The progress in the development of electrical engineering, machine building, refractories, and electrodes and the appearance of water-cooled wall panels and roofs allowed steelmaking to be jumpwise intensified in the last quarter of the twentieth century as a result of the wide application of ultrahigh-power arc furnaces and the related modern technology of melting using alternative energy sources. The technical and economic indices of electric melting continue to increase. However, the following problems are still challenging: the maximum increase in the arc furnace capacity at relatively low additional capital outlays and a decrease in the heat loads induced by a powerful electric arc on a furnace lining via an increase in the consumption of the energy from alternative sources and via a decrease in the electric energy consumed for a heat.

The following methods of heat intensification are used both separately and jointly in modern electric furnace steelmaking:

(i) the application of fuel–oxygen burners for heating and acceleration of scrap melting,

(ii) the gaseous oxygen oxidation of carbon additionally introduced into a furnace for increasing the heat input,

(iii) the gaseous oxygen oxidation of part of the charge iron to increase the heat input and to accelerate the formation of the main oxidizing slag,

(iv) the use of liquid cast iron as a charge component for the acceleration of scrap melting due to the physical heat and the heat of the oxidation reactions of the cast iron components,

(v) heating a scrap with the physical heat of waste furnace gases,

(vi) the application of special-purpose tuyeres for reburning of CO in the working space of the furnace,

(vii) the use of gaseous oxygen to intensify the oxidation period of the heat,

(viii) bottom or deep inert-gas blowing of a bath, and

(ix) the application of a specially prepared scrap and work with the liquid residue on a foamed scrap.

As a result of the extensive application of various intensification methods in modern arc-furnace plants, the specific consumptions of alternative energy carriers increased substantially: the consumption of natural gas increased to 8–10 m$^3$/t(steel), the consumption of coke or carbon increased to 15 kg/t, and the consumption of gaseous oxygen increased to 45 m$^3$/t. Therefore, the heat time in ultrahigh-power large-capacity furnaces decreased to 40–60 min. However, the yield of liquid metal decreased to 86–92% of the charged iron-containing materials (in old furnaces operating without significant heat intensification, the yield of an iron-containing metal was more than 96–96.5%). In modern arc furnaces, 8–14% of the iron in charge materials are lost in a heat: 3.5–8.5% of them are lost in the form of the charge-iron oxides, 2.5–3.0% of them are lost in the form of metal shot and a fine scrap fraction, and up to 1.5–2.5% are lost by waste gases. The problem of the recycling of the iron present in furnace slags and gas-cleaning slime becomes challenging due to the increase in the output of electric furnace steelmaking.

The use of various types of alternative energy in modern ultrahigh-power furnaces depends on the operating costs and the metal costs. The economic efficiency of the appearance of a certain type of alternative energy for steelmaking in an arc furnace depends substantially on the cost of one kWh of the heat energy assimilated by steel.

We compared the costs of one kWh of the heat energy absorbed by a metal and a slag at one of the Russian works for various energy carriers.

For the calculations, we used the following assumptions: the degree of the useful absorption of the heat released in electric arcs by the melt is 75%, the cost of the heat energy transferred to the bath from electric arcs includes the cost of the consumed electrodes, the assimilation of the heat from the oxidation of iron and other charge components (Mn, Si) by oxygen is 100%, the assimilation of the heat from the burning of natural gas in gas-oxygen burners is 50%, the degree of reburning of CO to yield CO$_2$ in the furnace volume is 50%, and the assimilation of the heat from the reburning of CO is 30%. The temperature of the poured cast iron was taken to be 1300°C. The costs of oxygen and its heating were taken into account for all versions of its use.
The calculation results given in the table demonstrate that the cost of one kWh of the heat energy transferred to the metal and slag is minimal when natural gas is burnt in gas-oxygen burners. This cost is well below the cost of the energy transferred to the metal and slag by arcs. The cost of the heat energy generated upon the oxidation of the iron of charge materials by gaseous oxygen is the maximum cost. The energy assimilated by the melt from the oxidation of the carbon introduced by scrap and coke is slightly more expensive than the energy introduced by arcs; however, the substitution of cheap coal for expensive coke substantially decreases its cost.

Therefore, to decrease the processing costs and, correspondingly, the steel cost, it is desirable to make steel in an electric arc furnace so that the fraction of the energy introduced by gas-oxygen burners and the oxidation of carbon by oxygen increases and that the amount of iron oxidized by gaseous oxygen decreases.

The use of liquid cast iron in a charge significantly decreases the charge melting time; however, the cost of one kWh of the energy transferred to the metal and slag is high due to the high cost of cast iron.

The energy balance of the typical heat in a modern ultrahigh-power electric arc furnace demonstrates that the fraction of the energy of burning of natural gas in gas-oxygen burners in the input part of the balance is relatively low, about 10% (Fig. 1). In most cases, modern electric arc furnaces have fixed wall gas-oxygen burners, whose power and operation time are limited because of a decrease in the degree of the use of heat when the scrap is heated. As the scrap temperature increases and approaches the melting temperature, the degree of the use of heat decreases sharply. Therefore, fixed wall gas-oxygen burners can efficiently work for less than 15 min from the time the furnace is turned on, and it is useless to increase the burner power, because it decreases the efficient burner operation time.

Nevertheless, metallurgists tend to find methods for the organization of cheaper scrap melting with a high consumption of “primary” or alternative heat carriers (natural gas, coal), especially with allowance for the lower total release of the greenhouse gas CO₂.

At present, metallurgists have proposed and partly use the following methods of increasing the consumption of alternative heat carriers for melting scrap:

(a) an increase in the number of fixed wall burners in an electric furnace without increasing the burner power,

(b) the application of burners that can change the flame direction and the application of high-power burners,

(c) the separation of the work time of fuel–oxygen burners and electric arcs (two-stage melting in an electric furnace, the concept of the fuel–arc furnace), and

(d) the separation of fuel burning and electric arc operation in space (SMS Demag unit, etc.).

Each of these methods has advantages and disadvantages and can be applied in practice.

As the number of burners increases, it becomes difficult to place them on the furnace walls, and the costs of furnace maintenance grow. Nevertheless, a 90-t Danarac furnace with 12 burners and a total power of 42 MW is known to operate successfully [1].

It is more convenient to increase the gas-oxygen burner power and to use rotating burners, in which the flame