

Heat-electrical regeneration way to intensive energy saving in an electric arc furnaces

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Abstract. Energy saving in steel production is of great significance for its large economical scale of 1500 mil t/year and high-energy consumption. Steady trend of last years is an increase of steel production in electric arc furnaces (EAF) with a very high consumption of electricity up to 750 kWh/ton. The intention to reduce so much energy consumption they can reach by many ways. One of such way is a transforming heat energy of liquid steel to electricity and destine it to steel electric arc process. Under certain conditions, it may lead to “zero” consumption of electric power in the process. The development of these conditions leads to the formation of energy-efficient heat schemes, with a minimum electricity consumption from the external network.

1. Introduction

Economic scale in steel production in the world reaches 1.5 billion tons per year [1] and is second only to the technology of cement production (3.3 billion tons per year). Overall energy analysis of the production of steel allows you to mark a significant increase in the consumption of electric energy (EE) of its production in recent years. The share of steel in the world has already exceeded 30% and tends to 50%. Specific consumption of EE in electric furnaces can exceed 700 kWh/t when you work on clean steel scrap; making steel melting process is definitely a leading electrical load of the steel industry [2]. Using various process methods, specific consumption of EE they can reduce below 200 kW/t. These activities include increasing the proportion of pig iron in furnace charge, and the application of oxygen and natural gas. On the other hand, the gross heat of liquid steel for kWh/t it is possible to convert to 150 – 240 kWh/t EE in the steam turbine cycle or combined gas-steam cycle. This opens up the possibility of energy self-sufficiency arc-furnace process due to use of heat of liquid steel, with "zero" consumption of EE [3]. In this case, the heat of liquid steel they use in the regenerative direction, but after conversion to EE. This method of energy saving we can define as "heat-electric regeneration" and it is relate to the scientific field of **intensive** energy saving.

2. Thermal technology of steel production and it's energy problems

Steel production is a central point to the steel industry. The overall energy intensity of steel is 500 - 1000 kg of conventional fuel (c.f.) per ton, depending on the production method. Therefore, energy conservation in steelmaking is located in the centre of attention of power engineers and metallurgists [4-6]. The main materials for steel production are pig iron and scrap metal. The main costs of energy enter in the process with a liquid pig iron (about 1000 kg. c.f. /t).



So one of the ways to reduce energy consumption is to reduce the proportion of cast iron and increasing the proportion of scrap. There are three main methods of steel production: open-hearth furnace, oxygen Converter (BOF) and electric arc.

The energy problem is that the BOF process cannot process more than 25% of scrap and has a very large total energy consumption - about 1000 kg. c.f. /t. The electric arc steelmaking process can recycle up to 100% scrap, but has a very high electric power consumption over 700 kWh/t [7-9].

The focus of reducing this energy consumption is to increase the share of pig iron and the use of additional sources of energy - oxygen and natural gas. The power consumption reduces, but the overall energy intensity of the steel increases. In these conditions, is of great interest to study the possibilities of reducing power consumption without increasing the fuel costs of its production [7].

3. The heat of liquid steel as a secondary energy resource

3.1. Fuel-free energy source

The finished steel is at the stage of melting, out of the process with a temperature of about 1600°C and contains about 1400 MJ/kg or about 50 kg. c.f. /t or 389 kWh/t of thermal energy. Practically all of this high-potential heat energy is lost into the environment, increasing the energy intensity of steel and total energy costs of its production. Thus, the liquid warmth of finished steel is a valuable secondary energy resource (SER). Currently, the heat of liquid steel transfers to the cooling water and is lost.

Water, its properties can only perform the functions of the cooler, but not the intermediate heat agent for future use. Previous investigation results [2, 7, 9, and 10] shows that as an intermediate heat transfer agent could be selected sodium-potassium eutectic or lead-bismuth alloy C-13.

Lead-bismuth alloy C-13 has a high boiling point of 1680°C and a low enough melting point 124°C.

This means that it can perceive the warmth of the liquid steel at 1600°C without boiling. Lead-bismuth alloy C-13 has a density of 10500 kg/m³, which exceeds the density of liquid steel 7500 kg/m³ and opens up the possibility of the high-speed horizontal casting of steel on an alloy C-13 [10, 11].

It is possible the perception of the total heat of liquid steel and the achievement of different temperature levels of the coolant depending on the scheme of heat transfer. When flows of steel and the heat agent running straight ahead the it is possible to obtain the temperature of agent slightly in excess of 124°C, for example, 200°C. In the case of counter current of a steel and C-13 it is theoretically possible to obtain maximum heat agent temperature of 1593°C [10].

