Dr hab. inż. Rafał KOBYŁECKI, prof. PCz
Politechnika Częstochowska
Wydział Infrastruktury i Środowiska
Katedra Zaawansowanych Technologii Energetycznych
ul. Dąbrowskiego 73, 42–201 Częstochowa

Częstochowa, 2026.03.27

The review of the Doctoral Dissertation of Mr. Behrouz Adibimanesh, M.Sc. Eng.

FORMALITIES

The current review was written based on the document of Jan. 21, 2026 (paper No. RN-521.5.2025) signed by Grzegorz Żywica, Ph.D., Sc.D., IMP PAN profesor and the Deputy Head for Scientific Affairs at the Institute of Fluid-Flow Machinery, Polish Academy of Sciences (IMP PAN). The document was followed up by the formal contract agreement No. 23.01/D/4 issued by the IMP PAN Institute on Jan. 23rd, 2026 and signed up with the author of the current review.

RELEVANCE OF THE TOPIC AND SCOPE OF THE DISSERTATION ASSESSED

The topic of the dissertation written by Mr. Behrouz Adibimanesh, M.Sc. Eng. is entitled *Mathematical and data-driven modeling of biomass conversion for energy optimization*. The Thesis consists of 127 pages including 42 figures, 13 tables and the summaries in Polish and in English. The list of bibliographical positions contains 190 publications in total.

The Thesis is composed in order to present and demonstrate a holistic and sophisticated information for both scientists and engineers and become a valuable tool for optimization of various energy conversion plants/systems particularly those dealing with biomass. In order to provide a holistic approach the following issues are addressed in the Thesis: 1/ Dynamics of biomass conversion in a fixed bed reactor, 2/ Application of machine learning for controlling the process of sewage sludge incineration, and 3/ The use of a 'digital twin' model for the optimization of energy conversion based on the data from an example commercial plant.

Accordingly, in order to provide new approach for the modeling of biomass conversion within a fixed bed downdraft gasifier novel numerical methods were developed including an in-house Dynamic Coupled Eulerian-Lagrangian (DCEL) method to determine particle shrinkage and its dynamics, and the results were compared against the advanced eXtended Discrete Element Method (XDEM) to evaluate the trade-off between computational cost and predictive accuracy. Furthermore system-level analysis and optimization activities were performed by the Author and machine learning techniques involving a data-driven model of a commercial sewage sludge incineration facility to predict sludge furnace temperature and heat transfer rates and identify the desired operating conditions for enhanced energy efficiency. Within the framework of the Thesis a real-time digital twin approach was implemented to create a virtual replica of the incineration system for energy optimization purposes.

Regarding the substantive issues addressed and discussed in the dissertation it can be stated that the research topic proposed and studied by the Author is with no doubt relevant and the problems are being investigated also globally by other researchers. Thus the Author's approach and proposed solutions should undoubtedly be assessed positively by the reviewer.

NOVELTY AND PRACTICAL ASPECTS

In relation to Author's concepts presented in the reviewed Thesis and the presentation and discussion of Mr. Adibimanesh' research results, the most important elements of novelty and originality included in the reviewed dissertation are in my opinion:

- The development and implementation of a two-dimensional model (dynamic coupled Eulerian–Lagrangian, DCEL) to study the transient processes associated with thermochemical conversion of biomass in downdraft gasifier and the comparison of the results with those of the 3D XDEM simulation. It was found out that the DCEL model predicts higher heat transfer rates through the porous zone than the XDEM – mainly due to the differences in modeling radiative heat transfer processes. Both models take into consideration the increase of feedstock porosity near reactor's walls porosity and thus the propagation of a nonuniform thermal front.
- The use of over 70 data records from a wastewater treatment plant (WWTP) as training sets for machine learning model of the sewage sludge incineration system and carrying out the corresponding parametric studies and sensitivity analysis. It was found out that the steam flowrate significantly affects the heat transfer rate and thus the fuel particle residence time in the drier. With the use of a machine learning technique and the plant

data it was shown that the proposed chained model provides the optimum solution and the best accuracy.

- Multi-factor scenario analysis of the operation of a sewage sludge incineration system in order to investigate the energy consumption at the plant with an attempt to reduce the operational costs and find energy savings solutions for the existing real plant.

STRUCTURE OF THE THESIS

The Ph.D. Thesis of Mr. Adibimanesh is divided into five (5) main chapters; the order and structure of which are generally logical and do not raise any major concerns or comments. Each chapter contains a brief conclusion section.

The first chapter of the dissertation is devoted to the introduction to the subject. It includes Author's comments on the background and motivation to carry out the works, as well as contains some basic information from the literature survey on the thermal conversion of solid biomass, some info on computational methods in process and system analysis, and the main issues studied i.e. numerical modeling of biomass gasification and machine learning methods. The summary of this chapter includes Thesis objectives.

