

REVIEW

of doctoral dissertation by M.Sc. Eng. Anna Jasińska

“Valorization of poultry manure through anaerobic co-digestion with locally available organic waste – an integrated approach for bioenergy production and nutrient recovery in a circular economy framework”

Supervisors: dr hab. inż. Anna Grosser, prof. PCz
prof. dr ir. Erik Meers

The doctoral dissertation by M.Sc. Eng. Anna Jasińska submitted for review was prepared under the supervision of dr hab. inż. Anna Grosser, prof. PCz, and prof. dr ir. Erik Meers within the joint PhD program between the Częstochowa University of Technology and Ghent University. The objective of the thesis was to develop an integrated approach to managing poultry manure through anaerobic co-digestion with sewage sludge and other locally available organic waste. The study focused on the following detailed objectives: i) increasing the efficiency and stability of the anaerobic digestion process, ii) enhancing energy recovery in the form of biogas, iii) assessing the quality and management potential of digestate, iv) embedding the proposed solution within the framework of the circular economy and EU climate policy. Poultry manure is classified as a substrate with high methane potential; therefore, its use as an energy source is justified and offers a range of benefits, both environmental and economic. However, due to an unfavorable C/N ratio relative to the values recommended for the anaerobic digestion process, the use of this waste as feedstock for fermentation chambers still requires further technological research aimed at developing optimal process conditions. As previously mentioned, this task was undertaken by the doctoral candidate. Based on a review of the literature, which indicated that poultry manure is most often co-digested with only one co-substrate, she conducted research using a multi-component mixture. Additionally, she investigated pre-treatment processes of the substrates, which may contribute to improving the stability of the anaerobic

digestion process. Particularly noteworthy is the comprehensive approach to the research problem. The doctoral candidate did not limit her work to analyzing the potential for increasing biogas production, but also carried out an in-depth study of the characteristics of the digestate and its potential applications.

The research topic undertaken by the doctoral candidate addresses current challenges related to the energy transition, climate change mitigation, and the shift toward a circular economy. Since one of the co-substrates studied was sewage sludge, the conducted research is also significant in the context of the need for wastewater treatment plants to achieve energy self-sufficiency. The results presented in the thesis should be regarded as a valuable body of data for both scientists and practitioners. Therefore, the choice of the thesis topic is justified and meets the expectations of the scientific community.

The doctoral dissertation by M.Sc. Eng. Anna Jasińska was prepared in the form of a thematically coherent collection of seven original papers published or prepared for publication. Five of the papers were published in the period 2023–2024 in the following journals included in the list of scientific journals of the Minister of Science and Higher Education: *Energies* (papers D1, D3, D6; IF = 3.2; MNiSW journal ranking: 140 points), *Critical Reviews in Environmental Science and Technology* (paper D2; IF = 11.4; MNiSW journal ranking: 200 points), and *Energy Reports* (paper D4; IF = 5.1; MNiSW journal ranking: 100 points). The remaining two papers (D5 and D7) are manuscripts prepared for publication. In all papers presenting the research results forming the basis of the dissertation (D4, D5, D6, D7), the doctoral candidate is the first author, with a total of three or four co-authors, including the two supervisors of the dissertation. According to the Candidate's declarations, confirmed by the co-authors of the respective papers, her scientific contribution to the preparation of the final versions of the publications included participation in the development of the research concept and methodology, conducting the research, reviewing and analyzing the literature, graphical presentation of results, interpretation of results, as well as writing the original draft and participating in the review and editing of the manuscript. In the case of the review articles (D1, D2, D3), the most significant contribution concerns publication D1, which was prepared with the co-authorship of both supervisors. The doctoral candidate's contribution included conceptualization, formal analysis, investigation (understood as reviewing and analyzing source materials), data curation, writing the original draft, visualization, and participation in the review and editing of the manuscript. I also consider the contribution of M.Sc. Eng. Anna Jasińska to publication D2 to be of substantial substantive value in relation to the topic of the

doctoral dissertation. This contribution included reviewing and analyzing source materials, organizing and processing data, and editing the manuscript—specifically subsections 2.2.2 “Anaerobic processes” and 3.2 “Conversion into biogas under anaerobic conditions.” I consider the inclusion of article D3 in the publication cycle forming the doctoral dissertation to be debatable. In this case, the doctoral candidate’s contribution consisted of data visualization based on reviewing source materials and the content of the article. If this data visualization required an original intellectual contribution from M.Sc. Eng. Anna Jasińska, the inclusion of this paper in the publication cycle is justified. However, if it was based on guidance from co-authors and involved preparing graphics according to their concept, in my opinion this article should not be included in the publication cycle constituting the doctoral dissertation.

