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Optimization of Magnetically Accelerated Arc Discharges for CO2 Conversion at Atmospheric Pressure

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Introduction

The aim of this work is to improve the conversion of CO_2 and energy efficiency of a device based on Magnetically accelerated Gliding Discharge (MAGD). The MAGD consists of two knife-shaped metal electrodes, sandwiched between pair of quartz glasses. A pair of two permanent NbFeB magnets is placed on the top of the glasses and create the magnetic filed perpendicular to the arc current. The formed **J**×**B** force acts in the direction of the gas flow and accelerate the arc. The difference between the velocities of the arc and gas flow sustains higher conversion and energy efficiency compared to the other investigated configurations in our lab [1,2]. During the optimization [2], we found that the thickness of electrodes influence the discharge performance, and the optimal one is *d* = 3 mm.

The present study shows that the choice of DC power supply (PS) also influences the conversation of CO_2 and particularly the energy efficiency. The results with single and three-phase power supplies for different gas flow rates (4–12 Ln/min) and applied powers (300 –550 W) are analyzed. The single-phase PS has output signal with half sinus pulses at 100 Hz, produced by full bridge rectifier with inductive filter. The three-phase PS uses 3-phase full bridge rectifier producing close to DC signal with minor oscillation at 300 Hz.

An Optical Emission Spectroscopy (OES) diagnostics is applied for estimation of the gas temperature. The spectra of high-pressure CO_2 plasmas are usually dominated by the C_2 Swan bands. The analysis of registered emission spectra through the open source MassiveOES [3] software gives information about vibrational (T_{vib}) and rotational (T_{rot}) temperatures. At our experimental conditions it seems like these temperatures coincide well within their uncertainties and can be used for assessing the gas temperature of the plasma.

[1] V. Ivanov, Ts. Paunska, S. Lazarova, A. Bogaerts and S. Kolev, *J. CO2 Util.* 2023, **67**, 102300.
[2] S. Lazarova, Ts. Paunska, V. Vasilev, K. Tarnev, S. Iordanova and S. Kolev *Plasma* 2024, **7**, 877–890.
[3] J. Voráč, P. Synek, L. Potočňáková, J. Hnilica and V. Kudrle *Plasma Sources Sci. Technol*. 2017, **26** 025010.

