Study of the temperature mode of a tunnel kiln using new Celsius© thermal sensors

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Abstract. The paper proposes a new approved system for control and monitoring of the working process parameters during production of building ceramic bricks for modern enterprises. We analyzed various devices for measuring the raw brick temperature, and identified the shortcomings of the existing instruments and measuring systems. To create high production efficiency, increase the competitiveness of products on the market, reduce the product cost as part of automation of long-term and energy-intensive technological processes, we proposed a method of organizing optimal control of drying process of ceramic bricks at the industrial plant using new Celsius © thermal sensors. A digital temperature sensor is used as a sensitive element, which eliminates the need for calibrating the primary transducer. The device can be installed on the object of examination using a threaded connection, magnetic mounting, or can be used to measure the temperature at the required depth due to remote primary measuring transducer. It is shown that device is universal and will be efficient for the needs of enterprises for which the control of thermodynamic parameters is the basis of the technological process.

1. Introduction

Development of construction industry is inextricably linked with increasing demand for building materials, and the requirements for the products quality are constantly increasing [1-7]. Therefore, the desire of managers to modernize existing production contributes to development of "healthy competition" among manufacturers. In order to increase the competitiveness of products on the market, first of all, it is necessary to automate long-term and energy-intensive technological processes, since the cost price of the product decreases [8-10].

One of the stages of production of building ceramic bricks is technological process of brick drying, which includes measuring and regulating parameters such as humidity, temperature and pressure [11].

In [12], drying refers to removal of excess moisture from any overwetted substance. During drying, water passes from a capillary or hygroscopic state to a vapor state. In this case, evaporation occurs under the condition that partial pressure or concentration of water vapor in the environment is less than the pressure of water vapor at the surface of the body to be dried. And the larger this difference is, the more intense is drying.
According to [13,14], drying of raw materials and products in ceramic industry is one of the important technological operations. It is applied to molded products to impart mechanical strength and reduce moisture, allowing to stack products in stacks during the subsequent firing or directly go to intensive firing of products without fear of cracking.

For each material and product, a certain drying mode is established, i.e. its permissible intensity, the highest heating temperature of material, parameters of drying agent (temperature, relative humidity and speed) and their change during different periods of drying. These parameters are individual for each technology, for example for production, processing of bricks or silicate or manufacturing of building ceramics.

Drying of brick occurs in drying chambers. Chamber dryers are loaded with bricks and they gradually change the temperature and humidity throughout the entire volume of dryer, in accordance with a given product drying curve and technology for manufacturing the building ceramics and brick production. During drying there is often a large reduction in volume of upper layers than the internal ones, which often leads to cracking of sample when it reaches a critical value.

Such a critical value is humidity corresponding to the lower limit of plasticity, i.e. the point where the clay mass during its drying goes from a plastic to a non-plastic state. In this regard, in the first moments of brick drying (especially at high temperatures and air circulation), the main task is to slow down the sudden evaporation of moisture from the surface.

Usually, the drying process in the brick production technology can be divided into three stages:

- Shrinkage period, in which shrinkage is proportional to the amount of evaporated water;
- Period of slow shrinkage;
- Period of steam water release.

The main interest is the period of intensive drying, during which the evaporation of shrink water occurs. Failure to comply with regimes of brick drying during its production can lead to cracking and warping of clay samples. One of the factors influencing the drying process of products is temperature and humidity of the surrounding air.

The main task during brick processing is selection of optimal operating modes of dryer, which ensures high quality at the maximum achievable productivity of a brick factory. Failure to comply with parameters of technological regime leads to failures in work. If at the beginning of dryer a lot of water vapor is formed in the raw material, then their pressure may exceed the tensile strength of raw material and a crack will appear. Therefore, the temperature and humidity in the first zone of dryer must be such that the water vapor pressure does not destroy the raw material needed for production of ceramic bricks.

If there is a decrease in the relative humidity of the coolant supplied to dryers, in the winter period below 65% in the first stages of drying the raw material, drying cracks appeared on it. Moreover, it is distinctive that when the raw material leaves the dryers with its residual moisture content of 3-4%, the cracks become invisible. However, during firing, the cracks open again and the output of the facing brick does not exceed 20%.