The material presented in the published and prepared for publication papers fully meets the criteria for doctoral dissertations. It confirms the general theoretical knowledge of M.Sc. Eng. Anna Jasińska in the discipline of environmental engineering, mining, and energy engineering, as well as her skill to single-handedly conduct scientific work and offer an original solution to a scientific problem, namely valorisation of poultry manure.

In reference to the published papers it should be emphasised that the scientific research of the Candidate has been recognized by scientific journals with high international reputation, and therefore by a group of international experts assessing manuscripts. The total IF of the said collection of papers is 26.1, and the number of points awarded by the Ministry of Science and Higher Education is 720.

The analysis of the structure of the dissertation submitted for evaluation confirms that it contains all the required elements. The work begins with abstracts in English, Polish, and German, as well as a list of important abbreviations and symbols. Subsequently, the doctoral candidate included a guide to the scientific articles forming the basis of the doctoral dissertation, divided into five chapters. In the first chapter, the Author presents a holistic context of the research problem addressed in the thesis, identifies research gaps, and provides justification for her own research. This chapter constitutes a logical introduction to the study objective and scope specified in the second chapter. This chapter also includes a clearly defined scientific objective as well as the practical aim of the research. The doctoral candidate also formulated three research hypotheses:

H1: Anaerobic co-digestion of poultry manure with sewage sludge and other organic waste significantly increased biogas production efficiency compared to mono-digestion of sewage sludge or poultry manure.

H2: Preliminary conditioning (pre-treatment) of the feedstock mitigate ammonia inhibition and improve process stability and efficiency.

H3: The digestate obtained from anaerobic co-digestion meets the quality requirements for use in agriculture and horticulture, and in practical can serve as an alternative substrate for mushroom cultivation.

The next chapter presents the list of publications constituting the doctoral dissertation. The fourth chapter includes a synthetic discussion of the results. In this chapter, the Author addresses the stated research hypotheses, referring the reader to publications that provide a detailed analysis of the results. A graphical overview of the conducted research (Figure 1) is particularly helpful for understanding the structure of the study. It presents the successive research stages and their objectives, indicates the publications in which their results are reported, and additionally demonstrates the holistic approach to the research problem addressed in the dissertation. In the following chapter, entitled “Conclusion,” the Author presents the primary achievements of the research discussed in the dissertation, dividing them into three subsections devoted to: verification of the research hypotheses, the scientific and practical significance of the obtained results, and future research directions. With regard to the formulated research hypotheses, the doctoral candidate confirmed two of them (H1 and H2). Based on the obtained results, it was demonstrated that the anaerobic co-digestion of poultry manure with sewage sludge improves process stability and biogas yield compared to mono-digestion (H1). With appropriately selected proportions of co-substrates, higher methane production was achieved while maintaining stable anaerobic digestion. It was also demonstrated that the application of thermo-alkaline methods significantly increased methane yield and improved substrate solubilization (H2). At this point, I would like to note that in Chapter 5.1, hypotheses H2 and H3 do not correspond to the hypotheses with the same numbering presented in Chapter 2.4 (the description assigned in Chapter 5.1 to H2 actually refers to hypothesis H3 formulated in Chapter 2.4, and vice versa). The conducted experiments also allowed for partial confirmation of the third research hypothesis. It was found that the digestate is characterized by high fertilizing potential and nutrient content suitable for reuse; however, full environmental safety cannot yet be guaranteed due to the possible presence of untested contaminants, such as organic micropollutants or pathogenic organisms. After presenting the conclusions resulting from the conducted research, the doctoral candidate outlined her other scientific achievements (Chapter 6). The guide to the articles concludes with a bibliography (Chapter 7), comprising 60 items thematically related to the subject of the doctoral dissertation.

After this part of the thesis, the Author includes the aforementioned scientific articles. The detailed scope of the work presented in these publications is as follows:

D.1. **Anna Jasińska**, Anna Grosser, Erik Meers (2023). *Possibilities and limitations of anaerobic co-digestion of animal manure – A critical review*. *Energies*. 16 (9), 3885.

D.2. Małgorzata Kacprzak, Krystyna Malińska, Anna Grosser, Jolanta Sobik-Szołtysek, Katarzyna Wystalska, Danuta Drózdź, **Anna Jasińska**, Erik Meers (2023). *Cycles of carbon, nitrogen and phosphorus in poultry manure management technologies – environmental aspects*. *Critical Reviews in Environmental Science and Technology*. 53 (8), 914-938.

D.3. Anna Grobelak, Klaudia Całus-Makowska, **Anna Jasińska**, Marek Klimasz, Aleksandra Wypart-Pawul, Dominika Augustajtys, Estera Baor, Daria Sławczyk, Aneta Kowalska (2024). *Environmental impacts and contaminants management in sewage sludge-to-energy and fertilizer technologies: current trends and future directions*. *Energies* 17 (19): 4983.

