OPINION

on the PhD thesis for awarding the educational and scientific degree "doctor" in higher education field: professional field - 4.2. Chemical Sciences, scientific specialty "Processes and Apparatus in Chemical and Biochemical Technology"

by **Stela Ivanova Minkovska, Assoc. Prof. PhD** , at the Institute of Catalysis-Bulgarian Academy of Sciences

Author: **Stela Plamenova Panyovska,** assistant

Title: CFD Modeling of Membrane Separation through Nanofiltration

Scientific consultants: Prof. Daniela Dzhonova-Atanasova, PhD and Prof. Iren Tsibranska, PhD - Institute of Chemical Engineering - BAS

1. Brief biographical data of the PhD candidate

Eng. Stela Panyovska completed her higher education in 2017 at the University of Chemical Technology and Metallurgy (Sofia), obtaining a Master's degree in CAD/CAE in Chemical Technologies. In the same year, she was appointed as a chemist at the Institute of Chemical Engineering, Bulgarian Academy of Sciences, where in 2020 she was elected to the position of Assistant. The PhD candidate's personal skills include proficiency in modern computer software and very good level of English.

2. Relevance of the research topic

The PhD thesis of Eng. Stela Panyovska addresses one of the topical issues related to the application of membrane technologies in modern water treatment, biotechnology, and the chemical industry, namely the use of computational fluid dynamics (CFD) in nanofiltration and membrane separation processes. The relevance of the research is justified by the well-known problems associated with membrane fouling, which significantly reduce the efficiency and economic viability of membrane systems. In the course of the research, it was demonstrated that CFD modeling allows for detailed analysis of the hydrodynamic and mass transfer processes near the membrane surface, taking into account the influence of different filtration modes, membrane geometry, rheological properties of fluids, and methods for hydrodynamic influence on shear stresses and concentration polarization. The presented approaches and analyses are scientifically sound and have potential for practical application in the optimization of membrane systems, which highlights both the theoretical and practical significance of the study.

3. Knowledge of the research problem

The conducted literature review demonstrates that the PhD candidate has a solid understanding of the issues related to the application of membrane technologies and nanofiltration. The analysis performed shows that the integration of reaction processes with membrane separation enables efficient product removal, overcomes inhibitory effects, and saves energy and space, while at the same time preserving the biological activity of thermosensitive compounds. Nanofiltration stands out as a highly efficient and economical solution for water purification and wastewater treatment, and the increase in publications in the field in recent years highlights the relevance of this technology. The application of CFD for the optimization of membrane reactors and modules demonstrates the potential for detailed analysis of hydrodynamics, mass transfer, and membrane fouling control, which further confirms the PhD candidate's in-depth understanding of the existing challenges in the research area. The

design of the literature review demonstrates the ability to handle scientific literature and make a critical assessment of existing data.

4. Characteristics and evaluation of the PhD thesis.

The PhD thesis is written on 148 pages and includes 62 figures and 2 tables. It is structured into seven chapters. A total of 169 literature sources are cited, at least 50 of which have been published after 2020. The PhD thesis represents an in-depth and comprehensive study related to the development and analysis of membrane-integrated bioreactors, which are finding increasingly broad application in modern industrial technologies. The research addresses problems of a clearly interdisciplinary nature and is fully aligned with current trends in the field of membrane processes and biotechnology. The scientific significance of the obtained results is determined by the application of computational fluid dynamics (CFD) methods for modelling hydrodynamic and mass transfer processes in membrane systems. The numerical investigations were carried out using the ANSYS FLUENT software package, based on the finite volume method for solving the Navier–Stokes equations, which ensures a high degree of reliability and credibility of the obtained results. The presented models and analyses are built upon previous experimental and applied experience in the concentration of antioxidants (polyphenols and flavonoids) from natural product extracts by nanofiltration. The practical significance of the PhD thesis is reflected in the possibility of using the obtained results for the optimization of the design and operating parameters of membrane-integrated bioreactors, for the reduction of membrane fouling, and for increasing the efficiency and selectivity of the processes. The results have potential applications in the food, pharmaceutical, and biotechnology industries.

