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PROBLEMS OF LOW-GRADE FUEL BURNING IN LOW CAPACITY BOILERS

The paper analyses main problems dealing with the burning of low-grade fuel in low capacity boilers and methods of these problems solution in order to improve energy-ecological efficiency.

Key words: *low-grade fuel, tars condensation, low-capacity boilers, burning problems.*

Introduction

Organic fuel occupies an important place among various sources of energy (more than 94 % of all energy resources, used in the world). In recent decades, as a result of steady growth of prices on high-grade fuel, special attention is paid to boiler units, providing efficient burning of cheap fuel.

There exists a great variety of low-grade fuels. High-ash coal or high moisture coal, salted coal, combustible shales, peat, combustible part of municipal waste, industrial waste (wood, wood-pulp), agricultural waste (straw, hull, sun-flower stalks, etc.), slime and intermediate products of coal dressing, intended for technological usage are referred to low-grade fuel. Common feature of low-grade power-generating fuel is low heat of combustion, that does not exceed Q_l^w=10…20 MJ/kg [1]. Such low heat of combustion of this fuel is determined by high content of the ballast: ash and moisture.

In energy sector of national economy many efficient methods of low-grade fuels burning in industrial boilers (low temperature and high temperature fluidized bed, low temperature vortex technology, gas generation with further burning of artificial gas) have been developed, whereas, while burning of such kinds of fuel in low capacity boilers some technical and ecological problems emerge.

The **aim** of the given paper is the analysis of the problems dealing with burning of low grade fuel in low capacity boilers and methods of their solution aimed at the improvement of energy ecological efficiency.

Ecological problems

All the processes, connected with burning of organic fuels in boilers of different capacity are sources of contamination. Their anthropogenic impact on the environment can be seen on different levels: local; regional and global.

For boilers, operating on solid fuel only CO emissions are standardized [2]. At burning of hard coal admissible content of CO is 10000 mg/m^3, while burning of bituminous coal and lignite, with the emission of volatile components from 17 % to 50 % CO content is 46000 mg/m^3, correspondingly/ For boilers, operating on wood, domestic standards, as far as we know, do not exist. According to [3] in European countries limiting values of CO emissions for boilers, operating on wood, of the capacity less than 50 кW is 5 g/m^3, organic gaseous substances – 0.15 g/m^3, solid particles – 0.2 g/m^3.

In GOST (State Standard) [4] emissions of harmful substances are regulated for wood, peat, bituminous coal and lignite. For boilers with manual furnace, rated for 100 – 300 kW, in case of burning wood and peat, CO emissions are within the limits of 5000 – 24000 mg/m^3. The authors did not find documents, limiting the emissions of contaminating substances for gas-generating boilers.

In [4] it is noted, that the content of solid particles in flue gases from boilers, operating on solid fuel, must be indicated in regulatory document for the given boiler.

In [5] data, regarding the operation of small capacity boilers for solid fuels are presented, it is shown that their emissions considerably exceed the norms.

While burning low-grade fuel, mineral residue – ash is formed. Although ash content of biofuels is rather low (Table 1), melting characteristics of the ash directly influence the operation of the boiler. Melting of the ash can give rise to slugging of the furnace and emerging of dense deposits on convective heating surfaces. Fly ash contaminates the environment.

Table 1

Characteristics of low-grade fuels

Low-grade fuel	Heat of fuel combustion, MJ/kg	Moisture of fuel, %	Ash content, %
Peat in pieces	10,07	40	6,6
Milled peat	8,5	50	5,5
Reed	15,5	16	2,0
Straw	13,12	8	5,0
Sunflower hull	15,5	15	2,0
Chips and sawdust	16,9	25	1,0
Wood waste	15,12	40	0,9

Due to high cost of the equipment, ash collectors are not installed at low-capacity boilers.

Tars condensation in gas ducts of boilers

On one hand, low-grade biofuels contain small amount of sulfur, that is why, it is possible to provide low temperature of flue gases at the output of the boilers (Fig 1), on the other hand, even foreign manufactures of boilers recommend the temperature of flue gases at the output to be not less than 200 °C [6]. It is explained by the fact, that in the process of gasification and burning of low-grade fuels in the boilers, tar deposits – complex mixtures of organic compounds – are accumulated on heat exchanging surfaces and smoke stacks.

