Istraživanja i projektovanja za privredu
ISSN 1451-4117
DOI:10.5937/jaes0-46355
www.engineeringscience.rs

Journal of Applied Engineering Science
Vol. 22, No. 2, 2024
Original Scientific Paper
Paper number: 22(2024)2, 1204, 393-401

# SIMULATION MODELING AND IMPROVEMENT OF THE WINDING DRUM COOLING CONDITIONS

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*At the Kaz-Metiz LLP plant, there has long been a problem of insufficient drums cooling due to the scale formation, which led to the need for frequent production stops to cool them. To solve this problem, simulation modeling of cooling drums with and without scale was carried out to investigate the heat spread over the body. The results of the stationary analysis in the Ansys application showed the heat propagation across the cross-section of the drum and proved that the resulting scale, having a low thermal conductivity, significantly reduces the heat exchange from the drum wall to water, as a result, the surface of the drum is significantly overheated. Subsequently, the improved drum cooling system was implemented in «Kaz-Metiz» LLP.*

*Keywords: winding drums, temperature, simulation modeling, Ansys application program, thermal conductivity, cooling, thermal analysis*

## 1 INTRODUCTION

The study aims to use simulation modeling in the Ansys application program to develop an improved drum cooling system at the Kaz-Metiz LLP plant, aimed at improving heat transfer efficiency and preventing scale formation, leading to more stable and reliable operation of production equipment.

The drums of the drawing bench (Fig.1) are designed for winding the processed metal (wire) and are an important assembly unit (Fig.2) of the bench (Fig.3) in the production of high-carbon steel wire in Kaz-Metiz LLP.

Fig. 1. Drawing bench drums

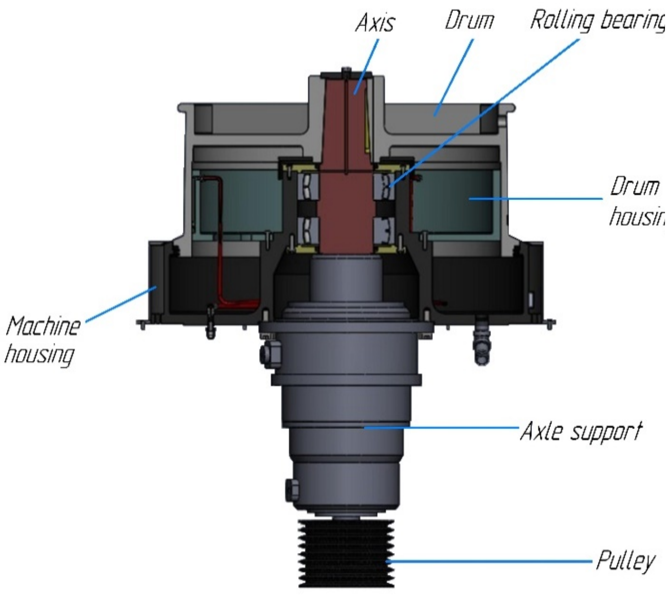



Fig. 2. Drum assembly

Fig.3. Kaz-Metiz LLP drawing benches (photo taken from the website of Kaz-Metiz LLP)

