ISSN: 0975-8585

Research Journal of Pharmaceutical, Biological and Chemical Sciences

Condensing Hot Water Boiler: Applicability, Design and Research.

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ABSTRACT

This article presents a characteristic of a condensing hot water boiler. This boiler is designed by the staff of Belgorod State Technological University named after V.G. Shoukhov. The function of the boiler and the relevance of its use from the perspective of energy conservation, improvement of comfort of heat consumers, environmental defense are specified. Grounding of higher thermal effectiveness of condensing hot water boilers and boilers with condensing economizers, compared with boilers non-condensing water vapors contained in exhaust gases is carried out. Design features and options of a condensing boiler are analyzed, namely of the boiler with horizontal and vertical furnace. Advantages and disadvantages of these options are reported. A description of the principle of condensing boiler operation is made. The links to the results of scalene numerical studies of processes occurring in the elements of the boiler and in the boiler as a whole are provided. A description of a heat generator test desk is made and the main results of its experimental research are provided.

Keywords: Heat supply systems, energy conservation reserve, oil conservation, contact and contact-surface economizers and water heaters, condensing hot water boiler, test desk.

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ISSN: 0975-8585

INTRODUCTION

Currently, in the Russian Federation there is a tendency to increase the number of independent heating modules of small thermal power for various purposes heat supply of consumers. Gas is used as fuel in such boilers. Compared with centralized systems where a source of thermal energy is a block heating station or a district boiler house of high power, system with independent heating modules have advantage of the lack of extended heat networks, faster, cheaper and the most adequate regulation of boiler station heat supply to consumers, and significant reduction of emissions of air pollutants from exhaust gases [1, 2]. The latter is very important in the light of toughening of emission standards, both in Russia and in the countries of the European Union [3].

The use of heat-producing units as the independent systems of hot water boilers and condensing type water heaters [4, 5], as well as installation of traditional contact or contact-surface economizers alongside the operative hot water boilers [6-9] will lead to some additional fuel economy and, as a consequence, reduction of pollutants emission from the exhaust gases. The reasons for this are as follows.

