Advances in Thermal Processes
and Energy Transformation
Volume 3, 2020, DRGA01, p.81-85
ISSN 2585-9102

Numerical model expressing the amount of capture of particulate matter by an electrostatic precipitator for small heat sources

Juraj Drga[1] ● Šimon Kubas[1] ● Lucia Martvoňová[1]

[1] *University of Žilina, Department of Power Engineering, Univerzitná 1, 010 23 Žilina*

Category : Original Scientific Paper
Received : 21 December 2020 / Revised: 29 December 2020 / Accepted: 30 December 2020

Keywords: boiler, electrostatic field, electrostatic precipitator, particulate matter

Abstract: The article deals with the issue of air pollution by particulate matter. At present, there is a high production of these substances in the sector of heating with small heat sources, compared to the automotive or energy industry. The purpose of this article was to create an experimental numerical model of an electrostatic precipitator and to calculate its efficiency of particle capture in a simulated community.

Citation: Drga Juraj, Kubas Šimon, Martvoňová Lucia: Numerical model expressing the amount of capture of particulate matter by an electrostatic precipitator for small heat sources, Advance in Thermal Processes and Energy Transformation, Volume 3, No.4, (2020), p. 81-85, ISSN 2585-9102

1 Introduction

The protection of human health is a very serious issue, especially today. Therefore, from our point of view, it is important to explore comprehensive options for reducing air pollution by human activity. EU action is also leaning towards protecting the environment, which is increasingly tightening emission limits [1]. The impact of such measures can be observed in the automotive industry, where more and more efforts are beginning to focus on the development and production of electric cars, hybrid vehicles, respectively. exploring alternative fuels [2]. In this area, the production of particulate matter (PM) is succeeding, but the area of heating with small heat sources lags far behind [3-5]. PM can have a serious negative impact on human health, especially on the respiratory tract. Figure 1 is a warning finger in the form of a graph showing the number of years of life lost per 100 inhabitants due to air pollution. Given the local conditions, it can be argued that Slovakia has climbed too high. From this point of view, it is logical to address the issue of reducing emissions even in non-industrial sectors, where the legislation is not as strict as in industrial sectors.

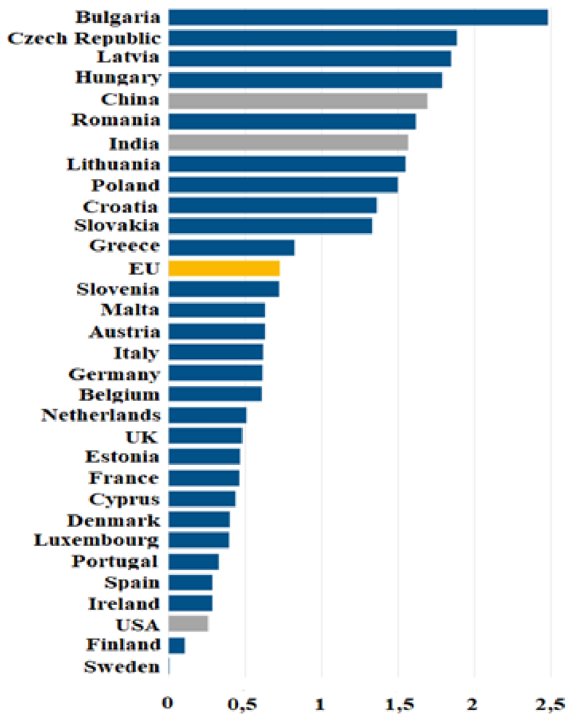


Figure 1 The number of years of life lost per hundred inhabitants due to air pollution [3]

2 Particulate matter

PM are particles of a pollutant of any shape, structure or density dispersed in the gas phase. According to size, they are divided into two basic groups:

- coarse particles PM10 (solid particles ≤ 10 micrometres = μm) - for better clarity only the size of 10 micrometres is smaller than the width of one human hair, with this size the particles can easily penetrate the lung tissues, where they settle, which over time can in the human body provoke a variety of health problems in the cardiovascular and respiratory systems. Sources of coarse particles are, for example: whirling dust from industrial roads, combustion of solids or exhaust gases from motor vehicles.
- fine particles PM 2.5 (solid particles ≤ 2.5 micrometres = μm) - these particles are so small that they can only be detected by electron microscopy. Sources of fine particles include all types of combustion processes, including residential wood burning, forest fires, power plants, agricultural processes, road transport, etc.

PM have multiple negative effects on human health (Table 1), with perhaps our airways suffering the most, which is because the only route of exposure for PM to the human body is inhalation.

Table 1 Effects of emissions on human health [3]

WHAT ARE THE EFFECTS ON HUMAN HEALTH	
$PM_{2,5}$	Stroke
O_3 ; PM ; NO_2 ; SO_2	Respiratory disease
PM	Lung diseases and lung cancer
O_3 ; PM ; SO_2	Cardiovascular disease
NO_2	Liver and blood disease

2.1 PM capture

There are several methods for capturing these particles, the most effective of which is electrostatic precipitation technology. This technology is very widespread in industrial production, where electrostatic precipitators reach a size of more than 6 m, but they are slowly being used in small heat sources, in the heating of family homes. It is in this sector that great efforts are needed to capture PM, because even compared to transport, the heating sector lags far behind in the statistics. There is also progress in this area on the development of alternative fuels that would reduce emissions and could be an adequate replacement for fossil fuels Holubčík [6] and Jandačka [7] and Variny [8]. Nowadays, automatic boilers for burning wood pellets are used more and more, which brings with them more advantages Holubčík [9]. The transition to this type of fuel significantly affects the environmental load, as pellets are produced from wood waste and thus relieve the production process from the production of emissions compared to fossil fuels to a large extent.

2.2 Electrostatic precipitation

Electrostatic precipitators are devices that, with proper optimization, can achieve efficiencies of up to 95%. They work on the principle of electrostatic precipitation of electrically conductive particles. They consist of two main electrodes, discharge and collecting. The discharge electrode is a conductive wire, fixed and insulated by insulators in the chimney. This electrode is connected to a negative source of high DC voltage 30-50kV. The positive pole of the voltage source is connected to the collecting electrode. This is represented by a conductive plate placed on the inner surface of the chimney. Figure 2 shows how particles react in electrostatic field.

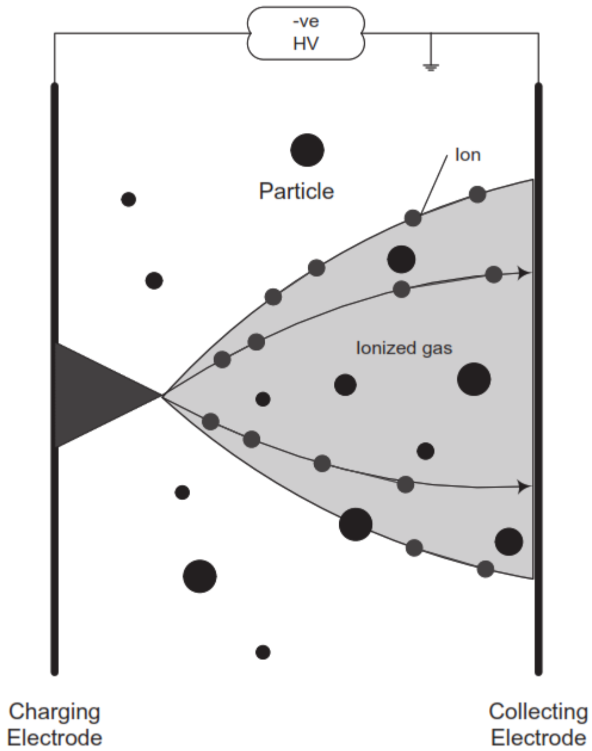


Figure 2 Behaviour of the particles in electrostatic field [10]

PM, which proceed from the boiler to the chimney, are charged with a negative charge by the discharge electrode and attracted by the opposite charge of the collecting electrode. This captures PM at the collecting electrode. In order for the process to be complete and efficient, it is necessary to arrange for cleaning of the collecting electrode from trapped particles, as clogging of the collecting electrode has a negative effect on the capture of PM in the precipitator. Among the precipitators that are already used today, resp. are part of the research, we distinguish precipitators located vertically on the upper part of the chimney, in the lower part of the chimney (Figure 3) or located horizontally between the boiler and the chimney.

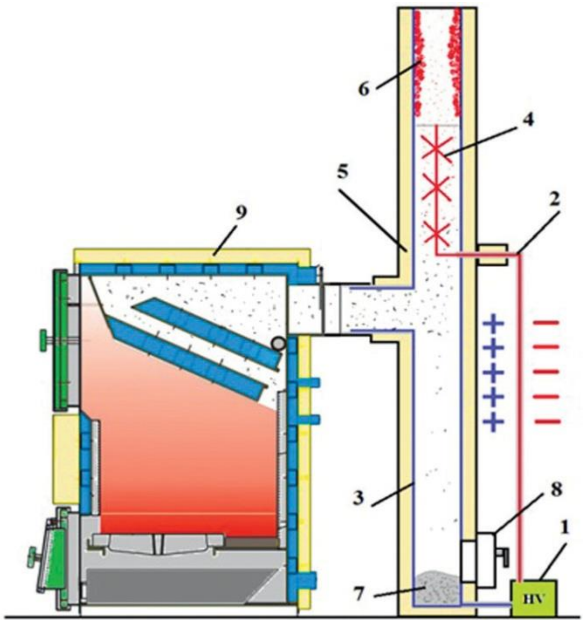


Figure 3 1 - high voltage source, 2 – charging electrode, 3 – collecting electrode, 4 – voltage concentration, 5 – insulation, 6 – settled dust, 7 – captured PM, 8 – open [11]

3 Numerical model

The following section will describe an experiment in which the effects of the use of electrostatic precipitators in the model community were assessed. PM productions from heating in small heat sources without and with PM capture were compared. The considered model municipality included 500 households with different heat sources. The calculations assumed that the heating period in the area is 240 days and the average daily heating time is 7 hours. The numbers of individual heat sources were chosen randomly. Table 2 shows the types and numbers of heat sources in households, in Table 3 you can see the types of fuels used.

Table 2 Types and numbers of heat sources

MODEL VILLAGE	Number of heat sources
Condensing boiler	150
Combination boiler	100
Fireplace	70
Gasification boiler	80
Automatic boiler	100

Table 3 Types of Fuel

Fuel
Dry wood (8% humidity)
Wood (20% humidity)
Wood (40% humidity)
Brown coal
Black coal
Wood briquettes
Waste

Table 4 shows the selected parameters of the electrostatic precipitator, which were considered in the particle capture calculations. The selected separator is a device inserted at the bottom of the chimney space behind the boiler.

