TASK 1: GENERATION OF PLASMA IN DC ARC PLASMA TORCH

EXPERIMENTAL PROCEDURE AND DATA PROCESSING INSTRUCTIONS.

INTRODUCTION.

The distinctive feature of the thermal plasma is a Local Thermodynamic Equilibrium (LTE). It implies that collision processes govern transitions and reactions in plasma and practically means that all plasma properties are dependent on local temperature (1). Temperature is equal for all species of plasma: electrons, ions and neutral particles. Thermal plasma, then, meets conditions:

1) The velocity distribution function for particles of every species follows Maxwell-Boltzmann distribution.
2) The population density of the excited states of every species follows Boltzmann distribution.
3) The particle densities (for neutrals, electrons, and ions) are described by the Saha equation for ionization equilibrium.

All this equations describe species and their states distributions for particular plasma composition as function of plasma temperature. Therefore, knowledge of a plasma temperature is crucial for characterization of the plasma.

PLASMA TORCH WSP®500H

Majority of plasma torches are designed to maintain arc in the axis of an arc chamber (1, 2). Using physical and chemical processes to keep particular shape and position of the arc is called arc stabilization. In the plasma torch WSP®500H, which is used for this practical course, stabilization and plasma forming media are argon and water (3). The torch consists of tungsten cathode, an arc chamber, and an external anode created by rotating water cooled copper disk (Fig.1.). An inner nozzle separates the cathode from water chamber in order to protect it from the oxidation by water products. Large effective surface of anode reduces its erosion and allows reaching hundreds hours of operation in air atmosphere. Between the cathode and anode three parts of arc can be distinguished according to a stabilization mechanism.

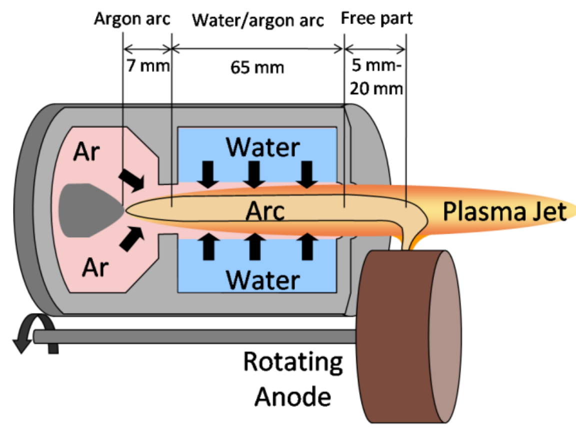

Fig. 1. The plasma torch with místo free part bych napsal arc in free jet

1. In the cathode section, the arc is stabilized by argon vortex. Argon is supplied along the cathode with tangential component.
2. In the arc chamber, the arc is surrounded by water vortex, formed by tangential injection of water. In the beginning and the end of the water-stabilized chamber, the water is emptied through exhaust gaps. Heating of the water by the arc causes evaporation from the inner surface of water vortex. The

steam mixes with the plasma flowing from the cathode section, and overpressure created in the chamber accelerates the plasma towards the exit nozzle.

3. The last part of the arc after the nozzle is the arc in a free jet. In order to attach to anode surface arc must curve. The part of arc connecting the anode is called anode attachment. In common configuration of a plasma torch, it is perpendicular to the main arc column and undergoes magnetic force of the arc column and drag by the plasma jet. This causes stochastic movement of the anode attachment over the anode surface. Movement of anode attachment causes continuous change of the arc length with amplitude up to 20% of its value (77-92 mm).

It is known that water mainly determines the heat processes in WSP®500H because of high enthalpy of steam plasma. The evaporation rate of the water, however, is self-regulating process and cannot be controlled. Thus, control of argon flow rate is main possibility to regulate plasma mass flux.

The power source used for the torch has a current stabilization. It keeps current on a set value even if operating conditions change. Therefore, variations of plasma conductivity can be seen on arc voltage changes.

