

Researches of air and fuel rate influence on oxygen level in emissions of new type medium power coal boiler

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Abstract. The article deals with sustained fire coal boilers requirements engineering from a creating energy saving and ecological compatibility point of view. The article gives experimental data obtained on boilers which was made by LLP «Карплаз», Karaganda, Republic of Kazakhstan.

1. Introduction

The research executed for high-power ecologically clean boilers requirements engineering and their certification paths. This research build upon usage of data obtained at LLP «Карплаз» which produce boilers of varying power for years. A coal has one major asset - it is domestic and as a result it is accessible and inexpensive.

Coal boiler is single acceptable alternative for heating. Coal has much the largest caloric power, is easy-to-use, and one coal load provides more long combustion period than wood or charcoal.

Conventional coal boilers require manual fuel load, they have fairly low efficiency and high level of carbon formation thereby flue needed to inspect and clean frequently. Air inflows bottom-up in natural way and fire bars are at the bottom of construction.

Introduction to prospective legislation of best available technology concept corresponds to accepted ecological legislation of EU countries approach to pollutant emission limitation from CHP. Republic of Kazakhstan ecological legislation harmonization with EU countries legislation is a development strategic direction of national legislation

If we focus on European legislation which enact employment of the best available technologies, then we can direct attention to gradual but significant reduction negative impact of heating enterprise pollutant emission on the atmosphere.

Regulation activity of emission reduction from organic fuel consumption installations performed in accordance with EU directives [1–3] by emission limitation of specific pollutant. These directives contain standards pollutants limit concentration into boiler plants flue gases emitted to atmosphere. For fulfill the regulatory requirements technologies (methods) included BAT references are used.

Therefore establishment of regulatory standards for specific pollutant emission from boiler plants is intended to phase reduce negative impact of CHP-plant to the atmosphere considering affordability and economic efficiency of BAT adoption [4], which provides these standards.



For example, according to Directive 2001/80/EC [2] sulfur dioxide (SO₂) limiting concentration is taken to be 2000 mg/m³ under normal conditions for existing boiler plants burning solid fuel with heating rating up to 100 MW, linear decrease is from 2000 to 400 mg/m³ under normal conditions for boiler plants with heating rating 100-500 MW.. Both factors - affordability and economic efficiency are taken into account in this case.

It is clear that engineering solution for SO₂ capturing have already been developed for low-power plants by that time. But with limited means to reduce sulfur dioxide emissions it is reasonable to equip by sulfur absorb plants large boiler plants first of all, where gross emissions reduction per unit of invested funds much greater.

Consequently, in accepting of Directive 2001/80/EC drastic reduction of CHP-plant negative impact was economically impractical with limited funds, because slight decline of gross emission at low power boiler plants demand for more costs.

The BAT concept in the EU as complex prevention and control of environmental pollution caused by anthropogenic activities provided by directives [5, 6] consider possible economic expenditures and environmental gains resulting from the implementation of BAT.

Fee collection for environmental pollution is kind of form of economic damage recompense that compensates impact of pollutants emission into the environment [7]. But at the present time in the Republic of Kazakhstan standard fee rates for emissions into the atmosphere of pollutants are such that in very rare cases emission fee will be greater than economic expenditures for introduction of new technologies and gas-cleaning equipment.

Despite the continuous technological development, which makes BAT precise definition difficult, it is still possible to choose the best technology among all available during relatively short period, which has been done in European BAT reference books. However, in order for determine the best technology in specific practical conditions criteria that depend on subjective decisions are necessary.

2. Research

Existing condition analysis of boiler plants burning coal, gas, fuel oil shows a large setting range of pollutant specific emission. These differences may result from main factors influence with boiler plant operation:

- boiler capacity;
- boiler operating life (and thus their technical condition);
- burn fuel structure;
- burn fuel quality;
- variety of implemented measures scope to suppress nitrogen oxide formation (or their absence);
- ARU technical condition and level of gas removal in them.

Specific emissions of harmful substances into the atmosphere from boiler plants must be control in order to audit of compliance with approved regulatory standards of specific emissions [8].