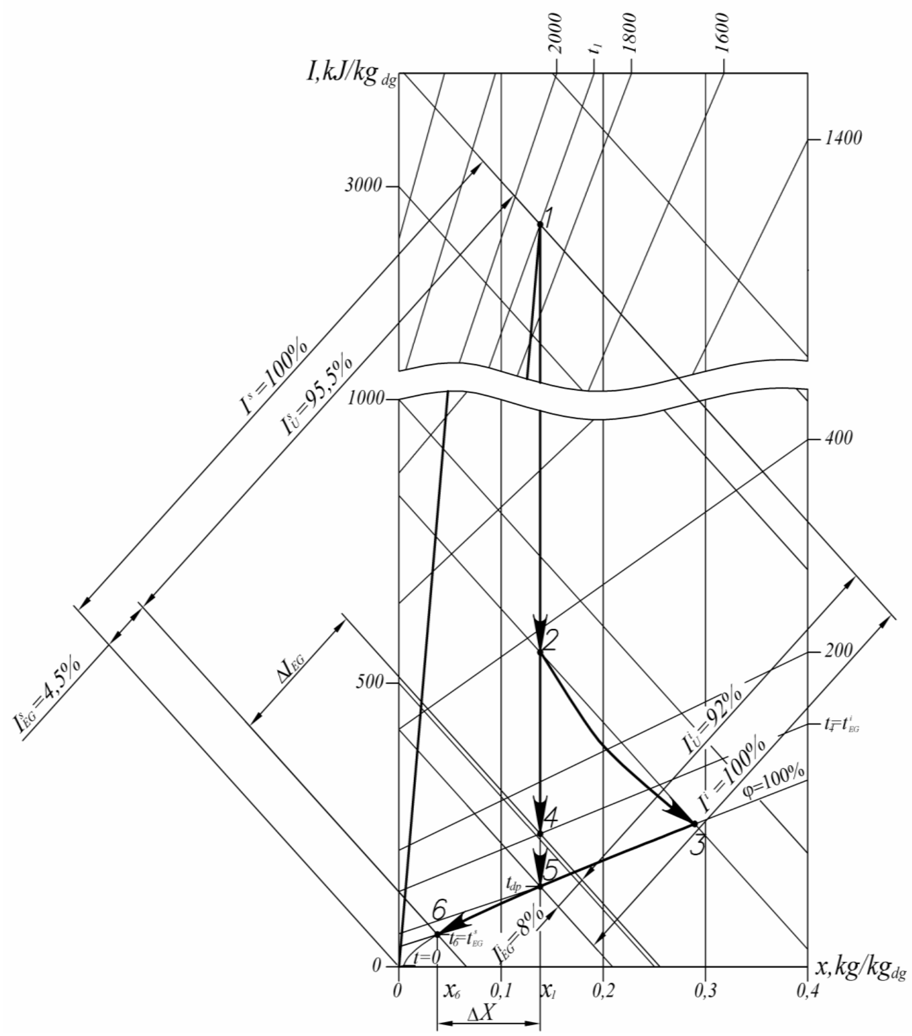

Figure 1: Variations of combustion products parameters in a traditional hot water boiler (vector 1-4) and in a condensing heat generator (vector 1-2-3-6)

The coefficient of efficiency of modern hot-water boilers installed in independent heating modules most often does not significantly differ from the above average efficiency coefficient of medium and high power hot water boilers. The principal item of heat loss in a heat producing unit is flue gas losses. They are caused by high temperatures (110-150 ºC and higher) of combustion products as they leave the boiler. Such values of outlet gas temperatures are maintained due to low intensity of heat exchange in boiler back-end surfaces due to a small value of the driving force of heat exchange processes – the temperature differences between the heating and the heated heat transfer agents. That is, to provide deep cooling of combustion products very advanced heat exchange surfaces are required, and this increases the weight, the materials consumption, the dimensions, and, consequently, the cost of the boiler plant.

At the same time it is know, that when the moisture content of exit gases x = 0,11-0,12 kg/kg the heat per 1 m^3 of the gases is: physical, determined by temperature - 195-220 kJ/m^3, and humid - 315- 325 kJ/m^3. If natural gas combustion products are cooled to a temperature that is below the dew point, which is 54-55 ºC for them, then condensation of a portion of contained water vapors with condensation heat emission will take place. Thus it is possible to achieve a significant reduction in waste heat losses.

A demonstrative example of a reserve of heat losses reduction from boiler plants can be a representation of fuel combustion products cooling processes in hot water boilers without condensation of water vapors and with condensation of water vapors from gases on *I-x* diagram (see Fig. 1). If analyzing the state parameters of gases cooling in heat-producing units to interpret the relative parts of heat usefully used, lost with flue gases, and so on through the corresponding enthalpies of fuel combustion products, it is seen that heat losses with exhaust gases of traditional boilers without deep cooling of gases I_{EG}^{i} through Q_i at their temperature of 110-150 °C (see point 4, Fig. 1) are $I_{\mathrm{EG}}^{i} = 7 - 9\%$ from generated heat, and the highest efficiency $_i$ of the heat generator equals to 90 – 92% respectively that corresponds to I_{U}^{i} .

For natural gas, the difference between the higher and the lower calorific values is about ΔQ_{s-i} = 10-12%. Therefore, when evaluating the efficiency of the same heat generator according to the gross calorific value ΔQ_s the value of ΔQ_{s-I} is added to flue gases sensible heat losses, and losses I_{EG}^{s} become equal to 18-20%, and the efficiency $_s$ value = 78-81%. This fact clearly demonstrates the great possibilities of real increase of heat generators efficiency by about ΔI_{EG} ≈5% by means of better use of the flue gases heat. For example, when the gases are released into the atmosphere at the temperature of $t_{\mathrm{EG}} \approx 35°\mathrm{C}$, the heat loss will be about I_{EG}^{s} ≈4,5%, and the efficiency $_B$ of the thermal unit will increase to 95% (equivalent to I_{U}^{s}) instead of 78-81% for boilers of the conventional design.

