Developing a Modern Automatic Boiler Control System

L.I. Filinkov
Astrakhan State University
Astrakhan, Russia
leonid_filinkov@mail.ru

Likhter A.M.
Astrakhan State University
Astrakhan, Russia
likhter@bk.ru

R.V. Nazarkin
Southern Branch of Gazprom Energo LLC
Astrakhan Gas Condensate Field, Russia
ruslan_nazarkin@rambler.ru

***Abstract*— The paper attempts to use modern IT technologies to address the issue of development of an automatic boiler control system (the case of Boiler Unit No.4 of the Lukoml Power Station). The solutions under consideration are related to the use of a neural network to detect failed sensors, a decision support system, and a number of algorithmic developments, and are aimed at maintaining the balance between the energy efficiency of the combustion process and the impact on the environment. Environmental impact assessment is carried out using a fuzzy logic system, where wind speed and wind direction, as well as relative humidity, serve as input parameters. In addition, the classification and ranking of data, on the basis of which the decision support system functions, is carried out. A criterion of ecological load is introduced, and its study is given.**

***Keywords*—boiler, system, ecology, algorithm**

I. Introduction

A boiler unit is a complex control object, and its operating parameters must comply with established production and environmental standards. Due to high-energy intensity processes occurring in a boiler unit, effective management of an industrial boiler unit is an urgent scientific, technical and production issue. Modern technologies in the field of automation make it possible to design a generic solution that sets a new higher standard in the automation and control of boiler units.

II. Control Object Characteristics

The technological control object is a straight-flow boiler unit TGMP-114, steam capacity 950 t/h, designed for operation under vacuum conditions. The boiler shell has 6 gas and black-oil burners, placed from the front and rear in one tier of three burners. The steam/water path of the boiler unit includes 2 regulated flows (both primary and secondary paths). Primary steam temperature is regulated by injection; secondary steam temperature is regulated by gas recirculation. In an emergency and during start-ups, the secondary steam temperature is regulated by injections. Air is heated in two regenerative air heaters of RVV-68G type. Two DO-31 axial-type blowers (Q=900,000 m3/h), two VDN-32B smoke exhausters (0-480 cubic meters/h, H=362-563kgf/m2) and exhauster for gas recirculation VGD-20U (Q=260,000 m3/h, H=258kgf/m2) are used for air supply and flue gas removal. According to its functional purpose, the power unit is an object with a continuous (round-the-clock) operation cycle with the possibility of long-term operation at a reduced load (in the range of 30-100%). Irregular shutdowns (in 7 - 60 days) for current repairs or in reserve lasting from a day to several months are possible.

III. Experimental Data

From June 1 to June 29, 2023 the operation of the boiler unit was observed, and then the technological parameters were processed using Matplotlib library. The number of notes for each parameter is 60·24·29=41760,

where 60 is the number of minutes in an hour,

24 is the number of hours in a day,

29 is the number of days of observation.

For convenience, time from start of observation is expressed in minutes on the abscissa axis. Fig. 1÷8 show the obtained dependences of technological and ecological parameters on time.

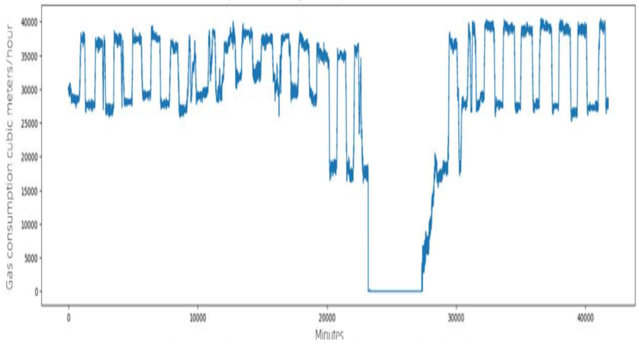

Fig. 1. Dynamics of natural gas consumption at the boiler.

