Preface

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It may seem surprising to find a book devoted to the physics of an industrial process, and one not familiar to many people. Yet the scope for applying physics to arc furnaces is wide indeed. Various states of matter are involved – the plasma of the arc itself, steel and refractories in the solid state, steel as liquid, slag as an ionic liquid, and the gases and fumes evolved within the furnace.

The arc consists of electrically conducting, high temperature plasma in which the electrical power is released. Here the important heat transfer mechanism of radiation touches on quantum physics. Since high currents are used high magnetic forces are exerted on all the conducting components, including the arc and metal bath. A range of arc instabilities is observed which have important consequences on the power system. Unsteady currents also lead to vibrations in the mechanical secondary system. Sometimes resonances and near-chaotic motions are seen.

The electrical operation is complex. As an element of an electric circuit the arc exhibits an irregular, non-sinusoidal voltage waveform which cannot be treated either as resistor, capacitor nor inductor; it has unique characteristics. Modelling is usually performed in an empirical fashion.

The major input material, steel scrap, comes in a large variety of shapes and size, apart from its chemical variability. Probably no two charges are alike so statistical methods are required. The physics of this material calls on particle mechanics, such as packing, and electromagnetic properties.

Control of the process, which is via a relatively crude vertical displacement of the electrode/arm/cable system weighing perhaps 30 tonne per phase, is much slower than the variations within the furnace. The attainment of an optimum control strategy is still an open question, so open that each furnace manager seems to have his personal answer.

One of the difficulties with understanding what goes on inside an arc furnace is the problem of measurement; it is extremely difficult to obtain access to interesting parameters within the furnace. Apart from the actual physical danger, there is no easy way to protect an instrument in such an environment. An arc furnace running at full power during scrap meltdown, with its noise, flames and vibrations, without doubt is initially rather terrifying. Today, as furnaces have become ever more powerful, there is no obvious way to 'see' what occurs inside. In fact rarely is an arc seen from outside; it is either surrounded by scrap, covered with foaming slag or obscured by fume. In certain periods, under very stable conditions, even the existence of an arc can be questioned.

One of us was fortunate to have started work on arc furnaces in the 1960's. At that time furnaces were of lower power, refractory lined, using less oxygen, and foaming slag techniques were not known. As a consequence arcs were more often visible, or could easily be made so. Heat times were also much longer so that a delay in arranging for special measurements (high speed photographs for example) could easily be accommodated by a cooperative steelmaker. Much of the information obtained in this period has facilitated a physical interpretation of later data collected 'external' to the furnace, for example, electrical measurements.

Most of the engineers and managers who have responsibility for arc furnaces do not have the opportunity or time to study all the widely dispersed, previously published information on arc furnaces. It is our intention that this book supplies at least some useful information which is helpful in their continual quest to extract improved performance from our mutual acquaintance – the electric arc furnace.

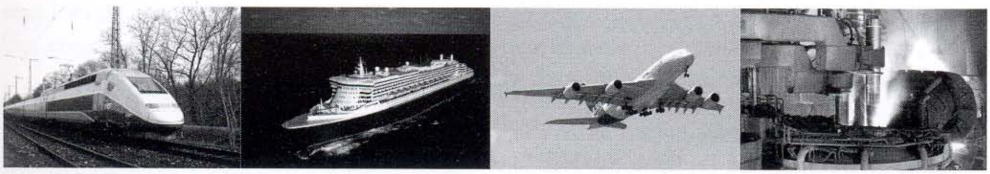
Units

SI units are used throughout this book but because the anticipated readership is expected to be mainly involved in the metal producing industries some more familiar units are also used. In particular electrical energy will be quoted in kWh rather than MJ and of course metal weights are metric, written as tonne, to avoid any misunderstanding.

In some cases quantities involving volume are quoted in cm^3 even though this is not a recommended subunit. This is justified for example for arc radiation since, of the alternatives, m^3 are too large and mm^3 are too small. In these preferred units radiation falls into the kW/cm^3 range, much easier to grasp than say 10^9 W/m^3. Also since radiation, arc power and voltage gradient are closely linked the latter is conveniently quoted as V/cm. Some spectroscopic and physical energies, such as dissociation and ionisation energies, are quoted in eV rather than J ($1\ eV = 1.6022 \cdot 10^{-19}$ J). Temperatures are quoted in either °C for items familiar to the steelmaker (steel, slag, etc.) or the scientifically more convenient K (0 °C ≡ 273 K) for arc physics and chemical reactions.

Magnitude of the power of a large arc furnace

An arc furnace is an impressively powerful unit. Those working around one each day may tend not to appreciate how powerful it really is. A comparison with machines more familiar to the wider public helps to put it in perspective as shown in **figure 1**. Both the TGV (the French Train à Grande Vitesse, 300 km/h) and cruise liner Queen Mary 2, (100,000 tonne) have electric motors. The Airbus A380 power has been calculated at cruising speed from the speed (1000 km/h), weight (560 tonne) and lift/drag ratio (19.5).



TGV 12 MW | Queen Mary 2 80 MW | Airbus A380* 80 MW | Arc furnace up to 150 MW

Fig. 1: Comparison of powerful machines (*with permission from Steve Brimley)

And the chemical power has not been included for the arc furnace! Let us compare the arc furnace with, say, a 300 t basic oxygen furnace (BOF), for which only chemical power is released. Assume 4.5 % C (13.5 tonne) eliminated in 0.4 h. For 80 % CO / 20 % CO_2 generation the energy release by decarburisation is 4.2 kWh/kgC. The average chemical power is therefore 142 MW. So the BOF chemical and arc furnace electrical powers are of similar magnitude.

Precision

As a consequence of the lack of precise data and the overall variation in many of the important parameters, many calculations result in estimates. To avoid a misleading indication of the precision it is then necessary to qualify these calculated values with such descriptive terms as – 'about', 'approximately', 'of the order of', '~', etc., which can become unfortunately a little repetitive. In like manner, often a graph of measured data usually shows an obvious scatter so that a separate statement of the errors is unnecessary.