Experimental setup

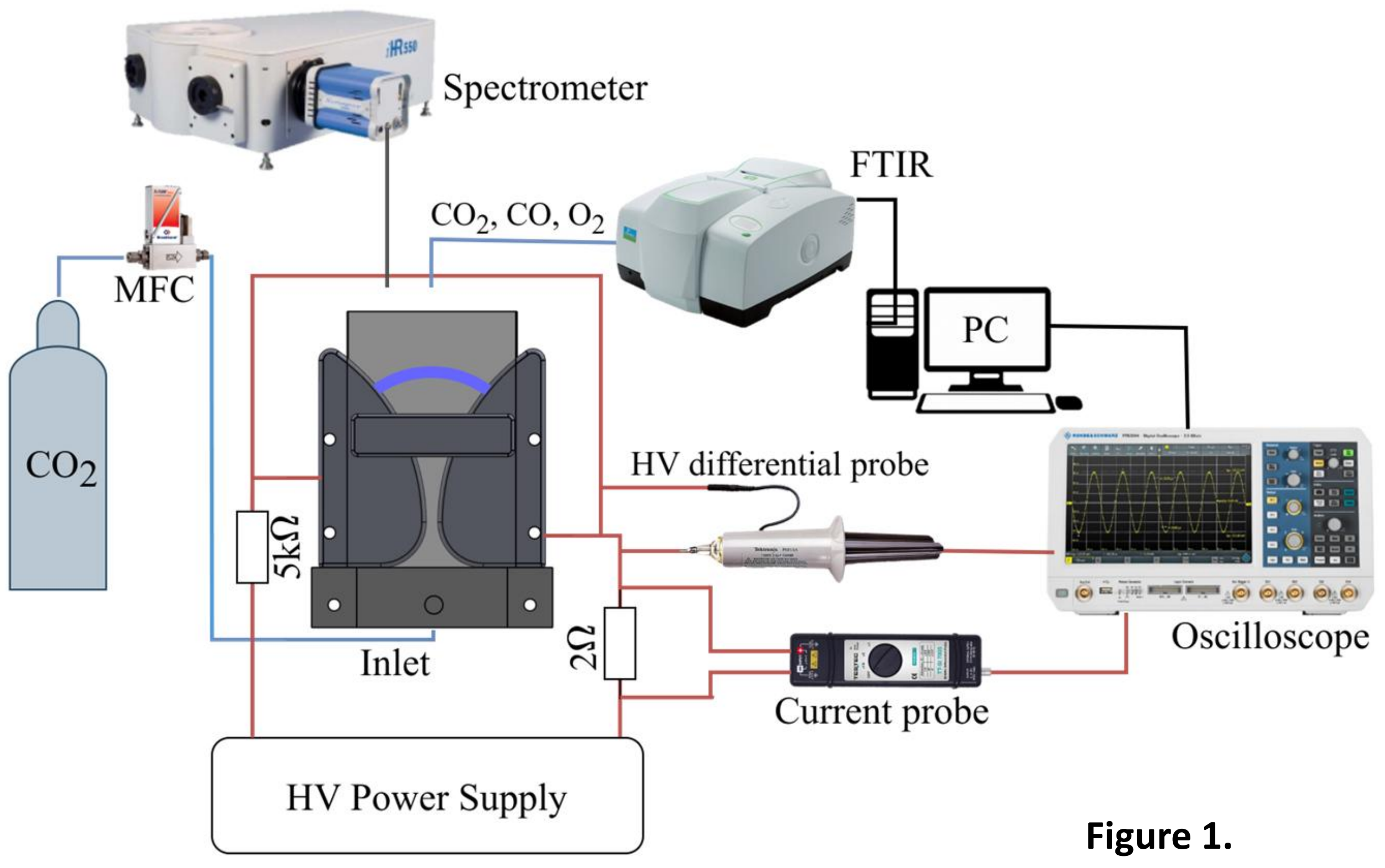

Figure 1.

- ➢ CO_2 gas is controlled by mass flow controllers;
- ➢ Magnetically Accelerated Gas Discharge
  - Knife-shaped Cu electrodes with thickness *d* = 3 mm, sandwiched between two quartz glass plates
  - The narrowest distance between the electrodes is 3.5 mm
  - Permanent magnets with dimension 40 ×7.4×60 mm;
- ➢ Active cooling system (not shown in the figure);
- ➢ Electrical parameters are measured by a HV differential and a current probe, connected to an oscilloscope;
- ➢ The gas analysis is made with Fourier Transform Infrared (FTIR) Spectrometry;
- ➢ The optical emission spectra are recorded by a Horiba iHR550 Imaging Spectrometer with resolution 0.025 nm.

➢ Quantities of interest:

- $Conv.rate\ [\%] = \frac{n_{CO_2}^{in} - n_{CO_2}^{f}}{n_{CO_2}^{in}} \times 100\%$, where $n_{CO_2}^{in}$ and $n_{CO_2}^{f}$ are the initial and the final concentrations of CO_2 respectively.
- $SEI\ \left[\frac{J}{mol}\right] = \frac{P[J/s]}{MFR\ [Ln/s]\times(1/22{,}4)[mol/Ln]}$, where MFR is the Mass Flow Rate of the gas.
- $\eta[\%] = \frac{Conv.rate\times\Delta H_R}{SEI} \times 100\ \%$, where $\Delta H_R = 279.8 \times 10^3\ \left[\frac{J}{mol}\right]$ is the reaction enthalpy for the CO_2 splitting reaction.

