Determining the critical modelling parameters in a simplified EAF arc-heat distribution model

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INTRODUCTION

The melting and refining of scrap and iron containing metal in electric arc furnaces (EAFs) is currently the second largest steel production process globally, and approximately 29% of the steel produced in the world is being produced in EAFs[1]. With world crude steel production increasing by 5.3% from 2016 to 2017[2], it is becoming increasingly desirable to design and operate EAFs as efficiently, economically and environmentally friendly as possible. A step towards this goal is minimizing heat losses to the off-gas and the environment, and in order to achieve this, the heat transfer processes inside an EAF should be well-understood. An improved understanding of the heat transfer processes inside EAFs could additionally aid planning for maintenance work and could lead to furnace design and operation practices that would increase the lifetime of furnace components.

Mathematical modelling is well-suited to the investigation of the heat transfer processes taking place inside EAFs, since the aggressive, high-temperature environment inside arc furnaces limits experimental measurement opportunities. In this work a low computational-complexity EAF arc-heat distribution model is implemented and used to study the sensitivity of the modelled heat distribution to changes in model parameters.

MODEL PARAMETER SENSITIVITY STUDY

The low computational-complexity EAF arc-heat distribution model of Fathi et al. as described in [3] is implemented and arc-heat distribution predictions from the model implementation are successfully verified against the model results reported by Fathi et al.[3] The implemented model predictions agree to within a tenth of a percent to the published results. For the purposes of the sensitivity study, the model parameters are varied and the effect on the arc-heat distribution is investigated over an arc current range of 1 – 90 kA and an arc length range of 5 – 100 cm.

In Figure 1 the percentage of the heat transferred from the arc in the form of arc electron flow (green), convective power (blue) and radiative power (yellow) is plotted against arc length. The varied parameter in Figure 1 is the current density at the cathode spot. Different parameter values are indicated by the different line styles. In Figure 2 the anode work function is the parameter that is varied. It can be seen from comparing Figures 1 and 2, that a change in the value of the current density at the cathode spot has a considerable influence on the arc-heat distribution, while variations in the anode work function only result in changes of 10% or less for each form of power dissipation over the investigated range of arc lengths. The same parametric study is conducted for various parameters (listed as independent variables in Figure 3), resulting in plots similar to Figures 1 and 2. Apart from this sensitivity study conducted over a range of arc lengths, a similar sensitivity study is also conducted over a range of arc currents.

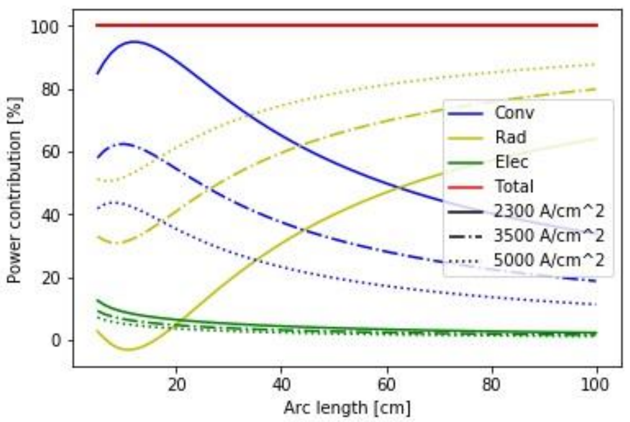

Fig. 1 Sensitivity of the arc power distribution w.r.t. the current density at the cathode spot.

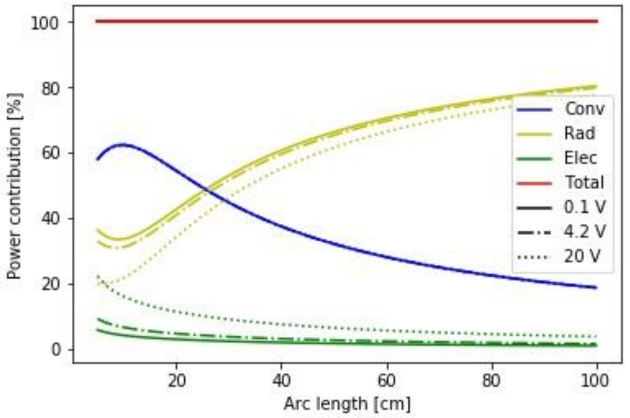

Fig. 2 Sensitivity of the arc power distribution w.r.t. the anode work function.