Most of the torch operation parameters are monitored by a torch control system and recorded to the file of WDA type, which can be opened by Excel. Here the recorded parameters are:

- ✓ arc current I and voltage U (I U)
- ✓ cooling water flow rates F; cooled parts are cathode **c**, anode **a**, and arc chamber **ch** (F_c, F_a, F_{ch})
- ✓ input/output temperatures of cooling water (T_c^{in}, T_c^{out}, T_a^{in}, T_a^{out}, T_{ch}^{in}, T_{ch}^{out})

Name	I	U	F_{ch1}	F_{ch2}	F_a	F_c	T_{ch1}^{in}	T_{ch2}^{in}	T_{ch}^{out}	$T_{a/c}^{in}$,	T_a^{out},	T_c^{in},	T_c^{out}
Column name	SCUR 8	SVOL 9	F1	F2	F4	F3	T1	T2	T9	T3	T6	T7	T8

Two important operating parameters are not monitored by the control system. The first is the argon flow rate, which is controlled from a separated system (Brooks flow meter). It must be noted that part of argon is pumped out of chamber with channel water and the leaked fraction depends on plasma torch operation conditions. The second parameter, which is not monitored during the torch operation, is position of the anode surface.

Only arc current and argon flow rate can be changed during torch operation. The temperatures and flow rates of input water and anode position are adjusted to optimal values before the operation. Arc voltage and output water temperatures are functions of process and input parameters; they rather describe the torch operation mode than control it.

GOAL OF THE EXPERIMENT:

1. Training in setting-up and operation of plasma torch.
2. To get skills in evaluation of properties of the thermal plasma and in analyzing of plasma torch performance.

EXPERIMENT PROCEDURE:

1. Running of the torch WSP®500H
    a. Set-up and operation of plasma torch (water flow rates, anode position, arc current – 400 A, argon flow rate - 12.5 slm).
    b. Monitoring of plasma jet generation (arc voltage, cooling water temperatures and flows rates, plasma jet observation).
    c. Recording of operating parameters.

2. Post processing of the operating parameters records. Evaluation of power balance and plasma properties:
    a. Importing of the data to a processing software (Excel, Matlab, ...).
    b. Calculation of power losses to the cooling water in the cathode, anode, and arc channel.
    c. Calculation of total power, evaluation of an efficiency of plasma generation.
    d. Evaluation of plasma mass flux, bulk enthalpy and bulk temperature. Evaluation of properties of generated plasma.

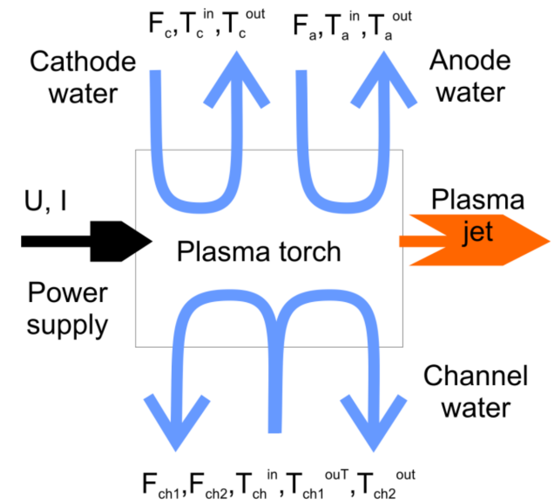

Fig. 2. Scheme of energy transfer in torch WSP-500H

THE PROPERTIES TO BE EVALUATED:

- ✓ total power, power losses, power remained in plasma, and efficiency of plasma generation;
- ✓ plasma mass flux, bulk enthalpy, bulk temperature, bulk velocity;
- ✓ mean plasma viscosity, plasma and electron density, heat capacity, heat conductivity, electrical conductivity;
- ✓ Reynolds number, Mach number.

POWER BALANCE

The energy source supplies total power (P_T), which is given by the product of arc voltage and current

$$P_T = U_A I_A$$

Part of the total power is lost to heating of the torch parts, which are cooled by water to avoid overheating. Thus the lost energy escapes in cooling water. The torch has two individually cooled parts – the cathode and anode. In the arc channel only small part of water is evaporated all other amount is in continuous circulation so that the constant conditions in arc boundary are kept. Plasma torch can be schematically represented by Fig.2. The measured values of voltage U, current I, flow rate F, and temperature T are noted.

