ENERGY TRANSPORT IN THERMAL PLASMAS

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ABSTRACT

In contrast to "cold" plasmas which are characterized by high electron temperatures and low heavy particle temperatures, thermal plasmas can be described by a single temperature which is the same for all species in the plasma and which also governs excitations as well as chemical reactions in the plasma, i.e. a thermal plasma approaches a state of thermodynamic equilibrium or of Local Thermodynamic Equilibrium (LTE).

Thermal plasmas found widespread applications for welding, for cutting and spraying, and for melting, as for example, in arc furnaces. Since thermal plasmas are strong emitters of radiation ranging from the U.V. over the visible to the infrared part of the spectrum, they are widely used in the lighting industry.

Over the past years there seems to be an increasing awareness of the potential which thermal plasmas hold in the area of high temperature chemistry and material processing. Such applications are described in a number of surveys [1-5] which provide a representative cross section of present activities in high temperature plasma chemistry and material processing.

Energy transport has been extensively studied from thermal plasmas to particulate matter injected into the plasma or to walls exposed to such plasmas [6,7]. Relatively little work has been done to clarify the energy transport in current-carrying plasmas, in particular in the electrode regions. Therefore, this survey will be devoted to the energy transport mechanisms in high current arcs with emphasis on the effects occuring in the anode region and on the anode itself. There is a twofold interest in these effects in connection with thermal plasma processing. First of all the high intensity arc is the primary tool for producing thermal plasmas. Integrity and lifetime of the anode are of great concern in many arc plasma devices because the anode is frequently subject to extremely high heat transfer rates. Secondly, many thermal plasma processes utilize transferred arcs (for example arc furnaces, welding arcs, etc.). In this situation, it is desirable to maximize and shape the heat fluxes for optimizing the process.

Experimental studies of the anode region of high current arcs at atmospheric pressure reveal two types of anode arc roots which strongly affect

the heat flux distribution. In relatively short arcs the action of the cathode jet leads to a diffuse anode attachment (cathode jet dominated mode). In contrast, simulations of long arcs clearly demonstrate a more or less severe constriction of the current path in front of the anode inducing an anode jet (anode jet dominated mode).

Modeling of the anode region under identical conditions confirms that the "natural" arc attachment in this situation will always be constricted, resulting in extremely high specific heat fluxes at the anode. The analysis also shows that enthalpy transport by the electrons is the dominating heat transfer mechanism in the anode region.

An analysis of the near-anode zone of high current atmospheric pressure arcs indicates that presently available anode fall theories are not adequate for describing this zone. A one-dimensional analysis of the near-anode zone predicts negative anode falls in the range from one to three volts depending on the anode current density and on the plasma temperature. The electron temperature is substantially elevated over the temperature of the heavy particles close to the anode.

Because of negative anode falls, the anode heat transfer model will no longer contain a term due to the anode fall. It is felt that this finding will be of great practical significance for the prediction of anode heat transfer in arc furnaces and in other applications which employ transferred arcs.

Calculations of the critical heat fluxes which lead to melting or evaporation of the anode surface in spite of intense water cooling of the rear face of the anode are in qualitative agreement with experimental findings.

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