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Prediction of energy source properties of free-burning arcs

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Abstract

Energy source properties of gas tungsten arc (GTA) strongly depend on physical property of a shielding gas. For its low electrical conductivity, helium (He) is employed as a shielding gas for conditions requiring high productivity in GTA-welding process. However, the high cost of He limits its applications. Therefore, an alternative shielding gas with lower cost and better energy source properties is required. In this paper, carbon dioxide (CO_2) was used as an alternative gas for its low cost. The basic energy source properties of CO_2 GTA were numerically predicted ignoring the oxidation of the electrodes. It was predicted that CO_2 GTA would have excellent energy source properties comparable to that of He GTA.

Keywords: Numerical simulation; Arc plasma; Material processing; Heat source; Carbon dioxide

1. Introduction

High-temperature arc plasma produced by employing gas tungsten arc (GTA) is highly controllable, since it is stabilized with shielding gas. Additionally, GTA requires low cost for equipment investment. Therefore, it is widely utilized for material processing such as melting, cutting and welding [1], or decomposition and detoxification of toxic waste [2]. Energy source properties of GTA strongly depend on the physical properties of the shielding gas. For instance, helium (He) is employed as the shielding gas for conditions requiring high productivity in GTA-welding process. The current channel of He arc plasma is constricted due to its low electrical conductivity. Consequently, the constriction increases the heat input intensity to the target materials [3] and, thus, leads to high productivity. However, the high cost of He limits its applications. Therefore, an alternative shielding gas with lower cost and better energy source properties is required. In this paper, by adopting carbon dioxide (CO_2), the basic energy source properties of CO_2 GTA are predicted. The properties of arc plasma and heat input intensity to a water-cooled copper anode are numerically analyzed ignoring oxidation of electrodes. The results are compared with those of conventional argon (Ar) and He GTA.

2. Arc-electrode model

The tungsten cathode, arc plasma and anode are described in a frame of cylindrical coordinate with axial symmetry around the arc axis. The calculation domain is shown in Fig. 1. The diameter of the tungsten cathode is 3.2 mm with a 60° conical tip. The anode is a water-cooled copper. The arc current is set to be 150 A. Ar, He or CO_2 is introduced from the upper boundary of the calculation domain. The flow is assumed to be laminar, and the arc plasma is assumed to be under local thermodynamic equilibrium (LTE). Physical properties of shielding gases are calculated in the same manner as that in literature [4]. The dependences of specific heat, thermal conductivity and electrical conductivity of the gases on the temperature are shown in Fig. 2. The boundary conditions and numerical modeling method are given in detail in our previous papers [5,6] and the most pertinent points are explained here. The differential Eqs. (1)–(6) are solved iteratively by the SIMPLEC numerical procedure [7]:

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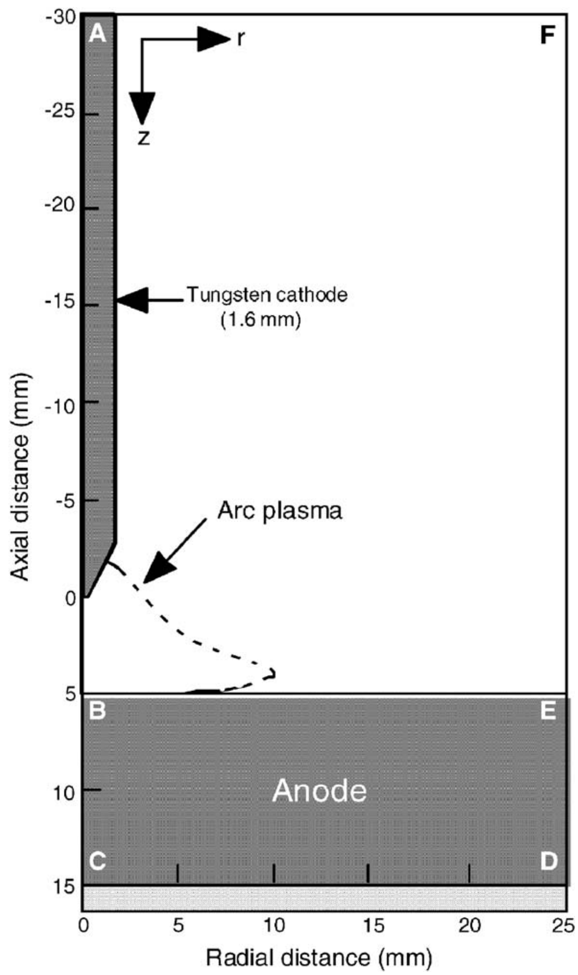

Fig. 1. Schematic illustration of calculated domain.

