

THE MEASUREMENT OF HEAT LOSS WITH USE OF A THERMAL IMAGING SYSTEM

T. Vítěz, P. Trávníček

Received: June 3, 2010

Abstract

VÍTEŽ, T., TRÁVNÍČEK, P.: *The measurement of heat loss with use of a thermal imaging system*. Acta univ. agric. et silvic. Mendel. Brun., 2011, LIX, No. 3, pp. 193–196

The aim of this work was to verify the method of determining the heat loss of boiler by using of thermal infrared camera. Waste sawdust and wood shavings from the manufacturing of wooden furniture has been used as fuel in considered boiler with an installed heat output of 130 kW. The temperature distribution on the shell of the boiler has been discovered by using of infrared thermal camera, subsequently heat loss caused by radiation and convection has been calculated. For calculating of heat loss caused by radiation Stefan-Boltzmann Law has been used, for calculating of heat loss caused by convection three approaches have been used, Mc Adams, Michijev's and King's. The results of the different approaches have been compared between themselves and the mean heat loss.

heat loss, combustion equipment, thermal imager, heat transfer coefficient

Heat loss is very important technical indicator of every heat device. There are three possibility of heat transfer. The first is conduction, the second is convection and third is radiation. Heat transfer between surface of heat device and environment is evoked only heat transfer due to convection and radiation. In case that the temperature is higher than approximately 600 °C efficiency of a heat transfer due to radiation is higher than heat transfer due to convection (Brügel, 1951; Deribere, 1954). It follows that in the area of high temperature is heat loss due to radiation higher than heat loss due to convection.

Measuring of the temperature of the boiler outer surface was based on the method of contactless measurement using thermal imaging systems, which use energy of infrared radiation for temperature measurement purposes. Infrared radiation is subdivided into three ranges (short-wave, medium and remote infrared range) within the wave length range between 0.78 µm and 1000 µm (Sakai *et al.*, 1994). Increasing temperature of the source results an increase of the energy of infrared radiation and the radiation maximum shift towards shorter wave lengths, for example, the maximum radiation of a human body is 9.3 µm (Vaško, 1963). The applied thermographic system conducts measurements

within the range of 7.5 to 13 µm (wave length) and –20 °C to 500 °C (reference temperature range).

Heat loss due to convection depends on a difference of a surface temperature, environment temperature and convective heat transfer coefficient. Convective heat transfer coefficient depends on a temperature difference, kind of fluid, kind of convection (free convection, compulsory convection) or form of contact surface. The convective heat transfer coefficient is calculated with use of criterial equations and dimensionless numbers (Corcione *et al.*, 2009). Calculating of dimensionless numbers and criterial equations is very difficult (Corcione *et al.*, 2009). However various equations and methods are given in science articles or literature (Bašta, 2000; Sartori, 2005). This methods makes calculating of criterial equations easier. Convective heat transfer coefficient is often expressed as functional dependence of temperature difference outside thermokinetic layer and surface temperature of vertical wall (Bašta, 2000).

Due to simplicity and universal applicability simplifying equations derived by three authors have been used. It follows that calculating of heat loss will be much easier and measurement of heat loss of heat devices, buildings and different equipment will be quick and cheap.

MATERIAL AND METHODS

Determination of material emissivity

A measuring point, at which the temperature was measured by using an OMEGA HH11 contact thermometer (accuracy of temperature measurement: ± 0.1 °C), was created on the casing of the combustion equipment. The most significant prerequisite was to prevent fluctuation of temperature in the course of time. The aforementioned point was also monitored using FLIR E320 thermal camera. In case that the temperature values proved to differ, the temperature in the thermal camera was calibrated by the means of setting up the emissivity value in the user interface of this device. The final emissivity value was determined at the time when the temperature value on both devices was balanced.

Thermal imaging measurement

In addition to emissivity of the monitored material, it is also essential (for thermal imaging measurement purposes) to measure the air temperature, air humidity and distance from the monitored object. The air temperature and humidity was measured by using an OMEGA RH81 thermo-hygrometre featuring the temperature measurement accuracy of ± 1 °C and humidity measurement accuracy of $\pm 4\%$ (at the temperature of 25 °C and relative humidity within the range of 10 %–90 %). The temperature and humidity was measured in the close vicinity of the thermal camera and combustion equipment, and the arithmetic mean was subsequently calculated on the basis of these values.

