DC TECHNOLOGY FOR SMELTING FURNACES

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INTRODUCTION

The development of the single electrode DC arc furnace was initiated by ABB in 1971. It was found that a DC arc plasma from a graphite cathode provides a very efficient heat transfer of the arc energy to the anode, represented by the charge in a furnace.

Originally, the DC furnace was developed for two purposes:

(1) As an alternative to the conventional three-phase AC electric arc furnace for scrap melting.

(2) As the final reduction stage in the ELRED process for melting prereduced material to produce liquid pig iron.

More recently, the DC furnace has proven to be an excellent tool as a smelting furnace. This is especially true if fine raw materials are used and if they are charged directly into the arc through a central bore in the electrode.

Today, DC arc furnaces for both steelmaking and smelting applications are in operation. The ABB DC technology have been used in commercial or pilot plant operation in a number of metallurgical systems:

-Steel scrap melting
-Smelting of iron
-Smelting of HCFeCr
-Smelting of FeMn
-Recovery of Co, Mo and Ni from waste catalysts
-Smelting of FeSi, FeSiW and Si
-Recovery of metals from steelplant dust
-Smelting of Ni and Ni-alloys
-Recovery of Ni from smelter dust
-Ladle furnace refining of steel

BASIC CONCEPT OF THE DC ARC FURNACE

The most important feature of the DC furnace is the use of a single, centrally located graphite or selfbaked electrode which is acting as a cathode. The current passes the melt and the furnace hearth wich is electrically conductive and is via a bottom copper plate connected to the positive pole of the rectifier. Figure 1 shows the layout of the DC furnace installation at Florida Steel Corporation.

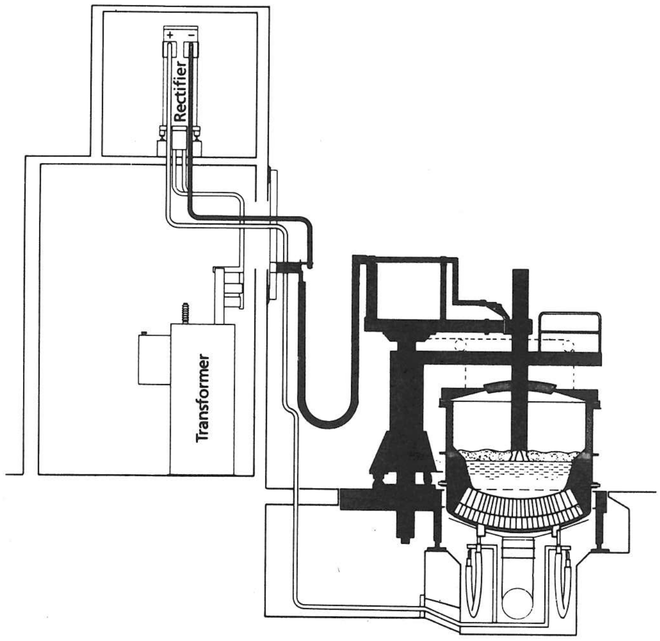

Figure 1. Layout of the DC furnace installation at Florida Steel

CHARACTERISTIC PROPERTIES OF THE DC ARC

Power concentration to the anode

A very important feature of the DC arc is the concentration of the arc power to the anode. This effect has been demonstrated by a simple experiment. In a test rig as shown in figure 2, a 250 mm graphite electrode was positioned over a steel plate with an air gap of 50 mm. The electrode and the plate were connected to a power supply that could deliver both AC and DC at 10 kA and 150V. The arcs were struck by a thin steel wire being inserted in the air gap and the power supply then being switched on.

The arcs were interrupted by a circuit breaker after a fixed arcing time of .5 second. in effect, rather brief arc pulses were used for this study. In the upper picture, seven arc pulses have been run, four with AC arcs and three with DC arcs and with positive polarity on the graphite electrode. A certain amount of arc erosion on the steel plate can be seen.

The picture below shows the result after one additional arc pulse with the graphite electrode connected as cathode. It can be seen that this polarity with only one arc pulse has damaged the steel plate more than seven previous arc pulses with AC and with reversed-polarity DC. The conclusion is obvious. Operating an arc furnace with DC and with the graphite electrode as cathode is the most efficient way of transferring the arc power to the charge in the furnace.

