Investigation of Methods for Determining Heat Losses from External Cooling of Surfaces of a Small-Capacity Hot-Water Boiler

E A Biryuzova

1PhD of Tech. Sci., Associate Professor, Department of Heat and Gas Supply and Ventilation, Saint-Petersburg State University of Architecture and Civil Engineering, 2-ya Krasnoarmeyskaya street, 4, city St. Petersburg, 190005, Russia

E-mail: biryuzova@rambler.ru

Abstract. For proper use of a new or a long time period operated boiler equipment, it is necessary to evaluate the effectiveness of its work, which is characterized by a coefficient of efficiency (efficiency). Its calculation requires greater accuracy as even tenths of its value can influence the decision on an application of one or the other boiler equipment kind or on a choice of the equipment producer. All the efficiency components can be determined experimentally (according to parameter chart of boiler equipment in operation) by means of modern instrument base, the exception is the value of the heat losses from heated boiler surfaces into the environment or from the external cooling boiler surface. In the literature there are no information and recommendations on the choice of methods for this value determining. And for the small-capacity boiler equipment there are no even indicative figures. To solve this problem, it is necessary to study all the factors that affect the desired value, as well as methods for determining it. The results of experimental studies of the operation of the small-capacity boiler equipment allow us to identify the relationship between the amount of heat loss from the heated boiler surfaces to the environment, the thermal power value and the equipment surface area. Based on the obtained results, graphical and analytical dependencies are developed to determine the heat loss from the heated boiler surfaces to the environment.

1. Introduction

The heat loss value from external cooling of the boiler unit surfaces (or from heated surfaces) is an important efficiency indicator of the boiler and burner equipment operation as a complex. And also it is an integral part of the parameter chart which is developed at commissioning works and then regularly updated by the organization operating this equipment, and it reflects the real efficiency indicators of the equipment operation.

The efficiency is determined by various ways there are experimental or analytical (calculated) methods. In either case, this indicator is based on the reverse balance method. In both cases, there are difficulties in determining the heat loss from the external cooling surfaces of the boiler unit, especially for small-capacity boilers.

In the context of experimental researches of indicators of the boiler equipment operation, heat loss values with waste gases $q_2$, and with chemical incompleteness of combustion $q_3$. Modern gas analyzers, such as the «Testo» brand, determine these values automatically by operating calculations.
according to the methods used in our country [17]. The heat loss from the external cooling surfaces of the boiler unit $q_5$ is not defined. And very often this value is either neglected or taken as indicative values [1, 2], which negatively affects the equipment operation evaluation.

The investigated heat loss value from external cooling of boiler plant surfaces (or from heated surfaces to the environment) depends on many parameters [11], such as:

- size of heated surface;
- quality of heat-insulating materials used on the boiler surface;
- thermal insulation thickness;
- the temperature of the heated surface;
- the ambient air temperature.

Therefore, the value measuring in automatic mode is impossible.

In addition, the surface temperature of the boiler unit is not uniform, as shown by experimental studies, i.e. varies depending on the proximity to the burner location, the burner type and many other factors.

2. Analytical methods for determining heat losses from external cooling of the boiler unit surface

Heat losses from external cooling of the boiler surface, %, according to the literature [1, p. 71], are determined:

$$q_5 = \frac{Q_5}{Q_{p}},100,$$

where $Q_5$ – heat loss to the environment, kJ/m$^3$; $Q_{p}$ – fuel combustion heat, kJ/m$^3$.

For a hot-water boiler, according to [2, p. 45], the heat loss from the outer surface cooling, %, can also be determined by the formula:

$$q_5 = q_{5_{\text{nom}}} \frac{N_{\text{nom}}}{N} \cdot 100,$$

where $q_{5_{\text{nom}}}$ – the heat loss from the external cooling under a nominal boiler load, is a reference datum determined by [2, p. 50, table 4.6]; $N_{\text{nom}}$ – rated capacity of the boiler, MW; $N$ – calculated capacity of the boiler, MW.

The results of the study of literature data [1, 2] can be given in tabular form (table 1).

| $N_{\text{nom}}$, MW | 1  | 2  | 3  | 5  | 10 | 20 | 30 | 40 | 60 | 100 |
|----------------------|----|----|----|----|----|----|----|----|----|-----|
| $q_{5_{\text{nom}}}$ | 5  | 3  | 2  | 1.7| 1.5| 1.2| 1.0| 0.9 | 0.7 | 0.5 |

However, the table 1 data, according to the authors [1, 2, 4, 8], there is only indicative data. In addition, it doesn’t contain information on small-capacity boiler plants, i.e. power up to 1–2 MW. Such plants are widely used at present as heat sources in individual and low-rise construction.