Table 4 Parameters of Electrostatic precipitator

ELECTROSTATIC PRECIPITATOR			
LIST	SYMBOL	VALUE	UNIT
Gas flow	Q	0,05	$m^3 \cdot s^{-1}$
Active precipitator length	L	2	m
Rate of precipitation	w	0,07	$m.s^{-1}$
Radius of collecting electrode	R	0,075	m
Gas flow rate	v	2,829	$m.s^{-1}$
Residence time	τ_S	0,707	s
Precipitation time	τ_O	1,1	s
Projection of the collecting electrode area	S	0,471	m^2
Specific settling area	f	9,4	$s.m^{-1}$
Waste	P	0,267	-
Separability	O	**0,73**	-

Different fuel variants were used for each type of heat source. Table 5 shows the PM productions for combustion boilers. Because the scope of this article is limited, Table 5 and Table 6 serve to clarify the achieved results of PM production. For every types of boilers, the production of PM was calculated in the same way, but for the purposes of the article, all these data will be summarized in table.

Table 5 PM production for combustion boilers

Fuel	Heat value	Flue gas production	Efficiency	Fuel consumption	Amount of flue gas	PM production	PM production
	[MJ.kg^{-1}]	[m^3.kg^{-1}]	[%]	[kg.h^{-1}]	[m^{3}h^{-1}]	[mg.m^{-3}]	[g.h^{-1}]
Dry wood (8% humidity)	16,5	10	70	6,23	62,34	100	6,23
Wood (20% humidity)	14,1	10	70	7,29	72,95	200	14,59
Wood (40% humidity)	10,1	10	70	10,18	101,84	400	40,74
Brown coal	20,6	10	70	4,99	49,93	350	17,48
Black coal	29,7	10	70	3,46	34,63	250	8,66
Wood briquettes	19	10	70	5,41	54,14	150	8,12
Waste	11	10	70	9,35	93,51	2000	187,01

Table 6 PM production for condensing boiler

Fuel	Number of heat sources		PM production	
Dry wood (8% humidity)	15		93,51	
Wood (20% humidity)	38		554,41	
Wood (40% humidity)	22		896,18	
Brown coal	30		524,27	
Black coal	23		199	
Wood briquettes	7		56,84	
Waste	15		2805,19	
Value	150	pcs	5129,5	g.h^{-1}

In Table 7, the annual PM productions of all considered boilers in the simulated area are expressed, together with the total calculated amount captured by PM by electrostatic precipitators. Their value reached almost 8.5 tons per year, which represents approximately ¾ captured PM from total production.

Table 7 Captured amount of PM per year.

MODEL VILLAGE	Number of heat sources	Flue gas production per year	Captured amount of PM
Condensing boiler	150	8617,62	6116,33
Combination boiler	100	1570,44	1114,62
Fireplace	70	952,93	676,34
Gasification boiler	80	468,8	332,73
Automatic boiler	100	348,12	247,08
Value	500	11957,9	8487,09
	pcs	kg.year^{-1}	kg.year^{-1}

4 Conclusions

The article dealt with the topic of PM capture in small heat sources using electrostatic precipitators. A numerical model was performed including the calculation of the amount of PM captured in one year in a simulated area with 500 heat sources. The total flue gas production per year reached almost 12 tons per year. The proposed precipitator would be able to capture 73 % of PM, which is almost 8.5 tons per year. This number could be increased significantly higher by appropriate optimization. On the contrary, the overall reduction of PM produced could be achieved by using quality fuels such as dry wood, black coal, briquettes...

As the state of the environment is under scrutiny worldwide and alarming in some areas, it is necessary to look for solutions to protect and maintain your environment. If we want to move forward as humanity, we must use our skills and technical capabilities not to destroy our planet, but to protect it.

Acknowledgement

This work has been supported by the projects APVV-17-0311 "Research and development of zero waste technology for the decomposition and selection of undesirable components from process gas generated by the gasifier" and VEGA 1/0479/19 "Impact of combustion conditions on the production of particulate matter in small heat sources".

References

[1] European Environmental Agency. *Air quality in Europe – 2020 report*, Luxembourg: Publications Office of the European Union, EEA Report Nov. 2020, doi:10.2800/92843

[2] BIELACZYC, P., WOODBURN, J., SZCZOTKA, A., PAJDOWSKI, P.: *The impact of Alternative Fuels on Fuel Consumtion and Exhaust Emissions of Grennhouse Gases from Vehicles Featuring SI Engines*. The 12th International Conference on Combustion & Energy Utilisation – 12ICCEU. BOSMAL Automotive research and Development Institute Ltd.

[3] European Court of Auditors, 2018. *Air pollution: Our health still insufficiently protected*. Luxembourg. doi: 10.2865/363524, QJ-AB-18-019-EN-Q

[4] LUKÁČ, L., KIZEK, J., JABLONSKÝ, G., KARAKASH, Y.: Defining the mathematical dependencies of NO_x and CO emission generation after biomass combustion in low-power boiler. *Civil and Environmental Engineering Reports*, Vol. 29, Issue 1, pp. 153-163, 2019. doi: 10.2478/ceer-2019-0031

[5] LUKÁČ, L., RIMÁR, M., VARINY, M., KIZEK, J., LUKÁČ, P., JABLONSKÝ, G., JANOŠOVSKÝ, J., FEDÁK, M.: Experimental Investigation of Primary de-NOx Methods Application Effects on NOx and CO Emissions from a Small-Scale Furnace. *Processes*, Vol. 8, Issue 8, pp. 1-18, 2020. doi:10.3390/pr8080940

[6] HOLUBČÍK, M., JANDAČKA, J., NOSEK, R.,: Optimization of the Production Process of Wood Pellets by Adding Additives, *International Journal Of Energy Optimization And Engineering*, Vol. 1, Issue 2, pp. 2012, 20-40 .

[7] JANDAČKA, J., HOLUBČÍK, M., PAPUČÍK, Š., NOSEK, R.: Combustion of pellets from wheat straw, *Acta Montanistica Slovaca*, Vol. 17, Issue 4, pp. 2012, 283-289 .

[8] VARINY, M., VARGA, A., RIMÁR, M., JANOŠOVSKÝ, J., KIZEK, J., LUKÁČ, L., JABLONSKÝ, G., MIERKA, O.: Advances in Biomass Co-Combustion with Fossil Fuels in the European Context: A Review. *Processes*, Vol. 9, Issue 1, pp. 1-34, 2021. doi:10.3390/pr9010100

[9] HOLUBČÍK M. , JANDAČKA J., DURČANSKÝ P.: *Energy properties of wood pellets made from the unusual woody plants*. AIP Conference Proceedings 1768(1):020013, 2016. DOI 10.1063/1.4963035.

[10] DASTOORI K., KOHLE M., MALLARD C., MAKIN B.: Electrostatic precipitation in a small scale wood combustion furnace, *Journal of Electrostatics*, Vol. 69, pp. 466-472, 2011

[11] HOLUBČÍK M.: *Znižovanie emisií tuhých znečisťujúcich látok v malých zdrojoch tepla na tuhé palivá pomocou elektrostatického odlučovač*, TZB Portal, 12 june 2020.

Advances in Thermal Processes and Energy Transformation
Volume 3, 2020, PETK01, p. 86-89
ISSN 2585-9102

Natural Gas Leak Detection and Quantification in the Gas Industry

František Šucha[1] ● Viera Peťková[2]

[1]Eustream, a.s., Votrubova 11/a, 821 09 Bratislava, Slovakia, frantisek.sucha@eustream.sk
[2]Eustream, a.s., Votrubova 11/a, 821 09 Bratislava, Slovakia, viera.petkova@eustream.sk

Category : Original Scientific Paper
Received : 14 December 2020 / Revised: 22 December 2020 / Accepted: 27 December 2020

Keywords : natural gas, detection and quantification leaks,

Abstract : One of the basic goals of Eustream is environmental protection Methane emissions are classified according to their origin in three different types: Fugitive emissions, Vented emissions, Incomplete combustion emissions.
Searching for leaks during transmission and gas distribution is an important diagnostic activity. Based on the results diagnostic (detection and quantification) the company Eustream prioritizes maintenance activities to eliminate the identified defects. This approach both increases the safety of the operational facilities and decreases losses due to by leaks.

Citation: Šuha František, Peťková Viera: Natural Gas Leak Detection and Quantification in the Gas Industry, Advance in Thermal Processes and Energy Transformation, Volume 3, No.4, (2020), p. 86-89, ISSN 2585-9102

1 Introduction

Natural gas is considered a comparatively and clean fossil fuel ecologically because on combustion it has the lowest specific emissions of carbon dioxide (CO_2 per unit of released energy) of any fossil fuel. The use of natural gas has also the advantage of moderating the growth of the greenhouse effect. Recently, attention has been focused on the emission of methane (CH_4), which is the most important component of natural gas. Methane emissions represent a serious problem, as methane is a greenhouse gas with a warming potential 25 times higher than that of carbon dioxide.

Methane is an active gas that prevents re-radiation of incident solar radiation into space, and therefore it contributes to the growth of atmospheric disorders and the continuous increase in the Earth's temperature. This effect is called the "total greenhouse effect". Frequent methane leakage into the air means that the advantage connected with a transition to using it as a fuel could in fact become a disadvantage. It is necessary for all important producers of methane emissions to realize that a reduction in methane emissions is a very important element in the strategy of preventing total climate change. As for the problems associated with safety and the environment, the European gas engineering companies traditionally apply a policy of "best practice", despite the fact that they are not always forced to do so by legislation and that there is no economic incentive to do so.

Eustream has become a member of the Oil & Gas Methane Partnership, a global partnership in which oil and gas companies have committed to new rules for monitoring, reporting and reducing methane emissions. It is a joint initiative of the Climate and Clean Air Coalition, the UN Environment Program, the Environmental Defense Fund and the European Commission

One of the basic goals of Eustream is environmental protection, and it therefore pays significant attention to methane emissions and their evaluation, and not only to achieve the lowest operating costs. Eustream attempts to identify all aspects relating to decisions connected with minimization of leakages and to find the optimum approach.

2 Background

Searching for leaks during transmission and gas distribution is an important diagnostic activity. The purpose is not only to reduce the losses but also to prevent dangerous situations and incidents that may occur when certain conditions are met. Diagnostic methods and devices for gas detection are the key factors, and the purpose of this paper is to provide information on the use of an optical gas imaging (OGI) system to find leaks.

A number of diagnostic methods and tools have been applied to detect natural gas. The system used by Eustream and the process for detecting and quantifying of leaks at gas facilities in Slovakia are described here.

