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CONTROL SYSTEMS OF SINTERING PROCESSES IN ROTARY TUBULAR KILNS WITH USING OF THERMOVISORS SCANNING

I.V.SHARIKOV[1], **T.O.KOIRANEN**[2]
[1] *Saint-Petersburg Mining University, Russia*
[2] *Lappeenranta University of Technology, Finland*

The article considers the role of the lining in the tubular rotary kilns used for heat treatment processes of raw material in the metallurgical, chemical and other fields of industries. The method of selecting a new design thermal insulation elements, ensuring reduction of heat loss to the environment and more accurately to provide the required thermal processing mode through simulation can be used with ANSYS FLUENT software package. A system of monitoring the state of the lining with a thermal imager and control system that provides consistency lining without stopping the operating kiln has been developed.

Key words: Tubular rotary kiln, lining, 3D-modeling, monitoring the state of the lining, control of the sintering processes.

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Introduction. Lining tubular rotary kiln plays an important role in the implementation of the basic technological functions tubular rotary kilns (TRK) and ensuring their economical effectiveness. From the efficiency and integrity of the lining operation selected compliance depends optimum mode of processing and heat loss to the environment. Experience shows TRK operation through the outer surface into the environment is lost up to 10 % of the total consumed energy [6]. Lining protects the steel furnace and the operating staff from the effect of high temperatures and the furnace environment. It provides the required density of the gas in the working chamber of the furnace, i.e. complete seal to maintain the pressure needed for the process. Lining – is one of the major structural elements of furnaces, which enables implementation of high termotechnological and thermal processes in the furnace environment in the presence of mechanical stress while maintaining over time the geometric shape of internal furnace space, its construction and mechanical strength. It is in close relation with the charge, the products produced and the furnace environment [6].

Lack of thermal insulation materials with sufficiently low thermal conductivity and high mechanical strength, forced to look for new designs of heat-insulating elements that would ensure minimal heat loss to the environment [1, 8]. In addition, for stable operation of kilns in operation, it is necessary to create a control system that would allow to control the state of the lining during its normal operation and maintain the insulating properties. From the above it is clear that the creation of new designs of heat-insulating elements together with the monitoring and control system, is a very important issue for the successful operation of a wide range of industrial processes in the TRK [9, 10].

In alumina production TRK is used to sinter bauxite, nepheline and calcination (decomposition) of aluminum hydroxide. The sintering process bauxite in rotary kilns are considered. As it was shown in formed earlier analysis of processes occurring in TRK using experimental data on the kinetics of heat in the calorimeter heat flux [12] and the establishment of one-dimensional mathematical model TRK [13], depending on the temperature of the hot flue gases that heat the charge, and the changes occurring in the charge, the kiln can be divided into 4 zones.

The first zone – dewatering and drying – is at the top (cold) side and the flue gas has a temperature from 200 to 1250 °C, and the batch temperature – from 20 to 700 °C. It is removed here all the moisture.

The second zone – calcination – a gas temperature is changed from 1250 to 1400 °C and charge temperature is changed from 700 to 1000 °C. In this zone, full decomposition of the charge limestone is completed.

The third zone – sintering – has the highest gas temperature 1600-1650 °C and charge temperature reaches values from 1200 to 1650 °C. Here decomposition of the soda is finished and take place the cake forming. This zone is located within the length of the fuel combustion flame.

The fourth zone – cooling – is located in the lowest part of the drum furnace for firing the torch. Here gas temperature decreases to 1500-1550 °C. Proceeding in a refrigerator cake is cooled to 60-70 °C.

The sintering process is characterized by the exhaust gas temperature and composition of material flow in the kiln and the cake appearance. At the normal passing of the process flue gas temperature in the exhaust gas pipe of the kiln is 180-200 °C. These conditions provide stable operation of electric filters and fans. Normal cake material has dark gray color with pieces measuring 40-50 mm. In the exhaust gases should not be more than 0.4-0.6 % CO and O_2 and CO_2 content should be in the range of 25-27 % [1, 8].

