

Thermostatic cover for improving energy and technological efficiency of steel mills

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Abstract. The article proposes a technical solution for reducing the energy costs of casting process and providing more stable production conditions, specifically, the use of a thermostatic cap. Two variants of steel casting are considered: with and without the application of a thermostatic cover using the example of a bucket with a capacity of six tons of steel. The technical challenge is to reduce heat losses through the bucket neck to ensure the stability of the melting temperature throughout the casting and to reduce the temperature of metal release from the steelmaking unit. The design of the thermostatic cover with specifications, as well as the duration of process steps in the steel casting with and without the use of a thermally insulated cap are described. The balance calculations were carried out using MathCAD environment, which confirmed significant energy savings with a slight increase in casting time associated with the appearance of an additional technological operation for installing the thermostatic cover after pouring. Using ANSYS Academic software, a study was carried out on the thermal fields of the ladle and steel at various stages of casting for two options, which confirmed the effectiveness of using a thermostatic cover.

1 Introduction

Currently in Russian Federation and other countries there is a tendency to increase steel production, according to World Steel Association. In 1970, 600 million tons were produced, in 2000 - 850 million tons, in 2010 production amounted to almost 1.414 billion tons, and in 2016 – 1.628 billion tons [1]. At the same time, the requirements for the quality of steel and the reduction of energy costs for the production of steel products are constantly growing. This article discusses one of the variants to reduce energy costs for the production of foundry products and providing more stable conditions for the casting process.

Steel-casting ladles are used at ferrous metallurgy enterprises for transportation and for pouring liquid steel in volumes from 0.5 to 480 tons [2-4]. Thermostatic cover are widely

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used in large enterprises with a full metallurgical cycle while at foundries with a capacity of less than 1 million tons of steel per year, this solution is rarely used [5]. Today in the world there are about 1000 mini-plants of various capacities and level of technology, which produce more than 15% of metal [6]. Meanwhile, at insignificant expenses for the application of this solution, significant effects are achieved [7, 8].

2 Materials and Methods

In this paper, as an example, a ladle with a refractory lining of 6 tons was taken, shown in figure 1, as well as a thermostatic cover made using high-temperature insulation, shown in figure 2. A feature of such ladle, in contrast to larger units, is their high specific surface area. For this reason, the heat loss of the metal in low-capacity ladle is higher, than in

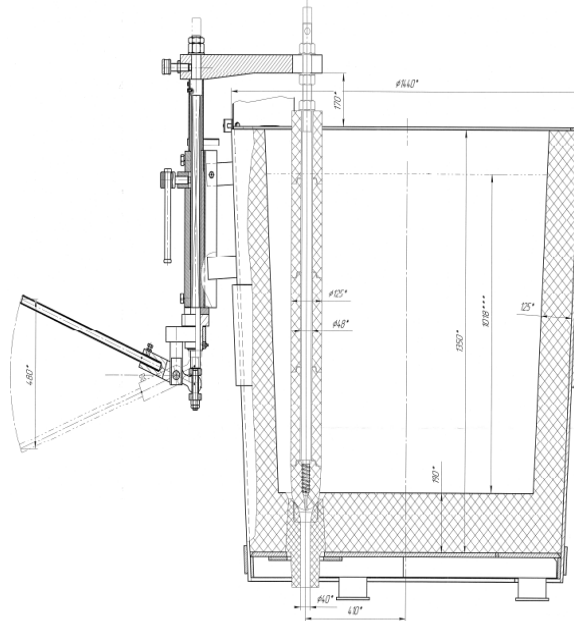


Fig 1. Locking pouring steel ladle.

large [9]. The cooling rate of the metal in such buckets is 1.5-2 times higher than that for large ladle, which means the relevance of using thermostatic caps is higher.

Losses of heat from the ladle lead to a decrease in the temperature of the liquid metal, accordingly, its additional overheating is required in an electric arc steel-smelting furnace (up to 1600-1650°C and higher) [10], this leads to a deterioration of the properties of steel products. The number of defects increases from overheated or supercooled metal in the case when the metal is cooled during casting [11, 12].