By graphical dependencies (figure 1), given in the literature [6, Fig. P. 2], it is equally impossible to determine the optimum heat loss value for small-capacity boilers.
Therefore, summarizing all literature and reference data, it is possible to draw a conclusion on expediency of conducting experimental studies as the only possibility for exact value determination of required value of heat losses from external cooling of a boiler surface.

3. Experimental methods for studying the heat loss values from external cooling of the boiler surface

Studies of technical literature [1–20] showed the absence of any recommendations, not only analytical, but also experimental methods for determining the heat loss values from the external cooling of the boiler surface.

Comparative analysis of known investigation methods of thermal processes in thermal engineering equipment, focus on the method of heat loss determining $Q_5$ in the intensity of heat transfer by natural convection from the external surfaces of a boiler, W, using experimental studies:

$$Q_5 = F \cdot \alpha \cdot (t_t - t_n)$$

where $F$ – the area of the calculated boiler surface, m$^2$; $\alpha$ – heat transfer coefficient of the investigated surface, W/(m$^2$·°C); $t_t$ – boiler surface temperature, °C; $t_n$ – air temperature, °C.

The value $t_t$, °C, is determined by the in situ measurements results of the boiler surface temperature.

During the temperature measurements the external boiler surface is divided into parts on the boiler sides: front of boiler, left side surface, right side surface, rear surface, top surface and other surface. Thus, the total heat loss to the environment can be represented in the form:

$$Q_{total\ surface} = \left[ Q_{front\ surface} + Q_{left-side\ surface} + Q_{right-side\ surface} + Q_{rear\ surface} + Q_{top\ surface} + Q_{other\ surface} \right].$$

Each side of the boiler, in turn, is divided into small parts of a rectangular shape, the dimensions of which are selected from the conditions of the boiler geometry and a relatively uniform distribution of

\[\textbf{Figure 1. Heat losses from external cooling of the surface of the hot-water boiler [6, 8]}\]
Temperature on the surface site obtained in the preliminary measurements. Temperature measurements are carried out at several points of each rectangle.

The air temperature and the boiler surface temperature are determined by means of modern measuring devices: optical digital pyrometer or thermal imager. Almost all temperature measurements are carried out by non-contact method for thermal (infrared) radiation of the studied object.

Temperature measurement of the studied surface is carried out for all modes of operation of the boiler plant.

The average temperature of the outer surface on each side of the boiler is calculated by the formula:

\[
n_i = \frac{t_{n1} \cdot F_1 + t_{n2} \cdot F_2 + \ldots + t_{n_i} \cdot F_i}{F_n},
\]

where \( t_{n1}, t_{n2}, \ldots, t_{n_i} \) – the surface boiler temperature measured experimentally, °C; \( F_1, 2, \ldots, i \) – the area of rectangular areas on which the external surface of the boiler is divided, \( m^2 \).

The heat transfer coefficient is determined according to [10, 11], as the heat transfer coefficient from heated surfaces, \( W/(m^2 \cdot ^0C) \):

\[
\alpha = \alpha_n + \alpha_k,
\]

where \( \alpha_n \) – the heat transfer coefficient of radiant heat transfer, \( W/(m^2 \cdot ^0C) \); \( \alpha_k \) – the heat transfer coefficient of convective heat transfer, \( W/(m^2 \cdot ^0C) \).

\[
\alpha_n = c_{np} \cdot \left(\frac{273 + t_n}{100}\right)^4 \cdot \left(\frac{273 + t_B}{100}\right)^4 \cdot \frac{1}{t_n - t_B},
\]

\[
\alpha_k = a \cdot \sqrt{t_n - t_B},
\]

where \( c_{np} \) – is the added emissivity of the bodies located in the room, \( W/(m^2 \cdot K^4) \), according to [10, 11, 14, 15] \( c_{np} = 4.9 \) \( W/(m^2 \cdot K^4) \); \( a - a \) is the coefficient taken to the horizontal wall with the heat flow directed upwards – \( a_{horizontal \ surface} = 3.26 \); downward – \( a_{horizontal \ surface} = 1.28 \); for vertical wall – \( a_{vertical \ surface} = 2.56 \); for horizontally positioned pipe – 2.09.

**4. Analysis of the carried out research results**

Experimental studies were carried out on small-capacity hot-water boilers:
- «Energy-3», the rated thermal power is 0.78 MW;
- «NEVALUX 8230», the rated thermal power is 0.03 MW.

