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Abstract. Heat treatment of aluminum ingots is a fairly energy-intensive production. Therefore, increasing energy efficiency in such processes plays an important role in reducing economic costs. The mathematical model of heat exchange occurring in the cooling chamber of aluminum ingots after homogenization annealing is considered. The model obtained made it possible to study the heat transfer in the cooling chamber. To improve energy efficiency and reduce economic costs, options for recycling hot air from the cooling chamber are offered. The estimation of economic efficiency from use of each of variants carried out.

Introduction

The existing technology of semicontinuous casting of aluminum alloys in the water-cooled crystallizer has the main technological problem - the formation of an inhomogeneous structure, micropores, cracks in the ingot due to uneven cooling of the ingot along the cross section. To solve this problem, heat treatment is carried out, one of the types of which is homogenization annealing, consisting in heating and holding ingots to a temperature higher than the dissolution temperature of the alloying components.

An important stage after homogenization of aluminum ingots is their cooling with a speed not exceeding the critical one, in order to avoid the hardening process of the alloy. For most alloy grades, this cooling temperature is 70 ° C / h. The fulfillment of this requirement is possible in several ways, but the most expedient, as shown in [1], is the cooling of aluminum ingots after homogenization annealing in a special cooling chamber, allowing to maintain a given cooling rate and increase the production of quality products.

Mathematical model of heat exchange in the cooling chamber

Application of existing methods of cooling aluminum ingots does not allow to maintain an equal cooling rate in all parts of each ingot. The existing cooling modes and methods do not take into account the geometric characteristics of the cooling chamber and the methods of placing ingots in the chamber, which allow to ensure uniform cooling and lower energy costs for the cooling process.

The solution of this problem was the development of a mathematical model of controlled convective heat transfer between cooling air and aluminum ingots. The resulting mathematical model describes the heat transfer in the cooling chamber of aluminum ingots, taking into account the geometric distribution of ingots in the cooling chamber. The mathematical model, the assumptions made to it, the description of the heat exchange process are described in more detail in [2,3].

The obtained mathematical model allowed performing an analytical study of heat exchange in the cooling chamber between air and aluminum ingots. The influence of structural factors (the diameter of

the ingot, the height of the channel between the rows of ingots) and the regime factors (the speed of the cooling air) were investigated. The study showed that maintaining a constant rate of cooling air does not allow obtaining high-quality products, since during the initial cooling period, aluminum ingots are hardened due to exceeding the critical cooling rate. Therefore, maintain a variable rate of cooling of ingots was proposed, which allowed a given cooling rate and reduce energy costs. The results of the investigations are presented in [4, 5].

Economic justification for increasing the energy efficiency of the heat treatment cycle

One of the results of the study, described above, was that the temperature of the cooling air at the outlet from the chamber is 120-130 ° C. Removing air with such a temperature into the environment is economically inexpedient, since its use will increase energy efficiency and reduce fuel costs in any technological process. Consider the options for using the heat of the cooling air for a specific heat treatment section and for the production of aluminum products (Figure 1) and the resulting fuel economy.
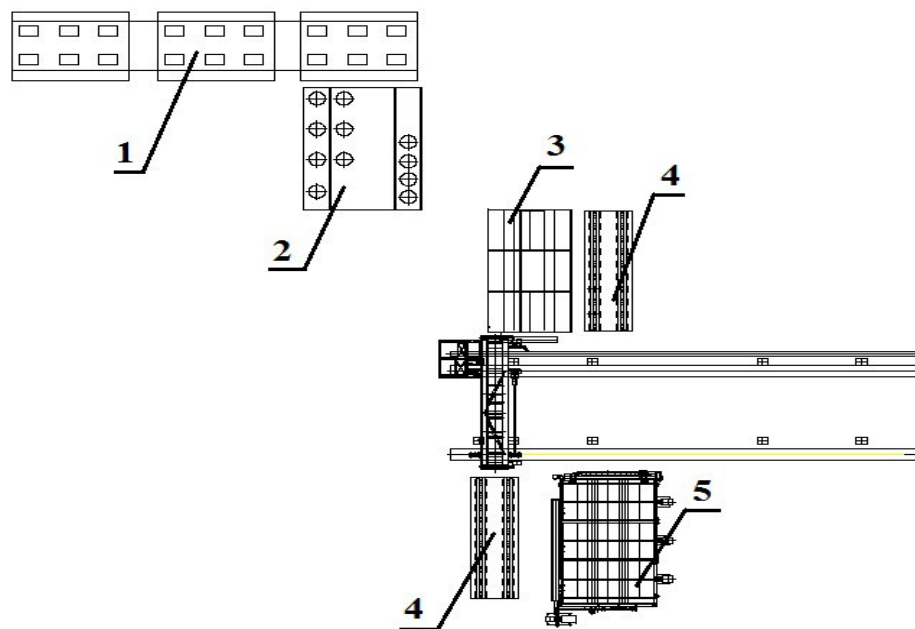

Figure 1. The plan of the heat treatment section 1-washing chamber, 2-drying chamber, 3-cooling chamber, 4-place for forming a cage, 5- homogenization furnace

The section shown in Fig. 1 consists of a homogenization furnace, a cooling chamber, and a color section of aluminum profiles, including washing, painting and drying chambers. Washing of the profiles is carried out by solutions heated by hot water from the boiler room. Drying is carried out by hot air heated from natural gas combustion products.