Specific emissions of i-th substance can be determined per unit input heat in firebox (g / MJ) or per ton of equivalent fuel (kg / ton of equivalent fuel) or evaluate as the concentration of this substance in 1 m³ of fire gases under normal conditions and excess air coefficient $\alpha = 1.4$.

Specific emission standards for boiler plants are set for the following pollutants: nitrogen oxides (in terms of NO₂), sulfur dioxide, carbon monoxide, solid fuel ash.

Sulfur dioxide, nitrogen oxides and carbon oxides concentration is determined against the dry gases volume which is equivalent of measurements conditions of these substances by instrumental methods. Nitrogen oxides (NO_x) are calculated in terms of nitrogen dioxide (NO₂).

Specific mass pollutant emission into the atmosphere per unit of thermal energy input in firebox (g / MJ), mass pollutant emission per 1 ton of equivalent fuel is define as main regulatory limit.

Mass concentration of pollutant in flue gases released into the atmosphere in mg / m³ (at a temperature of 0 °C, a pressure of 101.3 kPa and $\alpha = 1.4$) is taken as a derived quantity.

Specific emission of i-th substance (n) in grams per megajoule, per unit heat input in firebox is determined by equation (1):

$$n = \frac{M_i}{BQ_i^r} \quad (1)$$

where M_i – emission value in grams per unit time (g/s, g/h, t/year); B – fuel rate for the same unit of time (kg/s, kg/h, kg/year, for gaseous fuel - m³/s, m³/h, m³/year); Q_i^r – lower fuel calorific power, MJ / kg (for gaseous fuels – MJ / m³).

Specific emission of i -th substance (m) in kilograms per ton of equivalent fuel or in grams per kilogram of equivalent fuel is determined by the equation:

$$m = n Q_{eq. fuel}, \quad (2)$$

where $Q_{eq. fuel}$ – equivalent fuel calorific power, equal to 29.33 MJ / kg.

The concentration of the i -th pollutant substance in fire gases (μ) in milligrams per cubic meter emitted into the atmosphere corresponding to specific index n is determined by formula (3):

$$\mu = n \frac{Q_i^r}{V_r} \quad (3)$$

where V_r – fire gases volume under normal conditions in m³ / kg (m³/m³ for gaseous fuels) and $\alpha=1.4$.

At determining of sulfur oxides, nitrogen oxides and carbon monoxide concentration in milligrams per cubic meter dry gases volume is substituted into equation (3).

Specific emission regulatory standard at co-incineration of several fuels in boiler is defined as weighted mean value (4):

$$n_{cp} = \frac{\sum_{i=1}^n n_i \cdot B_i}{\sum_{i=1}^n B_i}, \quad (4)$$

where n_i – specific emission when operating on the i -th fuel, g / MJ; B_i – i -th fuel rate, g/s (g/year); $\sum_{i=1}^n B_i$ – total fuel rate per boiler, g/s (g/year).

Carbon monoxide maximum emission from the boiler is determined by the equation (5):

$$M_{CO} = \mu_{CO} \cdot \sum (V_{cri} \cdot B_i) \cdot 10^{-3}, \text{ g/s} \quad (5)$$

where μ_{CO} – measured carbon monoxide concentration in boiler exhaust gas at its maximum load when i -th fuel (or fuel mixture) burning, mg / m under normal conditions [9 –11].

The specific emissions values per unit of heat input in firebox per unit of burning equivalent fuel or per unit of emitted fire gases volume are specific emissions actual values corresponding to regulatory standard of maximum emission (MPE, g/s). Specific emissions actual values reflect attained level of boilers operation under projected burden at the winter maximum, take into account effect of previously implemented measures and represent pollutants specific emissions from these boilers that can be provided by current equipment operating and electricity and heat generating. These indicators are working tool for pollutants emissions control.

At switching to technological regulatory actions situation may arise when specific emissions actual values for many boiler plants exceed the established standards for boiler plants specific emissions.

Modern coal-fired boilers use technology that increases duration of heat carrier combustion which guarantees its full-fledged use. Figures 1–3 show a 300 kW boiler that has been tested at the coal mining enterprise of « Rapid » LLP. The boiler had a bunker for 1000 kg of coal, coal screw feeding (Figure 2). The air is fed by a fan at the screw feeder mouth. Coal feed rate and air flow rate are controlled by digital hand controls on the control panel.



