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ENERGY AND TECHNOLOGICAL MODELLING OF METALLURGICAL PROCESSES FROM OUT-OF-FURNACE IRON PROCESSING TO CONTINUOUS CASTING

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INTRODUCTION

The dynamics of economic development in a particular country or region shapes the results of gradual (evolutionary) changes in society and nature. The indicator of these changes is the level of energy efficiency of life.

It is this immutable condition for the development of society that determines the urgent need for rational energy consumption and reduction of its specific costs in all spheres of human activity. This direction is called energy saving[1].

Energy conservation is the implementation of legal, organisational, scientific, production, technical, informational and economic measures aimed at the efficient use of energy resources and the involvement of renewable energy sources in the economic turnover. Energy saving in production can be quantified by an indicator called energy intensity[2].

Based on the definition of energy saving as a set of measures aimed at efficient energy use, there is a requirement to limit the use of material resources of the environment, when it comes to the so-called non-renewable primary energy sources in the form of organic, mineral fuels (natural gas, oil) or raw materials (iron ore, limestone, magnesite, coal as a reducing agent, etc.), which is very relevant for the current conditions of steelmaking.

1. Modeling of cast iron out-of-furnace processes

To carry out energy-technological modeling of modern technologies for the production of converter steel, studies of technologies for refining cast iron and steel were carried out and the main energy-consuming articles of continuous casting of steel were determined, depending on the grade range, energy intensity of steel.

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[1] Annual Energy Outlook 2010. U.S. Energy Information Administration, Washington, December 2009. URL: [http://www.eia.doe.gov/neic/speeches/newell121409.pdf]

[2] European Energy and Transport trends to 2030. – European Commission, Directorate General for Energy and Transport. Greece, 2003.

Using developed mathematical models[3], energy-technological modeling of processes of out-of-furnace treatment of cast iron with the most common reagents was carried out.

Desiliconization of cast iron in production conditions is carried out by agglomerate, scale or mixtures based on them. The simulation was carried out for the following conditions: the final silicon content in cast iron is 0.3%, and the initial content varies between 0.4 ÷ 1.2%. Based on the simulation results, the dependence of the increase in the energy intensity of cast iron on the degree of desiliconization with agglomerate and scale was obtained (Fig. 1.1).

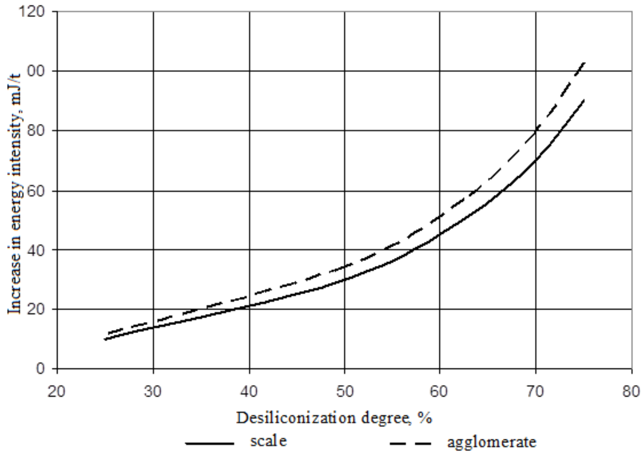

Fig. 1.1. Dependence of the increase in the energy intensity of cast iron on the desiliconization degree by scale and agglomerate

Figure 1.1 shows that the iron scale desiliconization operation is less energy intensive than the agglomerate.

To remove phosphorus from cast iron in conditions of out-of-furnace treatment, mixtures based on lime, soda, scale are used. For modeling, 3 mixtures of the above materials were selected in the ratio 2:1:2, 4:1:5, 2:0:3. As modeling conditions, the content of phosphorus in cast iron after treatment is 0.03%, and before treatment - within 0.04 ÷ 0.1%. The simulation results are shown in Figure 1.2.

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[3]Analiz energeticheskoi effektivnosti protsessov vnepechnoi obrabotki chuguna / Stoyanov A.N., Nizyaev K.G., Molchanov L.S.// XVII International scientific conference "New technologies and achievements in metallurgy and materials engineering": A collective monograph edited by Jarosław Boryca, Rafał Wyczołkowski. Czestochowa (Poland). 2016. P. 133–138.

