REFRACTORY ENGINEERING STRUCTURES

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STUDY INSTRUCTIONS

Refractory engineering structures

For the subject Refractory Engineering Structures of the 3rd semester study field Thermal Equipment and Ceramic materials you will obtain study material for part-time study.

Prerequisites

The subject does not have any prerequisites.

Subject objective and learning outputs

To create a specialist in the refractory lining of the metallurgical and ceramic industry with the ability to design the lining of thermal-technical plants on the basis of operation demands.

After studying this subject through a student should be able to have:

knowledge outputs:

To characterize the basic principles of using refractory and thermal-technical materials.

To characterize the lining of concrete types of furnaces and thermal equipment in regards to the production technology in which there are carried out.

The technology of preparing linings from shaped and unshaped materials and repair technology.

skill outputs:

The ability to decide about the entire storage of plant linings from the technological operation point of view.

To design a lining, which will have the longest lifespan in regards to the economic budget of a given country.

How to communicate with the teacher:

At the beginning of the semester the teacher requires entering a semestral work project on metallurical plant lining design. The design procedure will be consulted about during the semester via e- mail or through personal contact. The project will be submitted at the end of semester and the teacher will inform the student up to 7 days.

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1 BASIC USE OF REFRACTORY MATERIAL

Chapter division:

- **furnace lining composition;**
- **lining types from the thermal loss point of view;**
- **the effect of furnace shape on thermal losses;**
- **furnance ceilings.**

Study time: 50 minutes

Objective: After studying this chapter through

- **you will know the most important factors having an effect on the lining lifespan;**
- **you will know individual types of lining storage used in metallurgy and other operations;**

Lecture

DECISIVE VIEWS IN LINING DESIGN:

- *Level of working temperature*
- *Single wall heating or in the entire construction*
- *Cyclical operation(inconsistent heat flow) or uninterrupted operation (consistent heat flow)*
- *Corrosion environment – aggresivity, direct contact with a liquid mass, contact only with a fluid environment*
- *Time of thermal exposure*
- *The temperature on the steel structure surface*

- *Operation risk*
- *Economic aspects*

Through a combination of various refractory materials with various co-efficient values of thermal conductivity λ it is possible to obtain a refractory lining of various thermal-technical properties according to furnace operational needs.

1.1 Furnace linings

- The furnace lining itself is most often two- and three-layered.
  - **Working layer** – it is in direct contact with the surroundings (gaseous or fluid) and thus has to be resistant to chemical effects; high strength in pressure under heat. From the thermal loss point of view this layer should be minimal, because it is relatively considerably thermally conductive and it is able to accumulate more heat than lightened or insulated materials.
  - **Remaining layers** have to reduce heat losses, and are of less refractory, lightened and insulated materials.
- For lining durability it is important to have the smallest gaps and to be the thinnest, the gaps are also not always suitable for the lining, because of the properties of the mortar, which fills in the spar, they never achieve the properties of blocks $\Rightarrow$ dry brickwork; the use of monolithic linings with refractory concrete.

1.2 Lining types from a heat loss point of view

- Single layer furnace lining
- A wall with external insulation
- A wall with internal insulation

Single layer furnace lining:

The composition of a single layer (viz Fig. 1) or several layers with close values of thermal conductivity λ is used for a furnace with interrupted or periodic operation, and it is in cases when losses through the lining surface are approximately the same as accumulation losses ($q = q_{ak}$).

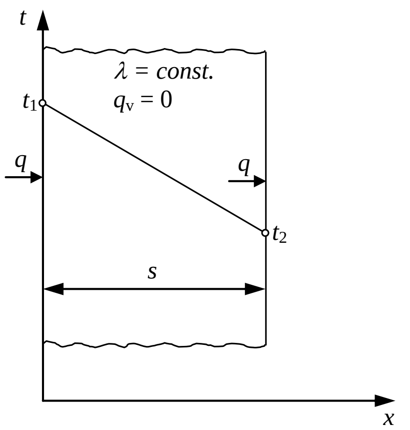


Fig. 1 Single layer furnace lining

A wall with external insulation:

It is used for furnaces with continuous operation, where losses in heat accumulation are small in comparison with losses through the surface of the linings ($q_{ak} < q$), (viz Fig. 2).

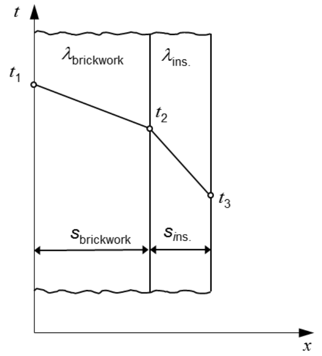


Fig. 2 Furnace wall with external insulation

A wall with internal insulation:

It is suitable for a furnace with continuous or periodic operation with a short operation time, that is for furnaces where it is possible to assume considerable accumulation losses ($q_{ak} > q$). The advantage of this type of lining is that it very quickly reaches working temperatures (viz obr. 3). For example, it is used in chamber furnaces for ceramic firing.

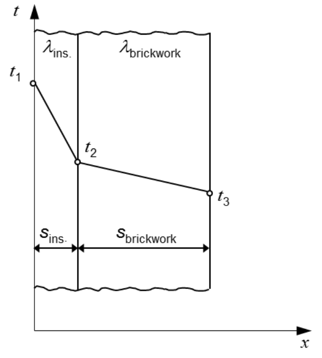


Fig. 3 Furnace lining with interior insulation

1.3 The effect of furnace shape on heat losses

- Rolling furnaces of the same thickness have linings with a smaller surface
- With the same type of lining rolling furnaces basically have less losses
- For a given thickness of external insulation there is required a thickness of internal lining for cylindrical furnaces less than that for square furnaces.
- For the prescribed thermal resistance of external insulation the insulation thickness for cylindrical furnaces is less than that for square furnaces.

From the point of view of heat loss, cylindrical furnaces are more suitable than square furnaces, nevertheless more square furnaces are built into operation, and those of a box shape, for they have more advantageous operation – technological properties.

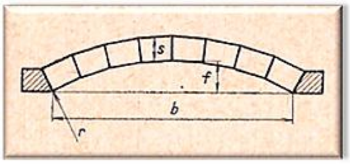
1.4 Furnace ceilings

- Flat ceiling
- Crown

The basic difference between a flat ceiling and a crown one consists in the fact that in a flat ceiling there occurs tensile stress, whereas in an crown one there is none.

Crowns:

In a span of 5,5 m there is used arched crowns; the rise of arch (b:f) for these crowns is 1:8, the crowns themselves bear a greater rise of arch, because its expansity is small. Silicate crowns bear 1:10, but not smaller (viz Fig. 4).



f - crown height b- crown height s - crown thickness

Fig. 4 Furnace crown

Taken from: Tichý, O. Tepelná technika pro keramiky

For a greater span than 5,5 m there is used a suspended ceiling ⇒ the blocks are suspended on load-bearing steel structures, which is not built in high temperatures. It is necessary to calculate that the interior walls under the effect of considerably high expandability cause the crown to lengthen, and for example there is designed a moveable funicular arch.

Concept summary:

After studying this chapter through the following concepts should be clear to you:

- **decisive views on lining design;**
- **furnace linings – the composition of furnace linings from the heat loss point of view;**
- **furnace ceilings.**

Questions:

1. What are the main decisive viewpoints in selecting suitable linings for given technological equipment?
2. What furnace shape is most suitable from the furnace heat loss point of view?

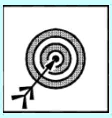
3. What types of linings do we use in furnaces, where it is necessary to very quickly reach a working temperature?
4. Why is it more suitable to use a crown ceiling than a flat one?

2 AN ANALYSIS OF STANDPOINTS HAVING AN EFFECT ON THE SUITABLE SELECTION OF REFRACTORY LININGS

Chapter divisions:

- **maximal temperature of using refractory material – heat resistance vs. bearing capacity in heat and flow;**
- **the effect of lining heating methods on the lifespan and resistance of furnace linings;**
- **calculating temperature inside linings- fixedly;**
- **lining corrosion – the effect of corrisive liquid flow on lining lifespan and consequent provisions.**

Study time: 580 minut



Objective: After studying this subject through

- **you will know why heat resistance is not enough as a basic and only characteristic of refractory material;**
- **you will be able to describe the issue of furnace linings from a thermal point of view;**
- **you will be able to calculate the temperature of lining interiors with flat, cylindrical, spherical, simple and complicated walls;**
- **you will be able to design refractory materials for furnace linings in regards to the corrosive effect of the surrounding environment.**

Lecture

In this chapter you will gradually go through individual points of view, which have to be taken into consideration when designing lining storage.

2.1 The maximal temperature of using refractory materials

Although material maintains a temperature of 1500 °C, itstill does not mean that it can be used up to those temperatures!

Material heat resistance:

- The maximal temperature of (heat resistance) use, given by the producer is only an orientation value, which always depends on operational conditions, mostly on the heating method (single-sided or in the whole construction)
- A lining is loaded mostly by pressure, that is why it is more suitable to focus on the *bearing capacity in the heat* (single-sided heating) or *flow in pressure* (heating in the whole construction), rather than on material heat resistance
- <u>**Above all, we require to preserve the permanence of a shape, deformations are not permitable !!!**</u>

2.2 Other important properties of refractory materials

Porosity, Absorbability, Thermal conductivity, Thermal capacity, Volumic mass, Chemical composition, Thermal expandability, Permanent length changes, Resistance against sudden temperature changes, Resistance against the effects of slag.

2.3 Heating methods

The heating method is another viewpoint, having an effect on the suitable selection of furnace lining, mostly in the selection of working material. **From the heating method it is mostly possible to determine the thermal loading of individual lining materials.** We divide heating into:

- Single-sided
- In the whole construction

2.3.1 Single-sided heating

If we are considering the continual uninterrupted heating of furnace linings, for determining the interior lining temperature we can use the equation of stationary heat conduction for composite flat, cylindrical or spherical walls.

If temperature depends only on one co-ordinate, for a flat wall it is possible to base it on equation:

$$\frac{d^2t}{dx^2} = 0 \qquad (K.\ m^{-2}) \qquad (1)$$

where t is temperature (°C),

x - co-ordinate in the direction of axis x (m).

For a cylindrical wall:

$$\frac{d^2t}{dr^2} + \frac{1}{r} \cdot \frac{dt}{dr} = 0 \qquad (K.\ m^{-2}) \qquad (2)$$

where r is the radius of the cylindrical wall (m).

If we are considering a simple flat wall (viz Fig. 1), after introducing surface conditions we get the following equation for calculating the density of heat flow:

$$q = \frac{\lambda}{s} \cdot (t_1 - t_2) \qquad (W.m^{-2}) \qquad (3)$$

where λ is the co-efficient of the thermal conductivity of the wall ($W.m^{-1}.K^{-1}$),

s - the wall width (m).

Most thermal plants consist of minimally two layers of various materials, and thus in solving heat transfer conductivity we transfer from an equation for a simple wall to an equation for a composite wall (viz Fig. 5).

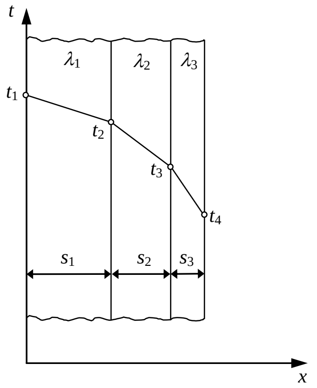


Fig. 5 A heat conductivity diagram of a composite flat wall

Solution assumptions for composite walls:

- Contact between individual layers is perfect, so that the surface temperatures of two contacting layers are identical.
- Heat flow density q in any location in the wall is constant.