The transmission system consists of pipelines with a total length of more than 2273 km, with pipe diameters mainly of 1200 mm and 1400 mm, and four compressor stations with a total installed power 541 MW.

Identification of leak sources in Eustream is specific because of the extraordinary design of the Slovak transmission system. The system consists of four, in some parts five, parallel lines of gas pipes with diameters DN1200 and DN1400. A ball valve station is located at approximately every 25 km, and every third or fourth ball valve station contains a complete interconnection of all the pipelines.

3 Methods

3.1 Detection

The identification of methane emissions was divided into two parts:

- location of leak sources in the pipeline system and turbo-compressor installations
- identification of leaks and methane ventilation during maintenance works.

Leaks in the pipeline system are mainly connected with insufficiently tight valves, flange joints, and cracks.

The following sources proved to be the most significant:

- external leaks at ball valves and other valves
- passing boundary valves, e.g., valves on emergency depressurization systems.

A project team of specialists at Eustream sets the goals for the project to locate and quantify gas leaks. The main goals are the localization and quantification of leaks. The assessment of the severity and danger of a leak and the determination of the priority for repair are also very important objectives. [2]

The first part of the project was to choose reliable, fast, and accurate measurement instruments for the search, visualization, and subsequent quantification of gas leaks into the air. A large number of diagnostic methods are available for detecting gas leaks, including study the use of a thermal OGI camera and a laser detector.

The focus was on a passive thermographic system that allows the visualization of leaks. An OGI camera can be used to scan large areas rapidly and pinpoint leaks in real time. An additional conventional infrared camera can deliver additional information about the inspected area.

Undetected gas leaks represent an increased threat to the technological equipment in operation plants. The task of increasing safety is key in all industrial operations and this is met by implementing a program of gas leak detection and quantification, and this can be done quickly and effectively using optical visualization equipment.

3.2 Visualization

It is common practice around the world to control each component (potential leak) and to “sniff” it with a hand-held gas detector. However, this is time consuming, laborious, and costly, and is limited by the number of components the inspector can reach during the inspection.

Current diagnostic devices and techniques for detecting gas leaks (e.g., bubble test, acoustic detector, and gas analysis) require the inspector to visit and inspect every element that is a potential source of a gas leak.

Thousands of different elements and components are installed in the Eustream’s operational facilities, and to control the approximately 45 000 components (valves, flanges, joints, ventilation chimneys, etc.) requires several workers working for several months. OGI cameras such as the FLIR GF320 allow quick and effective detection of hydrocarbon leaks from the pipelines.

These devices exploit the specific properties of methane and other hydrocarbons (infrared transmittance). They contain a spectral filter by means of which gases become visible. Pictures from the cameras are converted into digital form and by using a measurement device the leak can be quantified.

Using the OGI camera the leaking natural gas is directly visible against the background of the surrounding equipment. The leak is seen as a plume (Figure 1), and it is easy to identify the source, which needs to be repaired.

Figure 1 Identification of natural gas leaks.

Figure 2 Localization of gas leaks

The use of an imaging system makes it possible to check the selected components in a significantly shorter time. It is of great importance to use the imaging system in both the exterior and the interior spaces, in particular the latter where there a greater number of leaks occur (Figure 2). To use a laser detector in these areas is problematic.

3.3 Thermal camera (infrared)

In components such as a pipeyard (Figure 3) it is not possible to locate precisely where the gas leak into the atmosphere is. For example, there may be a gas leak into the air from the vent chimney, but it is not known which valve is leaking. In such cases the "classic" LW thermographic camera helps us greatly. [3]

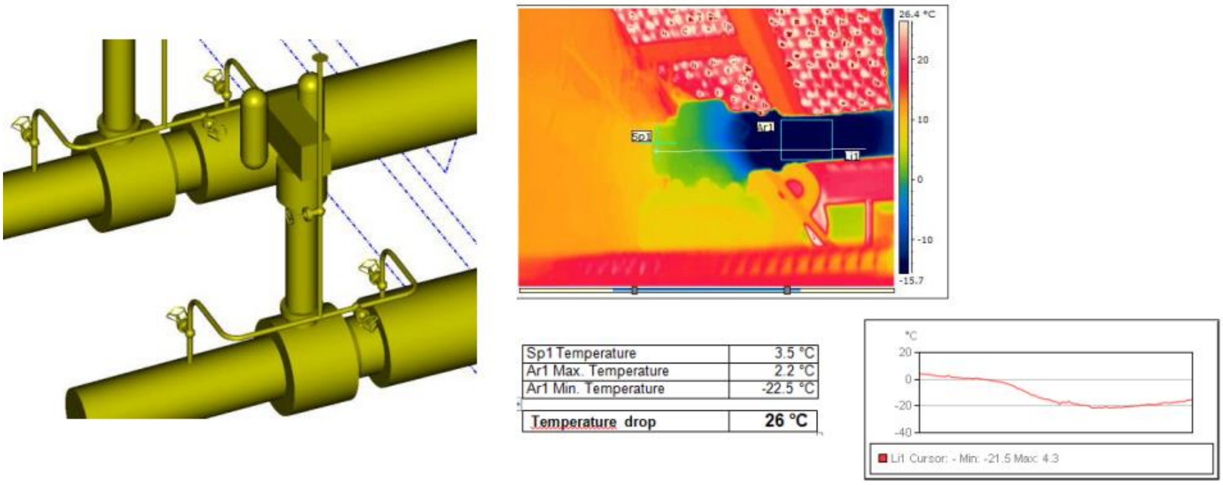


Figure 3 Pipeyard.

The conventional thermal camera exploits the fact that natural gas cools down on expansion and in doing so cools down its surrounding environment. A thermal camera enables these thermal differences to be visualized and thereby identify a natural gas leak. However, quantification of the leak is not possible by this technique.

3.4 Quantification [1]

The identified and visualized data are quantified using a particular method in a suitable form for further system processing. Various measuring devices can be used to determine (measure) the size of a gas leak (e.g., calibrated bag, rotary flowmeter, anemometer, and flow sampler).

The Bacharach Hi Flow Sampler (Figure 4) makes it possible to quantify each leak up to a flow rate of 250 l/min, and appears to be the most suitable method for quantifying natural gas leaks. Leaked natural gas is sucked into the instrument by means of a calibrated pump at a flow rate of 250 l/min.

The analyser simultaneously measures the percentage of methane in the mixture and evaluates the flow of methane, and displays the results directly on the device. The Hi Flow Sampler has a measurement accuracy of ±10%. By parallel connection of two instruments it is possible to increase the measuring range up to flow rates of 500 l/min, which sufficiently covers all current deficiencies in pipeline technologies. Using the Hi Flow Sampler a quantitative measurement is made to determine the leak rate and hence its priority for repair. The Hi Flow Sampler is the primary method used to measure the amount of gas leaked into the air.

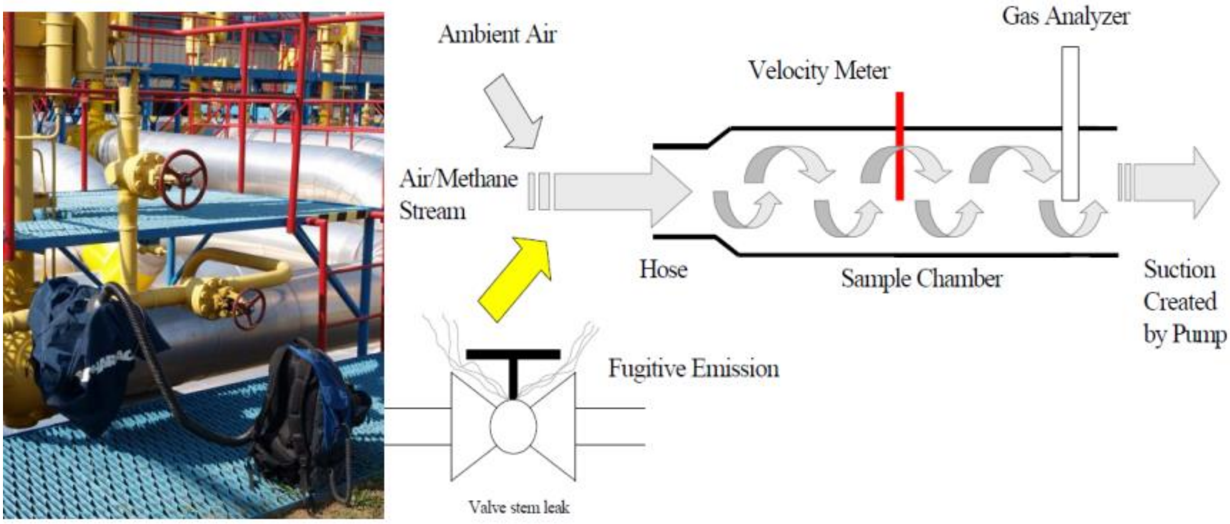


Figure 4 Quantification of methane using the Hi Flow Sampler.

4 Results

The location of possible sources of natural gas (methane) leaks is carried out on a large number of components across the entire Eustream transmission network. Based on the results of the survey (detection and quantification) the company prioritizes maintenance activities to eliminate the identified defects. This approach both increases the safety of the operational facilities and decreases losses due to by leaks.

For the purposes of system leak assessment Eustream's gas technology is divided into compressor stations, armature nodes, and gas pipelines. The evaluation methodology is defined in the Eustream internal regulations, which take into account the relevant legislation and standards. The leaks are divided into three groups according to their severity:

The system of measurement, identification, and continuous monitoring of the integrity of the pipe systems provides maximum security and reliability of gas transportation. By reducing gas leakage into the air to as little as possible the company not only makes considerable financial savings but also increases the level of life and health protection and the protection of the environment.

The reference list

[1] PEŤKOVÁ, V., SVOBODA, J.: *Termodiagnostika*, Košice, 2016

[2] ŇUKOVIČ, R., TÓTH, P., MIHÁLIK, V., ZELENAJ, A: Identification and Minimisation of Methane Emissions the Transmission Network. [Online]. Available: http://members.igu.org/html/wgc2009/papers/docs/wgcFinal00478.pdf (accessed September 6, 2017).