Results

Conversion rates of CO_2 and energy efficiencies

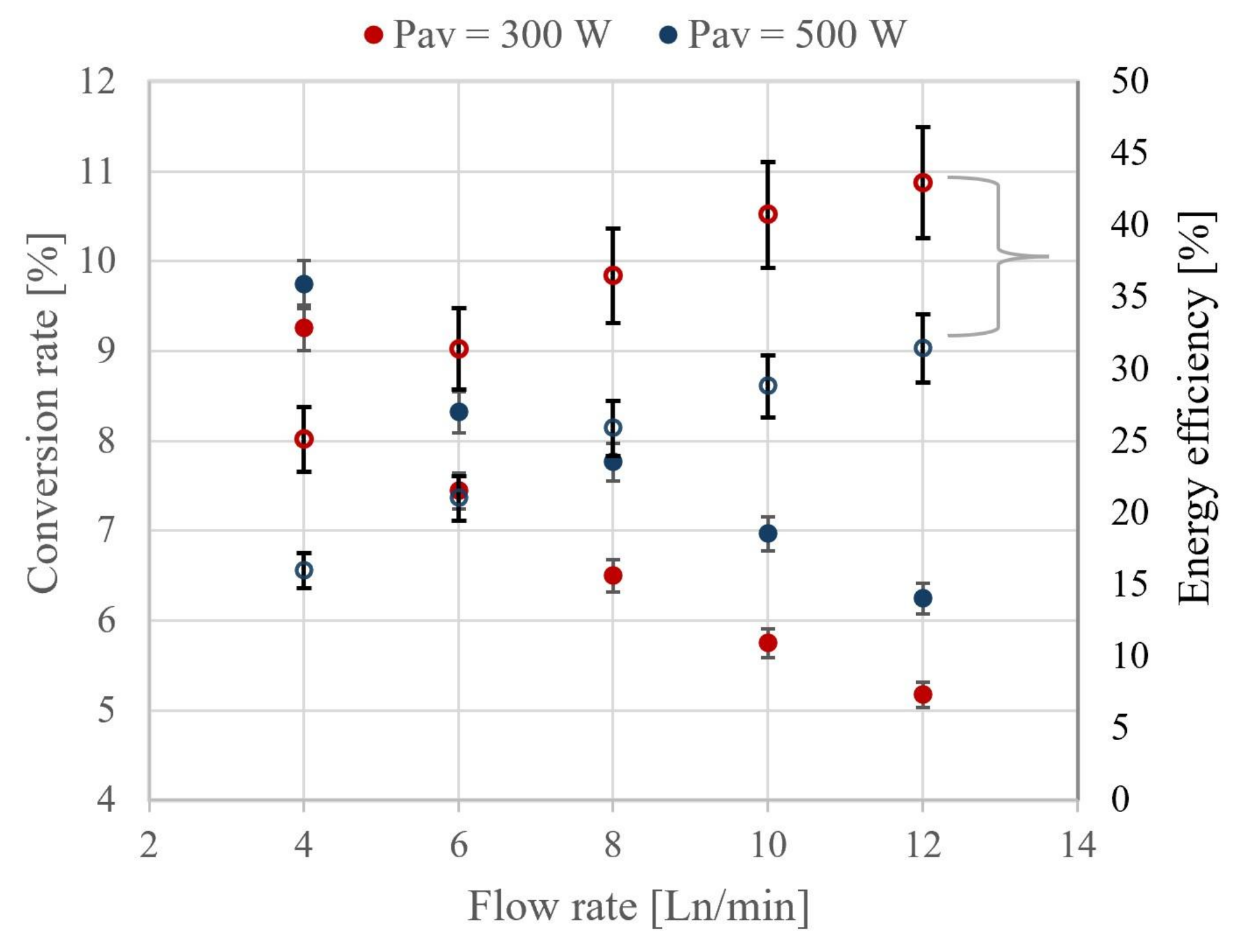

Figure 2. Conversion rate (solid symbols) and Energy efficiency (open symbol) as function of the flow rate. The results are with three-phase power supply.