Figure 1. Exterior of boiler with screw feed for 300 kW. Established at LLP «Rapid».



Figure 2. Boiler side-view - auger feeder for coal feed from a bunker.



Figure 3. Firebox and screw exterior.

Following parameters were controlled:

- coal feed rate control;
- circulation rate;
- boiler jacket water temperature, on the feed and on the return;
- hot gases temperature at outlet from the boiler;
- outside air temperature;
- O₂ and CO₂ level in outgoing gases.

Testing purpose was the possibility of using this boilers type for reasons of energy saving and ecological compatibility. During the tests was established following:

- coal feed rate and circulation rate should be selected for each type of coal, otherwise the firebox is damped either from an excess of coal (the coal does not burn out poured) or from the excess air that blows the furnace;

- furnace is not suitable for long-term use, so the constant presence of a human being is required.

Portable gas analyzer Optima 7 was used as a control device for analysis of smoke and process gases, as well as for repugnant substance emissions control. It measures up to 7 gases simultaneously. This gas analyzer is ideally suited for boilers and turbines adjustment and control, and for ecological monitoring [12, 13].

Table 1. Controlled parameters.

Parameters	Measurement range
O ₂	0...21 %
CO (H ₂)	0 ... 4000 ppm short-term measurement up to 10000 ppm
CO low	0 ... 300 ppm
CO high	0 ... 4000 ppm
CO very high	0 ... 4,00% maximum up to 10%
NO	0 ... 1000 ppm
NO low	0 ... 300 ppm
NO ₂	0 ... 200 ppm maximum up to 1000 ppm
SO ₂	0 ... 2000 ppm maximum up to 5000 ppm
T _{gas}	0 ... 650 °C
T _{env.air}	0... 100 °C
Draft / depression	-5 ... +35 hPa

3. Results and considerations

Table 2 shows measurements results in two modes - heating and temperature maintenance.

Table 2. Measurements results at heating and temperature maintenance modes

	40	60	80	100	120	143	147	133	122	110	94	115
T _{pipe} , °C	40	60	80	100	120	143	147	133	122	110	94	115
T _{water} , °C	11	13	15	19	23	30	45	55	60	57	51	54
O ₂ , %	20.8	19	14.2	11.8	8.4	3.5	3.6	3.8	4.7	6	7.5	6.6
t, min	5	15	23	25	37	45	66	78	95	115	140	169
Note	Heating mode						Temperature maintenance mode					

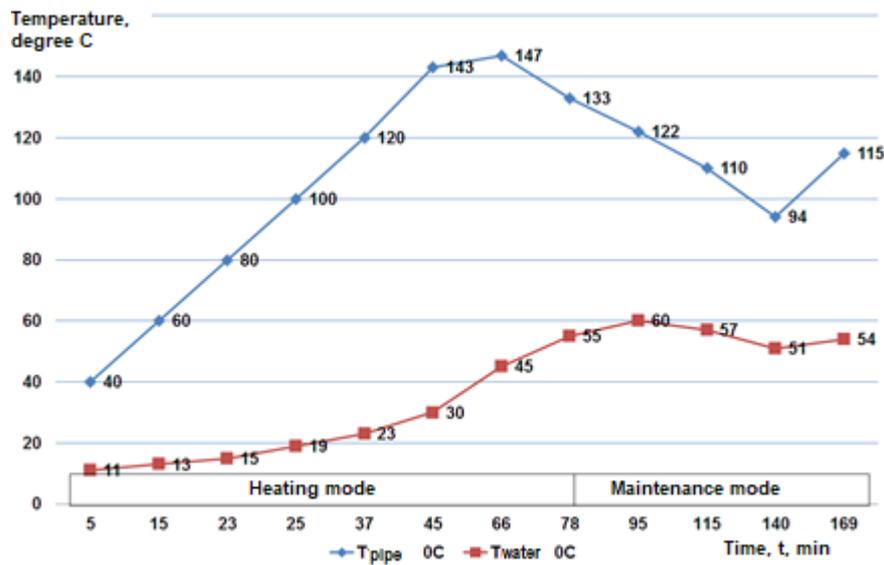


Figure 4. Schedule of boiler bringing into operation mode.