This means that the resultant equation for the heat flow density of a composite wall is gained by calcultating the individual relations of the densities of heat flow for individual walls and after correction we get:

$$q = \frac{(t_1 - t_4)}{\frac{s_1}{\lambda_1} + \frac{s_2}{\lambda_2} + \frac{s_3}{\lambda_3}} \qquad (\mathrm{W.m^{-2}}) \qquad (4)$$

Generally for a flat wall composed of *n* layers it is valid that:

$$q = \frac{(t_1 - t_{n+1})}{\sum_{i=1}^{n} \frac{s_i}{\lambda_i}} \qquad (\mathrm{W.m^{-2}}) \qquad (5)$$

In specific calculations we will not consider them with physical properties as with constants, but if we have available their dependence on temperature, we can calculate them according to regressive equations.

In most solution cases we do not directly know surface temperatures, but only the temperatures around these surfaces. In these cases we introduce a condition of the 3rd type and enter into the solution heat transfer co-efficient α between a heated (cooled) surface and the surroundings, which is composed of the heat transfer of convection and radiation.

For example in solving the equation of the heat of a simple cylindrical wall with a known temperature of internal surface t_1 and external surrounding temperature t_{ok} (viz Fig. 6) for the density of temperature flow we gain the following equation:

$$q = \frac{2 \cdot \pi \cdot (t_1 - t_{\mathrm{ok}})}{\frac{1}{\lambda} \cdot \ln \frac{r_2}{r_1} + \frac{1}{r_2 \cdot \alpha_{\mathrm{c,ok}}}} \qquad (\mathrm{W.m^{-1}}) \qquad (6)$$

where q is the linear heat flow density of the cylindrical wall (W.m^{-1}),

t_1 - the temperature of the interior wall surface (°C),

t_{ok} - the surrounding temperature on the external cylinder surface (°C),

λ - the co-efficient of a wall´s heat conductivity (W.m^{-1}.K^{-1}),

r_1 - the internal radius of the cylinder wall (m),

r_2 - the external radius of the cylinder wall (m),

$\alpha_{\mathrm{c,ok}}$ - the entire co-efficient of heat transfer (W.m^{-2}.K^{-1}).

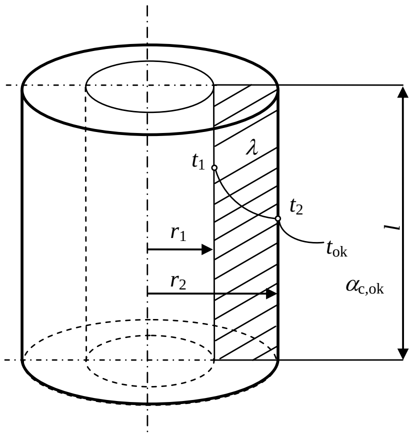


Fig. 6 Diagram of heat conductivity of a cylindrical wall

Materials loaded only on a single side are tested and evaluated by the **testing bearing capacity in heat**. In single side heated linings in refractory materials there arises a big temperature gradient and it is necessary to inspect these materials for **resistance against crack formation**. A refractory material has good resistance against crack formation, if it has:

- High strength (*at tension:* σ_t)
- High temperature (λ) resp. heat conductivity (a)
- Low elastivity module (E)
- A low co-efficient of thermal lengthened expansion (α)

2.3.2 Heating in the whole construction

It mostly deals with non-stable temperature flow, that is in determining the thermal state of linings it is on the basis of operational measurements and numerical methods - the finite element method, the differential method (of screens), the finite volume method, etc.) Materials loaded in such a way have to bear thermal shocks. On the wall of these plants there are placed greater claims, and thus the **temperature use of individial lining materials is basically lower than that for single-sided heating.** Materials loaded in such a way are put under **flow testing**.

2.4 Lining corrosion

Provisions for limiting corrosion come from an analysis of thermal-physical and thermochemical properties:

- Thermal physical properties of liquid flow – viscosity, surface stress (**moderately influential,** *due to slag additives*)
- Kinetic phenomena determined by a technological process – convection intensity etc. (**poorly influential,** the operation technology is given, *cooling of the lining*)

- The thermal chemical reaction between a refractory material and liquid flow (ternary diagrams, semi-operational and operational material tests = *the selection of suitable heat refractory materials*)

2.4.1 Suitable selction of heat refractory materials

Basic oxides, from which there is mostly slag composed of: CaO, Al_2O_3, SiO_2, or. FeO, MgO, Fe_2O_3, MnO. If there are predominantly present oxides C, A, S, it is possible to evaluate the reaction of slag with aluminosilicate heat refractory directly in a ternary diagram. (viz Fig. 7).

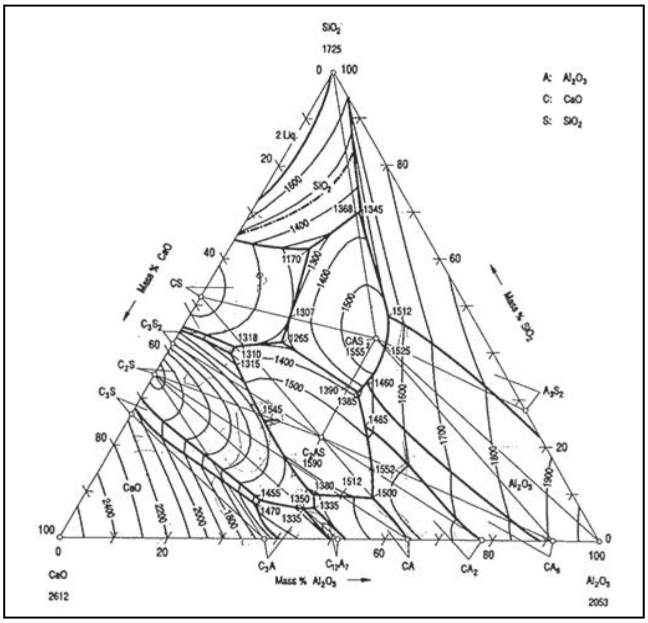


Fig. 7 Ternary diagram CaO-Al_2O_3-SiO_2

In determining the formation of compounds the melting temperature and the amount of liquid flow it is necessary to create a slag cut – heat refractory material as a pseudo-binary system (Fig. 8). We consequently look for non-variant system points, which go through the cut. From these points it is possible to consequently evaluate what temperature leads to the formation of liquid flow in reaction to slag.

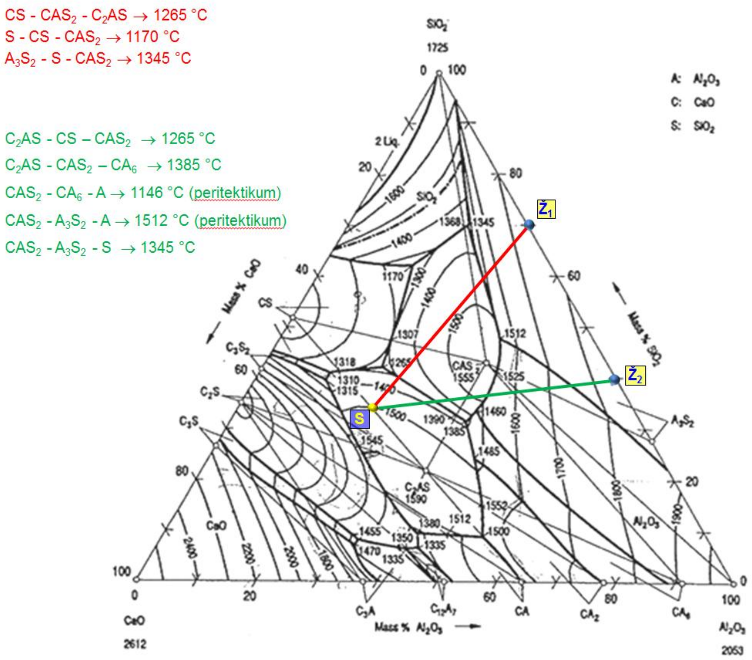


Fig. 8 The reaction of slag with aluminosilicate refractory material

In selecting refractory materials by exhibiting corrosion conditions :

- Materials are selected with the least porosity.
- The pores are filled up for example by carbon compounds, of course attention to their oxidation (antioxidants), in the steel-making industry this is shown in shaped refractory materials with a max. 5 % carbon.
- They substitute for the shaped refractory materials of monoliths.
- In extreme cases there are molten refractory materials (non-porous)

2.4.2 Adjusting the chemical composition of slag

In the steel-making industry, where a working refractory lining is from alkaline materials (dolomite, magnesite, magnesite-dolomite, etc.), it is possible to reduce wear by adding lime (CaO) into the slag, by which we reduce its acidity and thus its aggresive effect on heat refractory material. Correctly saturated slag contains a large amount of the saturated phase of CaO : $3CaO.Al_2O_3$ a $3CaO.SiO_2$ without losses in metallurgical properties (viz. ternary diagram C-A-S).

Another variant is slagging-off, or non-slag tapping.

2.4.3 Lining cooling

The speed of the chemical reaction is in the contact of the lining and liquid flow and thus the wear speed drops for thermodynamic and kinetic reasons with a reduction of temperature. At a certain temperature the thermal limit reaction temperature stops with the corrosion process. During the operation of a cooled lining at first as a result of corrosion the lining thickness decreases, cooling becomes more efficient and the temperature on the lining surface drops. The speed of lining wear gradually decreases until a state when the temperature drops on the working surface to the value of the linit reaction temperature. The corrosion process stops and the lining thickness remains practically constant.

Lining cooling is carried out using integrated metallic, water-cooled segments and it is used in blast furnaces and in intensified electric arc furnaces.

Summary conflict:

After studying this chapter through the following concepts should be clear to you:

- **heat resistance, bearing capacity in heat, flow in heat;**
- **lining heating methods;**
- **stationary and non-stationary heat distribution;**
- **corrosion;**
- **provisions against the corrosion of refractory materials by liquid flow.**

Questions:

5. Can you explain the concept of heat resistance, and how to test it?
6. Can you explain testing the bearing capacity in heat?
7. Can you explain flow testing?
8. Can you write a heat conductivity equation for a simple flat wall?
9. Which physical specification of refractory materials is necessary to know for the stationary calculation of the temperature of the lining interior?
10. Can you explain the difference between a condition of the 1st type and a condition of the 3rd type.
11. Which specification is necessary to know for calculating peripheral temperatues?
12. What is the corrosion of refractory materials?
13. How to prevent the corrosion of refractory materials?
14. Can you explain what resistance against crack formation is and how it arises?
15. Can you explain resistance against sudden temperature changes.

