Experimental Research of Thermal Resistance of Hot Water Heater Insulation

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Abstract - *The present article describes the experimental measurements of thermal resistance of the PUR insulation installed in the selected type of hot water heaters that are necessary for the purpose of identification of heat output or heat loss in the given heater.*

Keywords - thermal resistance, heater insulation, hot water heater.

I. INTRODUCTION

At present, availability of hot water at home is absolutely obvious. There are several ways how to ensure availability of hot water; one of the efficient and multi-purpose methods is heating water in tanks that are also referred to as accumulative heating of water. For the purpose of efficient use of the tanks for the preparation of hot water, optimal operating conditions and parameters (temperature, volumetric flow rate, insulation, efficiency, etc.) must be created. Thermal insulation and its thermal resistance represent two of the most important parameters within the assessment of water heaters in terms of the heat transfer.

II. METHODOLOGY FOR MEASURING THERMAL RESISTANCE OF A HOT WATER HEATER

The experimental measurement was carried out using a stationary hot water heater with indirect water heating (2) in which the heat was conveyed from an external primary source (electric water heater (1)). A hot water tank functions as an exchanger where the heated water circulates in a spiral that is wound in the entire space inside the tank and transfers the heat to the water contained in the tank (Fig. 1).

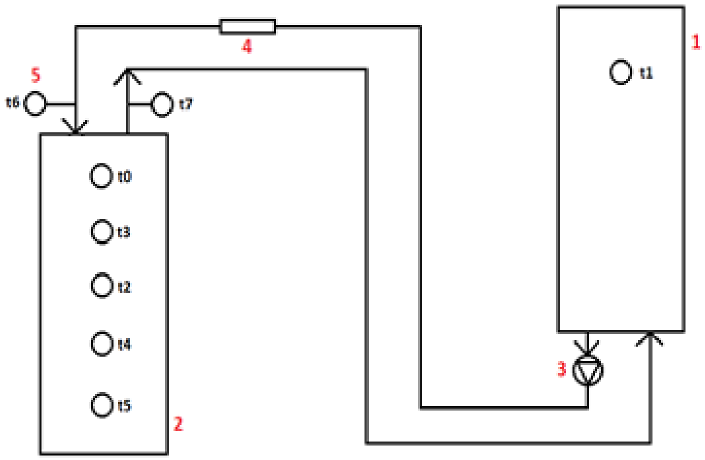

FIGURE 1: Diagram of connecting the tanks in the experimental research
1 – heat source (electric water heater), 2 – examined hot water heater 3 - HALM circulation pump, 4 – flow meter, 5 - temperature sensors

The insulation material used in the examined hot water heater was polyurethane (PUR) foam possessing very good insulation properties and its thermal conductivity coefficient λ reaches the value of 0.03 $W \cdot m^{-1} \cdot K^{-1}$. A disadvantage of such insulation material is that it is not recyclable and therefore it is regarded as unacceptable from the ecological point of view.

The examined hot water heater was used to perform the measurements, as specified in the prepared methodology, aimed at obtaining the data on changes in temperature detected by sensors during the tank cooling process. Such data were required for the purpose of identification of thermal resistance of the polyurethane insulation used in the examined hot water heater.

Prior to the measurement, it was necessary to check the system. Subsequently, the heat source was turned on and its operation was maintained until the temperature in sensor t_1 reached 45 °C. Distribution of hot water through the insulated pipes from the heat source to the examined hot water tank was carried out using a pump. 5 temperature sensors were installed on the hot water heater along its height for the purpose of recording the changes in temperature in time. The hot water heater was equipped with an outlet pipe through which water was drained from the bottom of the tank back to the electric heater. The measurements of changes in temperature were carried out for the period of approximately six days.

FIGURE 2: Electric heater (heat source)

FIGURE 3: Examined hot water heater

III. DETERMINATION OF THERMAL RESISTANCE OF INSULATION USING THE CURVE OF COOLING

The determination of thermal resistance of the insulation requires the use of the measured data regarding the changes in temperature in the analytical calculation of thermal resistance that applies to ideal conditions. For the purpose of clarity, these data were processed and evaluated in Excel (Fig. 4).

