e-ISSN 2719-3306 Mining Machines, 2023, Vol. 41 Issue 3, pp. 212-219

https://doi.org/10.32056/KOMAG2023.3.6

Pressure analysis and control in an industrial gas heating furnace as a way to reduce CO_2 emission

Received: 16.10.2023

Accepted: 26.10.2023

Published online: 31.10.2023

Mariusz WNĘK [1*]

Author's affiliation and address:

[1] Silesian University of Technology,
Faculty of Materials Engineering,
Krasińskiego 8, 40-019 Katowice

*** Correspondence:**

e-mail: mariusz.wnek@polsl.pl

Abstract:

Emission of carbon dioxide, which may affect the greenhouse effect leading to global warming is a critical aspect of the industrial use of thermal devices. The article presents the results of testing the combustion processes in the operating conditions in an industrial heating device fired by gas burners. technical, energy and operational parameters of the selected chamber for thermal process of the selected fuel input were characterized and analysed. A solution related to pressure control in the combustion chamber, which should be used to reduce the level of CO_2 emissions, which will enable a positive environmental impact is presented. Pro-ecological character of the presented solution is a very important practical effect. Especially nowadays, when there is a strong need to reduce the negative impact of production processes on environment, and all solutions leading to a reduction in CO_2 emission should also be perceived as very important for business.

Keywords: burning of fuels, combustion chamber, gas burners, gas fuel savings, reduced emission of CO_2

Publisher: **KOMAG Institute of Mining Technology, Poland**

1. Introduction

The economic aspect is the basis for eliminating the energy losses in the steel industry energy systems - which are the main industrial problem. Another very important issue that has emerged in recent years is the environmental protection. However, this aspect is not a natural need of steel industry energy enterprises but rather results from the requirements imposed by standards, laws or obligations. Economic factors are often an incentive for pro-ecological activities - discounts, access to cheap investment loans or even the possibility of additional funds [1]. Therefore, in the analysis of the presented problem, this issue is assessed in terms of below two aspects.

The following installations can be distinguished in the types of facilities selected for analysis:

a) fuel,

b) combustion air,

c) exhaust gas discharge,

and the systems:

a) temperature control of the technological process,

b) control of the amount of excess combustion air,

c) control of pressure in the combustion chamber,

d) control of oxygen concertation in exhaust gases.

Any actions that reduce consumption of gas fuel result in lower costs as well as reduced exhaust gases emission including: CO_2, which is an additional environmental aspect. Reducing the carbon dioxide emission may also have an economic aspect related to CER [2].

CER (Certified Emission Reduction) is one of the emissions trading units used under the Kyoto Protocol, which is part of the United Nations Framework Convention on Climate Change (UNFCCC). CER is emitted as a result of projects to reduce greenhouse gas emission in developing countries that are parties to the Kyoto Protocol. These projects must meet specific criteria and be approved by the Clean Development Mechanism (CDM), which is part of the Kyoto Protocol. The main goal of CDM projects is to reduce greenhouse gas emission, especially carbon dioxide (CO_2), through the use of more sustainable technologies or operating practices.

Once the project has been approved and the CER has been obtained, these credits can be sold, for example, on the international emissions market or on domestic markets, where they are used to meet countries' or companies' greenhouse gas emission reduction commitments. CERs play an important role in international efforts to reduce greenhouse gas emissions and fight climate change [2-5].

Savings from reducing the consumption of gas fuel and participation in the trade in CO_2 emission certificates may provide a given company with additional and significant funds that can be invested in any way, e.g. in the development of the company, modernization or improvement of employees qualifications.

2. Materials and Methods (Assumptions)

Analysis of main energy problems of installations and systems used in metallurgical industry and utility energy systems was carried out on the basis of continuous and chamber metallurgical heating furnaces [6, 7]. A proposal to solve the discussed problem based on operational tests is presented. The paper discusses a significant economic problem, the solution of which may bring significant economic savings as well as a positive impact on the environment.

Proper selection of the control component, i.e. valves (for gaseous fuel and air) with appropriate flow characteristics and an actuator with appropriate setting accuracy and variable rotational speed [8] is an important element in the characteristics control. The characteristics of the setting components should be close to linear, what would significantly facilitate control [9].