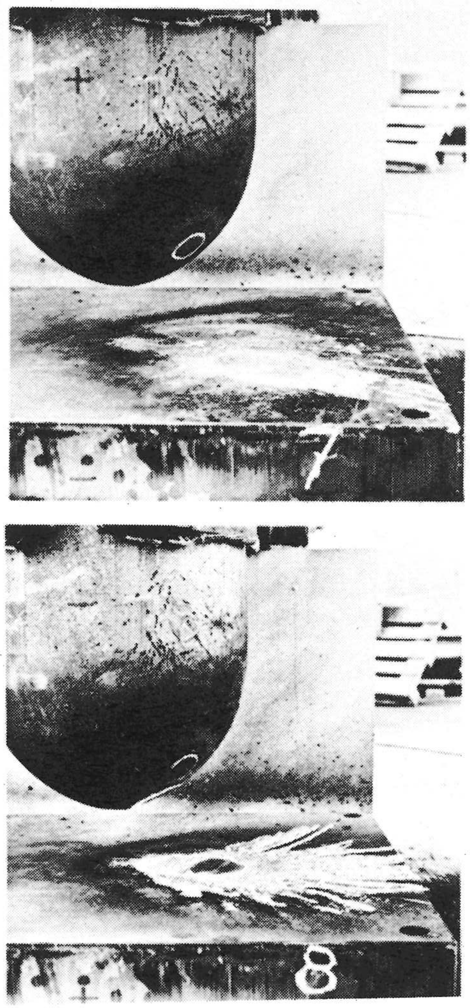

Figure 2. Test rig for arc studies.

The direct transfer of the arc power to the charge depends on three basic phenomena: Radiation, convection, and anode effect. For the arc voltages and currents that are of interest in metallurgical applications of a DC arc furnace, it appears that convection is the most important mechanism of heat transfer. The graphite-cathode DC arc is particular efficient in establishing a convective movement of gases, heated by the plasma, towards the charge.

Comparison between DC arc, AC arc and plasma gun

It is interesting to compare the primary distribution of the heating power of an arc with three types of arcs:

DC arc high current, low voltage
AC arc high current, low voltage
DC plasma low current, high voltage

In all three types, the arc heat is transferred by three different mechanisms:

-Radiation from arc plasma and tail flame

-convection by gases, propelled by the arc

-Electrode effect, at anode and cathode

Figure 3 shows an estimation of the distribution of the arc power. The three mechanisms combine in different ways to deliver the arc heat, in part to the melt and in part to the furnace walls, roof and the electrode itself. A portion of the heat delivered to the furnace will naturally again be radiated to the melt.

The following considerations are valid for the comparison. The DC arc and the arc from the DC plasma gun are both assumed burning vertically. The AC arc, however, burns at an angle, since in practical cases it always forms a part of a three-phase system and is thus influenced by a force resulting from magnetic-field interaction with adjacent arcs.