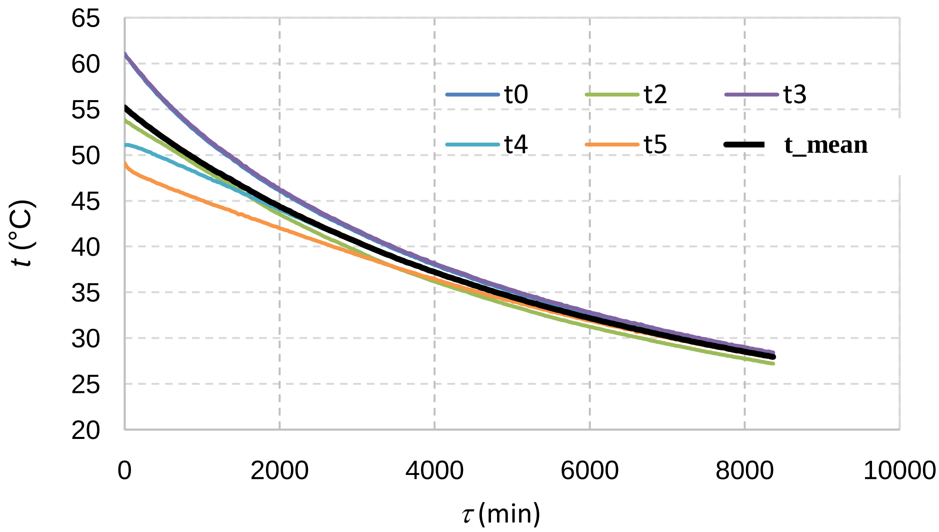

FIGURE 4: Curve of cooling the tank in time
t_1 to t_5 – surface temperatures of the heater wall (°C), t_{mean} – mean surface temperature of the heater wall (°C)

Fig. 5 below presents a simplified diagram of the examined tank in which α_1 and α_2 are heat transfer coefficients, P_S is the heat output, λ expresses the thermal conductivity coefficient of the material (polyurethane), and δ expresses the insulation thickness. This tank contained 5 temperature sensors arranged as shown in the Figure. Temperature t was calculated as the arithmetic mean of the measured temperatures in each period. The cooling period relevant to the calculation of thermal resistance was 660 minutes. Such period was chosen on the basis of bigger differences in the measured temperatures for the purpose of higher accuracy of the calculation.

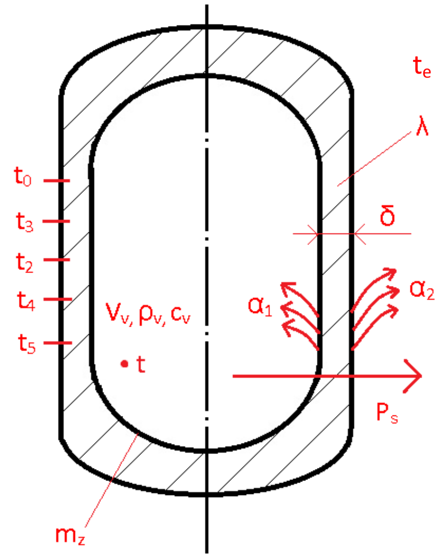

FIGURE 5: Simplified diagram of the tank

Table 1 contains the values of the measured parameters.

TABLE 1
MEASURED TEMPERATURES

Period	t_0 (°C)	t_3 (°C)	t_2 (°C)	t_4 (°C)	t_5 (°C)	t_{mean} (°C)	t_t (°C)	t_e (°C)	Δ_τ (s)
1.	61.08	60.97	53.84	51.09	49.13	55.23		21.63	0
2.	54.57	54.81	50.34	49.06	46.12	50.98	53.10	20.85	39,600

The mean surface temperature of the heater wall t_{mean} was calculated using the following formula:

$$t_{mean} = \frac{t_0 + t_2 + t_3 + t_4 + t_5}{5} \quad (°C) \tag{1}$$

and the total design temperature tt was calculated using the formula (2):

$$t_t = \frac{t_{mean,1} + t_{mean,2}}{2} \quad (°C) \tag{2}$$

The calculation of thermal resistance of the insulation was based on the calorimetry formula (3):

$$E = m \cdot c \cdot \Delta_t \quad (J) \tag{3}$$

which acquired the following form after being divided by the time variation Δ_τ:

$$P_{acum} = \frac{m \cdot c \cdot \Delta_t}{\Delta \tau} \quad (W) \tag{4}$$

or $P_{acum} = -\sum (m \cdot c) \frac{dt}{d\tau}$ (5)

where P_{acum} is the accumulation capacity of the tank and $\sum(m \cdot c)$ is the sum of the product of the weight and the specific heat capacity of the tank and water.