5. Main scientific and applied contributions

The PhD thesis of Eng. Stela Panyovska represents a significant contribution to the field of membrane integrated bioreactors and their application for concentrating biologically active compounds through nanofiltration. Through computational fluid dynamics (CFD) modelling using ANSYS FLUENT, the hydrodynamic conditions and the distribution of shear stresses were evaluated, enabling the determination of an optimal range of flow velocities and stresses that ensure minimal membrane fouling and safe conditions for the cell mass. The conducted CFD simulations provide new insights into mass transfer and concentration polarization under various filtration regimes, including normal flow and mechanical stirring, with results supported by experimental data. The developed method for evaluating transport efficiency in integrated bioreactor systems allows for comparative analysis of different design solutions and demonstrates practical applicability in the optimization of membrane processes. The PhD thesis confirms the scientific significance of applying CFD to improve membrane separation and the concentration of bioactive substances and demonstrates the candidate's deep understanding of the research problem.

6. Assessment of publications and personal contribution of the PhD candidate

The research results are presented in four scientific publications published between 2017 and 2020, of which two are into **Q3** journals (Chemical Engineering Transactions and University of Chemical Technology and Metallurgy), one in a **Q1** journal (Chemical Engineering Research and Design), and one in Scientific Works of University of Food Technologies. The publications have received 30 citations, proof of the relevance of the topic. On the topic of the dissertation, eight reports have been presented at national and international scientific events (abstracts of the last ones were not provided). Considering that in three of the publications the candidate is a co-author only with her two scientific supervisors, it can be concluded that the dissertation is her own work, carried out under their competent guidance. The PhD candidate has been awarded the Bulgarian Academy of Sciences Young Scientists

Award "Ivan Evstratiev Geshov" in the field of Energy Resources and Energy Efficiency (2021 competition), which demonstrates her high scientific potential for further development.

8. Abstract

The abstract (comprising 69 pages and containing 1 table and 37 figures) accurately and comprehensively reflects the main results presented in the dissertation.

9. Critical remarks and recommendations

The PhD thesis is written in good scientific English, with minimal technical errors, and the presented figures are precisely prepared. No fundamental objections to the content are required. At the same time, it would be of interest for the PhD candidate to comment on the behavior of the process in the transitional flow regime (Re = 1000–2000), which is not addressed in the PhD thesis. Since the goal is to maintain a permeable membrane, concentration polarization constitutes an obstacle to effective mass transfer. Although the reduction of polarization by increasing the flow velocity is well argued, it would be beneficial for the author to discuss the potential hydrodynamic and mass transfer characteristics in the transitional range and how they could affect the membrane's permeability.

CONCLUSION

The PhD thesis of Eng. Stela Plamenova Panyovska contains scientifically sound, original, and practically significant results, representing a contribution to the development of membrane technologies and providing a basis for future research and industrial applications. The conducted studies enrich scientific knowledge and offer opportunities for further extension and deepening, particularly with regard to industrial implementation.

I consider that the PhD thesis meets the requirements of the Law on the Development of the Academic Staff in the Republic of Bulgaria (LDASRB), the Regulations for the Implementation of the LDASRB, and the current Rules for the Acquisition of Scientific Degrees and for Occupying Academic Positions at the Institute of Chemical Engineering.

Due to the above, I confidently give my positive assessment of the conducted research and propose to the honorable scientific jury to award the educational and scientific degree "doctor" Eng. Stela Plamenova Panyovska in professional field 4.2. Chemical Sciences, PhD Program: Processes and Apparatus in Chemical and Biochemical Technology

19.01.2026

Reviewer: .....

(Assoc. Prof. Stela Minkovska, PhD)