- ➢ The energy efficiencies are in interval 20 – 45 %. The results are close to the optimum for discharges of this type known in literature.
- ➢ The conversion rates of CO_2 are in interval 5–10 %;

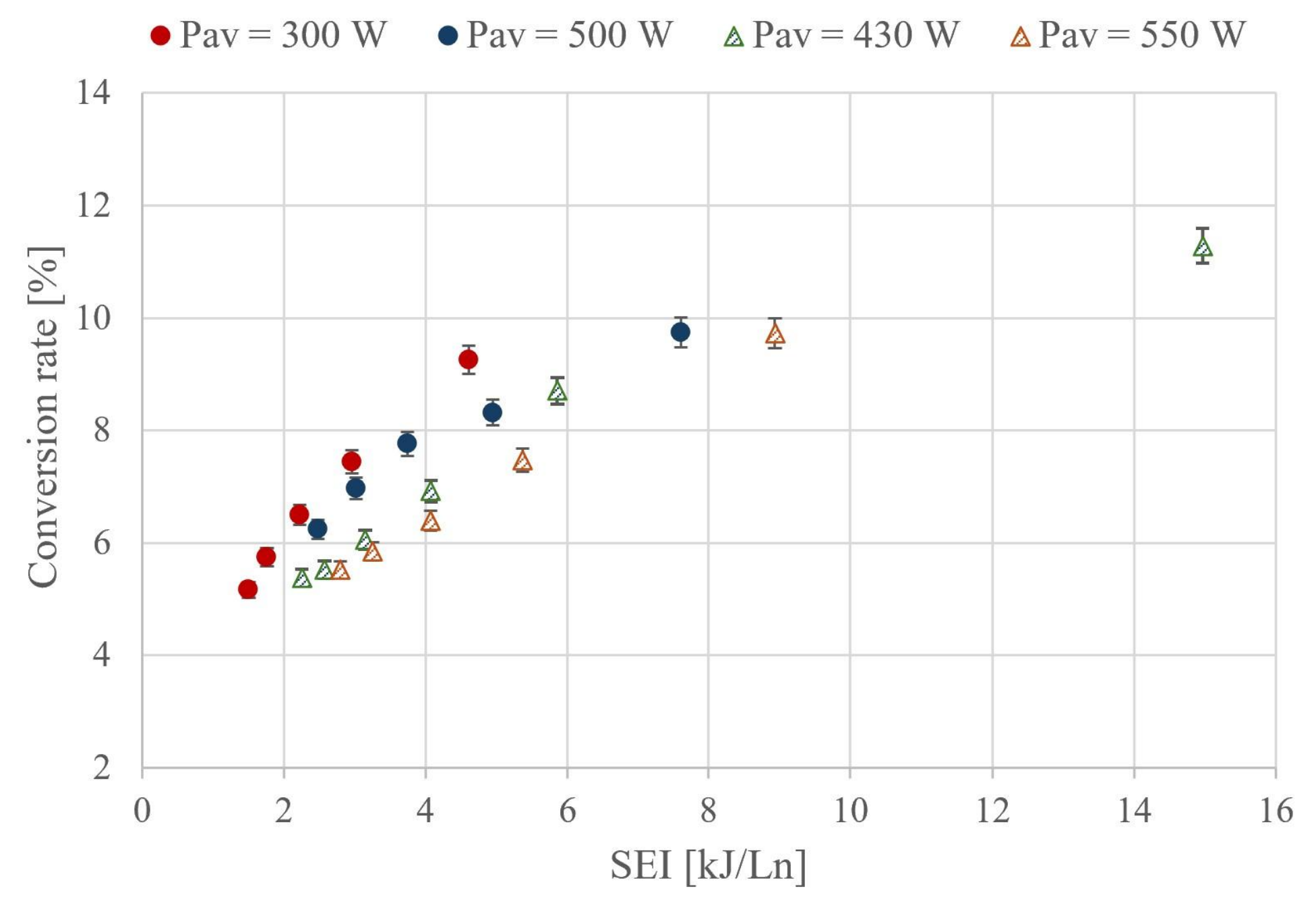

Figure 3. The conversion rate versus SEI for three-phase (circles) and single-phase (triangles) power supplies.

