EVALUATION REPORT

of PhD thesis in profesional field: 4.1 Physical sciences, scientific speciality - "Radiophysics and physical electronics" by defense procedure in Faculty of Physics, Sofia University "St. Kliment Ohridski"

Reviewer: Assoc. Prof. Dr. Valentin Mihailov PhD, "Institute of Solid State Physics", Bulgarian Academy of Sciences

Title of the thesis: **"Conversion of CO_2 in arc discharges at atmospheric pressure"**
Author: **Vladislav Valentinov Ivanov**

General description of the presented materials

1. Data for the documents presented

The candidate Vladislav Valentinov Ivanov has presented printed paper copy and electronic copy of dissertation work, an abstract, copies of the publications included in the dissertation and the obligatory comparison table with recommended requirements and a certificate of absence of plagiarism. A resume, statement of authorship and educational diplomas are also presented. The documents submitted for the defense correspond of the Law on the Development of Academic Staff in the Republic of Bulgaria (LDASRB), the Regulations for Implementation of the Law on the Development of Academic Staff in the Republic of Bulgaria (RIDASRB) and the Rules on Terms and Conditions for the Acquisition of Scientific Degrees and the Occupation of Academic Positions at Sofia University "St. Kliment Ohridski"

2. Brief biographical reference of the candidate

Vladislav Ivanov has acquired bachelor's degree in 2016. and a master's degree in 2018 in scientific speciality "Communications and Physical Electronics" from the Faculty of Physics, SU "St. Kliment Ohridski". He has acquired an additional qualification as a physics and astronomy teacher. From 2019 he has been a full-time PhD student at the "Radiophysics and Electronics Department" of the Faculty of Physics - Sofia University, by joining the work of the plasma study group supervised by Assoc. Prof. Stanimir Kolev. From 2013 to 2014 he worked at the Telerik Software Academy as a visualization and simulation software developer.

3. General characteristics of the candidate's scientific achievements

The PhD thesis is presented on 118 pages and includes 45figures, 4tables and bibliography of 84 references and consists introduction, 3 chapters and a conclusion. The doctoral work of Vladislav Ivanov is related to the experimental and theoretical study of sliding arc discharges operating at atmospheric pressure and low currents with the aim their application to CO2 dissociation. The work includes the computer modeling and experimental investigation of a magnetically stabilized arc discharge. Experimental studies also include sliding arc discharges without magnetic stabilization as well as magnetically accelerated discharges.

In the **Introduction,** a brief historical description of the development of the theory of DC discharges and the application of arc discharges for dissociation of CO_2 is given, and on this basis the goals and objectives of the dissertation are formulated.

Chapter 1 is a review. Glowing and arcing direct current discharges and the modeling of plasma processes at the macroscopic preasure are described. The main characteristics of the carbon dioxide molecule and the specifics of its dissociation are presented, as well as some implementations of, microwave and radio frequency plasma sources for CO_2 dissociation. Dissociation of CO_2 by sliding arc discharges, which is the subject of the present dissertation, is described in more detail.

Chapter 2 of the dissertation presents the developed numerical model of a magnetically stabilized low-current DC arc operating at atmospheric pressure in Ar gas flow. The equations of the numerical model are described and the obtained results are presented showing the influence of the distance between

the side walls on the stabilization of the arc and the effect of different gas velocities on the main parameters of the arc. A qualitative explanation is made for the predicted behavior of the arc.

Chapter 3 presents the experimental results of CO_2 dissociation research, measuring CO_2 conversion and energy efficiency. Three different gliding arc discharge configurations were tested - unstabilized gliding discharge, magnetically stabilized gliding discharge, and magnetically accelerated gliding discharge.

Finally, the **Conclusion** summarizes the obtained results, contributions, a list of publications and participation in scientific conferences.

The **abstract** is written according to the requirements and contains the main results and contributions of the PhD student.

4. Analysis of the applicant's scientific achievements.

The scientific contribution in the dissertation is the **development of a fluid model for a DC arc discharge with magnetic stabilization** operating in a laminar gas flow current of argon at atmospheric pressure. The developed model takes into account the influence of the magnetic field on ionization and the movement of charged particles. The obtained results describe the behavior of the arc when changing the gas flow, the magnetic force, the configuration of the electrodes and the discharge current. Various stable and unstable regimes in gas flow across the arc current are identified by the model. The ranges of gas velocities where magnetic stabilization can be achieved are found depending on the distance between the walls. This contribution belongs to the category - enrichment of existing knowledge by obtaining and proving new facts.