Fig. 1÷3 show the dynamics of the main technical parameters of the boiler unit. Fig. 1 shows the cycle of natural gas consumption by day (more during the day, less at night). In addition, it shows that there was a boiler unit shutdown in the middle of the month. Moreover, it can be seen that during the month the daytime natural gas consumption is around 37,000 cubic meters/hour, and the nighttime consumption is 28,000 cubic meters/hour. There are also a number of days when the gas consumption varies chaotically.

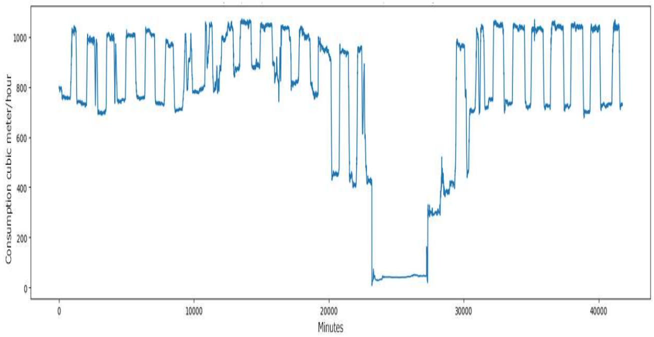

Fig. 2. Feed water consumption.

Fig. 2 and 3 show the cyclicity of the feed water and generated steam consumption by day (more during the day, less at night). Besides, it can be seen that the graphs in Fig. 1÷3 have the same form and characteristics.

979-8-3503-4094-5/23/$31.00 ©2023 IEEE

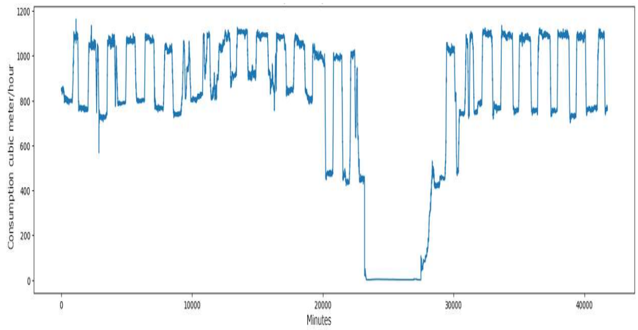

Fig. 3. Dynamics of boiler steam consumption.

Fig. 4÷9 show the dynamics of the main environmental parameters of the boil unit operation.

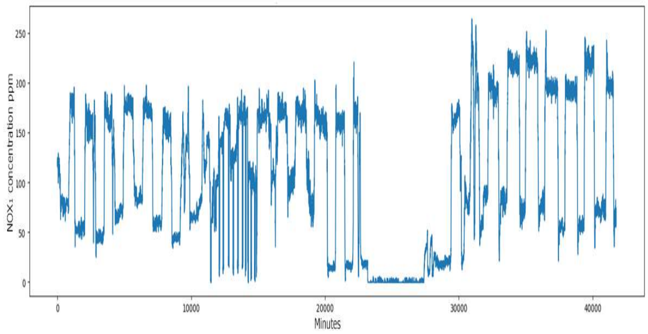

Fig. 4. Dynamics of nitrogen oxides content in flue gases.

Fig. 4 shows that the concentration of nitrogen oxides in the combustion products at the operation boiler unit varies from 50 to 200 ppm, which indicates that the boiler unit operation at low load allows reducing the concentration of nitrogen oxides in the combustion products by 4 times. In this regard, it is relevant to consider the nature of change in the specific value of the nitrogen oxides concentration to steam capacity (the ratio of concentration value to steam capacity).

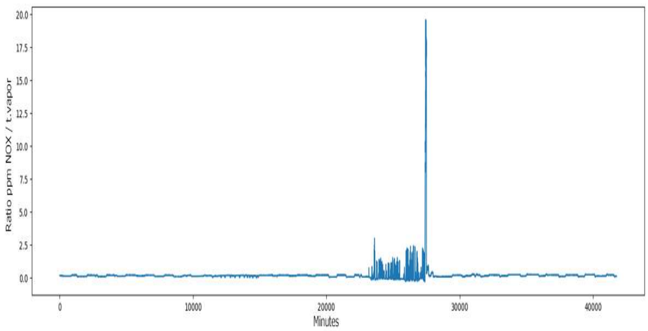

Fig. 5. Ratio of nitrogen oxide emissions to steam capacity for 29 days.

