REVIEW

On the defence of the dissertation **"Evaluation of mixed installations with alternative energy sources"** for obtaining the scientific degree **"Doctor of Science"**
Professional field **4.2. Chemical Sciences**,
Specialty **"Processes and apparatus in chemical and biochemical technology"**

Author of the dissertation: **Aleksandar Georgiev Georgiev, PhD., Professor**
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Reviewer: **Iliya Krastev Iliev, Ph.D., Professor**
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1. **Brief biographical data and characteristics of the scientific interests and scientific activity of the candidate for DSc degree**

Prof. Dr. Eng. Aleksandar Georgiev was born on March 22th, 1958, in Dobrich town. In 1981 he graduated from the Technical University of Sofia, specialty "Heat-and nuclear energy" and obtained master degree, then he is a full-time PhD student at the Department of Heating and Refrigeration Equipment at the Technical University of Sofia (1984-1987). In 1988, he obtained the educational and scientific degree "PhD" in scientific specialty 02.06.07 "Energy conversion technologies and systems". In the period April 1987 - December 1988 he was a research associate at the Institute of Meat Industry in Sofia. He entered the Technical University Sofia, branch Plovdiv department of "Mechanics" in 1988 as a senior assistant professor (1988-1990y) and main assistant professor (04.1990 - 05.2000), in 2000 acquired the title of "*Associate professor*" in scientific specialty 02.06.07 "Energy conversion technologies and systems". In the period 11.2011. - 02.2013 is the head of the Department of Green Energy at the European Polytechnic University, Pernik. On 12.12.2012, after a competition at the same university, he was awarded the academic position of "*Professor*" in the professional field 5.4.Energy with a scientific specialty "Energy Conversion Technologies and Systems". In October 2021, at the Institute of Chemical Engineering of the Bulgarian Academy of Sciences, he was awarded the academic position of "Professor" in the professional field 4.2. Chemical sciences, specialty "Processes and apparatus in chemical and biochemical technology". Professor Georgiev speaks German, English, Spanish and Russian.
The research and scientific-applied activity of Prof. Dr. Eng. A. Georgiev, reflected in the publications, projects and other activities is focused primarily on the problems of research of renewable energy sources (solar, wind and geothermal energy) and transformation systems of energy. The main directions of scientific research are: research of geothermal thermal systems; measuring the parameters of solar radiation; study of heat energy storages based on materials with phase change; study of the joint work of heat pump installations with solar collectors; research of wind installations; research of thermal energy installations.

2. **Relevance of the problem developed in the dissertation.**

The relevance and importance of the topic of the dissertation is determined by the current global strategic goal for the use of natural energy sources and resources and expressed in the "Energy Roadmap for 2050" important strategy of the European Union to achieve at least 27,5 % share of renewable energy in total energy consumption by 2030, while achieving and maintaining a high degree of safety, security and reliability in the construction and operation of these sites.
The significance of the developed dissertation is determined by the set goals, namely to be researched and evaluated both on different types of mixed installations based on alternative energy sources and on their main components. The developed dissertation covers the full range of solar installations, starting from vacuum solar collectors and reaching the most modern photovoltaic installations. The scope of work even includes heat pumps and micro-cogenerators and photovoltaic modules and a Stirling engine.

This whole mix of different mixed systems with alternative energy sources positions the developed dissertation work as undoubtedly relevant and significant.