In parallel with the creation of the computer model, the **developed real experimental reactor for CO2 processing** can be considered as a scientific and applied contribution. It is based on a sliding arc configuration, realizing the concept of magnetic stabilization presented in the theoretical part. Experimental studies of several different configurations of low-current arc discharges, including those with magnetic stabilization, have been carried out and they have been compared in terms of gas conversation and their energy efficiency. The magnetically stabilized configuration shows good qualities, both for conversion and energy efficiency, but only at low values of the gas flow. The addition of quartz side glasses to the discharge device was also found to have a positive effect on conversion and energy efficiency. The performance of the device also depends on the type of electrode material. Aluminum electrodes show better conversion values than stainless steel electrodes, but stainless electrodes have higher energy efficiency values. The measured values for the conversion in some conditions reach up to 7-8%, and for the energy efficiency values over 30% are reached, and these results are comparable to the results of other similar studies. The contribution can be attributed to a category - creation of new classifications, methods, constructions, technologies.

5. Scientific publications of the candidate included in the dissertation work.

The results of the dissertation are presented in **3 publications**. Two of the publications are in high impact factor scientific journals (1 **publication in Plasma Sources Sci. Technol. 30 0850072 2021, IF-4.00 and 1 publication in J. CO2 Util. 67 102300 2021, IF 7.84), falling in quartile Q1**. The other is in an impact-ranked scientific publication (**J. Phys.: Conf. Ser. 2240 012029 2022)**. The high IF of the journals in which the results of the dissertation are presented are sufficient evidence of the quality of the results obtained. It should be noted that in all publications and conference reports, the Vladislav is first in the list of authors, which gives me reason to assume that he has a major contribution in obtaining and presenting the obtained results The doctoral student took part in **3 international conferences**. 47th and 48th "European Plasma Physics conference" held in 2021 and 2022 respectively, and in 2021 he won the award for the best poster in the field of low-temperature plasma. He also participated in the 2021, VEIT conference. These indicators cover and exceed the requirements of the Law on the Development of the Academic Staff in the Republic of Bulgaria, the regulations of the Sofia University and the requirements of the Faculty of Physics for obtaining the educational and scientific degree "PhD".

6. Critical notes and recommendations

My critical note is that the presented model was developed for a magnetically stabilized arc operating in an argon environment, and the experiments were performed in an arc operating in a CO_2 environment. This does not allow applying the results of the theory when performing the experiments and quantitatively comparing the experimental and theoretical results. Computer simulations, can only be used to qualitatively describe arc behavior under changing conditions. An example is the experimental confirmation of the effect of transverse instability in a magnetically stabilized arc, for a flow channel wider than its effective radius predicted by numerical model. I imagine that the development of a model of a magnetically stabilized arc operating in a CO2 environment will be the subject of future work on the subject.

My other critical note, which can also be taken as a recommendation, is the presentation of the developed mathematical model. In my opinion, the thesis would have benefited if the process of running the simulations was described more clearly and consistently. Such a description would be very useful as a guide for future graduate and doctoral students who will use the developed model and the Comsol Multiphysics software for simulations of this type of plasma.

These critical notes do not dispute the candidate's scientific and scientific-applied contributions.

6. **Personal impressions of the candidate**

I do not know the candidate personally and my impressions are only from the preliminary defense seminar. The doctoral students demonstrated their presentation skills and competently answered the questions asked. The in-depth knowledge of the scientific problems related to the topic of the dissertation give me reason to believe that he is a well-established specialist in the field of plasma physics and has made a major contribution to obtaining the presented results.

7. Conclusion

After becoming acquainted with the dissertation work and other materials presented and based on the analysis of their scientific contributions contained in them, I confirm that the scientific achievements meet the requirements of the Law on the Development of Academic Staff in the Republic of Bulgaria and the Regulations for its application and the relevant Regulations of the SU "St. Kliment Ohridski" and requirements of the Faculty of Physics for the acquisition of the educational and scientific degree "PhD". In particular, no plagiarism was found in the dissertation, abstract and scientific publications submitted under the procedure.

My assessment of the dissertation is positive.

II. GENERAL CONCLUSION

Based on the abovementioned, I **recommend** to the scientific jury to award the PhD degree to Vladislav Valentinov Ivanov

15.05.2023 Prepared evaluation report:

Assoc Prof. Dr. Valentin Mihailov