In the rotary kiln for calcination of aluminum hydroxide are also observed temperature (technological) zones corresponding to specific stages of conversion of the initial hydroxide. Analysis of the gas flow material temperature and the furnace length allows to distinguish four zone.

The drying zone – the coldest upper part of the furnace, where the gas temperature is changed from 300 to 600 °C and the hydroxide – 40 to 200 °C. Here there is complete evaporation of moisture absorbent hydroxide.

Calcination zone – the middle part of the kiln. In this zone, the gases are heated to temperatures of 600-1050 °C and the hydroxide temperature is up to 200-950 °C. Thus there is a removal of chemically bound water and transforms hydroxide in anhydrous gamma-alumina.

The glowing zone is located in the area of the torch burning fuel and is going on here recrystallization of gamma-alumina and alpha-alumina, gas temperature is 1050-1400 °C, and alumina 950-1250 °C. Sometimes kiln drum diameter made slightly larger in the area than the diameter of the drum in the other zones. This achieves a reduction of material moving speed, and increasing the duration of its stay in this zone.

Cooling zone – the lower part of the furnace, where the temperature of the alumina is reduced from 1250 to 1000 °C. From this zone fed alumina in the refrigerator. With sufficient completeness of combustion and no air leaks in the flue gas should be 13÷15 % CO_2 and less than 0.8 % of CO. The calcined alumina should contain a certain amount of alpha-alumina.

Mathematical modeling of thermal fields in a fragment of the lining of tubular rotary kiln. One of the main factors determining the thermal efficiency of the kiln, is the quantity of heat resistance lining, as used in the rotary kiln heat loss through the body to the environment reach 10-15 % of the total heat of combustion [1, 8].

The absence of a fast heat-resistant material with good thermal insulation properties to a large extent determined the direction of the work to create a lining with high thermal resistance through the introduction of additional fibrous insulation material, which is achieved by changing the shape of the refractory. Heat insulator can be fibrous structure, such as mullite-silica wool with inorganic additives, basalt fiber and similar structures that can be used at temperatures up to 1600 °C. In this case, between the refractory and the oven is formed cells filled insulation material [9, 10].

The greatest decreasing of heat loss in the furnace environment and weight lining can be achieved through the installation of shaped refractory materials in high-temperature zone of the furnace, which also provides a large heat transfer with material and decreased thermal mass unit [4, 5]. In the Figure 1 it is shown the construction of the thermal insulation, which is based on the firebrick cabinet with legs formed by cells. Under mechanical and thermal loads that occur during operation, the reduced form provides better preserveable mechanical stability of refractory bricks and ensure high thermal efficiency.

The aim of this part of the study is to investigate the options for mounting a shaped refractory linings of various configurations, taking into account both thermal efficiency and structural reliability due to the value arising in refractory thermomechanical tension.

The task of the research is the need to obtain the temperature fields and the development of methods of calculation of temperature fields in the body of the refractory. Data on the temperature field in the masonry stove obtained based on mathematical modeling.

The heat balance (1) is applied for calculating thermal fields in a Cartesian coordinate system.

$$\frac{\partial t}{\partial \tau} = \frac{\lambda}{C\rho}\left(\frac{\partial^2 t}{\partial x^2} + \frac{\partial^2 t}{\partial y^2} + \frac{\partial^2 t}{\partial z^2}\right) + \frac{q_v}{C\rho}, \qquad (1)$$

t – system temperature, K; τ– lining heating time, s; λ – heat conductivity of lining material, , W/(m·K); ρ – lining material density, kg/m^3; C – lining material heat capacity, J/(kg·K); $\frac{q_v}{C\rho}$ – equation member taking into account insert source of thermal energy.