3 HEAT LOSSES

Chapter division:

- **heat losses;**
- **heat loss calculation in a non-stationary state;**
- **insulation effects on the entire thermal state;**
- **insulation effects on thermo-mechanical stability.**

Study time: 45 minutes

Objective: After studying this chapter through

- **you will know what heat losses are;**
- **you will be able to design a plant so that heat losses will be the lowest, in preserving the thermo-mechanical stability of given technological equipment.**

Lecture

In operating thermally-loaded equipment it very often depends on the fact that heat losses in the lining should be the minimum. For furnaces with continuous operation determining these losses is completely simple, because it is enough for us to calculate only the equation for stationary heat conductivity. For furnaces working cyclically, determining thermal flow through the brickwork is considerably more complicated, for the thermal field in the brickwork is non-stationary. Lost heat flow through the brickwork in this case is determined by the thermal flow from the external brickwork surface to the surrounding environment and the change of the lost heat flow of heat accumulation in the brickwork is thus:

$$P_z = P_{z,p} \pm P_{z,ak} \quad \text{(W)} \qquad (7)$$

where $P_{z,p}$ is the lost heat flow from the external brickwork surface(W),

$P_{z,ak}$ - the lost heat flow of heat accumulation in the brickwork (W).

Lost thermal flow from the external brickwork surface to the surrounding environment $P_{z,p}$ is calculted by the relation:

$$P_{z,p} = \alpha_c \cdot (t_p - t_{ok}) \cdot S \qquad \text{(W)} \qquad (8)$$

where α_c is the entire co-efficient of heat transfer from the external surface to the surrounding environment (W.m^{-2}.K^{-1}),

t_p - temperature of surface (°C),

t_{ok} - temperature of surroundings (°C),

S - the entire surface heat exchange (m^2).

The change of lost heat flow of heat accumulation in the brickwork can increase heat loss through the furnace brickwork (in heat accumulation into the brickwork) or to decrease (in a reduction of the furnace thermal input, when heat removal sets in from the brickwork to the furnace working area).

Lost heat flow of heat accumulation in the brickwork is determined by relation:

$$P_{z,ak} = V_z \cdot \rho'_z \cdot c_{p,z} \cdot \Delta\bar{t}_z \qquad \text{(W)} \qquad (9)$$

where V_z is the volume of furnace brickwork (m^3),

ρ'_z - volumic mass (kg.m^{-3}),

$c_{p,z}$ - specific heat capacity of the brickwork (J.kg^{-1}.K^{-1}),

Δt_z - the difference in mean brickwork temperatures per appropriate time segment (K.s^{-1}).

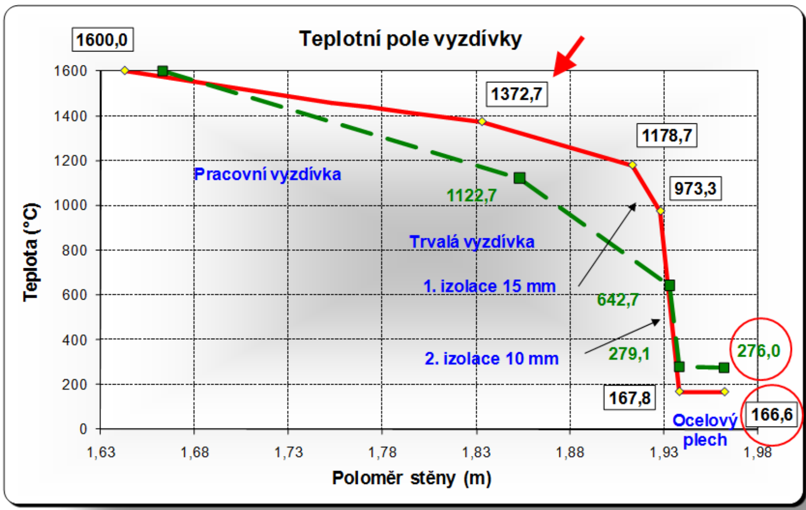
In equation (9) it is most difficult to state the value Δt_z. Its determination requires knowledge of the temperature course through the brickwork at appropriate time segments, which require the solving of non-stationary heat conductivity.

3.1 Insulation effects

Insulation materials reduce heat flow in linings, and thus they limit the transfer of heat conductivity, convection or both. The advantages and disadvantages of using insulation layers in linings:

- Insulation reduces heat losses through the lining
- Insulation reduces the coating temperature of equipment, by which we ensure its non-deformability.
- By reducing temperature differences on the edges of the blocks we limit crack formation, but we can reduce the load-bearing part of linings!
- permanent linings can work on bearing capacity limits!
- Great economic costs in acquiring insulation (special micro-porous and fibrous materials)

Insulation layers moreover reduce heat losses through the lining, but it is necessary to pay attention to the fact that we do not reduce the load bearing part of the furnace lining too much. Top quality insulation also leads to increasing the temperature of the furnace lining interior, which can exceed the maximal allowable limit of the stability of a given refractory material. The temperatures of the lining interior is necessary to determine in advance by calculation. A stationary calculation should be advantageous for us to determine maximal temperatures, which can be in the brickwork, in the case there are correctly determined peripheral conditions of calculation. In Figure 9 there is the temperature field of two linings. The first (green curve) depicts the lining temperature field with insulation and the second (red curve) is with insulation. In the diagram it is very clearly seen that the temperature of the coating for insulated linings is almost 110 °C lower (166,6 °C as opposed to 276 °C) than for those non-insulated, which is shown in the high retention of heat in the lining interior, of course the temperature on the boundary, working and permanent lining increases from 1122,7 (a non-insulated lining) to a value 1372,7 (an insulated lining). **So this high temperature can have instability in the permanent lining as a result!!!**



temperature Lining thermal field working lining permanent lining 1st insulation of 15mm 2nd. insulation of 10 mm steel plate wall radius (m)

Fig. 9 Insulation effect on heat loss through the lining vs. the thermo-mechanical stability of the lining

In the case that there is a calculation determining the thermo-mechanical instability of linings, it is possible to prevent this problem using three methods:

- By exchanging the material in places of thermo-mechanical instability, which means using a material with a higher bearing capacity in heat (heat resistance)
- By reducing the insulation ability of thermally insulated layers, which means using an insulation material with a higher co-efficient of thermal conductivity λ
- By reducing the internal temperature of the surroundings, which is possible but very difficult to fulfil in operation, in regards to a given technology of an operation.

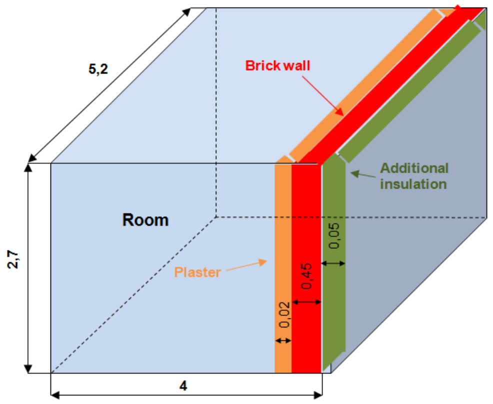
During any changes it is necessary to repeat calculations.

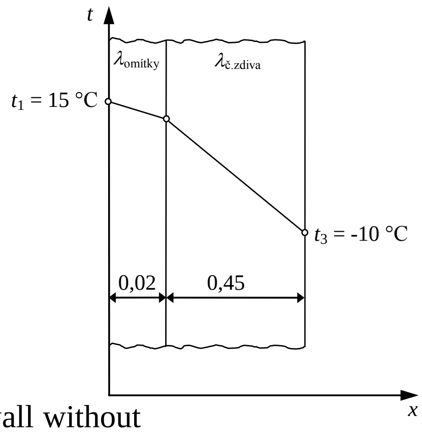
In the lining it is also necessary to observe temperatures, which can occur on the warmer sides of the insulation, in regards to its maximal thermal use ⇒ thermally damaged insulation does not insulate!

Solved example 1

The wall of a living room with a length 5,2 m and a height 2,7 m from red brickwork with a thickness 0,45 m which on a single side is provided with plaster with a thickness of 20 mm. The hourly thermal loss changes, when there is carried out additional insulation of the wall with foam polystyrene with a thickness of 5 cm. Interior surface temperature: 15 °C; external surface temperature: -10 °C; $\lambda_{\check{c},zdiva}$ = 0,67 W.m^{-1}.K^{-1}; $\lambda_{omítky}$ = 0,7 W.m^{-1}.K^{-1}; $\lambda_{polystyrén}$ = 0,035 W.m^{-1}.K^{-1}

The basic composition of a livingroom wall:





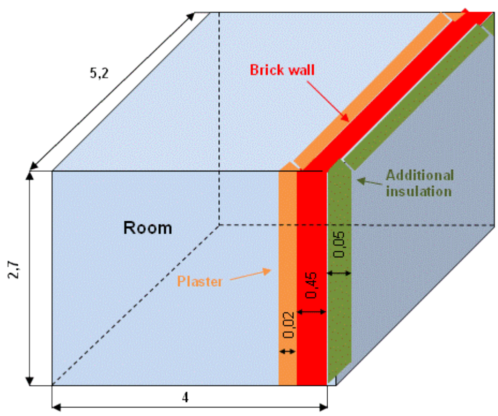
The density of thermal flow through a wall without additional polystyrene insulation:

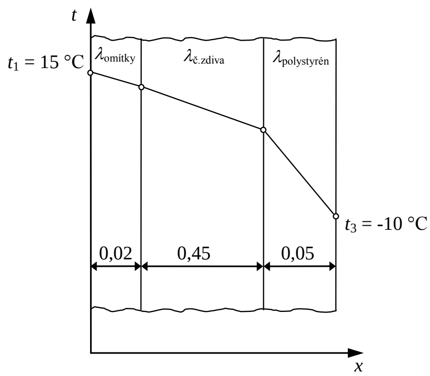
$$q = \frac{t_1 - t_3}{\frac{s_1}{\lambda_1} + \frac{s_2}{\lambda_2}} = \frac{15 + 10}{\frac{0{,}02}{0{,}7} + \frac{0{,}45}{0{,}67}} = 35 \ \ \mathrm{W \cdot m^{-2}}$$

Hourly heat loss in a wall without additional polystyrene insulation:

$$Q = q \cdot S \cdot \tau = 35 \cdot 5{,}2 \cdot 2{,}7 \cdot 3600 = 1{,}77 \ \ \mathrm{MJ}$$

Additional polystyrene insulation:





Density of heat flow through a wall with additional polystyrene insulation:

$$q = \frac{t_1 - t_3}{\frac{s_1}{\lambda_1} + \frac{s_2}{\lambda_2} + \frac{s_3}{\lambda_3}} = \frac{15 + 10}{\frac{0{,}02}{0{,}7} + \frac{0{,}45}{0{,}67} + \frac{0{,}05}{0{,}035}} = 11{,}7 \ \mathrm{W \cdot m^{-2}}$$

Hourly heat loss in a wall with additional polystyrene insulation:

$$Q = q \cdot S \cdot \tau = 11{,}7 \cdot 5{,}2 \cdot 2{,}7 \cdot 3600 = 0{,}59 \ \mathrm{MJ}$$

Hourly heat loss of a living room with additional insulated polystyrene is reduced 3 times (1,77/0,59 = 3).

Since in reality the coefficient of thermal conductivity λ is dependent on temperature, the calculation of heat losses is more calculated for temperature calculations on the boundaries of the individual layers of the lining interior. In this case it is simpliest to use an iteraction method. In calculating the temperature on the interface of more than two layers calculation without a computer is very time demanding. For this purpose it is completely enough to use the Microsoft Office Excel tabular calculator

Concept summary:

After studying this chapter through the following concepts will be clear to you:

- **heat losses;**
- **the method of calculating heat losses in a stationary and non-stationary state;**
- **the effect of insulation on the heat losses of furnace equipment.**

Questions:

1. What are heat losses and what variables characterizes them?
2. How do we calculate heat losses in a stationary state?
3. What total effect does insulation have on given technological equipment?
4. How many times higher is the co-efficient of steel thermal conductivity as opposed to a classic refractory material?
5. Why does the thermal conductivity of insulation material grow above a temperature of 600 °C?
6. With which do you ensure the thermo-mechanical stability of linings in the case of exceeding their thermal maxima?

