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Review
of the PhD Thesis by Vishwajeet, MSc Eng.

1. Introduction

This review was prepared in response to letter No. W9/PW/281/2024 of May 16, 2024, in connection with the resolution of the Council of Discipline of Science – Environmental Engineering, Mining and Energy at Wroclaw University of Science and Technology of May 15, 2024 (970/42/RDND08/2021-2024).

The legal basis for this opinion is the Act of 20 July 2018 – Law on Higher Education and Science (Journal of Laws of 2023, item 742 as amended), in particular the provisions contained in Article 187.

2. Content of PhD Thesis

The PhD Thesis written by Vishwajeet, MSc Eng. is entitled „Hydrothermal carbonization and plasma gasification of sewage sludge". The research work was carried out in the Faculty of Mechanical and Power Engineering at Wroclaw University of Science and Technology, under the joint supervision of Tomasz Hardy, DSc, Associate Professor at Wroclaw University of Science and Technology and Amit Arora, PhD, Associate Professor at National Institute of Technology Hamirpur in India.

The dissertation has the structure of a classic research work, containing the following main chapters: Introduction, Materials and Methods, Results and Discussion, and Summary. Moreover, an abstract written in English and Polish is included. At the end, references to various sources are provided in the number of 157 items of which one is a self-citation. The total length of the PhD thesis is 114 pages. In addition, a personal scientific output is enclosed on pages 115-116.

Chapter 1: The Author outlines the problem regarding the utilization of sewage sludge which is produced in a large amount all over the world. Gives a brief overview of hydrothermal carbonization (HTC) and gasification technologies, with a particular emphasis on plasma gasification. Highlights the key benefits of sewage sludge utilization using the plasma gasification technique, which result mainly from an extremely high temperature of the process. The advantages of both treatment methods (HTC and plasma gasification) are explained in the subsequent subchapters 1.5-1.6. The main goal of this study and the scope of investigations are defined in subchapter 1.1. The proposed schedule of the research work (subchapter 1.2) is clear and reasonable. The entire chapter proves the Author's extensive knowledge in the field of investigations.

Chapter 2: The following stages of research are described in general terms in this chapter, starting from sewage sludge sample collection, through hydrothermal carbonization and plasma gasification, and ending with solid residue management. A total of four samples, which came from the municipal wastewater treatment plants located in Denmark and Poland, were tested under different conditions. Sophisticated analytical tools and methods were used during these investigations, including thermogravimetry (TG), microwave plasma atomic emission spectroscopy (MP AES), atomic absorption spectroscopy (AAS), scanning electron microscopy with energy dispersive X-ray spectroscopy (SEM/EDX), and several others. Such advanced approaches certainly improve the quality of the scientific discussion conducted in the PhD thesis.

Chapter 3: The findings of the conducted investigations are presented in this chapter. First, the main interest was the influence of both the residence time and the temperature used for HTC treatment, primarily on the composition of the sewage sludge and ultimately on the heating value of the syngas obtained. Then, the focus was on the yield of H_2, CO, CH_4, and CO_2 along with the properties of the ash remaining after the plasma gasification process. The experimental results are very encouraging, however, their discussion could be more comprehensive. It would be also interesting to know the ultimate analysis of raw materials (before HTC treatment), which is not given. This information should certainly appear in future publications.

Chapter 4: The conclusions are consistent with the title and scope of the research work. They follow essentially from the experiments and analyses carried out. Unfortunately, some of the summarized results were not included in the main part of the dissertation.

3. Critical Remarks

The subject of studies, described above in Section 2, is interesting, current, and worth exploring. Although the overall PhD Thesis rating is high in general, there are several detailed questions and comments listed below.

1. *General*: References should be numbered in order of appearance in the text.
2. *Chapter 1:* The Sustainable Development Goals (SDGs) should be listed at least before they are discussed selectively in subchapter 1.3.