In condensing water heaters and economizers exhaust gases are deep cooled with sufficiently high intensity. However, there is a substantial drawback - the inability to use the obtained in a heat reclaim unit hot water in open hot water systems, due to its contamination by CO_2 and other components contained in fuel combustion products upon direct contact with them. This fact considerably narrows the scope of heat-transfer agent heated in the heat reclaim unit use. An alternate solution to the problem of beneficial use of a heat-transfer agent heated in a contact heat exchanger and contaminated upon direct contact with natural gas combustion products is the use of a double-loop circuit, i.e. combination of a contact heat exchanger with an intermediate surface heat exchanger. The intermediate heat exchanger with respect to the contact chamber of the heat reclaim unit can be remote, i.e. placed outside it, and integrated, i.e. placed inside the contact chamber [6, 8, 10]. However, when placing an intermediate surface heat exchanger inside the contact chamber of a contact-surface heat exchanger the processes of heat exchange of gas with circulating water and of the latter with the heated water occur simultaneously on one heat exchange surface. Therefore it is impossible to implement thermodynamically favorable counter-flow of both pairs of heat-transfer agents (gas - circulating water, circulating water - heated water). Counter-flow is observed only in one pair of heat transfer agents and in the other pair parallel flow will take place.

In case of producing of contact-surface heat reclaim units with side-mounted heat interchangers the size, the weight and the material consumption of the installation significantly increase.

MAIN PART

Fellows of Belgorod State Technological University named after V.G. Shoukhov developed a design of a condensing hot water boiler with deep cooling of fuel combustion products (Fig. 2) [10, 11]. This hot water boiler can be used for the purposes of various purposes heat supply f consumers. A distinctive feature of these boilers is the presence of two circulation loops. In the primary loop – the radiant part executed by analogy with the most effective types of fire-tube hot water boilers, hot water for heating is produced, and in the second loop - contact-regenerative part – a heat transfer agent for hot water supply is produced.

Combustion products of natural gas burnt in a furnace exit the radiant part with a temperature substantially higher than the temperature of flue gases leaving hot water boilers conventionally used in heat supply systems. This fact allows to increase the average temperature difference between heat transfer agents compared with traditional boilers. In addition, the heat transfer coefficient in the radiant part take on its maximum possible value, which is caused by maximum values of the coefficient of heat transfer from gases to the heat transfer surface (due to high radiation component of the heat transfer).