[3] ŠUCHA, F., SVOBODA, J.: *Vizualizace Plynů Pomocí Termografických Systémů*, Conference Proceedings, DIAGO® 2012, ciace technických diagnostiků ČR, o.s. , VŠB-TU Ostrava, 2012

Advances in Thermal Processes and Energy Transformation
Volume 3, 2020, TATI01, p. 90-103
ISSN 2585-9102

Refractory Materials for a Reheating Furnaces and their Development in Present Time

Miroslav Tatič[1] ● Ján Kizek[2] ● Ladislav Lukáč[1]

[1]Department of Thermal Engineering and Gas Industry, Faculty of Materials, Metallurgy and Recycling, Institute of Metallurgy, Technical University of Košice, Letná 9, 042 00 Košice, Slovak Republic, mtatic@centrum.sk, ladislav.lukac@tuke.sk
[2]Department of Process Technique, Faculty of Manufacturing Technologies with a seat in Prešov, Technical University of Košice, Bayerova 1, 080 01 Prešov, Slovak Republic, jan.kizek@tuke.sk

Category : Original Scientific Paper
Received : 20 December 2020 / Revised: 30 December 2020 / Accepted: 30 December 2020

Keywords : properties of refractory materials, refractories, reheating furnaces, wear lining

Abstract : Refractories are inorganic, nonmetalic, porous and heterogeneous materials composed of thermally stable mineral aggregates, a binder phase and additives. They are materials which are resistant to heat and exposure to different degrees of mechanical stress and strain, corrosion/erosion from solids, liquids and gases, gas diffusion, and mechanical abrasion at various temperatures. The contribution deals with composition of lining and with description destructive effect on refractories by which they are brick reheating furnaces in hot rolling mills such as pusher, walking beam and rotary hearth furnaces. In the contribution are summarized practical development experience applied to these aggregates.

Citation: Tatič Miroslav, Kizek Ján, Lukáč Ladislav: Refractory Materials for a Reheating Furnaces and their Development in Present Time, Advance in Thermal Processes and Energy Transformation , Volume 3, No. 4 (2020), p. 90-103, ISSN 2585-9102

1 Introduction

The modern steel technology requires ever higher quality refractories, which guarantee low specific consumption. In recent years we have observed steady increase in the proportion of unshaped materials compared to the total production volume. The unshaped refractory materials represent progressive types of products, which replace traditional linings from piece shaped materials. The advantages of using them are quick and easy method of making a monolitic lining without joints, in good resistance to sudden temperature changes and increased thermal insulation ability compared to linings from shaped materials [1]

In present time undergoing repairs and constructions of new linings the trend towards for extensive castables both in form prefabrications as well as in form monolithic castables installed directly on the construction side.

The use of modern castables brings significant productivity of assembly work in the implementation of linings, increases the quality of the final lining solution, prolongs its life time and reduces maintenance costs [1].

Even wear of the furnace lining unit has a significant impact on total operating costs. An ideal state of wear arises then all parts of lining are repaired at once.

All industrial processes requiring high temperatures are dependent from the property refractories. The development of technological processes is constantly raises ever new requirements for refractory products.
In that contribution we will deal exclusively with materials refractory in reheating furnaces.

2 Refractories for reheating

Refractories for reheating furnaces play a key role in containing energy consumption and in improving the efficiency of the reheating furnace. The life of the refractory lining and the efficiency of the reheating furnace depend largely upon the suitable choice, quality, and correct installation of the refractory in the furnace. In fact, a well-established relationship exist all these factors. The purpose of the refractory lining in reheating furnace is to prevent the heat loss from the furnace and to ensure attainment of the skin temperature of furnace close to ambient temperature so as achieve targeted specific fuel consumption. Refractories and insulation have a major role in minimizing heat losses from the side walls and roof.

The general requirements from refractories for reheating furnaces [2]:

- Ability to withstand high temperatures and trap heat within a limited area such as a reheating furnace.
- Ability to withstand sudden changes of temperature.
- Ability to withstand load at service conditions.
- Ability to withstand chemical and abrasive action of the materials such as liquid metal, slag, and hot gases etc. coming in contact with refractories.
- Ability to resist contamination of the material such as scale etc. with which it comes into contact.
- Ability to maintain sufficient dimensional stability at high temperatures after/during repeated thermal cycling.
- Ability to conserve heat.
- Ability to withstand load and abrasive forces and have to low coefficient of thermal expansion.

Properties of the refractories can be classified to resist four types of service stresses namely [2]:

- Chemical
- Mechanical
- Thermal
- Thermo-technical

A suitable selection of the refractories for the lining of the reheating furnace can only be made with an accurate knowledge of the refractory properties and the stresses on the refractories during service.

The relationship between service stresses and important properties of the refractories are at Table 1 [2].

Table 1 Relationship between type of stress and refractory property [2]

Sl.No.	Type of stress	Important refractory property
1.	Chemical	Chemical composition Mineralogical composition and crystal formation Pore size distribution and types of pores Gas permeability Resistance to slag, glass melts, and vapours
2.	Mechanical	Crushing strength Abrasion resistance Cold modulus of rupture and deformation modulus Porosity and Density
3.	Thermal	Pyrometric cone equivalent Refractoriness under load Refractoriness under load(differential) Thermal expansion under load(creep) Hot modulus of rupture Thermal expansion Reheat change (after shrinkage and after expansion) Thermal shock resistance
4.	Thermo-technical	Thermal conductivity Specific heat Bulk density Thermal capacity and temperature conductivity

3 Reheating furnaces for hot rolling mills

These types of reheating furnaces are traditionally lined with hard (dense) refractory such as bricks, castable, gunite, shotcrete, etc. Such dense refractory do not fare well when exposed to intense and continuous flame impingement, thermal cycling and alkali attack.

Routine processes like ramp-ups, ramp-down, and opening and shutting the furnace doors to charge or remove product can cause severe thermal shock and damage to refractory lining.

Once damaged, hard-refractory repair and patchwork is cumbersome, time-consuming, labour intensive, and expensive. Reheating furnaces often have to be shut down for days because the refractory first have to be completely cooled, then the repairs to be made followed by the and specific dry-out schedules. Finally, the reheating furnace is very slowly ramped back up to the operating temperature (sudden ramp-ups create thermal shock). A large portion of this energy is absorbed by the refractory lining and, due to the high thermal conductivity of dense refractories, a large percentage of this heat is conducted through to the steel casing of the reheating furnace. Furthermore, traditional linings of hard refractory are heavy, putting undue strain on the mechanical components and structure of equipment.

The reheating furnace is mainly consists of three zones namely:

- **Preheating zone**
- **Heating zone**
- **Soaking zone**

Furnace chamber consist of two side walls, two end walls one at soaking zone side and the other at preheating zone side, a hearth and a roof. The width of the furnace is required to have sufficient dimension to accommodate the length of steel material to be heated along width adequate clearance on either side so that the steel material does not rub the side walls during its forward movement.

An exceptions are rotary hearth furnaces, which they have circular cross section with rotating hearth of plate shape or ring. Individual furnace zones are separated by a hanging partition as well as spaces of loading, removing and cleaning. The roof of furnace hung up all the length respectively around the perimeter at the same height level.

Since the atmospheric conditions within the reheating furnace existing in three zones differ widely, there is necessity to have different types of refractories for these zones. Similarly, the qualities of refractories needed for hearth and roof to meet the operational requirements of the area.

The refractory lining of a reheating furnace can be done in several alternative ways.

The alternative solution which can be adopted for a reheating furnace can include:

- The classical brick lining
- The combination of brick lining with monolithic refractory materials

The installation techniques can be different depending on refractory materials used, i.e. laying, casting of monolithic, ramming, gunning, or shotcreting. In some reheating furnaces, precast slabs are also used.

Objectives for refractory lining solutions for reheating furnaces

- ➢ Meet the requirement imposed by operating conditions.
- ➢ Meet requirements of the adopted technology for the refractory solutions.
- ➢ Achievement of the targeted life of the refractory lining.
- ➢ Meet the targeted time frame for the refractory lining.
- ➢ Meet the environmental conditions imposed by the type of reheating furnace.
- ➢ Refractory solution is to be within the available budget.

4 Lining of individual parts of reheating furnace

❖ Sidewalls

Sidewals of the reheating furnace are required to be lined with multi-layer of refractories (Figure 1) [3]. Towards the furnace shell insulating refractories of needed qualities and in required thicknesses are to be used to ensure that the heat of the furnace is not transmitted to the furnace shell and the temperature of the furnace shell is not higher than the ambient temperature of the area.

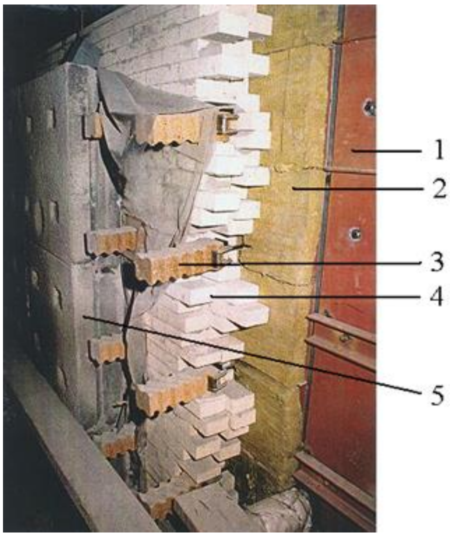


Figure 1 Individual layers of the lining of the side wall [3]

1 side wall armour,
2 insulating layer of ceramic fibers,
3 anchoring of working lining,
4 calcium-silicate insulating bricks,
5 working lining made of high-alumina gunning castable,

The refractories of the side wall needed towards the steel material side needs:

- ○ high refractoriness,
- ○ high resistance to thermal spalling,
- ○ high resistance to thermal shock,
- ○ low permanent linear change,
- ○ good abrasion resistance,
- ○ good resistance against chemical attack.

In the three zones of the reheating furnace different grades of alumina refractories are normally used for inner layers of the side walls.

❖ End walls (input and output side)

For the end walls also multi-layer lining of refractories is used (Figure 2) [4].

Lining towards the outer atmosphere consists of insulating refractories while for the inner layers towards the furnace different quality of refractories are suitable for the preheating zone side and soaking zone side end walls. The preheating zone side end wall refractories need to have good refractoriness as well as good abrasion resistance while the soaking zone side end wall refractories need to have high refractoriness, good thermal spalling characteristics and good emissivity to radiate heat. Presently monolithic refractories are preferred for this application.