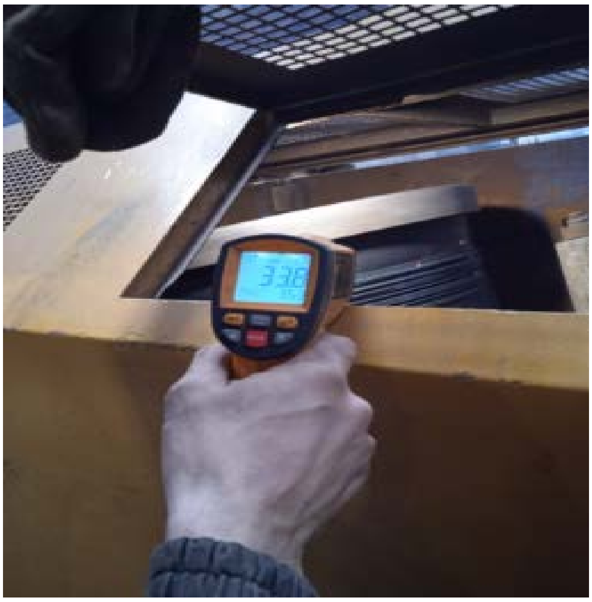


Fig. 4. Drum temperature measurement using a TK-5.04 thermometer

Wire Drawing Machines of Workshop No. 12 for the 2021 year in each month due to failures of the cooling system (heating drums) were idle on average (Table 1) for 8.5 hours, and therefore the wire capacity fell by 9,792 tons. The temperature in the drums was measured using a numerical non-contact thermometer TK-5.04 (Fig. 4). Analyzing the measurement results, the following temperature indicators were recorded: tmin=50°C, tmax=70°C.

Table 1. Drum temperature measurement results

| Wire diameter, mm | Drums temperature, $^0$C | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | №1 | №2 | №3 | №4 | №5 | №6 | №7 | №8 |
| 11 | | 70 | 54 | 51 | 56 | 70 | 70 | 57 |
| | 58 | 52 | 52 | 54 | 51 | 59 | 66 | 50 |
| | 66 | 57 | 56 | 56 | 48 | 58 | 50 | 50 |
| | 53 | 52 | 55 | 60 | 53 | 54 | 60 | 57 |
| | 56 | 56 | 51 | 63 | 55 | 60 | 49 | 40 |
| | 56 | 60 | 56 | 42 | 56 | 64 | 50 | 50 |
| | 70 | 50 | 57 | 60 | 62 | 55 | 63 | 50 |
| | 63 | 56 | 61 | 55 | 51 | 69 | 53 | 48 |
| | 57 | 51 | 53 | 57 | 70 | 65 | 49 | 53 |
| | 65 | 52 | 52 | 51 | 70 | 70 | 70 | 51 |

The average temperature in the workshop was: from December to May - 15 ° C; and from June to November - 24 □ C.

The winding drums are made of ZG45 steel grade. The process of winding the wire is accompanied by friction, which leads to the heating of the drum walls. Thus, heat generation is carried out due to the friction of the wire on the surface of the drum.

For cooling, a cooling system is provided inside the drum, which includes a narrow slot for spraying water. This slot provides a high-speed flow directed to the inner surface of the drum. A narrow sliding air cooling is used outside the drum wall. The wind is blown out of the gap of the wind ring of the spindle seat, creating an airflow directed at a certain angle. This cooling system is easy to maintain and has no sealed wear parts, in addition to the need to control the direction of the water cooling.

The principle of operation of the cooling system is as follows: Spraying water inside the drum creates an effective heat transfer mechanism. High-speed water flow provides intensive cooling of the inner surface of the drum. The narrow air cooling on the outside of the drum helps to effectively remove heat, creating an airflow that effectively cools the outer surface.

Heat transfer occurs due to the contact of the sprayed water with the surface of the drum. The effective thermal conductivity of water in a narrow slit ensures high cooling efficiency. Air cooling creates an additional heat transfer mechanism, where the airflow carries heat away from the surface of the drum, maintaining optimal temperature conditions of the winding device.

The quality and accuracy of the work performed on the drums are ensured by the cooling system. The higher the temperature on the winding device is heated, the lower the mechanical properties of the wire will be. In this regard, the deviation of the drum temperature regime from the nominal (40-50□C) is an urgent problem.

The inner hole or the bearing mounting seat is treated with epoxy putty - primer and anticorrosive paint to effectively prevent the precipitation (scale) formation, but due to deviations from the temperature norms, precipitation with a thickness of 1-2 mm is formed on the drums (Fig.5).

