International Journal of Energy and Environmental Engineering
ISSN: 2008-9163
Vol.2 / No.1 (pp.63- 67) / Winter 2011

IJEEE

Technical note:

Fuel combustion optimizing by regulated level of chemical underburn

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Received Date: 14 Jan.; 2011 Accepted: 9 Feb.; 2011

ABSTRACT

Variety of energy–ecology optimizing means that optimum result of fuel combustion is focused not only on the direct efficiency of its usage but also on minimum environmental damage. Best possible fuel combustion connected with controlled level of chemical underburn is considered to be one of the simpliest, cheapest and the most effective methods of optimizing. It is essential to notice that the meaning of common statement that minimum underburn responds to maximum efficiency of fuel combustion in boilers is undoubtedly incorrect. Radiation as well as convection heat reclaiming by screen surfaces surrounding boiler's firing depend on (in a very complicated way) various features: form, size, flames shining, location of maximum temperatures area and also on the shape of firing space aerodynamics.[2] Standardized balance boiler's tests show that maximum efficiency can be mentioned with highly noticeable chemical underburn responding to concentration 0,02 – 0,03 % level of volume (200–300ppm). What is more, nitrogen oxide, which originates in maximum temperature (with lack of underburn), is 35 times more toxic than carbon monoxide. It can be supposed that defining the permissible level of chemical underburn is a typical optimizing issue due to minimize the destination function. The issue should be resolved individually in every specific area of boiler's adjustment, with accounting such features as precise characteristics and details of firing – boiling set. That is why the optimizing issue is recognized to be really complicated and complex. To simplify and unify the issue, ecological and economical fuel combustion criteria were proposed as well as general energy–ecology criterion, which is simultaneously the searched destination function. Results of such research on boilers have shown that optimum combustion operation takes place within carbon monoxide concentration of 200–400 ppm. Automatic regulation of chemical combustion on such level results in a constant utilizing energy–ecology effect.

Keywords

Optimization, combustion, chemical underburn, boiler, flue gases analyzer

1.Introduction

Working for many years on theory and practice of effective and environment friendly fuel co bustion, authors constantly promote a principle of energy– ecological optimization [1].

Such approach means that optimum result of fuel combustion is qualified not only by direct efficiency of fuel consumption but also by minimal damage made to people and natural environment [2].

One of the simplest, cheapest and at the same time highly effective ways of such optimization is burning of fuel in a zone of controllable, remnant chemical underburn (RCU) [3]. This may sound paradoxical for many specialists. Most of

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boiler operation specialists are used to obey the unquestionable rule: products of non complete fuel combustion, especially when burning gas fuel, shall not be present in flue gases. This publication is intended to evaluate this question from energy-ecological optimization point of view, that is optimization regarding fuel savings as well as environment protection.

1.2. Idea Of Controllable Chemical Underburn

Usually concentration of incomplete combustion products in flue gases (CO, H_2 and CH_4) is considered as quantitative measure of chemical underburn. This factor determines a heat loss due to underburn (value $\boldsymbol{q}_3$ in a heat balance of boiler unit). Traditional (for saving fuel) requirement of the total lack of chemical underburn products in flue gases is explained with eagerness for reducing $\boldsymbol{q}_3$.

According to many years of boiler set up practice, in flue gases only traces of incomplete combustion products are permissible, what corresponds with CO concentration of 30÷50 mg/m^3. In the branch publications it is recommended to arrange combustion with the air excess factor ($\boldsymbol{\alpha}$) higher about 0,03÷0,04 than "critical" value (with some allowance for potential variation of factors that affect completeness of combustion). Just appearance of underburn products [4] in flue gases is considered to be the critical value.

Results of extensive research made by authors' team evidence good reasoned possibility, both for economical and ecological reasons, of increasing maximum permissible level of carbon monoxide concentration while burning earth gas in boilers equipped with blow-in turbulent burners.

Let's first consider incorrectness of the statement, which seems to be obviously true, that minimal underburn corresponds with maximum efficiency of fuel consumption in boilers. Both, radiation and convection ways of heat receiving by waterwalls surrounding boilers furnace in a complicated way depends on many factors: shape, dimensions and luminosity of the flame, location of maximum temperature zones and the overall aerodynamics of the furnace space. Considerable influence of electricity consumption for driving fans and exhaust of flue gases on general energetic efficiency of a boiler shall also be kept in mind. in Standard balance trials of a boiler show, that its maximum efficiency is noted at highly perceptible chemical underburn, corresponding with CO concentration in flue gases reaching 0,02÷0,03% vol. (200÷300 ppm, or 250÷375 mg/m^3).

