https://www.sworldjournal.com/index.php/swj/article/view/swj18-01-071
DOI: 10.30888/2663-5712.2023-18-01-071

UDC 66.041:666.92:628.511.4

EFFICIENCY OF LOW-CALORIFIC FUEL USE IN COUNTERFLOW LIME KILNS

ЕФЕКТИВНІСТЬ ВИКОРИСТАННЯ НИЗЬКОКАЛОРІЙНОГО ПАЛИВА В ПРОТИТОЧНИХ ВАПНЯНО-ВИПАЛЮВАЛЬНИХ ПЕЧАХ

Foris S.N. / Форись С.М.
c.t.s., as.prof. / к.т.н., доц.
ORCID: 0000-0001-7104-640X
Pererva V.Y. / Перерва В.Я.
c.t.s., as.prof. / к.т.н., доц.
ORCID: 0000-0003-0665-6812X
Usenko A.Y. / Усенко А.Ю.
c.t.s., as.prof. / к.т.н., доц.
ORCID: 0000-0001-7467-6220
Forys O.M. / Форись О.М.
postgraduate/аспірант.
Ukrainian State University of Science and Technologies, Dnipro, str. Lazaryana, 2
Український державний університет науки і технологій, м. Дніпро, вул. Лазаряна, 2

Abstract. *Highly expensive energy carriers require revision of the existing engineering approaches in heating industrial furnaces. The paper presents the results of research into the performance of a shaft kiln for lime-stone burning, which was fired with mixtures of natural gas and a fuel gas of a low calorific value. Based on studying various schemes of fuel distribution between the burners, the optimal operation mode of the kiln with reduced consumption of natural gas by 30% was identified.*

Key words*: limestone, low-calorific fuel, kilns, natural gas, optimal operation mode.*

Problem statement. Lime production is an energy-intensive process. A significant part of lime is produced in shaft kilns, which is explained by the simplicity of the kiln design, low capital costs and high thermal efficiency of such units.

As a rule, enterprises use expensive natural gas in lime kilns. On average, the specific consumption of natural gas per tonne of active lime is 200-220 kg of fuel equivalent. The share of fuel in the cost of lime is about 50-60% [1-4].

Relevance of the research. The issue of reducing the consumption of purchased fuel at enterprises by means of their own energy resources is relevant. One of the possible solutions to the problem is to switch the units to partial or full heating with low-calorific gas (blast furnace gas, biogas, generator gas).

For example, according to expert estimates [1], it is technically possible to fire furnaces with a natural-blast mixture with a calorific value of about 10 MJ/m^3. Specific savings of natural gas are about 25 kg of fuel equivalent per tonne of lime. A further increase in the share of blast furnace gas will lead to an increase in heat losses with effluent gases. However, the issue of replacing natural gas requires a deeper study, as the change in fuel type will inevitably affect the gas-dynamic operation mode and performance of the furnace.

The paper sets the task of a calculation and theoretical study of the possibility of replacing natural gas with blast furnace gas in lime kilns and evaluates the efficiency of such a measure.

Research methods. The object of study was a shaft counterflow furnace [2]. The working height of the furnace is 18 m, the diameter of the shaft is 4.3 m, and there are peripheral burners and a central burner. The scheme of the studied furnace is shown in Fig. 1.

The kiln structure consists of a vertical cylindrical shaft. Limestone is loaded from above by a skip hoist, while lime is discharged at the base of the kiln. The gas moves in counterflow with respect to the material. The furnace working space consists of three technological zones: a limestone heating zone, a burning zone, and a lime cooling zone where air is heated. Fuel is supplied through two tiers of side burners and a central burner (core). Part of the flue gas exiting the kiln is recirculated to the central burner.

The applied condition for replacing natural gas was the equivalent heat output by the furnace burners. Meanwhile, the capacity of the existing burners was considered as a technical limitation for the maximum blast furnace gas consumption.

The influence of blast furnace gas on the operation of a lime kiln was studied using a mathematical model of the unit. The mathematical model considers gas dynamics and heat exchange in a counterflow lime kiln with central and peripheral gaseous fuel supply [3-4].