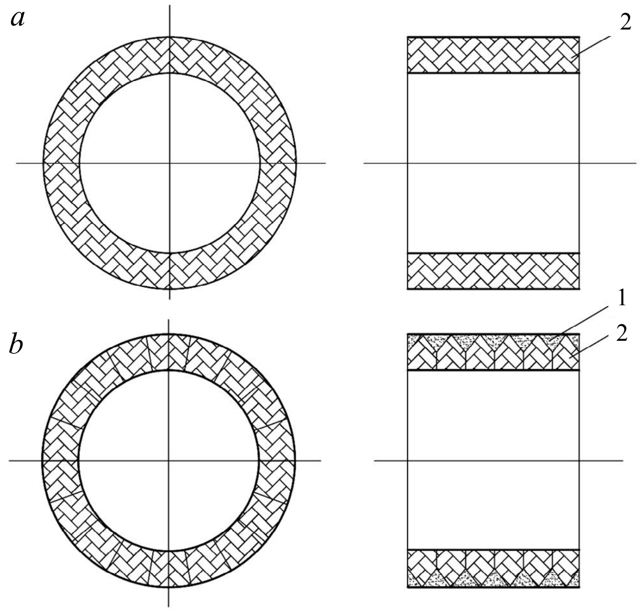


Fig.1. Construction of rotary kiln lining, with using only chamotte (*a*), with using chamote and fiber structure (*b*)
1 – fiber structure, 2 – chamotte

The initial and boundary conditions for the solution of differential equations were used from high-temperature sintering zone of a rotary kiln [12, 13]:

• the temperature on the inner surface and the rotary kiln t_{in} = 1873 K;

• the temperature of the environment t_{env} = 300 K;

• thermal conductivity of refractory fireclay is defined as a function of temperature $\lambda_{cham} = (0,72 + 0,0005t)1,16$, t – temperature chamotte refractory material, °C

• thermal conductivity of basalt fiber λ_{bas} = 0,06 W/(m·K);

• density of chamotte ρ_{cham} = 1800 kg/m^3;

• density of basalt fiber ρ_{bas} = 200 kg/m^3;

• convective heat transfer coefficient on the outside of the kiln α = 30 W/(m^2·K) [5, 6].

The thickness of the lining to take in accordance with the technological requirements of the rotary kiln [1].

The solution of differential equations are derived by means of a software package ANSIS 14.0 using the finite element method. As a generator of a finite element mesh used package ICEM CFD 14.0. was used. The resulting finite element mesh are shown in Figures 2 [9].

On he basis of (1) the temperature field of fireclay refractory lining and the new design lining in Figure 3.