3. Review of the dissertation and analysis of the results

The dissertation is presented in 8 chapters and contains 345 pages, of which 23 pages with literary sources and publications of the author.
The dissertation is written in accordance with the criteria for design of such works.
The literature review is made in the first chapter of the dissertation and contains an analysis of 229 literature sources. Of the presented sources, only 6 (2.6%) are in Cyrillic, and the remaining 223 (97.4%) are in Latin. In a volume of 100 pages, the author reviews the existing mixed systems that contain elements such as phase change materials (PCM), heat pump, solar panels, water seasonal storage and underground ~~heat~~ thermal energy storage, which can be combined with electrical appliances (e.g. photovoltaic /thermal, PV/T collectors) and a second heat pump to improve the energy efficiency of the system. The author makes a critical analysis of mixed systems and the chapter concludes with clearly formulated conclusions for the individual components, as well as for different types of mixed systems with alternative energy sources. The analysis shows that the author is very familiar with the problems in the field of research, which he develops in his dissertation.
The second chapter of the dissertation is dedicated to the goals and objectives of the dissertation. In my opinion, based on many years of research and experiments over 30 years, the author has correctly formulated the main goal, namely "Research and evaluation of different types of mixed installations based on alternative energy sources and their main components." To achieve the main goal, the author has formulated nine main tasks of the dissertation, based on the literature review.
To solve the tasks the author uses a rich toolkit of methods and approaches, which include: solving problems through differential equations, statistical models through the method of experimental planning, software products (AKIM block) based on differential equations, many experimental stands to verify the created mathematical models. For example, the linear source method was used to estimate thermal performance, and the "Two Variable Parameter fitting" method was used to evaluate the experiment in Chile, as well as the "Geothermal Properties Measurement" method. In some of his research, the author used simulation methods with software products (TRNSYS). In the numerical modeling of a storage with phase-change materials, the finite element method based on Comsol multiphysics was applied, and in the numerical modeling of a latent thermal storage using the enthalpy porosity technique used in ANSYS Fluent. My assessment of the methods used is that the author has chosen the right approach to achieve the goals and objectives.
Chapter 3 is devoted to the components of mixed installations with alternative energy sources, as the author presents in detail the results of his research on: vacuum solar collector with flat absorber and heat pipe, heat storages. In the same chapter, a theoretical vacuum solar storage with a heat pipe and a flat absorber is studied. The methodology created by the author allows the calculation of the outlet temperature, the efficiency of the collector and the useful heat flow of the collector at set values of the input parameters.
The author describes the conducted experimental study of a vacuum collector with a heat pipe. An interesting point is that no active experiment is used, but nevertheless the experimental results were used to create statistical models that describe the efficiency of the collector and the useful heat flux density. Based on these results, the author of the dissertation created four statistical models describing a vacuum solar collector with a heat pipe and a flat absorber, studied experimentally.
In the same chapter, the author dwells on the created program block AKIM, which serves to calculate the temperature of the fluid in the individual layers of the mixing water storage with stratification. At the heart of the unit is a model of simple differential equations, and as a result of the program the fluid temperatures in the various layers of the storage at any time, as well as the inlet temperatures of the storage. The use of the AKIM program block, based on the verified mathematical model, allows to simulate the processes in liquid mixed storages of different sizes in the absence of experimental data.
In the same chapter, the author describes in detail the stationary installation and mobile installation in Chile

for determining the thermal characteristics of seasonal heat energy storages. A rich experimental result was presented and appropriate conclusions were made. Prof. Aleksandar Georgiev and his team from the Technical University - Sofia, Plovdiv branch designed and developed a latent thermal storage, whose design characteristics are shown in detail in the dissertation.
In ch. 4 the author has analyzed mixed installations with alternative energy sources and focused on the following cases: solar collectors with water storages, refrigeration system with built-in solar collectors and thermal storage, borehole thermal energy storage with solar collectors, photovoltaic-thermal solar installations, a ground- source heat pump system with solar collectors, a ground-source heat pump system using phase-change materials, a mixed micro-cogeneration system with photovoltaic panels and a Stirling engine for local heating. In Ch. 4 the author has presented several schemes of mixed systems, according to which the experiments have been carried out, the research methods are described in detail, as well as the tools with which the calculations have been made.
In Ch. 5 the author has presented the general conclusions from the dissertation.
Ch. 6 shows the main contributions of the author in the dissertation as five of them are presented as scientific, seven as scientific-applied and five as applied contributions.
In Ch. 7 are presented 229 literature sources analyzed in the dissertation.
In Ch. 8 the author has presented a list of 36 publications related to the topic of the dissertation.

4. Key scientific, applied scientific and applied contributions

I accept the dissertation's reference for the main contributions in the presented works, which are of scientific, scientific-applied and applied nature. However, my assessment of the contributions differs from that of Prof. A. Georgiev. Below I have arranged the contributions according to my assessment and recognition.

4.1. Scientific contributions

- A mathematical model for a vacuum solar collector with a heat pipe has been created. Subsequently, the computer program was created, with which simulations were performed in different modes.
- A mathematical model of a mixed water storage with stratification of the working fluid has been created. With the selected mathematical model, a computer program was created, which facilitates its verification on the basis of the conducted experiments.
- A mathematical model of an industrial water storage with two separate coils was created, which was studied experimentally. The verification of the model is done with the help of the created computer program.