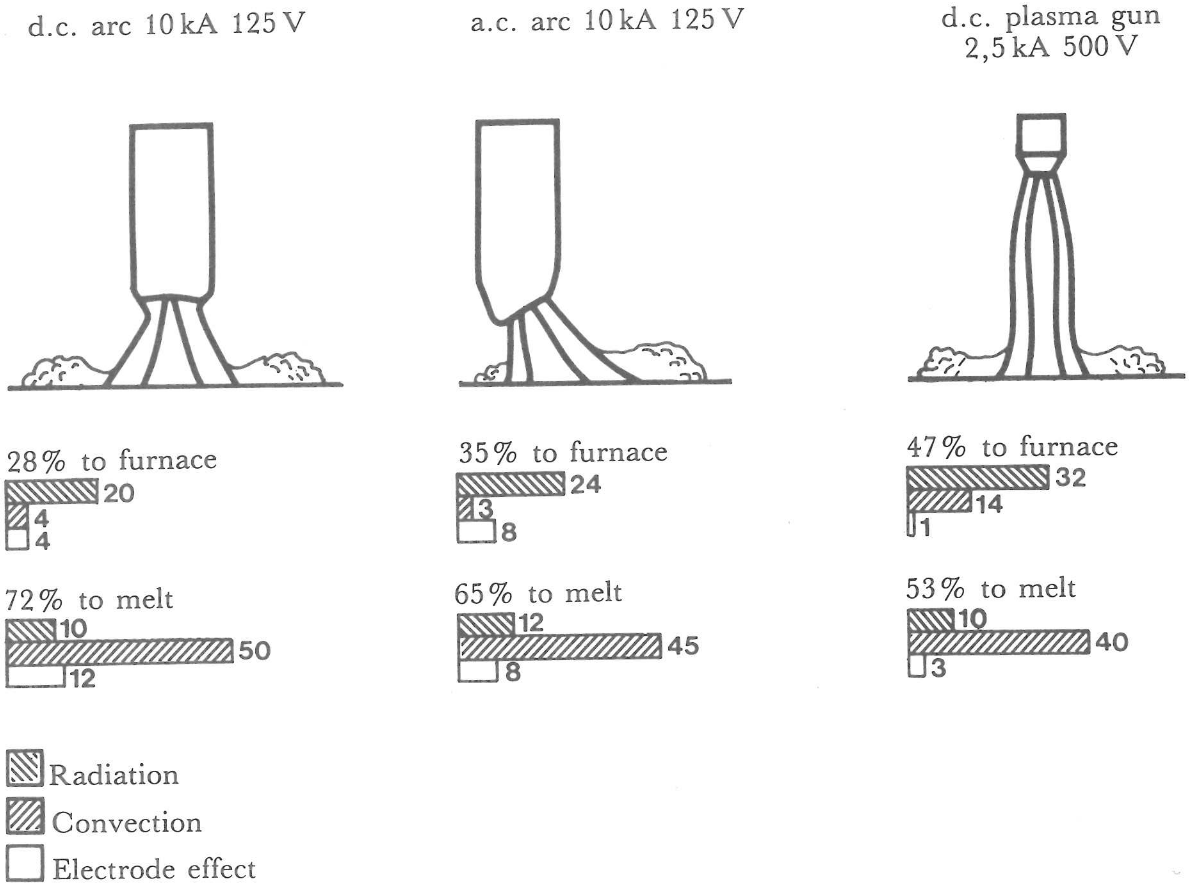

Figure 3. Arc heating power distribution.

Convection is the most important mechanism of heat transfer in all three cases. However, it is developed most effiently with the DC arc. For the AC arc it is somewhat lower because of the alternating direction of the arc current. With the low current plasma gun, convection depends to a considerable degree on the externally supplied plasma gas, delivered through the gun. In this case, it is assumed that as large portion of the heat is transferred by convection with the plasma gun as with the DC arc. However, the plasma gun deliver less convective heat to the melt and somewhat more to teh furnace walls and roof than the DC arc. Radiation is highest with the plasma gun because of the high voltage operation, and consequently the longest arc. The plasma gun will have the largest proportion of radiant heat delivery to the furnace walls and roof.

The heating power from the electrode effect is proportional to the arc current and is thus highest with the DC and AC arcs. The anode effect is about three times higher than the cathode effect. A DC arc consequently has the most advantageous heat delivery to the melt from this mechanism.

Convection in and around the DC arc and the arc from a plasma gun.

It is of considerable interest to study the convective gas movements in and around the DC arc plasma and also to compare these with the gas movements in an arc plasma transferred from a plasma gun.

Figure 4 shows a frame from a high speed film of a 30 kA, 270 V DC arc. From this film, it could be determined that the velocity of the convective gas movement in the middle of the arc is about 200 m/s.

Arrows indicate the convective movements. It is obvious that the arc operates like a gas pump. The arc develops a waist half an electrode diameter from the tip. In this area, gases surrounding the arc are pulled in and then forcibly propelled towards the melt, which is the anode. It stands to reason that not only surrounding gases but also any kind of fine material delivered close to the arc will be pulled into the arc stream and propelled towards and into the melt.

