Editorial

Thermal Plasma Sources

Thermal plasmas are plasmas at or close to atmospheric pressure in which all species (atoms, ions, molecules and electrons) are at approximately the same temperature, usually of the order of 10 000 K to 20 000 K. They are produced by a wide range of sources, using direct-current, alternating-current, radio-frequency and microwave power.

Thermal plasma sources are of great industrial importance, being widely used in many applications such as cutting, welding, spraying, waste treatment, powder synthesis, circuit breakers and arc lamps [1-4]. One of the main advantages of thermal plasmas is that they provide very high energy densities (> 10^9 J m^{-3}) and therefore produce a highly reactive medium [2]. The high convective and/or electrical heat fluxes produced using thermal plasma technology allows the rapid treatment of materials in various forms (e.g., surfaces, gases, liquids and solid particles). Moreover, due to the high quenching rates that can be obtained (10^6 K s^{-1}), thermal plasma processes are particularly suited to synthesizing nano-materials.

For many years, thermal plasmas have been described to a first approximation using the assumption of local thermodynamic equilibrium (LTE). This assumption implies that the temperatures of all species are equal. While it is the electrons that are heated initially by an electric or electromagnetic field, their energy is rapidly transferred to the heavy species because of the high collision rate associated with the high electron number densities (> 10^{23} m^{-3}) in the plasma core. Although the assumption of LTE is extremely useful, in real applications of thermal plasma sources, stabilization gases (or liquids), or walls (including electrodes) are present and therefore introduce discontinuities in the plasma properties. The presence of materials to be treated by the plasma also creates spatial inhomogeneities, for example in suspension plasma spraying, in which liquid precursors are injected in the plasma, or in arc cutting or arc welding, in which the heat flux is incident on a cold surface. Plasma properties can also be greatly altered when the electrodes suffer from erosion, the extent of which depends on surface and material properties.

As a consequence of these phenomena, non-negligible diffusion processes occur, as well as a reduction in electron number densities in the edge regions. In such cases, departures from LTE are expected and the standard academic description of thermal plasmas fails [5].

In addition to being a high enthalpy source, another important characteristic of thermal plasma sources is related to high plasma velocities ranging between a few hundreds of m s^{-1} for radio-frequency inductively-coupled discharges and arc discharges up to a few thousands of m s^{-1} for water-stabilized subsonic plasma torches, depending on the plasma properties and on the ambient pressure [1]. The high velocities are taken advantage of in particular in thermal plasma spraying field. Higher plasma velocities can be reached when using supersonic plasma flows. The high velocities in plasma jets can induce deviations from chemical equilibrium in plasma composition. Moreover, when flowing into a quiescent ambient atmosphere, flow turbulence phenomena occur.

The transient behaviour of thermal plasmas is of great interest in most types of sources. Plasma instabilities are often an obstacle for the reproducibility of experiments and therefore require much effort to determine their physical origins. It is important to compare the characteristic times of plasma instabilities to others characteristic times (times for heat and/or momentum transfer, chemical reaction times, residence time, etc.) to estimate how strongly materials to be plasma treated will be affected by instabilities. In many cases, as shown in this special issue, the plasma instabilities have non-negligible effects on transient plasma properties and on the influence of the plasma on surrounding materials.

This special issue highlights the above plasma characteristics found in different thermal plasma sources. While the list is not exhaustive, it points to the main research issues, i.e., the control of heat and mass transfer between stabilization gases (or liquids) and the plasma or between materials to be treated and the plasma, plasma–wall interactions (erosion) and plasma instabilities.

For example, water-stabilized arc sources allow the generation of very high enthalpy and velocity plasmas [6] depending on the arc stabilization process. In direct current (dc) arc plasma torches [7] or in low-voltage circuit breakers [8], research is directed towards understanding the transient behaviour of the electric arc. Modelling of such processes implies a three-dimensional treatment of the fluid flow and electromagnetic equations. The results of such advanced modelling are difficult to validate by the use of measurements because the arc in confined within a solid exterior.

In pulse-modulated induction thermal plasmas, instabilities are a favoured method for the control of plasma temperature and radical density. Significant increases in departures from LTE, and changes to the thermal and species fluxes, are found as a consequence of the rapid modulation of the plasma [9].

The amplitude of electric arc fluctuations can also be controlled by improving the technology of dc arc plasma torches. In this case, the use of multiple-electrode plasma torches, sometimes equipped with an axial injection of material, is of interest [10].

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Finally, we note that the special issue gives examples of the main excitation methods for plasma sources. These are the direct-current transferred arcs used in circuit breakers [8] (and also in arc welding and arc furnaces, for example), the direct-current non-transferred arcs used in plasma torches of various types [6, 7, 9] and the inductively-coupled radio-frequency sources [8], in which electrodes are not required.

We commend the papers in this special issue to the reader. They provide an excellent introduction to a selection of the many thermal plasma sources in use today, and point to, as we have alluded to above, some of the main research issues in the thermal plasma field.

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