4.2. Scientific and applied contributions

- A mixed installation containing vacuum solar collectors with a heat pipe and a water thermal storage with a four turn pipe windings has been tested experimentally. The created general mathematical model, describing the joint work of the two elements, has been programmed and verified on the basis of conducted experiments.
- The Chilean installation constructed for implementation of TRT has been redesigned to conduct natural experiments on solar energy charging and discharging of underground storages. Long-term experiments were performed under the two mentioned regimes. A comparison was made between the calculated values with the commercial product TRNSYS and the measured values during the charging and discharging process, and the results showed a good match.
- A solar thermal system combined with photovoltaic panels has been designed and manufactured. A new set of virtual tools has been developed and proven, providing on-line or off-line calculation of the error when performing experiments. The experiments performed characterized the energy efficiency of the cheap construction of PV/T panel and helped to verify the proper operation of the developed virtual tools.
- The ground source heat pump (GSHP) system was experimentally tested in the following five operating modes of the system: charging of water tanks (CWT), Charging of borehole thermal energy storage (CBTES), direct solar heating (DSH), heating with GSHP (GSHPH) and heating by solar assisted heat

pump (SAHPH). A detailed energy analysis was performed for the mentioned regimes, taking into account all energy sources and calculating the respective losses and system coefficients of energy efficiency for each regime.

- During the construction of the BHE of the GSHP system, temperature sensors were installed every 10 m in depth to monitor the change of the temperature field. Diagrams were obtained confirming the heating (when charging - CBTES mode) and cooling (when heating – GSHPH mode) of the soil layer over time. The temperature field was also measured after the end of the two modes in the so-called natural relaxation.
- A model was created, built in the simulation environment of "TRNSYS studio", which allows to study different modes of operation of the GSHP system and to analyze the impact of system parameters on the performance characteristics. Attention was paid to the following elements of the system: solar collector, water storage, heat pump, ventilation and house. With the model thus created, a simulation of a house heated by this installation was made.
- Numerical modeling is presented, evaluating a new type of construction for the application of PCM in underground horizontal heat exchangers (GHE), integrated with ground source heat pumps (GSHP). PCM is mixed directly with the soil around the GHE - this is a new approach, not yet studied for horizontal ground heat exchangers. The results show that the merging of PCM with GHE effectively meets the heat loads of GSHP and reduces the sharp fluctuations in heating or cooling of the ground heat exchanger. The conducted simulations are for cases with and without PCM, solved for a simulation period of two years.
- Three different installations have been built (one stationary in Chile, one mobile with an electric heater in Bulgaria and one with a heat pump in Spain) to conduct the new effective Thermal response test (TRT). Borehole heat exchangers (BHE) have been built in Valparaiso, Chile and Plovdiv, Bulgaria, where TRTs have been carried out to determine the thermal properties of the soil. The obtained results are processed by various mathematical methods. Simulations were made with the commercial software TRNSYS, comparing the calculated values with the experimental data. It is planned to create a cadaster in Bulgaria to be used in future geothermal projects.
- Latent storage using phase change materials (PCM) is designed and built in TU Sofia, Plovdiv branch, which is equipped with a specialized autonomous measuring system developed by the research team in Plovdiv. Several types of paraffin were studied, whose thermal properties were studied in detail. Mathematical modeling and simulation of storage processes was performed in two different ways - by the finite element method based on Comsol multiphysics and by the enthalpy porosity technique used in ANSYS Fluent.

4.3. Applied contributions

- It is proposed to increase the efficiency of a solar installation, which will work in the winter, by implementing a heat pump unit. A methodology for Evaluation of mixed installations with alternative energy sources calculating the parameters of the system has been created, with which sample calculations have subsequently been performed.
- An existing photovoltaic (PV) panel has been converted into a photovoltaic-thermal (PV/T) panel. Comparative experiments of the mixed installation (consisting of two different panels) were performed, proving the advantage of the combined PV/T element, producing both more electricity and additional heat energy during cooling.
- A concentrating photovoltaic-thermal (CPV/T) system has been created, which is connected to the heat pump evaporator (HP) - the PV modules are cooled by the refrigerant passing through the HP evaporator. The installation is designed for heating of buildings. A theoretical and experimental study was conducted, showing the efficient production of electricity and heat with the described system.
- A new construction of a mixed ground source heat pump (PSP) system has been created, consisting of two borehole heat exchangers, three flat-plate solar collectors (SC), a reversible heat pump (HP) and a fan coil. A methodology for determining the thermal characteristics in the following five modes of operation has been developed: CWT, CBTES, DSH, GSHPH and SAHPH.

- The simultaneous and experimental operation of a Stirling engine and photovoltaic (PV) panels for the production of electricity from a central heating system on solid fuel, aimed at both heating buildings and satisfying the boiler's electricity consumption or supplying the home with electricity, has been studied theoretically and experimentally. The heating capacity of a multi-family house in Mugla, Turkey was provided with a micro-cogeneration system, and the experiment was carried out within three months.

5. General description and assessment of the submitted materials

The author of the dissertation Prof. Dr. Eng. Georgiev presented all the necessary documents according to the Regulations on the terms and conditions for obtaining scientific degrees and holding academic positions at BAS and Regulations for the implementation of the Law on the Development of Academic Staff in the Republic Bulgaria.