As it can be seen from Fig. 5, this parameter significantly exceeds its average value during the firing-up period; it is explained by the fact that the steam generation doesn't occur during this period, and there is no sense to consider this parameter for analyzing the environmental friendliness of the combustion process. In this connection, it is necessary to analyze this parameter only during the boiler unit operation time (Fig. 6, 7).

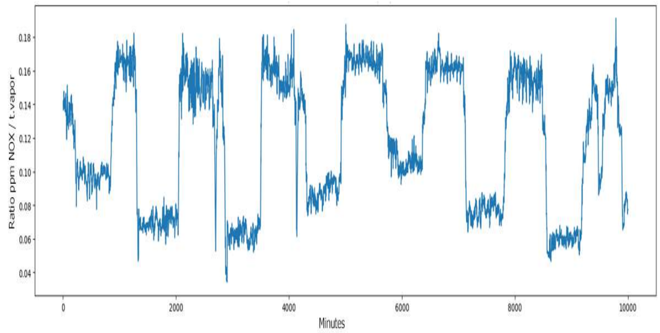

Fig. 6. Ratio of nitrogen oxide emissions to steam capacity during the first 7 days.

As it can be seen from Fig. 6÷7, this parameter varies approximately from 0.08 to 0.16 during a day. It indicates that there are modes that provide the least specific (per 1 ton of steam) environmental harm (and it should be taken into account while developing an algorithm for the boiler unit operation).

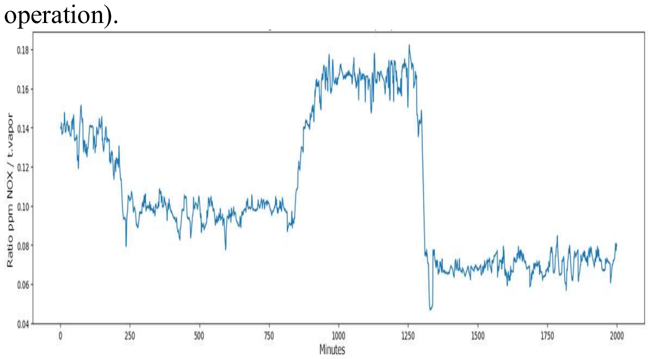

Fig. 7. Ratio of nitrogen oxide emissions to steam output during the first 2,000 minutes.

It is known that the lower oxygen concentration in the combustion products, the lower the emission of nitrogen oxides as well. Fig. 8 shows the range of changes in oxygen concentration in combustion products during the first half of the month (20,000 minutes).

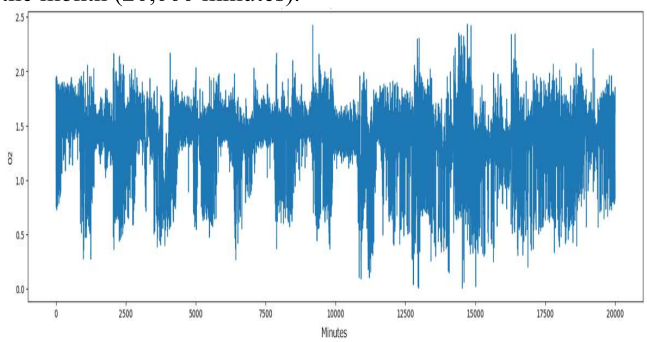

Fig. 8. Oxygen content in flue gases for 20,000 minutes.

When scaling the abscissa axis up to 200 minutes (see Fig.9) a chaotic change of oxygen concentration in combustion products from 0.8 to 1.8 % is observed, which is probably due to the error of the method of measuring oxygen in combustion products (solid electrolyte lambda-probe), as well as the presence of convective flows and the structure of gas ducts.