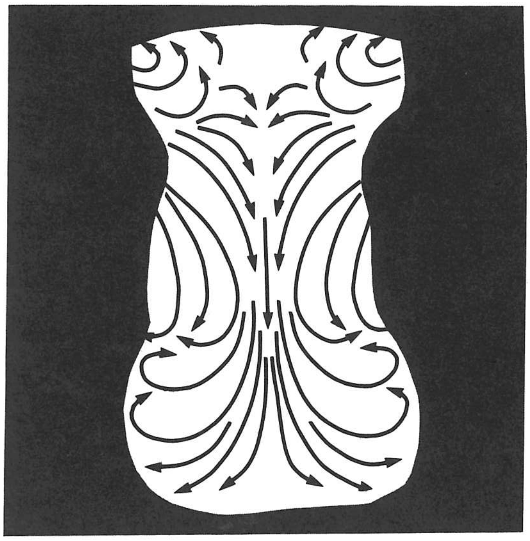

Figure 4, DC arc plasma, 30 kA, 270 V

The situation with an arc from a plasma gun is quite different. In this case the arc is already supplied with plasma gas from the gun itself and this gas expands rapidly because of the heat from the arc. The arc from a plasma gun is thus unable to pull into itself any additional gases or material in its vicinity. On the contrary, it would tend to throw to the side any material, such as fines, delivered towards the plasma cone.

THE DC SMELTING FURNACE

The smelting furnace can be designed like the conventional submerged furnace, or as a furnace operating with an open arc, the PLASMARC furnace, figure 5. In the PLASMARC furnace all the raw materials are fed through a bore in the graphite electrode. The choice between the two furnace concepts depend on the actual metallurgical system.

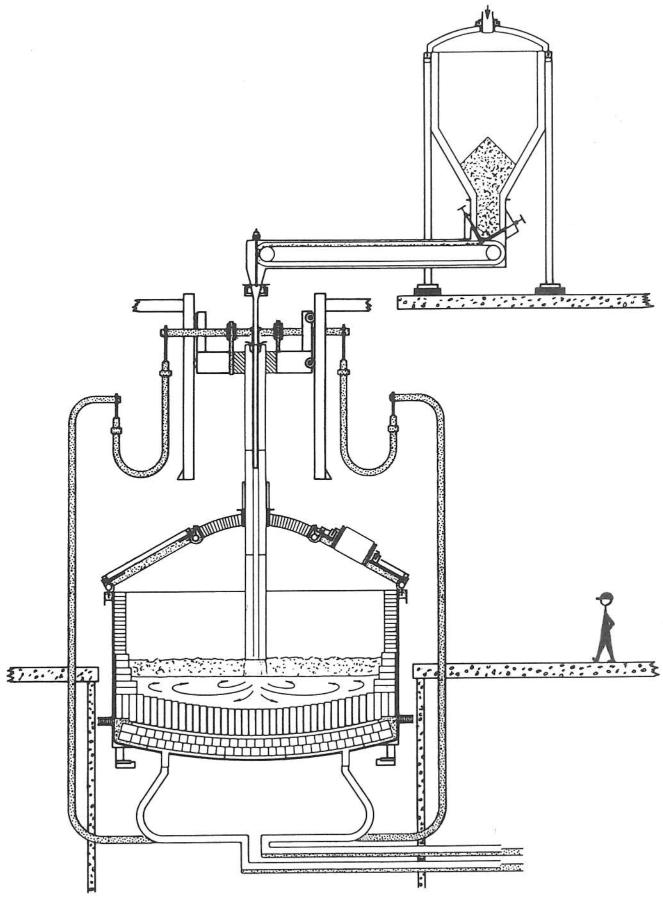

Figure 5. The PLASMARC furnace.

Conductive hearth

Carbon blocks or rammed carbon lining, of the same type as used in many conventional AC smelting furnaces gives a good conductive hearth. An air duct with an integrated axial fan, cools the outside of the furnace bottom shell. The electrical resistance of such conductive hearth is low. In a shell with an inner diameter of 5.8 m a resistance of about 2.2 microohm is typically achieved. Thus when such a furnace is operating with 100 kA, a voltage of 2.2 V would exist between the melt and the furnace bottom.

Therefore the furnace bottom is provided with an electrically insulated flange to separate the bottom at 2.2 V in the related case from the earth. The electrical energy generated in the conductive hearth amounts to 220 kW. The temperature distribution in the hearth is shown in figure 6.

