Review on doctoral dissertation

The author of the dissertation: **Ing. Andrey Kutsay**

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The title of the Ph.D. dissertation: **Technology and equipment for lignocellulosic waste conversion to biofuels and bioproducts with high added value**

The general remarks on dissertation

The doctoral dissertation, presented by Andrey Kutsay consists of 7 chapters (152 pages), a list of 110 references, a list of his own references (10 publications +3 conference proceedings + 7 posters), a list of 40 figures and 32 tables, and 28 appendices. The Annotation Sheet provides information about Author, Supervisors and Affiliation. The annotation and keywords are repeated in Czech in the first few pages. The dissertation is written in English.

The main issue addressed in the dissertation is devoted to biogas biorefineries incorporating various pre-treatment techniques of raw material and products processing methods in order to enabling a comparative assessment of mass and energy balances, technical maturity, and economic viability.

In view of the contemporary development of biorefineries with minimizing of material waste, replacement of fossil-based products with bio-based alternatives, it is appropriate to take up the topic of research on the innovative biogas biorefinery based on lignocellulosic biomass and to create a general parametric model of biorefinery plant, which would not require the investment to be subsidized.

The theoretical part - State-of-the-art analysis

In the theoretical part of the dissertation, after a short introduction concerning the concept of biorefineries and biomass conversion processes, the author started with a critical review of existing biorefineries and biogas production. The author presented existing biorefineries, however focused on the biogas production as the main technology describing the stages of the process and their parameters, as well as biogas cleaning with removal CO_2 to upgrade biogas

to biomethane. The review of published works is broad, focusing on the most recent reports, and also includes many important works, including biogas relating patents, from the last decades of the 21st century. The theoretical part concludes by presenting the motivation for undertaking research on lignocellulosic biomass treatment in biogas biorefinery.

The author formulated hypothesis that

"*Lignocellulosic waste treatment in biogas biorefinery producing simultaneously green chemicals and energies can meet industrial attractivity independent on green subsidies*"
and general objectives:

-"*To create a general parametric model of biogas biorefinery enabling a comparative evaluation of mass and energy balances, technical maturity, and design economics, including sensitivity analysis.*
-To investigate an innovative technological set treating lignocellulosic biomass in biorefinery concept to reach investment attractiveness without any subsidies"

These objectives were further detailed in the specific objectives and definition of the scientific objectives of the work.

The first part of the work (called theoretical) gives credit to the author's ability to organize the existing literature on biogas biorefineries and the achievements of many researchers. The review is written very clearly, and it is comfortable to read.

The practical part

This is a somewhat unusual dissertation, as it has no experiments but focuses on design calculations with an economic evaluation of different versions of a biogas biorefinery.

The author considers six types of biogas biorefineries based on wheat straw wastes as substrate:

1) conventional plant for production of heat and electricity;
2) conventional plant with biogas upgrade for production of biomethane and residue;
3) intensified biogas plant for production of heat and electricity;
4) biogas -fibre biorefinery for production of fiber, heat and electricity;
5) biogas- algae biorefinery with autotrophic algae for production of heat and electricity;
6) biogas- algae biorefinery with mixotrophic algae for production of heat and electricity.

The author ensures that all plants considered are new, there is no case for retrofitting, assuming that all plants are parts of existing agricultural farms, with the constant delivery of substrate. Each presented plant was designed with detailed mass and energy balances. The mass and energy balances were based on process flow diagrams (PFD), which were attached in appendices.

Analyzing the assumptions and selected parameters of the individual biogas plants, I must conclude that the author presented them with a high degree of engineering expertise based on literature data with the use of engineering practice, principles of transport phenomena, and with the help of basic software. This applies to both substrate pretreatment methods such as mechanical shredding (size reduction) and hydrothermal pretreatment (steam expansion), as well as the actual anaerobic fermentation process and subsequent product processing steps such as digestate treatment, biogas combustion, biogas upgrade with the use of PSA technique.

All the calculations of the mass and energy balances of the individual processes or apparatuses have been done correctly, although I miss the Sankey diagrams which explicitly illustrate the mass and energy balances of the process. However, the process flow diagrams (PFDs) compensate for this lack. The concepts of two biogas biorefinery variants seem artificial and doomed to be unprofitable in advance, namely the biogas-fiber biorefinery and the biogas-algae biorefinery. This has been confirmed by economic evaluation.

This part of the work *Economic evaluation technique* is worth emphasizing - taking into account capital cost estimation, estimating purchased equipment costs, production costs, revenues, margins and profits made it possible to calculate the discounted cash flow rate of return (discounted payback period). This allowed the doctoral student to carry out a full economic evaluation of individual technological options. All the assumptions made and prices of the factors used are reasonable - such an economic model of the process deserves praise.

In addition, a sensitivity analysis was carried out in *Discussion* chapter to evaluate the impact of specific parameters on the results of the economic analysis. The only relevant sensitivity that was carried out was the impact of the price of a key product. The sensitivity analysis specifically focuses on the variation of the electricity and biomethane, fiber and algae selling price.

In order to gain a better understanding of the advantages and disadvantages of the biogas-algae biorefinery concept a SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis was performed. The SWOT analysis considered only the Biogas-algae biorefinery, however as it includes general points it can be applied to all other concepts of biorefinery plants discussed in the thesis.

Generally the results of the thesis are valuable and can be applied in the practice.

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Novelty

As far as the scientific novelty of this doctorate is concerned, I have considerable doubts because the approach used to achieve the objectives of the work is typically engineering and

well known. It is a collection of some very good engineering works. It is a good project, maybe more of a premise, assumption for a technical process design but scientifically t adds nothing new. Therefore, it is difficult for me to judge.

Conclusions

However, in view of the enormous amount of project work, the good knowledge of biogas production (biogas biorefineries) and the high level of the calculations carried out, as well as the discussion of the results, I am inclined to give a favourable opinion on the awarding of the doctoral degree to engineer Andrey Kutsay.

Reviewed by:

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