Journal of Physics: Conference Series

PAPER • **OPEN ACCESS**

Fire-tube boiler optimization criteria and efficiency indicators rational values defining

To cite this article: P A Batrakov *et al* 2018 *J. Phys.: Conf. Ser.* **944** 012009

Fire-tube boiler optimization criteria and efficiency indicators rational values defining

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Abstract. Technical and economic calculations problems solving with the aim of identifying the opportunity to recommend the project for industrial implementation are represented in the paper. One of the main determining factors impacting boiler energy efficiency is the exhaust gases temperature, as well as the furnace volume thermal stress. Fire-tube boilers with different types of furnaces are considered in the study. The fullest analysis of the boiler performance thermal and technical indicators for the following engineering problem: Q=idem, M=idem and evaluation according to η, B is presented. The furnace with the finned ellipse profile application results in the fuel consumption decrease due to a more efficient heat exchange surface of the furnace compared to other examined ones.

1. Introduction

Energy efficiency is the efficient use of energy resources. The purposes of energy efficiency are the resources saving, efficient energy consumption, fuel costs reduction, performance improving [1]. The Russian Federation is the world's third largest energy consumer and its economy has a high level of energy intensity [2]. Therefore, energy efficiency and energy saving are included in the five strategic areas of the Russian Federation prioritized technological development. Taking this into account, when using the efficient heat exchange surfaces, in improving the low and medium power fire-tube boiler furnace design it is necessary to obtain the technical and economic calculations results making it possible to recommend the given project for industrial implementation.

2. Problem statement

Optimization problem formulation includes several stages: optimality criterion selecting, optimized parameters selecting, necessary limits applying and objective optimization function recording.
The most common optimization criteria are the economic and technological performance indicators.
The fire-tube boiler mass and size and performance characteristics optimization problem is possible to be recorded as follows:

$$f\,(T_{ex}, q_v) \rightarrow \max;$$
$$390\text{ K} \le T_{ex} \le 400\text{ K};$$
$$250\text{ kW/m}^3 \le q_v \le 1100\text{ kW/m}^3$$

where T_{ex} is the exhaust gases temperature; q_v is the furnace volume thermal stress.
One of the main factors impacting the heat loss with exhaust gases is the temperature T_{ex}. For decreasing T_{ex} the heating surface area is increased. T_{ex} value influences not only the unit efficiency but also the capital costs required for additional heat exchange equipment installation. Tex reduction

leads to the efficiency increase, fuel consumption and costs decrease. However, in this case the heating surface areas are increased (at the low temperature difference the heat exchange surface area is necessary to be increased), consequently, the installation and operating costs are increased. Therefore, for the newly projected boiler units or other heat consuming systems T_{ex} value is defined according to the technical and economic calculation in which Tex influence not only over the efficiency but also over the capital and operating costs value is taken into account. State-of-the-art boiler units using gaseous fuel have Tex from 390 to 400 K.

The value $q_v = Q/VT$ represents the heat amount released at the fuel certain quantity combustion per time unit and accounted for 1 m^3 of the furnace volume. If the value qv does not range the limits defined practically, fuel is not cleanly burnt for the period it is in the furnace. The boiler units operating experience has shown that for the different kinds of fuel, combustion methods and furnaces designs, the accepted value qv varies over a wide range. For the low and medium power fire-tube boiler using the gaseous fuel, qv varies from 250 to 1100 kW/m^3.

Further the gradient projection method as the descent method variation is considered. The algorithm described below is intended to solve the following problems:

$$\text{Min } f(x),$$
$$\varphi_i (x) \leq 0. \ I = 1. \dots, m,$$
$$\varphi_i (x) = 0. \ I = m+ 1. \dots, l,$$

where f, φ_i are the continuously differentiable functions and the given algorithm is the direct generalization of the steepest descent method. The operation principle of both methods is the same – to trend towards the minimized function speediest decrease. Only in the steepest descent method searching for the absolute minimum this direction is antigradient, while in the gradient projection method solving the conditional minimization problems it is defined taking into account the restrictions and results from the orthogonal antigradient projecting for the particular linear variety. The last approximates the acceptable area boundary part in parallel to which the ordinary iteration step will be taken. Generally, as the boundary is nonlinear this step will get out of the feasible set even if the initial point belongs to it. Thus, in the gradient projection method the movement along infeasible points is possible. However, the restrictions violation level is strictly controlled and keeps low by means of the steps lengths correcting and limiting.