Publisher: **KOMAG Institute of Mining Technology, Poland**

Linearization of flow refers to the process of transforming nonlinear flow relationships of liquids or gases into approximate linear relationships to facilitate the analysis, design, and control of flow systems. This is particularly useful in engineering such as chemical engineering, fluid mechanics, and automation.

Flow linearization involves approximating nonlinear equations describing the flow using the linear differential equations or difference equations around a certain operating point or equilibrium point. The operating point is the state in which the system is stable and in equilibrium.

The linear model obtained by linearization can be used to analyse system stability, design controllers, and predict system behaviour in response to variable operating conditions or input changes.

3. Pressure in an industrial heating furnace

3.1. Pressure control in a combustion chamber

Temperature – resulting from the requirements of the technological process is the most important parameter controlled in industrial heating furnaces fired with gas fuel. The gas fuel stream depends on the set furnace temperature, while air and exhaust gases mass flow follow the fuel stream and should be proportional to it [9, 10, 11]. However, the exhaust gas flow is very difficult to measure, therefore it cannot be a controlled parameter. Measurable and therefore the controlled parameter can be the exhaust gas pressure in the furnace, the value of which is usually in the range $p_E \in [-30 \div +30]$ Pa and is a function of the exhaust gas stream discharged into the chimney, so it depends on the degree of opening of the chimney gate valve or damper and on the exhaust gas temperature.

Depending on the ratio $\dot{\boldsymbol{m}}_{\boldsymbol{E}}$ (discharged by the exhaust system) to $\dot{\boldsymbol{m}}_{\boldsymbol{EB}}$ (exhaust gases produced in the burners), a negative or overpressure is generated in the furnace. Both cases lead to a drop in the furnace temperature and a reduction in its thermal efficiency, although the mechanism of these unfavourable phenomena is different in both cases. An additional problem that occurs with negative pressure is the increase in the share of oxygen in the O_{2E} exhaust gases and thus the formation of an oxidizing atmosphere in a furnace.

Therefore, the exhaust gas pressure in the heating furnace chamber is, or rather should be, one of the main controlled parameters. The correct distribution of static pressure is an important factor for proper operation of the furnace, but it is not uniform in the working space (Fig. 1).

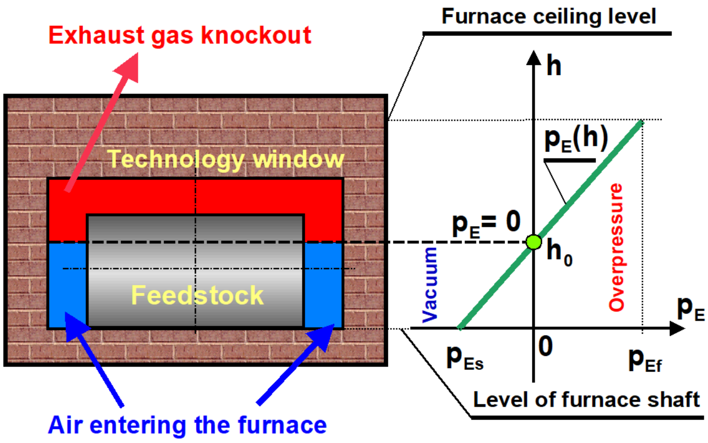

Fig. 1. View of the technological window and distribution of manometric exhaust gas pressure relative to the height of the furnace

Considering additionally state-of-the-art heating solutions, such as recuperative or regenerative burners, the distribution of manometric pressure in the furnace can be described by the following relationship:

$$p_E(h) = p_{EB}(h_B) + g(\rho_A - \rho_E)h \tag{1}$$

where:

ρ_A – atmospheric air density, kg/m^3;

ρ_E – density of exhaust gases in a furnace, kg/m^3;

g – acceleration due to gravity, m/s^2;

h_B – position of the burner in relation to the furnace shaft, m.

Equation (1) shows that the distribution of pressure in the furnace is influenced by the following:

– position of burners with regenerators in relation to the furnace shaft – h_B,
– pressure p_{EB} generated at the inlet by the burner sucking exhaust gases (for recuperative or regenerative burners),
– surface area of the slot in the feeding window *A(h)*.

