L. A. Bodnar, Cand. Sc. (Eng), Assistant Professor; D. V. Stepanov, Cand. Sc. (Eng), Assistant Professor; R. V. Slyvko, Engineer

EXPERIMENTAL STUDIES OF 1500 KW STRAW-FIRED THERMAL GENERATOR OPERATION INDICES

Application of thermal generators, operating on alternative type of fuel, in particular, straw, is shovn to be one of the most actual problems. Experimental studies of 1500 kW straw-fired generator operation indices are carried out. The rezults of the studies are analyzed. The comparison of calculated and experimental data, regarding the temperature of the gases at furnace outlet is performed. Possibility of the application of Normative Method of boiler units thermal calculation in the process of designing termal generators, operating on alterrnative types of fuel is analyzed.

Keywords: *straw, alternative types of fuel, boiler, efficiency factor, furnace heat exchange****.***

Introduction

In many European countries straw occupies an important place in their fuel-power balance. Combustion of straw is a rational method of obtaining thermal energy. According to statistics [1] Ukraine annually consumes approximately 180 ... 210 million . of tons of reference fuel and belongs to energy-depending countries. Prices for imported conventional energy carriers constantly grow. As it is stated in Energy Strategy of Ukraine [2] for the period till 2035, it is planned to increase the usage of biomass for energy generation up to 13.1 millions of . tons of oil equivalent

Ukraine possesses the equipment and demonstration projects concerning the efficient usage of straw for heat supply. But as it was mentioned in [3], the market of heating equipment can not provide sufficient amount of thermal generators of various types and sizes, intended for straw combustion, of domestic manufacturing. For wider implementation of straw combustion technologies scientifically- substantialed methods of thermal generators design are needed. Analysis of the information published in Ukraine, showed that experimental research of power engineering and ecological indices of straw combustion boilers practically are not carried out. In literature [4] the recommendations on thermal-engineering tests of hot-water boilers with periodic combustion of straw bales are given. The survey of literature sources showed that recommendations on the design of straw-fired thermal generators are not available in free access.

The aim of the given paper is the analysis and generalization of the results of experimental stydies of operation indices of 1500 kW straw-fired thermal generator.

Main part

Boiler of 1500 kW for straw bales combustion is located on the territory of grain complex at one of the enterprises of Vinnitsa Region. Thermal generator is intended for heating of the air, arriving in the drier of the grain complex. Fig 1 shows the general view of the thermal generator. The boiler has two furnaces and a common heat exchanger, located over the furnace. Two bales of straw are loaded simultaneously in the furnace. First. fuel is burnt in one furnace. when the temperature of air at the outlet of heat exchanger decreases, the straw in the second furnace is burnt. Furnace has water cooling. Water, heated in the furnace, arrives into finned air heater, where it heats the air, arriving into the heat exchanger of the boiler. Water cooled in the heat exchanger, passes to the furnace for cooling of its surface. Mass of straw bales. loaded in the furnace is 300 kg ± 20 kg. The boiler is equipped with automatic devices and sensors.

Fig. 1. General view of thermal generator for straw combustion

The following parameters are measured automatically and sent on the display of control panel: air temperature at the outlet of boiler heat exchanger; water temperature at the outlet of furnace coaling jacket; gases temperature at the inlet into heat exchanger. The last parameter is measured by means of thermocouples, located in the outlet window of the furnace. Temperature of gases at the outlet of the boiler in the course of the experiment was masured by means of mercury-filled thermometer with the scale division value 5 ° C. For determination of air consumption for combustion, speed and the temperature was measured in the duct where the air was supplied, by means of hot-wire anemometer. Cross-section of the duct was also measured. Heat exchanger of the boiler is manufactured as shell and tube unit with the area of heating surface 136 m^2. Furnace of the boiler has two rows of holes for air supply for combustion. Area of the walls surface of the furnace is 23.3 $m.^2$ Fig 2 shows the process of straw bale loading in thermal generator and the process of straw bale burning.

Fig. 2.The process of straw bale loading in thermal generator and burning

In the course of the experiment the following indices were recorded: air temperature at the outlet of heat exchanger of the boiler; water temperature at the inlet and outlet of the furnace; flue gases temperature at the outlet of the furnace. Air consumption per boiler was 36000 m^3/h.