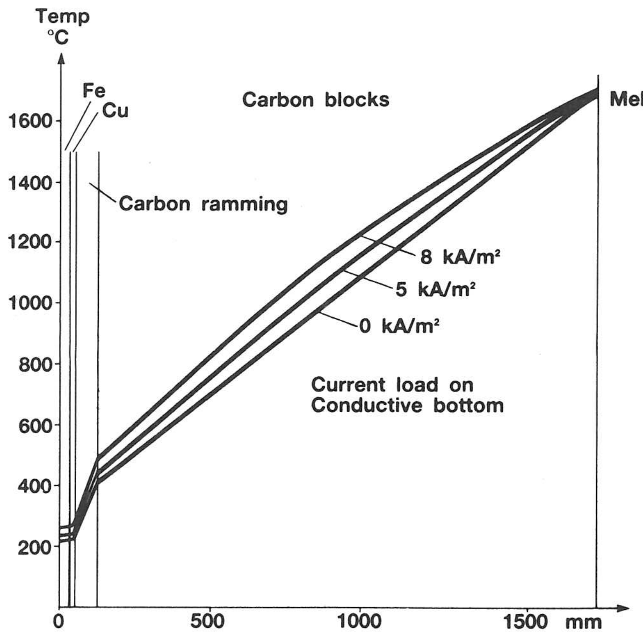

Figure 6. Temperature distribution in a carbon bottom lining.

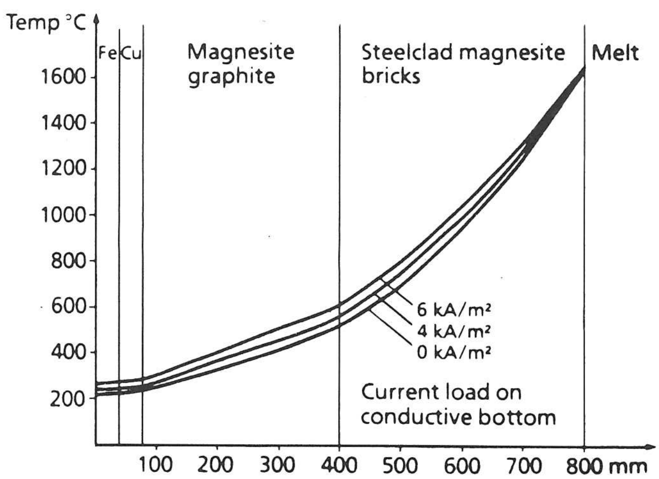

Figure 7. Temperature distribution in a magnesite-graphite and steelclad magnesite bottom.

The bottom lining temperature rise resulting from the current passage is manageable. Figure 7 shows similar temperature distribution for an alternative lining of the conductive hearth with a wear lining of steelclad magnesite bricks and back up lining of magnesite-graphite bricks. This type of lining is used in the PLASMARC furnace for production of HCFeCr at Middleburg Steel & Alloys Ltd, South Africa.

Electrical equipment

The first DC installations was designed with diode rectifiers. When using a diode rectifier short circuit currents are limited and the arc current stabilized by a reactor on the primary side of the furnace transformer. Such a reactor also effectively dampens the amount of harmonics fed back to the supply network from the rectifier.

The diode rectifiers are in the latest installations replaced by a thyristor converter which offers additional control possibilities. The current surges can be dynamically controlled by automatic regulation of the firing pulse delay. Short circuit current limiting reactors can then be eliminated or reduced, depending on the supply network conditions and requirements. Thyristor control, however, increases the amount of harmonic generation which, again depending on the network may call for counter measures such as filter circuits tuned to the harmonic frequencies.

Power capabilities

The largest graphite electrode commercially available today has a diameter of 700 mm. According to estimates made by electrode suppliers, such an electrode could be used for an arc current of 125 kA DC, which is 25 % more than with the same electrode used for AC. The reason for the higher current capability of electrodes in a DC operation is the uniform current distribution in the conductive graphite area. With AC the current is concentrated at the electrode surface due to skin effect and to the proximity effect from adjacent electrodes.

Combining an arc current of 125 kA with an appropriate arc voltage, 900 V for a typical PLASMARC operation, yields a power of 110 MW in the arc plasma. This is far more power than the recently completed upgrading of the PLASMARC furnace at Middleburg Steel & Alloy Ltd, from 18 to 40 MVA which is the most powerful single electrode DC furnace for smelting applications so far in operation.