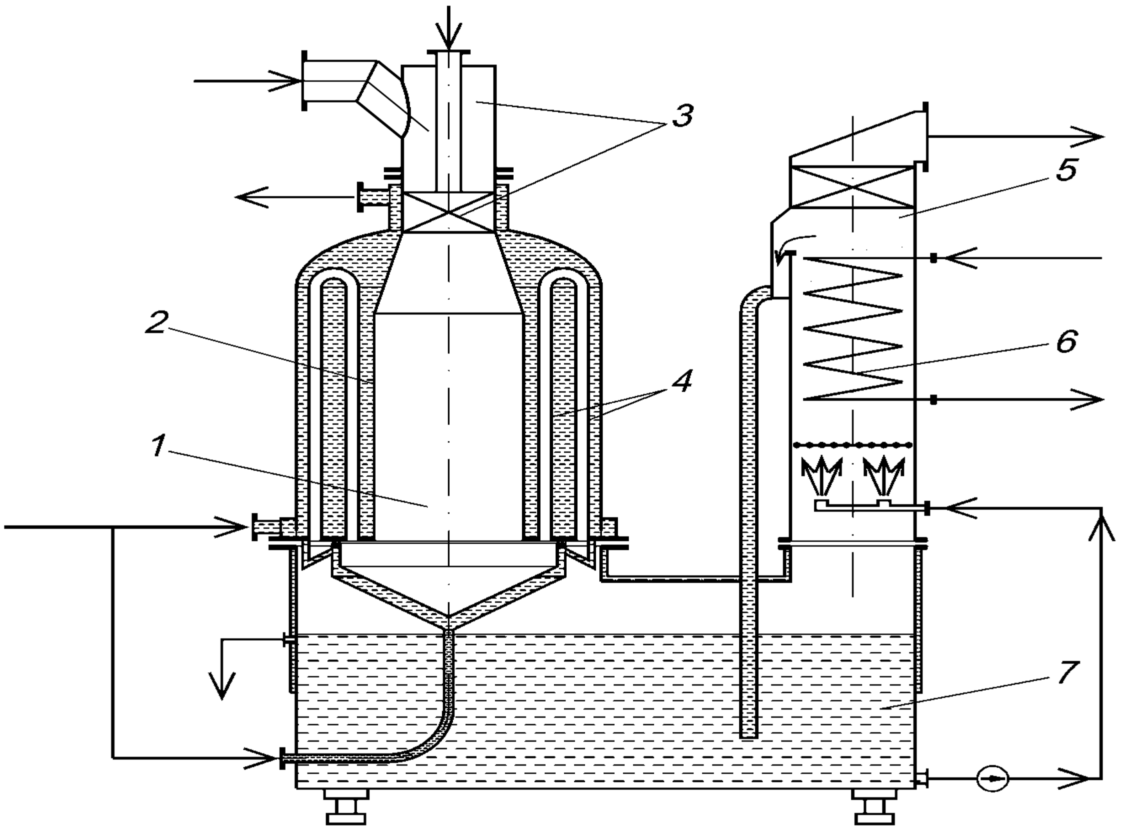

Figure 2: Scheme of a condensing hot water boiler:
1 – radiant part; 2 - flame tube; 3 - burner; 4 - flue tubes; 5 - contact-regenerative part; 6 - tube pack contact-regenerative part; 7 - adiabatic part

In the adiabatic part combustion products pass through the torches of dispersed condensate and are partially cooled. At that gases capture condensate drops and carry them to a bearing-distribution grid, over which phase inversion takes place: if under the grid the gas was the continuous phase and the liquid - disperse, then over the grid the liquid becomes the continuous phase and the gas - the dispersed phase distributed as bubbles in the liquid. This two-phase gas-liquid emulsified system is characterized by an extended contact surface, high values of relative velocities of the phases, developed flow turbulence, all of which results in a high efficiency of heat exchange between the gas and the liquid phases. Gases are cooled adiabatically to hydrothermal equilibrium at the temperature of wet bulb thermometer (see vector 2-3 in Fig. 1).

In annular space heat energy of gases is transferred to the condensate (see. Vector 3-6 in Fig. 1) and from the latter - through pipe walls – to the heated water passing sequentially through several horizontal rows of pipes in counter-flow to the upward two phase gas-condensate flow in emulsified mode. Above the tube bundle gas velocity decreases, the condensate is drained into the pockets and is returned to the condensate tank through descent pipes. Passing through the drop catcher, gas is released from condensation and removed from the contact-regenerative part cooled and with significantly reduced moisture content.

Use of this heat generator in independent heating modules will allow to save additionally up to 15% of natural gas for heat production using condensation heat contained aqueous vapors combustion products.
There are two main variants of the radiant portion of the boiler arrangement: horizontal and vertical (Fig. 3). An advantage of the horizontal configuration of the radiant part [11] is the possibility to use any industrial gas burners, whereas in case of vertical configuration of the radiant part only a limited range of gas burners can be used, since the majority of produced burners do not have the working position “the burner over the torch”. At the same time, during operation of horizontal furnaces torch deformation inevitably takes place, i.e. the torch along the length of the flame tube “hikes” up. In this case, there is uneven heating of the cross section of the flame tube and the tube grid, resulting in uneven thermal expansion of flame tube elements and, consequently, in an increase of thermal stresses in it and in the radiant part as a whole. This can lead to serious accidents, or even to a complete failure of the boiler. Boiler furnaces with vertical arrangement of the radiant part [10] are not characterized by this disadvantage. Therefore, even if it is necessary to use special burners it is most preferable to use vertical arrangement of the radiant part.