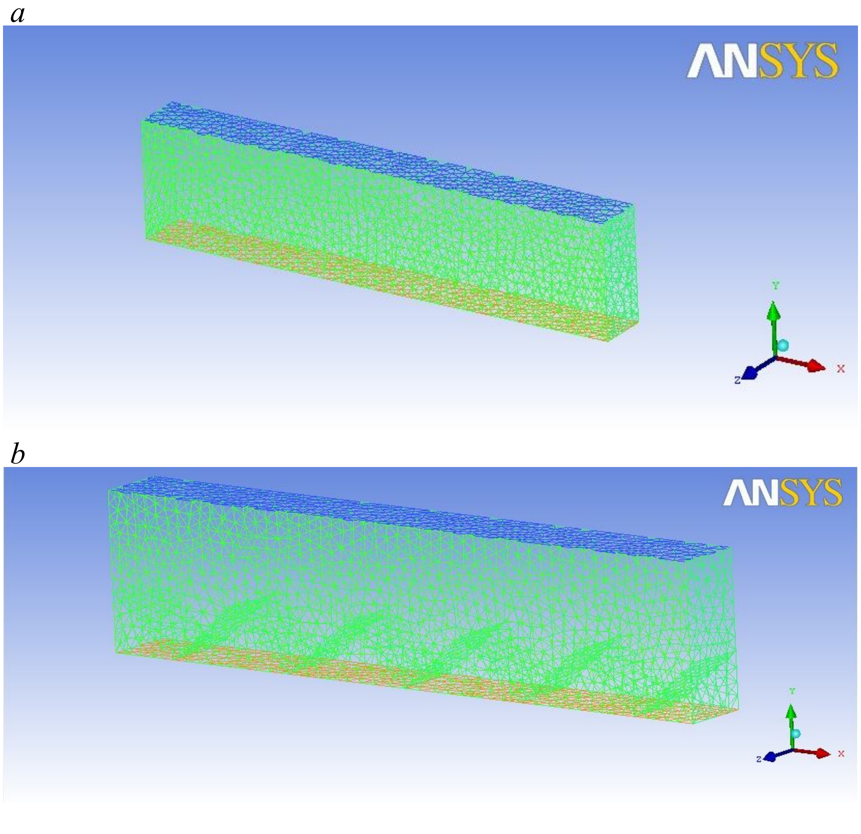
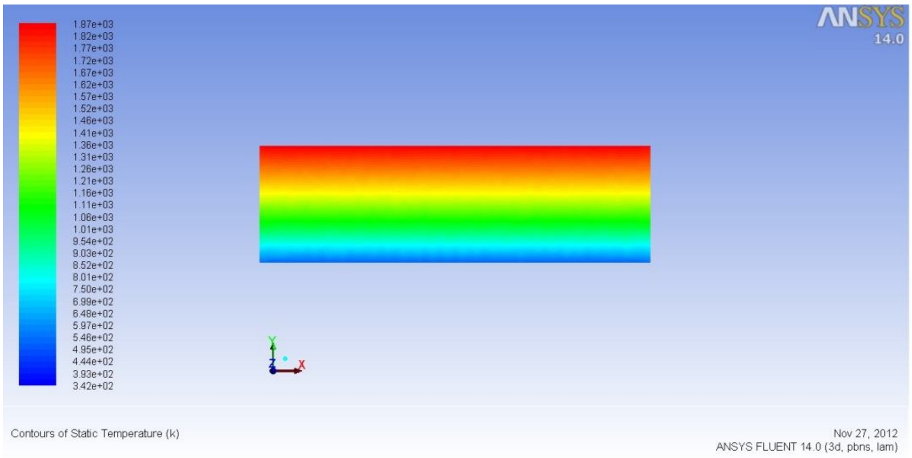


Fig.2. The finite element mesh for the standard (*a*) and new (*b*) construction lining
a – the number of items 46672, number of nodes 8153, the average size of a finite element 0.02 m;
b – the number of items 47693, number of nodes 8124, the average size of a finite element 0.02 m

a



b

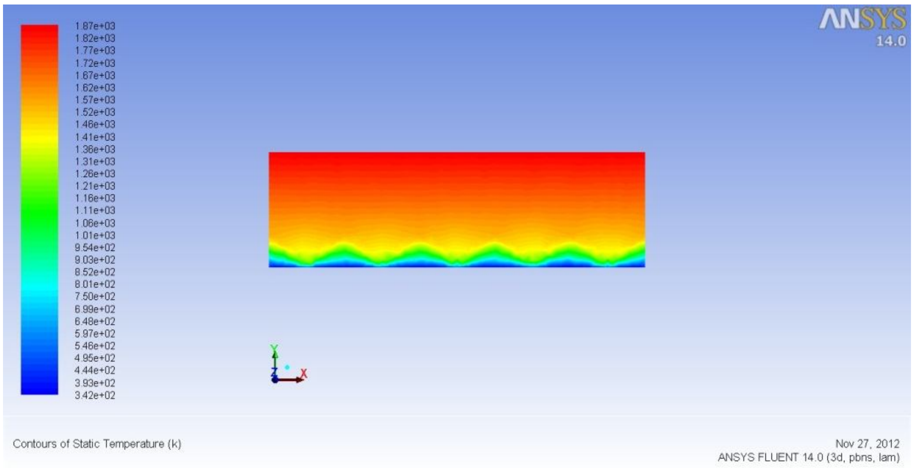


Fig.3. The temperature field in the standard (*a*) and the new proposed (*b*) construction of the kiln's lining

a – q = 6427 W/m^2 – the heat flux through the external surface, T_{ext}= 514 K – the average temperature on the external surface of the kiln; *b* – q = 2671 W/m^2 – the heat flux through the external surface, T_{ext} = 389 K – the average temperature on the external surface of the kiln

