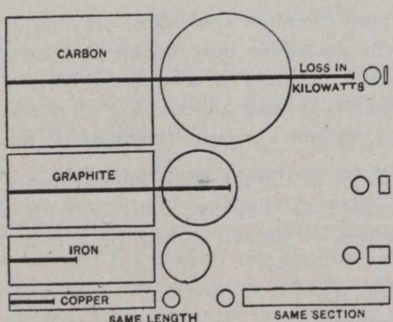
the furnace; electric heat being much more expensive than heat from fuel, the only way it can be expected to compete successfully, as far as the cost of the heat is concerned, is by the best possible utilization of the energy; it is possible to control the losses to a far greater degree in electric than in combustion furnaces. The practice in the heat insulation of combustion furnaces would be quite inadequate for well built electric furnaces.

The reduction of the heat losses in electric furnaces, which have no chimney losses, involves the flow of heat through solids, a subject which until recently has not been given the attention which its importance demands. Apparently the only way a high temperature furnace can be insulated effectively with present materials is to provide for a certain allowable flow of heat through the walls, which shall be as small as possible, but not so small as to run the risk of over-insulation, which is more serious than insufficient insulation, as the walls and roof are then destroyed.

There are two kinds of losses of heat from the interior of an electric furnace, namely, those through the walls and through the electrodes, which are subject to the control of the designer, assuming, of course, that the doors and openings of other kinds are made as few and small as possible. A few years ago the writer made analytical studies of these two sources of losses, some of the conclusions of which were

Fig. 7.




Comparison of sizes and losses.

quite surprising, showing that former practice had been in some respects far from correct. The chief results are briefly as follows:—

The usual formulas used for calculating the thermal resistance of such bodies as the walls of furnaces were found to be very greatly in error, as much as 100 per cent. and over, for thick walls. In general, for a flaring conductor, like one of the thick walls of a rectangular furnace, the proper mean cross section is not the arithmetic mean between those at the two ends, but the geometric mean, that is, the square root of their product.

Using the strictly correct formulas, it was found that the losses diminished very rapidly at first as the walls are increased in thickness, but that after the thickness has been increased to about one-half or three-fourths of the inside diameter, any further improvement in reducing the losses becomes small. The space in the inside of a furnace should be as small as possible to hold the charge, as the losses for the same charge increase rapidly with an increased inside surface. The losses in a large furnace can be made far smaller relatively to the charge than in smaller ones.

Concerning the losses in and through the electrodes, the problem was far more involved, and former practice was in some respects found to have been radically wrong. An electrode naturally should be a good electrical conductor in order to reduce the resistance losses. But it then also is a good heat conductor and therefore will tend to abstract considerable heat from the charge in the inside, thereby chilling it. Increasing its cross section decreases one of these losses and increases the other, thereby complicating matters. The results of the analysis are briefly that, by so proportioning an electrode that the current in it will heat its inner end to the furnace temperature, the total combined losses will be the least possible, and the electrode will at the same time abstract no heat from the charge; it will then in effect act as a perfect heat insulator, better even than the walls, as far as chilling the product is concerned.

Another result was that our former practice to base the size of electrodes on certain allowable current densities was found to be entirely wrong. Still another unexpected and surprising result was that graphite with its higher heat conductivity was more economical in size and losses than carbon, and that the metals were far better than either, the best electrode material being copper, quite the contrary to what would have been supposed. The accompanying illustration, Fig. 7, shows the relative sizes and losses when the electrodes for the same furnace are made of different materials. It is a good illustration of the commercial value of an analytical research. As the physical constants for determining electrodes did not exist, the writer had to determine them by means of tests made under electrode conditions, whereby certain troublesome factors in the theoretical analysis become eliminated. The complete analysis, description of the test, and the data for the calculation of electrodes are given in the original papers.

In conclusion, the following statistical data concerning existing commercial furnaces may be of interest.

For the melting and refining of steel there seem to be at present nearly 100 arc furnaces in use mostly in France and Germany, although the few in this country include the largest ones. They are chiefly of the Heroult and the Girod types. They are mostly of about 300 to 800 kilowatts, and are for charges of 2 to 5 tons; the largest ones are in South Chicago and Worcester, having a capacity of 15 tons and requiring about 2,000 kilowatts. There are also several ore reduction arc furnaces in use and under construction on the Pacific Coast, and in Domnarfvet, Sweden, the latter producing 2,500 tons per year and requiring 400 kilowatts, or about 6,500 pounds of pig-iron per horsepower per year. In Norway two furnaces are under construction, each for 7,500 tons annually, requiring 1,850 kilowatts.

The Government of Sweden is about to make available 600,000 horsepower, a large part of which will be used for reducing iron. Electric furnace reduction of iron is said to save about two-thirds of the carbon, only one ton of charcoal being used instead of three, per ton of iron. The escaping gas is three times richer as it contains no nitrogen, and is only one-eighth in amount, hence correspondingly less heat is carried off by it. Finely powdered ore can be used without briquetting; there is less labor cost and less cost of erection.

Of the induction furnaces there are between 30 and 40 in operation, mostly in Germany. They are mostly of 200 to 500 kilowatts; maximum 750. The charges are from 1½ to 5 tons; maximum 8½ tons. In some cases the material is charged hot and in others cold.

## SAO PAULO COAL IMPORTS.

The United Kingdom enjoys a practical monopoly of the coal trade with the Brazilian State of Sao Paulo. The imports during the past five years have been as follows:—1906, 173,399 tons; 1907, 191,844 tons; 1908, 180,493 tons; 1909, 184,322 tons; 1910, 220,916 tons.