It was established that in order to eliminate formation of cracks in raw material during the initial drying period, the relative humidity of the coolant supplied to the dryers should be in the range of 70–75%, and its temperature at the raw entry positions in the dryers should not exceed the raw temperature by 5–7 °C.

Modern production of ceramic bricks is focused on the market, the main criterion of which is competitiveness. The competitiveness of products is higher, when its cost is lower and its quality is higher. One of the ways to improve the competitiveness of products is optimization of the production process [8].

2. Technology description

At each stage of drying bricks in order to reduce scrap and minimize costs, it is recommended to install a system for controlling and regulating humidity of both the coolant supplied and the products obtained. One solution could be in the use of humidity sensors and temperature sensors. For example, humidity and temperature sensors as a means of measurement are used to control the position of control valves
with parameters such as relative humidity, temperature, moisture content. Further, the measured signal can be supplied to the control units of ventilation systems (supply and recirculation of the drying agent) or control valve control units and transfer the direction of movement of the drying agent. Thus, the problem of organizing the optimal control of drying process of ceramic bricks is very important. To do this, one needs to know how the temperature and humidity of the product change during the entire drying process. However, the limited space in the drying oven does not allow performing any measurements using sensors that are directly connected to the computer.

To solve this task, the scientists of the “Heat and Gas Supply and Ventilation” Department of Vologda State University carried out a set of activities related to choice of a temperature measurement scheme at some local points of the raw brick preparation, the development of a temperature measurement system, and its introduction at an industrial enterprise.

A preliminary survey of the measurement technology market for temperature monitoring was conducted, as well as a review of patents for independent measuring devices. Among the enterprises which produce such systems, we can distinguish Rotronic, TermoChron Revisor and Dallas Semiconductor. However, their systems for measuring thermodynamic parameters of working fluids are very expensive for mass use, and also have low ranges of temperature measurements.

From the devices for autonomous collection of experimental data, we analyzed the simplest device [15] for continuous measurement and recording of temperature of the outer surface of pipes consisting of a base, a housing with a lid, a cable outlet and a sensing element made of a core with a wire thermistor. Temperature readings are recorded sequentially, at regular intervals, directly onto a computer via cable output, which in industrial environments makes little environmental pressure due to high temperatures and limited space, and the measurement system has a low level of reliability and durability.

A device for temperature control [16] was also analyzed, containing a sensitive element in the form of a temperature sensor and an ambient temperature sensor, the outputs of which are connected to the input of an analog-digital device (ADC). The output of the analog-digital conversion of ADC is connected to the input of the reprogramming unit, which is a kind of algorithm when recording the values of threshold temperature on a computer. The disadvantage of this device is the need to use preliminary mathematical calculations when moving this device from one production to another, or when replacing a sensitive element, as well as using thermoelectric converters that require compulsory preliminary calibration before operating in different temperature conditions.

Thus, the task was to develop our own system for measuring the working fluid temperature. The developed device [17] was aimed at expanding the arsenal of technical tools in this area, as well as at improving the usability of the measuring device by fixing it on the measurement object using a threaded or magnetic connection.

This is achieved due to the fact that the device casing is filled with heat-insulating material, which allows it to withstand large thermal loads in the temperature range from -55 to 125 °C aimed at the electronic parts of the device. There are no elements in the device that are not protected from mechanical and thermal damage; all components are located inside the case. A digital temperature sensor is used as a sensitive element, which eliminates the need for calibrating the primary transducer. The device can be installed on the object of examination using a threaded connection, magnetic mounting, or can be used to measure the temperature at the required depth due to remote primary measuring transducer.

This set of measures ensures high reliability of the device, expands its application area, improves its usability and accuracy of measurement of temperature data.

The temperature measurement device is a self-sufficient system, which, after setting the user-selected setpoints by means of microcontroller, measures the temperature and records the results in a secure section of the built-in flash data memory. Recording is done at a user-defined rate using a programmable timer. The data is stored as sequential results of temperature values in the memory cells of buffer. The device allows one to save temperature values from 1 to 255 minutes at regular intervals. The device has a unique 64-bit laser-manufactured temperature registration identification number. The autonomy of the work is provided by the power source. The measurement medium can be gas, liquid and solid.
Information on temperature data can be transferred from Flash memory to a personal computer for further processing [17].