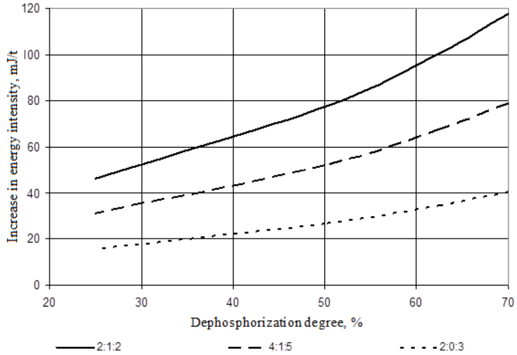

Fig. 1.2. Influence of the degree of cast iron dephosphorisation by a mixture of lime: soda : scale with different proportions of components on the increase in the energy intensity of cast iron

Sulphur removal from cast iron in production conditions can be carried out by a number of reagents, among which the most common are granular magnesium, lime, their mixture, magnesium wire, calcium carbide and exothermic magnesite briquettes. The modelling was carried out under the following conditions: the final sulphur content in cast iron is 0.02%, and the initial content varies between 0.04% and 0.08%. The modelling results show the dependence of the increase in the energy intensity of cast iron on the degree of desulphurisation by the listed reagents (Fig. 1.3).

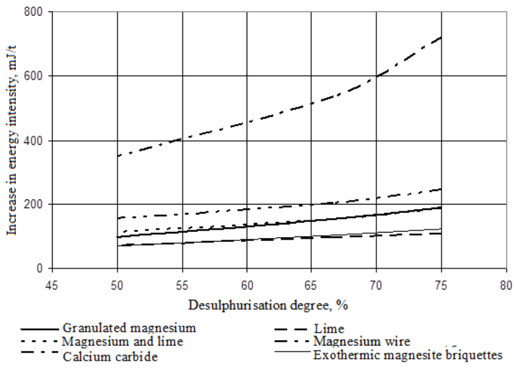

Fig. 1.3. Dependence of the increase in energy intensity of cast iron on the degree of desulphurisation by different reagents

Figure 1.3 indicates that the desulfurization of cast iron with calcium carbide is the most energy-intensive operation of all the out-of-furnace processes of cast iron. Exothermic magnesite briquettes add the same energy intensity as lime, which are the least energy-intensive of the listed reagents.

2. Simulation of oxygen converter process with upper oxygen purge

The main factor affecting the energy intensity of converter steel is the specific consumption of liquid cast iron[4,5,6]. This figure is about 90% (Fig. 1.4).

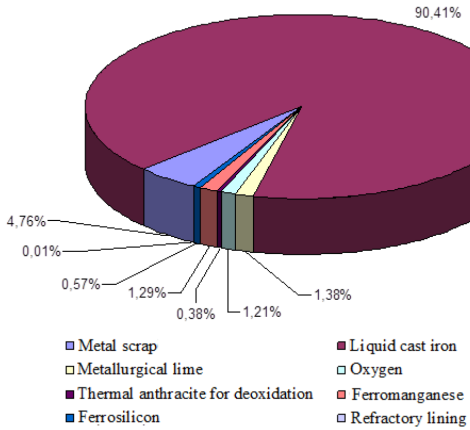

Fig. 1.4. Share of charge materials in energy intensity of converter steel

This factor, in turn, is determined by the chemical heat of cast iron, namely, the content of silicon in cast iron. Increasing the silicon content in cast iron not only increases the specific consumption of cast iron, but due to this leads to an increase in the energy intensity of converter steel by almost 20 MJ/t of steel for every 0.1% of silicon (Fig. 1.5). From this position, the question arises of the feasibility of off-furnace desiliconization of cast iron.

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[4] Stoyanov A.N., Nizjaev K.G., Molchanov L.S., Righkin A.V. Uncontrolled parameters influence on material and energy consumption for BOF heat. *Metallurgical and Mining Industry*. No.5. 2017. p.52– 57.

[5] Harakterystyka materialo- i energovytrat pri vyrobnyztvi stali v konverternyh cehah Ukrainy, Germanii i Kitayu / K.G. Nizyaev, O.M. Stoyanov, L.S. Molchanov, S.V. Semiryagin, Jekongo Mujel Odrej Maks (student ME-02-15M). Metal ta lyttya Ukrainy. № 1. 2020. S. 64 – 71.

