FACULTY OF MECHANICAL ENGINEERING
DEPARTMENT OF PROCESS ENGINEERING
Assoc. Prof. Ing. Lukas Kratky Ph.D.

Prague, 19th May 2022

The Reviewer's Comments on the PhD Thesis

The Author: Ing. Karin Astrid Senta Rindt

The Title: Accumulation of heat in basalt at high temperatures in packed and fluidized bed

The Comments on the Thesis

The thesis scopes to a globally attractive topic of Carnot batteries as a sustainable decentralized system for thermal energy storage. Its detailed scope was focused on thermal energy storage systems for heat accumulation in basalt due to its temperature resistance to 750 °C. I appreciate this convenient idea on an industrial scale because it allows the direct use of raw exhaust gas at high temperatures to form a Carnot battery.

Professional level

The introduction comprehensively reviews the motivation found in renewable energy production, the need for energy storage, and thermal energy systems. The state of the art of Carnot batteries was clearly and precisely overviewed. The summary of different Carnot battery layouts and in-date overview of Carnot battery pilot plants and demonstrators are highly-valued outputs of the review. Solid materials and their temperature limits were discussed, based on which high-temperature stability of basalt was highlighted.

The student defined the three aims of the thesis as follows.

1. Experimental analysis and mathematical modelling of basalt charging and discharging.
2. Physical characteristics of basalt rock (density, dilatometry, surface changes).
3. Performing a demonstration of an energy storage system using a laboratory fixed and fluidized bed reactor packed with basalt.

The practical part of the thesis starts by presenting the typical chemical composition of natural and cast basalts.

TECHNICKÁ 4
166 07 PRAGUE 6
CZECH REPUBLIC

+420 224 352 550
LUKAS.KRATKY@FS.CVUT.CZ
WWW.FS.CVUT.CZ

The dominant part of the thesis experimentally identifies the specific heat capacity of basalt in dependence on its temperature. This chapter logically describes the tested materials, methods and gained results. The student reached original results both in heat charging and discharging of basalts. The experimentally gained results are adequately discussed with the similar results of published papers. The validity of the presented data was confirmed. Finally, the author presented a standard empiric approach to data modelling, in which the polynomic function of the fourth-order is fitted using the least square method. The dependence of charging capacity on temperature and process time was presented in 3D planar graphs and individual coefficients for the proposed empiric polynomic function. I have several tasks to clarify some comments, calculations and results presented in this subchapter. My questions are defined by "The Questions for the Defence" formulated below.

The experimental chapter continues on the topic of the identification of density and volumetric changes at high temperatures for basalt rocks. The student selected standard analytical procedures and laboratory equipment to identify set properties. The reached experimental results are valuable and extend a knowledge database. Nevertheless, I miss a critical discussion and comparison of presented data with available papers or handbooks.

The last part of the thesis was dedicated to the demonstration comparing the charging behaviour of fixed and fluidized beds. The laboratory test equipment and analytic procedures were applied to evaluate the charging potential. Technical sand and basalt were used during the experiments. The experimental layout, data processing and presentations of the results are correct. The author proposed the multi-layered configuration of a fluidized bed as a suitable flexible configuration for such a Carnot battery. I have several tasks to clarify some comments, calculations and results presented in this subchapter. My questions are defined by "The Questions for the Defence" formulated below. Nevertheless, this final chapter clearly demonstrates the suitability of heat accumulation at high temperatures in a fixed and fluidized bed with basalt rock.

TECHNICKÁ 4
166 07 PRAGUE 6
CZECH REPUBLIC

+420 224 352 550
LUKAS.KRATKY@FS.CVUT.CZ
WWW.FS.CVUT.CZ

Formal and language level

The thesis is at a standard quality level and contains all the necessary formal requirements. The text is written clearly and understandably. Graphic artwork evinces a standard quality. The in-date review serves valuable information about the problem.

Bibliography

The author used 73 in-date references in the text. Citations in the manuscript and their format listed in the bibliography respect the European Copyright Act No. 121/2000, even with all the citation practices. Nevertheless, the reference style for websites (date of citation is missing) and style for [1] are incorrect. It is clear which information is referenced and which information is her contribution and novelty.

The Comments on the Aims and The Novelty of the Thesis

The thesis carefully discusses the experimental methods, the methods of data evaluation, and the presentation of gained results. All the parts were precisely discussed in individual subchapters of the manuscript and critically compared with available databanks. I have to state that all the aims were fulfilled.