The device, if necessary, can be equipped with a threaded or magnetic connection, while the temperature sensor can be remote outside the device, which will provide an opportunity to measure the temperature in the recessed areas of the surface of the object under study.

To fix the temperature, the device is placed with the side with the temperature sensor on the measured surface. The measurement is carried out in accordance with a predetermined timer program with a record in the data storage buffer. Upon completion of the measurement, the user removes the device from the survey object and then extracts the data using the USB connector.

![Figure 1. General view of the sensor (left) and the option of placing it in the raw brick (right).](image)

3. Results

We consider a specific case, which is organization of optimal control of the process of drying ceramic bricks. In this case the device (Figure 1) is embedded in a prototype brick sample. The main task of such an autonomous system is to record the function of temperature inside the brick for the period of sample passing through the tunnel dryer (Figure 2). In accordance with the works [18, 19], the experiment plan was developed and the measurement procedure was performed. Results obtained from the instrument's flash memory are processed using standard Microsoft Office applications.
Figure 2. Temperature chart for a raw brick.

Convective drying of a raw brick is carried out in the tunnel kiln due to the heat of hot air (50 - 60 °C), which moves countercurrent to the direction of trolley movement. Comparing the experimental data on change in temperature and humidity parameters of a brick with the technology of moisture removal in such devices from [18] and [19], one can draw conclusions about the drying periods. For example, according to the schedule (Figure 2), the following conclusions were made: in the section AB, the sensor temperature rises from the ambient temperature to the temperature of raw brick; BCDE section is characterized by temperature change after loading the sample into the drying chamber; EF is cooling the brick up to the outside temperature. According to the experience, it can be said that the temperature inside the workpiece decreases at the CD section due to energy input of the heat supplied to evaporate moisture. After the brick is completely dried, its temperature rises (section DE).

4. Conclusions

We developed a unique system for measuring the temperature of the working fluid and a method for determining the drying efficiency by measuring the temperature and humidity characteristics of the raw brick during the entire process for the company Sokolstrom.

Thus, the use of possibilities of modern technology of receiving and transmitting information opens new innovative possibilities for managing the processes taking place while manufacturing the ceramic bricks.

After analyzing the existing scientific and technical developments, as well as assessing the competitiveness of the product, we can distinguish several of the most well-known devices: the Swiss company Rotronic and the American company Dallas Semiconductor (Table 1).

Table 1. Comparative analysis of the technical device characteristics with the foreign analogues

| Device characteristics                  | Rotronic          | iButton            | Celsius ©          |
|----------------------------------------|--------------------|--------------------|--------------------|
| Dimensions                             | 59 cm³             | 1.5 cm³            | 20 cm³             |
| Amount of control points               | from 1 to 2        | 1                  | from 1 to 32       |
| PC connection via                      | USB interface for  | Data reading from   | 1. USB interface   |
|                                        | settings and data  | the device is carried| for settings and   |
|                                        | transmission       | out using specialized| data transmission |
|                                        |                    | and software        | 2. Bluetooth connection |
| Measurement range                      | from −25 to +80°C  | from −55 to +125°C | from −55 to +125°C |
| Protection from dust, moisture and     | The case is made of | The case is stable  | The case is stable |
| dynamic impact                         | plastic            | to vibrations, shocks | to vibrations, shocks |

A comparative analysis showed the advantages of the Celsius© measuring complex over the existing analogues by several criteria: the number of control points of temperature and humidity can reach 32 pcs at the same time. In production, where access to the sensor is very difficult, it is possible to remotely
collect information via Bluetooth connection and control the device. The case of the device can be made of alloyed or stainless steel, capable of withstanding high loads.

The patented Celsius© measuring complex based on the developed temperature sensors and automated control system [17] can be used in various fields of science and production, where space limitations do not allow any measurements using sensors directly connected to a computer and where human presence is impossible for some time.

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