[6] Stoyanov O.M., Nizyaev K.G., Molchanov L.S., Ryzhkin A.V. Analiz vplyvu nekontrolevanyh parametriv na materialo- i energoemnist konverternoi plavky. Metalurgiyna ta girnychorudna promyshlovist. №1. 2017. S. 18 – 24.

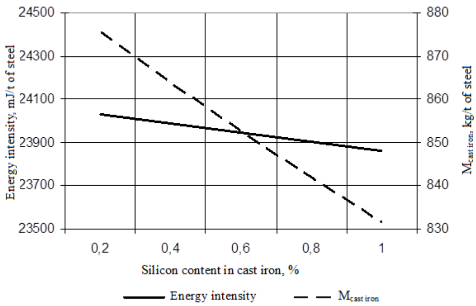


Fig. 1.5. Influence of silicon content in cast iron on its specific consumption and increase in energy intensity of liquid steel

3. Modeling of steel out-of-furnace treatment

The purpose of out-of-furnace metal treatment is to prepare steel for continuous casting at the CCM. It includes steel heating, neutral gas purging, alloying and sometimes modification, and slag treatment for desulphurisation. Two main types of slag mixtures are used as the latter: synthetic slag (SS) and solid slag mixtures (SSM), which are added to the ladle in the form of lumps or powder[7]. For these three desulphurisation options, the modelling of the increase in the energy intensity of steel was carried out at the conditions of the initial sulphur content in steel of 0.02÷0.06 % and the final one of 0.01 %. The modelling results are shown in Figure 1.6.

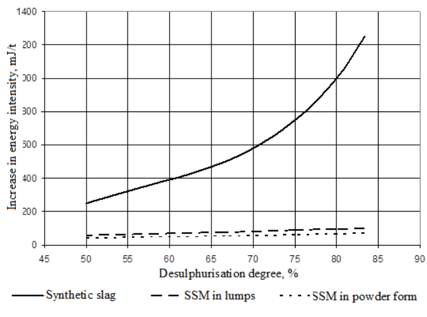


Fig. 1.6. Comparison of the increase in energy intensity of steel during desulphurisation at CCM with slag mixtures at different degrees of desulphurisation

[7] Analiz energeticheskoi effektivnosti protsessov vnepechnoi obrabotki chuguna / Stoyanov A.N., Nizyaev K.G., Molchanov L.S.// XVII International scientific conference "New technologies and achievements in metallurgy and materials engineering": A collective monograph edited by Jarosław Boryca, Rafał Wyczołkowski. Czestochowa (Poland). 2016. P. 133–138.

Figure 1.6 illustrates the high energy intensity of synthetic slag processing compared to HSM, which is related to the method of slag feeding into the ladle, since the SS prepared in the furnace is added to the ladle in a molten state. In Fig. 1.7 the data on the distribution of the increase in energy intensity of steel by main genders are shown.

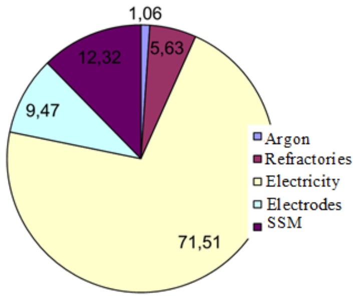


Fig. 1.7. Weight average percentages of steel capacity increase during processing at the ladle-furnace unit

4. Basic technological provisions of continuous steel casting

Continuous casting is a much less energy-intensive way to produce steel billets compared to casting in a top-shelf mould and siphoning.

The energy intensity of the continuous casting process is determined by a number of factors, including the energy intensity of refractory materials (shotcrete in the ladles, devices to protect the jet from secondary oxidation, locking devices, etc.), slagging mixtures in the furnace and crystalliser, copper lining of the crystalliser, cooling water, process gases (natural gas, argon, oxygen and acetylene), electricity for equipment and automation systems, etc.

Almost all of the above items of energy consumption in the continuous casting process depend on the design features of CCMs and are almost the same for all machines. This includes, among others, the copper liner of the crystalliser, the energy intensity of which depends on the design of the crystalliser and, accordingly, the method of its manufacture. The specific energy consumption of such materials will be relatively constant, unaffected by the steel grade being poured. The same applies to refractory materials, process gases and electricity.

In contrast to the above factors, the specific energy intensity of cooling water and slagging mixtures depends on the steel grade being poured at the CCM. It is the specific energy consumption of these materials that will change the energy consumption of the process of continuous casting of steel of different steel grades into long, bloom and slab billets.