I found two novelties of the thesis, theoretical and practical core one. The theoretical novelty can be found in a demonstrated summary of different Carnot battery layouts and an in-date overview of Carnot battery pilot plants. The second novelty, the core one, was identified in experimental analysis and mathematical modelling of basalt charging and discharging.

The Comments on the Publications of the Author

Although the author's publications are acceptable without any problems, fulfil the demanded quantity of PhD studies and defence, and the topic was widely presented at international conferences, I have to state that I personally miss a broader publication activity of the author.

- One Scopus based publication in Acta Polytechnica was only reached.
- No experimental results and models have been published in a journal indexed in Scopus or Web of Science databases. There is a high publication potential for this part.
- The reference [KR2] did not meet standards in referencing; no authors are listed, and the term "group of authors "can not be accepted as a reference style.

TECHNICKÁ 4
166 07 PRAGUE 6
CZECH REPUBLIC

+420 224 352 550
LUKAS.KRATKY@FS.CVUT.CZ
WWW.FS.CVUT.CZ

The Final Overview

The thesis primarily aimed to experimentally identify and model basalt charging and discharging behaviour and demonstrate its suitability in a laboratory fixed/fluidized storage systems. Regarding the quality of presented information, I have to state that the author proclaimed her professional skills to prepare a critical review, collect and adequately use gained information, independently form a methodology of experimental works, plan and perform experiments, analyze reached experimental data followed by their modelling, and present them carefully. Therefore, my observations and comments, or my questions for the defence, do not diminish the quality of the thesis.

Finally, the standard professional quality and the absence of significant criticism endorse me to recommend accepting the thesis for its defence.

Assoc. Prof. Ing. Lukas Kratky, PhD.
the reviewer

The Questions for the Defence:

Please answer all these questions during the defence. Support your statements by demonstrative calculations, graphs, figures, etc.

1. Regarding the methodology to evaluate the specific heat capacity of basalt, a rock sample of temperature 300-750°C was put into the water being in a calorimeter. As you put a hot piece of basalt into the water, water starts to be intensively evaporated along all its heat transfer surface, does not it. However, the effect of water evaporation and energy transformation is not included in your model Eq. (4.4). Therefore, I would like to ask You to clarify the experimental methodology and your model to calculate specific heat capacity.
2. Regarding Fig.4.6-4.7, both the vertical axis are labelled as specific heat capacity at constant pressure, as defined by your List of symbols. However, it is generally known that

TECHNICKÁ 4
166 07 PRAGUE 6
CZECH REPUBLIC

+420 224 352 550
LUKAS.KRATKY@FS.CVUT.CZ
WWW.FS.CVUT.CZ

specific heat capacity is a standard physical property of material independent of time. Therefore, I would like to ask You to explain the correct meaning and physical interpretation of values presented on the vertical axis for both graphs.

3. Static change of basalt heat capacity is demonstrated by smooth curves in Fig. 4.6-4.7. The author mentioned that ten rock patterns were used to identify a specific heat capacity. Please present the mean values of measured experimental points with standard deviations and all the fitted models for experimental pathways of 300°C, 400°C, 600°C and 700°C for natural basalt.
4. Regarding Fig.4.16-17, the empiric polynomic function was used to describe the mutual relationship among specific heat capacity, temperature and process time. Is your empiric model for charging dynamics of basalt generally valid, or are there any limitations to its usage, i.e. as for particle size?
5. Particle size analysis was done for both technical sand and basalt product. Please present the polydisperse particle size distribution curves in the form of frequency and cumulative distribution. Figure 5.5 is not understandable to me. How did you evaluate the mean diameter, sphericity and porosity for technical sand and basalt?
6. Can you comment on how single air velocities of 0.3 m/s for fixed and 0.7 m/s for fluidized beds were found? Then, respecting the theory of flow in a fluidized bed, I would like to ask You to calculate and demonstrate minimum fluidization velocities for both cases, followed by a choice of experimental ones. Why did you not reach fluidization with basalt?
7. The pressure drop in the fixed bed was nearly constant, while the pressure drop slightly linearly increased in time for a fluidized bed. Is there any physical interpretation of these results?
8. Applying your strategic experimental findings and professional engineering knowledge, please discuss the commercial potential of the Carnot battery's fixed or fluidized bed configuration with basalt in terms of technological set-up (PFD scheme), energy balance, scaling limits, reliability, TRL level, investment and operational costs.

TECHNICKÁ 4
166 07 PRAGUE 6
CZECH REPUBLIC

+420 224 352 550
LUKAS.KRATKY@FS.CVUT.CZ
WWW.FS.CVUT.CZ