The temperature of the coolant in this case exceeds the temperature of steel scrap melting point (1500°C) what opens up opportunities for its pre-heating and melting for steel-making process.

Strogonov and Platonov carried out relevant research [2, 10]. Thus it was investigated the area of maximum and minimum temperatures of the coolant and the possibility of further application of this heat. For the C-13 maximum temperature of 1593°C, it is possible to melt the steel scrap.

For the agent minimum temperature of 200°C, possible use of heat is the production of hot water or steam. Also known the combined scheme, which provides heating of the heat agent to 1500°C and produce hot water or steam. None of the known schemes did not provide generating electricity.

3.2. The declining trend in electricity consumption in electric steelmaking

The production of steel in an oxygen blown Converter did not require significant amounts of electricity (about 30 kWh/t).

With the development of electric steel production, the situation with power consumption has changed dramatically.

When working on 100% scrap, the power consumption may exceed 700 kWh/t. It makes the steelmaking process leading electrical load (Fig.1) [7].

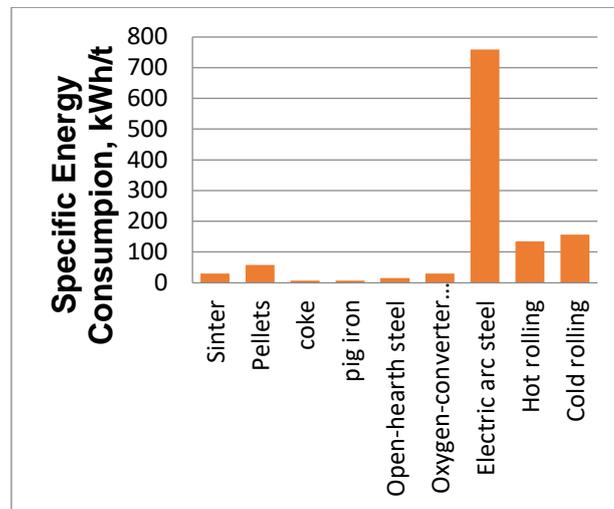


Figure 1. Specific energy consumption for semi-products of ferrous metallurgy

Usually at Russian factories, its own power plants cannot cover such large electrical load. This forces companies to buy electricity from the regional power grid, which costs 2.5 – 3 times the price of electricity of own generation. These circumstances are extremely aggravated the relevance of the full reduction of power consumption from the regional power grid, in production of steel. The main directions of reducing the EE is an increase in the proportion of pig iron and the appropriate amount of oxygen to purge, and the application of oxy-fuel energy source. With various combinations of these additional energy sources total energy consumption can be reduced to 400 – 200 kWh/t or even lower. The dependence of EE consumption in Electric Arc Furnace (EAF) of the portion of the pig iron shown in Fig. 2 [3].

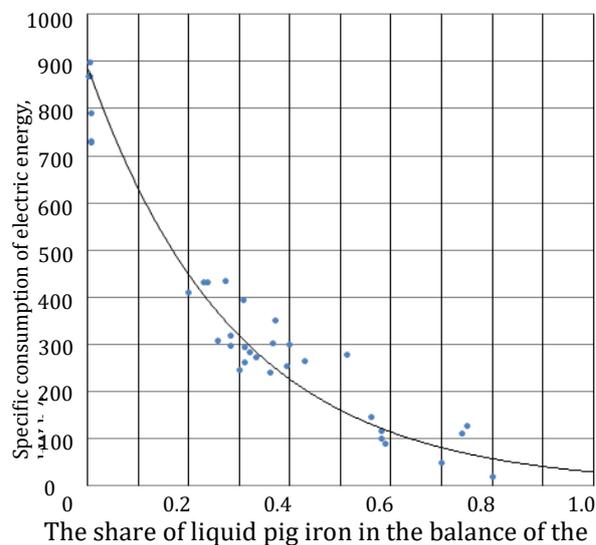


Figure 2. The dependence of EE consumption of the portion of the pig iron in the charge

Analysis of trends in the reduction of EE consumption from the share of iron shows that the proportion of cast iron 0.55 power consumption reduces to 155 kWh/t.

To assess this value, note that the molten steel contains in equivalent 389 kWh/t of thermal energy. If this warmth they convert into electricity in a standard steam turbine cycle with an efficiency of 0.4, it is possible to get just 155 kWh/t of electricity [3].