Therefore, when the furnace is operating, it is very important to maintain the proper distribution of exhaust gas pressure in the combustion chamber, which is a significant controlling problem. The basis of this problem is that most industrial heating furnaces do not have automatic control of exhaust gas pressure or existing solutions do not meet their destination.

The solution to this problem is related to:

– selection of a sensor to measure small values of exhaust gas manometric pressure,
– selection or design of an adjusting component with appropriate flow characteristics to control the exhaust gas stream [11, 12, 13],
– determining the optimal exhaust gas pressure p_{Eopt} at which the sum of energy losses caused by false air entering the furnace (2) and exhaust gases escaping into the surroundings (3) through the gaps in the technological windows is minimal,
– selection of a PLC controller or regulator and its settings.

$$d\dot{m}_{Ao} = \alpha \cdot dA(h)\sqrt{2 \cdot p_E(h) \cdot \rho_A} \tag{2}$$

$$d\dot{m}_{Eo} = \alpha \cdot dA(h)\sqrt{2 \cdot p_E(h) \cdot \rho_E} \tag{3}$$

where:

α – flow number 0.7 ÷ 0.8;

A(h) – a slot surface area, m^2;

p_E(h) – manometric pressure in the furnace, Pa;

ρ_A – air density, kg/m^3;

ρ_E - density of exhaust gases in the furnace, kg/m^3.

Moreover, to properly control the exhaust gas pressure of the heating furnace, it is necessary to know the temperature and pressure control characteristics (Fig. 2) and the energy characteristics (Fig. 3).

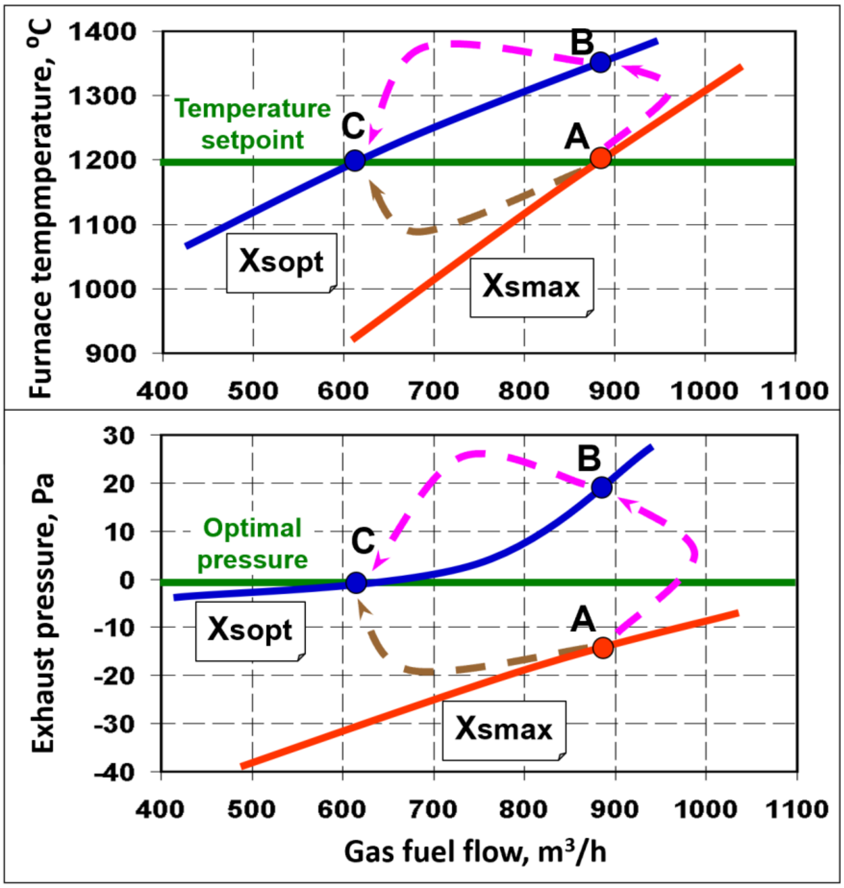

Fig. 2. Regulating temperature and pressure characteristics of the heating furnace