4 LINING DESIGN IN THE AREA OF PIG IRON PRODUCTION

Chapter division:

- **blast furnace lining;**
- **blast heater lining;**
- **the lining of portable pig iron mixers.**

Study time: 200 minutes

Objective: After studying this chapter through

- **you will know the composition of the linings of individual metallurgical plants used in iron production;**
- **you will know the reason and principle of cooling linings;**
- **you will know how to elsewise protect the linings of furnace plants against corrosion by slag;**
- **you will know the most about loaded places in the lining and the methods of repair.**

Lecture

In this chapter there will be gradually gone through the linings of individual equipment in iron production. The focus will be mostly on critical places of the lining and materials, which are used in these places, or could be used.

The main part of this chapter is devoted to furnaces, and deals with their equipment:

- Blast furnaces
- Blast heaters
- Equipment for transporting pig iron (a portable mixer)

4.1 Blast furnaces

A blast furnace (BF), serving for the production of pig iron is the biggest melting plant. Its height reaches from 30 to 50 m and its diameter of its hearth is up to 15 m. In regards to the fact that piece solid charges enter the furnace, the blast furnace lining is loaded by combined mechanical, chemical and thermal loading.

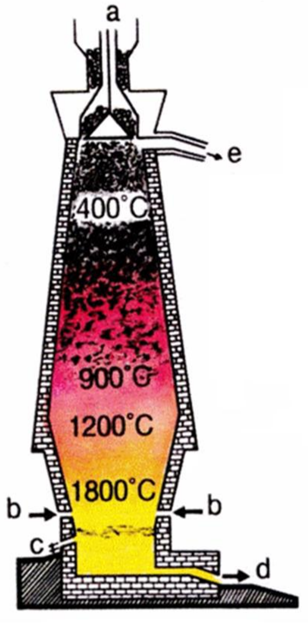


Fig. 10 Temperature distribution of the blast furnace interior.

For this reason it is necessary to also select a composition of blast furnace lining, which changes according to the height of the furnace. The temperature distribution in the furnace is in Fig. 10.

Blast furnace linings can basically be divided into three parts:

- Upper shaft part
- Middle shaft part
- Lower shaft part and hearth

Upper shaft part

Loading is mostly by abrasion (of low temperatures). There is mostly used here high aluminite materials with low porosity. Sillimanite, mullite, or SiC.

Middle shaft part

Loading by the corrosive effects of gaseous steam (mostly alkalines) and thermal tension. It is necessary for building material to be resistant to crack formation. Highly burnt aluminosilicate materials: corundum, MCC refractory concrete, or SiC. . Lining cooling is necessary!

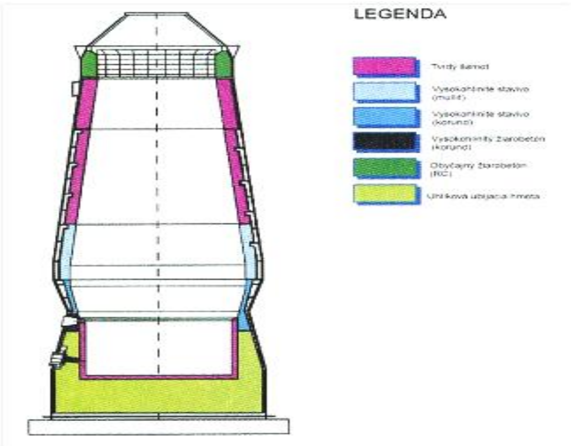
Lower shaft part and hearth

The most heavily loaded part of a BF and it is mostly by the chemical effects of alkalines and slag. Here there are used microporous carbon materials, carbon blocks with low porosity or a lining. Lining cooling is necessary!

Lining lifespan jis usually limited by hearth wear !!

The most up-to-date hearth lining is a ceramic pot, when a pernanent lining is made up of carbon blocks and a working lining of aluminosilicate materials, the best is synthetic mullite, concrete prefabricates of Al_2O_3 with a very low content of cement. Mullites with „low“ thermal conductivity (max. 3 $W.m^{-1}.K^{-1}$) act as a insulation layer and thus protects carbon blocks against high temperatures. The wall of a ceramic pot is made as a monolith.

In Fig 11 is a detailed schematic diagram of a classic blast furnace lining.



Hard fire clay

Highly aluminic building material (mullite)

Highly aluminic building material (corundum)

Highly aluminic refractory concrete (corundum)

Common fire clay

Carbon lining

Fig 11 A detailed diagram of a classically brick-lined blast furnace

Taken from: FRÖHLICHOVÁ, M., TATIČ, M. Žiaruvzdorné materiály v čiernej metalurgii

4.1.1 Cooling blast furnace linings

In order to maintain a BF for 20 years, it is necessary to cool it. The speed of the chemical reaction in the contact between the lining and liquid flow and thus the wear speed drops due to thermodynamic and kinetic reasons with reducing temperature. Ample cooling of the bottom and walls causes that thermal wear processes are carried out only to certain limits restricted by isotherms, after reaching or exceeding it, a thin layer of consolidated metal or slag is formed on the lining surface. Its vitreous surface then protects the lining against further wear and is called „**garnissage**“

Types of cooling:

- Water
- Expansion
- Evaporated
- Cooling materials at a higher boiling point

Reducing heat losses in cooled locations is possible to affect by the structure of the cooling elements, the cooling method and not to a small extent the insulation.

Types of cooling elements:

- Tubular
- Box

For a tubular cooling element, which is made up of a tube or a bundle of tubes, heat removal is carried out on the side of the cooling media mostly by convection (a high speed of flowing cooling media = a high co-efficient of heat transfer α. It is suitable for high thermal loading).

A box cooling element is adjusted in its shape to the shape of a furnace. It has a large cross-section and thus a low speed of flowing cooling media = a low co-efficient of heat transfer α. The flow direction is from downwards up.

Water cooling

The higher the temperature flow P, more intensive heat removal has to be ensured in order for cooling elements not to get burnt up. Heat flow is determined by measuring the mass rate of flow of cooling water at the inlet and outlet of a cooling element. Thermal loading is mostly determined experimentally, a pure calculated solution has limited accuracy due to the difficult determination of peripheral conditions.

Most metallurgical plants have a lack of water, so there is introduced a circulation system of supplying water. A lack of cooling water is one of the main causes that it is released in all plants from water cooling, which is marked out by its simplicity, but a considerable consumption of water and is transferred to mostly evaporated cooling, where water consumption is considerably lower.

Heat removal from a cooling element lining

Heat flow P acting on the wall of a cooling element can be either stationary, or non-stationary. The character is determined mostly by the technology of the production process, the kind of furnace and element location. For non-stationary heat flow there is used a partial differential equation of non-stationary heat conductivity and numerical methods.

In the case that the heat distribution in the wall of a cooling element is uniform, it has the most general validity of a condition of the 3rd. type, which supposes knowledge of the co-efficient of heat transfer to the surrounding environment and temperature environment. On the internal side it is possible to count a condition of the 1st. type, which means that we know the temperature of the internal surface of brickwork t_1, or we consider it equal to the temperature of the surroundings.

$$P = \frac{t_{\mathrm{ok},1} - t_{\mathrm{v,p}}}{\dfrac{s_{\mathrm{vyzdívka}}}{\lambda_{\mathrm{vyzdívka}}} \cdot \dfrac{s_{\mathrm{článek}}}{\lambda_{\mathrm{článek}}} + \dfrac{1}{\alpha_{\mathrm{k}}}} \cdot S \qquad \text{(W)} \qquad (10)$$

where $t_{\mathrm{ok},1}$ is the temperature of the internal surroundings (°C),

$t_{\mathrm{v,p}}$ - the temperature of cooling water of an average (°C[3]),

$s_{\mathrm{vyzdívka}}$ - lining width (m),

$\lambda_{\text{vyzdívka}}$ - the co-efficient of the lining´s thermal conductivity (W.m^{-1}.K^{-1}),

$s_{\text{článek}}$ - the wall width of the cooling element (m),

$\lambda_{\text{článek}}$ - the co-efficient of thermal conductivity of the cooling element wall (W.m^{-1}.K^{-1}),

α_{k} - the co-efficient of heat transfer by convection from the cooling element wall into water (W.m^{-2}.K^{-1}),

S - shared surface (m^2).

Water cooling of the thermal load is determined by measuring the mass rate of flow and water temperature difference at the inlet and outlet of the cooling element:

$$P = Q_{\text{m,v}} \cdot c_{\text{p}} \cdot (t_{\text{v,2}} - t_{\text{v,1}}) \qquad \text{(W)} \qquad (11)$$

where $Q_{\text{m,v}}$ is the mass rate of flow of cooling water (kg.s^{-1}),

c_{p} - the specific thermal capacity of cooling water (J.kg^{-1}.K^{-1}),

$t_{\text{v,1}};\ t_{\text{v,2}}$ - inlet; outlet temperature of the cooling water (°C).

In regards to this the heat removal from the wall of a cooling element is mostly by convection, and it is possible to write:

$$P = q \cdot S = \alpha_{\text{k}} \cdot (t_{\text{p}} - t_{\text{v,p}}) \cdot S \qquad \text{(W)} \qquad (12)$$

where t_{p} is the surface temperature, which is in contact with cooling water, in Fig. 11 it deals with temperature t_3 (°C).

From equations (11) and (12) it is possible to derive an equation for calculating the heat transfer co-efficient by convention from the wall of the cooling element into water:

$$\alpha_{\text{k}} = \frac{Q_{\text{m,v}} \cdot c_{\text{p}} \cdot (t_{\text{v,2}} - t_{\text{v,1}})}{(t_{\text{p}} - t_{\text{v,p}}) \cdot S} \qquad \text{(W.m}^{-2}\text{.K}^{-1}\text{)} \qquad (13)$$

The heat transfer co-efficient by convection from the wall of a cooling element into cooling water α_{k} is also possible to determine from experimental equations:

- <u>Tubular cooling element</u>

$$\alpha = 0{,}023 \cdot \frac{\lambda_{\text{v}}}{d} \cdot Re^{0,8} \cdot Pr^{0,4} \qquad \text{(W.m}^{-1}\text{.K}^{-1}\text{)} \qquad (14)$$

where λ_{v} is the water heat conductivity co-efficient (kg.s^{-1}),

d - tube diameter (m),

Re - Reynolds´ criterion (1),

Pr - Prandtl´s criterion (1).

$$Re = \frac{v \cdot d}{\nu} \qquad (1) \qquad (15)$$

where v is the speed of flowing water (m.s^{-1}),

ν - the kinematic viscosity of water (m^2.s^{-1}).

$$Pr = \frac{\nu}{a} \qquad (1) \qquad (16)$$

where a is the water heat conductivity co-efficient (m^2.s^{-1}).

$$a = \frac{\lambda}{\rho \cdot c_\mathrm{p}} \qquad (\mathrm{m^2.s^{-1}}) \qquad (17)$$

where λ is the water heat conductivity co-efficient (W.m^{-1}.K^{-1}),

ρ - water density (kg.s^{-3}),

c_p - the specific thermal capacity of water (J.kg^{-1}.K^{-1}).