The part of power transferred to plasma can be calculated as difference of supplied power and heat came out with water

$$P_P = P_T - \dot{Q}_W \,.$$

Heat losses to cooling water can be evaluated by calorimetry as we know water flow rate and temperatures of input and output water.

$$Q_W = c_W m_W \Delta T_W \,.$$

Ratio of power transferred to plasma P_P and total power P_T represents efficiency of plasma generation process

$$\eta = \frac{P_P}{P_T} .$$

MASS FLUX CALCULATION

Plasma mass flux is important property of plasma jet. Argon flow rate and water evaporation rate in sum defines plasma mass flux. The water evaporation rate, as was calculated in (4) from spectroscopic measurements, is shown in Table 1 for currents 300, 400, 500 and 600 A.

TABLE 1 EVAPORATION MASS FLOW RATE AT DIFFERENT ARC CURRENTS

Current, A	300	400	500	600
Mass flow rate, g/s	0.204	0.272	0.285	0.325

Supplied argon flow rate F_{ArS} (in slm – standard liters per minute) is measured but part from this is pumped out with the water in arc channel. Remaining part of argon was found to be dependent on both supplied argon flow rate and arc current (5). In Table 2 the measured values are shown.

TABLE 2 PART OF ARGON REMAINING IN PLASMA FOR DIFFERENT RATES OF SUPPLIED ARGON AND ARC CURRENTS

	Arc current, A		
Supplied flow rate, slm	300	400	500
12.5	37 %	33 %	31 %
17.5	46 %	42 %	37 %
22.5	49 %	46 %	39 %

Using the data from the tables, the plasma mass flow rate can be evaluated as sum of argon and water mass flow rates

$$\dot{m}_P = \dot{m}_T + \dot{m}_W \, .$$

Percentage of the argon in plasma is also important parameter. It determines the plasma composition and its characteristics. Molar ratio of argon and water R_M can be evaluated using data in Tables 1 and 2.

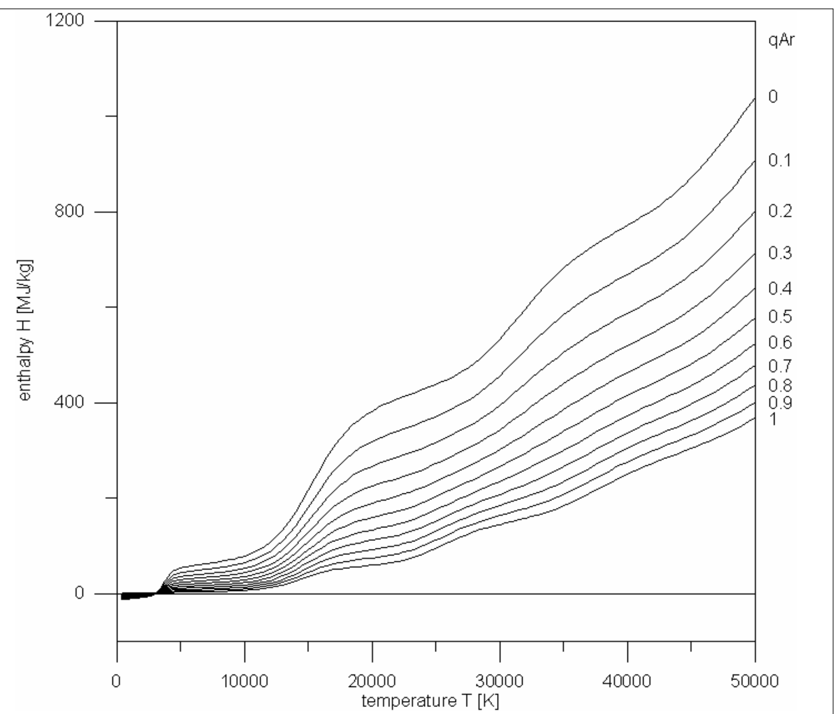

Fig.3. Enthalpy of the mixture $(H_2O)_{(1-q)}Ar_q$.