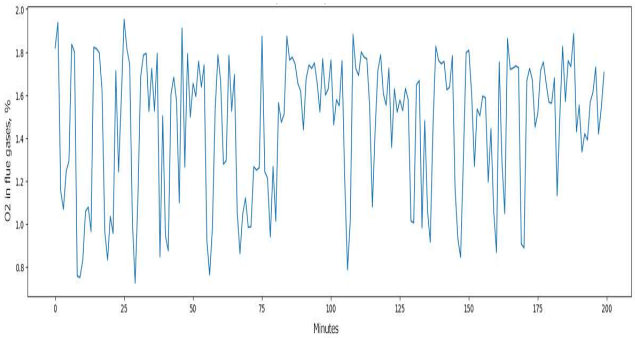

Fig. 9. Oxygen content in flue gases during 200 minutes.

In addition to the nitrogen oxides concentration, the carbon monoxide (CO) content of the combustion products is measured in the flue gases during the experiment. The presence of carbon monoxide makes it possible to assess the completeness of fuel combustion and the presence of chemical underburning. As can be seen from Fig. 10, carbon monoxide is almost absent in the combustion products, and rare bursts most likely indicate transient modes.

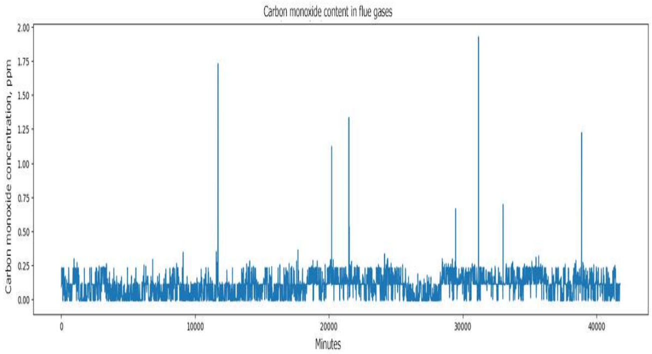

Fig. 10. Carbon monoxide concentration in flue gases.

IV. Defining Input Data and Developing a Decision Support System (DSS)

A set of parameters should be defined for the DSS; an expert (e.g., a DSS user) determines the weight coefficient for each parameter. Thus, it is possible to connect different parameters (for example, wind speed and boiler unit efficiency) in one logical chain and to adjust the influence of each of these parameters on the control object, which makes the control system as flexible as possible.

We will consider the features and limitations of the input parameters:

1. Limitations and requirements that are mandatory in accordance with the regulations.

For example, such limitations include technical guidance documents (hereinafter TGD) that regulate the content of carbon monoxide and nitrogen oxides in flue gases. Thus, for carbon monoxide the maximum concentration should not exceed 119 µg/cubic meter. [2]. The RF Government Decree [4] provides an exhaustive list of substances that have a negative impact on human health, as well as the tariffs for their emission established by the State.

The number of boiler unit operating hours per year is also limited because of the repair periods. This input parameter for the DSS is one of the mandatory requirements.

2. Requirements and limitations determined as important by the experts that arrange the combustion process.

The operator has information that a certain boiler unit cannot be used at maximum capacity for some technological reasons; then it is better not to use this boiler unit to cover peak loads, but to cover only the base load. Thus, with the help of boiler unit operators it is possible to rank the options of implementation of any parameter or action.

3. Requirements that increase economic efficiency.

Efficiency is one of the important parameters of boiler unit operation. If several boiler units are installed in the boiler room, the required heat capacity should be provided by a set of operating boiler units that has the maximum total efficiency at a specified load.

4. Advisory requirements and constraints.

This category includes those input parameters that are not mandatory but, based on common sense, should be taken into account by the control system. For example, the article [3] considers the boiler unit control system depending on weather conditions. In this case, it is not only a question of regulating the boiler unit capacity depending on the outside temperature. It is proposed to minimize the impact of the boiler unit on human health. It is well known that under certain meteorological conditions (doldrums, fog) atmospheric pollution from boiler units has the maximum adverse effect on the health of people near the boiler room. These conditions can be easily formalized using fuzzy logic. The logic of the control system is based on an ordered consistent list of fuzzy production rules of the if-a-then-b type, where Parameter A is wind speed, fog, etc. Parameter A is obtained using an API request from the website https://openweathermap.org/. This block of requirements generates a recommendation on the possibility/impossibility of further operation of the boiler room without capacity reduction.