Fig. 5. Drum surface precipitations

In this study, numerical modeling methods using Ansys software were employed to analyze heat transfer in wire drawing drums under various cooling conditions. The research methodology included modeling heat transfer, comparing results, and making decisions based on the analysis of the obtained data.

## 2 MATERIALS AND METHODS

### 2.1 Research part

To identify the qualitative and quantitative indicators of precipitation from the surfaces of the drum, a sample was taken and qualitative and quantitative analyses were carried out in laboratory conditions. Sediment sample: brown, wet, friable. For qualitative analysis, 0.20 g of sediment mixed with 0.30 g of boric acid was pressed into a tablet and the atomic emission spectrum was recorded on the “LAES Matrix Continuum” instrument (Fig. 7). For quantitative analysis, the sample was dried to constant weight at 120°C. 0.1 g of the sample was dissolved in a mixture of mineral acids using a Mercury microwave preparation device. The solution was analyzed on an Agilent MP-AES 4210 atomic emission spectrometer (Fig. 8). According to the quantitative analysis, the sediment contains aluminum 73 g/kg, calcium 24.6 g/kg, iron 26.8 g/kg, magnesium 3.3.

Fig.6. «SELA Matrix Continuum» apparatus for precipitation qualitative analysis

Fig.7. Agilent MP-AES 4210 apparatus for measuring the elements’ mass concentration in a sample

Precipitation on the surfaces of mechanisms increases the temperature, and the increase in surface temperature will be the greater, the thicker the scale layer and the lower its thermal conductivity [1, 2]. Scale formation and its effect on thermal conductivity under various conditions has been studied quite extensively [3, 4, 5, 6]. Precipitates have low thermal conductivity [7, 8], which in turn leads to a significant decrease in the heat exchange intensity, overheating of the drum body occurs, due to which the drawing bench needs to be stopped. In Kaz-Metiz LLP, in the production of wires, water from the well is used to cool the drawing bench drums, during the use of which scale is formed. This means that the drum cooling system used in Kaz-Metiz LLP is inefficient.

### 2.2 Simulation modeling

The goal is to build a model of heat propagation when using water from a well with sediment (basic version) and without sediment on the drum (proposed version), which allows a deeper understanding of thermal processes and for further cooling unit research, without compromising the entire production process. Employing the Ansys application program heat transfer simulation studies are performed. In the Ansys program, the dependence of properties on temperature is taken into account in a tabular way. In thermal analysis, the following characteristics of the objects under study are entered into the table: temperature, thermal conductivity, density, and heat capacity (Table 2).

At the simulation stage, the following parameters were determined:

1. Drum surface: with scale (basic version) and without (suggested version).
2. Software tools used: Ansys Application Program
3. Characteristics of the objects of study: temperature, thermal conductivity, density, heat capacity.
4. Tabular data: In the thermal analysis, tabular data were used, taking into account the dependence of the properties of materials on temperature.