Analysis of wheat straw composition was not performed. For calculations statistical average indices [5] are taken W^p = 14,49%, C^p = 40%, N^p = 0,35%, H^p = 5%, S^P = 0,16%, O^p = 36%, A^p = 4%, Q_{lc} =14,48 MJ/kg. (the lower calorific value of fuel). The efficiency factor of the boiler is determined by reverse heat balance. Heat losses as a result of chemical and mechanical incompleteness of combustion were taken on the base of the analysis of experimental data, obtained by the authors [6]: q_3 = 1%, q_4 = 4%, q_5 = 1,5%. Efficiency factor of the boiler during the experiment changed in the range of 71 – 73 %. Air excess factor changed within the range of 1,8 – 2,8 %. Similar data were obtained in the research [7].

For thermal calculation of the generator mathematical model, realized in Microsoft Excel is constructed. In the process of mathematical model construction, recommendations, developed by the authors in [8] were used.

Thermal generator operates in non-stationary mode. To provide the necessary temperature level of the air, supplied for drying, the combustion process takes place continually in both furnaces. At the same time, in one of the furnaces the remaining straw is burning down, in the other furnace the next loaded portion of fuel is burning. Due to such constructive realization of the furnace, basic indices of the boiler remain of the stable temperature level. Fig 3 shows the change of heat carriers temperatures during the experiment.

As it is seen from the Figure, temperature of the air changed with in the limits of 118 ... 131 °C.

Temperature of the water at furnace outlet is 87 ... 90 °C. When the temperature of water, at the outlet of the furnace reaches the value higher than 90 ° C, inlet ventilator is switched off in order to prevent boiling of the water in the boiler.