The thermal screening measurement was conducted at a constant distance from the combustion device. Three pictures were taken in the course of one hour. The distance of the camera from the combustion device was determined by using Leica DISTO[™] A5 laser EDM device (measurement accuracy ± 1.5 mm at a distance between 0.2 and 200 m). The thermal imaging measurement as such was conducted by using FLIR ThermaCAM E320 thermal camera (FOV: 25°).

The average temperature of the surface was calculated using ThermaCAM QuickReport software in which each pixel of the picture was allocated to one temperature value. An arithmetic mean was subsequently created on the basis of all values.

Calculation of heat losses due to convection

The convective heat transfer coefficient was determined according to Mc Adams, C. King and F. Michijev (Bašta, 2000).

The convective heat transfer coefficient according to Mc Adams:

$$\alpha_k = 1,78 \times \Delta t^{0,12} \quad [\text{W} \cdot \text{m}^{-2} \cdot \text{K}^{-1}]. \quad (1)$$

The convective heat transfer coefficient according to C. King:

$$\alpha_k = 1,51 \times \Delta t^{0,33} \quad [\text{W} \cdot \text{m}^{-2} \cdot \text{K}^{-1}]. \quad (2)$$

The convective heat transfer coefficient according to F. Michejev:

$$\alpha_k = 1,55 \times \Delta t^{0,33} \quad [\text{W} \cdot \text{m}^{-2} \cdot \text{K}^{-1}]. \quad (3)$$

Heat loss was calculated according to the equation:

$$q_t = \alpha_k (t_1 - t_2) \quad [\text{W} \cdot \text{m}^{-2}], \quad (4)$$

where:

α_k convective heat transfer coefficient $[\text{W} \cdot \text{m}^{-2} \cdot \text{K}^{-1}]$

t_1 temperature of air $[\text{°C}, \text{K}]$

t_2 temperature of surface $[\text{°C}, \text{K}]$.

Calculation of heat loss due to radiation

Total intensity of a grey-body radiation was calculated according to Stefan-Boltzmann law. Then total intensity of an environment radiation was subtracted from total intensity of a grey body radiation.

The equation for calculation of heat losses due to radiation is following:

$$I = (\sigma \times \varepsilon_s \times T_s^4) - (\sigma \times \varepsilon_t \times T_t^4) \quad [\text{W} \cdot \text{m}^{-2}], \quad (5)$$

where:

ε_semissivity of grey-body $[-]$

ε_temissivity of environment $[-]$

T_sthermodynamic temperature of grey-body $[\text{K}]$

T_tthermodynamic temperature of environment $[\text{K}]$

σStefan-Boltzmann constant $[\text{W} \cdot \text{m}^{-2} \cdot \text{K}^{-4}]$.

Calculation of total heat loss

Total heat loss of a combustion device was calculated according to equation:

$$Q = S \times (I + q_t) \quad [\text{W}], \quad (6)$$

where:

I intensity of grey-body radiation $[\text{W} \cdot \text{m}^{-2}]$

q_t heat loss due to convection $[\text{W} \cdot \text{m}^{-2}]$

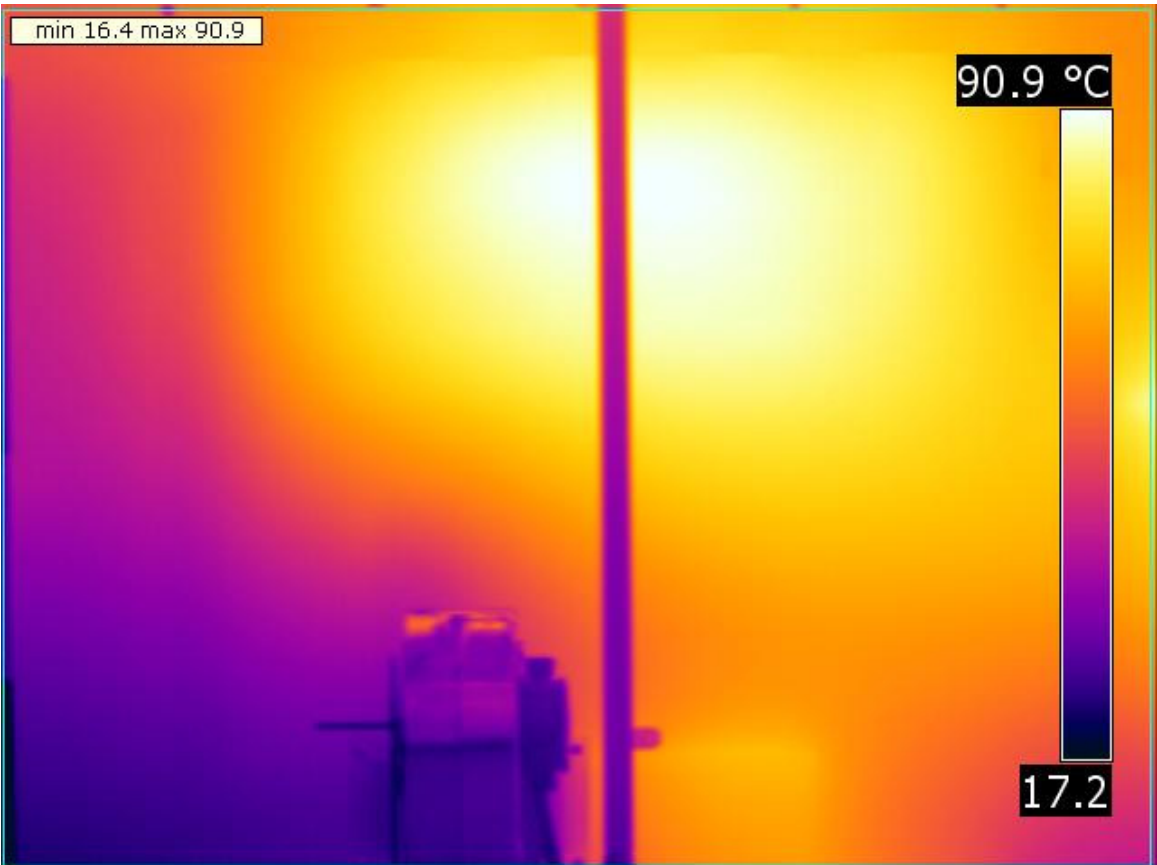
S outer surface of boiler $[\text{m}^2]$.

RESULTS AND DISCUSSION

Mesured boundary conditions (important for correct evaluation of thermal measurement imaging) are stated in Tab I.

I: Boundary condition of thermal measurement imaging

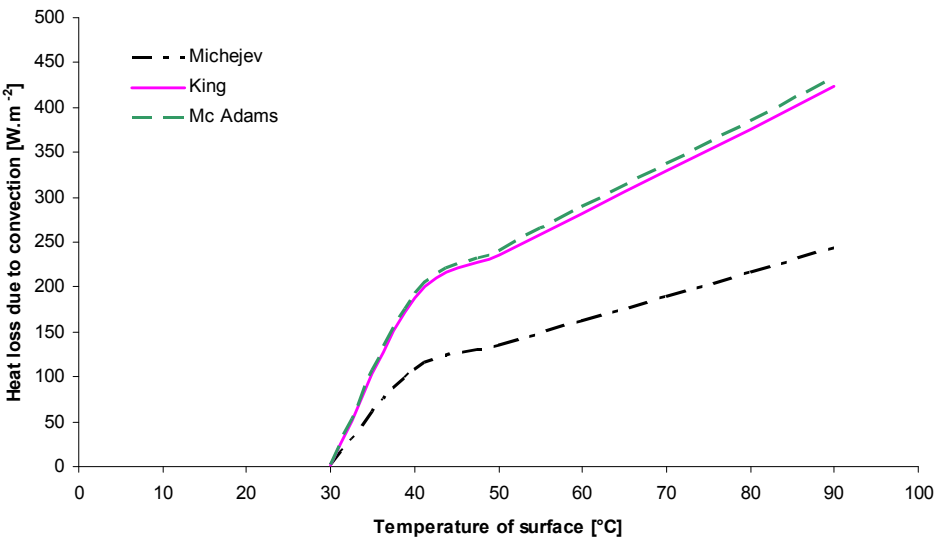
Type of Limit Condition	Value	Unit
Emissivity	0.89	–
Reflected temperature	34.8	°C
Air temperature	29.7	°C
Air humidity	17.6	%
Distance	3	m