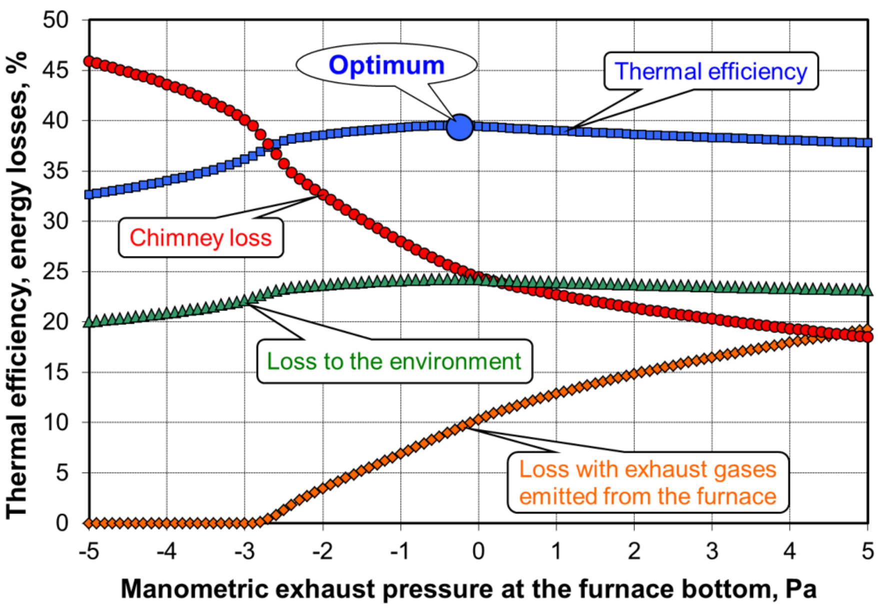

Fig. 3. Energy characteristics of the heating furnace

Publisher: **KOMAG Institute of Mining Technology, Poland**

3.2. Operating tests of pressure control in the combustion chamber

The object of operational research was a step stove in which square bars 150 x 150 x 2300 mm are heated before plastic processing (rolling) to a temperature in accordance with the requirements of the technological process, and the feed is placed in contact in the furnace in two rows.

The furnace is fired with high-methane natural gas with the following parameters: heat of combustion W_g = 39 MJ/m^3, calorific value W_d = 35 MJ/m^3.

Furnace operating parameters:

- average temperature of warming-up zone furnace 1300ºC,
- average temperature of heating zone 1300ºC,
- feed temperature 1200ºC,
- average combustion air temperature 230ºC,
- heating zone burners – ceiling flat-flame burners,
- warming-up zone burners – ceiling flat-flame burners,
- average exhaust gas temperature ahead of the recuperator 846ºC,
- average exhaust gas temperature after the recuperator 568ºC,
- achieved output 15 Mg/h,
- dimensions of the furnace chamber 11150 x 7540 x 1500 mm,
- dimensions of the furnace input and output window: 7540 x 400 mm,
- chimney height 21 m,
- internal diameter of the furnace 0.8 m,
- loop recuperator with exchange surface 47 m^2.

In the presented object, the exhaust gas pressure in the furnace chamber was controlled manually by the operator by changing the position of the chimney valve. As a result of the modernization, the exhaust gas pressure control system was equipped with an automatic system based on a PLC controller with an input module and a state-of-the-art measuring system consisting of an intelligent APR-2000 GALW differential pressure transmitter with the following technical data:

- set range: -10÷10 Pa,
- acceptable static overload 35 kPa,
- main error ≤ ±1%,
- temperature error for 10ºC ≤ ±0.1%,
- operating temperature range -25÷85ºC (ambient temperature), measured medium -40÷120ºC in direct measurement (above 120ºC, measurements using the extended impulse tube),
- 12÷30 V DC power supply in a two-wire system,
- current output signal 4÷0 mA + HART in a two-wire system.

As a result of the automatic control of exhaust gas pressure in the furnace chamber, the gas consumption decreased from 55.5 m^3_N/Mg do 52.6 m^3_N/Mg, what means reduction in gas fuel consumption by 43.5 m^3_N/h. Assuming that price of natural gas is 1.83 PLN/m^3 [4] the savings are as follows:

- daily about 1 911 PLN,
- monthly about 57 300 PLN,
- yearly about 698 000 PLN.

