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BURNING EFFICIENCY OF LIQUID FUEL IN HEATING SYSTEM WITH CONDENSING BOILERS

BY

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Abstract. The paper presents the results of a study concerning the efficiency of a heating installation with a condensing boiler using liquid fuel, equipped with an accumulator and burnt gases separator. The given up heat in the gas separator is taken over and accumulated through a heat pump. The energetic efficiency of the primary heating functioning regime was established at 94% after the measurements and at 95.8% through calculus.

Key words: efficiency; oil fired boiler; heat pump; separator; fuel; combustion process; condensation; energy balance; energy saving; ecological advantages.

1. Introduction

The combustion process of liquid fuel is different from the gaseous one, because it passes first through a spraying process then follows a mixing with the necessary combustion air, while the second one diffuses in the combustion air. The results of fuel combustion are heat and gases. Modern burning installations are provided wiht heat recovering from the water vapours content in burnt gases. Such systems are in boilers with condensation. Water condensation is in function of the gas components, of air humidity and the exceeding air by burning temperature less then 58°C.

The advantages compared with heating installations without heat recovering are the followings:

a) Reduction of heat losses because of the diminished temperature of burnt gases, reduction of relative losses at the chimney.

b) Obtention of useful supplementary heat as result of vapour condensation in the burnt gases.

These two effects increase the efficiency of the combustion process and reduce fuel consumption for the same thermal efficiency. By burning low gas the combustion efficiency can achieve maximum 111%.

The liquid fuel compared with the gases has a reduced hydrogen content, that leads to a diminished water vapour content in the burnt gases and therefore the dew-point of burnt gases is lower then in case of burning gas fuel.

In function of the components of the liquid fuel, of air humidity and exceeding air, the temperature reaches around 50°C.

While burning liquid fuel it must be considered the sulfur content because by temperatures less than 160°C the sulfur-trioxide react with water and it result sulfur-acid that condenses and this very acid condens must be neutralized before evacuation. All elements in contact with this condens must be protected against corrosion. By burning fuel oil EL the maximum efficiency could be 106%.

The equipments producer for heating installations generally are centered on developing the systems with gas fired equipments for the following reasons: a) higher efficiency and potential compared with the liquid one; b) problems regarding execution and neutralizing of condense; c) lower dew-point of burnt gases by liquid fuel; d) lower return temperature that imposes a complex regulation.

2. Components and Functioning of the Analysed Heating System

As shown in Fig. 1 the schematic heating installation has the following components: boiler, wet gas separator with a heat pump and a heat accumulator. The main components of the boiler are: a conventional burner with reduced oxides and a heat exchanger.

The burner works with 1.1 air exceeding coefficient. The heat exchanger is washed by the burnt gases and they reduce their temperature about 160°C.

According to his utility the recovered heat is used in the heating installation or it is accumulated. The burnt gases are passed through the wet gas separators, being obliged to path through *o per* hold plate that realizes dispersion in small bubbles and after this stage it passes through a water layer. The gas cooling to a temperature close to that of the water is realized through the intensive contact between water and gas. Meantime it is produced a complete separation of SO_2 and NO_x from the burnt gases. The heat furnished to the water is utilized in preheating domestic warm water or through a heat pump it can be transferred in an accumulator. Condens is given up in the washing bath, it is continually neutralized with sodium carbonate and then evacuated in the canalization.

In preparing domestic warm water it is performed a preheating using the heating pump in the separator and then it is heated to the useful temperature by the counter-circuit boilers.

