



Standard Practice for Measuring Plasma Arc Gas Enthalpy by Energy Balance¹

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1. Scope

1.1 This practice covers the measurement of total gas enthalpy of an electric-arc-heated gas stream by means of an overall system energy balance. This is sometimes referred to as a bulk enthalpy and represents an average energy content of the test stream which may differ from local values in the test stream.

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Summary of Test Method

2.1 A measure of the total or stagnation gas enthalpy of plasma-arc heated gases (nonreacting) is based upon the following measurements:

2.1.1 Energy input to the plasma arc,

2.1.2 energy losses to the plasma arc hardware and cooling water, and

2.1.3 gas mass flow.

2.2 The gas enthalpy is determined numerically by dividing the gas mass flow into the net power input to the plasma arc (power to plasma arc minus the energy losses).

2.3 The technique for performing the overall energy balance is illustrated schematically in Fig. 1. The control volume for the energy balance can be represented by the entire envelope of this drawing. Gas enters at an initial temperature, or enthalpy, and emerges at a higher enthalpy. Water or other coolant enters the control volume at an initial temperature and emerges at a higher temperature. Across the arc, electrical energy is dissipated by virtue of the resistance and current in the arc itself. A heat balance of the system requires that the energy gained by the gas must be defined by the difference between the incoming energy (electrical input) and total coolant and external losses. This is a direct application of the First Law of Thermodynamics and, for the particular control volume cited here, can be written as follows:

$$\text{Energy In} - \text{Energy Out} = \text{Energy to Gas} \quad (1)$$

¹ This method is under the jurisdiction of ASTM Committee E-21 on Space Simulation and Applications of Space Technology and is the direct responsibility of Subcommittee E21.08 on Thermal Protection.

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$$\bar{E}I - Q_{CR} - \sum_{i=1}^n W_{H_2O_i} C_p (\Delta T_0 - \Delta T_1)_{H_2O_i} - \sum_{j=1}^p M_j H_j$$

= Energy to gas

where:

C_p	= water, specific heat,
E	= plasma arc voltage,
H_g	= exhaust gas enthalpy,
H_{in}	= inlet gas enthalpy,
H_j	= heat of vaporization corresponding to the material M_j ,
I	= plasma arc current,
M_j	= mass loss rate of electrode insulator, interior metal surface, etc.
Q_{CR}	= energy convected and radiated from external surface of plasma generator,
$\Delta T_{0_{H_2O}}$	= $T_{0_2} - T_{0_1}$ = water temperature rise during plasma arc operation,
$\Delta T_{1_{H_2O}}$	= $T_2 - T_1$ = water temperature rise before plasma arc operation,
T_{0_2}	= water exhaust temperature during plasma arc operation,
T_{0_1}	= inlet water temperature during plasma arc operation,
T_2	= water exhaust temperature before plasma arc operation,
T_1	= inlet water temperature before plasma arc operation,
W_g	= gas flow rate,
W_{H_2O}	= mass flow rate of coolant water, and
$\bar{E}I$	= average of the product of voltage, E , and current, I .

2.4 An examination of Eq 1 shows that, in order to obtain an evaluation of the energy content of the plasma for a specified set of operating conditions, measurements must be made of the voltage and current, the mass-flow rate and temperature rise of the coolant, the mass-flow rate and inlet ambient temperature of the test gas, and the external surface temperature and housing of the arc chamber. For all practical purposes, the external surface temperature of the water-cooled plasma arc is minimum. Consequently, it will be assumed throughout this discussion that negligible energy (compared to the input energy) is lost from the external plasma generator surface by convective or radiative mechanisms and that the internal loss of electrode or plasma generator material is small compared with the energy input. In addition, as some plasma generators utilize