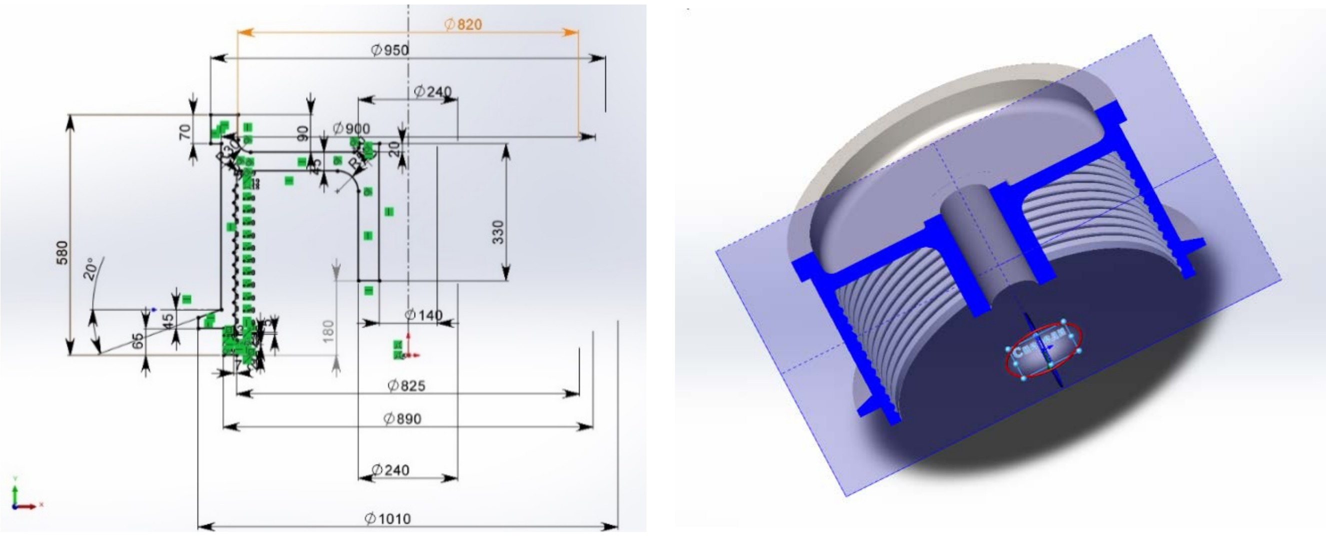
The expected simulation results include:

1. Heat distribution: it is expected to obtain a temperature distribution over the drum under conditions of use, the presence of scale and without it.
2. Cooling efficiency: the study should show how much the proposed option reduces overheating of the drum surfaces compared to the basic version.
3. Scale effect: It is expected to confirm that scale formation significantly reduces heat transfer.

Table 2. Initial data for modeling

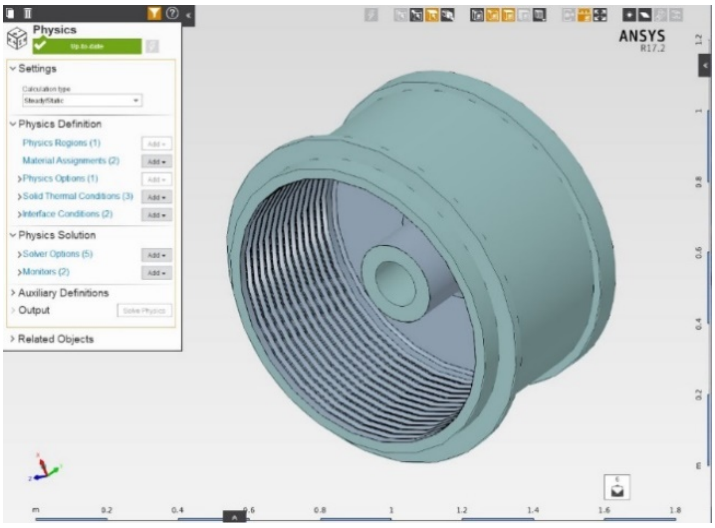
| Name of parameters, the unit of measurement | Drum | Basic version | Proposed version |
|---|---|---|---|
| Thermal conductivity, Wt/m·K | 70 | 2,5 | 0,58 |
| Temperature, °C | 70 | 25 | |
| Density, kg/m$^3$ | 7800 | 2200 | 1000 |
| Heat capacity, J/kg·C | 480 | 840 | 4200 |

A geometric model of the drum was created (Fig. 8, a), loaded into the Ansys program (Fig. 8, b), and initial data for calculation was entered (Fig. 8, c). In the model, it is assumed that heat transfer in the system occurs through the thermal conductivity of the drum material, while also taking into account the influence of water flow rate, sediment thickness, and ambient temperature on the efficiency of heat transfer. The influence of water flow velocity, sediment thickness, and ambient temperature on heat transfer efficiency is also taken into account. The heat exchange surfaces' contact zone is highlighted in green (Fig.8, a), and all other (outer) surfaces of the drum are set with a temperature boundary condition tmax=70°C (Table 1).