In [7] the results of research of solid fuel gasification and methods of artificial gases clearing from tar are presented. To remove tar it is suggested to apply stepwise scheme of gas cooling that provides successful tar-water separation. At the first stage of condensation, heavy tar is condensed at the temperature 130 – 150 °C, at the second stage, where gas is cooled to 25 – 40 °C – light tar is condensed. Cleaning of sewage water is carried out by means of tar settling and filtration through quartz filters. The drawback of the given scheme is formation of stable tar – aqueous emulsions in tar water. The given scheme can be applied in industrial productions of producer gas. In low capacity boilers operating on organic fuels, methods of tar deposit prevention can be used, since this is more efficient means than cleaning of polluted surfaces.

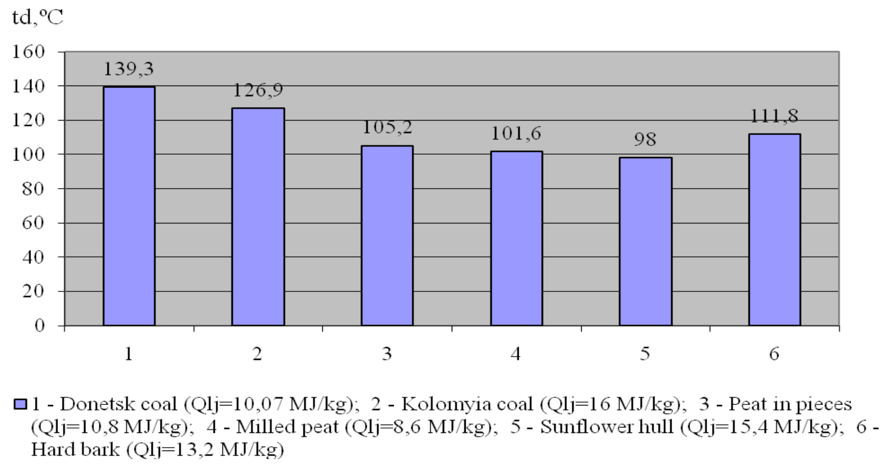

Fig 1 Dependence of dew point temperature on the kind of low-grade fuel

Dutch company ECN [8] studies the properties of tars, characteristic features of their condensation and cleaning of gaseous products of their burning. Researchers of ECN classified tars into 5 classes, see Table 2.

Table 2

Tars classification

Class	Property of the class
Class 1	Heavy tars, condensed at high temperatures, even at very small concentrations
Class 2	Heterocyclic components (like phenol, puridine, crezol), that generally exhibit high water solubility, due to their polarity
Class 3	Aromatic components – light hydrocarbons
Class 4	Light polycyclic aromatic hydrocarbons
Class 5	Heavy polycyclic aromatic hydrocarbons

Fig. 2 shows the dependence of tar dew point temperature on its concentration in flue gases [8].

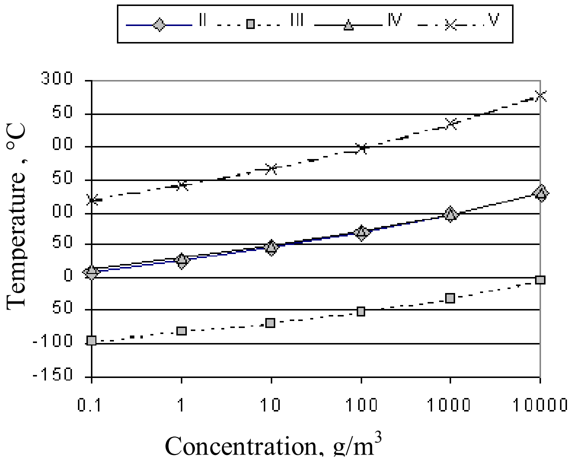

Fig. 2. Dependence of tar dew point temperature on its concentration

As low temperature tars contain far less molecules than high temperature tars, their dew point temperature is lower [8].