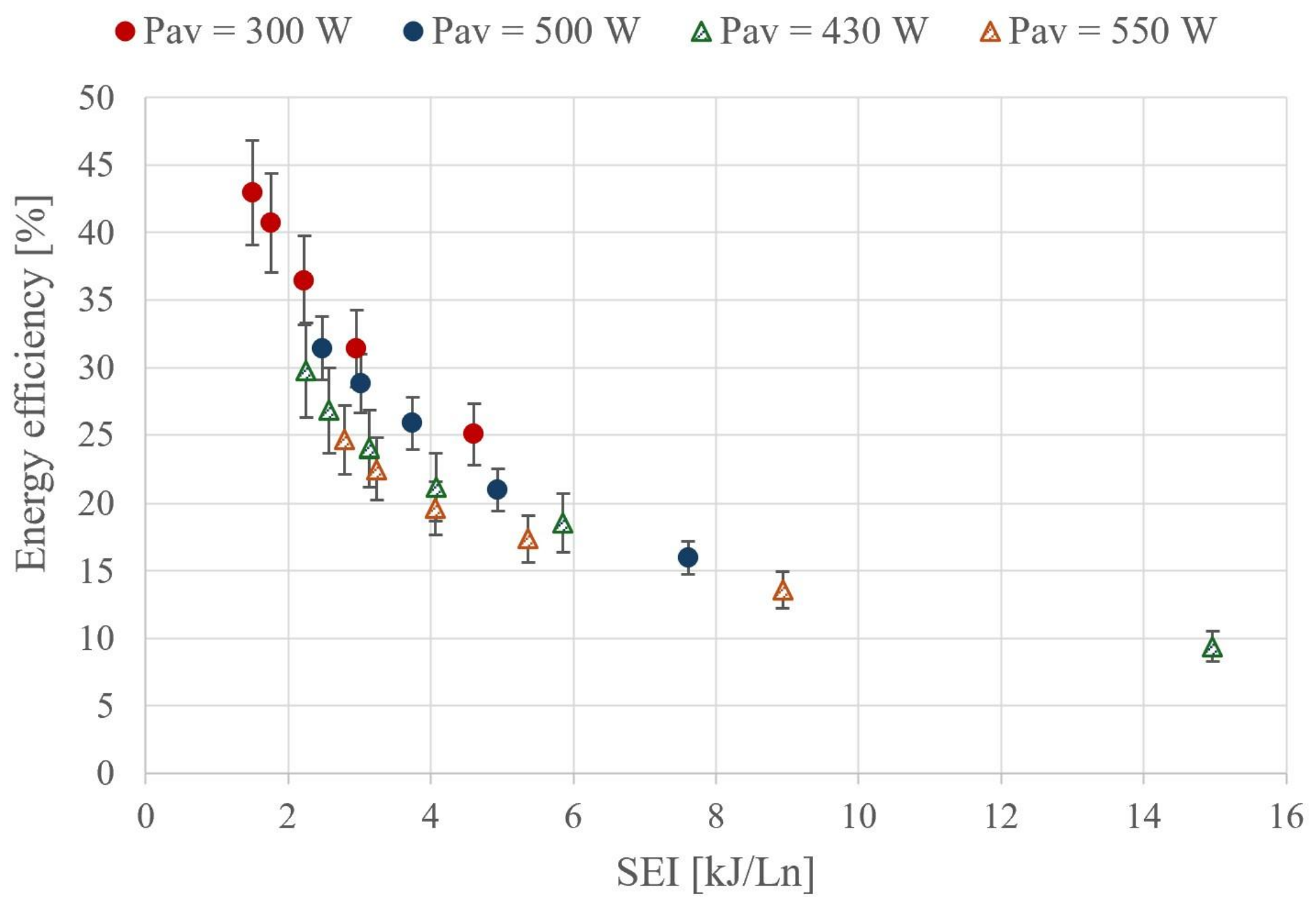

Figure 4. The Energy efficiency versus SEI for the three-phase (circles) and single-phase (triangles) supplies.

