DIAGNOSIS OF A DOMESTIC HOT WATER PREPARATION SYSTEM CONSISTING OF A 24 kW WALL MOUNTED BOILER AND AN 80 L WATER TANK

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1. INTRODUCTION

Instantaneous preparation of the Domestic Hot Water (DHW) is a default feature of any gas fired combination boiler. Consequently, this hot water preparation system is the usual solution in dwellings heated by their own boiler.

There are many cases when DHW delivery must be ensured on high comfort level – quick delivery (10 seconds or less) and / or supplemental DHW flow for a certain period of time. In these cases, the optimum solution is to connect a hot water tank to the boiler. Function by the DHW heating mode, there are two tank types mostly used: tanks with heat exchange surface (coil-type exchanger) and tanks with mixing heating. The analyzed DHW preparation system consists in an 80 l mixing heating tank connected to a 24 kW conventional (non – condensing) gas fired combination boiler – wall mounted.

2. DESCRIPTION OF THE DOMESTIC HOT WATER PREPARATION SYSTEM

Schematic of the analyzed Domestic Hot Water Preparation System (DHWPS) is presented in fig. 1. The option was tank with mixing heating because this tank type can be easily connected to an usual combination boiler (with instantaneous DHW preparing), with minimum adjustments.

DHWPS delivers hot water in the temperature range of 30 ÷ 65°C. The user can set DHW temperature (tDHW) by acting the thermostat 21, which has -4 deg hysteresis. Boiler starts to operate in two situations:

1) System delivers DHW flow; in this case, the equivalent cold water flow enters the system through C connection; flowmeter 6 signals the water flow (D DHW) and boiler starts up.

2) Thermal charging phase is activated; this means that tank thermostat activates tank pump 16 when water temperature is 4 deg lower than the set temperature; consequently, the flowmeter 6 signals the water flow and boiler starts up. When water temperature reaches the set value, tank thermostat deactivates tank pump and boiler shuts down.

The only change imposed by boiler connection to the water tank refers to the temperature of DHW supplied by the boiler (tbo): tbo = tDHW when boiler operates autonomously, while tbo = 73°C (maximum set value) when hot water tank is connected to the boiler. Two
considerations indicate this maximum temperature value as optimum:
1) Higher $t_{bo}$ means higher boiler output, which means higher efficiency [1];
2) Boiler operation time decreases when $t_{bo}$ / boiler output decreases, so maximum set $t_{bo}$ value means minimum boiler operation time.

3. DIAGNOSYS

The testing phase revealed to the manufacturer an inefficient and completely defective operation mode of the boiler in DHWPS thermal charging phase, namely short On / Off cycles consecutively repeated. The problem becomes more stringent when set value of DHW temperature increases.

The goal of the study developed in the Thermal Machines Department of the Technical University „Gh. Asachi” of Iaşi was to establish the cause of DHWPS defective operation in thermal charging phase and to find the proper solution.

The first step of the study was to analyze DHWPS operation in the incriminated conditions. DHWPS was therefore put into operation creating conditions for thermal charging activation. DHW temperature was set to the maximum value - $t_{DHW} = 65^\circ C$. The electronic board of the boiler was connected to a computer. A dedicated software application made possible both reading and recording of all signals sent to the electronic board by sensors used to monitor the following parameters:

- $t_{bo}$ [°C] – indicated by temperature probe 9 – NTC thermistor, Brahma ST06 type, having an accuracy of 2%;
- $t_{DHW}$ [°C] – indicated by a temperature probe (Brahma ST06 type) placed on the hot water tank, next to the thermostat 21;
- $D_{DHW}$ [l/min], indicated by flowmeter 6 – Fugas U0176 type, having an accuracy of 3%.

Besides, the Pulse Width Modulation (PWM) applied to the gas valve modulating regulator was also recorded.

The curves generated by the recorded signals are presented in fig. 2. As can be seen, these curves confirm the defective operation of DHWPS – short On / Off cycles consecutively repeated. There are marked with 1 and 3 the moments when boiler is ignited while 2 and 4 marks the moments when flame extinguishes. The values of the recorded parameters in these points are given in Table 1.

Conforming to the flame adjusting algorithm [2], [3], after the ignition procedure ($t_{ig} = 15$ s, $PWM = 12\%$), the gas rate goes to $PWM = 100\%$. After 2 s ($\tau_{M}$), gas modulation starts and sends the gas rate to $PWM = 0$, which means minimum boiler output ($P_{min}$), namely 8 kW; 34 s after ignition, boiler stops (gas valve is deactivated, boiler pump stops) because the overheating temperature is reached ($t_{bo} = t_{ov} = 75^\circ C$). As long $t_{DHW} < 65^\circ C$, tank pump runs, generating flow; a new ignition is initiated after the safety time $\tau_{stop} = 48$ s and a new short burning cycle takes place. This operation mode is still active even 23 min after the first ignition generated by $t_{DHW}$ decreasing to $(65 - 4)^\circ C$.
During the safety time ($\tau_{\text{stop}}$) tank pump runs but boiler is not operating. In these conditions, can be admitted that temperature indicated in points 1 and 3 by DHW probe ($t_{\text{bo}}$) is the temperature of water on the bottom of the tank. Consequently, the difference between $t_{\text{bo}}$ in point 2 and $t_{\text{bo}}$ in point 1 (13.3 deg) or the difference between $t_{\text{bo}}$ in point 4 and $t_{\text{bo}}$ in point 3 (12.8 deg) indicates the water temperature increasing in boiler ($\Delta t_{\text{bo}}$). Analytically, this temperature increasing can be expressed as [4]