The coverage of the minimum national requirements for scientific degree "Doctor of Science" candidates by groups of indicators is as follows:

Indicator А: Diploma for ASD "Doctor" №17880/08.06.1988, (50 points)

Indicators Г: Scientific publications in editions that are referenced and indexed in world-famous databases of scientific information (Web of Science and Scopus), outside the habilitation thesis (min. 100 points) Fifteen publications are presented as follows: (Г1, Г2, Г3, Г4, Г5, Г6, Г7, Г8, Г9, Г10, Г11, Г12, Г13, Г14, and Г15) (266 points);

Indicators Д: Citations or reviews in scientific journals referenced and indexed in world-famous databases with scientific information or in monographs and co-authored volumes (*Web of Science и and Scopus*). 129 citations of 11 papers are presented (Д11, Д12, Д14, Д15, Д19, Д20, Д26, Д27, Д28, Д33, Д34) (258 points). The evidentiary part contains bibliographic data for the citing publication, a reference to the respective database, and excerpts from the citing publication with the respective reference.

When comparing the submitted materials with the minimum requirements (Table 1) for holding the scientific degree "Doctor of Science" in the professional fields according to PPZRASRB and PURZAD of BAS, it can be concluded that the minimum requirements for obtaining the scientific degree "Doctor of Science" have been fulfilled and even significantly exceeded.

Table 1. Indicator group Minimum number of points Number of points of the candidate

Group of Indicators	Minimum points	Points of the candidate
А	50	50
Б	100	100
Г	100	266
Д	100	258
Total	**350**	**674**

The candidate has presented evidence that he meets the additional criteria of Institute of Chemical Engineering at BAS, which is well illustrated in Table 2.

Table 2. Additional criteria of the Institute of Chemical Engineering (ICE)

Additional indicators	T.а (publications)	T.б (citations)
Requirements covered by the applicant	**36 (15+11)**	**244**
Minimum points for „Doctor of Science“	25 (15)	50

6. Reflection of the scientific publications of the candidate in the Bulgarian and foreign literature

Data on the citations of the scientific works of the candidate and representativeness of the publications

According to the attached reference of the works presented in the competition are cited in publications referenced in WoS (a total of **129 citations**); A significant number of scientific publications have an impressive number of citations in prestigious international publications, such as:

Publication (4) is cited **14 times**; (5) - **102 times**; (7) - **23 times**; (8) - **16 times**; (12) - **45 times**; (20) - **13 times.**

The author of the dissertation work, prof. Georgiev has an **h index of 12** (with a total number of citations in Scopus 645, only for 2021-78 citations).

(See https://www.scopus.com/authid/detail.uri?authorId=7005013460), which shows a very high impact of his scientific publications, especially in foreign literature.

7. Critical remarks and recommendations

The dissertation work on the volume, relevance and presentation of the results in the world scientific literature fully meets the criteria for such work. It is noteworthy that the main scientific results have been published in the world's most renowned publications and it would be difficult to find serious omissions due to the fact that these publications go through several levels of review by world-renowned experts in the field. However, my remarks refer to the construction of the content of the dissertation. The author has set out the goals and objectives of the dissertation in a separate chapter (Chapter 2). In my opinion, their place is in Chapter 1, because it is logical to present the goals and tasks as a consequence of the critical literature review. Similarly, the last chapters (6, 7 and 8) can be presented as appendices to the dissertation, and not as separate chapters.

8. Personal impressions and opinion of the reviewer

I know prof. Dr. Eng. A. Georgiev from my participation in the scientific conferences organized by him AESMT (2018-2021). I have a look at his entire scientific activity as a reviewer in the competition for the academic position of "Professor". Prof. Dr. Eng. Georgiev is fluent in German, English, Spanish and Russian, which allows him to monitor scientific exchange, work on important international projects, participate in international scientific events and create a modern training base. He has high competence, which is why he maintains solid international contacts. He knows how to work in a team and pass on his experience. He is highly responsible in his professional activity both as a lecturer and as a researcher.

CONCLUSION

The presented materials meet the requirements of ZRASRB, the Regulations for its application, and the internal Regulations for the terms and conditions for holding scientific degrees at the Institute of Chemical Engineering, BAS. Based on the acquaintance with the presented scientific publications, their significance, the contributions contained in them, I find it reasonable to propose Prof. Dr. Eng. Aleksandar Georgiev to take the scientific degree "Doctor of Sciences" in the professional field 5.2. Chemical Sciences, specialty "Processes and apparatus in chemical and biochemical technology".

Date: 15.02.2022 **MEMBER OF THE**

(Prof. Iliya Ili