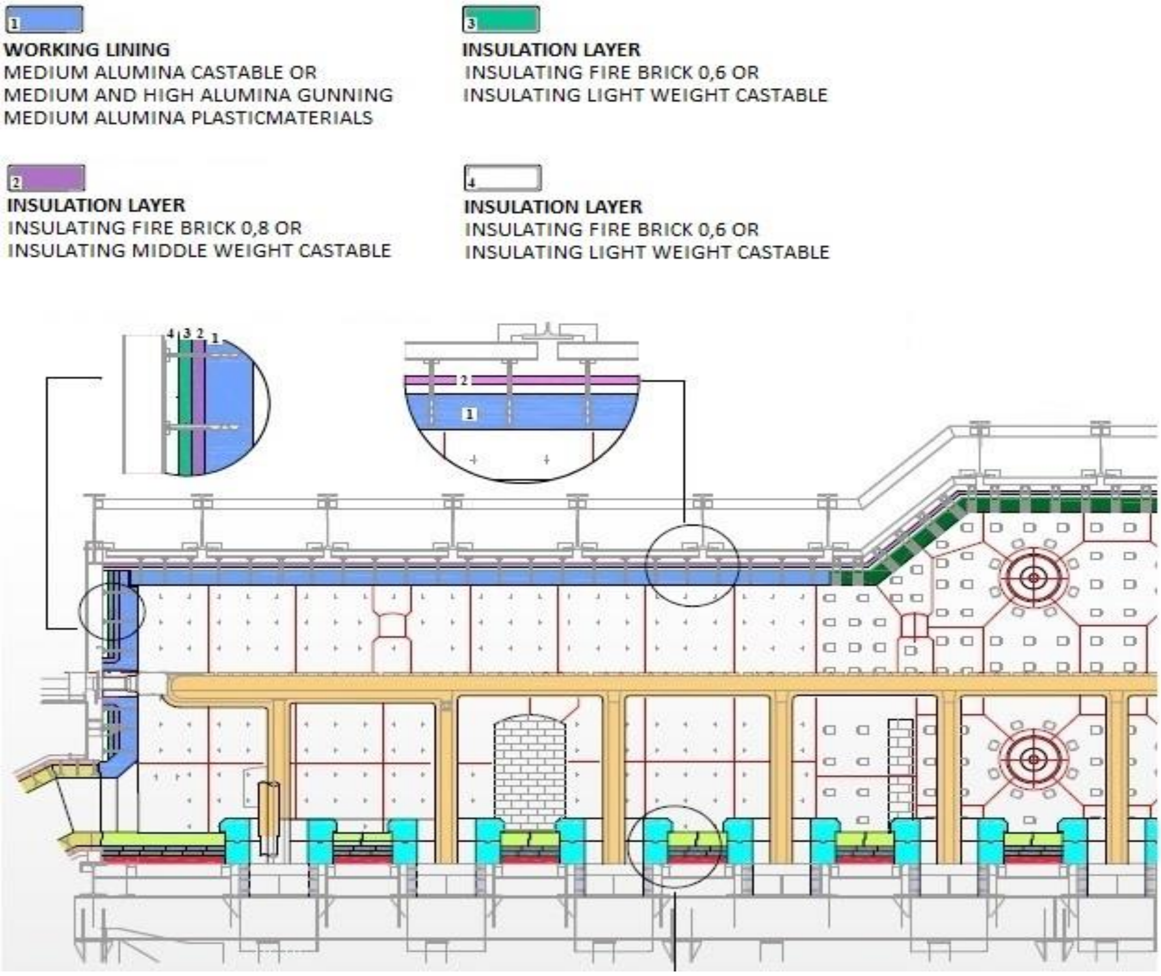


Figure 2 Refractories of input end walls [4]

- **Hearth of the reheating furnace**

The hearth of reheating furnace continuously faces high temperature abrasion as well as build-up of scale. The refractories chosen for this area is to withstand these two adverse conditions. It should also have volumetric stability.

Low cement medium to high alumina castables with stainless steel reinforcement are preferred solutions for the lining of the hearth. In the soaking zone, where steel material is pushed out or taken out by an ejector, lining with fused cast high alumina blocks are preferred since these blocks have got very high resistance to abrasion. Lining with basic castables also provides good performance for the hearth refractories.

In Figure 3a is hearth from fused blocks with content Al_2O_3 [3,6] and in Figure 3b is monolithic hearth of castable with content 95% Al_2O_3 on basis tabular corundum [5].

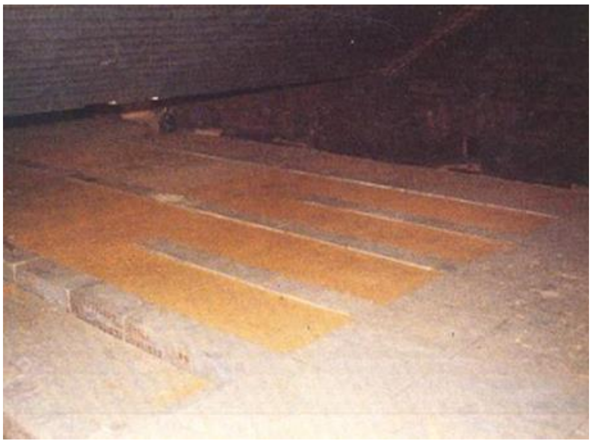


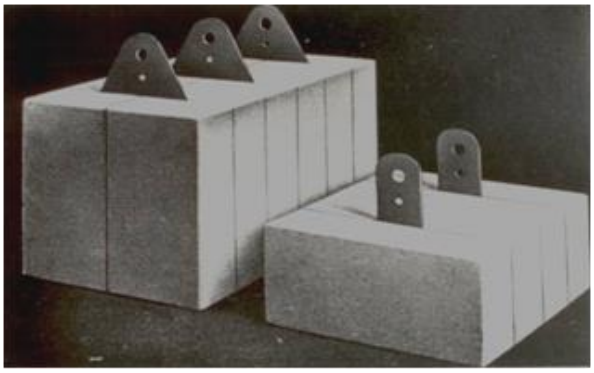
Figure 3a Hearth reheating furnace from fused

Figure 3b Monolithic hearth reheating blocks [3,6] furnace of castable [5]

❖ **Roof**

In case of the refractories for the roof of the reheating furnace, the choice of refractories depends on the type of roof the furnace has. Roof refractories need to have good thermal spalling resistance, good refractoriness as well as good abrasion resistance. Since roof refractories are required to radiate heat to the surface of steel being heated, it should have good emissivity. Presently roofs cast with low cement alumina castable refractories are preferred over brick lined alumina refractories. Behind these refractories there is necessity to install insulation refractories of adequate thickness to prevent the loss of heat through roof.

In Figure 4 a, b is a view of the bricks with an individual hanger from Didier-Werke used in seventies in pusher and walking beam furnaces [3,6].



a)

b)

Figure 4 Bricks with an individual hanger from Didier-Werke

In Figure 5 a, b, c is a view of the roof made from low cement and dense castable prefabrications.

a)

b)

c)

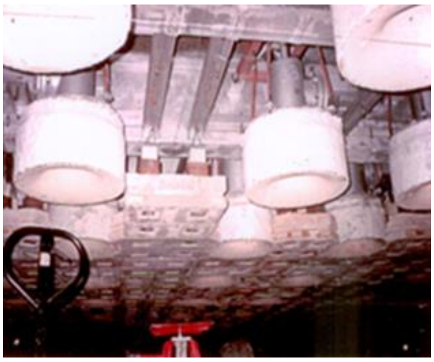


Figure 5 The roof of the reheating furnace made from prefabrications [6]

❖ Burner blocks

Burner blocks are normally made of castable refractories. For burner blocks normally castings are made, and they are dried and fired [2].

Pre-shaped refractory burner blocks play an important role in reheating furnace operation and melt shops production since they are responsible for heating the billets/slabs so that they reach the temperature required for rolling [7].

They are made of LCC castables with a high alumina content and low cement content (1,0 – 2,5% CaO). The older types of burner blocks achieved a service life 1 year and the types currently used have service life of more than 3 years.

Table 2 shows the chemical composition of standard and newly developed castable used for the production of burner blocks [7].

Table 2 Refractory castable chemical composition [7]

Chemical composition (%)	Standard product	New castable
Al_2O_3	75,7	60,8
SiO_2	17,4	36,7
CaO	1,6	0,9
Fe_2O_3	1,3	0,6
Others	4,0	1,0

The newly developed castable is characterized by lower values at thermal shocks and excellent resistance to cracks formation propagation. This was also confirmed by inspections after3 years of operation. Figure 6 shows the dependence of modulus of elasticity (E) on the number of thermal shock cycles(n°) in standard and newly developed castable [7].

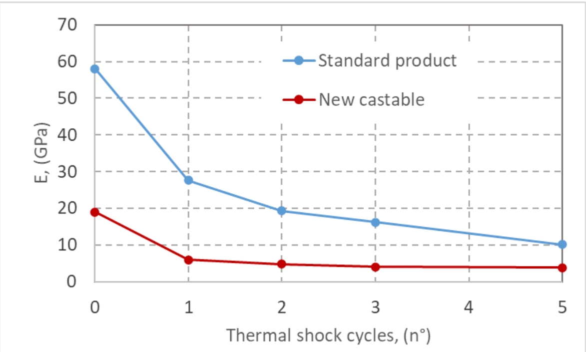


Figure 6 Thermal shock resistance [7]

5 Insulation of the water-cooled support system of heating furnaces

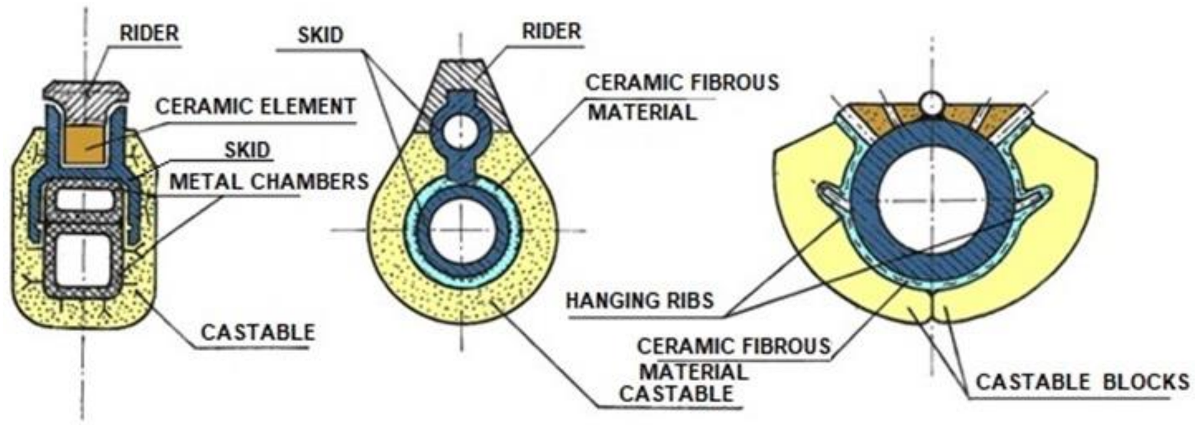
The insulation of the water-coolled support system of heating furnaces is exposed to considerable thermal and mechanical stress and the chemical action of scale and flue gas. Requirements applied in construction of thermal insulation are specified by conditions of the pusher or walking beam furnace. These are the following requirements [6,10]:

- Use of refractory materials that are characterized by low thermal conductivity and ensure minimal heat losses by cooling water in support system when determining the optimal insulation thickness (up to 10-12kW.m^{-2}).
- Limitation or determination of thickness (specially on longitudinal skids and frames), while achieving the smallest shielding of the bottom surface of the heated metal from the working space of the furnace.
- High thermal stability and mechanical strength of the insulation material. The main cause of significant thermal stresses in insulation is temperature gradient after cross section reaching an average value about 1000°C, especially in zones with a high working space temperature. Another cause of stresses in thermal insulation there may be different values of the thermal expansion of insulting material itself and also the metal elements, which the insulation is fixed to the pipes. In addition continuous vibration of the longitudinal skids has a significant effect on the insulation strength as the charge is moved. This is significantly higher in pusher furnaces where large dynamic bumps occurring when the charge is pushed arising overcoming resistant of the hearth in soaking zone.
- Resistance of insulating material (or outer layer) against to the effect of scale. This is especially important for high temperature heating zones where the temperature reaches a value from 1200 to 1400°C, a variety of refractory materials is exposed to intensive erosion as a result of wears and loss strength. In practice, there have also been cases of harmful effects of flue gases on insulation, when burning liquid fuel with increased sulphur content.
- Technological procedure for mounting insulation on the furnace support system which allows shortening the installation time, which is performed in the final stages of repair of the heating furnaces.

The optimal duration of insulation can be considered 2-2,5 years, with corresponds to the period between the two intermediate repairs. After this time there is maximum wear of the insulation on the longitudinal skids, cross rails and uprights, which represents the volume of about 50 – 60 % total insulation.

When assessing the heat loss of water-cooled elements these factors are the most important:

- **thickness**
- **quality**
- **service life of insulation materials**



a) b) c)

*Figure 7 Methods of insulation of longitudinal skids [6,10***]**

Coarse insulation on the skid reduces heat loss but increases the effect of overlap on the slabs (shielding effect). In general, insulation with thickness of 38 – 64 mm is the optimal value, on the one hand in terms of adequate losses insulation and also from the point of view of minimal heat radiation from the material just above the skid.

The quality of the insulation materials used for longitudinal skids is very diverse. We can consider the heat loss of the material as a measure of quality in the range from 12600 to 37900 W.m^{-2} For this reason, the choice of insulation material is of great importance [10,11,12]. According to Vereecke F.J.[11] another important circumstance when choosing an insulating material is its service life. Heat loses on water-cooled skids with insulation can be up to about 37,86 W.m^{-2}. Therefore, durability must be the predominant factor in choosing insulation and service life with regard to the given properties and thickness of insulating material.

Methods of insulating a water-cooled support system

There many types of skid insulation available on the European and world marked, which can be devided into three types [6,10,11]:

- preformed (resin bonded glass fiber insulation),
- cast refractory materials,
- combination of both types has been used more frequently in recent years.

The characteristic of preformed materials is:

- high price
- easier installation
- lower installation cost,
- higher heat loss values.

The typical properties of castable refractory materials are:

- lower materials cost,
- higher installation cost,
- lower heat loss values.

Before selecting either type, one should seriously consider the operating condition. Strong slag formation and scale reduces service life considerably. Due to mechanical damage there is also a decrease in service life due to incorrect insertion of short brams into the pusher furnaces In The Unided Kingdom, different types of insulated skids are used . There a number of different insulating materials of pusher furnaces skids, for example, plastics, castable material reinforced with mesh. These materials alow up 75% reduction in heat loss trough the skids[10]. For walking beam furnaces, where are no vibration as a result of the furnace charging device, it is possible to use double insulation consist of cast refractory material reinforced with ceramic fibers. Figures 7 and 8 show several types of longitudinal skid insulation currently used . The use of double insulation in the form of moldings has recently found application in pusher furnaces. The original design of double insulation by means of refractory material did not apply not applicable as shock occured as a result of pushing the slabs into the furnace [6,10].

Figure 8 Insulation of longitudinal skids [3]

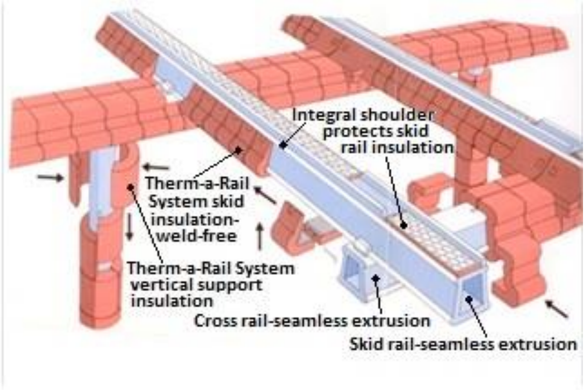
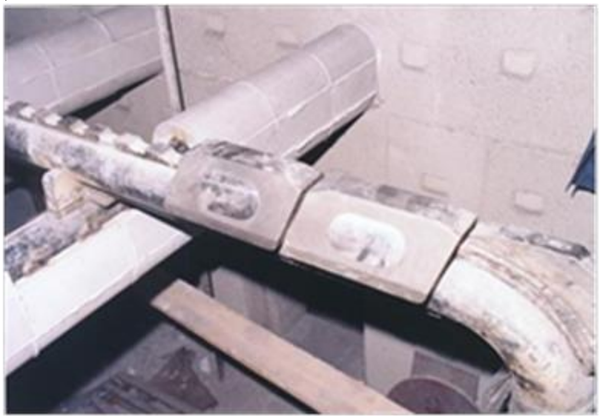


Figure 9 Insulation of longitudinal skids with CAMERON system [13]

a)



b)

Figure 10 Skids with riders [15,16]

The characteristic properties of each type of insulation, i. thickness of metal, quality and service life can be compared to the cost of installation for a large specific use. The payback period (time) will be shown by the best system CAMERON´s Therm-A-Rail (Scotland, Edinburg) system is one of the most perfect insulation systems, which consist of double- layer moldings (Figure 9) [13]. The advantage of this system is very fast assembly and replacement of damage parts.

Longitudinal skids and cross rails have a trapezoidal cross section and shape of the fitting itself correspond to this

Riders – the construction elements, which reduce metal contact with cold part of longitudinal skids and their wearing, working under the temperature of 1100-1200°C and high mechanical loads for metallurgical pusher-type and walking beam furnaces.

Usage of riders ensures the following [17]:

- Metal heating quality increasing of before rolling as a result of temperature drop decrease along section of heated slabs or billets and work pieces up to 5-20°C.
- Decrease in fuel consumption (under curred furnace performance) by 8-17%.
- Increase of furnace performance (under current fuel flow rate) by 20%.
- Decrease of metal loss by 0,1-0,2% (for pusher-type furnaces).
- Ensure capability for sheet rolling in negative allowance field and increasing flatness of finished rolled products.
- Decrease of metal cut-off piece consumption due to form deformation when rolling.
- Energy saving in stand drives by means of decreasing forces when metal rolling.

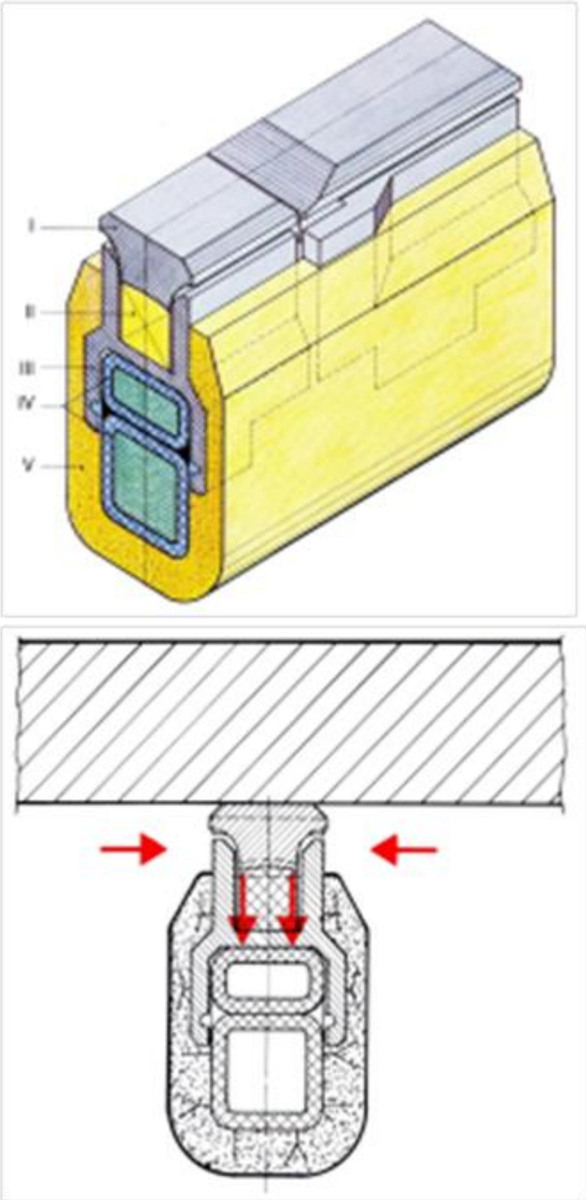
Figure 10a [15] shows the view of skid with riders in so-called hot skids from Salem Engineering Company Ltd (Milford, England). This developed and patented system by Peine Salzgitter AG (since 1998-Salzgitter AG) was designed for a pusher furnace with an output of 300 tons per hour. Figure 10b shows the view of skid with riders used in the pusher furnace in VSŽ Oceľ s.r.o. type Italimpianti [16].

One of the most progressive systems is the design according to the company Koppers-Wistra (Figure 11 and 12) [18]. From the recapitulation of the knowledge about pusher furnaces with ADAPT skids follows:

- Better thermal uniformity which results in more even material properties of the final product.
- No grooves and scrathes, which guarantees a fault-less surface.
- Lower sliding resistance, which ensures better mobility during heating process.
- Furnace design without a fixed soaking hearth i. with double-side heating which ensures stable performance or there may be only a slight in performance with increasing slab thickness.
- Sturdy and strong skid construction, which has guaranted durability of the skid insulation, lower heat and water consumption.
- Reducing the cost of removing fixed hearth every 2-3 years.

