NATURAL GAS-FUELLED WALKING BEAM FURNACE: PROSPECTS FOR APPLICATION IN THE METALLURGICAL INDUSTRY OF KAZAKHSTAN

[1]Zoya GELMANOVA, [1]Alibek BATYRBEK, [1]Abdul Walid Fayez WAZANI

[1]Karaganda industrial university, Temirtau, Kazakhstan, zoyakgiu@mail.ru, alibek_batyrbek@inbox.ru, W.F.Wazine@gmail.com

https://doi.org/10.37904/metal.2025.5108

Abstract

Natural gas-fired walking-tray furnaces are an innovative solution for heat treatment of metals, providing increased energy efficiency and reducing environmental impact. The article analyzes the prospects for introducing this technology into the metallurgical industry of Kazakhstan. Particular attention is paid to comparison with traditional heating methods, identifying key benefits such as reduced emissions of carbon dioxide, nitrogen oxides and particulate matter, as well as the cost-effectiveness of switching to natural gas. The scientific novelty of the study lies in the comprehensive assessment of the design features of continuous furnaces with a walking pallet and the development of innovative approaches to automated control of temperature conditions. The article presents new data on the possibilities of optimizing the processes of heating blanks using intelligent control systems, which allows minimizing production losses and improving product quality. The practical significance of the study lies in the development of recommendations for adapting this technology to the conditions of Kazakhstan's metallurgy, including the modernization of existing production facilities. The introduction of continuous furnaces with a walking pallet on natural gas will allow enterprises to significantly reduce operating costs, reduce their carbon footprint and increase competitiveness in the global market. In addition, the importance of developing gas transportation infrastructure for the successful integration of this technology in regions with limited access to natural gas is emphasized. The proposed solution opens up new opportunities for the modernization of metallurgical enterprises in Kazakhstan, ensuring a balance between production efficiency, environmental safety and economic benefits.

Keywords: Continuous furnace, walking tray, natural gas, metallurgy, energy efficiency

1. INTRODUCTION

The metallurgical industry of Kazakhstan plays a key role in the development of the country's economy, ensuring the production of strategically important materials for industry. In the context of rapid technological progress and the need to improve environmental sustainability, the issue of modernizing metallurgical equipment is becoming increasingly important [1,2].

The modern metallurgical industry is in the process of active transformation aimed at increasing energy efficiency, reducing environmental impact and introducing automated control systems. One of the promising areas of development is the use of continuous furnaces with a walking pallet operating on natural gas. These technologies allow not only to improve the quality of heat treatment of metals, but also to significantly reduce emissions of harmful substances into the atmosphere.

Analysis of modern scientific literature shows that traditional metal heating technologies, such as continuous pusher pan furnaces and ring furnaces, have a number of disadvantages, including high energy consumption and uneven heating of workpieces [3,4]. In recent years, research has focused on optimizing heat treatment processes using innovative furnace designs, automated temperature control systems, and switching to more environmentally friendly fuels, including natural gas [5,6].

Walking tray continuous furnaces are considered one of the most promising solutions due to their ability to provide uniform heating of the metal, reduce processing time and improve energy efficiency [7]. However, scientific publications note that for maximum effect, these technologies need to be adapted to the specific conditions of metallurgical enterprises, including taking into account the composition of raw materials, availability of energy resources and economic factors [8].

The novelty of this work lies in the comprehensive analysis of the potential for the introduction of continuous furnaces with a walking pallet on natural gas in the metallurgical industry of Kazakhstan. The study considers not only technological aspects, but also economic feasibility, issues of automation of control and environmental sustainability of this technology.

2. MATERIALS AND METHODS

The following methods are used to describe the application process of natural gas walking tray furnaces in the metallurgical industry:

1. Theoretical analysis: Analysis of literary sources on the topic. Review of modern metal heating technologies and their comparison.

2. Economic Analysis: Cost comparison with traditional methods.

3. Engineering and technological analysis: Definition of design features of furnaces with a walking pallet. Study of automated temperature control systems. Development of recommendations for the implementation of technology in the conditions of Kazakhstan.

4. Environmental assessment: Assessment of technology compliance with international environmental standards ISO 14001.

The continuous wide-strip hot rolling mill 1700 was designed in 1959 by the Novokramatorsk Machine-Building Plant “NMBP” (Kramatorsk, Ukraine) and was put into operation in January 1968. The design capacity is 4.0 million tons /year. The shop includes 4 continuous furnaces.

The furnace is a continuous, recuperative, five-zone furnace with double-sided heating with end loading and pusher-type delivery. Continuous furnaces are used to heat the workpiece (slabs) before delivering it to the rolling mill for the production of finished products (rolled products for cold rolling shops and hot-rolled coil and sheet products). Heating of slabs in a continuous furnace is carried out using coke-blast furnace gas with a calorific value of 1350 to 1600 kcal/Nm³.