Publisher: **KOMAG Institute of Mining Technology, Poland**

Each CER unit represents 1 Mg of CO_2 and is a universal unit for measurement to indicate the global warming potential of greenhouse gases. Each not emitted tonne of CO_2 can be sold on the emission allowances market as a CER.

723 Mg of CO_2 was not emitted into the atmosphere per year, which can be used on the CO_2 emission allowances market getting additional funds for the company development or its modernization [3, 4, 5].

3.3. Summary of the problems related to pressure control in the combustion chamber

The main reason for failure to maintain the proper distribution of exhaust gas pressure in the combustion chamber of a metallurgical heating furnace is the lack of automatic pressure control and problems in determining its optimal value. It is not possible to manually control the exhaust gas pressure to a satisfactory level.

Maintaining the proper exhaust gas pressure in the heating furnace allows for achieving significant energy savings, which has been confirmed by the operational tests of the step stove. As a result of changing the manual control of exhaust gases pressure to automatic control, gas consumption was reduced and significant financial savings were achieved.

4. Conclusions

Energy and control analysis of the basic problem of excessive consumption of gaseous fuel in installations and systems used in the metallurgical energy industry, as well as operational tests on the basis of which a possibility of solving the problem were indicated. The analysis regarding the work subject was carried out for the sample industrial metallurgical heating furnace and concerned an economic aspect related to the environmental protection.

The basic and discussed problem was pressure control in the combustion chamber. The presented solution increases the energy efficiency of the heating furnace, which translates into significant economic effects while reducing CO_2 emissions, thus also constituting an important, pro-ecological solution.

Additionally, the results of the presented solution can be used in diagnostics and in designing the installations for the industrial furnaces, taking into account their long-term operation.

References

[1] https://www.europarl.europa.eu/news/pl [accessed: 07.10.2023]

[2] https://op.europa.eu/webpub/eca/special-reports/emissions-trading-system-18-2020/pl/ [accessed: 07.10.2023]

[3] https://www.kobize.pl/uploads/materialy/materialy_do_pobrania/raport_co2/2023/KOBiZE_Analiza_rynku_CO2_czerwiec_2023.pdf [accessed: 07.10.2023]

[4] https://tge.pl/ [accessed: 02.10.2023]

[5] https://pl.investing.com/commodities/carbon-emissions [accessed: 02.10.2023]

[6] Revun, M.P., Zinchenko, V.Y., Ivanov, V.I. et al.: „Optimal Thermal Control of a Chamber Furnace". Steel in Translation 48, 505–508 (2018). https://doi.org/10.3103/S0967091218080120

[7] Weiren, M., Kuangdi, X.: „Pusher-Type Heating Furnace, Structure and Classification of". The ECPH Encyclopedia of Mining and Metallurgy, 2022 Springer, Singapore. https://doi.org/10.1007/978-981-19-0740-1_84-1

[8] https://www.auma.com/pl/?no_redirect=1 [accessed: 05.10.2023]

[9] Niu, S.S., Xiao, D.: „Process Control Overview". Process Control. Advances in Industrial Control (2022). Springer, Cham. https://doi.org/10.1007/978-3-030-97067-3_1

[10] Tomeczek J.: Termodynamika, Wydawnictwa Politechniki Śląskiej, Gliwice, 1999

Publisher: **KOMAG Institute of Mining Technology, Poland**

[11] Wnęk M.: Digital modification of chimney gate valve characteristics as a way to reduce the fuel consumption and CO2 emission. Metal 2019, s. 2020-2026. https://doi.org/10.37904/metal.2019.994

[12] Puszer A., Rozpondek M., Wnęk M.: Cyfrowa linearyzacja charakterystyki regulacyjnej przepustnicy kominowej. X Jubileuszowe Seminarium Naukowe „Nowe technologie i materiały w metalurgii i inżynierii materiałowej" Politechnika Śląska, Katowice 2002, s. 217

[13] Wnęk M.: Cyfrowa linearyzacja przepływowej charakterystyki regulacyjnej zasuwy kominowej. Hutnik, 1 (2016), s. 18-22

Publisher: **KOMAG Institute of Mining Technology, Poland**