Even more logical is "moving" the burning mode to the zone of chemical underburn due to minimal ecological detriment. It is enough to remind that nitrogen oxides (NOx) the most intensively generated in maximal temperature, that is at the lack of underburn, are substances about 35 times more toxic than carbon monoxide, because such is a relation of maximum permissible concentration of both these substances in inhaled air (respectively 0,085 and 3,0 mg/m^3).

The above circumstances show clearly that determination of permissible level of chemical underburn is typical optimization issue that aims to minimize some target function. Complicated character if this issue consists in necessity of its individual solving in each case of set up the boiler, considering characteristics and details of all accompanying appliances of the complete furnace – boiler unit.

1.3. Criterion Form Of Fuel Combustion Optimization Issue

Different approaches to determination of the mentioned goal function are possible. Aiming to define the simplest optimum criterion of a furnace process following were applied:

- as the characteristic of combustion environment friendliness– coefficient of flue gases toxicity $\boldsymbol{G_{sp}}$ (converted into NO_x, according to I. Y. Sigal [5]);
- as the ration of the fuel consumption efficiency– balance efficiency of the boiler unit (gross) $\boldsymbol{\eta_{br}}$.

At the same time toxicity coefficient was determined on the basis of CO, NOx and 3,4-benzopyrone concentration in flue gases, while efficiency– according to standard method of boiler balance tests [4].

Aiming to unify these coefficients following equations of ecological ($\boldsymbol{A}_1$) and economical ($\boldsymbol{A}_2$) criteria representing relative change of above selected characteristic parameters:

$$A_1 = \frac{G_{sp} - G_{sp}^{\min}}{G_{sp}^{\max} - G_{sp}^{\min}}; \qquad (1)$$

$$A_2 = \frac{\eta_{\text{br}}^{\max} - \eta_{\text{br}}}{\eta_{\text{br}}^{\max} - \eta_{\text{br}}^{\min}}$$ where:

G_{sp} i η_{br} - current values of parameters, according to which, ecologicalness and efficiency of combustion process is evaluated;

$G_{sp}^{\min}, G_{sp}^{\max}, \eta_{\text{br}}^{\min}, \eta_{\text{br}}^{\max}$ – minimal and maximum of possible (registered during all trials) values of respective factors in considered variation range of coefficient values.

It was logical to apply the sum of above both criteria as generalised energy–ecological criterion (***A***), which is the target function, looked for:

$$A = A_1 + A_2 \qquad (2)$$

$A = A_1 + A_2$ (2)

Equation (1) shows, that values of criteria A_1 and A_2 are within the range from 0,0 (the best possible combustion mode) up to 1,0 (the worst recorded mode). Value of criterion ***A***, according to equation (2) may vary from 0,0 (when energetic and ecologic optimum are in line) up to 2,0 (the most unfavourable case when the worst modes of boiler operation, both regarding energy saving as well as environment protection, are in line).

1.4. Test Conditions And The Study Methodology

With use of the above defined idea of general energy – ecologic criterion a range of research works were done, allowing to submit a proposition on reasoned increase of permissible level of chemical underburn when burning gas fuel in boilers. The main part of test was carried out in real operation conditions on vertical pipe steam boilers with turbulent burners of different types, providing different rate of gas and air streams mixing in the furnace space. Measurements were taken according to standard method described in details in [4]. Determination of CO, O_2, NO_2 concentration and temperature of flue gases was done by mean of flue gases analyzer "TESTO-300M". Determination of 3,4-benzopyrone ($C_{20}H_{12}$) in flue gases was done with simplified method [6,7].

To look for the above mentioned optimum, first maximum and minimum values of G_{sp} and η_{br} were determined at successively changed values of non controllable factors. Then their current values were determined at given rate of controllable parameter (that was a volume of air stream blown to burners) and respective values of A_1, A_2 i ***A*** criteria were calculated.

1.5. Analysis Of Results

Fig. 1 presents data typical for research carried out, representing relation of selected efficiency and ecologicalness coefficients of the boiler operation and CO concentration in flue gases. Data were obtained on steam boiler with rated output 20 t/h with two double-flow turbulent burners with rated output 8,1 MW each, located in front of the boiler in one vertical axis.