- ➢ The conversion rates and energy efficiencies for the three-phase power supply stay above that with single-phase* power supply for the same SEI;
- ➢ The results with the three-phase supply are mainly in the SEI interval 1.5 – 4, whereas these with single-phase* power supply are in the SEI interval 2–6;

All our previous published date [1,2] are obtained with the single-phase power supply

OES diagnostic results

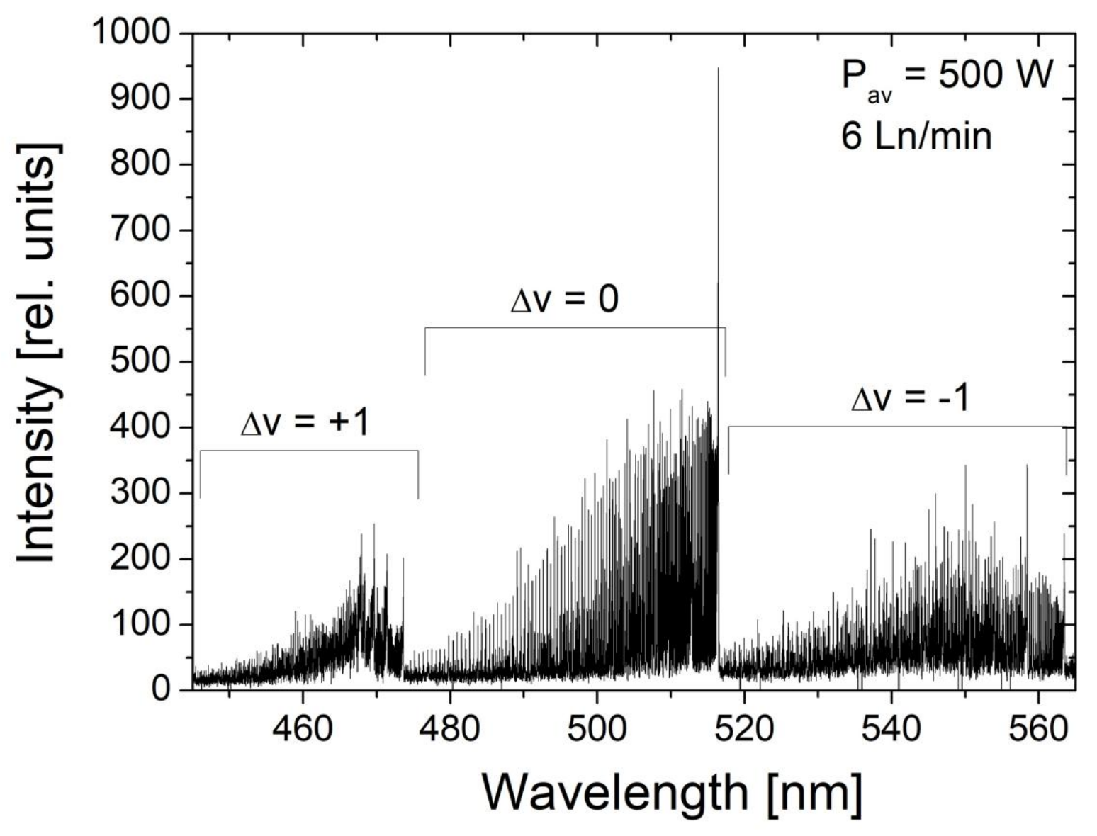

Figure 5. Experimental C_2 Swan bands emission between 445 and 565 nm. The spectrum was acquired for a power of 500 W and a gas flow rate 6 Ln/min.