The general view of a pusher-type heating furnace is shown in **Figure 1.**

Figure 1 Pusher-type heating furnaces

The nominal pressure in the working space under the furnace arch is not less than 2.0 mm H_2O. Injection burners 49 pcs. The distance between the longitudinal axes of existing furnaces No. 1-2, 2-3, 3-4 is 24 meters.

The main disadvantages of the installed continuous furnaces are vibration of the entire frame when pushing the metal. Due to the constant vibration of the furnace frame, the heat-insulating brick of the air ducts collapses. The imperfection of the design of individual elements excludes the possibility of automatic regulation of the thermal mode, leads to a difference in temperature and pressure in the furnace zones and uneven heating of the metal. Due to insufficient circulation of the steam-water mixture, there is a deflection of the glide pipes in horizontal and vertical sections.

All furnaces have insufficient vacuum for full gas consumption (95,000 m³/hour) according to the design. The hydraulic scale removal chute has a slight slope, as a result of which scale removal is performed manually.

Existing continuous furnaces consume energy resources in the amount of 2.4 GJ/ t, which significantly exceeds modern designs of furnaces with walking beams and using natural gas to heat slabs.

In order to achieve the planned production figures of 4.5 million tons and reduce energy consumption to 1.8 GJ/ t, a decision was made to replace pusher-type continuous furnaces with walking beam continuous furnaces that meet the following conditions. Walking-beam heating furnaces are shown in **Figure 2.**

Figure 2 Walking-beam heating furnaces

Receiving, heating to a temperature of 1160 -1250°C, and issuing slabs for subsequent rolling on a 1700 mill with a heating accuracy of 20°C and having uniform heating across the slab cross-section to the maximum temperature. The productivity of the continuous furnace should be up to 400 t/hour for cold charging and up to 500 t/hour for hot charging of slabs (t slabs ≥ 300°C).

The new continuous furnaces should ensure the reduction of fuel consumption to a minimum by means of an optimized recuperative (no-heat) zone, proper design of the refractory lining (in order to minimize heat losses) and adequate air preheating (utilization of exhaust gas energy). Reduction to a minimum of the number of “cold stripes” on the billets from their contact with the glide tubes by means of an appropriate placement of the beams with an offset of the beams when discharging from the furnace. Rapid restoration of productivity and product quality indicators after a planned or unplanned mill shutdown, due to the calculated reserve of the characteristics of the fuel combustion zones, as well as automatic temperature control in the zones based on a mathematical heating model. The quality of fuel combustion should be monitored by a CO_2 analyzer installed on the roof of the recuperative zone in front of the exhaust gas outlet in order to exclude the influence of air leaks on the accuracy of the measurement results. Analysis of the CO_2 content (indication only) ensures safe operation due to complete combustion of the fuel before the exhaust gases leave the furnace, regardless of the specified or actual ratio of the fuel mixture components. This also eliminates the afterburning of the fuel with the participation of air sucked in through the tube bundles of the recuperator, which would have a very unfavorable effect on the service life of the recuperators.

The continuous furnace has automatic control of the metal heating process, furnace loading mechanisms, control of the furnace movable beam walking mechanisms, furnace unloading mechanisms, and meets the condition of reducing metal loss to a level of no more than 7 kg/t, reducing electricity consumption for metal heating by no less than 1 kWh/t; automatic control must use a pressure measuring transducer, a measuring transducer of exhaust gas temperature before the recuperator, and a combustion air flow sensor.

3. RESULTS AND DISCUSSION

The use of natural gas instead of traditional solid or liquid fuels allows for a re-duction in fuel costs by 20–30%, given its lower cost and high calorific value. Additionally, the costs of cleaning and disposal of combustion products are reduced, which is especially important for enterprises in Kazakhstan with high environmental standards.

The design of the walking pallet ensures uniform heating of the workpieces, minimizing heat loss. This allows energy consumption to be reduced by 10–15%, which is especially important given high energy prices.

Natural gas emits significantly less carbon dioxide (20–40%) compared to coal or fuel oil. This reduces the risk of paying fines for exceeding environmental standards and improves the company's image as an environmentally responsible enterprise [9].

Due to the continuous heating process and the ability to fine-tune the temperature regime, the productivity of the continuous walking pallet furnace increases by 10–25%. This allows enterprises to process more products in the same time interval [9].

The furnace design and use of natural gas reduce wear and tear on the internal components of the equipment, reducing repair costs and increasing the service life of the furnace by 20–30%.