1: Temperature distribution field at front side of the combustion device

II: Calculated results of heat loss

	Mc Adams	C. King	F. Michejev
Heat losses due to convection [W·m ⁻²]	85	147	150
Heat loss due to radiation [W·m ⁻²]	204	204	204
Total heat loss [W·m ⁻²]	288	351	354
Total heat loss for a surface [W]	297	361	365



2: Dependence of surface temperature on heat loss of combustion device

Based on the thermal imaging measurement it was determined that the average temperature of the monitored area was 60.9 °C. The maximum temperature in the area was 90.9 °C and the minimum temperature in the area was 16.4 °C. The minimum temperature in the area was lower than the air temperature due to the fact that a small part of the boiler surface was cooled by the floor. However, this anomaly did not affect any additional calculations. For the temperature distribution field see Fig. 1.

Results of heat loss calculation are stated in Tab. II. Heat loss was calculated for an average temperature of surface 60.9 °C. Surface of combustion device was 1.03 m².

The total surface of combustion device was 4.37 m², however the surface of contact with a heat exchanger wasn't calculated. Providing that temperature all surfaces of combustion device is 60.9 °C so total heat loss is according to Mc Adams – 1 260 W, according to C. King – 1 578 W and according to F. Michejev – 1 595 W. Average value of heat losses is 1 447 W. When heat power of combustion device is 130 kW, then heat loss by heat transfer are in the range of 0.97% to 1.23%. Average value of heat losses is 1.11%. Dependence of heat loss on the convective heat transfer coefficient and temperature of surface is seted in the Fig. 2.

SUMMARY

The work is focused on evaluation of a rapid and universally applicable method for determining heat loss of combustion and other thermal devices. This method compared with other methods, based on calculations of the energy balance requires less devices and it is less demanding for measurement. The described method may find practical use primarily in smaller devices that are not equipped with continuous measurements (temperature of heating medium, flow of heating medium, etc.). This is essentially a combustion device, heaters, and the measurement of heat loss of buildings. To verify the method was used combustion device with a heat output 130 kW, which burns a mixture of waste sawdust and wood shavings from the manufacturing of wooden furniture. First of all temperature field have been measured by using of thermal imaging camera. Thermal energy, which is shared with its surroundings by radiation and convection, was then calculated for radiation by the Stefan-Boltzmann Law. Heat loss by radiation was 204 W·m⁻². In calculating of the heat loss caused by the convection, three approaches were considered for calculations of the coefficient of free convection along a vertical wall according to Michijev, Mc Adams and King. Convection heat loss calculated according to Michijev was 150 W·m⁻², to Mc Adams was 85 W·m⁻², and to King was 147 W·m⁻². The mean of convection heat loss then was 127 W·m⁻². Total heat loss depending on the chosen approach was 1 260–1 594 W, the mean was 1 447 W. In according to the total heat output of the combustion device, the total heat loss was in the range of 0.97% to 1.23%. The median value of total heat loss of combustion device was 1.11%.

REFERENCES

- BAŠTA, J., 2000: Otopná tělesa. STP, 38–39.
 BRÜGEL, W., 1951: Physik und Technik der Ultrarotstrahlung. Curt R. Vincentz Verlag, 31–42.
 CORCIONE, M., HABIB, E., 2009: Multi-Prandtl correlating equations for free convection heat transfer from a horizontal tube of elliptic cross-section. International Journal of Heat and Mass Transfer 52, 1353–1364.
 DERIBERE, M., 1954: Les Applications Pratiques des Rayons Infrarouges. Dunod Paris, 20–28.
 SAKAI, N., HANZAWA, T., 1994: Applications and advances in far-infrared heating in Japan Trends in Food Science & Technology 51, 357–362.
 SARTORI, E., 2005: Convection coefficient equations for forced air flow over flat surfaces. Solar Energy 80, 1063–1071.
 VAŠKO, A., 1963: Infračervené záření a jeho užití. SNTL, 25–271.

Address

Ing. Tomáš Vítěz, Ph.D., Ing. Petr Trávníček, Ústav zemědělské, potravinářské a environmentální techniky, Mendelova univerzita v Brně, Zemědělská 1, 613 00 Brno, Česká republika, e-mail: tomas.vitez@mendelu.cz