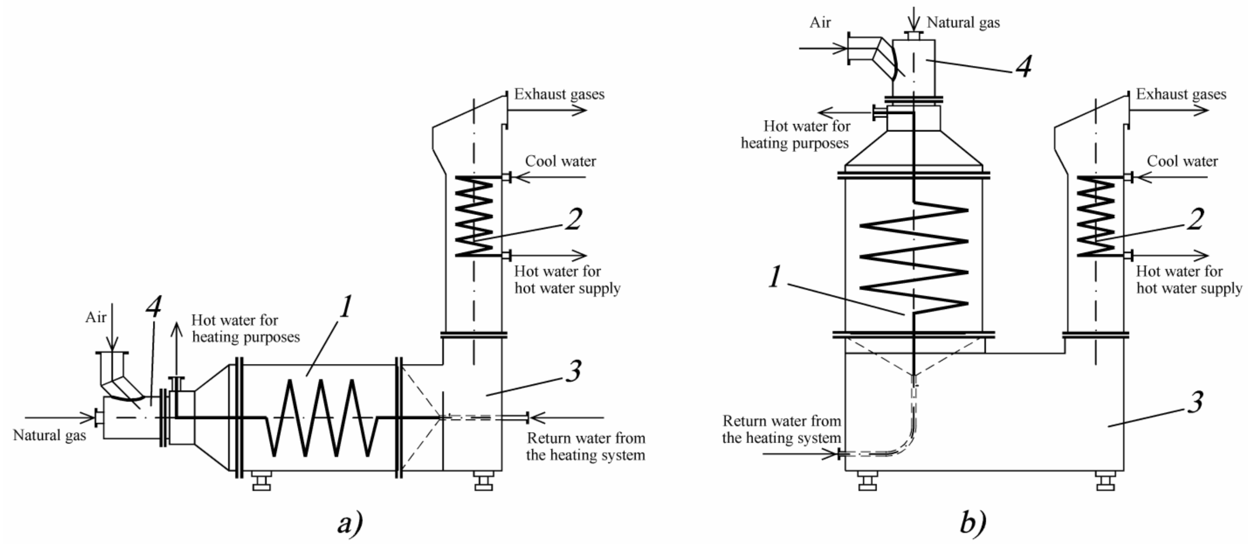

Figure 3: Configurations of the radiant part of a condensing got-water boiler:
a - horizontal position; b - vertical position;
1 – radiant part; 2 - contact-regenerative part; 3 - adiabatic part; 4 - gas burner

Fellows of Belgorod State Technological University named after V.G. Shoukhov, carried out computational investigations of natural gas combustion processes for different conditions of natural gas and air feeding into the furnace [12, 13].

The results of the analysis of energy losses in hot water boilers of different designs [14], both traditional and condensing showed that in terms of the best use of heat the dual-circuit condensing boiler developed by the fellows of BSTU named after V.G. Shoukhov is quite effective and more preferable than, for example, single-circuit condensing boilers. In order to verify the correspondence of the condensing boiler basic design characteristics to the actual parameters that determine the heat generator efficiency, and correspondence of the temperatures of heated heat transfer agents to the requirements of regulatory documents of the Russian Federation a test desk of a boiler pilot was made (see Fig. 4). In this test desk the heat exchanger 2, in which heating water moving in a closed loop is cooled, is an imitator of the heating system. Cooling of heating water in the heat exchanger 2 is carried out directing into its tube side cold water B_X, which, as well as heated water $B^{\Gamma}_{\Gamma BC}$ after the contact-regenerative part and the heater 3, during the tests was discharged into the drain.

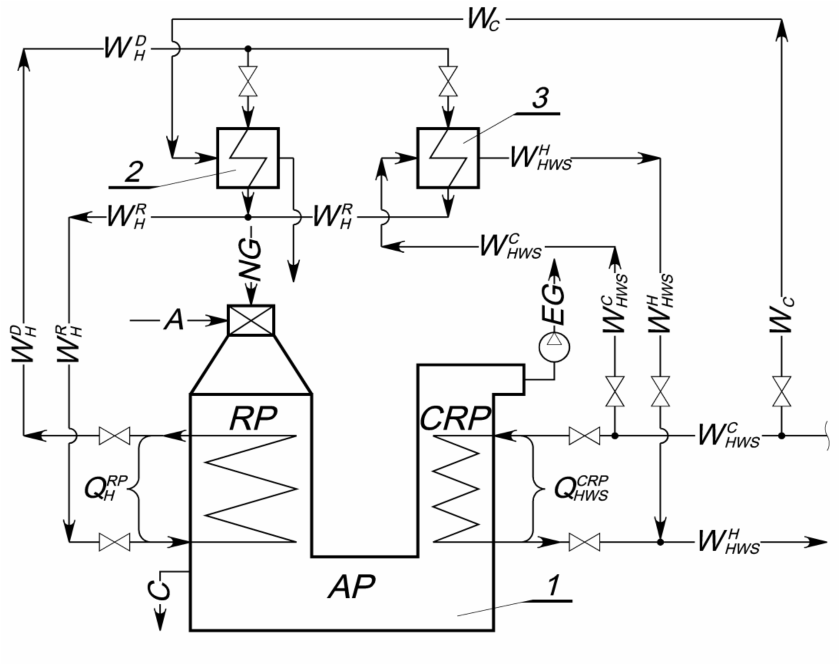

Figure 4 Simplified diagram of the test desk of a condensing hot water boiler:

1 - condensing hot eater boiler; 2 - heating water cooling heat exchanger; 3 - water-water heater - boiler; RP – radiant part; CRP - contact-regenerative part; AP - adiabatic part; NG - natural gas; A - air; EG - exhaust gases; C - condensate; $Q_{\mathrm{H}}^{\mathrm{RP}}$, $Q_{\mathrm{HWS}}^{\mathrm{CRP}}$ - heat assimilated effectively in the radiant and contact-regenerative parts; $\mathrm{W}_{\mathrm{H}}^{\mathrm{R}}$, $\mathrm{W}_{\mathrm{H}}^{\mathrm{D}}$ - upstream and downstream heating water; , $\mathrm{W}_{\mathrm{HWS}}^{\mathrm{C}}$, $\mathrm{W}_{\mathrm{HWS}}^{\mathrm{H}}$ – hot and cold water for hot water supply; B_c - cooling water

Measurements of flow rates, temperatures and pressures of all heat transfer agents, indicated in Fig. 4, were carried out using appropriate verified instruments.

The main calculated and measured parameters determining the effectiveness of the condensing hot water boiler are given in the table.

Table: The main calculated and the actual technical parameters of the condensing hot water boiler.

Sr. No.	Parameter name	Units	Parameter values	
			Calculated	Actual
1	Natural gas consumption	nm^3/h	23,5	11,0–23,28
2	Excess air coefficient	–	1,1	1,09–1,14
3	Temperature of heating water: upstream/downstream	°C	95/60	(75–105)/(50–65)
4	Temperature of exhaust gases (after contact-regenerative part)	°C	35	20–45
5	Temperature of water for GWM initial/end	°C	~10/55	~10/(40–64)[*1]
6	Temperature of combustion products after the radiant and before the contact-regenerative part	°C	250 (Q_Σ=43%) 370 (Q_Σ=100%)	177 (Q_Σ=46%) 340 (Q_Σ=97%)
7	Portion of heat assimilated effectively in the contact-regenerative part	%	22,6	18,3–19,65
8	Waste heat loss	%	3,88	1,74–6,4
9	Thermal efficiency at fuel higher calorific value [*2]	%	96,12	98,26–93,6
10	Generated condensate consumption at nominal load	l/h	~30	~30
11	Dimensions: length×width×height	m	1,1×1,0×2,2	1,1×1,0×2,2
12	Weight	kg	460	460

[*1] According to the current standards and GOST of the RF the temperature of water for GWM is 55-60 ° C;
[*2] only waste heat loses were considered

ISSN: 0975-8585

CONCLUSION

The relevance of use of independent systems for various purposes heat supply is grounded in the article. Reserves of significant reduction of waste heat losses of boilers using combustion products deep-cooling apparatus allowing to use effectively not only sensible heat of moist gases but also the heat of condensation of aqueous vapors contained in them are indicated. The condensing hot water boiler developed by the fellows of Belgorod State Technological University named after V.G. Shoukhov is presented. The principle of its operation, design options, the test desk scheme are described. The main results of experimental studies of the boiler are provided. As can be seen from the table, measured during the test characteristics of the condensing boiler are very close to the calculated values, and the temperatures of the heated heat transfer agents meet the requirements of the regulatory documents.

SUMMARY

Thus, the use of independent heating systems with installation of the condensing hot water boiler developed in BSTU named after V.G. Shoukhov as a heat source significantly (almost by a factor of 2) reduces the consumption of natural gas for heating and hot water supply of residential, public and industrial facilities, increases the reliability of heat supply systems, reduces the cost of heat consumed by a factor of 3.5-4.

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