The three publications listed above are review papers and constitute the theoretical background for the conducted research. They provide a comprehensive overview of the current state of knowledge in the field of anaerobic digestion and nutrient management. From the perspective of the evaluated dissertation, publication D1 is considered the most significant. It is a very well-prepared literature review on the anaerobic digestion of manure, with particular emphasis on poultry manure and the role of co-digestion in overcoming process limitations. An important aspect is also the fact that M.Sc. Eng. Anna Jasińska is the first author of this publication, while the remaining authors are the supervisors of the dissertation.

The information presented in these publications justifies the research undertaken by the Candidate (the results of which are presented in subsequent publications) and demonstrates that the subject of the dissertation aligns with current trends in the development of a sustainable circular economy.

D.4. **Anna Jasińska**, Anna Grosser, Erik Meers, Anna Robles Aguilar (2024). *Energy recovery from poultry manure in the process of semi-continuous anaerobic co-digestion with sewage sludge*. *Energy Reports*. 12, 3969-3981.

The subject of this paper is the assessment of the feasibility of anaerobic co-digestion of poultry manure with sewage sludge and its impact on increasing biogas production compared to the mono-digestion of sludge. The process was carried out in a semi-continuous mode in two parallel reactors. One of them was fed exclusively with sewage sludge. In the

second reactor, after a period of mono-digestion, a co-substrate was introduced, with its share gradually increased from 2.5% to 60% (based on VS). The experiment was conducted over 270 days, during which process parameters such as biogas and methane production kinetics, specific methane yield, volatile fatty acids, alkalinity, pH, ammonium nitrogen, total Kjeldahl nitrogen, and total carbon levels were monitored. Additionally, based on the characteristics of the poultry manure, the potential for greenhouse gas emissions was estimated. It was demonstrated that the introduction of poultry manure significantly increased methane production. The most stable process performance and the highest biogas yields were achieved when the share of poultry manure in the mixture ranged between 20% and 40%. A detailed comparison of the characteristics of digestate obtained from both the mono-digestion of sewage sludge and its co-digestion with poultry manure was also performed. It was found that the co-digestion product contained higher concentrations of N-NH₄⁺, Ca, and K, whereas higher amounts of Mg, Na, P, and Fe were observed in the digestate from sludge mono-digestion. Another noteworthy conclusion relates to the GHG emission calculation results, which demonstrated the advantage of anaerobic co-digestion of poultry manure over other methods of managing this type of waste.

D.5. **Anna Jasińska**, Erik Meers, Anna Grosser (2025). *Sustainable digestate management as a supplement to the casing layer in mushroom cultivation*. Manuscript prepared for publication.

The next paper is a continuation of research on the quality of digestate. It expands the research scope by including experiments aimed at assessing the potential of digestates as components of the casing layer used in *Agaricus bisporus* cultivation. Mushroom yield, biological efficiency, cap diameter, and chemical composition were evaluated over two flushes, while the casing layer and substrate were analyzed both before and after cultivation. The paper emphasizes that digestate, when applied in limited amounts (3-5%), can improve the physicochemical properties of the casing layer and contribute to nutrient recycling, while also reducing the environmental burden associated with peat extraction. These findings align with the principles of the circular bioeconomy. It should also be emphasized that, in addition to their scientific value, the conducted experiments have strong practical significance, as the doctoral candidate investigated the practical utilization of digestate.

D.6. **Anna Jasińska**, Anna Grosser, Erik Meers, Dagmara Piłyp (2024). *Stimulating methane production from poultry manure digest with sewage sludge and organic waste by thermal pretreatment and adding iron or sodium hydroxide*. *Energies*, 17 (11), 2679.

The main objective of the research presented in this publication was to determine the effect of selected pretreatment methods on the efficiency and kinetics of the co-digestion process of poultry manure with sewage sludge and organic waste. The specific objectives, constituting successive stages of the research, were: 1) selection of the third component of the co-digestion mixture, 2) determination the most favorable inoculum-to-substrate ratio for the co-digestion mixture, 3) determination of the most favorable pretreatment parameters based on changes on volatile fatty acids, ammonium nitrogen, extracellular polymers substances and non-purgeable organic carbon, 4) evaluation of the anaerobic co-digestion based on the results the BMP tests and kinetics studies. The selection of the third substrate was made from the following types of organic waste: by-products of vegetable fat refining, fats present in wastewater from dairy production (flotation-thickened sludge), grease trap sludge from a meat-processing plant, and fruit waste. The highest methane potential was observed for waste with a high fat content (grease trap sludge), and this substrate was selected for further research. Subsequent analyses focused on the impact of different pretreatment methods (thermal, thermochemical with iron addition, and thermochemical with sodium hydroxide) on substrate solubilization as well as on the course and yield of methane production. The obtained results confirmed one of the research hypotheses, demonstrating that pretreatment of the feedstock leads to higher methane production and improved substrate solubilization. The best results were achieved for thermochemical pretreatment with 4.5 g NaOH/L, where methane yield increased from 340 mL/gVS_{add} to 501 mL/gVS_{add}.