Since the operation of boilers on low-grade fuels is accompanied by deposition of tar-containing substances of heat exchange surfaces and smoke slacks, then in the process of development of small-capacity boilers the possibility of tars condensation must be taken into account.

The authors have studied the influence of heat exchange intensity on both sides of heat exchange surface in convective part of the boiler on the temperature of heat exchanger tube wall. Such information is necessary for selection of flue gases cooling method, when condensation of tars in heat exchanger does not take place. For gas-tube hot-water boiler with such initial parameters: capacity $Q \leq 32$ kW; fuel – wood (fuel composition C=51 %, H_2=6.1 %, O_2=42.3 %, N_2=0.6 %, A=1 %, W=25 %); three-way tube bank; excess air coefficient α=1.4; water temperature mode 60/80 ºC; at different values of convective heat exchange coefficient from the wall to the water α_w=200…900 W/m^2·K. Convective heat exchange coefficient on the side of gases changed within the limits of α_g=7…19 W/m^2·K. The temperature of the tube bank wall on the side of gases was determined depending on boiler load, (Fig. 3).

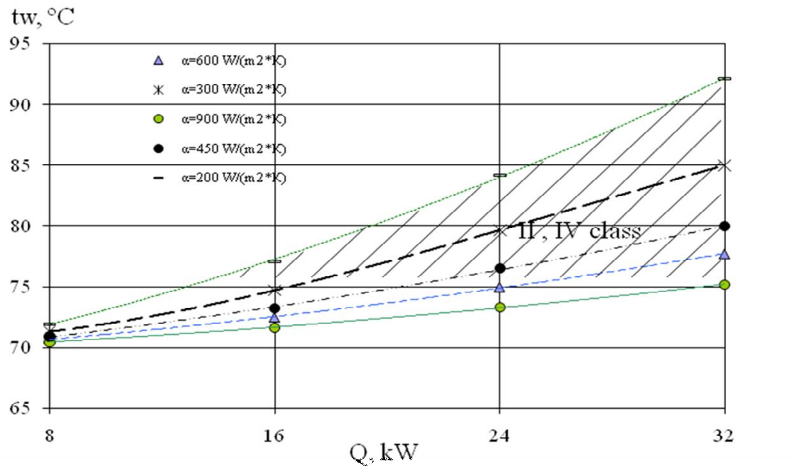

Fig. 3. Dependence of boiler heat exchanger wall temperature on the side of gases on the load (water cooling)

It should be noted that in combustion products of the wood and its waste as well as in other low-grade fuels [9, 10] tars concentration may be within the limits from 1000 to 10000 mg/m^3. This was taken into account while selection of tar condensation temperature. At temperature of boiler heat exchanger wall on the side or gases 75 ºC and higher, classes II and IV tars, i. e., heterocyclic components and light polycyclic aromatic hydrocarbons are deposited.

If air at the temperature of 10/50 ºC at the input and output correspondingly with convective heat exchange coefficient α_a=15…90 W/m^2·K moves in convection tube bank, then the temperature of bank wall will change, as it is shown in Fig. 4.

In case of air cooling, if the temperature of wall is 100 – 140 ºC, classes II and IV tars will be deposited, and if the temperature is 240 ºC and higher, class V tar will be deposited – heavy polycyclic aromatic hydrocarbons. We may expect that air heat generators will operate more efficiently on low grade fuels (wider range of reliable operation, than in hot-water boilers).