The optimal secondary cooling regime for ingot is determined by many factors that depend on the properties of the steel being cast, the type of CCM, etc. Secondary cooling must ensure rapid and complete solidification of the steel ingot, which allows for a reduction in the length of the secondary cooling zone and the entire CCM; and the permissible amount of deformation of the ingot metal. The conditions that contribute to the fulfilment of these requirements often contradict each other, and it is necessary to find the best solution for the adopted design of the secondary cooling zone. When the secondary cooling intensity increases to a known limit, heat removal increases and ingot solidification time decreases, which allows for higher casting speeds. However, too much cooling increases the number of cracks and deteriorates ingot quality.

In practice, water-air secondary cooling of the billet is widely used, where the ratio of water to air flow depends only on the carbon content of the steel in different parts of the secondary cooling zone. Figure 1.8 shows this dependence for the conditions of a 300×400 mm bloom 6-strand CCM at OJSC Dzerzhinsky Iron and Steel Works. The secondary cooling zone (SCZ) consists of 4 sections: the first two form zone A, and the last two form zone B.

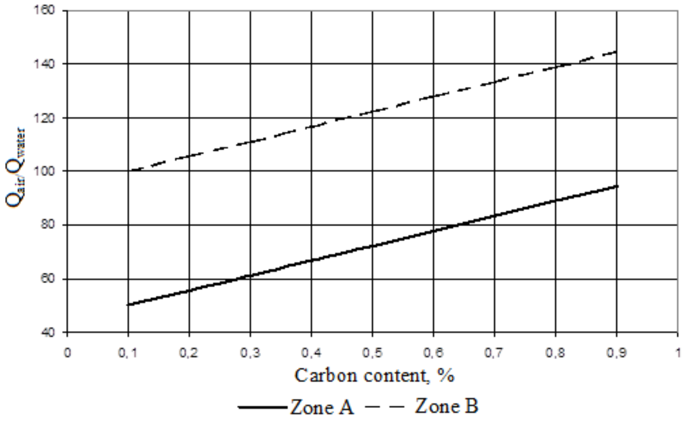
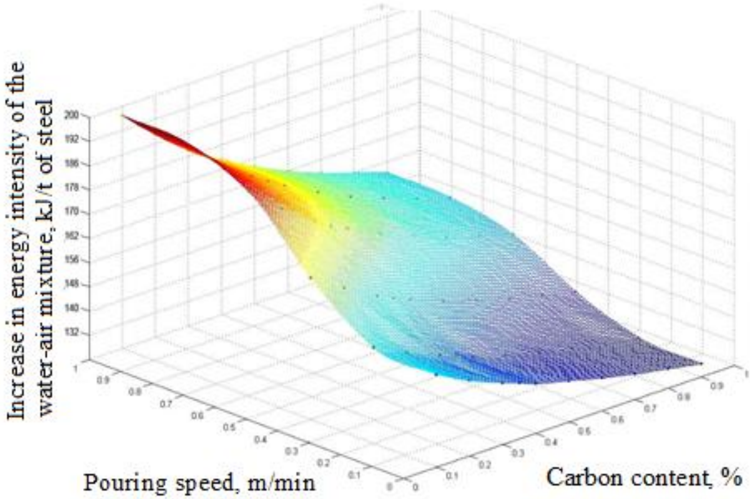
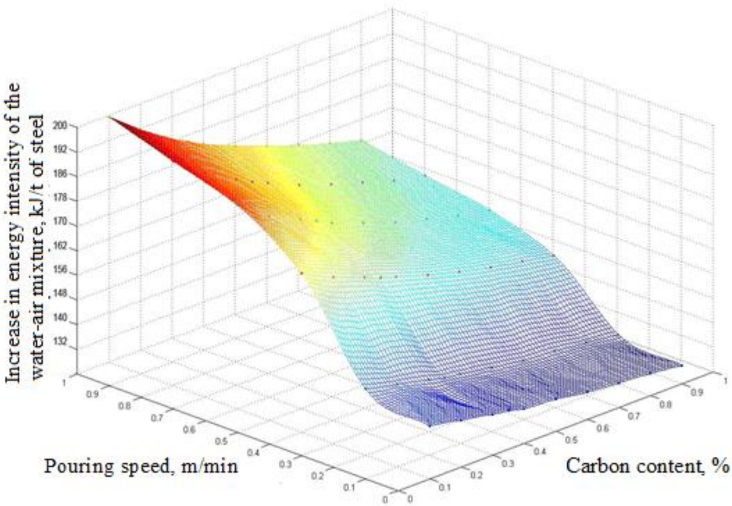