Materials and products made of alumino-silicate fibres obtained the widest application in the nineties of the last century. They are divided into three classes according to their oxide content:

- Mullite-silicate (approx.50% Al_2O_3) with a temperature of use up to 1150-1200°C
- Mulitte (60-65% Al_2O_3) with a temperature of use up to 1350-1400°C
- Corundum (95% Al_2O_3) with a temperature of use up to 1600°C



I –rider, II- ceramic element, III –metal chamber, IV – skid, V ¬– insulation

Figure 11 ADAPT system from KOPPERS-WISTRA [18]

The first two classes contain glass fibers, third class polycrystalline. The limit temperature of fibers use is associated with a change in their structure:

– crystallization of the glass phases in glass fibers,
– small crystals growth in polycrystalline fibers.

In the manufacture of fibers, additions are added to improve the properties. For example, the working temperature of the mullite-silicate fiber can be increased by 200°C at 8% Cr_2O_3.

Companies Johns - Manville, Carborundum, Babcock and Wilcox, Bloomengineering (USA), Morganite Ceramics Fibres, Thermal Ceramics (Great Britain), SEPR(France), Calderis (Austria, Germany), RATH (Germany, Austria) produce a wide range of fibers and products [6,12]. The products of the above companies under brand Fiberfrax, Cerafiber, Triton-Kaowool, Superwool in the form of finer and coarser fibers, felts, boards, blankets, modules, fabrics, papers and cords are designed for use at temperature 1250 - 1400°C. The polycrystalline oxide fibers from Imperial Chemical Industries (Great Britain) Saffil type are designed at temperature 1500 -1600°C. The organic or innorganic binders are added to it in order for said material to be in the required form or specified properties depending on operating conditions.

The insulation technology consist in wrapping the pipe with fiber or felt reinforced with refractory wire with pitch 100-200 mm, or in wrapping pipes with a fibrous cord. A layer of mullite-silicate fibre of thicknes 50 mm, reduces heat loss during skids cooling 15-20 times. Cooling water consumption decreased from 1660 to 550 $m^3.h^{-1}$ and its temperature from 70 to 25-30°C, for example when using Triton - Kaowool type fiber instead of the classic refractory material. Fuel saving represented approx. 15%. Used fibres with the addition of chromium oxide brand Fiberfrax company Johns-Manville, resulted in a reduction in heat loss through the pipe walls on average from 250 to 12kW.m^{-2} [3,6,19].

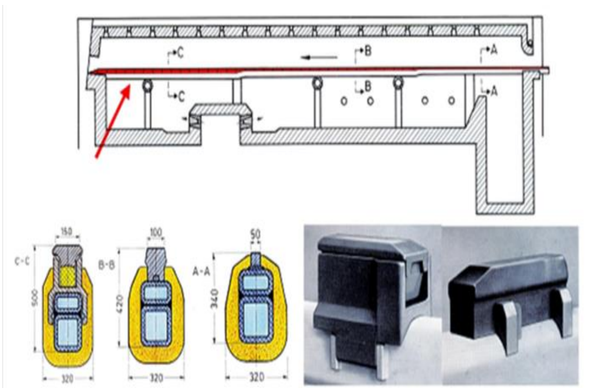


Figure 12 ADAPT system from KOPPERS-WISTRA in individual zones of the furnace

Another way to make fuel consumption more efficient is the use of fiber tiling modules. The first tests of pusher furnace with tiling modules were performed in the USA on Rouge Steel Co wide hot strip mill in 1980 [19].

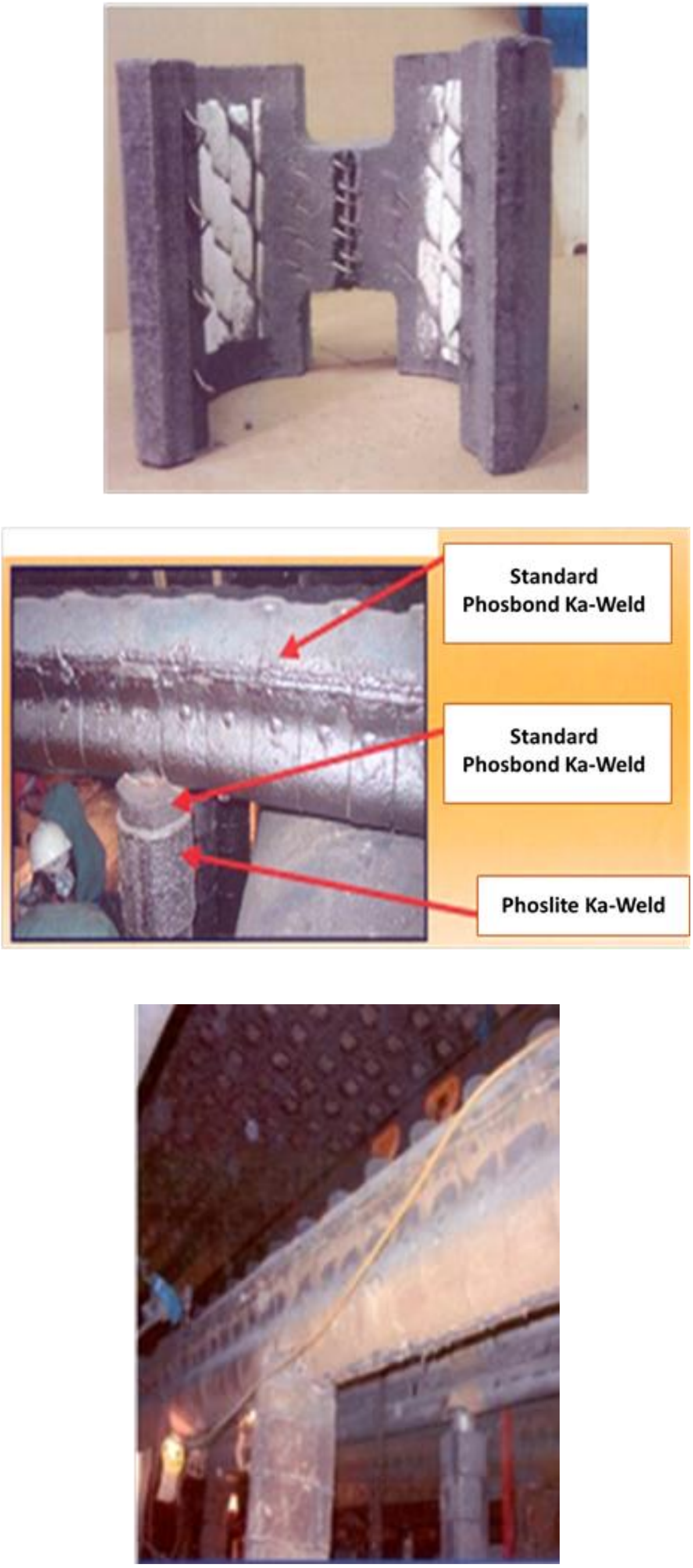


Figure 13 Insulation system from Ka -Weld [20]

Two tests were performed in order to determine the most suitable type of insulation for operation. The modules were installed on the roof and side walls. The tests confirm, that the modul was the most suitable with the temperature of use up to 1650°C for use on the roof. In each test a panel of ceramic fiber modules was evaluated in an arrangement of 4 times 5 modules. The panel area was 1,86 m^2. Temperatures were measured in the center of each panel using an optical pyrometer. For the side walls the modules were suitable for use up to 1480°C. After the operational tests, the pusher furnaces were insulated with ceramic fiber modules in the range of 85-95%. The operational experience with these modules was very good, no more serious problems occurred [19].

One of the last very efficient insulating systems consisting of tiling modules is Ka-Weld (USA), which is characterized by:

- easy installation,
- high strength,
- reduction of heat losses by cooling water up to 90-95%,
- resistance to scale.

The individual modules are two layer. The inner side is made of fibrous material, the outer side of lightweight castable, containing 40-98 % Al_2O_3, according to purpose of use and the height of working temperature (Figure13) [20].

In conclusion can state following:

- Thermal insulation of the support system in the pusher and walking beam furnaces reduces fuel consumption by 10-25% compared to a non-insulated system, increases maximum productivity of furnace by 17% and considerably improves the heating quality of the slabs.
- Two-layer insulation appears to be the most effective, wherein the outer layer consist of castable or castable blocks, which are neutral to the effects of scale and flue gasses, the inner layer consist of refractory fibrous material with high thermal insulation property.
- The monolithic refractory castable layer as a protective layer is universal. It allows to insulate pipes of different diameters by doubling and different curve section.
- Advantage of suspended block insulation over monolithic is that it can be installed in a few shifts at least two weeks are required to make the insulation in the classical way (monolithic design).

They were listed at the beginning of the chapter on insulation of water cooled support system of reheating furnaces the basic requirement for the thermal insulation of the support system were given. In terms of insulation strength, continuous vibration has a significant effects when relocating the charge. Dynamics impacts when pushing charge cause wear of the insulation, especially in the nodes, where the longitudinal skids meet the transverse and perpendicular systems (cross rails, vertical supports).

6 Results and discussion

Before discussing technical issue that need to be considered in reheating furnaces, it is important to understand the definition of the refractory material, types of refractory material and various methods that can be used install refractory materials.

When choosing the best refractory material for a given application it is important to consider what challenges are present. For example, does the refractory application have high abrasion issue or a large thermal profile variation (like can be seen in some reheating furnace hearths) As soon as the technical conditions are known, must be decided, what kind of material should be chosen and what installation method is best to suit a specific project (furnace condition, timing, costs, goal of furnace life etc.).

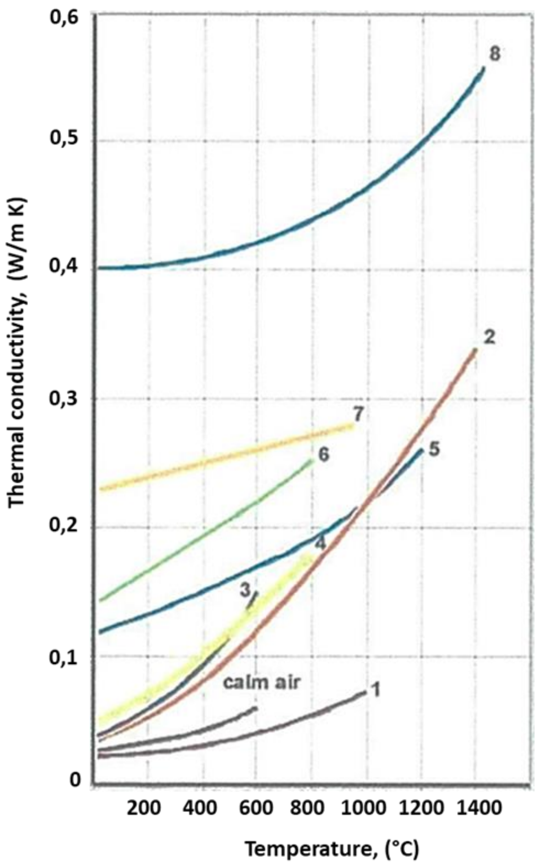
Monolithic refractory materials are an excellent choice of monolithic materials based on the experience of the 20 years, which are shaped and form a monolithic cladding without joints. The installation of monolithic refractories is usually more efficient and faster than relining or constructing a new reheating furnace versus brick installation. When the appropriate, state-of-the-art monolithic refractory is specified, the physical properties will be equal to or better then properties of brick.