a) geometric model in the form of a drum frame

b) model in a grayscale image

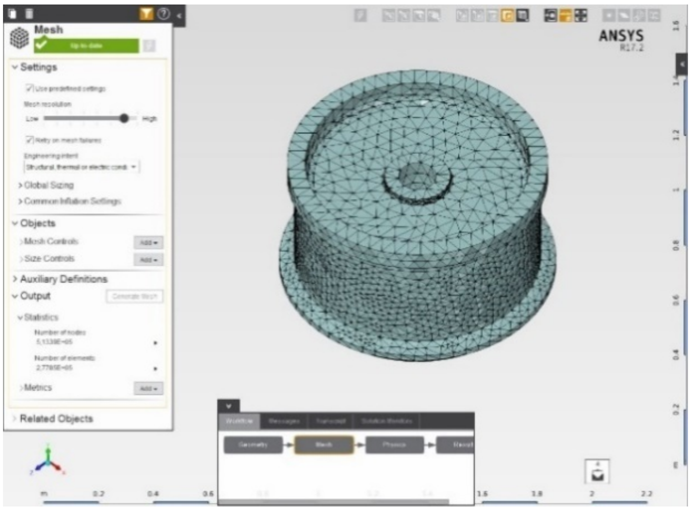



c) input of initial data for calculation

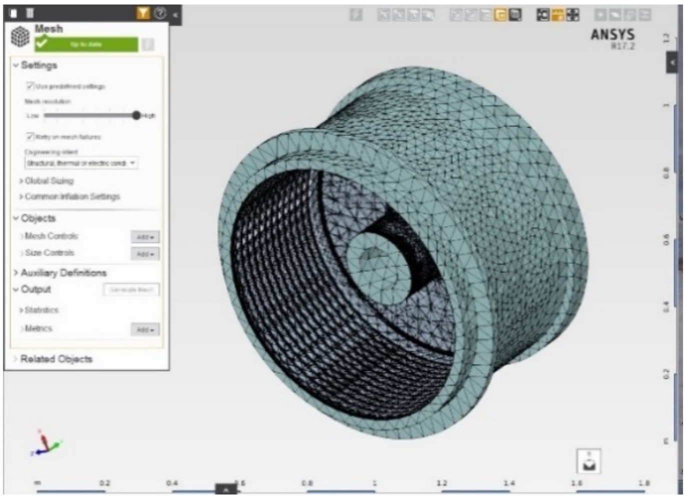
Fig. 8. Problem solution preprocessor preparation

For the constructed geometric model of the object, its finite element (discrete) model is created, i.e. a grid of nodes and elements is applied to the area of space occupied by the object. The area is divided into smaller parts (finite elements) of a relatively simple form, interconnected at some points (nodes).

The elements have common node points and collectively approximate the shape of the area. The construction of such a grid is one of the most important stages in finite element analysis. For the basic version, 513390 nodes and 277850 elements were used in the construction (Fig.9, a), in the proposed version - 496590 nodes and 305370 elements (Fig.9, b).




a)