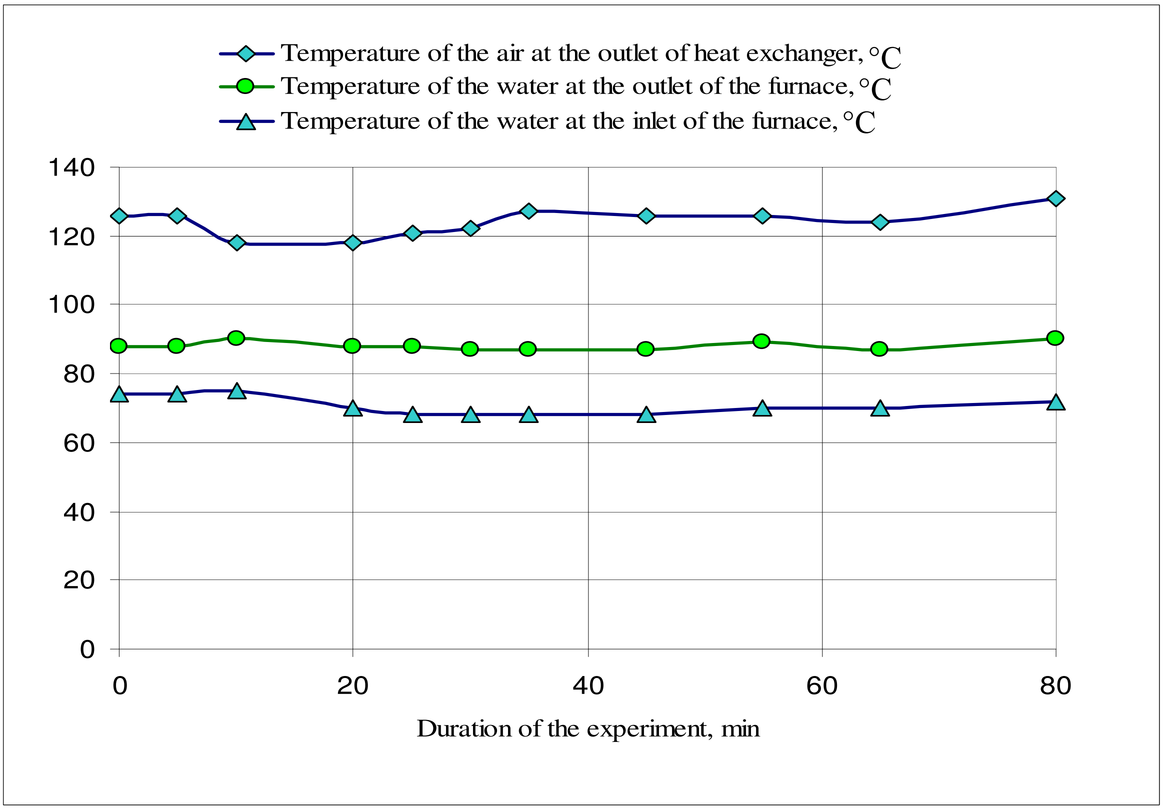

Fig. 3. Change of air and water temperature during the experiment

By means of thermocouple the temperature of the gases is measured at the outlet of the furnace. The obtained data are compared with the calculation data. For heat exchange calculation in the furnace the recommendations of Normative Method (NM) of thermal calculation of steam generating units are used [9]. Technique of total heat exchange calculation in the furnace is based on the application of similarity theory to burning process. The technique takes into consideration self absorption of heat emission in wall-adjacent layers of furnace environment in Buger criterion, considered to be main radiation characteristic of combustion products. Normative method was developed on the base of numerous experimental data for thermal calculation of energy boilers, burning natural gas, coal, fuel oil, peat and shales. In the process of calculation of thermal generators, intended for burning straw bales, the problem of adaptation of NM technique of heat exchange calculation in the furnace to characteristic features of fuel burning in such boilers appears.

Temperature of gases at the outlet of the furnace is determined by the formula (1)

$$\vartheta_m'' = \frac{T_a}{1 + M \cdot B\tilde{u}^{0,3} \left[\dfrac{\sigma_0 \cdot \psi_{av} \cdot F_w \cdot T_a^3}{\phi \cdot B_w \cdot (Vc)_{av}} \right]^{0,6}} - 273, \tag{1}$$

where T_a – adiabatic temperature of fuel burning, that corresponds in Table $I-\vartheta$ to useful heat absorption of the furnace Q_f; B_w – working fuel consumption, kg/s; M – parameter, that takes into consideration the impact of burners location level, degree of furnace flue gases balasting and other factors on the intensity of heat exchange; $B\tilde{u}$ – efficient value of Buger criterion by (2)

$$B\tilde{u} = 1{,}6 \cdot ln\left(\frac{1{,}4 \cdot Bu^2 + Bu + 2}{1{,}4 \cdot Bu^2 - Bu + 2}\right); \tag{2}$$

$(Vc)_{av}$ – average total heat capacity of combustion products, kJ/(m^3·K)

$$(Vc)_{av} = \frac{Q_T - I''}{\vartheta_a - \vartheta''_f}; \tag{3}$$

$\sigma_0 = 5{,}67 \cdot 10^{-11}$ kW/(m^{2}K^4) – blackbody coefficient; I'' – enthalpy of combustion products at temperature of gases at the outlet of the furnace ϑ''_f and excess air at the outlet of the furnace α_f; ψ_{av} – average coefficient of thermal efficiency of walls. To determine the coefficient ψ_{av} it is necessary to select from the Table 6.3 NM [9] the value of ζ coefficient, that takes into consideration thermal resistance of contamination or covering by insulation. But there is no coefficient ζ value for combustion of alternative fuels. For calculations $\zeta = 0{,}6$ is taken both for wall-mounted bare –tube and fin-tube walls in ball furnaces for all types of fuels.

Parameter M for ball furnaces in NM

$$M = M_0 \cdot (1 + \rho) \cdot \sqrt[3]{r_v}, \tag{4}$$

where M_0 – coefficient for ball furnaces M_0=0,46; r_v – parameter of flue gases balasting; $\rho = R/F_w$ – relation between the surface R of fuel-burning area (layer) and the surface of furnace walls F_w; for the given case (furnace is cylindrical) the surface of the layer is suggested to be determined by the formula $R = d \cdot h$, where d – diameter of the furnace and h – depth of the furnace.

Fig. 4 shows the comparison of experimental and calculation data of gases temperature at furnace outlet.