3. Theory

For comparing the heat exchange surfaces, the following values as: heat quantity Q transferred through the surface, fuel consumption B, mass M are pointed out as the main characteristics.

To solve the problem where fire-tube boilers with different types of furnaces and varying mass are considered [3], the heating surface cannot absolutely be a criterion to evaluate the compared variants. Accordingly, the following formulation of the technical problems main types is proposed:

1. Q = idem, M = idem – evaluation by η, B.
2. Q = idem, B = idem – evaluation by M.
3. B = idem, M = idem – evaluation by η, Q.
4. Q = idem, F = idem – evaluation by η, B, M.
5. B = idem, F = idem – evaluation by η, Q, M,

Where Q is the heat quantity transferred through the surface, M is the fire-tube boiler mass, η is the fire-tube gross efficiency, B is the fuel consumption, V is all the boiler design volume, F is the cross-sectional area.

The fullest analysis of the fire-tube boiler performance thermal and technical indicators is possible in solving the following engineering problem:

By maintaining the fixed heat exchange surface area of the furnace section and boiler as a whole (Q = idem, M = idem – evaluation by η, B).

The transfer from the circle profile to the ellipse and finned ellipse ones at the exhaust gases recommended temperature constant interval corresponds to the fuel consumption reduction approximately by 1.1 m^3/hr due to the more efficient heat exchange surface of the finned ellipse profile furnace compared to other considered variants (Fig. 1) where points indicate the boilers operation nominal characteristics.

The transfer from the circle profile to the ellipse and finned ellipse ones results in the furnace volume reduction and at the furnace recommended thermal stresses constant interval corresponds to the fuel consumption decrease approximately by 15–17 Nov. 20161.1 m^3/h (Fig. 2) in the exhaust gases specified temperature range.

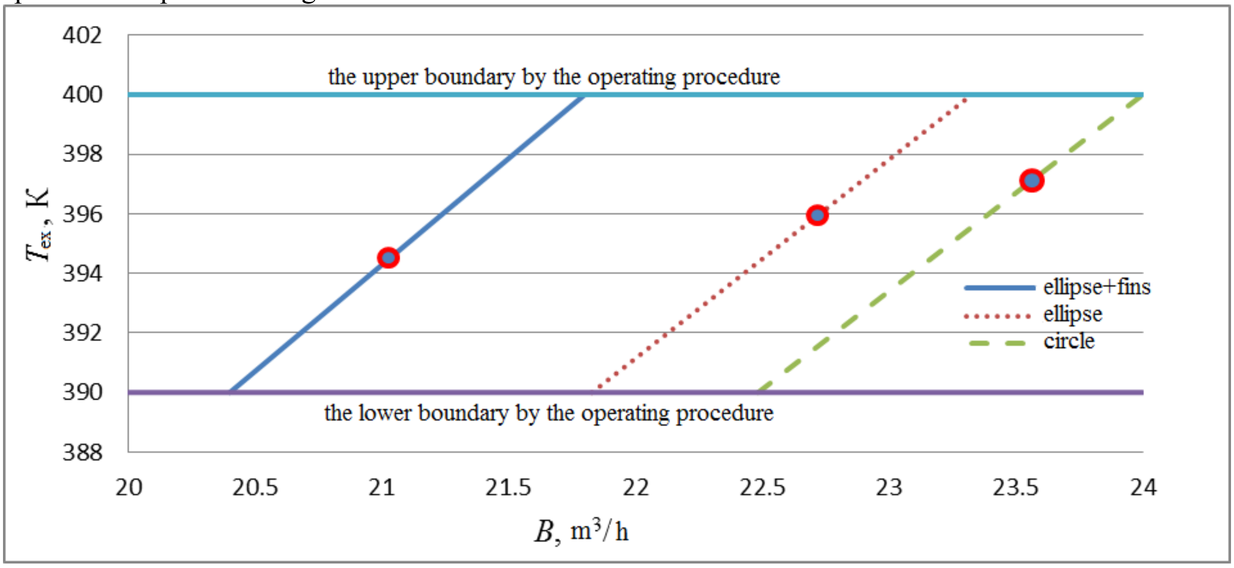

Figure 1. The exhaust gases temperature dependence on the fuel consumption.

