O P I N I O N

on the defence of the dissertation work " Evaluation of mixed installations with alternative energy sources"

for the award of scientific degree "Doctor of Science" , professional field: 4.2. "Chemical Sciences", specialty: "Processes and apparatus in the chemical and biochemical technology"

with candidate Prof. Dr. Aleksandar Georgiev Georgiev

Member of the Scientific Jury: Prof. Dr. Sonia Stoyanova Tabakova, Institute of Mechanics, BAS

1. **Short biography and characteristics of the candidate scientific interests and activity of the candidate**

Prof. Aleksandar Georgiev obtained his PhD thesis degree in 1988 with specialty "Energy-conversion technologies and systems" at TU-Sofia. From the end of 1988 he is teaching different subjects related to Thermodynamics and Heat transfer at TU-Sofia, branch Plovdiv. From 2021 he is full professor at the Institute of Chemical Engineering, BAS. Meanwhile, prof. Georgiev has been invited-researcher in the University of Siegen, Germany for 1 year and in the Technical University "Federico Santa Maria", Valpariso, Chile for 2 years and in other universities for shorter periods. In the period 2011- 2013, prof. Georgiev was professor on "Energy-conversion technologies and systems" as head of the department "Green Energy" at the European Polytechnic University (EPU), Pernik.

As a whole, the scientific interests of prof. Georgiev are in the field of: renewable energy sources, solar heating and cooling systems, sun tracking systems and shallow geothermal energy.

2. **Importance of the problem under research in the dissertation work**

The discussed problems in the dissertation are from the area of the new energy sources, especially the renewable or more generally the alternative energy sources. Although that the submitted dissertation work covers a period of more than 30 years of publications, the posed problems in it have not lost their importance. A great part of them is connected with the subjects of the scientific projects. Prof. Georgiev has been a coordinator of 8 scientific projects: 7 - national and 1 international project with Kazakhstan, and a participant in 10 projects: 2 inner projects of the Technical University "Federico Santa Maria", Valpariso, Chile; 1 project Brazil - Chile; 6 projects of the European program COST; 1 project of the program Bulgaria - India financed by the NSF.

3. **Review of the dissertation work and results analysis.**

The dissertation work contains 345 pages, 201 figures and 29 tables. The bibliography covers 229 scientific sources. The text is structured in a standard manner: introduction, bibliographic review, goals and objectives of the dissertation, the main research part in two chapters, general conclusions, main contributions, bibliography and list of author's publications in the full text of the dissertation.

The bibliographic review is extensive, spread on more than 100 pages, and concerns the main aspects of the thermal installations: single and mixed with more than one installation. The main components, known from the bibliography of solar collectors, of thermal accumulators and of mixed thermal installations with alternative energy sources, are discussed in details. A special attention is paid on the methods of experimental data processing, as well as on the processes modeling, their mathematical description and numerical realization for given cases.

On the basis of the conclusions derived from the bibliographic review, the goals of the dissertation are formulated as: "Research and evaluation of different types of mixed installations based on alternative energy sources, as well as their main components". More precisely, the connected with them objectives are 9, which include construction of installations, experimental work with them and mathematical models for analysis and comparison with the experimental results.

In the next 3-rd chapter, all components of the mixed thermal installations with alternative energy sources are investigated: vacuum solar collector with flat-plate absorber and heat pipe, thermal storages: mixed water storage with stratification, water storage with four turn pipe windings, thermal response test of seasonal underground thermal energy storages; latent thermal storage with phase change materials.

The proper application of the mathematical models, which are different for the various components, makes a good impression. Generally, statistical models are used for experimental results processing, but special models are constructed for some of the components. I shall stop my attention on the seasonal underground thermal energy storages and their thermal response tests. Three installations, located correspondingly in Valparaiso, Chile (stationary installation), TU-Sofia, branch Plovdiv and Valencia, Spain (mobile installations), have been constructed. Three different mathematical models have been used to define the thermal characteristics of the ground on the basis of the obtained experimental results: line source model that gives an approximate formula for the evaluation of thermal conductivity coefficient of the ground, from which the borehole thermal resistance is found; two-variable parameter fitting method to evaluate simultaneously the thermal conductivity and thermal resistance of the borehole; a full model of the fluid flow in the borehole (straight tube) and of the heat transfer based on the cross-section averaged variables (velocities, pressure and temperature) is realized by the specialized software TRNSYS. The first two methods, although approximate, give quite rapid results to estimate the thermal characteristics. The third method is more complicated, depending on the software, but it gives many additional possibilities to change the number of the heat exchangers, their geometry and others. The latent thermal storage with phase change materials (paraffin) is another interesting accumulator from the point of view of modelling. Two numerical models for analysis of the heat transfer and fluid dynamics during the stages of charging and discharging of the latent thermal storage are proposed. The first model considers a mesh of radially situated cylinders with the phase change material (from solid to fluid state at heating of the working fluid inside the container of the accumulator and vice-versa from fluid to solid state – at cooling). The full system of momentum and heat transfer equations of the working fluid are solved in the region of the accumulator, while inside the containers, the paraffin is accepted as motionless with a phase change described by the heat transfer equation with a jump discontinuity of the heat capacity function including the latent heat and generalized heat conduction coefficient and density at coupled boundary conditions on the walls of the cylinders with the fluid in the container. The numerical realization is performed by the use of the module Multiphysics of the software COMSOL. The results show, that two inlet and two outlet pipes connected with the container are enough for the full charge or discharge of such latent storage in technologically acceptable period of time. The second model is concentrated only to a single cylinder of the latent thermal storage, in which the phase change material (paraffin) is moving, i.e., the full system of Navier-Stokes equations and the heat transfer equation in enthalpy formulation are solved, which makes possible the evolution of the phase-change boundary in time to be followed. Then, it can be exactly predicted when the latent thermal storage will be totally discharged or charged, which is essential for the design of this type of accumulators. The numerical realization is performed by the module Fluent of the software ANSYS.