   The disadvantages of both technologies (hydrothermal carbonization and plasma gasification) should also be presented compared to the provided advantages. – additional information is needed.
3. *Chapter 2*: The statement "*HTC (...) makes coal in ½ hour instead of millions of years*" seems to be exaggerated.

   The description of the symbols from equation (6) is missing.

   Regarding the TG analyzer: gas flow is not mentioned, temperature sensors measure temperature (not heat), surrounding gas may be different (not only air), etc.

   Although the help of supervisors is certainly invaluable, the author should avoid phrases such as "*We applied ...*" (page 32), "*We convert ...*" (page 42), or "*we change ...*" (page 43). That is a PhD Thesis.

   SI units should be used throughout the manuscript, whereas "*inches*" can be found on page 50. What is more, Polish words like "*glina*" can be also found there.
4. *Chapter 3*: Comparing the data in Table 3.1.1, I cannot entirely agree with this conclusion "*Increased carbon content (...) is generally the results of higher temperatures and longer residence durations.*".

   The values in the statement "*The carbon content of dry sewage sludge is greatly increased (from 38.94 to 37.57) by HTC treatment.*" as well as in Table 3.1.2 should be checked.

   The total content of ash and volatile matter is much higher than 100% (A + VM >>> 100%) in Table 3.1.3 – How to understand these values? – an explanation is needed.

   The data in Table 3.1.4 are duplicated with those presented previously in Table 2.1.1 on page 19.

   The whole expression ($-E_a/RT$) in the Arrhenius equation (9) should be an exponent (an index of the power).

   Generally, units are missing in the discussion of the apparent activation energy on pages 74-79, including all figures provided.

The discussion (about ½ page only) regarding the plasma gasification process is rather poor and confusing. What is more, all figures (3.3.1 – 3.3.7) are difficult to read because instead of different colors, three shades of blue were used.

Analyzing the data in Tables 3.4.1 – 3.4.2, I do not agree with the second part of this conclusion: "*In Table 3.4.1 the percentage of Fe in secondary sewage sludge increases when the HTC temperature increases. Increasing the temperature does not affect the percentage of Fe in the rest of the two sewage sludge.*" as well as with the next conclusion: "*But according to Table 3.4.2 one very interesting thing is that the parentage of Fe in sewage sludge increases after plasma gasification in secondary sewage sludge cases at almost every temperature.*". Data, labels, or conclusions must be checked and verified. Moreover, only the Fe content is discussed, while the content of other elements (K, Mg, Mn, Al, Na, and Ti) is not mentioned at all.

The labels in Figures 3.5.1 – 3.5.19 are illegible and hence it is difficult to follow the accompanying discussion. Moreover, the results of only one sample (Primary Sewage Sludge) are presented.

However, I would like to emphasize that I do not believe that the above critical comments will significantly affect the quality of the reviewed PhD Thesis.

In my opinion, the main achievement of the PhD Candidate is to develop a Waste-to-X concept of sewage sludge conversion into valuable synthesis gas and useful solid residue, which employs both hydrothermal carbonization and plasma gasification technology.

4. Final Conclusion

The PhD Thesis submitted for evaluation **is an original solution to a** very important **scientific problem**, which is the disposal of sewage sludge in a manner consistent with the Waste-to-X strategy, leading to the generation of valuable and useful products. **PhD Candidate demonstrates general theoretical knowledge in the represented discipline of science and the ability to independently conduct scientific work**. In my opinion, the evaluated **PhD Thesis meets the requirements specified in applicable legislation** (Article 187 Section 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 also believe that the PhD Thesis by Vishwajeet, MSc Eng. titled „Hydrothermal carbonization and plasma gasification of sewage sludge" is included in the discipline of science – *Environmental Engineering, Mining and Energy*. In connection with the above evaluation, **I am requesting that the PhD Candidate be admitted to the next stages of the procedure for awarding a doctoral degree.**