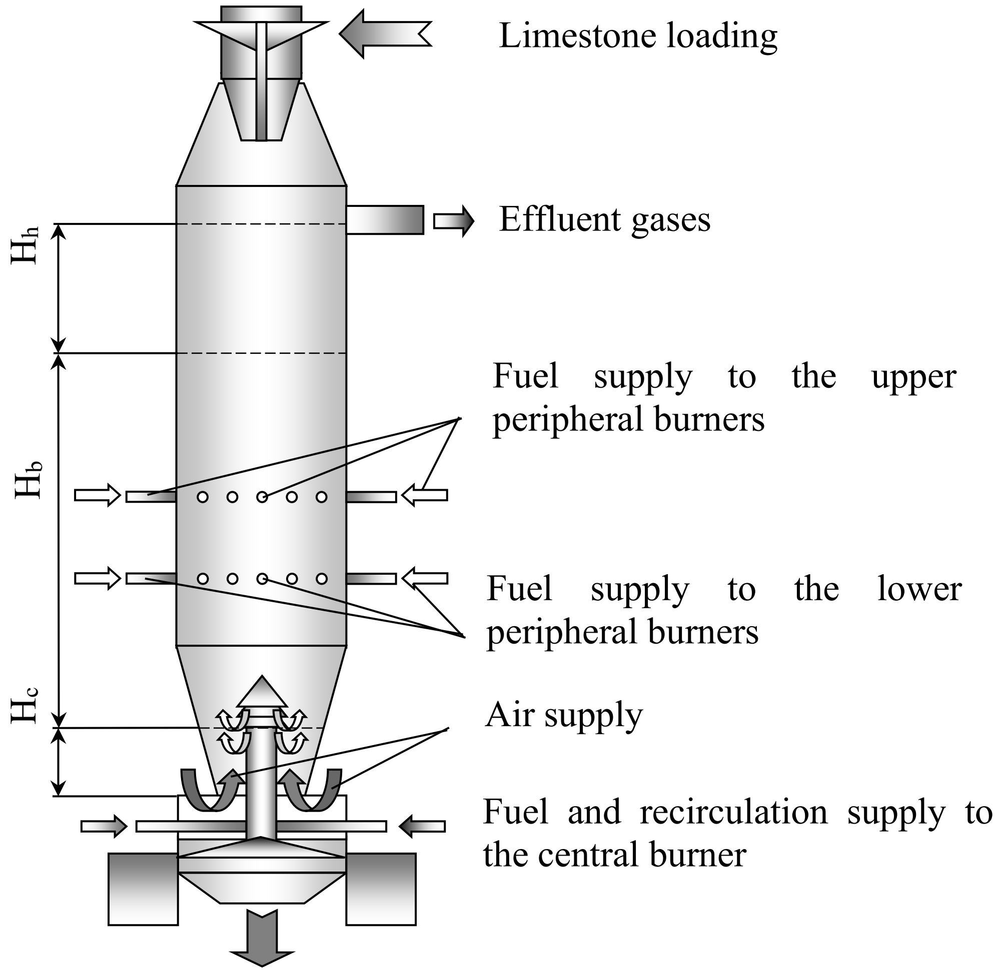

Figure 1 – Process flowchart of the lime kiln using gaseous fuel.
H_{heat} – height of the limestone heating zone, H_{burn} – height of the burning zone, H_{cool} – height of the cooling zone.

Analysis of the research results. According to the estimates, the maximum permissible volume share of blast furnace gas in the natural-blast furnace mixture is about r_{bg} = 0.8 (Fig. 2). Meanwhile, the calorific value of such a mixture is 9.4 MJ/m^3 . The optimal mode of operation of the natural gas furnace was adopted as the base: total natural gas consumption of 1100 m^3 /h; air flow to the central burner of 1000 m^3 /h; recirculation flow of 750 m^3 /h; air flow to the bottom of the furnace of 9500 m^3 /h; limestone consumption of 314 t/h; limestone burning rate of 85% [3].

The results of the study of the blast furnace gas influence on the furnace operation are shown in Figs. 2-4. According to the data obtained, depending on the supply of blast furnace gas to the central or peripheral burners, the furnace behaves differently. Thus, ceteris paribus, an increase in blast furnace gas consumption (r_{bg} = 0÷0.8) to the central burner leads to a slight deterioration in furnace performance. The temperature of the gases in the central zone drops (Fig. 4) and this contributes to a deterioration in the quality of limestone burning (Fig. 3)