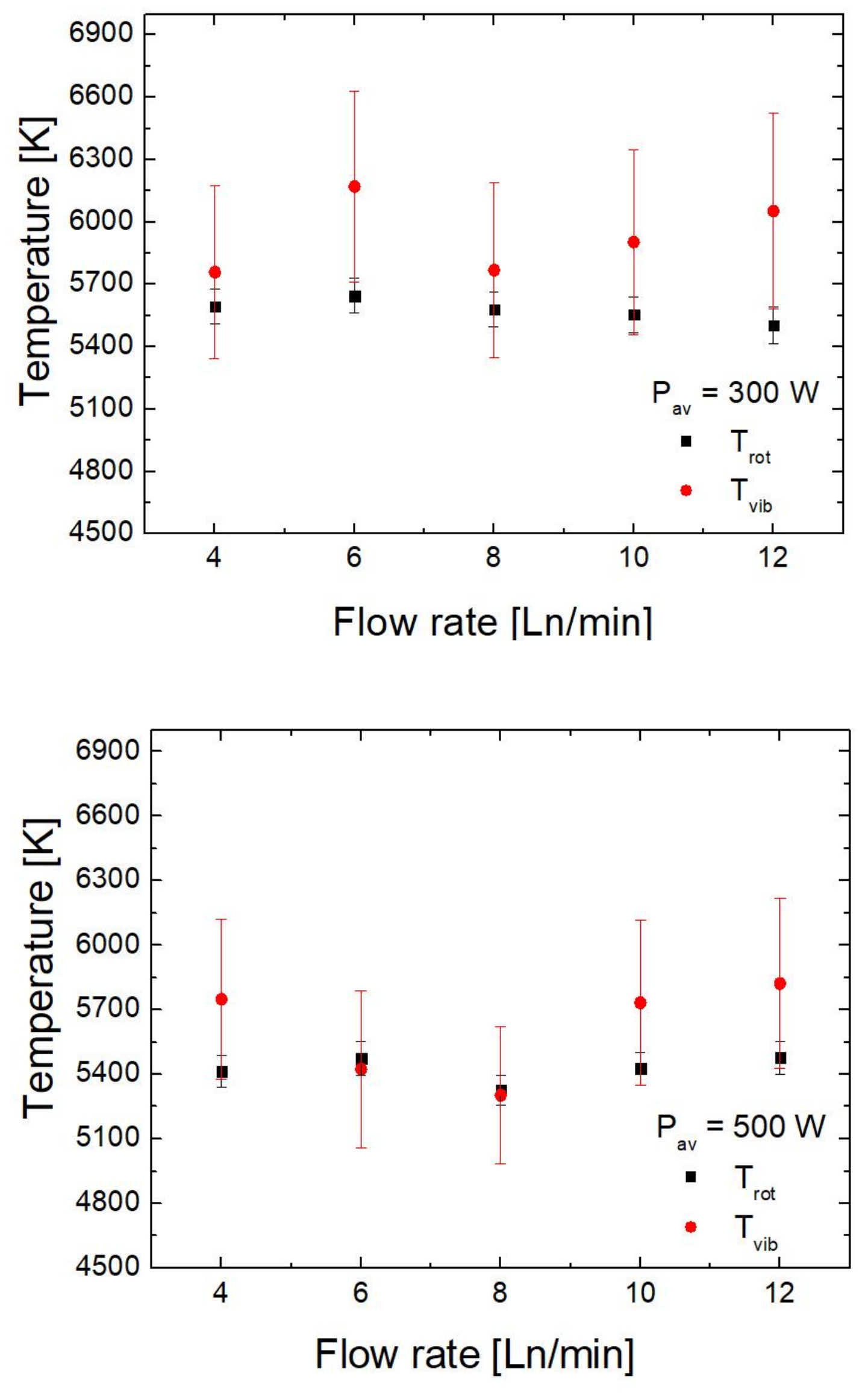

Figure 6. The Rotational and Vibrational temperatures versus Flow rate at Pav = 300 W in a) and 500 W in b). The results are determined by the Δv = 0 transition group.

- ➢ T_{rot} and T_{vib} coincide well within their uncertainties;
- ➢ T_{rot} and T_{vib} are not significantly affected by the gas flow rate and applied power values;
- ➢ The values of T_{rot} and T_{vib} can be used for assessment of the gas temperature.

Conclusion

Overall, this study shows that the MAGD discharge as a device for CO_2 conversion can be further improved by modification of the DC power supply. The results show that the three-phase power supply ensure higher energy efficiencies compere with our previous achieved values. They are very similar to the best-known results in the literature.

The spectroscopy diagnostic with obtained values for T_{rot} and T_{vib} can be used for assessment of the gas temperature. The values indicate that the processes of the thermal dissociation of CO_2 are dominant in our plasma.

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