- Box cooling element

$$\alpha = 232 \cdot \sqrt[3]{\Delta t} \qquad (\mathrm{W.m^{-2}.K^{-1}}) \qquad (18)$$

where Δt is the temperature difference between the external surface of a cooling element and cooling water ; in the case of boiler incrustation between the external surface of the boiler incrustation and cooling water (K).

In the case we are considering the wall of a cooling element with boiler incrustation, the equation (10) will be expanded for the thermal resistance of the wall of boiler incrustation ($S_{k,t}/\lambda_{kt}$).

4.1.2 Repairing blast furnace linings

Most often guniting or shotcreating – spraying a mixture on the lining (the lining repair technology is explained in more detail in Chapter 9). There is used a mixture of high aluminate refractory concrete with a low content of Fe_2O_3. After blowing out a BF the wall is cleaned from adhesive substances by pressure water (4 to 8 hours). It is best to spray it under computer control, for manual spraying it is necessary to cool the furnace out. The surface temperature of the repaired lining in contact with the spread material should move at an interval of 370° to 430 °C and in the furnace working space a max. 260 °C.

4.2 Heat blowers

They are used to preheat the air blown into the BF, by which the output of the BF increases and fuel is saved (coke). This concerns regenerators, for every BF there are 3 to 4.

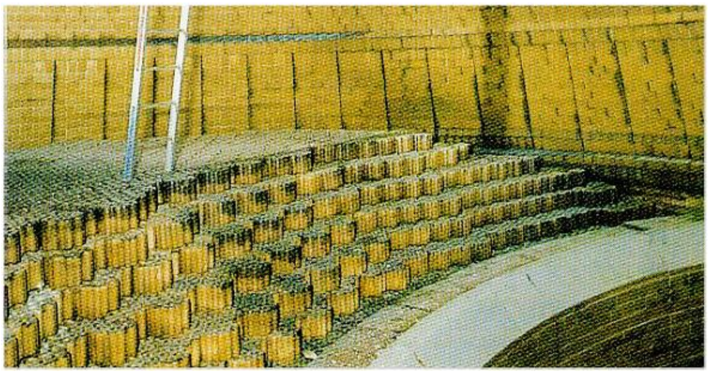


Fig. 12 Grated heat blowers

Taken from: FRÖHLICHOVÁ, M., TATIČ, M. Žiaruvzdorné materiály v čiernej metalurgii

The basic structure of the heat blower element is grated (viz. Fig. 12).

In ceramic burners blast furnace gas is burnt usually enriched by coke industry gas. After exit from a blast furnace blast furnace gas is purified in a blast gas dust collector. In Figure 13 there are heat blowers with a blast furnace.

The heat blower lining single-sidely and both-sidedly loaded, depending on the area. The most loaded places are:

- The upper part of the combustion shaft
- The cupola
- The upper part of the thermal accumulation fill

Fig. 13   (Cowper) heat blower and blast furnace.

The most loaded part of the heat blower is as mentioned above the blower cupola. For this reason it is necessary to use a special composition of lining. The lining cupola is made up of five layers and it is connected to the coating of the cupola itself without gaps, and it is put on the load bearing rings.

Currently the newest trend is the Kalugin heater, reminiscent of a cylinder. The structure is distinguished mostly in its layout of combustion chambers, which is located in the upper part of the structure. Heating combustion products are in a downward direction. It can basically be said that a combustion chamber does not exist. Gas combustion is carried out in the top parts of the ceramic fill. The advantage of this conception is its structural simplicity, as opposed to other types of combustion chambers.

In designing heat blower linings it is necessary to keep in mind that gannister building material can be used only in these parts, in which it is not possible to have a temperature drop below 600 °C, in regards to volumic changes of silica during its repeated warming and consequent cracking.

Among the most progressive trends in the development of heat blower liners there is the technology of spreading a highly radiational coating on the multi-shaped blocks (grated) composed of the parquette method in a thermally applied fill. The results are high energy savings and the reduction of CO_2. A radiational coating consequently has an increased air blast temperature of more than 15 °C, extending the time of air blast blowing by 10 % and reducing gas consumption for heating the heater by 7 %. A radiational coating in applied on the grating in high temperature areas (the upper part of the heater), and on the surface of the grating with particle dimensions from 25 nm to 2 μm. The surface of the gratings is treated by corrective technology before the spreading of the coat, and through a reduction of surface tension, which enables the highly-radiational material to infiltrate into the surface cavities of the block and to form a continuous coating on the grating.

Among the progressive trends in the development of heat blowers there is also the introduction of thin-walled grated blocks.

4.3 Equipment for transporting pig iron (portable mixers)

This concerns equipment, used in transporting pig iron from a blast furnace to a steelworks. In a steelworks pig iron is casted from mixers into a casting ladle and consequently into equipment for steel production (convertors, a tandem furnace, electric arc furnace).

A portable mixer is a vessel of a cylindrical shape, a hollow, almost enclosed cylinder, which is horizontally placed on a portable undercarriage (viz. Fig. 14).

It is tilted using pins, which are located on its front side, pig iron is casted through a throat, which also serves as a pouring ladle, by turning the mixer slighly along the longitudinal axis. Its capacity is around 100 to 600 tonnes.

The mixer lining is most often made up of 3 to 4 layers. They consist of a **working layer**, **permanent layer** and **insulation layer**. The insulation layer can be made of two layers.

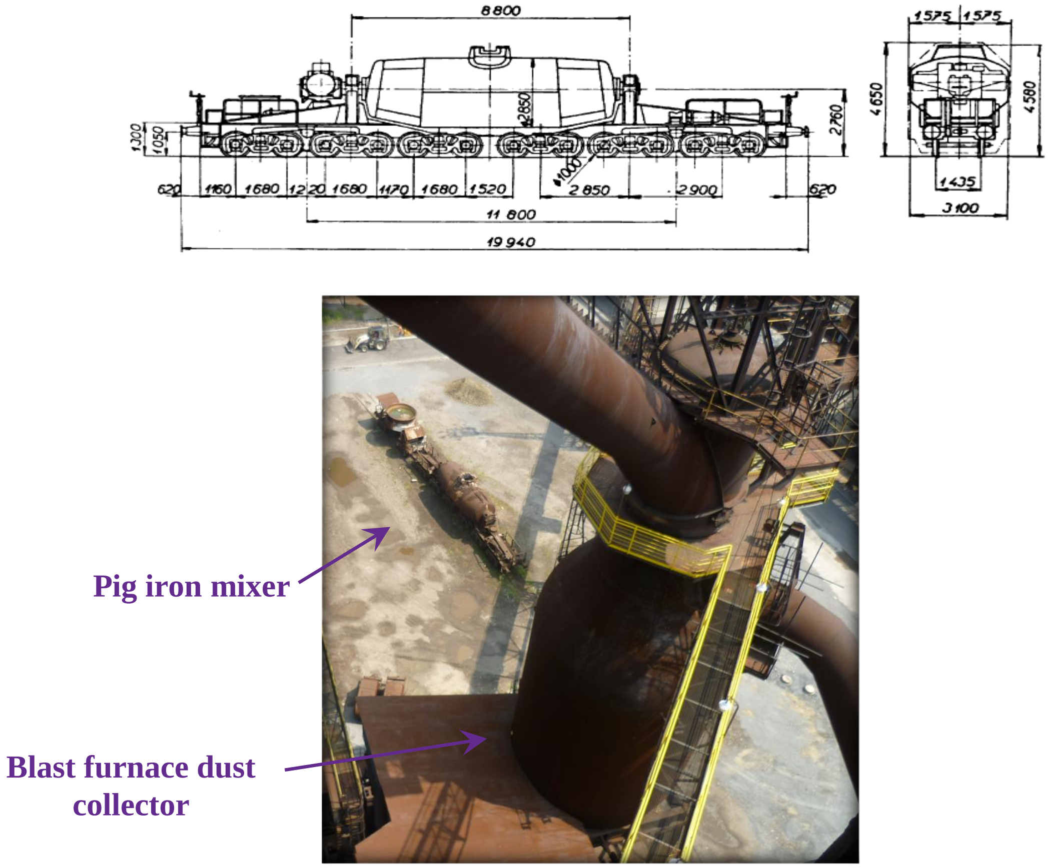


Fig. 14 Portable mixer of pig iron with a blast furnace dust collector

Working layer

The layer, which is in contact with the pig iron. It is most often made of highly aluminate material on the base of mullite, andalusite or bauxite. As opposed to corrosion it increases their impregnation resistance by carbon substances and thus reduces their porosity. Of course these products have higher thermal conductivity λ, and that is why it is necessary to increase the insulation ability of the lining. Introducing desulphuring and other processes leads to a drop in lifespan so much that new materials are developed on the base of Al_2O_3-SiC-C with bituminous bonds and it is mostly in areas of the metal impact in casting sulphur Fe into the mixer and also in the slag zone. Presently the linings of portable mixers are most often for the chemically- bound blocks on the base of bauxite.

Permanent layer

Most often fire clay, the use of hard fire clay.

Insulation layer

Fibrous insulation, for increasing thermal-insulation abilities, offers the possibility of using micro-porous insulation materials in combination with fibrous insulation materials.

During operation the lining is under pressure stresses, which are in balance with tensile stresses in the coating. **The principle that is valid is the**

lining has to solidly lean on the coating!!!

4.3.1 The selection of suitable material for the lining working surface

The selection of an optimal refractory material in the working layer depends mostly on the slag regime.

Bauxite blocks have a higher content of Al_2O_3 and thus greater resistance against slag with a ratio of CaO/SiO_2 above 0,9.

Andalusite blocks have higher resistance against flow, of course thanks to a higher percentage of SiO2 (as opposed to bauxite), there is less resistant slag with a percentage of CaO/SiO_2 above 0,9 and slag with a higher content of MnO.

These materials have an increased resistance against corrosion :**Al_2O_3-SiO_2-SiC** and **Al_2O_3-SiO_2-C** materials and **Al_2O_3-C** products bound with bitumen or pitch.

- In non-burnt materials containing C and SiC carbon is the guiding component of corrosion kinetics and a slowing down component of lining wear and thus the liquid flow does not soak building material surfaces and thus slows down the penetration of slag into the brickwork.
- Attention to carbon elimination in an oxidation atmosphere. It is partially possible to reduce this elimination using **antioxidants**, of elements with a high affinity to oxygen, by which it reduces CO released from oxidation on new secondary carbon (Al, Si, SiC).
- One of the possible preventions against oxidation is by adding glass (for example borosilicate), of which softness and melting at low temperatures consequently have the form of glass-like layers, which contain the particles C and SiC. This protective film increases resistance against oxidation and prevents the oxidation of the cold sides of materials.
- A small amount of open pores worsens the penetration of liquid flow into a material.

4.3.2 Mixer repairs

A pig iron mixer is usually repaired by the guniting using refratory concrete at a width up to 30 mm. Adverse guniting is possible to repair only by an accessible mixer location.

A second possibility is the method of **shotcreting**. The width of the sediment layer is 180 to 200 mm. The advantage of this method is that it is possible to carry out an application on some cold or hot surface and it is very quick.

Before casting pig iron, the mixer lining has to have the required temperature, and that is why a lining is heated on the stations for which it is determined. A newly built-in lining is dried and consequently heated according to the prescribed heating curve.

