GENERATION OF THERMAL PLASMAS IN LIQUID-STABILIZED AND HYBRID DC ARC TORCHES

Milan Hrabovsky
Institute of Plasma Physics AS CR, Za Slovankou 3, Prague, 182 11, Czech Republic

Plasma jets generated in dc arc torches are utilized in several plasma processing technologies like plasma spraying, plasma cutting and decomposition of persistent chemical substances. Performance characteristics of a torch in specific plasma processing application are determined by plasma jet characteristics, especially by temperature and velocity profiles, by composition of plasma as well as by plasma flow structure and stability. These characteristics can be adjusted for given application by torch design, choice of plasma gas and by arc current. There are some limits of range of adjustable plasma jet characteristics that are given by a principle of stabilization of arc. In commonly used plasma torches the arc is stabilized by flowing gas that flows along the arc column in the arc chamber. Plasma jets with substantially different characteristics can be generated in arcs stabilized by liquid. Plasma torches with water-stabilized arc (Gerdien arc) are utilized in plasma spraying for specific applications. Besides apparent advantage of liquid generators that no gas supply is needed, there is many other differences between gas and liquid generators in plasma processes, plasma properties and especially in performance characteristics in plasma processing. Operation regimes of the two principles are shown in Fig. 1 where a relation between arc power and mass flow rate of plasma is given.

Fig. 1. Operation regimes of water-stabilized, gas-stabilized and hybrid plasma torches.
Water-stabilized torches are characterized by very low mass flow rates and high power. Plasma enthalpy is thus several times higher than enthalpy of plasmas generated in gas-stabilized torches. High enthalpy is accompanied by very low plasma density. Other plasma parameters substantially differ from the ones in gas torches as well.

Physical limits of the two principles do not allow generation of plasmas with parameters in a wide region between the two principles. For better control of plasma jet characteristics a new type of dc plasma torch has been designed which utilizes combined gas-liquid stabilization. In this hybrid torch a plasma produced in an arc with vortex gas stabilization enters the chamber where it interacts with vortex of liquid. The hybrid stabilization offers possibility of adjustment of plasma parameters from high enthalpy, low density plasmas typical for liquid stabilized torches to lower enthalpy, higher density plasmas generated in gas stabilized torches. By combination of parameters of the two sections a wide range of plasma characteristics can be obtained. If low enthalpy gas like argon is used in the upstream section and water in the liquid section, the torch preserves high plasma temperature typical for water torches, but plasma density and momentum flux in plasma jet can be controlled in a wide range.

Basic mechanisms that control properties of a liquid-stabilized and hybrid arcs are evaporation from the inner wall of the liquid vortex surrounding the arc column and production of plasma by heating and ionization of the vapor. The evaporation is induced by the absorption of a fraction of Joule power dissipated within the conducting arc core. The evaporation and heating produce an over-pressure inside the arc chamber and plasma is accelerated towards the exit nozzle. A sheath of cold vapor always exists close to the phase boundary between liquid and plasma. The sheath absorbs most of energy transferred from the plasma by radiation and dominantly influences heat transfer in the arc.

In water-stabilized torches an oxygen-hydrogen plasma jet is produced. The composition of plasma can be advantageous for some applications for its chemical activity due to presence of oxygen, hydrogen and OH radicals. Thermodynamic and transport properties of steam plasma lead to high heat transfer to the injected material by thermal conduction, high ratio of plasma enthalpy to electrical conductivity results in high arc voltage and thus high arc power. However, presence of oxygen leads to high erosion rate of both electrodes as fragile oxides are created on their surfaces. Therefore consumable graphite cathodes are used, anodes are made of internally cooled rotating copper discs that are positioned downstream of the nozzle exit. Stability of flow in plasma jet is influenced by the interaction of plasma flow with anode jet created at the electrode surface. The jets are highly turbulent also due to very high plasma flow velocities accompanied by low densities.

Extremely high plasma enthalpy and plasma temperature and very low plasma density result in very high efficiency of utilization of enthalpy of plasma for heating of material injected into plasma. This is advantageous in all applications where high heat fluxes and high temperatures are needed. In plasma spraying the water-stabilized torches provide almost one order higher spraying rates than gas torches. At present the only industrial scale application of water stabilized arc is plasma spraying. Several promising applications of oxygen-hydrogen plasma jets appear besides plasma spraying, namely waste treatment and plasma chemical vapor deposition.

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References