Uniform heating of blanks allows achieving stable product quality, reducing the level of defects by 5-10%. This creates additional competitive advantages for products on the market.

Depending on the size of the enterprise and the level of technology implementation, the payback period of a walking pallet kiln is 3-5 years. Savings due to reduced operating costs and fines for environmental violations quickly compensate for the initial investment.

The company uses a traditional furnace with fuel costs of 1 million tenge per month. Switching to a continuous furnace on natural gas can reduce these costs to 700 thousand tenge per month. The savings will amount to 300 thousand tenge per month, or 3.6 million tenge per year. Taking into account the increase in productivity and reduction of defects, the total economic effect can reach 5 million tenge annually.

The environmental impact can be divided into quantitative and qualitative indicators, which are associated with the reduction of harmful emissions, increased environmental sustainability of production and compliance with international environmental standards.

Quantitative indicators of the environmental effect. Reduction of carbon dioxide emissions (CO_2): When burned, natural gas releases less carbon dioxide per unit of heat than coal or fuel oil [9, 10].

Reduction indicators: CO_2 emissions when using natural gas are about 56 kg per 1 GJ of energy; for coal and fuel oil – 90–100 kg per 1 GJ of energy.

If a plant consumes 100 GJ of energy per day: conventional furnace (coal): emissions are 9 tons CO_2 / day; natural gas furnace: emissions are 5.6 tons CO_2 / day; difference: emissions reduction of 3.4 tons CO_2 / day or 1,241 tons CO_2 / year.

Natural gas has a lower combustion temperature, which reduces the formation of nitrogen oxides. Reduction rates: NO_x when using natural gas: 50–100 mg/m³; NO_x when using coal: 200–400 mg/m³.

Result 1. Reduces NO_x emissions by 50–75 %. Reduces particulate matter and soot emissions: Burning natural gas produces virtually no particulate matter, unlike coal or fuel oil. Comparison: traditional furnace (coal): particulate matter emissions up to 200 mg/m³; natural gas furnace: emissions less than 5 mg/m³.

Result 2. Reduction of particulate emissions by more than 95%. Natural gas contains virtually no sulphur, whereas coal and fuel oil contain it in significant quan-tities. Comparison: coal: SO_2 emissions up to 700 mg/m³; natural gas: SO_2 emissions – less than 5 mg/m³.

Result 3. Reduction of SO_2 emissions by 99%. Reduction of emissions of harmful substances (CO_2, NO_x, SO_2, solid particles) leads to improvement of the ecological situation near the enterprise. This reduces the level of air pollution and the risk of respiratory diseases among the population. The absence of solid combustion waste (ash, slag) eliminates contamination of soil and groundwater with decay products. Natural gas does not form acid rain (caused by SO_2 and NO_x), which preserves the surrounding flora and fauna.

The introduction of natural gas furnaces allows companies to comply with international standards such as ISO 14001 (environmental management). This opens up access to new markets and reduces the risk of fines. Reducing emissions and switching to more environmentally friendly fuel improves the company's image as a responsible business. This can attract new investments and strengthen the trust of customers and partners.

For a plant consuming 36,500 GJ of energy per year: CO_2 reduction: ~12,410 tons /year; NO_x reduction: ~ 36 tons /year. SO_2 decrease: ~ 24.8 tons/year. Reduction of particulate matter: more 2 tons/year. This effect is expressed in a reduction in the costs of compensating for environmental damage; an increase in the service life of equipment due to the absence of corrosive and abrasive effects of waste; and a general improvement in the sustainability of ecosystems around the enterprise.

4. CONCLUSIONS

Natural gas-fired walking tray furnaces demonstrate significant energy efficiency improvements over traditional coal- or oil-fired furnaces.

One of the key advantages of natural gas furnaces is their environmental safety. This allows enterprises to comply with international environmental standards, such as ISO 14001, and avoid fines for exceeding emission standards. Reducing harmful emissions also improves the environmental situation near the enterprises, which has a positive effect on public health and the environment.

Uniform heating of blanks in continuous furnaces with a walking pallet helps to improve the mechanical properties of the metal and reduce production defects by 5-10%. This allows enterprises to produce higher quality products, which increases their competitiveness in the global market. In addition, automation of heating processes and precise temperature control ensure the stability of production processes, which is especially important for large metallurgical enterprises such as JSC “Qarmet” and LLP “Casting”.

The use of natural gas and modern furnace designs allows not only to reduce fuel costs, but also to reduce equipment maintenance and repair costs. The design of a furnace with a walking pallet minimizes vibrations and wear of internal elements, which increases the service life of the equipment by 20-30%. This leads to significant savings on repair work and increases the overall reliability of production processes.