Summary concept:

After studying this chapter through the following concepts should be clear to you:

- **the concept of the working, permanent and insulation layers of linings;**
- **how we use materials for blast furnace linings, heat blowers and portable mixers;**
- **lining cooling.**

Questions:

1. For what do we say „garnissage“ and how is it formed?
2. Which blast furnace lining part is loaded the most?
3. What is blast furnace lining lifetime and with what is it possible to reach?
4. What types of lining cooling and cooling elements do you know?
5. Can you write an equation for calculating the heat flow through a wall composed of a single layer of refractory building material with a cooling element for a surface condition of the 3rd kind on both edges.
6. Which of the heat sharing processes distributes heat the most for heat removal from a lining while using water cooled elements?
7. Can you describe the lining of a heat blower:
8. Under what temperature cannot the gannister temperature drop and why?
9. Can you describe a pig iron mixer lining?
10. What are antioxidants?

5 LINING DESIGN IN THE AREA OF STEEL PRODUCTION – FURNACES

Chapter divisions:

- **convertor lining;**
- **tandem furnace lining;**
- **electric arc furnace lining;**

Study time: 40 minutes

Objective: After studying this chapter through

- **you will know the composition of the lining of furnaces used for steel production;**
- **you will know the causes of lining wear of steelworks plants.**

Lecture

Purifying pig iron produced in a blast furnace, partially removed mixtures (S, P and Si) in pig iron mixers is carried out in steelworks plants:

- Converter
- Tandem furnace
- Electric arc furnace

5.1 Converters

Purifying iron (the production of steel) in a converter is carried out by blowing in pure oxygen through a jet. Division:

- Through the top (LD)
- Through the bottom (OBM)

A converter is a steel vessel of an oval (pear-like) shape with a capacity up to 400 tonnes, bricked in by alkaline refractory materials. In the upper third of the steel coating there are pins, which enable tilting the converter in various metallurigical operations (casting pig iron, batching scrap, tapping, casting slag out). The working position of a converter is vertical. In this position there is carried out a whole technological process (deoxidation, alloying and adding slag additives). Tapping happens through a taphole, slag is casted out through the throat.

Today converter linings are **zonal** for even wear, and composed of two types of building material with various properties according to the method and intensity of loading so that is reaches even wear and increasing the durability of linings as a whole. For converters it concerns a combination of various types of MgO-C building materials.

Converter bottoms

The bottom is made up of a permanent layer and working lining. The entire permanent lining is made up of a combination of standard fire clay shapes and casted manganese building materials. The working lining is made up of wedge-shaped MgO-C blocks.

Since the bottom is a very loaded part of a converter, there exists exchangeable bottoms which after 500 to 600 meltings are changed completely (the rewalling of the entire converter lining is after 2000 to 3000 meltings = furnace life). An exchangeable converter bottom is in Fig. 15.

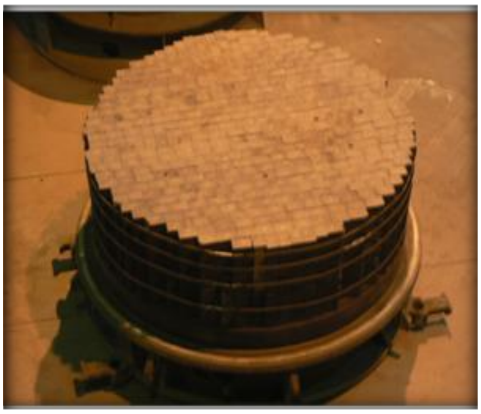


Fig. 15 An exchangeable bottom and its installation into a converter

Converter walls

Converter lining walls are variously loaded a thus have to distribute in these areas:

- Charging – MgO and MgO-C building materials bound with pitch or bitumen and antioxidants
- Pins – MgO-C building materials bound with pitch or bitumen with antioxidants or without them
- Slag lines – MgO-C building materials bound to pitch and bitumen, building materials from molten magnesium with antioxidants.
- Throats – Cased blocks from MgO-C

Tapholes

They are composed of a ringed outlet block (of rings) from MgO-C with a content of very pure MgO (98 up to 99 %). A longer life is achieved with isostatically pressed tubes.

The period of brick-lining furnaces to the complete knocking down of a furnace lining is called the **furnace life**.

5.1.1 Converter lining wear

Convertor linings are mostly are worn by corrsion by oxidized slag and the effects of temperature fluctations. For the wear of alkaline linings are directionally-given proportions in a system of MgO-CaO-SiO_2. In the proportion CaO/SiO_2 < 1 it is non-coexistent and it is diluted in the slag. In practice slag burns with additives of dolomite lime, burnt dolomite or caustically burnt magnesite usually at a level of 8 %, by which the border of its dissovability is moderatelly excceded. Excess MgO settles on the lining surface in a coating form of a characteristic type. Increasing the number of coolings causes an increase in lining wear. During very long downtimes this leads to a cooling of the brickwork surface, through which there arises a very high temperature difference between the internal and external parts = tension $\Rightarrow$ cracks. During repeated converter starts this leads to a sharp heating up of linings, which causes the peeling of external layers.. Long downtimes also cause carbon burn-up from the building material.

5.1.2 Converter lining repairs

It is presently possible to repair converter linings using several methods:

- Guniting
- Shotcreting
- Slag splashing
- Slag coating
- Blowing out the bottom
- Burning off growths on the throat and convertor walls by special jets

The individual procedures are described in detail in Chapter 9.

5.2 Tandem furnaces

A double-hearth furnace, in which one hearth there is purification using gaseous O_2 (as for the converter) and in the second hearth there is used heat and burnt CO waste gases for CO_2 for preheating solid charges. after each tapping the hearth functions are exchanged (viz. Fig. 16)

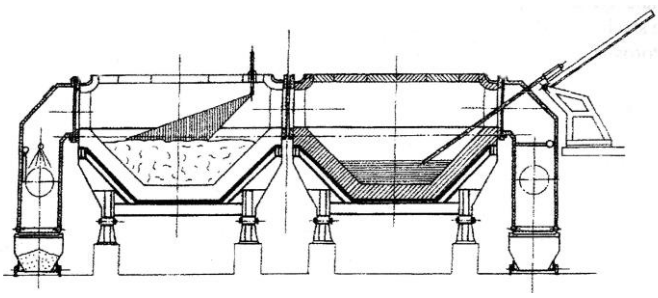


Fig. 16 Tandem furnace

A tandem furnace is currently operated by ArcelorMittal Ostrava a.s.

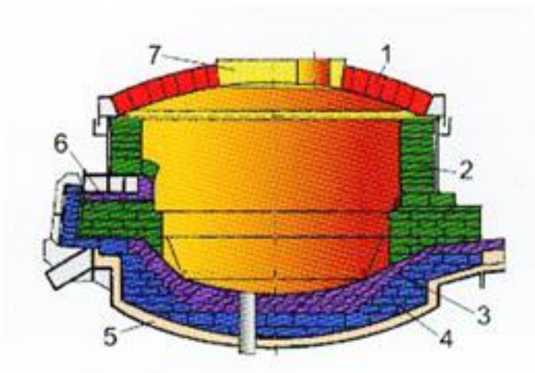
The most loaded places of tandem furnaces are the central furnace bridges (located opposite purifying jets), the vault (combustion product outlet) and ferroclips (alterating temperatures). In the furnace vault there are used **suspended** built magnesium – chromium bricks with special granulity. The blocks are suspended on additional structures using steel „anchors“, and thus it is possible to exchange them.

The lifespan of a tandem furnace is cca 580 meltings. Tandem furnace repairs are carried out by guniting using cleansing blowers on the most loaded places. This concerns themass on the base of ground reversible magnesium chromium materials soaked by water and soluble glass. During its whole life there are carried out cca 6 guniting repairs.

5.3 Electric arc furnace

It concerns equipment for the steel production from pig iron, by which energy is supplied in the form of an electric arc using an electrode. The great advantage of this process is the very great accuracy of temperature regulation. Of course the process has a high consumption of energy and is very noisy. On a furnace lining there are placed high demands, and the furnace interior reigns at temperatures of around 1800 °C. For this reason some parts of the furnace have to be cooled.

An electric arc furnace lining is very complicated, and is composed of various types of refractory materials. An illustration of one possible material arrangement of an electric arc furnace lining is Fig. 17.



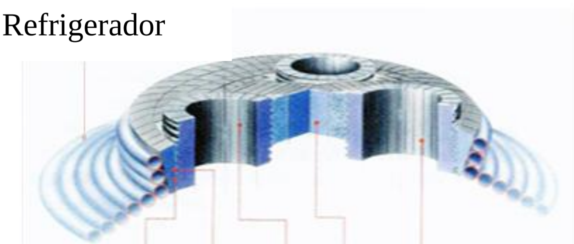
1. Shaped refractory material cover
2. Wall (MC, nebo MA-spinel)
3. Soil from rammed alkaline matter
4. Permanent lining bottom (MgO)
5. Insulation layer (fire clay)
6. Tamped matter of the slag opening
7. Monolithic electrode centre

Fig 17 Classic electric arc furnance lining

Taken from: FRÖHLICHOVÁ, M., TATIČ, M. Žiaruvzdorné materiály v čiernej metalurgii

One of the critical parts of an electric arc furnace are the vaults, which because of high thermal loads are often cooled. Furnace vault linings are produced either from blocks, or from monolithic mixtures. An example of a vault from blocks is in Fig. 18, an example of a monolithic vault is in Fig. 19.

Refrigerador



Cooler Cast-iron refractory concrete Mortar Vault block Electrode ringed block

Fig 18 Vault of an electric arc furnace produced from blocks

Taken from: FRÖHLICHOVÁ, M., TATIČ, M. Žiaruvzdorné materiály v čiernej metalurgii

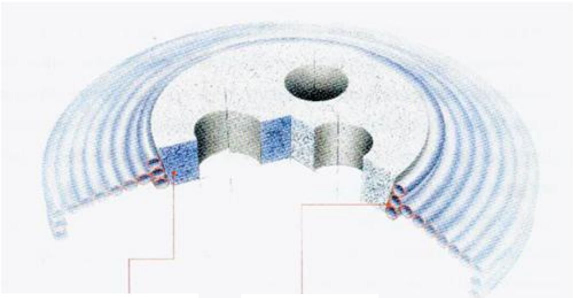


Fig. 19 Monolitic vault of an electric arc furnace

Taken from: FRÖHLICHOVÁ, M., TATIČ, M. Žiaruvzdorné materiály v čiernej metalurgii

Another critic part of an electric arc is the slag line, where there is contact between a lining and molten metal, slag and the gaseous phase. A possible solution is the technology of foamed slag.

5.3.1 Repairing electric arc furnace lining

Soil and walls are regularly repaired. They use a sector plate thrower suspended on a crane above the opening, and use coating material on the whole circumference of the brickwork or part of it, or a rotory thrower, where the mixture is transferred under pressure through a pipeline to a nozzle, where it is moistened and thrown on a damaged place. A classic rotatory thrower coats 1 tonne of mixture per 15 to 20 minutes. For the repairman´s mixture there is used for example calcinated magnesite with a grain size up to 3 mm. For HP a UHP furnaces there is used MC materials with a content of C > 20 %, in order to reach a high conductivity around the cooling box. Vaults, where the dominant part is made up of metallic cooling elements , around the eletrode are most often made in a monolith (casted or a highly aluminate thixotropic mixture with a content of Al_2O_3 85 až 90 %).