Mass continuity equation:

$$\frac{1}{r}\frac{\partial}{\partial r}(r\rho v_r)+\frac{\partial}{\partial z}(\rho v_z)=0, \tag{1}$$

Radial momentum conservation equation:

$$\frac{1}{r}\frac{\partial}{\partial r}(r\rho v_r^2)+\frac{\partial}{\partial z}(\rho v_r v_z)= -\frac{\partial P}{\partial r}-j_z B_\theta+\frac{1}{r}\frac{\partial}{\partial r}\left(2r\eta\frac{\partial v_r}{\partial r}\right) +\frac{\partial}{\partial z}\left(\eta\frac{\partial v_r}{\partial z}+\eta\frac{\partial v_z}{\partial r}\right)-2\eta\frac{v_r}{r^2}. \tag{2}$$

Axial momentum conservation equation:

$$\frac{1}{r}\frac{\partial}{\partial r}(r\rho v_r v_z)+\frac{\partial}{\partial z}(\rho v_z^2)= -\frac{\partial P}{\partial z}+j_r B_\theta+\frac{\partial}{\partial z}\left(2\eta\frac{\partial v_z}{\partial z}\right) +\frac{1}{r}\frac{\partial}{\partial r}\left(r\eta\frac{\partial v_r}{\partial z}+r\eta\frac{\partial v_z}{\partial r}\right). \tag{3}$$

Energy conservation equation:

$$\frac{1}{r}\frac{\partial}{\partial r}(r\rho v_r h)+\frac{\partial}{\partial z}(\rho v_z h)=\frac{1}{r}\frac{\partial}{\partial r}\left(\frac{r\kappa}{c_p}\frac{\partial h}{\partial r}\right)+\frac{\partial}{\partial z}\left(\frac{\kappa}{c_p}\frac{\partial h}{\partial z}\right) +j_r E_r+j_z E_z-R, \tag{4}$$

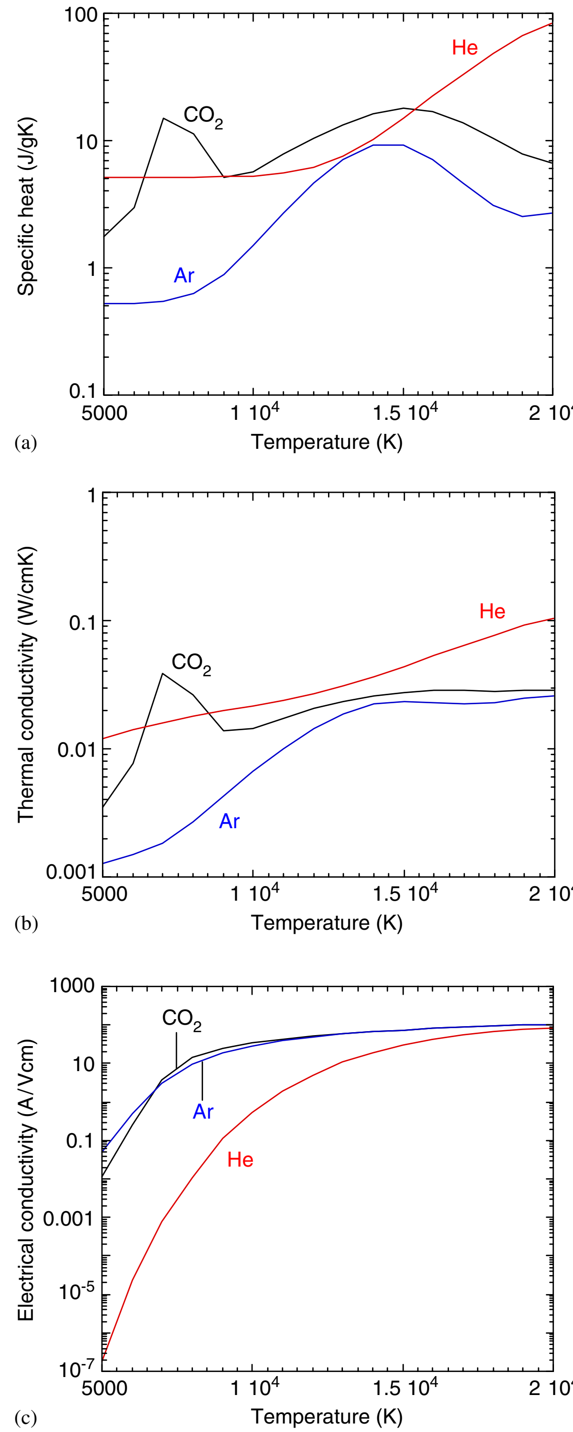

Fig. 2. Dependences of specific heat, thermal conductivity and electrical conductivity of gases on temperature. (a) Specific heat, (b) thermal conductivity and (c) electrical conductivity.

Current continuity equation:

$$\frac{1}{r}\frac{\partial}{\partial r}(rj_r)+\frac{\partial}{\partial z}(j_z)=0, \tag{5}$$

Ohm's law:

$$j_r=-\sigma E_r,\quad j_z=-\sigma E_z, \tag{6}$$