D.7. Anna Jasińska, Anna Grosser, Erik Meers, Dagmara Piłyp (2025). *Evaluation of saponification and chemical pretreatment for poultry manure co-digestion: methane production, EPS fraction analysis and kinetic study*. Manuscript prepared for publication.

This paper presents the results of experiments in which feedstock pretreatment was carried out using an alkaline method (performed with NaOH at concentrations ranging from 0.9 to 5.4 g/L at ambient temperature) and saponification (conducted at 70°C with the same NaOH doses as in the alkaline method). The presented results provide further confirmation of one of the research hypotheses that properly selected pretreatment parameters enable the intensification of methane production. It was demonstrated that saponification is a more effective and stable pretreatment method than conventional alkalization of a mixture of poultry manure, sewage sludge, and fatty waste. The doctoral candidate rightly concluded that thermo-chemical saponification represents a promising approach for enhancing the

energy recovery potential of anaerobic digestion processes treating nitrogen-rich and low-biodegradability wastes.

Reading the paper provided a basis for formulating several questions and comments of a polemical nature. However, they do not affect my final assessment of the scientific value of the paper:

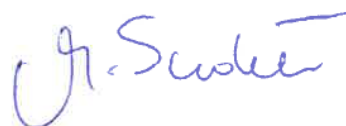
1. The paper contains a discrepancy in the observations formulated regarding the quality of the digestate. On page 28, it is stated: “Compared with digestate from sewage sludge alone, **the co-digestion product contained higher concentrations of nitrogen, phosphorus, calcium, and potassium...**”. In publication D4, however, the following conclusion is presented: “The digestate from the waste mixture contained more Ca, K and NH_4^+ , while **a higher amount of Mg, Na, P and Fe was found for the sludge digestate product**”.
2. The results of the scientific research conducted in the scope of this doctoral dissertation contribute new cognitive insights while also having significant practical relevance. How do you assess the technological readiness level of the solutions you have investigated? What challenges or barriers do you foresee in their implementation?
3. In the declaration of co-authorship, the doctoral candidate specified the nature of her contribution to the publications, which is a very important element enabling the reviewer to assess the doctoral dissertation. It would also be helpful in the evaluation process to provide an estimated percentage of the doctoral candidate’s contribution.
4. The dissertation contains inconsistencies in the order of authors for the manuscripts D.5. and D.7. For D.5. the following two variants are provided: 1) Anna Jasińska, Erik Meers, Anna Grosser – in the list of publications (this order is also given in the declaration of co-authorship), 2) Anna Jasińska, Anna Grosser, Erik Meers – in the manuscript. For D.7., the following discrepancies occur: 1) Anna Jasińska, Anna Grosser, Erik Meers, Dagmara Piłyp – in the list of publications (this order is also given in the declaration of co-authorship), 2) Anna Jasińska, Dagmara Piłyp, Erik Meers, Anna Grosser – in the manuscript.

To sum up, in my opinion, the reviewed doctoral dissertation represents a high scientific level and contributes new insights in the area of energy recovery from waste streams via anaerobic digestion processes. I also appreciate the applied research methodology, the broad scope of analyses conducted, and consequently the high labor intensity of the research carried

out. The thesis constitutes an original solution to a scientific problem and demonstrates the Doctoral Candidate's considerable general knowledge in the discipline of Environmental Engineering, Mining, and Energy Engineering, as well as her ability to plan and conduct scientific research, prepare and critically discuss results, and draw conclusions.

Thus, the evaluated doctoral dissertation meets the formal requirements for this type of work as specified in Article 187(1) and (2) of the Act of 20 July 2018 – Law on Higher Education and Science (Journal of Laws of 2023, item 742, as amended). I hereby request the Scientific Council of the Discipline of Environmental Engineering, Mining, and Energy Engineering at Częstochowa University of Technology to admit M.Sc. Eng. Anna Jasińska to the further stage of the proceedings for the award of the doctoral degree.

At the same time, recognizing the very high substantive level of the dissertation, the novel cognitive contributions it contains, and the practical applicability of the conducted research, I conclude that, in my opinion, the work deserves distinction.

A handwritten signature in blue ink, appearing to read "J. Szwed", is located in the lower right quadrant of the page.