Σ

Concept summary:

After studying this chapter through the following concepts should be clear to you:

- **the concept of zone lining;**
- **the composition of converter lining;**
- **exchangeable converter bottom;**
- **tandem furnace lining;**
- **suspended blocks;**
- **electric arc furnace lining;**
- **possible furnace repairs for steel production.**

Questions:

1. Can you explain the concept of zone lining.
2. What material is mostly used for the lining of a converter´s working layers?
3. What are the two biggest causes of converter lining wear?
4. What does the concept furnace life mean?
5. Which parts of a tandem furnace are loaded the most and why?
6. What does it mean that the blocks are "suspended “ and in what parts of a furnace are they used?
7. Which parts of an electric arc furnace are loaded the most?

6 LINING STRUCTURES IN STEEL PRODUCTION AREAS – SECONDARY METALLURGY

Chapter division:

- **casting ladle lining;**
- **intermediate ladle lining;**
- **screening and submersible tubing;**
- **equipment lining for the vacuum treatment of steel .**

Study time: 40 minutes

Object: After studying this chapter through

- **you will know the composition of casting ladle linings;**
- **you will know the concept of zone linings;**
- **you will know measures against slag corrosion for casting ladles;**
- **you will know the composition of intermediate ladle linings;**
- **you will know the composition of equipment lining for the vacuum treatment of steel.**

Lecture

This chapter will go through:

- ❖ Casting ladles
- ❖ Intermediate ladles
- ❖ Equipment for the vacuum treatment of steel
- ❖ Ceramics for continuous casting

6.1 Casting ladles

A casting ladle is a vessel of a conical shape (viz Fig. 20) for tranferring steel from a furnace (TP, Converter, EOP) k ZPO (fluid steel casting equipment), where as a semi-operation a pot furnace is joined to the working down of steel by an electric arc (the warming up and additives), or equipment for the reduction of hydrogen in steel (a vacuum station) and other equipment. The content of a casting ladle is up to 200 tonnes of steel. There also exists a small casting ladle with a content of several tens of tonnes of steel.

Fig. 20 Casting ladle

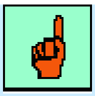
A casting ladle lining is set for temperatures up to 1680 °C, a partial temperature alteration (800 to 1680 °C), for alkaline liquid flow and acidic slag. There presently doesn´t exist an exact principle for a casting ladle lining, but there exists several types of linings:

- Zone lining made up of blocks
- Zone lining made up of blocks in walls and with a monolithic bottom
- Complete monlithic lining

Casting ladle lining from shaped material

The casting ladle lining is most often made up of a working layer, a permanent layer and an insulation layer. A lining´s working part is made up of various types of alkaline refractory materials. Most often there are dolomite or magnesium materials, the latest trends are AMC materials with a great proportion of Al_2O_3 (60 up to 80 %), MA materials or highly aluminate materials (bauxite). There are magnesium- chorium materials for the special production of steel.

The greatest lining wear is the slag line, where there is the wear of refractory materials due to the effects of acidic slag. In these locations there is best shown MgO-C materials with a content of carbon up to 10 %. Another critical location is impact places of steel flow (the bottom and bottom parts of the wall), where there are used higher quality alkaline materials, or it is made stronger in these places, which means that there is a greater thickness of the blocks used.



A working lining and the wall is dry, which means it does not use mortar or anything similar to it. After drying and heating the lining the heat effect leads to block expansion, which causes its cohesinveness and stability.

A permanent lining can be made out of fire clay or higher quality materials such as silimanite nebo andalusite, or it can be monolithic.

An insulation layer is made up of a single layer of fibrous aluminosilicate insulation, or it can be made up of two layers, which are made up of micro-porous insulation plates and fibrous plates.

In lining selection the most important factors are:

- The time the steel stays in the casting ladle
- The empty ladle time
- The time in the casting ladle after tapping
- The make of the treated steel
- Inert gas consumption for chemical and temperature homogenization

Before casting steel a casting ladle lining has to be heated up and regularly heated with a gas with a combustion material temperature around 1000 °C.

Monolitic casting ladle lining

The lining is again made up of a working lining, a permanent lining and an insulation later. The permanent and insulation layer of a lining are the same as in the case of ladles from shaped materials, and the working layer is made out of refractory concrete, that is. „thixotropy refractory concrete.“ The greatest advantage of a monolithic lining is that it does not have fissures, into which steel or slag corroding the lining can penetrate. Another advantage is that is does not have sharp corners between the bottom and the walls, which supports the laminar flow of liquid steel, which reduces heat-resistant material consumption and increases the recovery of steel. A monolithic lining is created using a pattern with built-in vibrators. The development of monolithic linings was directed towards refractory concrete on the basis of bauxite, tabular corundum up to corundum-spinel, where the best results are now born by a synthetic spinel with a regulated grain size so that there is limited the formation and spread of cracks in the lining during operation.

When drying out a lining it is often necessary to remove considerable amounts of spare water contained in new monolithic linings. That is why drying has to be carried out during slow temperature growth. During drying the lining is heated and spare water is removed. As soon as a temperature reaches 100 °C, water begins to evaporate and the temperature immediately increases in the pores. If pore permeability is high enough, the increased pressure begins to push water out from the lining and drying will continue without problems. If the permeability is low, tthe pressure will constantly increase and this causes a growth in the boiling point of water. In this way a mass can reach temperatures to 200 °C and will still contain spare water in a liquid form, this unstable state can lead to an explosion.

For new linings or repaired monolithic linings due to heating at sintering temperatures a ceramic bond is formed. In the non-uniform cooling of refractory concrete linings crack formation is possible, and that is why these linings are constantly maintained at higher temperatures. The drying and heating of monolitic linings from a time and technical point of view is one of the most demanding operations of preparing monolitic linings.

6.1.1 Casting ladle lining repairs

Just in connection with the monolithic linings linings we can speak about **endless linings**, whose principle is founded on the gradual repairs of partially worn linings during consumption of only 30 to 50 % of the original amount for a new lining installation, which is a great economic contribution of monolithic ladles as opposed to walled ones.

At the moment of lining wear at the lower boundary there is not the ladle, so as brickwork walls it is knocked down, but the surface of refractory concrete is ground off from slag, a mould is set into which there is completely poured the wastage of the refractory concrete lining, so that it does not lead to the demolition of the non-consumed material of the working lining. Such repairs are possible to carry out several times and always after the repair the lining acts as new, and that is why a monolithic lining is also called endless. From experience during operation it has been confirmed that consumed synthetic spinel exhibited thermal shock, but does not crack or peel off. It is also valid for spinel layers poured in after repairs.

Classic wall casting ladle during operation is repaired by guniting or shotcreating. Another possibility is after rewalling cooling only the working layers of the lining.

6.2 Vessels for degasing steel (DH, RH)

The equipment is determined for the vacuuming of large volumes of metals. Liquid metal is sucked by a suction tube into a vacuum chamber which is electrically heated and through the outlet tube metal is released back into the ladle or into the furnace.

- Lower part – MCr blocks from molten grains
- Center part – very dense MCr building material
- Upper part – common MCr building material
- Permanent and insulation layer – aluminosilicate blocks
- Possible substitution of MCr blocks by magnesium-carbon blocks

There is also becoming more common low cement refractory concrete on the base of Al_2O_3 and the spinel.

In regards to negative pressure the precision of blocks is necessary which means that the fissures between them are minimal!

6.3 Intermediate ladle and ceramics for continuous casting

Heat resistant materials in the casting parts of fluid steel casting coming in contact with liquid steel, slag, casting and covering particles, are thermally and mechanically loaded. The lining is made up of three lining layers:

- Working lining – magnesium mixture → spraying up to an 8 cm layer
- Permanent layer – aluminosilicate refractory concrete
- Insulation – aluminosilicate insulation heating materials

The intermediate ladle lining was warmed up from 1100 to 1200 °C.

Plates with shaft locking, screening pipes and submersible nozzles fall under ceramics for continuous casting.

Plates with shaft locking are on the base of Al_2O_3-C nebo ZrO_2-MgO, and more often today with AZC materials.

Screening tubes are mostly from isostatically casted ceramics on the base of Al_2O_3-SiO_2-C.

Submersible nozzles: The biggest problem, which occurs for submersible nozzles, is the growth of casting openings to Al_2O_3 sedimentation on interior nozzle surfaces. In order to reduce the thermal conductivity of the heating materials used, there are materials on the base of CaO-ZrO_2- C a Al_2O_3-C which substitute using carbonless materials. For the interior part of nozzles there is most often used today non-carbide aluminosilicate materials with a content of Al_2O_3 od 60 – 80 % for the casting of manganese steels with a high oxygen content using spinel materials.

Concept summary:

After studying this chapter through the following concepts should be clear to you:

- **what is the structure of casting ladle linings;**
- **slag line;**
- **monolithic lining;**
- **endless lining;**
- **RH, DH vessels**
- **the structure of intermediate ladle linings.**

Questions:

1. Which part of the casting ladle is loaded the most?
2. Which factors have the greatest influence on casting ladle lining wear?
3. What does dry walling mean?
4. What does the concept „endless lining“ mean?

5. Which materials are most often used in the slag lines of casting ladles?
6. Which forming technique produces screening pipes?

7 COKE-OVEN BATTERIES

Chapter divisions:

- **what coke-oeven batteries are used for;**
- **coke-oven battery linings.**

Study time: 15 minutes

Objective: After studying this chapter through

- **you will know the composition of coke-oven battery linings.**

Lecture

Coke-oven batteries are used for coke production. Coke is the solid remnant after high thermal coal carbonization, containing cca 85 % of carbon. High-thermal carbonization – the heating of coal at a temperature cca 1000 °C without access to air, through which coke and coke gas in formed. The acquistion price of a coke-oven battery moves around 1 billion up to 5 billion crowns. Coke-oven battery endurance is 20 years (the record is 34 years!).

Waste products during coke production are:

- Coke gas
- Tar, benzol, phenol, ammononium sulfate, sulfur
- Heat

Part of the formed temperature is used for coking coal charges.

The most used material today for coke-oven battery linings are:

SILICA – the most used material for building the heating walls of coke-oven batteries due to its high resistance to heat changes at high temperatures (it is not used there where a temperature can drop under 600 °C – modification alterations of SiO_2, which there are transferred volumic changes)

FIRE CLAY – moderately good resistance to thermal changes, practically all kinds of fire clay are used up to highly illuminate on the base of mullite - regenerators (frequent temperature alterations), the door (frequent temperature alterations), ceiling parts, smoke vents. If we take into consideration that we use fire clay also as insulation material (the layers between the coat and working layer), so it is the most often used building material in coke-oven batteries.

REFRACTORY CONCRETE – mostly packing and insulation material - stand pipes, oven doors, smoke vents, the sealing of oven frames (fine grain)

Materials on the base of Al-SiC (high λ) - chamber floors

Necessary silica qualities used in coke-oven batteries:

- it has to be perfectly modified, that is with minimal additional growth
- it has to ensure good heat access between the heating and the coke chamber
- High abrasion resistance

Σ

Concept summery:

After studying this chapter through the following concepts should be clear to you:

- **which materials are most often used in coke-oven batteries;**
- **what properties does silica used in coke-oven batteries have to have;**
- **which material in used the most in coke-oven batteries.**

Questions:

1. What is the lifespan of coke-oven battery linings?
2. Which conditions have to be fulfilled for silica use in coke-oven batteries?
3. Why do we use fire clay in coke-oven batteries?