According to the experimental studies results of the required heat loss value \( q_s \), graphical dependencies were built (figure 2, 3), on the basis of which the analytical dependences are given in the polynomial equation form of the second degree.

The obtained values of \( q_s \), according to the experimental studies results, have significant differences from the values given in the literature data and from the values calculated by the known methods.

The difference in the obtained values ranges from 30 to 60%, which clearly shows the inability to focus only on the analytical studies results, as well as the relevance of the research.
Generalizing the obtained data, we present a formula for determining the heat loss value $q_s$ from the external cooling of the boiler surface, $\%$, in the form of:

$$q_s = 18.25N^2 - 27.379N + 12.245,$$

where $F$ is the area of the outer surface of the boiler, $m^2$; $N$ is the thermal capacity of the boiler, MW.

5. Conclusion
There is a need to clarify and supplement the reference data on the heat loss value from the external cooling of the boiler surface, to evaluate the efficiency of boiler equipment, as well as to develop
measures for energy saving for hot-water boilers located in the investigated range in terms of thermal power capacity. The obtained dependence for determining the value of \( q_5 \) allows to take into account the influence of not only thermal power, but also the size of the outer surface of the boiler plant, which is especially important at the present time with high demand for compact water heating units of small-capacity.

References
[1] Roddatis K F 1977 Boiler plants (Moscow: Energia) p. 432.
[2] Esterkin R I 1989 Boiler plants (Leningrad: Energoatomizdat) p. 280.
[3] Kuznetsov N V, Mitor V V, Dubovsky I V and Karasina E S Thermal calculation of boiler units (normative method) 1973 (Moscow: Energia) p. 296.
[4] Handbook of boiler plants of low productivity / edited by K F Roddatis 1989 (Moscow: Energoatomizdat) p. 488.
[5] Shumilin E V and Psarov S A 2013 Thermal calculation of boiler: practicum (Khabarovsk: publishing house of Pacific State University) p. 78.
[6] Lummi A P and Munz B A 2009 Calculation of the hot-water boiler (Yekaterinburg: SEI HVE USTU–UPI) p. 41.
[7] Delyagin G I, Lebedev V I and Permyakov B A 1986 Heat-Generating plants (Moscow: Energoatomizdat) p. 586.
[8] Styrikovich V A 1959 Boiler units (Moscow – Leningrad: Gosenergoizdat) p. 487.
[9] Lumme A P, Filippovsky N F and Cherepanov E V 2006 Calculation of boiler (Yekaterinburg: publishing house «Vremya», risograph USTU–UPI) p. 50.
[10] Torgovnikov B M, Tabachnik V E and Efianov E M 1983 Design of industrial ventilation: a Reference book (Kiev: Budivelnik) p. 256.
[11] Biryuzova E A 2004 Improving the burning of natural gas for heating cast iron sectional boilers with horizontally-slotted (bottom) burners: the dissertation for the degree of PhD of Technical Sciences (St. Petersburg: SPSUACE) p. 265.
[12] Nefedova M A 2017 Energy-Saving technologies in the operation of small-capacity boilers: the dissertation for the degree of PhD of Technical Sciences (St. Petersburg: SPSUACE) p. 168.
[13] Preobrazhensky V P 1978 Heat engineering measurements and devices (Moscow: Energia) p. 660.
[14] Biryuzova E A and Lomakina L S 2010 Methods of experimental studies of heat and gas supply systems (St. Petersburg: SPSUACE) p. 426.
[15] Shkarovsky A L and Biryuzova E A 2014 Devices and equipment of construction laboratories. Instruments and methods of operational research and testing (St. Petersburg: Publishing house of Polytechnic University) p. 119.
[16] Nefedova M A, Biryuzova E A and Mostafa Fazlavi 2017 Low pressure injection burner: the patent for the invention №2618137, Russian Federation; IPC F23D 14/10 (2006.01) / publ. 02.05.2017, Bulletin № 13
[17] Ravich M B 1966 Simplified method of heat engineering calculations (Moscow: Nauka) p. 415.
[18] Staskevich N L, Severinec G N and Vigdorchik D YA 1990 Handbook on supply and use of gas (Leningrad: Nedra) p. 762.
[19] Biryuzova E A, Pushchina E A and SHmigirilov V A 2015 Operation of thermal power plants (St. Petersburg: SPSUACE, Center of labor protection, industrial safety, social partnership and professional education) p. 258.
[20] Volikov A N 2006 Thermal calculation of steam and hot-water boilers (St. Petersburg: SPSUACE) p. 130.