At performance and functional ability monitoring of complex dynamic objects represented by ensemble of a controlled object and an automatic control device, selection of controlled quantity and their normal values can be performed by analyzing differential equations describing the behavior of the system. In this analysis, of course, system purpose and criteria for evaluation its behavior are taken into account. Therefore, for automatically controlled objects, zones of normal values of quantities are often determined from requirement to maintain stability of standard conditions.

Controlled quantities selection can also be carried out in such a way as to satisfy specified control adequacy, time or cost criteria, etc.

Presence of measurement instrumentation imprecision leads to specific errors characterizing measurement quality.

There are errors of first kind which determine probability of assigning suitable control objects to unusable (not within the normal limits), and errors of second kind in the presence of which the unsuitable products are classified as suitable (within the normal limits).

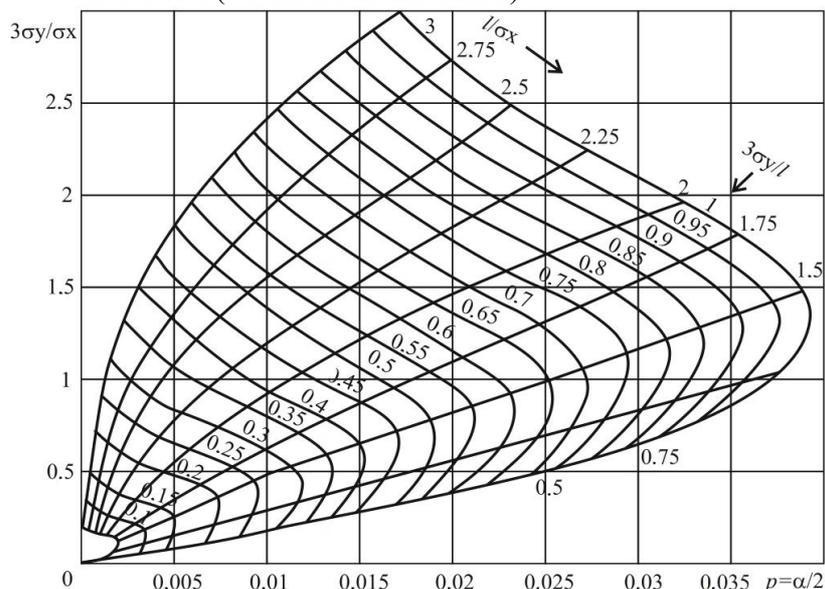


Figure 5. Errors of first kind probability, (vendor risk).

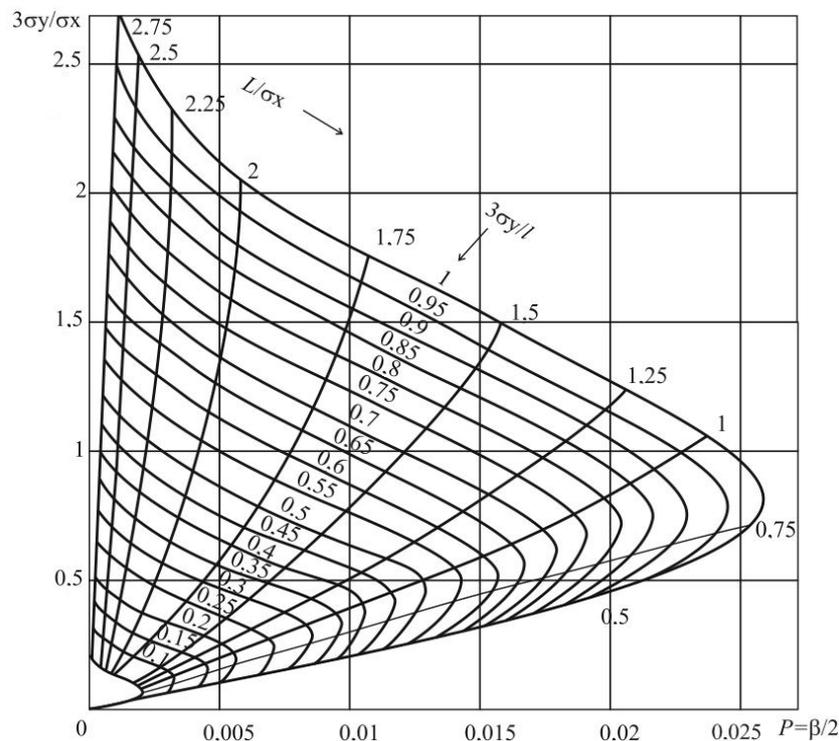


Figure 6. Probability of errors of second kind (buyer risk).