The object of the study is a 6-ton steel-teeming ladle, which has a conical shape with a height of 1.507 meters and an outer diameter of 1.44 meters. The ladle is filled with liquid steel at 1.018 meters from the bottom. The side wall with a thickness of 0.125 meters consists of three layers of different refractories [13].

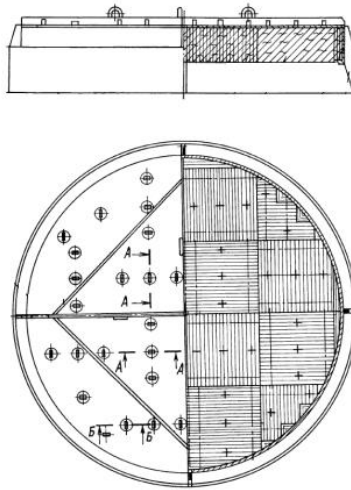


Fig 2. Thermostatic cover

After spillage the ladle is covered with a thermostatic cover, consisting of a steel frame with a thickness of 20 mm, covered with fiber refractory material with a thickness of 25 mm.

The thermophysical properties of the liquid steel, slag, steel shell and refractory materials, used in the calculation are shown in Table 1 [4, 14-16].

Table 1. The thermophysical properties of the liquid steel, slag, steel shell and refractory materials

Material	Thermal conductivity λ , W/(m·K)	Density ρ , kg/m ³	Specific heat C_p , J/(kg·K)
Periclase bricks (GOST 4689-74)	1.98	2700	1514
Mullite-siliceous bricks (GOST 24704-81)	1.34	2200	1183
Asbestos chrysolite fluff (TU 21-22-10-72)	0.218	450	850
Steel (casing)	50	7800	480
Liquid steel	30	6750	800
Slag	3	3000	2090
Multisiliceous fiber (cover)	0.13	200	1075

3 Results

To evaluate the energy effect, two casting options were considered, the first option - pouring without using a thermostatic cover, the second option using the thermostatic cover. Technological operations carried out with a ladle are shown in Table 2.

Table 2. Duration of technological operations

No.	Version 1. Existing position	Time, min	No.	Version 2. Pouring without using the thermostatic cover	Time, min
1.	Drain metal into the ladle	2.5	1.	Drain metal into the ladle	2.5
2.	Elevation the filled ladle to the transport position	0.7	2.	Elevation the filled ladle to the transport position	0.7
3.	Transporting the ladle to the temperature measurement point	1	3.	Transporting the ladle to the temperature measurement point	0.7
4.	Temperature measurement	1	4.	Temperature measurement (Measurement is performed in parallel with the work on the hook detaching from the ladle, engaging and elevation the thermostatic cover)	1
5.	Transportation ladle to the place of pouring	3.8	5.	Crane operation for installing the thermostatic cover (disengaging the hook from the ladle, elevation and installing the thermostatic cover)	5.3
6.	Time pouring	9	6.	Transporting the ladle to the temperature measurement point	3.8
			7.	Time pouring	9
Total time		18	Total time		22

Table 3 presents the results of calculations carried out in MathCAD environment to reduce the temperature of the steel in the ladle and the heat loss performed according to the formulas and methods reflected in the literature [17-19]. The use of a thermostatic cover has affected the total time of the process, held with a ladle for 5 minutes, which undoubtedly increased heat loss during additional crane operations at the time of installing the thermostatic cover on the ladle. From the obtained results it can be seen that the main heat losses are higher in the variant without the use of a cover, due to the larger share of losses through the slag. The final temperature of the metal is higher in the version with a cover. Despite the increase in time, the total heat loss using the lid decreased by 184.69 MJ, and the final temperature of the metal at the end of casting increased by 87.15°C.