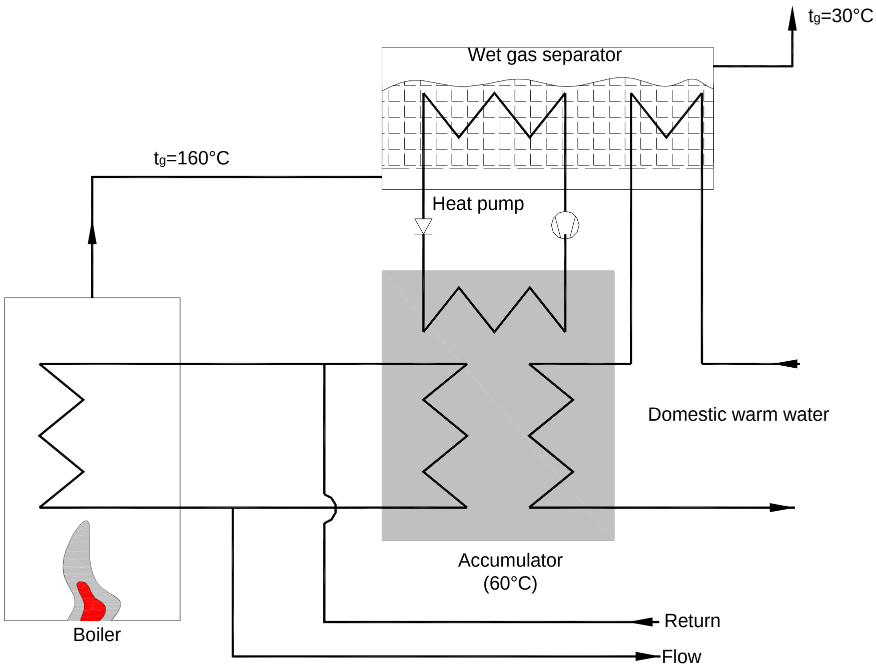

Fig. 1 – Schematic heating installation.

3. Efficiency of the Heating System

In this study is made a distinction between the installations functioning for heating and domestic warm water preparation. The highest efficiency is achieved by the functioning in order to realize domestic warm water because the burnt gases are cooled being washed with cold water and the heating pump does not consume energy. If the system works at heating regime the burnt gases temperature is reduced through the functioning of the heating pump. It can be proved that energy saving is realized even by transforming electrical energy in primary energy.

Efficiency is defined with the general relation η = utility/consumption. The energetically balance in heating regime according to Fig. 2 is

$$\eta = \frac{Q_N}{Q_B + Q_L + P_{\mathrm{el}}/\eta_{\mathrm{prim}}}, \tag{1}$$

where: Q_N is the utile heat; Q_B – fuel heat content at the low calorie power; Q_L –

air heat content; P_{el} – electrical energy consumption; η_{prim} – primary energy efficiency (~ 1/3).

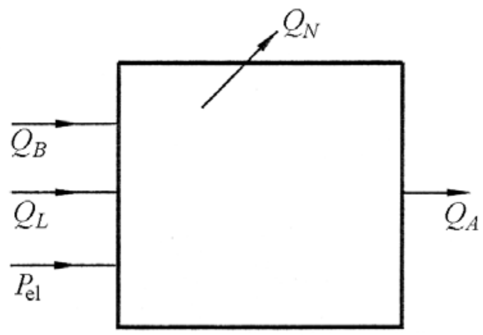

Fig. 2 – Energy balance of the combustion process.

The useful heat could be calculate with the energy conservation balance applied to the energy balance in Fig. 2, with the eq. (1)

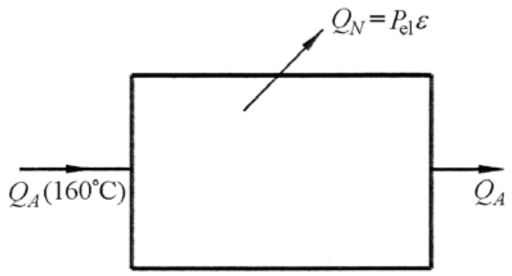

Fig. 3 – Energetically balance of the wet separator for burnt gases.

$$Q_N = Q_{B,O} + Q_L + P_{el} - Q_A, \tag{2}$$

where: $Q_{B,O}$ is the fuels heat content by the superior caloric power; Q_A – burnt gases heat content.

When calculating the useful energy the electrical power is not determined in function of the electrical sources efficiency, because it can be used only the thermal power of electricity.