Thus, under these conditions it opens the opportunity to implement the EAF process with "zero" consumption.

Of course, we mean the equality of consumed and output EE to the network capacity.

However, when you consider that at the steel plant, pig iron and oxygen are own sources of energy and possible power generation at the heat of liquid steel is also a private, full payment of purchased electric energy represents a large energy and economic interest.

To implement such energy-saving effect it is necessary to develop thermal scheme of the heat of liquid steel usage and generation on it base electric power.

4. Development of energy-saving thermal scheme of heat-electric power regeneration

As shown above, the interval of temperatures below 1500° C and above 200° C remained unexplored for energy saving in the manufacture of electric arc steel. Meanwhile, just in this interval of temperature currently, in the energy sector, they generate an electric power in a steam turbine, gas turbine and steam-gas cycles. In contrast to the previous mentioned schemes, for the generation of electricity, this scheme does not require attainment of higher heat agent temperature of 1500° C and above. It is sufficient to heat the heat agent up to 600° C to 1000° C to produce superheated steam of high parameters. For gas turbine generation the thermal resistance of the turbine blades limits a high temperature of a working gas, which is currently below 1500° C. Thus, it is sufficient to heat the heat agent up to temperature 1500 – 600° C in order to use it in various cycles of electricity generation. In the organization of heat transfer, from a technological point of view, the cooling of the liquid steel to the crystallization temperature of 1500° C and a complete solidification requires the minimum time, i.e. when the greatest temperature difference of steel and heat agent takes place. This achieves in the forward flow of liquid steel and cold heat agent by heating it to a temperature of completing solidification 1500° C.

This forms the second part of the counter-current heat exchange with the heating of the second part of heat agent flow is also up to 1250° C. The same temperature of both heat agent flows allows combining them into a single flow without loss of exergy. The combined flow of heat agent with temperature of 1250° C go to a steam generator to generate superheated steam of energy parameters for the following production of electricity. Therefore, the heat of liquid steel uses for electricity production in a classic steam turbine cycle with internal heat regeneration and efficiency up to 40%. The scheme in accordance with the above technological requirements shown in Fig. 3.

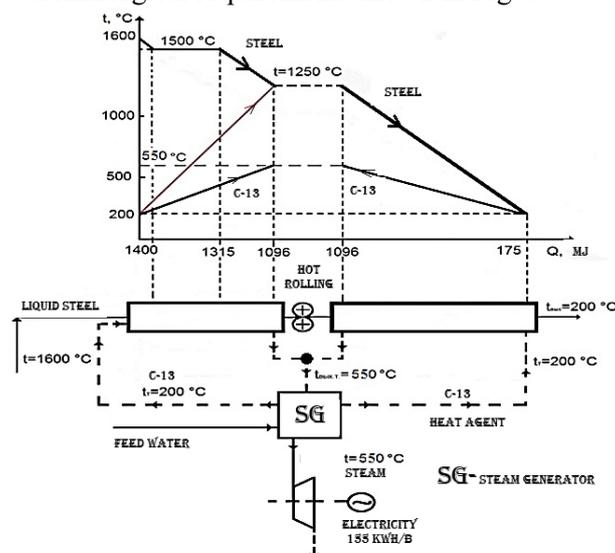


Figure 3. Thermal scheme of power generation at the heat of liquid steel.

Thus, in the steam turbine cycle with internal heat regeneration and efficiency up to 40% it is possible to transform the heat of liquid steel equivalent to 389 kWh/t in 155 kWh of electricity per one ton of cooled steel.

Theoretically, on the heat of liquid steel is also possible, in combined-cycle electricity generation with efficiency up to 60%, to produce up to 240 kWh/t of electricity. In this case, a new thermal scheme requires a separate development, and in this paper, it is not considered.

5. Conclusions

The energy problems of the steel production process characterized very high consumption of electricity (200 – 750 kWh/t).

The heat of liquid steel (389 kWh/t) is the last unused energy resource; meanwhile, the heat of liquid steel can be effectively converted into electricity.

This requires the use of high temperature heat agents, such as lead-bismuth (C-13), or sodium-potassium eutectic. It is possible to generate 150 – 240 kWh electricity per one ton of liquid steel.

Under these conditions, it may lead to “zero” consumption of electric power in the electric steel process.

The production of electricity in the heat of the liquid steel and returning it in the steelmaking process we define as the thermoelectric power regeneration. It is related to the latest scientific methodology of *intensive* energy saving.

6. References

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