There are four main types of monolithic refractories that are used in reheating furnaces. The types include:

- **Cast** - Under this monolithic type, there are four types of cast products as follows:
  - Hand Cast,
  - Vibration Cast,
  - Pump Cast,
  - Self – Flow.
- **Shotcrete**
- **Gunning**
- **Plastic**

Each type has specific advantages and disadvantages which should be considered when picking one over another.

New types of refractory materials are characterized by very low thermal conductivity. Comparison of thermal conductivities of individual groups of insulation materials is shown in Figure 14 [22]. The results in practice confirmed the assumption of higher service life of linings by incorporating more effective insulation. Due to the more effective insulation the thermal profiles in the layer of permanent and working lining will be levelled, while the mechanical stress is reduced in these layers. As a result, cracks and fissures should form more slowly. In addition, more effective insulation increases amount of accumulated in the working and permanent layer of lining. This contributes to smaller temperature fluctuations with an impact on their service life [22].



Curve	Material	Bulk density (g.cm^{-3})
1	Microporous insulation board	0,35
2	Ceramic fibre board	0,25
3	Mineralwool board	0,15
4	Calcium silicate board	0,25
5	Lightweight refractory brick	0,50
6	Vermiculite board	0,40
7	Lightweight refractory concrete	0,80
8	Lightweight refractory brick	1,04

Figure 14Comparison of thermal conductivity of individual groups insulation materials [22]

The discussion of technical problems also concerns the wall thickness in the reheating furnaces. An example of a wall thickness design in reheating furnaces is shown in Figure 15 [23]. Figure 15 shows three different wall design next to one another. The walls have to the same thermal peripheral conditions and consist of three layers. The wall thicknesses were designed so that a furnace casing temperature of 80°C will be achieved. The heat loss in stationary state is the same due to the given conditions and are in range of 802 to 809 W.m^{-2}. There are differences in regard to the storage heat. This is important for furnace operated periodically.

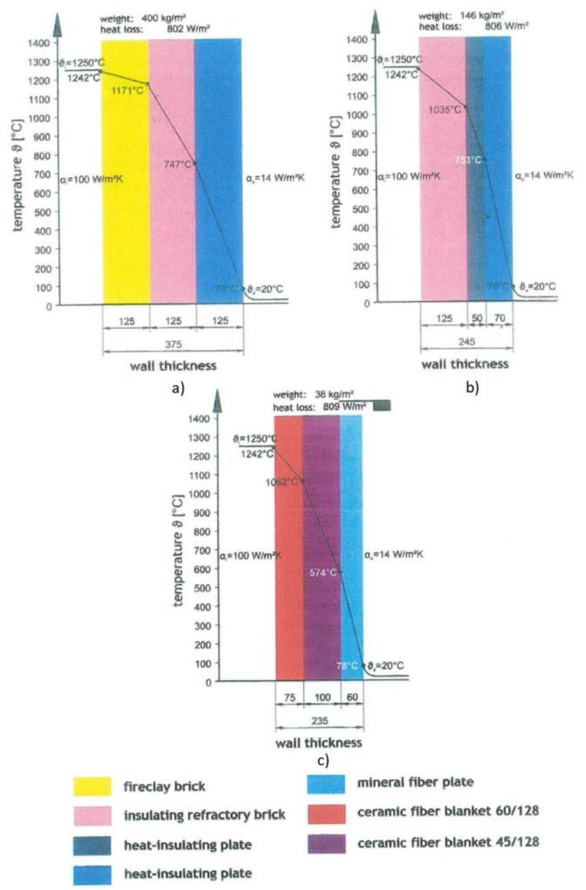


Figure 15 Three different wall designs with the same peripheral conditions

The physical properties of the lining in the individual wall design are given in Table3 [23].

Table 3 The physical properties of the lining in the individual wall design [23].

Technical data	Example a)	Example b)	Example c)
Furnace casing temperature [°C]	80	80	80
Heat losses [W.m^{-2}]	802	802	802
Weight of lining per unit area [kg.m^{-2}]	400	146	38
Wall thickness [mm]	375	245	235
Furnace working space temperature [°C]	1250	1250	1250
Furnace ambient temperature [°C]	20	20	20

Overview of used refractory materials in three examples of structural design is shown in the legend in Figure 15 [23].

In conclusion, it can be stated an increase in demand for thin-walled linings in the near future and here there is possibility of installing microporous materials with extremely low thermal conductivity. The installation of microporous materials usually requires an additional layer of another refractory material due to their low resistance to mechanical stress, and a relatively low operating temperature, approximately 1000°C.

Conclusion

Intensive development of all types of refractory materials has taken place over the last twenty years, which are used in furnace linings. This allows current manufacturers of rolled material a wide choice of refractory materials for a specific production according to the service life, quality of materials produced in rolling mills and economic evaluation of production.

The paper summarizes some scientific and operational knowledge, associated with the development of refractory materials at present.

The trend towards the widespread use of refractory castable and fibrous materials is significantly being promoted. This brings an increase in the quality of linings and their service life and ultimately energy savings and cost reduction.

The development of new Technologies in the production of rolled materials constantly evokes new quality requirements for refractory products and shortening the repairs of reheating furnaces.

The reference list

[1] RUSNOK, S., ZEITLER, J.: *Nové metódy vyzdívání ohřívacích pecí válcoven.* 10.mezinárodní metalurgická konference Metal 2001**,** 15.-17. května 2001, Ostrava,Tanger s.r.o.

[2] Refractories for a Reheating Furnace, [Online], Available: https://www.ispatguru.com/ refractories-for-a-reheating-furnace/ [2020-07-28].

[3] TATIČ, M., LUKÁČ, L.: *Priemyselné pece I - Pece v hutníctve a strojárenstve*, TU v Košiciach, Hutnícka fakulta 2009.

[4] SEVEN REFRACTORIES, Slovenia: Refractory lining in walking beam furnaces [Online] Available: https://www.sevenrefractories.com/ wp-content/uploads/Seven-Refractories-Brochure-REHEAT-02.2016_WEB_brez-tabele2.pdf [cit. 2019-03-24].

[5] HIRJAK, R., BOUNZIOVÁ, J., KOŠČ, J., CHUDÍKOVÁ, D., PETROV, V., ŠIMKO, R., MIŠANEKOVÁ, V.: *Application of Castables Manufactured by RMS,a.s.Košice in Pusher Furnaces*, Refractories Interceram Manual 2017, Special edition, pp.016-021.

[6] TATIČ,M.**:** *Vývoj narážacích pecí v súčasnosti*, Habilitačná práca,HF-TU,Košice,2007.

[7] DOMICIANO, V., INOCENCIO, E.: *Pre-shaped refractory castable for reheating furnace burner blocks*, UNITECR 2017**,** September 26.-29th 2017, Santiago de Chile, pp.400-402.

[8] SIPRA s.p.a., *Refractory materials-installation and planning*, Italia, Pushing furnace 60t/h bottom and electrofused blocks revamping, [Online] Available: sipra-bs.com/references/pushing-furnace-and-electrofused-blocks-revamping/ [2020-11-20],

[9] CYPIN, C.J., ANUFREJEV, V.G., MICHALEV, G.A., STARCEV, D.A.: *Izolacija podovych trub nagrevatelnych pečej*, Čermetinformacija,Ijuľ 1988.

[10] HOPKINS, N., GHANDI, K.C.: Energy saving as applied to large multizone pusher and under- fired walking beam furnaces, *Iron and Steelmaking* No.4, pp.295-298, 1975.

[11] VEERECKE, F.J.: Furnace design improvements for efficient heating, *Iron and Steel Engineer*, No.8, pp.33-39, 1977.

[12] TATIČ, M., VARGA, A.: *Izolácia chladiaceho systému narážacích pecí***,** Zborník referátov: Medzinárodná vedecká konferencia Žiaromateriály, pece a tepelné izolácie,22.- 24 apríl 2008, Štrbské Pleso, Vysoké Tatry, pp.202-209.

[13] Cameron Therm, A-Rail/System, firemná literatúra Cameron Iron Works Ltd., Scotland, Edinburg 1978.

[14] VARGA, A., TATIČ, M.: Evaluation of Thermal Regime of The Slabs Heating in The Push Furnace in VSŽ a.s. Košice, *Metalurgija***,** Vol.38, No.3, pp. 171-176, 1999.

[15] Salem Engineering Co. Ltd., England-firemná literatúra 1978.

[16] VSŽ Oceľ, s.r.o.- Technické podklady a fotodokumentácia,1997.

[17] ENCE GmbH: Riders (Skid buttons), (online) Available: https://stellite-parts.ru/en/rolling equipment/hot riders/ [2020-10-02].

[18] Koppers Wistra, Stoβofen mit Adapt-Schienen helfen Walzwerksprobleme losen, firemná literatúra, Dusseldorf, 1975.

[19] HORSLEY, J.O., BOOGS, J.A.: Practical energy conservation measures in hot mill operation-

Rouge Steel Co., *Iron and Steel Engineer*, No.4, pp.35-41, 1983.

[20] Ka-Weld, Skid Pipe Insulation for European Market, Bloomengineering, Pittsburg,PA, USA.

[21] CAPRIO, J., CIARROCCA, M., RHOADS, B.: *Technical Refractory Challenges to Consider in Steel Reheat Furnaces*, [Online] Available: urc4u.com/technical-refractory- challenges-to-consider-in –steel-reheat-furnaces/, URC-United Refractory Co. PA, USA [2021-03-16].

[22] NEVYHOŠTĚNÝ, V.: *Keramika ve výrobě oceli a litiny*, XXIV. Celostátní školení tavičů a mistrů oboru elektrooceli a litiny s kuličkovým grafitem, Žďár nad Sázavou, Svratka,25. až 27. září 2019, Brno: Česká slévárenská společnost, 2019, pp. 68-74.

[23] *Refractory Engineering: Materials- Design-Construction*, Deutsche Gesellschaft, Feuerfest- und Schorsteinbau e.V, Vulkan Verlag, Bonn 2016.