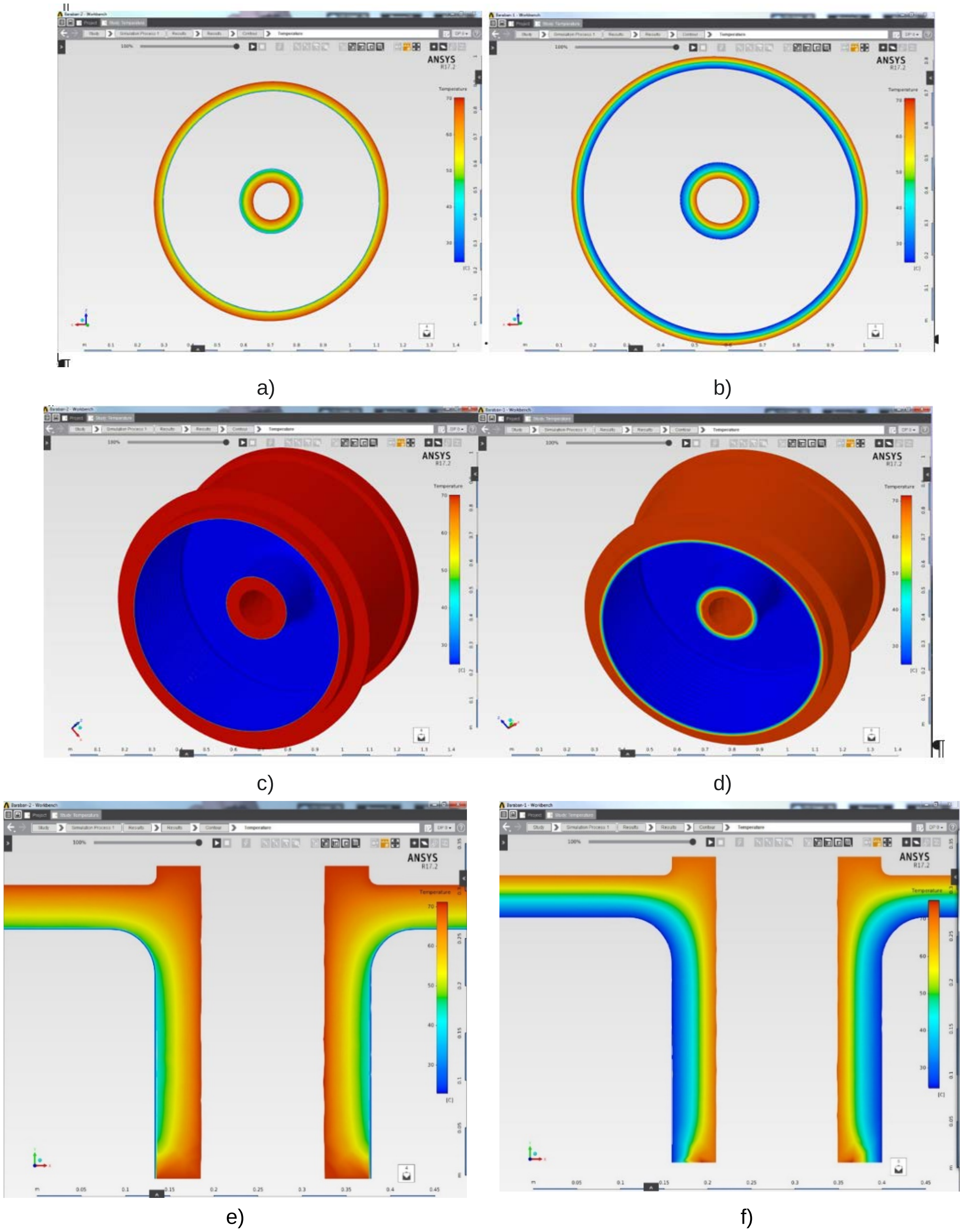

b)