The efficiency, in function of the caloric power, will be

$$\eta = \frac{Q_{B,O} + Q_L + P_{el} - Q_A}{Q_{B,U} + Q_L + P_{el}/\eta_{prim}}. \tag{3}$$

The combustion calculus with complete change allows the following relations for heat flow:

$$\begin{cases} Q_{B,Q} = mi_O\,, \\ Q_B = mi_U\,, \\ Q_L = \lambda l_{\min} m\left[c_L t_L + x_L\left(r_0 + c_D t_L\right)\right], \\ Q_A = \lambda l_{\min} m_{tr}\left[c_A t_A + x_A\left(r_0 + c_D t_A\right)\right], \end{cases} \tag{4}$$

where: m is the combustion flow; i_0 – superior specific enthalpy (by combustion); i_U – inferior specific enthalpy (by heating); c_L – specific heat of combustion air; t_L – temperature for combustion air; x_L – humidity ratio of air; r_0 – latent vaporizing heat for water; c_D – specific heat of water vapours; m_{tr} – flow of dry combustion gases; c_A – specific heat of dry combustion gases; t_A – temperature of combustion gases; x_A – humidity ratio (by saturation) of combustion gases; λ – air exceeding; $l_{\min}$ – minimum flow of fresh air.

If the energy balance is expressed in function of the combustion flow we obtain the efficiency as ratio to the inferior caloric power

$$\eta = \frac{i_0 + \dfrac{P_{\text{el}}}{m} + i_L - i_A}{i_U + \dfrac{1}{\eta_{\text{prim}}}\cdot\dfrac{P_{\text{el}}}{m} + i_L}. \tag{5}$$

The specific enthalpy of fresh air is

$$i_L = \lambda l_{\min}\left[c_L + t_L + x_L\left(r_0 + c_D t_L\right)\right]. \tag{6}$$

The specific enthalpy of combustion gases is

$$i_A = \frac{m_A}{m}\left[c_A t_A + x_A\left(r_0 + c_D t_A\right)\right]. \tag{7}$$

With the combustion calculus in a complete changing it results the ratio between the flow of burnt gases and the combustion flow.

With the energy balance of the wet separator (Fig. 3) is determined the ratio between the heat pump electrical power and the combustion flow in function of the burnt gases temperature; ε is the efficiency of the heat pump. The ratio between the electrical power and the combustion flow is

$$\frac{P_{\text{el}}}{m} t_A = \frac{i_{A(160^{\circ}\text{C})} - i_{A(t_A)}}{\varepsilon}. \tag{8}$$

3.1. Heat Regime Functioning

In calculus were considered: i_0 = 45.5 MJ/kg; i_U = 42.7 MJ/kg; t_L = = 20°C; φ_L = 40%.

In Fig. 4 is represented $\eta(\eta_{prim} = 1,\ \eta_{prim} = 1/3)$ in function of the caloric power and the burnt gases temperature. For t_A = 25…35°C is obtained $\eta(\eta_{prim} = 1/3)$ = 95.8…96.4%.

The diagram represents also the ratio between the pumps of electric power and combustion flow. The ratio decreases form 0.45 to 0.37 $kWh/kg_{liquid\ fuel}$ for t_A = 25…35°C.

In function of the value of the inferior caloric power this energetic ratio could be 0.031…0.038 $kWh/kg_{liquid\ fuel}$.

For the studied boiler the ratio in heating regime is 0.37 $kWh/kg_{liquid\ fuel}$ and after performing the calculus in stationary regime, t_L = 35°C; $\eta(\eta_{prim} = 1/3)$ = 95.8%. Based on the calculation of the energy balance as presented in Fig. 3 for a conventional heating system with liquid fuel and t_A = 160°C we obtain η = 93%.