We can include the total environmental and economic load criterion to the same category of input parameters [5]. It is an economic parameter, and the authors make an attempt to regulate the technological process of fuel combustion in the boiler unit based on the minimization of payment for emissions.

The parameter of total environmental and economic load of the generation unit is determined by the following formula:

$$F = \sum_{i=1}^{n} T_i * \frac{c_j * V_{\text{dg}} * \text{B}_d}{MEC_{\textbf{iaver.day.}}}, \quad (1)$$

where F is the total environmental and economic load of the generation unit (in conditional units); T_i is the tariff for pollutant emission, thousand rubles/t; c_j is the mass concentration of j pollutant substance in dry flue gases, mg/nm^3, measured with stationary devices; V_dg is the volume of dry flue gases produced by complete combustion, 1 kg (1nm^3) of fuel, where αo = 1,4 nm^3/kg of fuel (nm^3/nm^3 of fuel); B_d is the design fuel consumption; when calculating emissions in grams per second, B_d is in t/h (thousand.nm3/h); when calculating emissions in tons per year, B_d is in t/year (thousand.nm^3/year); $MEC_{iaver.day}$ is the maximum emission concentration of i pollutant substance (mg/m^3) for the specified period of time.

The article [5] shows a graphical dependence of the total environmental and economic load of the generation unit on the steam capacity. A similar graph (Fig. 11) is constructed on the basis of the data obtained during the current experiment.

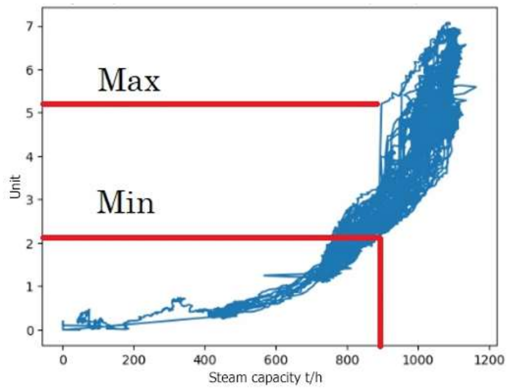

Fig. 11. Total environmental and economic characteristics.

Fig. 11 shows that at the same steam capacity (e.g., 900 t/h), the value of the total environmental and economic characteristics varies from 2.2 to 5.2, which indicates that it is possible to find such operating modes of the boiler unit, which will minimize the value of this parameter. The study [8] provides an operating algorithm that can be applied to control a boiler unit based on the minimization of total environmental and economic load condition.

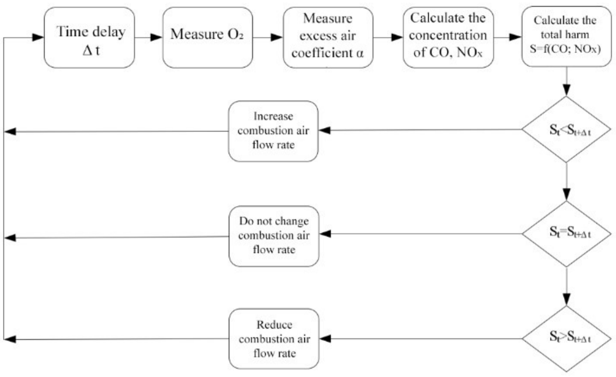

Fig. 12. Algorithm [7] of boiler unit control system operation on the condition of total environmental and economic load minimization.