Table 3. Temperature and heat losses during manufacturing operations

Parameters	Drain metal	Elevation ladle	Transport	Temperature measurement	Installing the thermostatic cover	Transport	Pouring	Total loss
Temperature loss without cover, °C	20.57	4.33	6.14	6.07	-	22.78	100.59	160.48
Temperature loss with cover, °C	20.57	4.33	4.30	6.09	31.88	0.94	5.22	73.33
Heat loss without cover, MJ	98.74	20.80	29.47	29.11	-	109.33	235.93	523.38
Heat loss with cover, MJ	98.74	20.80	20.63	29.22	153.03	4.49	11.78	338.69

Calculations show that when metal is released from a steel-smelting furnace with a temperature of 1600°C, the metal is cooled to a temperature below permissible at 1520°C, this means that the products will have defects associated with the low fluidity of steel. To do this, the staff is forced to overheat the metal in accordance with the calculations at 87.15°C. In the variant with the use of a cover, the metal is cooled to 1526.67°C, that ensures optimum pouring temperature throughout the pouring process. This step will reduce the temperature difference from the moment the metal is released to the end of pouring, which will reduce the number of scraps in production and ensure the stability of quality [20].

To verify the calculated data, we simulated the thermal state of the ladle during the pouring period.

When taking into account the influence of the thermal state of the ladle on the heat loss of the metal, the model takes into account the influence of radiant and convective heat exchange, and thermal conductivity between the surfaces of the ladle. To determine the decrease in temperature of the liquid steel from the beginning to the end of the casting, all heat losses for this period were taken into account, which consist of:

- heat loss by heat conduction through the walls of the ladle;
- heat losses by convection and radiation from the ladle casing and cover;
- heat loss by radiation from the slag mirror covering the metal.

The formulation of the problem of numerical investigation and determination of the boundary conditions was carried out in ANSYS Academic Student Release modules ANSYS Fluent and ANSYS CFX. Processing and analysis of the results were also carried out in the ANSYS environment.

Figure 3 shows two variants of the ladle (with and without cover) at full load of 100%. The temperature of the melt at the beginning of this stage, respectively, is 1531°C for a ladle with a cover and 1540°C for a ladle without a cover calculated in the second chapter. The temperature of the slag in the embodiment with a cover below 5.6°C.

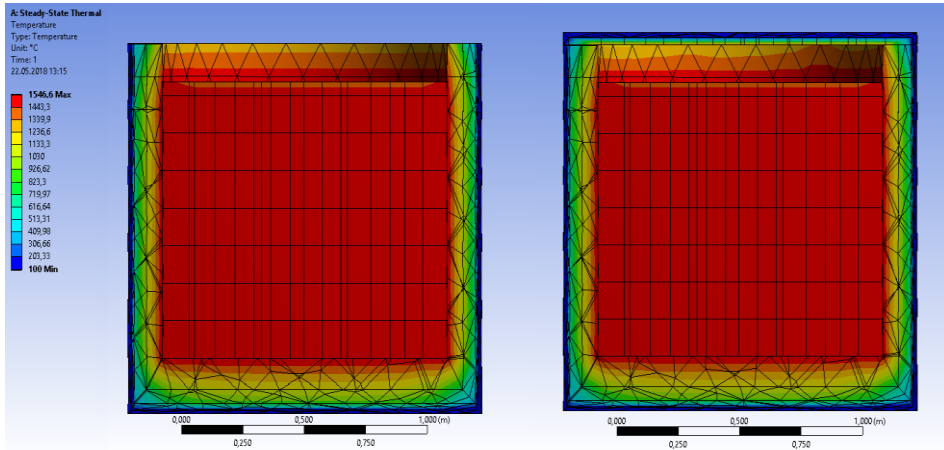


Fig. 3. Temperature field at a melt level of 100%

Figure 4 shows two variants under load ladle 75%. Melt temperature in a ladle without cover (1536.1°C) slightly lower than the temperature in the ladle with a cover (1537.1°C). The figure shows that the temperature of the inner walls of the ladle with a cover is higher than in the first embodiment. The slag temperature is also higher in the second version (1423.86°C). All temperatures are close to the calculated data.