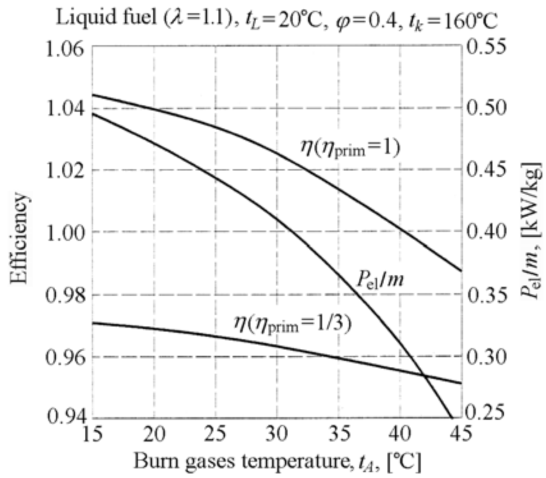

Fig. 4 – Efficiency during heating functioning.

3.2. Domestic Warm Water Regime Functioning

During the domestic warm water preparation the heat pump is not functioning and the wet gases separator is cooled with cold water. As cold the initial water as more the temperature of the separator and burnt gases decreases. Other important factor is the efficiency of heat exchanger used for the preheating of water, as higher it is as more heat is transferred to water and the temperature of the separator decreases.

In Fig. 5 are represented the efficiencies in warm water preparing. It could be observed that for water temperatures of 10°…20°C the efficiency in function of the caloric power will be 102.9…104.2%.

In calculus we supposed a temperature difference of 5 K between cold water and gases separator after preheating and then follows water heating till 60°C in a boiler with backward flow.

4. Efficiency Measurements

To verify the calculus were made measurements in a heating installation with 23 kW heating power.

4.1. Heat Regime Functioning

For measurements were maintained constant the main flow and temperature of cold water. The efficiency measurements were performed by constant return flow and temperature of cold water. After a mixing between main flow and return water of the heating installation, in stationary regime a constant temperature difference between flow and return water is maintained.

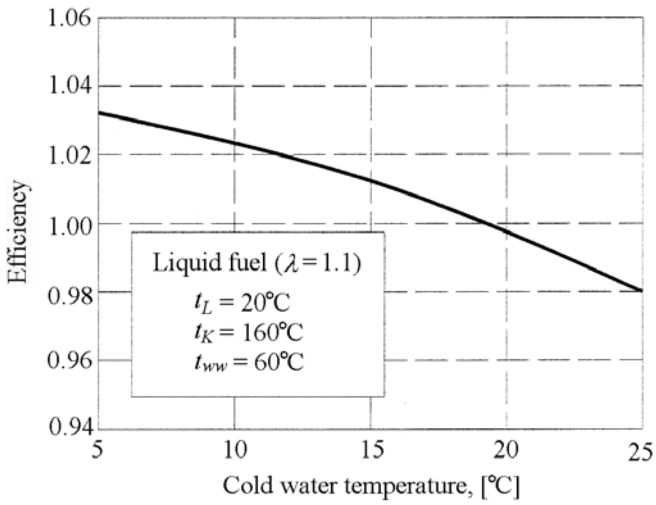

Fig. 5 – Efficiency for domestic warm water preparation.

The liquid fuel consumption was measured with an analytical balance. With measurement apparatus were established the temperature of burnt gases and the temperature of cold and preheated water.

With a register was measured the electrical energy consumption. Thus, it was measured directly the thermal energy furnished by the fuel and electrical energy, respectively the transmission through water warming.

In Fig. 6 are represented the results of the measurements. In stationary heating regime for the maximum load it is necessary to switch from accumulator to boiler, the mean temperature difference between flow and return is of 65°/52°C.