EVALUATION OF BULK PLASMA PARAMETERS

Knowing the mass flow rate of plasma and the heat flux the bulk enthalpy of plasma can be calculated as the ratio of the plasma power and mass flux:

$$H_P = \frac{\dot{Q}_W}{\dot{m}_W} \, .$$

As it was noted before for determined composition of thermal plasma all plasma properties are related to plasma temperature only.

Using dependence of enthalpy on the temperature, plasma temperature can be determined from the graph shown in the Fig.3 (6).

Using the dependence of other plasma properties on temperature, they can be determined from tables and graphs published in (6) and attached as Appendix 1.

Finally knowing all plasma parameters, dimensionless Reynolds and Mach numbers can be calculated for description of flow in of the plasma jet. The nozzle diameter D_N = 5.6 mm can be considered as characteristic dimension L. Reynolds number is expressed by equation

$$Re = \frac{\upsilon_P L}{\nu_P},$$

where υ_P and ν_P are plasma velocity and kinematic viscosity. Mach number is ratio of plasma velocity and sound velocity in plasma

$$M = \frac{\upsilon_P}{c_P}.$$

NOTES

Last stage of the task is writing of short report (about 2 pages) in English or Czech based on the measurements and evaluations of plasma parameters. In conclusion of the report behavior of plasma torch must be described shortly; most important operational parameters, properties of plasma must be summarized and plasma jet must be characterized.

During the calculations particular care must be paid to units of measured and processed quantities. All quantities must be expressed in SI.

It is recommended to create table or program for automatic calculation of power balance and plasma characteristics, as the same calculations for different conditions will be done in next experiment.

REFERENCES

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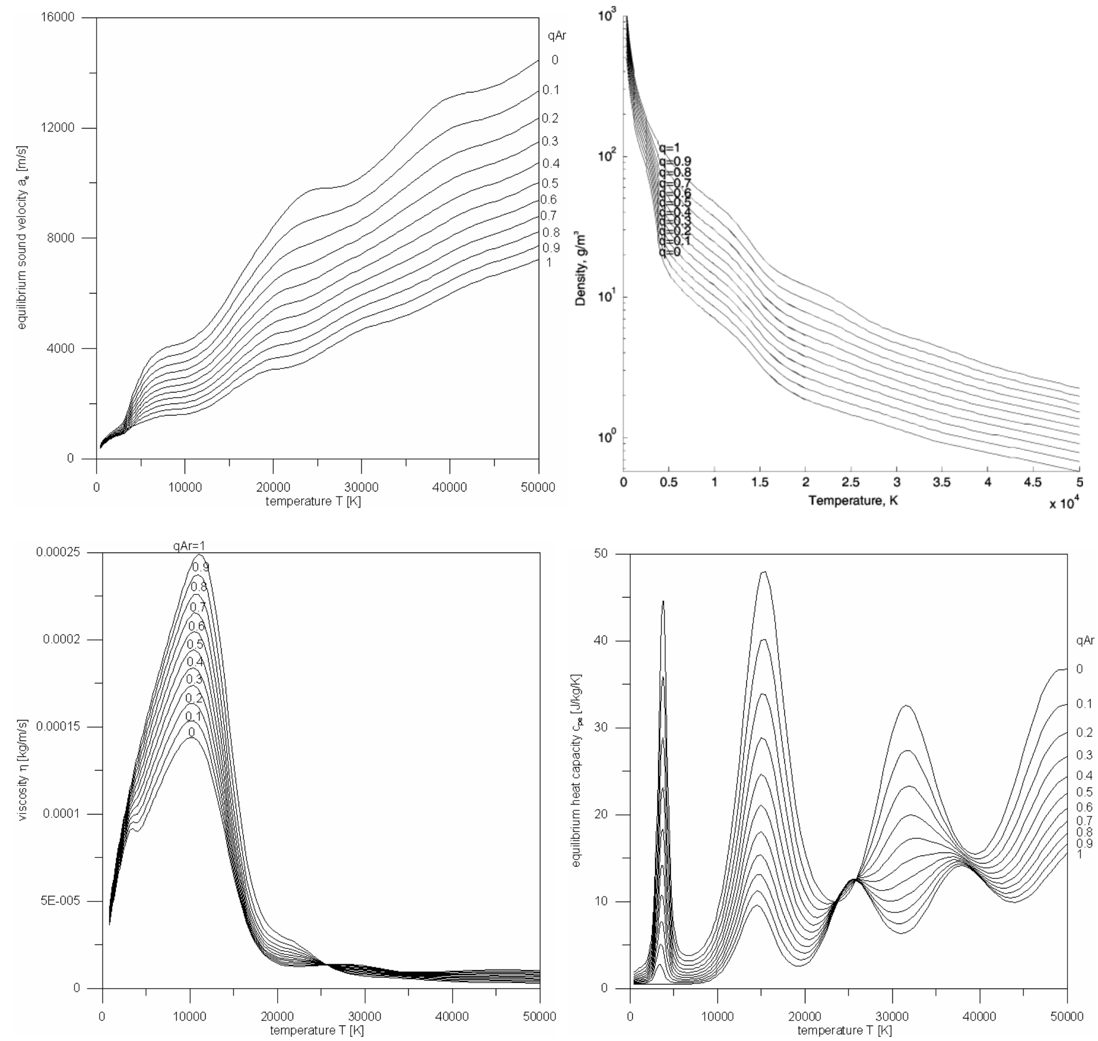
7. ttp://www.ipp.cas.cz/Ntp/