RESULTS

Figure 3 summarizes the results of the parametric study on both a range of feasible currents and a range of feasible arc lengths. The maximum difference between the percentage power radiated from the arc in the base case, and the percentage power radiated when a parameter value is varied, is plotted. Only the parameter sensitivity to radiation heat transfer is plotted, since the variation in heat transfer through arc electron flow is generally around ten percent or less (see e.g. the green plots in Figures 1 to 2), and the sum of the electron flow, convection and radiation heat transfer must always be 100%. Therefore, the convection heat transfer variation only differs with ten percent or less from the radiation heat transfer variation and consequently the effect of a parameter change on only one of these two heat transfer modes is considered to be representative of its effect of both.

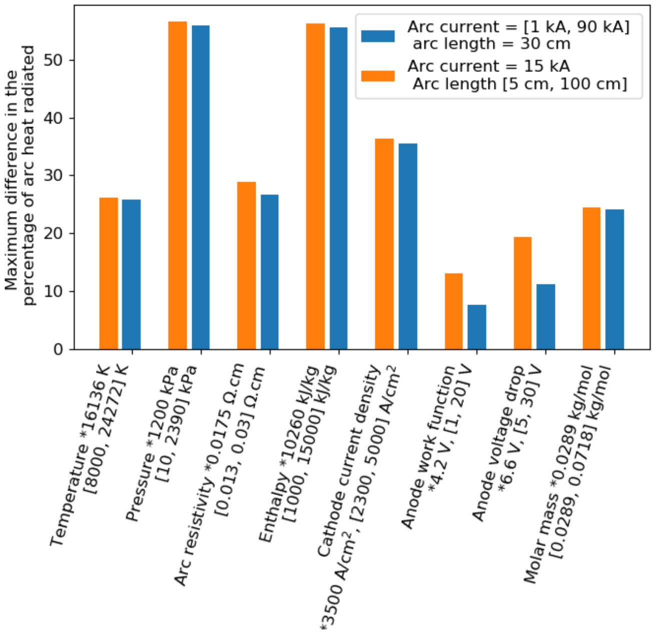

Fig. 3 Parameter sensitivity across an arc current range of 0 – 90 kA. Investigated parameter ranges are indicated in square brackets and base case values with a *.

It can be seen in Figure 3 that changes in the parameters describing the arc pressure, and the enthalpy change between the arc and the freeboard gas, result in the biggest variations of about 55% in the predicted arc-heat distribution. The values of the anode work function and the anode voltage drop has a minimal influence on the arc-heat distribution – 20% or less over the arc length range and 12% or less when the range of arc currents is considered. Considering the stochastic nature of the arc and the large amount of variation and uncertainty this introduces to most of the parameters used in an arc model, it is concluded that it is not initially necessary to model these phenomena in more detail.

Furthermore, Figures 1 and 2 are representative of the majority of plots of power contribution versus arc current or arc length obtained in the sensitivity study. It is generally notable that the percentage power contributed by electron flow is largely unaffected by changes in parameter values. The largest changes in electron flow heat transfer are observed for the anode voltage drop and anode work function (Fig. 2) parameters, with a variation of about 15% at very short arc lengths.

It is further interesting to note that generally, and as is also the case in Figures 1 and 2, radiation is the dominant heat transfer mode at low currents and long arc lengths, but convection is dominant at large currents and short arc lengths. The fact that convection can be a dominant heat transfer mode for the high temperature process rather than radiation, despite it being a fourth power function of temperature, can possibly be attributed to the high velocities in the arc.

CONCLUSION AND OUTLOOK

A simplified EAF arc-heat distribution model is implemented and used to investigate the arc-heat distribution's sensitivity to the various model parameters. The advantages of a simplified model is that it provides quick approximations and is useful for investigating the large number of scenarios required for a sensitivity study.

Both convection (at large currents and short arc lengths) and radiation (at low currents and long arc lengths) heat transfer are found to be dominant modes of heat transfer from the arc. The arc-heat distribution is found to be especially sensitive to the model parameters describing the arc pressure and enthalpy change between the arc and the freeboard gas. On the other hand, it is minimally sensitive to the model parameters describing the voltage drop and work function at the anode.

These results will be used to inform model decisions in planned subsequent more detailed models. The availability of both simpler, computationally cheap models and higher fidelity, computationally expensive models will then allow for multi-fidelity modelling investigations.

REFERENCES

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