Thus, for this section, it is possible to utilize heated air from a homogenization furnace in the following schemes:
- supply of heated air as an oxidizer of natural gas to a homogenization furnace,
- heating the air with detergent solutions in the washing chamber,
- drying profiles in the drying chamber,
- use of heated air for air heating of the workshop.

Let's consider how in each scheme fuel consumption at recycling of heated air from a homogenization furnace is reduced and, accordingly, the energy efficiency of the heat treatment process is increased. The economic effect of the supply of hot combustion air together with fuel in the

homogenization furnace will be determined as the difference in the combustion with natural gas of cold and hot air. Fuel economy during the heat treatment of 20,000 kg of aluminum ingots per hour with heating them from the initial temperature of 20 ° C to the final 550 ° C will be 9.5 m3 / h. The economic effect of the introduction of hot air heating solutions in the cleaning chamber will be determined by the reduction in natural gas consumption for heating the water in the boiler room. As a result of the application of this scheme, fuel savings can be 8.1 m3 / h. When using hot air for drying profiles, the economic effect is caused by a reduction in the gas consumption for heating the drying air, since hot air can be directly used as a drying agent. With this scheme of utilization of air, fuel economy can reach 6 m3 / h. As a result of the use of hot air for heating, it is possible to refuse traditional water heating, which is not effective in production plants. The fuel economy can be up to 5 m3 / hr when using this scheme. In all schemes, the gas flow was determined from the heat balance equation.

As can be seen from the above, any of the described schemes leads to an increase in the energy efficiency of the heat treatment process by reducing the consumption of organic fuel [6, 7]. It is only necessary to determine the most cost-effective scheme by comparing net present value (BHD). In addition to finding the most optimal scheme for utilizing hot air - improving the energy efficiency of the entire heat treatment process, let us consider the economic feasibility of using a cooling chamber in a heat treatment cycle. The results of the change in the BHD at the 10-year horizon when the cooling chamber is used to the cycle of heat treatment and the use of heated air for the above described schemes for its utilization at the discount rate E = 0.12 are shown in Fig. 2.
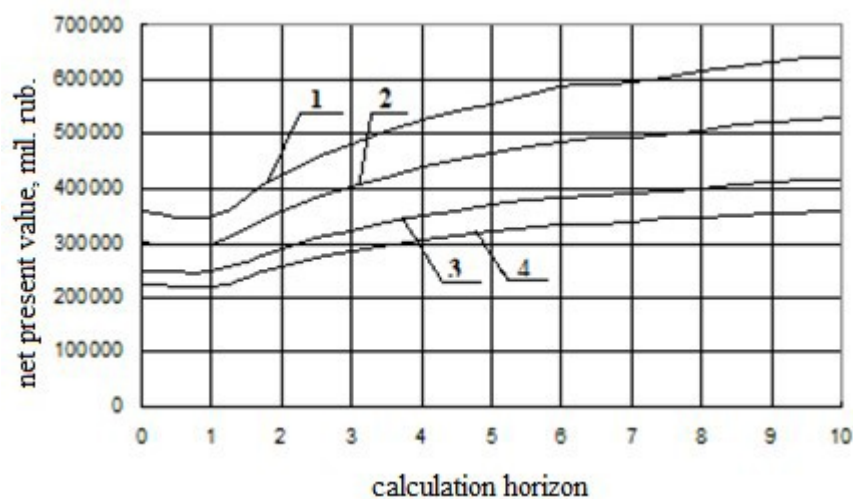

Figure 2. Change in net discounted income by years of the calculation horizon: 1 - a diagram of the use of heated air in a homogenization furnace, 2 - a diagram of the use of heated air in a washing chamber, 3 - a diagram of the use of heated air in a drying chamber, 4 - a diagram of the use of heated air for air heating.

Discounted payback period for various schemes is:
- scheme for using heated air in a homogenization furnace - 0.1 year,
- scheme of using heated air in the washing chamber - 0.16 years,
- scheme of using heated air in the drying chamber - 0.15 years,
- scheme for using heated air for air heating - 0.17 years.

The choice of the most profitable option for using heated air is determined by the highest value of net discounted income and the shortest payback period. From the considered schemes in this case, it is most expedient to use heated air for feeding to combustion in a homogenization furnace.

The conducted research shows that by utilization of hot air during homogenization of aluminum

ingots it is possible to reduce fuel consumption for the heat treatment process and increase the energy efficiency of the entire process.

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