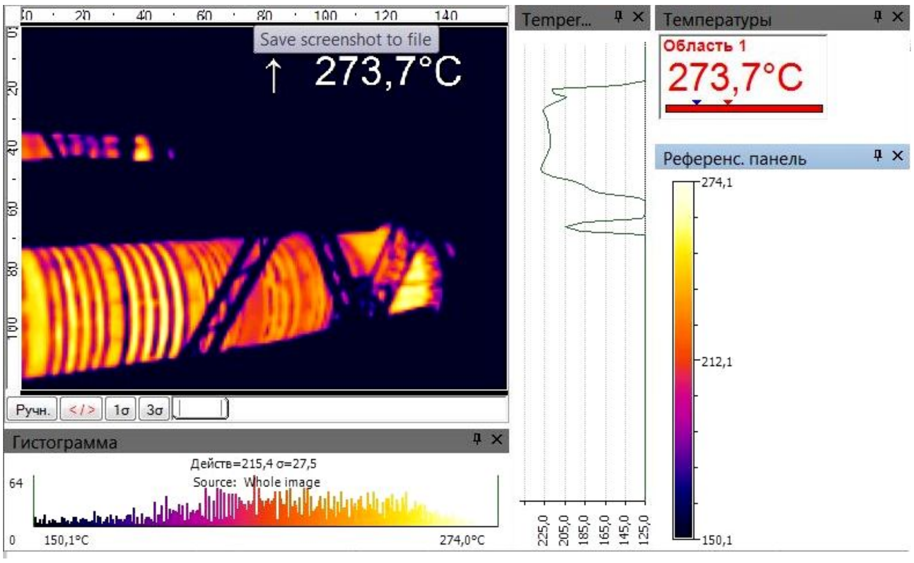


Fig.4. The temperature field on the surface of a rotating furnace lining

Based on the thermogram can be drawn conclusions about the new construction of the lining:

1. By creating a layer of basalt fibers on the outer edge of fireclay lining result in lower temperature of 125 K.

2. The decrease of the heat flux through the new design lining is 2.4 times less than the standard lining.

3. Application of the new liner design reduces fuel consumption, as reduce heat loss to the environment. Harmful emissions can be reduced.

4. Application of the new design will reduce the share of the lining of heat loss proportional to the decrease of the heat flux.

To check the adequacy of the model study conducted by JSC "BaselCement". Thermal imager OptrisPI-230 model was carried out to survey the temperature field of the lining a rotary kiln. Results are presented in Figure 4.

Based on the presented thermal image it is seen that the surface temperature of the rotary kiln at a temperature equal to the lining surface by using the calculated model AnsisFluent medium. Results confirm adequacy of model.

In the course of the work done research work has developed a mathematical model of lining a rotary kiln, allowing to estimate the temperature field inside lining and on its outer surface and use it to build process control firing in the condition of the lining.

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The furnace lining is inseparable integral part of chemical-thermal furnace «material – medium – lining» of the system. Therefore, it should be considered only in conjunction with other elements of the kiln system. In the rotary kiln lining skull is covered with a layer which ensures its protection against thermal radiation and the moving charge. The skull thickness must be supported on constant level. If the surface temperature exceeds the value set by the technological requirements, it indicates a decrease in the thickness of the skull, exposed linings and the need to change the thermal conditions inside the furnace [9].

Skull in a rotary kiln is formed by sticking a moving charge in the kiln space. Typically, at a temperature less than 1600°C a stable to thermo-mechanical destruction skull is formed on the surface of the scull.