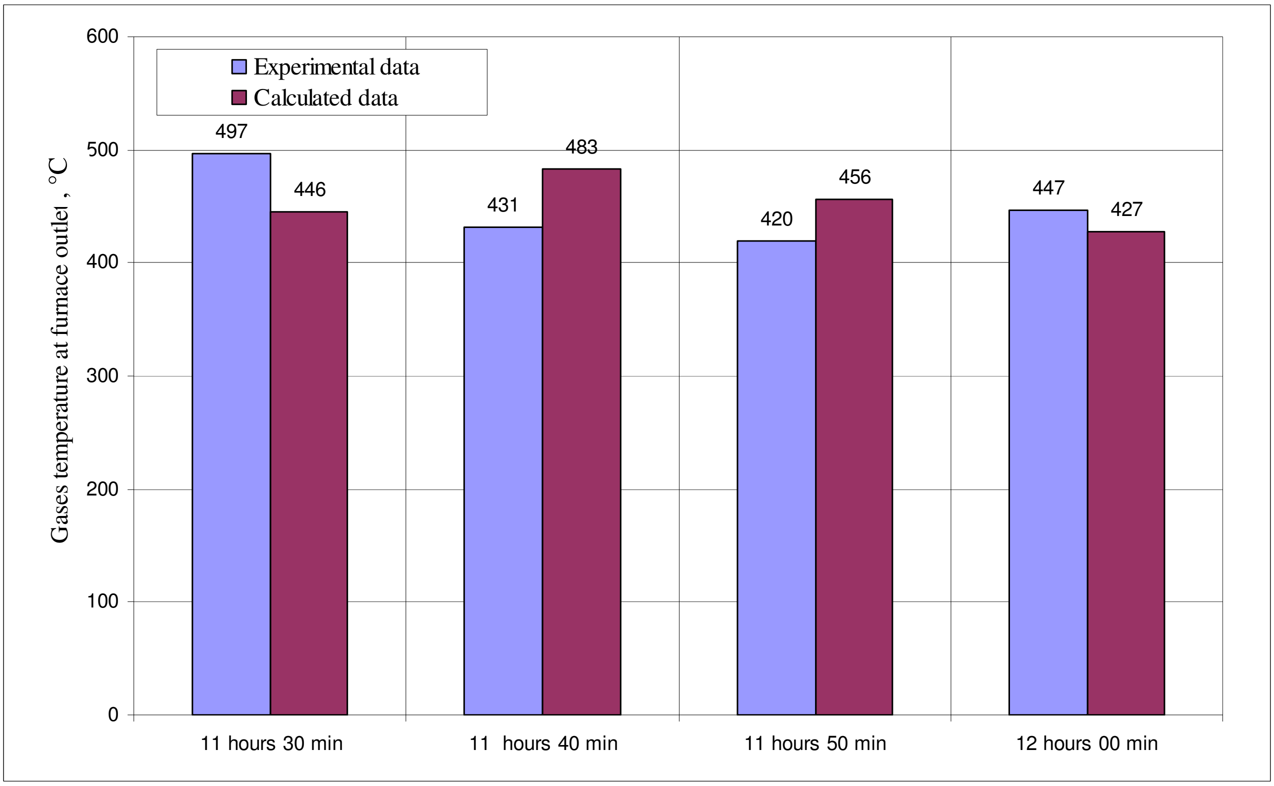

Fig. 4. Comparison of experimental and calculated values of flue gases temperatures at furnace outlet

It should be noted that the burning surface area changes in the course of straw bale burning. As it is seen in Fig 3, divergence between experimental and calculated values is -11,9%....17,34%. Such discrepancy, in our opinion, is the result of insufficiency of initial data for calculation (of fuel content) as well as reference documentation for thermal calculation of the generators operating on alternative types of fuel, in particular, straw bales. At the given stage of research, NM is suggested to be applied for engineering calculations but it should be adapted, regarding characteristic features of boilers design.

Conclusions

Research, carried out , showed that the application of thermal generators, operating on alternative types of fuels, in particular, straw, is one of the most urgent problems. Experimental studies of 1500 kW thermal generator, intended for straw bales combustion are carried out. Comparative analysis of calculated and experimental data, concerning the temperature of flue gases at the furnace outlet is performed. Discrepancy between experimental and calculated values is -11,9%....17,34%. Such discrepancies are connected with insufficiency of initial data for calculation (of fuel content) and reference documentation for thermal calculation of thermal generators, operating on alternative types of fuel. Possibility of Normative method application for heat exchange calculation in the furnace of thermal generators, operating on alternative types of fuel is analyzed.

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Bodnar Lilia – Cand. Sc. (Eng), Assistant Professor with the Department of Power Engineering, Bodnar06@ukr.net.

Stepanov Dmytro – Cand. Sc. (Eng), Assistant Professor with the Department of Power Engineering.

Slyvko Roman – Engineer.
Vinnytsia National Technical University.