The introduction of natural gas walking tray furnaces provides significant economic benefits for enterprises. This not only reduces the cost of compensating for environmental damage, but also improves the company's image as an environmentally responsible enterprise, which can attract new investors and strengthen the trust of customers and partners.

Kazakhstan has significant reserves of natural gas, which makes its use in the metallurgical industry economically advantageous and strategically important. The introduction of continuous furnaces with a walking tray on natural gas can be an important step in the modernization of metallurgical enterprises of the country.

However, for the successful implementation of this technology, it is necessary to develop gas distribution infrastructure, especially in regions with limited availability of natural gas. State support and investment in infrastructure development can accelerate the process of introducing innovative technologies and increase the competitiveness of Kazakhstan's metallurgy in the world market.

The introduction of natural gas-fired walking-tray furnaces also contributes to the development of Kazakhstan's scientific and technical potential. The participation of Kazakhstani scientists and engineers in the development and adaptation of this technology to local conditions can be an important step in strengthening the country's scientific base and developing local production. This opens up new opportunities for cooperation with international companies and the integration of Kazakhstani enterprises into global supply chains.

In the long term, the introduction of natural gas-fired walking-tray furnaces could become an important element of the sustainable development strategy of the metallurgical industry in Kazakhstan. This will not only reduce the carbon footprint and comply with international environmental standards, but also improve the energy efficiency and competitiveness of enterprises. Further research and development in the field of automation of thermal process control and optimization of furnace design could open up new opportunities for increasing productivity and reducing costs.

Thus, natural gas-fired walking-tray furnaces are a promising solution for the metallurgical industry of Kazakhstan, combining high energy efficiency, environmental safety and economic benefits. The introduction of this technology will not only increase the competitiveness of enterprises, but also contribute to the sustainable development of the industry and the improvement of the environmental situation in the country. For the successful implementation of this technology, further research, infrastructure development and government support are needed, which will allow Kazakhstan to strengthen its position in the global metals market and become a leader in the field of environmentally sustainable production.

REFERENCES

[1] ABDRAKHMANOV, A.T., et al. Innovations in the Field of Metal Heat Treatment. *Scientific Research of Kazakhstan*, 2023, vol. 5, no. 1, pp. 70-80.

[2] SMITH, J., TAYLOR, R. Walking Beam Furnaces: An Overview of Natural Gas Usage. *Energy Efficiency in Metallurgy*, 2021, vol. 34, pp. 115–130.

[3] JUN, Zh., LING M., MOHAMED, E.Z., AMMAR, H.E., WENJIA, L., QI Y., JIACHEN, W. Industrial reheating furnaces: A review of energy efficiency assessments, waste heat recovery potentials, heating process characteristics and perspectives for steel industry. *Process Safety and Environmental Protection*, 2021, vol. 147, pp. 1209-1228. https://doi.org/10.1016/j.psep.2021.01.045

[4] SILVIA, M.Z., CRESCENZO, P., LORENZO, O. Multi-Mode Model Predictive Control Approach for Steel Billets Reheating Furnaces. *Sensors,* 2023, vol. 23, no. 8, pp. 3966. https://doi.org/10.3390/s23083966

[5] PEPE, C., ZANOLI, S.M., COCCHIONI, F. Energy saving and environmental impact decreasing in a walking beam reheating furnace. *Conference: Energy Quest*, 2016, pp. 135-146. DOI:10.2495/EQ160131

[6] Koushik, C., Sunil, K. Increase in energy efficiency of a steel billet reheating furnace by heat balance study and process improvement. *Energy Reports,* 2020, vol. 6, pp. 343–349. https://doi.org/10.1016/j.egyr.2020.01.014

[7] GUANGWU, T., BIN, W., DENGQ, B., YUFENG, W., RICK, B., CHENN, Q.Zh. Modeling of the slab heating process in a walking beam reheating furnace for process optimization. International Journal of Heat and Mass Transfer, 2017, vol. 113, pp. 1142–1151. https://doi.org/10.1016/j.ijheatmasstransfer.2017.06.026

[8] FENGSHENG, Q., JIANXIANG, Xu., YUNYI, H., BAOKUAN, L. Digitization and greening of industrial reheating furnaces: A review of mathematical model, heating pattern, control system and energy analysis in the reheating furnace. *Applied Thermal Engineering*, 2025, vol. 263, 125320. https://doi.org/10.1016/j.applthermaleng.2024.125320

[9] FANTUZZI, M., MORI, C., RAMBALDI, F. Arcelormittal poland's FlexyTech walking beam furnace. *Steel Times International,* 2009, vol. 33, no. 3, pp. 37–41.