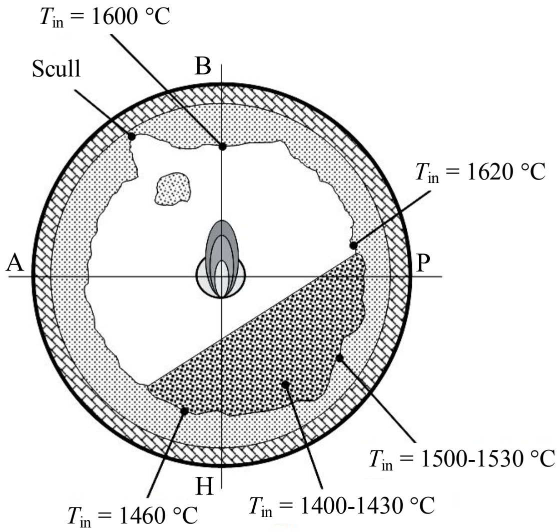

Fig.5. Chipping scull in a rotary kiln

At increasing the temperature inside kiln above 1600°C scull viscosity decreases, resulting in spall and expose the liner [9]. Changing the thickness and exposure of the lining shown in Figure 5. An increase in temperature leads to the formation of a viscous structure, reduce the forces of adhesion of skull and the lining. Further in this zone can be observed clutch burnout oven, which can lead to disruption of the process and stop mode kiln for repair.

Currently, control of overheating zones of rotary kilns is done manually, pyrometer at set intervals of time [1]. The disadvantage of this method consists temperature state estimation at furnace lining, which may lead to the inability to detect zones of overheating and destruction of the lining.

The purpose of this part of the work is to develop a lining monitoring system that would allow to continuously monitoring and signaled to the operator about their occurrence in real time. The principle of the system is based on a computer vision. Sensors measuring the thermal field on the surface of the furnace, the imager is transmitting the video signal in the unit of ACS (automatic control system), which analyzes and finds overheating laying zone of the furnace. The general scheme of this system is shown in Figure 6.

The circuit monitors the status of the lining of the rotary kiln, which comprises an infrared sensors, locating along the length of the kiln in the hottest areas. These sensors are thermal imaging, which measure the two-dimensional temperature field on the surface of the kiln lining. A digital signal from infrared detector is transmitted to the control unit of the system, which is used to analyse of the thermal load on the lining. Next signal from this is passed to the operator control mode technology, so that it can decide to change the mode of the radiation inside the furnace chamber, thereby reducing overheating.

The general scheme of the block control automation to control the heat load of the lining shown in Figure 7.

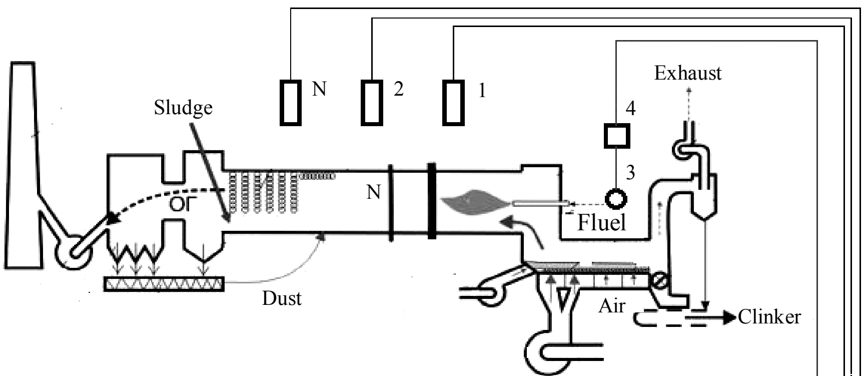

Fig.6. Scheme of control condition of the lining of the rotary kiln
1, 2, N – an infrared detectors; 3 – actuator; 4 –controller