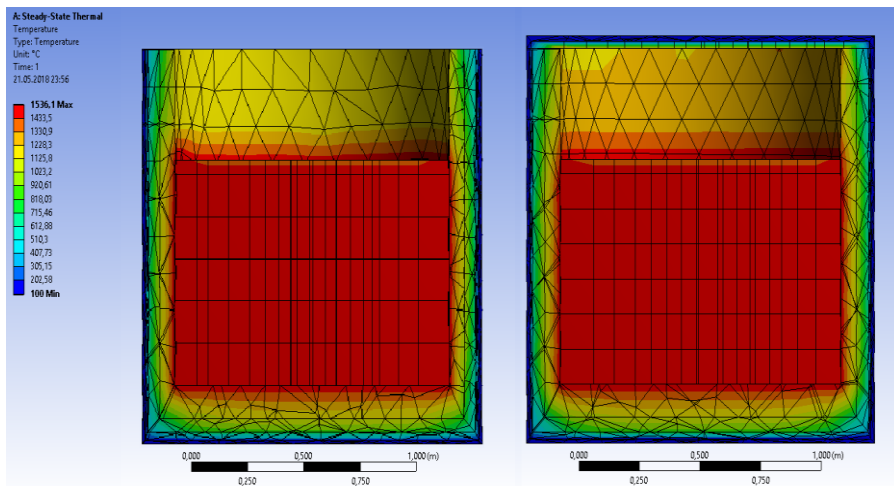


Fig. 4. Temperature field at a melt level of 75%

Figure 4 shows two variants under load ladle 50%. Melt temperature in a ladle without lid (1513.2°C) lower than the temperature in the ladle with a cover (1536.5°C) by 23.3 °C. The figure shows that the temperature of the inner walls of the bucket with a lid is higher than in the first embodiment. The slag temperature is also higher in the second version. (1423.21°C) by 17.91°C.

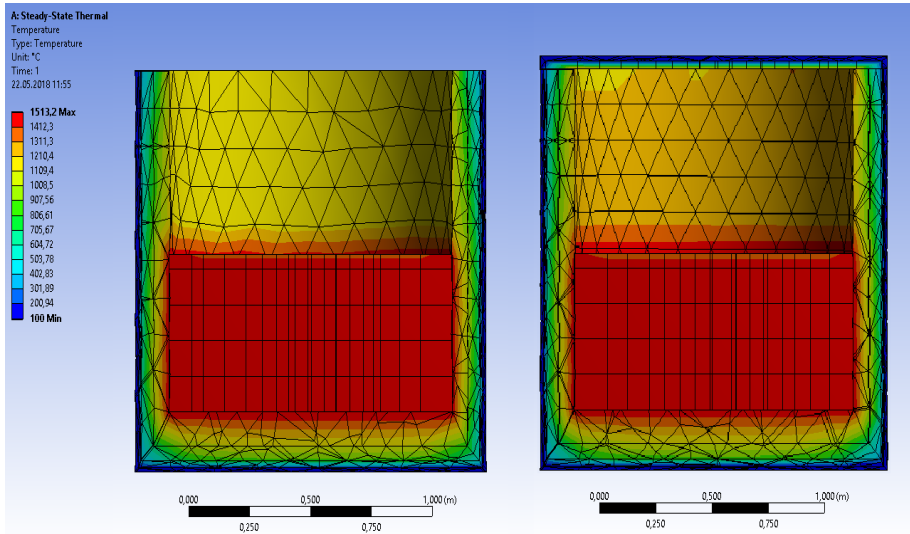


Fig. 5. Temperature field at a melt level of 50%

Figure 4 shows two variants under load ladle 25%. Melt temperature in a ladle without cover (1489.4°C) lower than the temperature in the ladle with a cover (1535.4°C) by 46 °C. The figure shows that the temperature of the inner walls of the ladle with a cover is also higher, as in the previous stages. The slag temperature is higher in the second version. (1422.35°C) by 39.95°C.