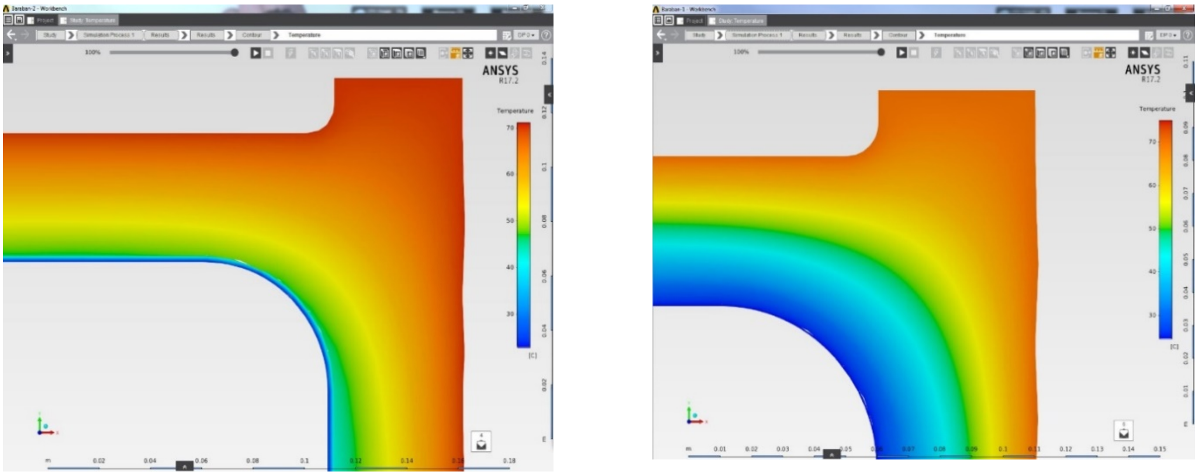
Fig.9. Construction of a finite element drum model

## 3 RESULTS AND DISCUSSION

After the preprocessing preparation is completed, the simulation is started, and it becomes possible to visually see the spread of heat on the surface. The results of the drum surface heat transfer (Fig.10) are obtained after stationary analysis.

**Basic version** **Proposed version**






g) h)

Fig.10. Simulation results of heat exchange over the drum body

All research objects are simulated simultaneously, and geometric parameters and physical properties have not changed (Fig. 10, c, d). In longitudinal sections and the on-end surfaces there is a large temperature drop (Fig. 10, e) in comparison with the proposed option (Fig. 10, f). On an enlarged scale, the model's internal surface is visible due to the presence of sediment thickness, the heated surface does not contact the cooling source (Fig. 10, g). By its physical properties, the sediment as an insulating material significantly reduces the heat exchange process, as a result, the surface heats up more. When the surface is cooled without sediment, the walls are cooled sufficiently and the total temperature of the entire drum body is much lower (Fig. 10, h).

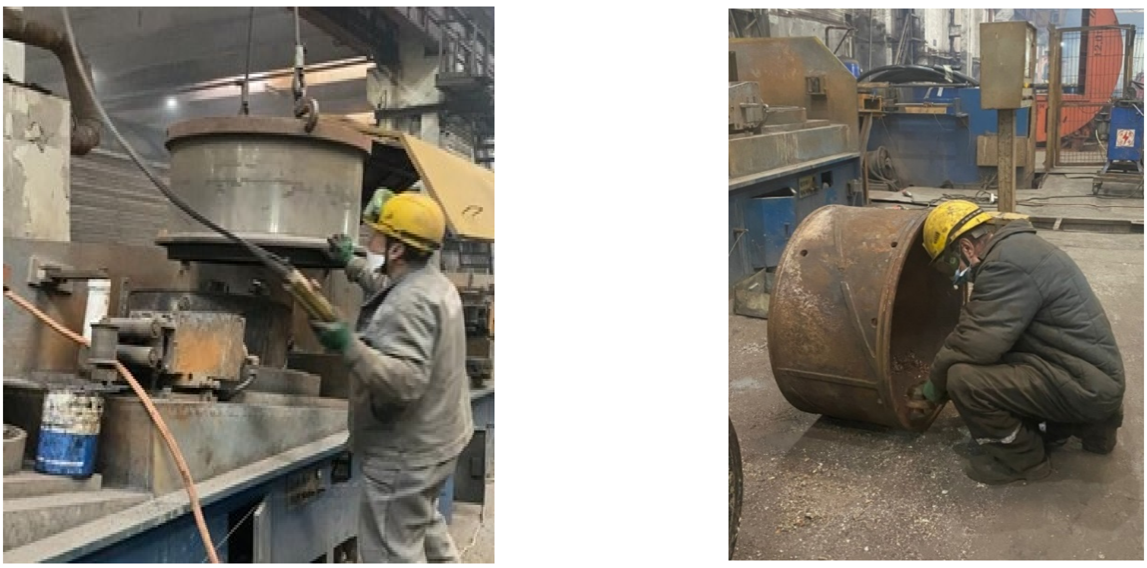
The modeling conditions include boundary conditions of temperature as well as thermal conductivity within the material of the drum. The preliminary expectation was that the introduction of sediment parameters into the model would lead to a significant deterioration in the efficiency of heat transfer through the drum. These assumptions were confirmed by the results obtained.