8 GLASS FURNACE

Chapter division:

- **basic characteristics of glass furnaces;**
- **glass furnace linings;**
- **glass furnace regenerator linings.**

Study time: 25 minutes

Objective: After studying this chapter

- **you will know the composition of glass furnace linings;**
- **you will know the composition of glass furnace regenerator linings.**

Lecture

Glass furnaces are used for melting glass for glass production. They can be classified as:

- Pot
- One-day tank
- Continual tank (viz Fig. 21)
- Electric

Tank furnaces currently prevail over pot furnaces. During gas heating or with liquid fuel there have prevailed recuperative furnaces (80 %), and electric furnaces are spreading (smaller consumption of heating materials – recuperators are falling off). The lifespan of a tank furnace is 6 to 8 years. Melting temperatures move in a range of temperatures 1450 to 1650 °C. The consumption of refractory materials is 6 to 10 kg per tonnes of glass (for an electric furnace it is cca 4 kg/t of glass).

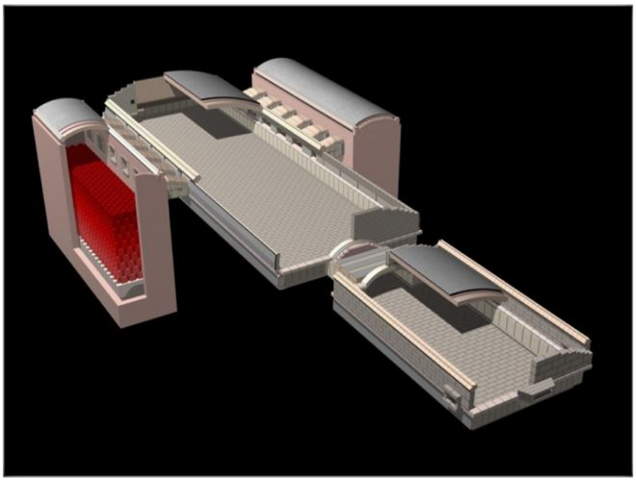


Fig. 21 Glass tank furnace

The most important places of glass furnace linings are:

- the glass surface level, where there forms excessive corrosion in contact with the glass – refractory material – furnace atmosphere
- the flow rate between the melting and the working parts – due to a quicker flow of glass
- furnace bottoms – vertical corrosion: holes are formed due to metal effects, mostly zinc and lead, by introducing fragments into raw glass batches
- the centre part of the regeneration chamber – condensation of alkalitic sulphate at t = 800 up to 1000 °C.

<u>The composition of glass tank furnace linings</u>:

Vaults are most often from silica

Walls are walled-in electrical melted refractory AZS materials (corundum-badeleytové) with a content of ZrO_2 30 up to 40 %. Most loaded wall places have special molten materials Al_2O_3- ZrO_2-Cr_2O_3 in the system. There is also used isostatic casted ZS (ZrO_2 -SiO_2) blocks or corundum with a content of Cr_2O_3, or ceramically bound (burnt) products on the base of AZS and Al_2O_3-ZrO_2-Cr_2O_3, which have good resistance against corrosion such as electric melted ones and also good resistance against sudden temperature changes (a lower proportion of the vitreous phase). Parts, which do not come into contact with liquid flow, are from classic aluminosilicate materials.

<u>Composition of tank glass furnace regenerator linings</u>:

Upper part: temperatures 1100 up to 1500 °C low ferritic magnesium blocks, or AZS or corundum.

Centre part: tempertures 800 up to 1100 °C and sulphate effects; MCr or MA (spinel) or M_2S (forsterite)

Lower part: temperatures up to 800 °C; fire clay

Concept summary:

After studying this chapter through the following conceppts should be clear to you:

- **glass tank furnace lining;**
- **regenerator lining.**

Questions:

1. Which places of a glass tank furnace are loaded the most?
2. What special materials do we use for glass furnace linings, coming in direct contact with the liquid flow?
3. Why do we use fire clay in a coke-oven battery?

9 LINING REPAIRS

Chapter divisions:

- **guniting;**
- **shotcreating;**
- **slag splashing;**
- **slag coating.**

Study time: 25 minutes

Objective: After studying this chapter through

- **you will know the traditional technology for repairing metallurgical plant lining;**
- **you will know non-traditional and special technology for repairing metallurgical plant linings.**

Lecture

During operation it is necessary to repair metalluririgical and other plant linings, which is much cheaper and quicker than exchanging whole lining pieces. As was written above, we try to make linings from various kinds of materials, that is zone linings, and for the reason that there is the same lining way and various loaded places. Nevertheless and despite this it is necessary to additionally repair some very loaded places during operation. If a lining repair happens without cooling it out, we are talking about a **hot repair**. In the opposite case we dealing with a **cold repair**, for which it is possible in most cases to repair greater amounts of lining, or to exchange entire working linings by leaving permanent and insulation layers.

9.1 Guniting

This deals with spraying mixtures on linings (viz Fig. 22).

Fig. 22 Guniting

Taken from: http://www.nzta.govt.nz/projects/victoria-park-tunnel/gallery-2011.html

They are usually mixtures with a high content of CaO , rich in MgO, which are joined either silicates (water glass) or phosphates.

A top-quality guniting mixture should have little linear contraction, a little amount of reflected materials (↓ granulity ⇒ ↓ reflection power), high heat resistance and resistance against thermal shock

This technique is possible to use for cold and hot repairs and guniting materials can be of many types.

- ***Semi-dry and wet guniting** - spraying the mixture on a lining – the dry mixture is taken through a hose with compressed air into the guniting gun, in which it is mixed with water and thrown on a vertical structure or on ceilings. The dry mixture is mixed with water until it is in the nozzle just before spraying*
- ***Fiery guniting** - a method founded on the use of exothermal metallic-ceramic substances, which we coat on a damaged lining with a special instrument. To initiate a reaction and to melt down correction matter there is used a propane-butane-oxygen burner or an electric arc.*

9.2 Shotcreating

It deals with spraying a mixture on the lining. The difference from guniting is that a *ready made mixture is pumped to the nozzle*. A solidification activator (a catalyst) still transfers it into the nozzle plus compressed air for mixing the refractory concrete mixture with the catalyst and for the spraying itself. With the nozzle material it can be applied to any cold or hot surface (viz Fig. 23). This method is 2 to 3 times faster than guniting.

Obr. 23 Shotcreating

Taken from: http://www.jetcrete.com.au/services/shaft-lining-with-shotcrete.aspx
http://www.alpinecompanies.com/retaining-walls-denver.html

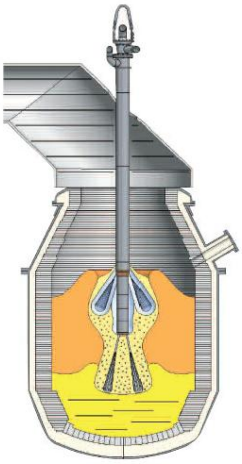
9.3 Slag splashing

Spraying fluid slag using compressed nitrogen. Liquid slag in used, forming during the melting process in a converter. By shifting the nozzle and changing the identity of the blown oxygen it is possible to regulate the places of slag impact (viz Fig. 24). Spraying time: 1 up to 5 minutes.

9.4 Slag coating

After tapping part of the slag is retained in the furnace and used for the repair of damaged places. During coating vessels places are then repaired with slag, by which slag creates a new working layer and protects the blocks against damage.

Slag is adjusted: by the saturation of magnesium material in the case of need it thickens. It is usual combined with guniting, because it is not possible for coating to reach critical places mostly the area around the pin.



Obr. 24 Slag Splashing

Taken from http://www.berrymetal.com/products/bof.htm

9.5 Other methods

There exists other lining repair methods, such as for example the injection of special substances with additives of black-coal pitch by a special mouthpiece across the coating opening (for blast furnaces), lining, which is coating necessary batches of repairman substances using blades of different types on damaged brickwork places and its smoothing it out using gravel (for coke-oven batteries), or only rewalling working layers or only slag lines.

Σ

Concept summary:

After studying this chapter through the following concepts should be clear to you:

- **hot repair and cold repair;**
- **guniting;**
- **shotcreating;**
- **slag splashing;**
- **slag coating.**

Questions:

1. What does the concept of hot repair mean?
2. What is the difference between guniting and shotcreating?
3. Can you explain the principle of slag splashing?
4. Can you explain the principle of slag coating.

LITERATURE USED

[1] STAROŇ, J., TOMŠŮ, F. *Žiaruvzdorné materiály – výroba, vlastnosti a použitie.* Lubeník: SLOVMAG, a.s., 2000. 445 s.

[2] FRÖHLICHOVÁ, M., TATIČ, M.. *Žiaruvzdorné materiály v čiernej metalurgii.* 2012. 372 s. ISBN 978 – 80 – 553 – 0906 – 4.

[3] PŘÍHODA, M.**,** RÉDR, M. *Sdílení tepla a proudění.* 2. přeprac. vyd. Ostrava, 2008. 177 s. ISBN 978 – 80 – 1748 – 4.

[4] RÉDR, M., PŘÍHODA, M. *Základy tepelné techniky*. Praha, 1991. 677 s. ISBN 80 – 03 – 00366 – 0.

[5] HAŠEK, P. *Tabulky pro tepelnou techniku.* 2. vyd. Ostrava, 1980. 247 s.

[6] TICHÝ, O**.** *Tepelná technika pro keramiky*. 1. vyd. Praha, ČSVTS 2004, 211 s. ISBN 80 – 02 – 01570 – 3.

[7] BOHÁČ, Z., ČASTOVÁ, N. *Základní numerické metody.* 3. vydání. Ostrava, 1997. 84 s.

[8] RÉDR, M., GOTTWALD, M., ŘÍMAN, A., REJČ, R. *Tepelné výpočty a optimalizace vyzdívek průmyslových pecí.* Praha, 1975. 351 s.

[9] HAŠEK, P., KLEČKOVÁ, Z. *Energetika v metalurgii.* Skriptum VŠB Ostrava, 1993.

[10] PŘÍHODA, M., HAŠEK, P. *Hutnické pece.* Skriptum VŠB Ostrava, 1987.

[11] RÉDR, M. aj. *Tepelné výpočty a optimalizace vyzdívek průmyslových pecí*. SNTL 1975.

[12] HAŠEK, P.: *Energetika v hutích.* Skriptum VŠB Ostrava.

[13] HANYKÝŘ, V., KUTZENDÖRFER, J. *Technologie keramiky*. 2. vyd. Silikátový svaz, Praha. 2008. 387 s. ISBN 978 – 86821 – 48 – 1.

[14] WALKENBACH, J. *Microsoft office Excel 2007 Programování ve VBA*. 1. vyd. Computer Press, a.s. Brno 2008. 912 s. ISBN 978 – 80 – 251 – 2011 – 8.

[15] WALKENBACH, J. *Microsoft office Excel 2007 - Vzorce a výpočty.* 1. vyd. Computer Press, a.s. Brno 2008. 712 s. ISBN 978 – 80 – 251 – 1765 – 1.

[16] TALER, J., DUDA, P. *Solving Direct and Inverse Heat Conduction Problems.* Springer Verlag Berlin Heidelberg 2006. 889 s. ISBN 978-3-540-33470-5.