Maximum value η_{br} of the boiler unit corresponds with minimal sum of its energetic loss depending on the volume of air flow:

- stack loss;
- loss due to chemical underburn;
- electrical energy requirement for driving fan and flue gases exhaust.

It appears from the presented diagrams that optimum combustion modes are within the carbon dioxide concentration range of 200÷400 mg/m^3.

While approaching the zone of complete combustion results with noticeable lowering of the boiler efficiency and considerable worsening of ecologic combustion coefficients.

Fig.2 illustrates results of the same data processing according to above presented method of energy saving and ecologicalness of fuel consumption.

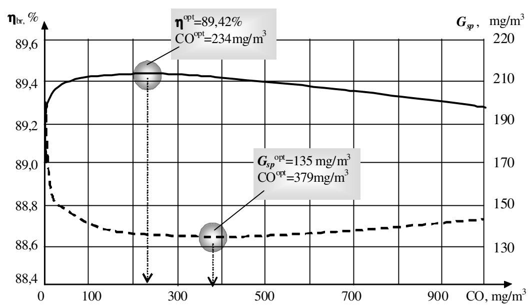

Fig.1: Dependence boiler efficiency and combustion products on the flue gas CO concentration

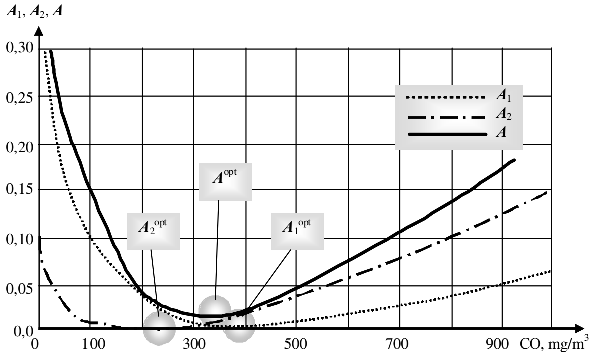

Fig.2 : Search for the optimum CO concentration by the criterial method (condition for experiment the same as for Figure 1)

As it appears from the diagrams, optimum of respective criteria A_1 and A_2, as well as minimum value of generalised criterion A are within quite narrow range of CO concentration variation, that is 230÷380 mg/m^3, what in turn corresponds with range of air excess coefficient variation of about 0,01.

Similar data, slightly differing in details, were obtained for the other types of boilers and different burners. It shall be noted, that with increase of CO concentration from optimum, value of A criterion, as well as value of original factors (G_{sp} i η_{br}) on the beginning change slightly. This gave possibility to consider concentration of CO in flue gases on the level of 500÷600 mg/m^3 as „critical". In turn "protective" margin of air excess coefficient value, recommended during set up boilers, equals 0,02÷0,03 of the critical value, what guarantees continuous operation of the boiler in the mode close to energy–ecological optimum.

However the margin mentioned shall be applied only for boilers equipped with traditional automatic units, still quite often operated in Poland.

The most positive result of the controllable method of remnant chemical underburn is achieved with use of numerical systems of fuel combustion quality control [8], which operate on the basis of "current" results of the gas analysis. In this case there is no need to use idea of "critical" concentration of CO or applying "protective" margin of air excess.

This type of units in a continuous way maintain mode of combustion and the whole boiler operation in the zone close to optimum, while optimum itself is corrected depending on calorific value of the fuel, technical condition of the boiler, climatic conditions and other affecting factors.

1.6. Conclusions

1. Complete lack of chemical underburn products in flue gases does not indicate high efficiency and ecologicalness of fuel combustion in boiler units. In most cases maximum efficiency as well as minimal toxicity of flue gases, in practice of set up boilers, is achieved at the CO concentration in flue gases within the range 200÷400 mg/m^3.
2. The method of fuel combustion with controllable remnant chemical underburn (RCU) on such level provides continuous energy – ecological result. At the same time suggested range of RCU is very close to all traditional blow-in turbulent burners.
3. When setting boilers up, recommended concentration of CO equalling 500 mg/m^3, above which signs of non stable resonant burning appear, may be considered to as "critical". In these conditions concentration of H_2, CH_4, 3,4-benzopyren, formaldehyde as well as other products of incomplete combustion may considerably increase.
4. When setting up boilers with traditional automatic system (without continuous analysis of flue gases) recommended margin of the air excess coefficient, compared to "critical" mode, equals on average 0,02÷0,03.
5. The best result of RCU method application is achieved if boiler is equipped with system of automatic control "fuel - air" relation on the basis of continuous analysis of flue gases content.

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