The analysis of the simulation results allows us to draw the following conclusions: the efficiency of heat transfer when using water-forming sediment decreased almost twice (Fig. 10, a, e, g), while the surface temperature of the drum in the presence of sediment increased significantly, reaching critical values. Given the high sliding speed of the wires on the drum, the overall temperature may also rise.

Based on these results, a decision was made to improve the cooling process of the drum of the drawing mill with a cooling medium that does not form scale. To do this, it is proposed to use distilled water purified from dissolved mineral salts, organic substances, and other impurities. This approach is aimed at optimizing heat transfer and preventing problems associated with sludge formation.

### *3.1 Experimental part*

To modernize the drums' cooling system, dismantling is carried out (Fig. 11, a), cleaning of the drums and jackets from precipitation (Fig. 11, b), the drums and the cooling system installation to the frame body (Fig. 11, c), the pump with heat exchangers (Fig. 11, d, e), pouring distilled water into the tank, starting the system and sealing the joints.



a) b)

c)

d)

e)

f)

Fig. 11. Cooling system modernization process

After modernization, the measured temperature value (Table 3) (within 3 months) shows that the indicators are within the permissible limits.

Table 3. Results of drum temperature measurement after modernization,°C

| Wire diameter, mm | №1 | №2 | №3 | №4 | №5 | №6 | №7 | №8 | month, year |
|---|---|---|---|---|---|---|---|---|---|
| 11 | 40 | 38 | 44 | 44 | 43 | 45 | 39 | 40 | 11.2022 |
| | 44 | 45 | 45 | 48 | 49 | 50 | 51 | 40 | |
| | 45 | 46 | 40 | 46 | 42 | 49 | 50 | 46 | |
| | 48 | 46 | 41 | 45 | 42 | 48 | 50 | 45 | |
| | 49 | 48 | 42 | 47 | 43 | 49 | 49 | 46 | 12.2022 |
| | 40 | 49 | 45 | 48 | 42 | 48 | 49 | 46 | |
| | 40 | 49 | 46 | 45 | 41 | 49 | 49 | 46 | |
| | 45 | 50 | 48 | 45 | 40 | 49 | 49 | 46 | |

The conducted experiments and simulation modeling revealed that the implementation of the improved cooling system resulted in a significant reduction in drum temperatures. The temperature measurement results presented in Table 1 and 3 clearly demonstrate that the proposed drum cooling system yields more stable temperature readings compared to the previous version. This indicates the effectiveness of the measures taken to modernize the drums and enhance cooling efficiency.

## 4 CONCLUSIONS

1. A qualitative and quantitative analysis of the scale formed on the surface of the drum was carried out.
2. An effective simulation model has been developed to study the thermal characteristics of the drum in complex modes of operation of the drawing mill.
3. The obtained data on the heat transfer of the drum are used to assess the temperature parameters and calculated effects on the working bodies of the drawing mill.
4. The changes made to the cooling system are aimed at improving the efficiency of heat transfer. The use of distilled water instead of water, which forms scale, contributes to more efficient cooling of the drum surface.
5. The optimized cooling system prevents the formation of scale, which significantly improves heat transfer and prevents overheating of the drum.
6. As a result of the modernization of the cooling system, significant changes have been noted, such as the absence of downtime of the technological system due to the prevention of overheating of the drums. These changes contribute to improving the efficiency of production.

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*Paper submitted: 06.09.2023.*

*Paper accepted: 10.05.2024.*