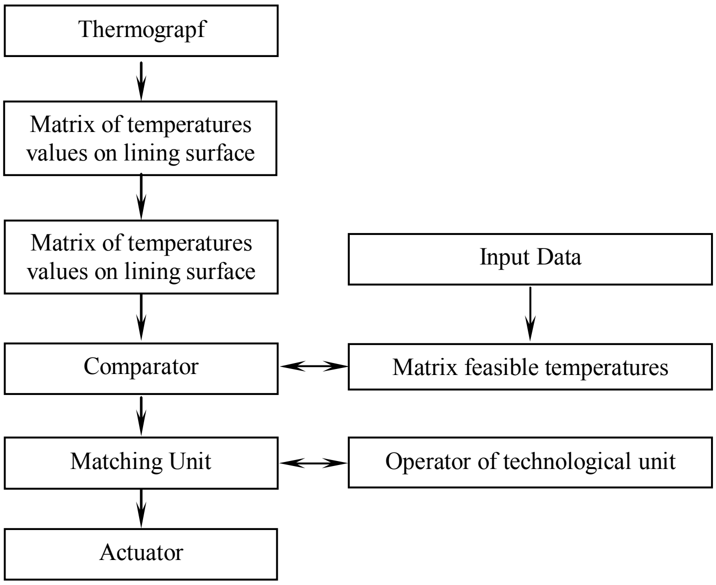

Fig.7. ACS termal load control lining

The composite components presented in Figure 7 schemes the automation control for the heat load of the lining.

The imager performs the function of the sensor space temperature field the surface of the rotary kiln surface.

The video signal from the imager is converted into a matrix Tm, characterizing the thermal field on the surface of the lining at the time τ_m. This matrix can be represented as the expression:

$$T_m = \begin{bmatrix} t_{1,1} & \dots & t_{1,n} \\ \dots & \dots & \dots \\ t_{m,1} & \dots & t_{m,n} \end{bmatrix}, \qquad (2)$$

where the matrix elements $T_{m,\,n}$ – are the values of temperatures on the surface of the kiln. Each of the elements of the matrix corresponds to separate group of pixels of the image produced by the thermal imager.

The signal enters the comparator unit where there is a comparison matrix Tm values given matrix T_{const}, which has the form:

$$T_m = \begin{bmatrix} t_{1,1} & \dots & t_{1,n} \\ \dots & \dots & \dots \\ t_{m,1} & \dots & t_{m,n} \end{bmatrix}, \qquad (3)$$

where elements of the matrix – the maximum permitted temperature at the surface of the kiln.

If the five elements $T_{m,n}$ vertical to column matrix values matrix exceed values corresponding elements matrix $T_{m,n}^{\text{const}}$, it indicates the occurrence of overheating in the lining of the rotary kiln zone [2, 3].

Further, if this condition is satisfied, the operator receives a notification of the occurrence of local hot spots. He may decide to change the radiation regime within the kiln or leave it unchanged, depending on the requirements of the technological regime [4, 11].

Then the signal enters the controller unit, which activates an actuator that controls the burner. The actuator changes the position of the torch and changing thermal conditions inside of the kiln chamber.

This system controls lining temperature of the rotary kiln and it will allow on-line time regime to obtain information about the presence of zones of overheating and take quick decision to reduce the heat load on the hot spots, thereby extending the service life of the lining and thus decreases repair time of the kiln.

Conclusion

1. The processes of heat distribution in the lining of the TRK is analysed at the same time as the flow of technological processing inside charge in the kiln.

2. The mathematical model of the process and the proposed construction of heat-insulating elements providing decrease of heat flows into the environment has been developee.

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3. The proposed design allows to reduce heat loss and to reduce the temperature of the outer surface.

4. A system for scanning the surface temperature and energies has been proposed. It allows to define a mathematical model in terms of the internal destruction of the protective layer and to guide in these places dust stream, regenerating protective layer scull without stopping the kiln.

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***Authors*: I.V.Sharikov**, *Dr. of Engineering Sciences*, *Professor*, *yvshar@mail.ru* (*Saint-Petersburg Mining University*, *Russia*), **T.O.Koiranen,** *Dr. of Engineering Sciences*, *Professor*, *tuomas.koiranen@lut.f* (*Lappeenranta University of Technology*, *Finland*).

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