In chapter 4, on the basis of the studied components, prof. Georgiev examined different types of mixed installations with alternative energy sources: solar collectors with water storage, refrigeration installation with built-in solar collectors and thermal storage, borehole thermal energy storage with solar collectors, photovoltaic-thermal installations, ground source heat pump system with solar

collectors, ground source heat pump installation using phase change materials, mixed micro-cogeneration system with photovoltaic panels and Stirling engine for local heating.

For the mixed installation the same methods, as for the separate components, are also applied. Here, again, I shall stop my attention in particular on the borehole thermal energy storage with solar collectors. After its reconstruction some valves are connected to the storage in order to work in two different regimes: thermal response test, when it's charging is only electrical and solar regime - when the borehole thermal energy storage is charged by solar energy. During the second regime two phases could be carried out: charging (when the solar energy is supplied to the ground) and discharging (when some heat from the ground is extracted by an installed heat exchanger). On the basis of the performed thermal response tests, simulations by means of TRNSYS DST module (TYPE 141) have been performed for the borehole thermal energy storage with solar collectors in order to determine the heat losses. The numerical results agree in magnitude with the experimental ones.

4. Main scientific and applied- scientific research contributions.

The author summarized his results into 17 contributions of the dissertation: 5 scientific, 7 scientific-applied and 5 applied contributions. I accept this distribution of the contributions, and highly appreciate the following scientific contributions: the construction of three different installations to conduct the new effective thermal response test of the ground and the modeling connected with them; the construction of a latent thermal storage with phase change materials and the modeling connected with it.

The personal contribution of the candidate is evident. He organized some teams in different institutes, where he has worked, in order to develop, construct, experiment and model various mixed installations with alternative heat energy sources. I find that the major part of the obtained results contain original constructions and methodologies, which lead to new knowledge connected with the considered problems.

5. Description and assessment of the submitted scientific publications

The candidate is author of 116 scientific publications, which include 1 monograph, 30 papers with impact factor, 3 papers cited in Scopus, etc. The independent citations are more than 800 up to now; major part of them is in journals with impact factor. His "h-factor" is 11 according to Scopus. The dissertation work is based on 36 publications: 15 - in journals with impact factor, 11 - in specialized international journals or in full text in collections of international scientific forums with editor and publisher, 15 of which are published during the last 5 years. Prof. Gergiev is the only author of 10 publications and is in the first place in 7 of the publications. My opinion is that the contributions of all co-authors in all collective works are equal in rights, since there are no distribution protocols. The journals, where the papers are published, have high impact factor: 6 papers are in Q1 journals, 1 paper - in Q2 and 8 papers – in Q4.

These works correspond and surpass the minimal requirements given in the Law on Development of the Academic Staff of the Republic of Bulgaria and the additional criteria of the Institute of Chemical Engineering, BAS for the "Doctor of Science" degree.

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

Prof. Aleksandar Georgiev is well known by the scientific society in Bulgaria and abroad with his scientific research, with his management and teaching activity. An undoubted testimonial of his results significance is the progressive increase of their citations. 11 of the publications presented for the completion are cited 129 times in international journals with impact factor or impact rank, while one single paper has 62 citations.

7. **Critical notes and recommendations on the scientific works of the candidate**

I have some critical remarks concerning the text editing of the dissertation: some typos, lack of parameters descriptions in some formulas, lack of some citation sources, from where the corresponding formulas are taken, etc. The connection between the corresponding author's papers is not given in the text, which makes the reading of the dissertation difficult in places. The candidate is familiar with these remarks.

The present dissertation work is the crown of the scientific research of prof. Georgiev and I highly recommend him to translate it in English and form it as a book to be submitted to some prestigious international publishing house.

8. **Personal opinion for the candidate**

I know personally prof. Georgiev for more than 30 years, since joining the department "Mechanics" at TU-Sofia, branch Plovdiv as assistant professor. His fellowships at the University of Siegen, Germany and at the Technical University "Federico Santa Maria", Valparaiso, Chile had a decisive role for his scientific progress as a researcher. The accumulated experience there has given him afterwards the opportunity to enrich his scientific contacts by participation in different European and other international projects. I have participated with him in some projects and admire his teamwork. He is definitely a generator of ideas, extremely hard-working and persistent in achieving his goals.

9. **Conclusion**

Prof. Georgiev has fulfilled several times the minimal requirements for the scientific degree "Doctor of Science" in the Institute of Chemical Engineering, BAS. Following the scientific research of the candidate in total and having in mind the requirements for the scientific degree "Doctor of Science" in accordance with the Law on Development of the Academic Staff of the Republic of Bulgaria and the Rules for its Implementation, I give a **positive assessment** of his work. I find reasonable **to propose to the esteemed scientific jury to vote in favour of the candidature of prof. Aleksandar Georgiev for the scientific degree "Doctor of Science" in professional field 4.2. "Chemical sciences" with scientific specialty "Processes and apparatus in the chemical and biochemical technology" for the needs of the Institute of Chemical Engineering, BAS.**

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