$$
\Delta t_{\text{bo}} = \frac{60 \cdot P}{\rho_w \cdot c_p \cdot D_{\text{DHW}}} \deg,
$$

where $\rho_w = 1000 \text{ kg/m}^3$ is density of water, $c_p = 4.186 \text{ kJ/kg \cdot deg}$ is specific heat of water at constant pressure and $P [\text{kW}]$ is boiler output. It results that temperature increasing achieved by boiler at minimum output ($P_{\text{min}} = 8 \text{ kW}$) is $\Delta t_{\text{bo}} = 21.2...22.5 \deg$. The maximum $t_{\text{bo}}$ value possible to be get in this case in one uninterrupted boiler operation is $t_{\text{bo}}^{\text{max}} = t_{\text{bo}} - \Delta t_{\text{bo}} = 52.5...53.8 \deg$. That is why boiler operates intermittently when DHW set temperature is 65°C. As long the fixed set value of DHW delivered by boiler is 73°C it means that maximum admitted temperature increasing in boiler is $\Delta t_{\text{bo}}^{\text{max}} = 10.3...10.5 \deg$. The correspondent minimum necessary water flow, calculated with formula

$$
D_{\text{DHW}}^{\text{min}} = \frac{60 \cdot P_{\text{min}}}{\rho_w \cdot c_p \cdot \Delta t_{\text{bo}}^{\text{max}}} \text{ [l/min]},
$$

### 4. SOLUTION

As formula (1) shows, there are two ways to reduce $\Delta t_{\text{bo}}$ so as to make possible to prepare DHW at the maximum set temperature of 65°C:

1) By reducing $P_{\text{min}}$: this solution can’t be applied because $P_{\text{min}} = 8 \text{ kW}$ corresponds to the minimum admitted outlet gas valve pressure, namely 2 mbar; according to the boiler manufacturer instructions, this is the minimum gas pressure which ensures a stable flame;

2) By increasing $D_{\text{DHW}}$: this solution implies to use another tank pump type, able to ensure a higher water flow.

We mention that default tank pump is Grundfos UPS 15-40 130 type.

Taking into account that $t_{\text{DHW}} - t_{\text{bo}}$ in points 1 (2.3 deg) or 3 (2.5 deg) indicates the difference between water temperature on thermostat level and water temperature on tank bottom, results that water temperature on tank bottom is 62.5...62.7°C when DHW temperature on thermostat level reaches the maximum set value, namely 65°C. As long the fixed set value of DHW delivered by boiler is 73°C it means that maximum admitted temperature increasing in boiler is $\Delta t_{\text{bo}}^{\text{max}} = 10.3...10.5 \deg$. The correspondent minimum necessary water flow, calculated with formula

$$
D_{\text{DHW}}^{\text{min}} = \frac{60 \cdot P_{\text{min}}}{\rho_w \cdot c_p \cdot \Delta t_{\text{bo}}^{\text{max}}} \text{ [l/min]},
$$

### Table 1

<table>
<thead>
<tr>
<th>Point</th>
<th>$t_{\text{bo}}$ [°C]</th>
<th>$t_{\text{DHW}}$ [°C]</th>
<th>$D_{\text{DHW}}$ [l/min]</th>
<th>PWM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>61.7</td>
<td>64</td>
<td>5.4</td>
<td>12</td>
</tr>
<tr>
<td>2</td>
<td>75</td>
<td>64.3</td>
<td>5.1</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>62.2</td>
<td>64.7</td>
<td>5.4</td>
<td>12</td>
</tr>
<tr>
<td>4</td>
<td>75</td>
<td>64.7</td>
<td>5.2</td>
<td>0</td>
</tr>
</tbody>
</table>
is 10.9…11.1 l/min. According to Grundfos catalogues, the adequate model pump in these conditions seems to be UPS 25-70 130. Consequently, the test was repeated using this pump.

System operation in thermal charging phase when tank is equipped with the new pump type (Grundfos UPS 25-70 130) it is shown in fig. 3.

As can be seen in fig. 3, the new pump ensures an average water flow $D_{\text{DHW}} = 12.2$ l/min in thermal charging phase, which corresponds to $P = 8.8$ kW; this boiler output, corresponds to $\text{PWM} = 8\%$ – established after the ignition procedure, when gas modulation is active. In the new conditions, thermal charging of the water tank takes $t_{\text{on}} = 161$ s and requires only one burning cycle.

5. CONCLUSION

The test performed in the laboratory of the Thermal Machines Department revealed the cause of DHWPS defective operation in thermal charging phase, namely thermal power need lower than minimum boiler output. Solution adopted was to increase the thermal power need (in thermal charging phase) over the minimum boiler output by increasing DHW from 5.1…5.4 l/min to minimum 11 l/min. Consequently, the existent pump (Grundfos UPS 15-40 130) was replaced with a new one – Grundfos UPS 25-70 130. With this new pump, the water flow becomes 12.2 l/min, making thus possible to heat up water in tank from 61°C to 65°C (thermal charging) in 161 s, in only one burning cycle. In this case, the minimum boiler output, reached just before flame extinction, is 8.8 kW.

The results of the test performed with the new tank pump validate the solution adopted, confirming this way that objective of the present study was accomplished.

REFERENCES