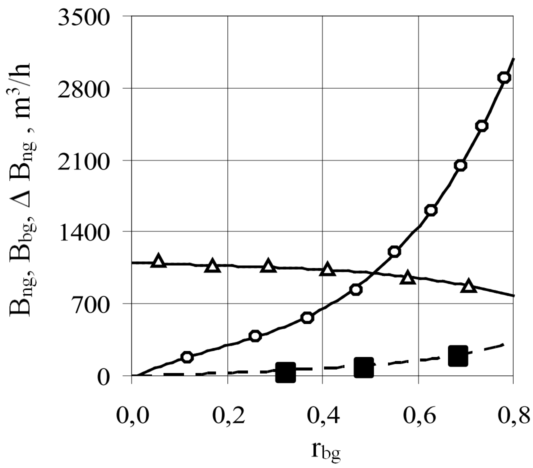

Figure 2. Dependence of the fuel consumption on the share of blast furnace gas

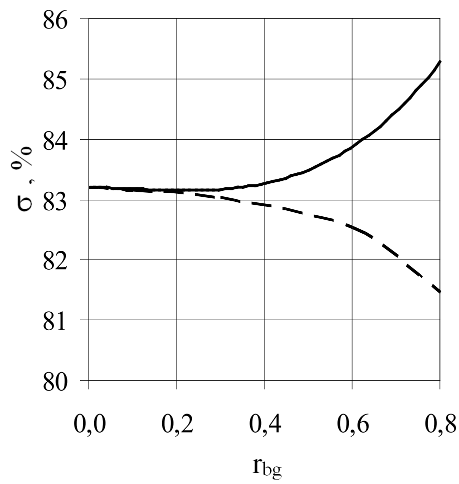

Figure 3. Changes in the degree of lime-stone burning vs the share of blast furnace gas

Consumption of natural gas B_{ng}
Consumption of blast furnace gas B_{bg}
Reduction of the natural gas consumption ΔB_{ng}
Share of blast furnace gas (peripheral burners)
Share of natural gas (Central burner)

In this case, the chemical underburning of the fuel is reduced, but heat losses with the effluent gases increase. When blast furnace gas (r_{bg} = 0 ÷0.8) is supplied to the peripheral burners, the temperature near the furnace walls in the bed decreases in a similar way. However, the operation of the side burners is characterised by the presence of an excess of oxygen.

On the other hand, an increase in the flow rate of the natural-blast mixture at the periphery turbulises the wall region, thereby improving mixing conditions. In the end, both factors have a positive effect on the operation of the kiln and contribute to an increase in the degree of the material burning (Fig. 2).

In addition, high-temperature zones are localised in the area of the peripheral burners. Overheating during the limestone burning process leads to a decrease in lime activity. The lime gets sintered and not activated. Therefore, the supply of blast furnace gas softens the firing and increases the yield of active lime. The optimum temperature for limestone burning is 1100°C. The sintering temperature on the surface is 1200°C. During sintering, an inactive part is formed on the surface of the material, which, when crushed, reduces the overall quality of the lime.