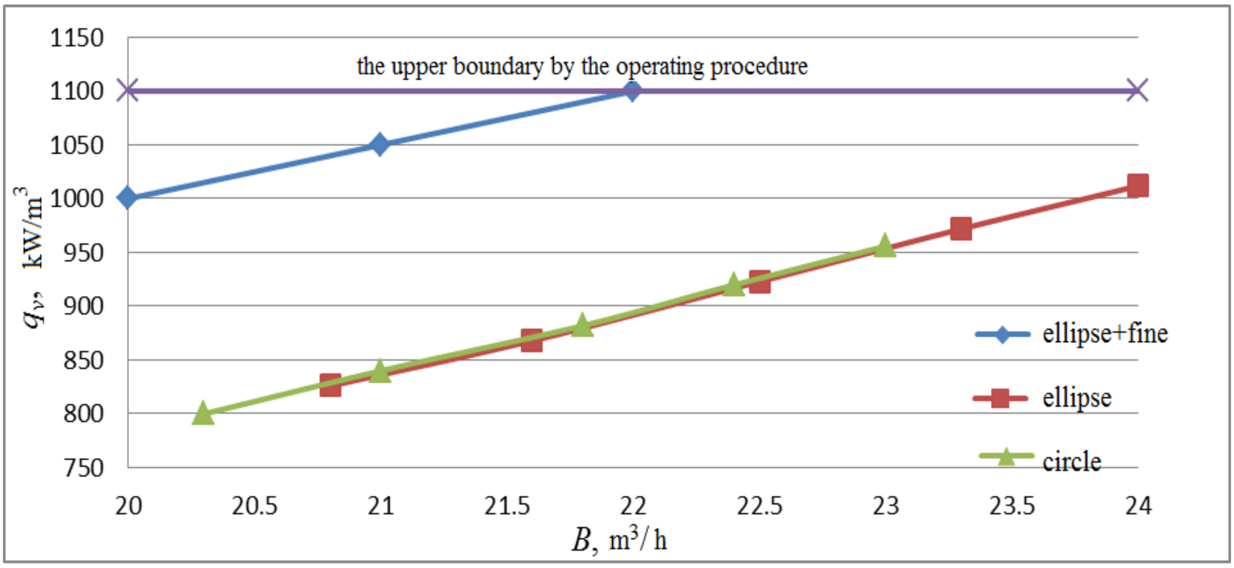

Figure 2. The furnace volume thermal stress dependence on the fuel consumption.

According to Fig. 3 one can define the area which includes the function maximum $\eta = f(a/b, \delta)$, where a/b is the minor and major semiaxes lengths ratio, δ is the finning coefficient that corresponds to $\eta = 0.95$, $a/b \approx 1.3$ and $\delta \approx 1.32$ when meeting the conditions: $1.0 \leq a/b \leq 1.5$; $1.0 \leq \delta \leq 1.4$; $390 \leq Tex \leq 400$ K; $250 \leq qv \leq 1100$ kW/m^3.