V. Specific requirement for the developed control system

In addition to its primary function of controlling the boiler unit, the control system must be able to identify sensor failure. The article describes an approach that allows to monitor the correct operation of all sensors and promptly identify the failed ones. This is achieved by an algorithm that predicts the reading of a particular sensor using available readings from other sensors. If the predicted value exceeds the confidence interval, the sensor is considered faulty. Mathematically, this condition is given by:

$$if \ \left| \frac{y_{mea} - y_{pred}}{y_{meas}} \right| > \sigma, \tag{2}$$

where σ is the relative error of the measuring instrument, based on the technical documentation for the measuring instrument.

Conclusion

The article presents the results of the experiment to study the dependences of boiler unit operation parameters on time. It makes an attempt to propose a boiler unit control system that, in addition to the standard input parameters, is proposed to be supplemented with the parameter of total environmental and economic load. The article shows that the criterion of total environmental and economic load, which includes both environmental and economic characteristics of the boiler unit, can be successfully applied in the decision support system for boiler unit control. Minimizing the value of this parameter will help meet modern environmental requirements for the value of atmospheric emissions with the best economic indicators. The available experimental data are used to plot the dependence of this parameter on steam capacity and to conclude that there are operating modes at which the value of this parameter will be minimal. In addition, it is proposed to supplement the boiler unit control system with a function that allows to promptly determine the correctness of the sensors, the information from which serves to form a DSS effective solution [9-14].

References

[1] Filinkov L.I., Likhter A.M., Kokuev A.G., Denisov D.V., Glebov V.V. Detecting sensor failures based on environmental and economic parameters of boiler room operation using neural network // Vestnik of Astrakhan State Technical University. Series: Management, Computer Science and Informatics, No.2, 2022, pp.14-21.

[2] Russian National Standard P 51733-2001.

[3] Filinkov L.I., Likhter A.M., Rybakov A.V. An approach to building a decision-making system to reduce emissions from boilers based on fuzzy logic // Environmental problems of natural and urbanized territories. Proceedings of the 11th International Research and Applied Conference. - Astrakhan: 2022.- pp. 33-40.

[4] Decree of the Government of the Russian Federation No. 913 dated 13.09.2016.

[5] Filinkov L.I., Likhter A.M. Studying the criterion of the total environmental and economic parameter of a boiler unit // Management of Large Systems. The 18th All-Russian School-Conference of Young Scientists. South Ural State University, Chelyabinsk, pp.216-222.

[6] Filinkov L.I., Likhter A.M., Glebov V.V., Denisov D.V. Neural network for detecting a failed sensor (Certificate of registration of computer program No. 2022610380 dated 11.01.2022).

[7] Filinkov L.I., Likhter A.M. A program for controlling the airflow rate for combustion in the boiler under the condition of minimizing the total harmful emissions from the boiler room into the air (Certificate of registration of computer program No. 2020615344 dated 21.05.2020).

[8] Filinkov L.I., Likhter A.M. Analysis of approaches to create a decision-making support system to reduce emissions from boiler house. // Caspian Journal: Management and High Technologies. 2019, No.3., pp. 10-17.

[9] Kravchenko T.K. et al. Informatization of economic decision-making // Journal of scientific publications of graduate students and doctoral students, 2008. No. 9. P. 46–55.

[10] Larichev O. I. Theory and methods of decision making, as well as Chronicle of events in Magic Countries – M.: Logos, 2000. – 296 p.

[11] Korneev S.V. Decision support systems in business // Networks & Business, 2005. No. 6 [Electronic resource]. – Access mode: http://www.management.com.ua/ims/ims096.html.

[12] Gorsky P. Clarification of the concept of "decision support system" [Electronic resource]. – Access mode: http://www.devbusiness.ru/development/dms/dmss_terms.htm.

[13] Chastikov A.P., Gavrilova T.A., Belov D.L. Development of expert systems. CLIPS environment. – St. Petersburg: BHV-Petersburg, 2003. – 608 p.

[14] Finaev Valery Ivanovich, Beloglazov Denis Aleksandrovich, Pavlenko Elena Nikolaevna, and Shadrina Valentina Vyacheslavovna. "A system for automatic optimization in conditions of incomplete data using the example of a drum boiler" News of the Southern Federal University. Engineering Sciences, no. 11 (160), 2014, pp. 227-234.