Design parameters

The PLASMARC furnace can, independent of the metallurgical system, be operated at a furnace resistance of 8-12 mohm. The electrical system for a given power is designed for a lower current compared to a conventional submerged furnace. The shell diameter must be designed individually for each metallurgical system. The typical surface load is some 600 kW/m2 which is much higher than at most submerged processes.

A DC submerged furnace is in principle designed with the same design parameters as the AC submerged furnace. It is however possible to increase the furnace resistance since there will be no current passage between the electrodes. The furnace shell diameter can be reduced to some 80 % since there is a complete and even heat distribution around the electrode.

ADVANTAGES WITH THE DC TECHNOLOGY

Energy savings

The losses in the power supply system is less in a DC furnace. The additional losses in the rectifier are compensated by less losses in the DC circuit. The calculated energy saving for a scrap melting furnace is 2.4 %. This figure can be compared to the actual measured savings over a 6 month operation period for the DC furnace in Florida Steel Corporation, 1.8 %. The calculated saving for a smelting furnace are higher.

The DC furnace has a more compact design which will decrease the thermal losses if the process is unchanged. A PLASMARC furnace on the other hand will have more thermal losses compared to a submerged furnace since a liquid slag is exposed to the furnace wall and roof. The net effect of less electrical losses, more thermal losses and the higher metal yield in the PLASMARC process is about the same energy consumption as for the conventional submerged furnace.

The DC submerced furnace has less energy consumption than conventional AC submerged furnace and the PLASMARC furnace. The calculated energy saving for a DC submerged furnace for smelting of FeSi75 is more than 5 % compared to the conventional AC submerged furnace.

Raw material flexibility

The PLASMARC furnace operates with fine grained raw materials. Successful tests have been carried out with extremely fine grained flotation concentrate and also with dust. It is then possible to upgrade the ore by suitable ore dressing measures without having to spend money on pelletizing or briquetting.

The raw materials for a submerged process must be chosen to give the right resistivity. This limitation does not exsist in the PLASMARC process. The raw materials can be selected to give the best chemical conditions. Ferroalloys with very low impurity content can be produced.

Also the DC submerged furnace can process fine grained raw material. Successful trials has been carried out on production of FeSi where 20 % of the raw materials were charged through a bore in the submerged electrode. This technique can decrease the energy consumption and also increase the metal yield.

High metal yield

The metal yield is very high in the PLASMARC furnace. The observed Cr yield in the smelting operation in Middleburg Steel & Alloy Ltd is more than 93 %. This high yield is explained by the very effective coupling between material and power input in the PLASMARC process. The materials are fed directly to the hottest zone, the arc plasma. The materials are fed drectly to the hottest zone, the arc plasma. The reduction process is working close to equilibrium. The chromiumoxide content in the slag is low.

Low electrode consumption

The electrode consumption is very low for a DC furnace. The observed savings for comparable furnaces are 50-70 %. The graphite consumption for the Florida Steel furnace is 3.2 kg/MWh which can be compared to more than 8 kg/MWh for the AC furnace operating in the same plant.

The consumption for the less oxidizing metallurgical system in the PLASMARC furnace in Middleburgh Steel & Alloy is 1.5-2 kg/MWH.

The low electrode consumption is explained both by the polarity only one electrode. The effect of the polarity alone was demonstrated when a 2 MVA single phase AC furnace at Gullspång Alloys in Sweden was rebuilt to DC operation. The electrode consumption for a slag melting process was reduced to less than 50 %.

Low investment cost

The PLASMARC furnace is less expensive than the conventional AC submerged furnace. The investment for a 20 MVA PLASMARC furnace including:

- -20 MVA transformer 45 kA rectifier
- -capacitor bank and filter for the harmonics
- -electrical control equipment
- -graphite electrode including holder, mast and arm
- -furnace shell, 7 m diameter
- -roof
- -lining

is some 60-80 % of the investment for an AC submerged furnace including:

- -3*7 MVA transformers, 80 kA electrode current
- -capacitor bank
- -electrical control equipment
- -3 selfbaking electrodes
- -furnace shell, not rotating, 10 m diameter
- -roof
- -lining