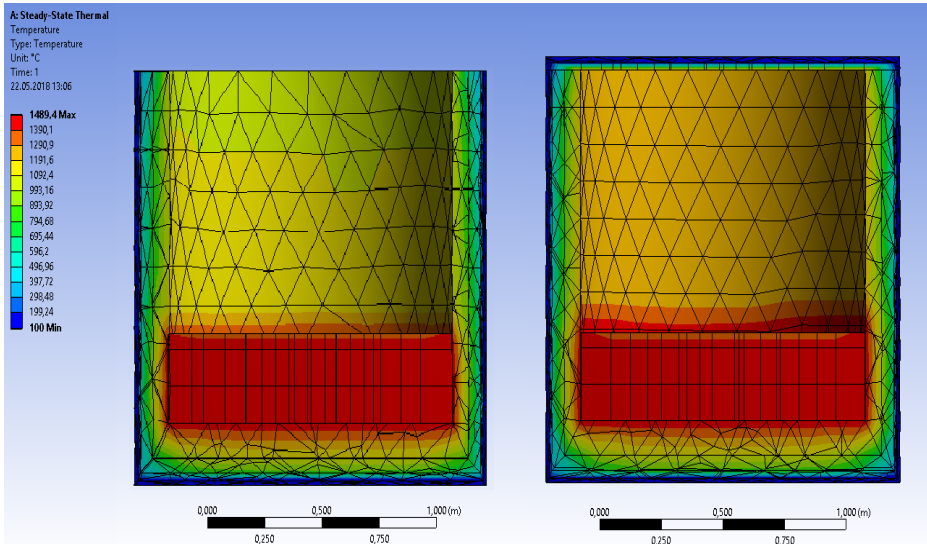


Fig. 6. Temperature field at a melt level of 25%

4 Discussion

Thus, numerical simulation of steel casting made it possible to get an idea of the state of the melt in the ladle space, determine melt temperatures and ladle and cover surfaces. The

results of modeling the temperature of the metal for a variant of casting the steel without the use of a thermostatic cover are shown in Table 4.

Table 4. The results of the simulation for the ladle with no cover

Parameters	Ladle loading			
	100%	75%	50%	25%
The estimated temperature of the melt, °C	1540.00	1527.00	1510.00	1485.00
Simulated melting temperature, °C	1540.00	1536.10	1513.20	1489.40
The estimated temperature of the outer wall of the ladle, °C	99.39	99.41	99.43	99.46
The simulated temperature of the outer wall of the ladle, °C	102.60	104.40	106.20	108.50
The calculated temperature of the slag surface, °C	1426.00	1414.00	1398.00	1376.00
Simulated slag surface temperature, °C	1430.20	1420.60	1405.30	1382.40

In Table 5 shows the results of modeling temperature changes for the variant with the use of a thermostatic cover.

Table 5. Simulation results for ladle with cover

Parameters	Ladle loading			
	100%	75%	50%	25%
The estimated temperature of the melt, °C	1531.00	1531.00	1530.00	1529.00
Simulated melting temperature, °C	1531.00	1530.80	1529.6	1528.30
The estimated temperature of the outer wall of the ladle, °C	99.39	99.49	99.41	99.40
The simulated temperature of the outer wall of the ladle, °C	102.60	104.40	106.20	108.50
Estimated surface temperature of the cover, °C	91.49	102.83	117.94	139.16
Simulated cover surface temperature, °C	92.60	105.40	120.63	140.20
The calculated temperature of the slag surface, °C	1418.44	1417.91	1417.19	1416.00
Simulated slag surface temperature, °C	1424.6	1423.86	1423.21	1422.35

The results of the work for the conditions of the steel bucket with a capacity of 6 tons, lead to the following conclusions:

1. The use of thermostatic covers will reduce the total heat loss from the ladle by 184.69 MJ during the period of transportation and casting of steel from the ladle;
2. Reduction of heat losses will allow to reduce the temperature of metal overheating in the furnace by 87.15 °C;
3. Reduction of the temperature difference between the metal in the casting will reduce manufacturing defects.

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