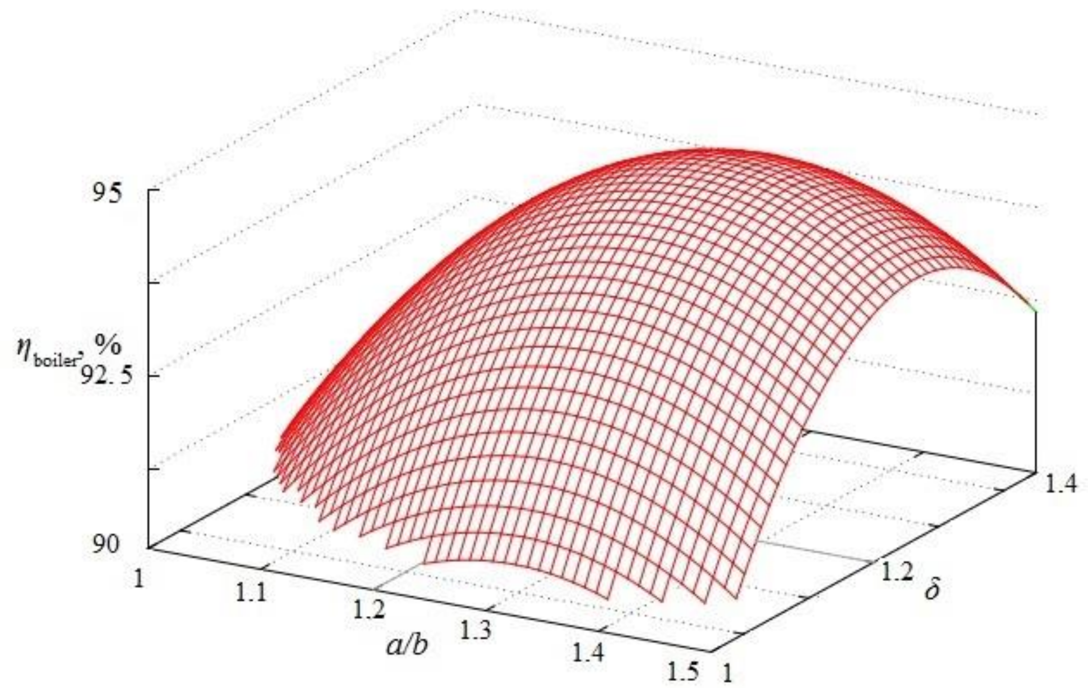

Figure 3. The calculation dependences for η = f (a/b, δ).

According to Fig. 4 one can define the area which includes the function maximum B = f (a/b, δ), that corresponds to B = 21.6 m^3/h, a/b ≈ 1.3 and δ ≈ 1.32 when meeting the conditions: 1.0 ≤ a/b ≤ 1.5; 1.0 ≤ δ ≤ 1.4; 390 ≤ T_{ex} ≤ 400 K; 250 ≤ qv ≤ 1100 kW/m^3.

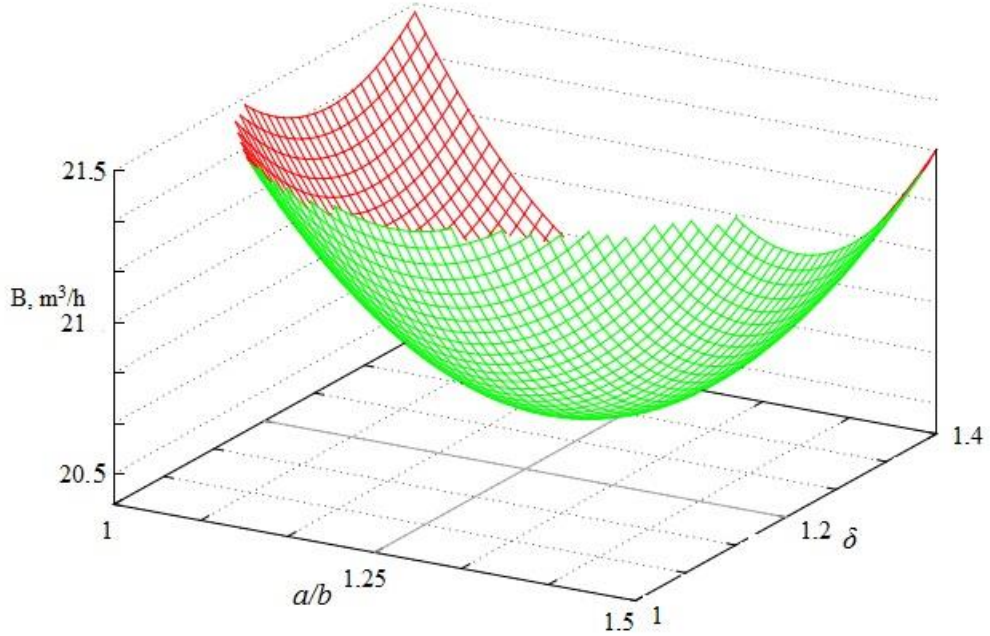

Figure 4. The calculation dependences for B = f (a/b, δ).

IOP Conf. Series: Journal of Physics: Conf. Series **944** (2018) 012009 doi:10.1088/1742-6596/944/1/012009

4. Conclusion

Thus, the general range of maximum values for gross efficiency η calculated by the descent method is possible to be pointed out. The range of minimum values for gas consumption B was defined according to the same method. Moreover, in both cases maximum, minimum values of these thermal and technical characteristics correspond to $a/b \approx 1.3$ and $\delta \approx 1.32$.

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