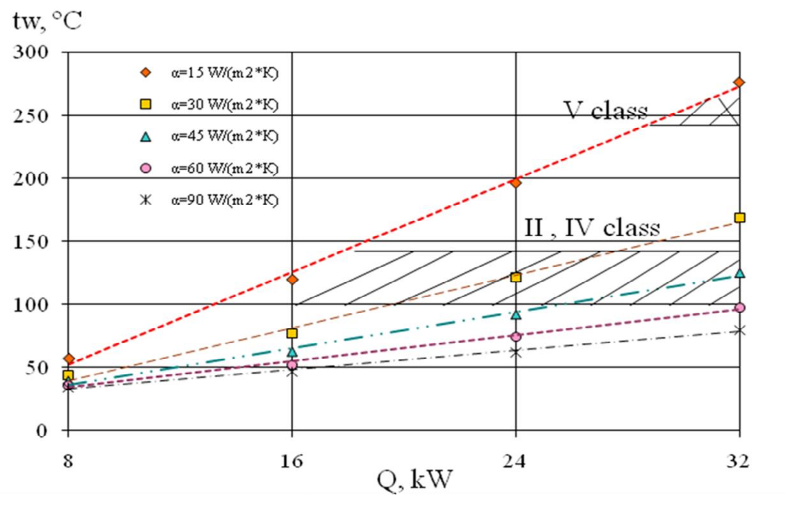

Fig. 4. Dependence of boiler heat exchanger wall temperature on the side of gases on the load

In authors opinion, the combined usage of surfaces (first, air cooling of flue gases, then, water cooling) allows partly, to solve the problem of tar deposition on boiler surfaces and provide places of their deposition in order to facilitate the access for cleaning.

For water cooling of the boiler, methods of tar condensation prevention are given in Table 3, in the table authors also classified other problems dealing with burning of low-grade fuels and methods of these problems solution.

Table 3

Problems of low-grade fuels burning and methods of these problems solution

№	Problem	Methods of solution
1	Emissions of solid particles (ash) [1, 3, 13]	1) Creation of two-chamber furnaces. 2) Installation of segment partitions at the output of boiler, trapping ash in the boiler *. 3) Installation of ash-collectors. 4) Creation of recirculation.
2	Deposition of tars in gas ducts of the boiler [7, 11, 12]	1) Creation of high temperature zones. 2) Correspondence of boiler capacity to real heat demand. 3) Usage of buffer vessels for smoothing out of non-uniformity of consumption and boiler operation. 4) Insulation of smoke stacks. 5) Maintaining of low moisture of fuel. 6) Maintaining of circulating water temperature at not less than 65 º C. 7) Installation of secondary radiators in the furnace (zones of high temperatures), catalysts. 8) Optimization of air supply by portions (primary, secondary, tertiary) in order to organize qualitative burning of fuel. 9) Prevention of long operation of the boiler in minimal mode.
3	Ash melting, slagging of fire grate [3, 13]	1) Water cooling of fire grate. 2) Air cooling. 3) Using of vibrating fire grate*. 4) Low-temperature burning *. 5) Support of uniform distribution of fuel and coal layer over the surface of grates to provide uniform supply of primary air. 6) Usage of rotating cone furnace. 7) Stepwise burning of fuel (by means of furnace division into primary and secondary chamber). 8) Usage of underfeed stoker.
4	Low temperature in the combustion zone of wet fuel burning [14]	1)Supply of heated air into combustion zone. 2) Coating of internal surface of the furnace with heat storing materials (ceramics, majolica).
5	Emission of CO [11]	1) Qualitative mixing of flue gas with secondary air . 2) Usage of secondary radiators.

* – for boilers of average capacity.

Conclusions

As a result of prices increase on natural gas alternative sources of energy – low-grade fuels begin to attract attention . Energy branch of national economy has Various efficient methods of burning low-grade fuels in industrial boilers have been developed, but there appear certain technical and ecological problems while burning such kinds of fuel in low capacity boilers.

The authors of the given research underlined basic problems, dealing with burning of low-grade fuels in small capacity boilers and methods of these problems solution. One of the main problems is tars deposition on heat-exchanging surfaces and smoke stacks of the boiler. To determine tars condensation modes in the boiler the study of the influence of heat exchange intensity on both sides of heat exchanging surface in convective part of the boiler on the temperature of heat exchanger tube wall was carried out. It was determined that in case of air cooling of flue gases the temperature of heat exchanger wall is 100 – 275 ºC, depending on the load of the boiler, and in case of water cooling – 75 – 95 ºC, i. e., in the latter case, the probability of tars deposition on heat exchanger walls is higher.

In authors opinion, combined usage of surfaces (first, air cooling of flue gases, then – water cooling) will allow to solve partially the problem of tars deposition intensity on the surfaces of the boiler.

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