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Expert Review

on the dissertation of the doctoral student

Ing. Pavel Skopec

for his Ph.D. Thesis

"Desulphurisation during oxyfuel combustion in a fluidized bed"

submitted at the
Faculty of Mechanical Engineering/ Department of Energy Engineering
Czech Technical University in Prague

Conventional power plant technologies based on fossil fuels are a significant foundation for our current energy supply – research and development of the past decades created a proven, competitive and stable technology, through which the emissions were be continuously reduced and, simultaneously, the efficiency improved. Despite, or maybe because of the extensive state of knowledge the conventional power plant technologies are under extreme pressure concerning their environmental impact based on their usage.
Conversely, renewable energy sources are in comparison to conventional power plant technologies considered as *cheaper, endlessly available* and *free of environmental impact* in the long term. Regardless of which amount of renewable energy sources in an energy mix of the future will be economical, ecological and secure, fossil power plant technologies will

have to make a noteworthy contribution to the energy supply in the upcoming two to three decades worldwide and surely also in Europe and especially in the Czech Republic. Linked to this is the need to develop power plants based on fossil fuels; efficiency increase, flexibility of load change and *Carbon Capture and Storage* are already successfully initiated directions which will also play a key role in reducing greenhouse gas emissions by 2050 and, in addition, offer future-oriented export opportunities for the German economy.
One process concept of CO_2 capture for power plants for the generation of electricity is the so-called *Oxyfuel Process*. In this *Oxyfuel Process* the combustion of, for example, coal takes place with a reaction gas consisting of oxygen and recirculated flue gas.
Extensive studies and developments of the *Oxyfuel Processes* have been carried out over the past two decades, especially for pulverized coal firings and for circulating fluidized bed combustions; by contrast there was less interest in bubbling fluidized bed combustions. The altered energy policy and economic framework increasingly require load and fuel flexible power plants, which is why bubbling fluidized bed combustions are gaining more importance especially for smaller capacities.

In his dissertation, Mister Skopec has set the task to examine the changed conditions in the *Oxyfuel Process* - in particular the gas composition – on the effect of the direct desulphurization in bubbling fluidized bed combustions on a laboratory and pilot scale. Compared to conventional combustion with air as reaction gas the *Oxyfuel Process* results in considerably changed gas compositions because of the omission of nitrogen and the high flue gas recirculation. The results are altered reaction conditions for the incorporation of sulfur into additives. For an application of the fluidized bed combustion in the oxyfuel mode, not only the advantages of an efficient load and fuel flexible mode of operation with CO_2 capture but also the reduction of further emissions, such as SO_2, are very important. At present, only a few examinations are available in a scale that is relevant for practical implementations. The task chosen by Mister Skopec is therefore of great scientific and practical interest.

Mister Skopec begins his work with a brief introduction in terms of energy policy and then describes the various CCS technologies whereby he, according to the topic, extensively deals with the topic of the bubbling fluidized bed combustion.
The focus of his work is on the examination of the reaction conditions for desulphurization using limestone as an additive in the bubbling fluidized bed in the oxyfuel mode for two different plants with different capacities (laboratory and pilot plant).
In chapter 2 of his paper, Mister Skopec first describes general aspects of the *Oxyfuel Process*. The description is kept short and concise due to the extensive literature, which is of advantage.
Similarly, chapter 3, in which Mister Skopec dedicates himself to the basics of desulphurization with limestone as an additive, is limited to the necessary context. These

basics are well known and widely described in textbooks and specialist books, which is why Mister Skopec has kept his statements with reference to the literature also short.
Chapter 4 once again constitutes the aims of the work, which is very helpful in classifying the work.
In chapter 5 of his work, Mister Skopec is dedicated to the theoretical analysis of the *Oxyfuel Processes* in conjunction with the pilot plants. Essentially, these are steady state mass, energy and material balances. These theoretical considerations are important but it would have been of advantage if Mister Skopec had indicated important constraints and parameters more detailed. It is not clear from the description which fuel (fuel composition) is assumed and which losses are taken as the basis for balancing. An adiabatic combustion temperature of about 1.200 °C seems to be very low.
Chapter 5 of the paper describes the experimental plants. Here, some information on the measurements sites/sampling points would have been useful. The description of the approach during the implementation of the experiments is well understandable.
Chapter 7 of his work contains a comparison of the theoretical balance with the results of the measurements. Such an evaluation of plausibility is very important.

In chapters 8 and 9, Mister Skopec compares the results of the conventional combustion with air as reaction gas with those of the *Oxyfuel Process*. To achieve equal desulphurization efficiencies, higher temperatures are expected to be required in the *Oxyfuel Process*. This results in a pronounced maximum in the *Oxyfuel Process* (at the selected conditions 80 to 95 % at about 880 °C). The important result for the practice here is that the *Oxyfuel Process* can achieve similarly high desulphurization efficiencies as in the conventional operation. This result is supported by the analyses of the bed material and the fly ash. Interesting is the fact that these results are also very consistent with the findings from the *Oxyfuel Process* in circulating fluidized beds. Good is the realization that the same results are achieved in the scale-up in terms of the desulphurization.
In the discussion of the results, little attention is paid to the separate examination and the interactions of the influencing variables O_2 concentration, SO_2 concentration, stoichiometry of additives as well as the coherent discussion of chemical kinetics and the associated heat and mass transport.
In chapter 10, Mister Skopec sententiously summarizes his work. Chapter 11 contains a short summary.

In my opinion - despite the points of criticism - Mister Skopec's work has advanced the state of knowledge for the direct desulphurization with limestone in bubbling fluidized beds in the oxyfuel operation.
Therefore, I would recommend to accept the dissertation as fulfillment of the doctoral performance and to continue the procedure.

In consideration of the task, methodical procedure, creativity and innovative character I rate the dissertation of Mister Ing. Pavel Skopec as "very good to good" (1,5).

Dresden, 13.03.2019

Prof. Dr.-Ing. Michael Beckmann