Ensured permitted allowance are used to drastic decrease in errors of second kind. This means that the tolerance zone c_u, c_l is narrowed to a size at which β becomes negligibly small. Obviously, this should increase errors of first kind. To ensure that the errors do not exceed the set value, it is necessary to ensure a determined precision of monitoring device [14,15].

Figure 6 shows a nomogram that allows to estimate necessary accuracy of the monitoring device if the tolerance zone is reduced by $3\sigma_y$, i.e., equal to $l-3\sigma_y$, errors of first kind α ratio of tolerance zone to mean square deviation of the controlled quantity are set.

Maximum error value of second kind does not exceed 10^{-4} for variation range in the accuracy characteristic of controlling device $3\sigma_y/l$ presented on nomogram. It is necessary to improve significantly standard accuracy to ensure that error of the first kind is no greater than at non-guaranteed error. Thus for $\alpha+\beta=0,04$, $l/\sigma_x=2,5$ at non-guaranteed tolerance zone $3\sigma_y/l \approx 0,87$ (refer to nomogram at Figure 5), and for guaranteed tolerance zone $[l-3\sigma_y]$ at $\alpha=0,04$, $\beta=0,0001$, $l/\sigma_x=2,5$ device accuracy can be estimated by expression $3\sigma_y/l \approx 0,3$.

Therefore, control error check is necessary during the measurement procedure. It is desirable to take measures taking into account control errors of first and second kind. So as to exclude errors of the second kind, that is to not let devices that have metrological characteristics not corresponding to the normal ones specified in documentation be sent to consumer.

In our case, it is required to provide specified accuracy ratio of ordinary measuring instrument and required accuracy of control parameter. It is required to determine the errors of first and second kind.

Having set accuracy ratio, we define errors of first kind in the nomogram in Figure 5.

Accuracy ratio comes out of ratio from 1: 5 to 1: 3, we choose the average ratio of 1:4.

We will calculate tolerance zone value of normalized controlled parameter of 180 mgm.

Symmetric tolerance zone l of coordinate measuring Y of harmful impurities detected content, mgm, not more than for converter with nominal value and normal conditions - temperature 0°C and pressure 101.3 kPa:

0°(when Y value is located in the range from 5 to 180 mgm) -

$$l = \pm(0.5 + 0.01Y)$$

from 40° up to 70° (when Y value is located in the range from 5 to 50 mgm) -

$$l_z = \pm(2 + 0.03Z)$$

$$l_y = \pm(2 + 0.03Y)$$

Under normal law of distribution of controlled quantity and specified probability 0,95 mean square deviation of the controlled parameter (6).

$$\sigma_x = l/h \quad (6)$$

Student's coefficient can be approximately set to 2, it follows that (7)

$$\sigma_x = 1.15 \quad (7)$$

and at ratio of 1:4, selected mean square deviation of standard (8), (9)

$$\sigma_y = \sigma_x/4 \quad (8)$$

$$\sigma_y = 1.15/4 \approx 0,3 \quad (9)$$

To calculate errors of first and second kind probability it is necessary to calculate the relation (10)

$$\frac{3\sigma_y}{l} = \frac{3 * 0.3}{2.3} = 0.39 \quad (10)$$

And according to the nomograms 1 2 in Fig. 1 we find errors of first and second kind

$$\alpha = 0.02$$

$$\beta = 0.007.$$

Similarly, we find that errors of first and second kind at all points have the same values.

4. Conclusions

It is necessary to ensure firebox automatic ignition at reduction of gas temperature in the pipe or at O₂ increase.

There is a need to take certification work to confirm produced power and ecological cleanness of entrained emissions at high-power boilers manufacturers. There are two ways to control this:

- test operation at special stationary stand;
- tests on mobile calibration outfit.

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