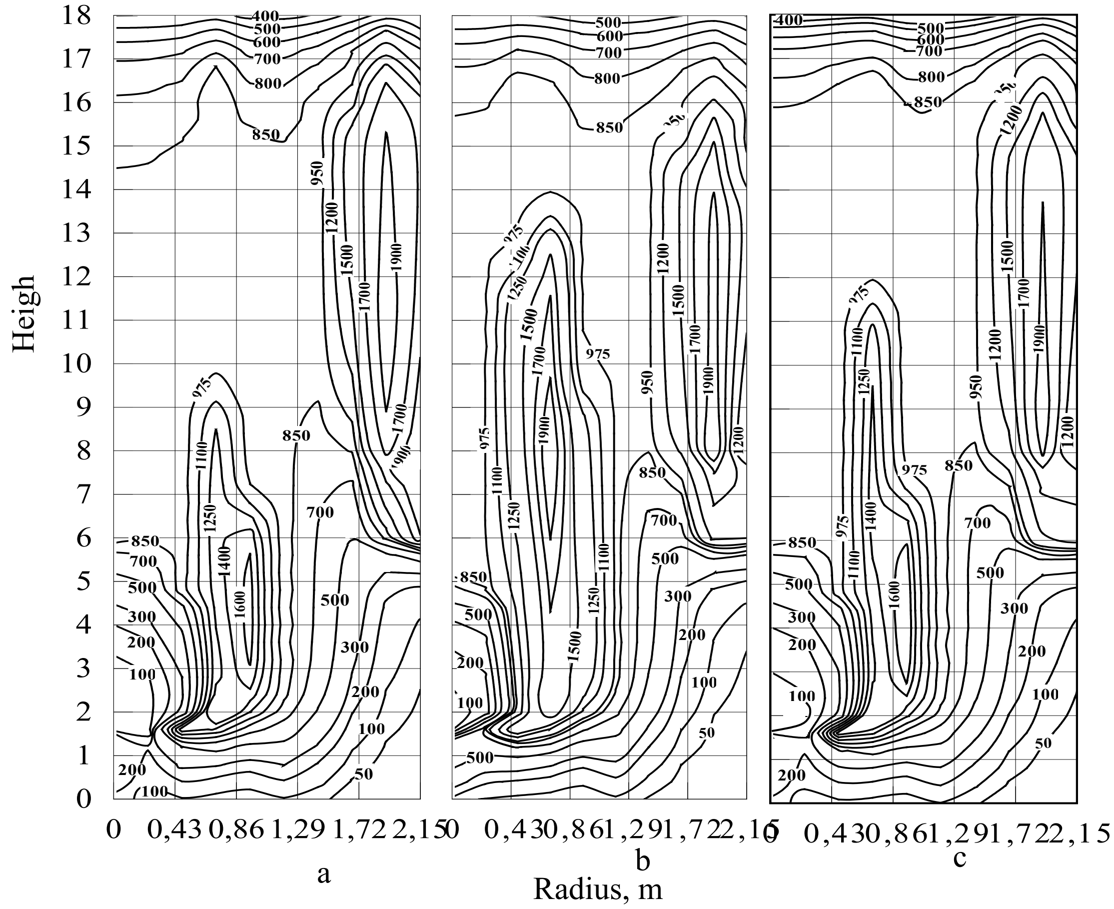

Figure 4. Temperature in the furnace volume when blast furnace gas is supplied
a) central burner (r_{bg} = 0,8);
b) peripheral burner (r_{bg} = 0,8);
c) furnace (r_{bg} = 0,8).

Thus, the ambiguous effect of blast furnace gas consumption on furnace operation leads to an interesting result from a practical point of view: when the furnace is heated with a natural-blast mixture in the range of calorific value of 9.4 ÷ 33.5 MJ/m^3 , the main parameters of furnace operation (the structure of the heat balance of the furnace and the quality of the product) practically do not change.

This conclusion is explained by the fact that the shaft furnace does not have a developed volume of working space like reheating furnaces and boiler units. In a fixed bed, the main heat transfer from gases to the material surface is carried out by convection. Therefore, when replacing natural gas with low-calorific fuels, there is no effect of a sharp drop in the radiation component of heat transfer.

An assessment of the economic performance of this energy-saving measure showed that when heating the furnace with a natural-blast mixture with a calorific value of 9.4 MJ/m^3, the estimated hourly natural gas savings in absolute units are about 322 m^3 /h (Fig. 2).

Conclusions. Based on the results of the study of the impact of blast furnace gas on the operation of the furnace, it is shown that the lime quality deteriorates when blast furnace gas is supplied to the central burner and improves when the gas supplied to the peripheral burners. The joint supply of blast furnace gas in the calorific value range of the natural-blast furnace mixture of 9.4 ÷ 35 MJ/m^3 allows preserving the furnace performance. At the same time, the blast furnace gas replacement ratio is close to 100%. The proposed mode of heating the furnace with a capacity of 200 tonnes per day with a natural-blast furnace mixture reduces consumption of natural gas by 30%.

List of references

1. Gubinsky, M.V., Fedorov, S.S., Foris, S.N., Agadzhanyan, A.V. Efficiency of the use of blast furnace gas in a countercurrent lime kiln (2011) Metallurgical and Mining Industry, 3 (3), pp. 133-137.

2. Fedorov S.S., Gubinskii M.V., Foris' S.N. Mathematical Simulation of the Structural Properties of Packed and Fluidised Beds / Journal of Engineering Physics and Thermophysics - May 2016, Volume 89, pp 627-635.

3. Foris S.M. Mathematical modelling of mine lime kilns / S.M. Foris, S.S. Fedorov, M.V. Gubinsky // System technologies. Regional inter-university collection of scientific works. - 2008. - Vol. 2. - P. 98 - 104.

4. Forys S.N. Development and implementation of rational modes of operation of mine lime-quartz kilns / Forys S.N., Fedorov S.S., Fedorov O.G. // Metallurgical Heat Engineering. Collection of scientific papers of the National Metallurgical Academy of Ukraine. - Dnipro: PPGrekO.S., 2007. - P.278-287.

Abstract. *Highly expensive energy carriers require revision of the existing engineering approaches in heating of industrial furnaces.*

The paper presents the results of research into the performance of a shaft kiln for lime-stone burning, which was fired with mixtures of natural gas and a fuel gas of a low calorific value. On the basis of studying various schemes of fuel distribution between the burners, the optimal operation mode of the kiln with reduced consumption of natural gas by 30% was identified.

The lime quality indicators increase when the blast furnace gas is supplied to the central burner and improve when supplied to the peripheral burners.

The joint supply of blast furnace gas in the calorific value section of the natural blast furnace mixture 9.4 ÷ 35 MJ/m3 allows keeping the performance of the furnace unchanged. At the same time, the coefficient of replacing natural gas with blast furnace gas is close to unity

The proposed mode of heating the furnace with a capacity of 200 t/day with a natural blast furnace mixture provides 30% natural gas savings.

Key words*: limestone, low-calorific fuel, kilns, natural gas, optimal operation mode.*