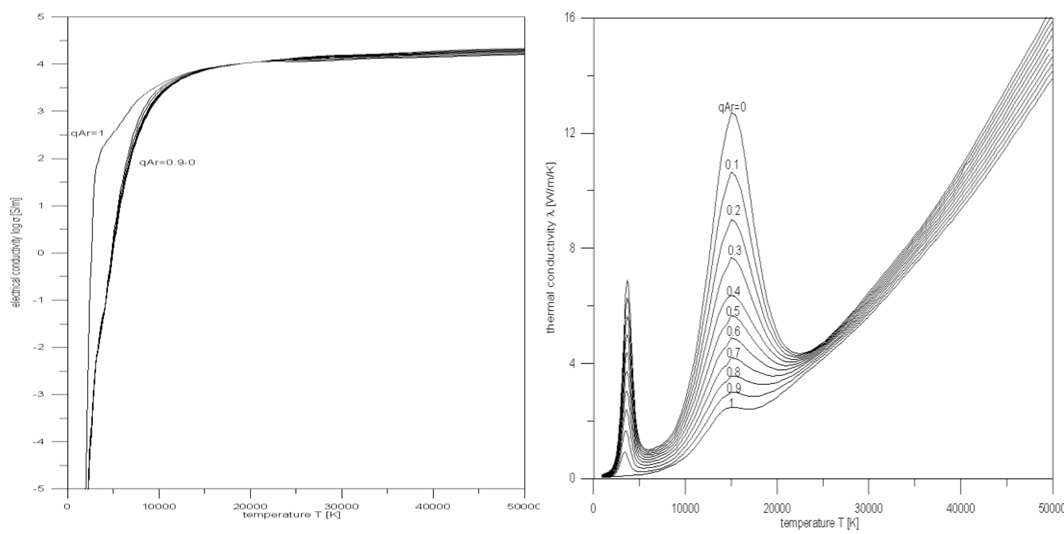
APPENDIX 1

PROPERTIES OF MIXTURE $(H_2O)_{(1-Q)}AR_Q$ (HERE Q-MOLAR RATIO)



SOUND VELOCITY, DENSITY, VISCOSITY AND HEAT CAPACITY IN DEPENDENCE ON TEMPERATURE AND COMPOSITION.

PROPERTIES OF MIXTURE $(H_2O)_{(1-Q)}Ar_Q$ (HERE Q-MOLAR RATIO)



ELECTRICAL AND THERMAL CONDUCTIVITY IN DEPENDENCE ON TEMPERATURE AND COMPOSITION.