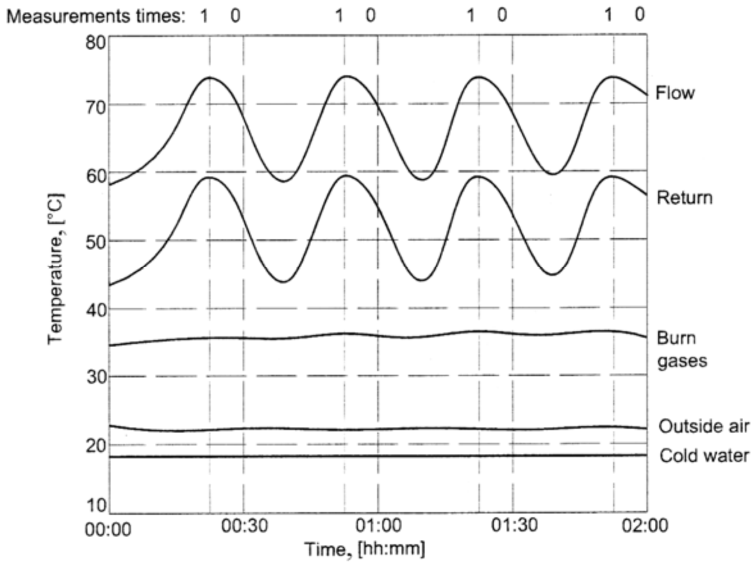

Fig. 6 – Efficiency for domestic warm water preparation.

The mean thermal power of the burner by disconnection of the accumulator is with 16.9 kW less then the total thermal power of the burner.

The absorbed power of the heat pump is 0.75 kW by full functioning capacity of the installation. To prepare 320 kg/h warm water are necessary 18 kW, that means an efficiency

$$\eta = \frac{Q_N}{Q_{B,U} + P_{\text{el}} / \eta_{\text{prim}}}. \tag{9}$$

The measured values differ from the calculated one because of the measurement errors.

4.2. Domestic Warm Water Regime Functioning

While in the measuring the efficiency were maintained a constant water flow and temperature, it was not necessary to switch between accumulator and boiler; therefore in stationary regime the temperature was constant.

After the installation becomes stable, at a constant temperature level, during a period of one hour were registered the temperature of cold water, warm water, burnt gases and it was calculated the fuel consumption. With the measured values were established the mean values of temperatures and the fuel consumption.

Cold water flow: 565 kg/h with t = 17.9°C was heated until 54.2°C with an energy consumption of Q_N = 23.9 kW.

The cold water having 22.7°C after preheating in the separator was with 5 K lower then the temperature of the burnt gases (27.8°C). In function of the fuel consumption the calculated power of the burner was 23.3 kW and for P_{el} = 0 we obtain an efficiency of 102.7%.

4.3. Burnt Gases

During the test were measured the contents of O_2, SO_2, NO, NO_2 and CO. With a content of 2% O_2 and without CO (registered only by start and stop of the burner) it results 1.1 air exceeding. It was not registered SO_2, NO_2.

The NO content was of 51 ppm or 98 mg/kWh while the maximum allowed limit is 110 mg/kWh. Thus, it was demonstrated the separation of sulfur and the azotes oxides reduce.

5. Conclusions

To obtain a higher efficiency even by burning liquid fuel, it was realized a combustion installation that consider the energy content to increase the efficiency. The system assures a temperature of 15…35°C of burnt gases and therefore an efficiency of 101…104% in all thermal power ranges, even for domestic warm water preparation.

The advantages compared with low temperature boilers are: energy saving, simply maintenance and ecological advantages through low emissions of CO_2, sulfur and azotes oxides, because of reduced fuel consumption.

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EFICIENȚA PROCESULUI DE ARDERE AL COMBUSTIBILULUI LICHID ÎN INSTALAȚIILE DE ÎNCĂLZIRE CU CAZANE ÎN CONDENSAȚIE

(Rezumat)

Se prezintă rezultatele studiilor privind radamentul unei instalații de încălzire cu un cazan în condensație pe combustibil lichid, prevăzută cu un boiler şi un separator de gaze arse. Căldura cedată în separatorul de gaze este preluată si acumulată prin intermediul unei pompe termice. Randamentul energetic în circuitul primar al functionării în regim de încălzire a fost de 94% după măsurători şi de 95,8% din calcul.