Chapter No. 2 is focused on the fixed bed gasification of biomass and the dynamics of biomass conversion in such conditions. Some data on the fundamentals of biomass gasification, biomass characteristics, gasifier types are also given. Dynamic Coupled Eulerian-Lagrangian Method (DCEL) was discussed and the methodology and problem solution were proposed including the results of DCEL simulation (batch and continuous modes) and the comparison of the results with those obtained from a DCEL method and XDEM simulations. The obtained data were analyzed and discussed at the end of this chapter.

The following chapter (No. 3) deals with machine learning issues and its application for the monitoring of the sewage sludge incineration. The problems addressed were simulated numerically and validated. Parametric studies and sensitivity analysis were also carried out and the results were presented and discussed in this chapter.

The next chapter (No. 4) is devoted to the closed-loop energy optimization with Author's intention to use a 'real time digital twin model' for the studies. The methodology of Author's investigation is briefly described and the data from a waste water treatment plant are used for comparison of the results. Some scenario simulation results are also presented.

The summary of Author's results obtained and discussed in the Thesis is included in the last chapter (No. 5). This Chapter is then followed by the list of bibliographic references and the list of figures and tables.

TECHNIQUE LEVEL AND EVALUATION OF THE DISSERTATION

In my opinion, the technical level of the dissertation – including the adopted concept, structure, description, analysis, and evaluation of the substantive content and results presented by the author – is satisfactory. The work is written in a well-formed style, and the presented content and arguments are mostly logical and coherent. The layout of the dissertation raises no major concerns, and the language and formulations used are, for most of the manuscript, clear and understandable.

The research results presented in the dissertation are undoubtedly original and, in my opinion, constitute a real, practical contribution to the development of current knowledge – primarily in the field of biomass processing and thermolysis (thermal treatment).

CRITICAL REMARKS AND COMMENTS

After reading over the manuscript I must say that there aren't many substantive errors or mistakes in the manuscript. The reviewer's overall assessment of the work is positive. My main comments are as follows:

1. The list of symbols lacks units in some places, furthermore SI units are not consecutively used throughout the manuscript. In some places of the Thesis the citation sources are also missing (eg. page 27).
2. Instead of using the term 'pyrolysis', as you did in p. 29, I'd suggest to use the word 'thermolysis' that is more accurate to describe thermal treatment of fuels. Also instead of the term 'speed' (of pyrolysis) it is better to use the word 'kinetics'.
3. Chapter 2.1.2: it would be more clear for readers if the Author would summarize the main features (advantages/disadvantages, technical data, etc.) of the gasifiiers in a form of a table.
4. Does the 'drying' start always at temperatures >100^{0}C (in p. 31 you mention that)?
5. Do the results shown in Fig. 2.6 refer to the INKA gasifier?
6. Fig. 2.8: what was the initial mass of the biomass samples?

7. Fig. 2.9: why there are some differences at the very upper surface of the results shown? No explanation is given.
8. Why no particle size effect was observed for the results shown in Fig. 2.11? At least the time needed to start the devolatilization should differ.
9. What were the criterion for choosing the particles shown in Fig. 2.14?
10. No info on particle size is shown in Fig. 2.15.
11. Why there are differences between the results for XDEM simulations and DCEL and experimental data as shown in Fig. 2.16? Please comment.
12. Table 3.1: what was the 'state' of the fuel – 'dry', 'as received', or?
13. Table 3.3: the air flowrate should be in [kg/s].
14. What was meant as 'system values' for the data presented in Table 3.4?
15. Eq. (4.2) what do you exactly mean by AFR? Also the term 'R' (eq. 4.22) was not explained in the list of symbols.
16. Why there are such differences (peaks) in the data shown in Fig. 4.3? Please comment.
17. Fig. 4.5b: Do the data mean that at oxygen concentration roughly equal to 0.1 the corresponding λ=2.2?
18. Why the biogas was combusted intermittently as you show eg. in Fig. 4.8? And what was meant by 'unacceptable operation' as you stated in p. 99? Also in p. 104 the Author mentioned 'historical sensor data'. Where they shown anywhere? I'd also suggest to omit ch. 5.2 since it shouldn't be a part of a Ph.D. Thesis.

CONCLUSION

In summary of the current review I believe that the doctoral dissertation of Mr. Behrouz Adibimanesh, M.Sc. Eng., entitled *Mathematical and data-driven modeling of biomass conversion for energy optimization* and submitted for the evaluation as Author's Ph.D. Dissertation, contains original elements (both scientific and practical) and provides new know-how for the development of knowledge in the fields of both mechanical engineering and energy engineering. The Ph.D. Candidate has demonstrated general theoretical knowledge in the discipline of mechanical and energy engineering, as well as the ability to independently conduct scientific investigations. In my opinion, the composition and substantive content of the dissertation meet the requirements for doctoral dissertations set forth in the relevant regulations in Poland, and I therefore request its acceptance and admission to public defense.