m}^3$, while burning of bituminous coal and lignite with the yield of volatile compounds from 17% to 50% - 46000 $\mu\text{g}/\text{m}^3$, correspondingly. For boilers, operating on wood, national standards, as far as we know, are not available. In the standards of European countries standardization of harmful substances is carried out depending on the class of the boiler, type of fuel loading (manual, automatic), capacity of the boiler [2, 5]. Besides, not all harmful substances are normalized in various standards. In EN 303-5 [5], for boilers, operating on the wood, only CO emissions, organically fixed carbon, dust are standardized. In Austria, for industrial boilers [2] emissions of CO, NO_x, volatile organic compounds, solid particles are standardized. In Denmark for small capacity boilers [2], operating on biomass, only CO emissions are standardized, for boilers of 1 MW – CO, NO_x, solid particles.

In accordance with the norms [6, 7] for correct comparison of the data, obtained while measurement of harmful substances concentration in flue gases of boilers they are reduced to the following conditions: content of oxygen in combustion products 6%, $\alpha=1.4$, temperature 0 °C, pressure 101.3 kPa.

In the standards of European countries concentration of harmful substances is given at various contents of oxygen in combustion products. For instance, in EN 303-5 figures are given at the content of oxygen – 10%. That is why, we performed recalculation of experimental data for CO to compare it with EN 303-5 data. As it is seen from Table 1, range of CO emissions during the experiment is within 1879 – 3886.6 mg/m³, and in EN 303-5 for boilers of less than 50 KW with manual load of fuel, the norm of CO emissions is within the limits of 5000 – 25000 mg/m³ (depending on the class of the boiler). Thus, CO emissions for gas generator boiler, operating on the wood is far less than European norms.

According to [4] in Austria for boilers up to 300 kW the norm of CO emission is 4300 mg/nm³ (at

$\alpha = 1$), and $\text{NO}_x = 585 \text{ mg/nm}^3$. As it is seen from Table 1, content of CO for the conditions of the experiment exceeds that norm 23 – 42%, and NO_x – 7.5 – 27%.

Limiting indices of polluting substances in FRG [2], for 15 – 50 kW boilers and oxygen content in flue gases 13% for CO is 4000 mg/m^3 . As a result of the experiment, after recalculation in terms of oxygen content in flue gases 13% we obtained the following range of data – $1366.7 - 2730 \text{ mg/m}^3$.

Hence, comparison of ecological indices of 40 kW gas generator hot-water boiler operation with foreign standards showed correspondence of harmful substances emissions to existing European standards.

Gas generator boilers help to reduce the emission of polluting substances, that is why, they are promising for introduction both in industry and in municipal branch. In our opinion, in standards the type of burning wood, its humidity should be taken into account, also it is necessary to regulate the content of resins in flue gases, induce the manufacturers of boilers to introduce modern technologies for efficient burning of low grade types of fuel.

For efficient combustion of fuel and further reduction of harmful emissions in combustion products it is necessary to improve the design of the boiler. For the reduction of CO emission the system of air supply should be optimized. The number of holes for air supply in loading chamber must be regulated for uniform air supply. Foreign manufactures of gas generator boilers also install in secondary combustion space secondary emitters, enabling to reduce CO emissions. Such experience should be used for the improvement of the design of experimental specimen of the boiler, considered in the given paper. Installation of heat exchange intensifiers in gas-tube part of the boiler will help to decrease the temperature of flue gases and increase the efficiency factor of the boiler.

Conclusions

1. Authors studied ecological indices of experimental specimen of 40 kW gas generator hot water boiler, operating on moist wood.
2. It is shown that ecological indices of gas generator boiler, operating on wood, are within the limits of European norms.
3. For efficient operation of the boiler it is possible to improve the system of air supply into loading chamber and nozzle for gasification.
4. The results obtained are the step to further investigation of boilers, operating on biomass for arrangement of data and creation of feasible calculation methods of small capacity gas generator hot water boilers, operating on solid fuel and wide application of such boilers for heat supply of buildings and structures.

REFERENCES

1. Халатов А. А. Сжигание и газификация альтернативных топлив / А. А. Халатов, И. И. Борисов, С. Г. Кобзарь и др. // Промышленная теплотехника. – 2006. – № 4. – С. 53 – 63.
2. Жовмир Н. М. Анализ нормативных требований к эмиссии загрязняющих веществ при сжигании биомассы / Жовмир Н. М. // Промышленная теплотехника. – 2012. – № 1. – С. 77 – 86.
3. Проблеми спалювання низькосортних палив в котлах малої потужності [Електронний ресурс] / Л. А. Боднар, С. Й. Ткаченко, О. В. Дахновська // Наукові праці ВНТУ. – 2012. – № 4. – Режим доступу до журн.: <http://praci.vntu.edu.ua/article/view/2656/2862>.
4. Котли опалювальні водогрійні теплопродуктивністю до 100 кВт. Загальні технічні умови: ДСТУ 2326-93. – [Чинний від 1995-01-01]. – К. : Держстандарт України, 1994. – 17 с. – (Державний стандарт України).
5. Справочник потребителя биотоплива / [под. ред. Виллу Вареса]. – Таллин : Таллинский технический университет, 2005. – 183 с.
6. ГОСТ 30735-2001. Котлы отопительные водогрейные теплопроизводительностью от 0,1 до 4 МВт. Общие технические условия. – [Дата введения 2003-01-01]. – Минск, 2003. – 16 с.
7. Установки котельные. Установки, работающие на газообразном, жидком и твердом топливе. Нормы выбросов загрязняющих веществ: СТБ 1626.1-2006. – [Дата введения 2006-07-01]. – Минск, 2006. – 8 с.

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