The real capacity of the accumulation tank may be expressed as follows:

$$P_S = \frac{(t - t_e)}{\frac{1}{\alpha_1} + \frac{\delta}{\lambda} + \frac{1}{\alpha_2}} \quad \text{(W)} \tag{6}$$

while the thermal resistance of the insulation is determined by the following formula:

$$R = \frac{S}{\frac{1}{\alpha_1} + \frac{\delta}{\lambda} + \frac{1}{\alpha_2}} \quad (\text{K}\cdot\text{W}^{-1}) \tag{7}$$

Following the substitution of thermal resistance in the formula (6), we obtained the modified formula for the calculation of the real capacity of the tank:

$$P_S = \frac{(t - t_e)}{R}$$

where t is the temperature in the tank, t_e is the temperature of the environment, and R is the thermal resistance.

Formulas (4) and (7) are subjected to the condition that $P_s = P_{acum}$. Hence, the thermal resistance was calculated using the formula (8):

$$R = -\frac{(t - t_e)}{\sum (m \cdot c)\frac{dt}{d\tau}} = -\frac{(t - t_e)}{\sum (m \cdot c)\frac{\Delta_t}{\Delta \tau}} \tag{8}$$

The following applies to the sum of the product of the weight and specific heat capacity of the tank and water:

$$\sum (m \cdot c) = m_w \cdot c_w + m_t \cdot c_t \tag{9}$$

where $m_w = \rho_w \cdot V_w$ a $m_t = \rho_t \cdot V_t$.

The following formula applies to the tank volume:

$$V_t = \pi \cdot d \cdot H \cdot \delta_t + 4\pi \cdot r^2 \cdot \delta_t \tag{10}$$

The determination of the value of the thermal resistance of the insulation in the given period at the mean temperature of the environment was based on the following partial values:

- mean temperature of the environment t_e = 21.24 °C;
- density of water ρ_w = 990 kg·m^{-3};
- tank steel density ρ_t = 7,850 kg·m^{-3};
- specific heat capacity of water c_w = 4,180 J·kg-^{1}·K^{-1};
- specific heat capacity of steel in the tank c_t = 470 J·kg^{-1}·K^{-1};
- volume of water V_w = 150 L;
- tank height H = 0.915 m;
- tank diameter d = 0.439 m;
- outer jacket thickness δ_t = 2.5 mm.

Following the substitution of partial parameters into the formula (8), the value of thermal resistance of the insulation in the given period ***R*** was **0.4662 K·W^{-1}**. The obtained value of thermal resistance can be used to express the heat transfer coefficient *k* that represents an inverse value of thermal resistance.

The relationship between the thermal resistance of the insulation and the cooling of the tank is shown in Fig. 6.

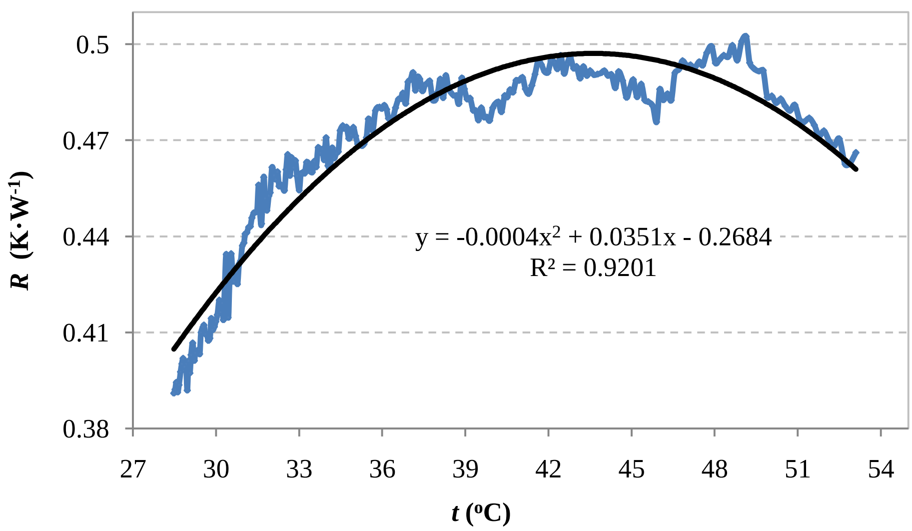

FIGURE 6: Relationship between the thermal resistance of the insulation and the cooling of the tank

The graphical representation above indicates that the value of thermal resistance of the insulation during the period when the tank was cooled ranged between 0.3913 and 0.5024 $K \cdot W^{-1}$.

IV. CONCLUSION

The energy efficiency of the heat accumulation system significantly depends on particular operating conditions in which it is used. The most important factors affecting heat losses in hot water heater tanks include the hot water demand, tank heater output, and the related thermal insulation of the tank. The higher value of thermal resistance of the insulation, the better it resists heat transfer and acquires better thermal insulation properties.

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