Fig. 1.8. Dependence of the ratio of air and water volumetric flow rates on the carbon content of the steel being poured

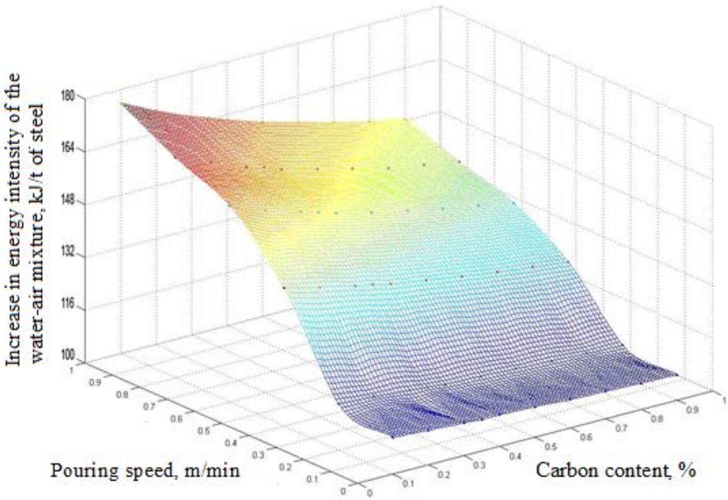
In turn, water consumption for cooling depends on the carbon content and the steel casting speed. The dependence of water consumption in the four areas of the CCM on the carbon content of the steel being cast and the casting speed is shown in Fig. 1.9.


Increase in energy intensity of the water-air mixture, kJ/t of steel
Pouring speed, m/min
Carbon content, %

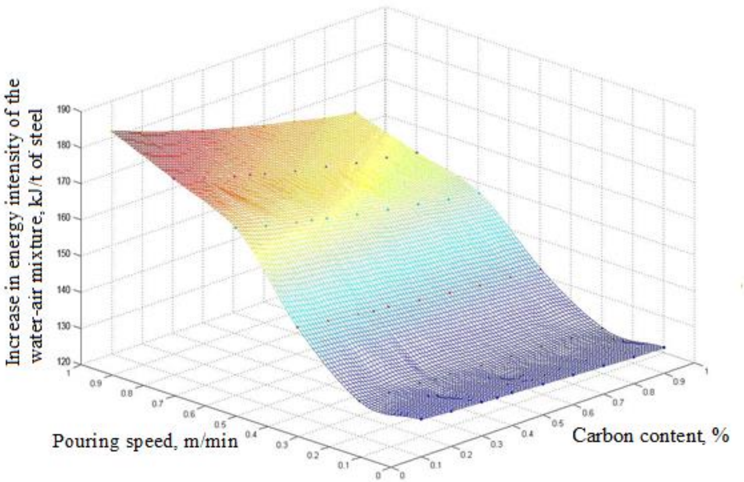
a


Increase in energy intensity of the water-air mixture, kJ/t of steel
Pouring speed, m/min
Carbon content, %

b



c



d

a) zone 1, b) zone 2, c) zone 3, d) zone 4

Fig. 1.9. Water consumption as a function of casting speed and carbon content of steel

CONCLUSIONS

Based on the energy and technological modelling, the article identifies the main factors that significantly affect the increase in the energy intensity of steelmaking, while the quantitative values of the energy intensity of metal, depending on the technology used at different stages of steelmaking, may differ by an order of magnitude. It is noted that there is a need to develop separate types of end-to-end steelmaking technologies depending on the steel grade and casting conditions.

SUMMARY

Conducted energy-technological modeling of steelmaking processes. It is shown that at different stages of steel production, the increase in energy intensity of steel differs significantly and depends on the chosen technology, equipment and materials used. It has been established that for modern methods of off-blast refining of cast iron, the least energy-consuming technology is the use of mixtures based on lime and magnesium. For the oxygen-converter process, liquid cast iron contributes the largest increase in energy consumption, and for conditions of non-furnace processing of steel, the consumption of electricity for heating the metal. An assessment of the impact of the speed of steel pouring on the MBLZ and the carbon content in the metal on the energy costs of the process is also given.

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