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FINDING NEW SEWAGE SLUDGE TREATMENT SOLUTIONS FOR THE ARCTIC CITY OF KIRUNA

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ABSTRACT: As Sweden's northernmost city, Kiruna has very particular demands for its sewage sludge treatment. This study tests hydrothermal carbonisation (HTC) as a treatment option for Kiruna to stabilize the sewage sludge, facilitate its transport by volume reduction and prepare the sludge for recovery of resources. The study consists out of an experimental part and a lifecycle assessment (LCA) development, which also gives options to use the results in other LCA scenarios incorporating HTC. Preliminary results show that HTC is a treatment that can fulfil Kiruna's demands and that an optimization of the treatment's settings can greatly increase the efficiency and effectiveness of the HTC treatment.

Keywords: Sewage sludge management, hydrothermal carbonisation, lifecycle assessment, EASETECH

1. INTRODUCTION

Kiruna is Sweden's northernmost city. The mining town has about 15 000 inhabitants in its urban centre and about five thousand more distributed over the municipality´s 20553 square kilometre surface, i.e. half the size of Denmark. The municipality is situated in arctic climate, and there is little farming within the area. The nearest biogas plant is about 310 km (road distance) away at the city of Boden. The local options for sludge use have already phased out or are being phased out at the moment. A local demand for energy or resources from the sludge is not existing. An upcoming treatment solution should therefore mostly focus on stabilizing the sludge and make it storable, as well as reducing its volume and thereby facilitate transport. Additionally, an upcoming treatment solution should ideally prepare the sludge for a further extraction of material resources or energy, which might be demanded by upcoming legislation.

Hydrothermal carbonisation (HTC) is a promising candidate for a treatment solution that can fulfil the requirements. During HTC, the wet sludge is heated up in a closed vessel to temperatures above 130 °C. Due to pressure and temperature the sludge is hygenized and a hydrochar is formed. The hydrochar can then be separated from the process liquor using less energy than conventional sludge dewatering and drying (Escala, Zumbühl, Koller, Junge, & Krebs, 2013). Wang et al. (2019) defined 160-250 °C as a feasible temperature range to produce hydrochar that can be used for energy recovery and a process liquor that can be treated biologically.

This study has the aim to test if Kiruna's sewage sludge can be treated with HTC, find optimized settings for the treatment and evaluate the environmental impact of the treatment in comparison to other treatment options by utilizing a lifecycle assessment (LCA) approach. Although the study focuses on the demand of Kiruna, the results can also be utilized in other scenarios where HTC is an option for sewage sludge treatment.

2. METHOD

The study consists out of an experimental part with HTC experiments in lab scale (see 0) and a second part where the experimental results are used to develop a lifecycle assessment model (see 0).

2.1 Experiments

In the HTC experiments it is systematically tested how variations of the factors treatment temperature, retention time and moisture content of the sludge affect the treatment of both fresh and intermediately stored sludge. By optimization of the factors, effective treatment conditions can be found.

The HTC experiments were conducted in a MARS 5 microwave reaction system with 40 g of material in each vessel. All experiments were conducted in triplicates. Later experiments were conducted in a büchiglasuster novoclave autoclave reactor. These experiments were conducted with 80 g of material in each vessel and due to the higher volume not in triplicates.

After the HTC treatment the samples were centrifuged in an Eppendorf 5804 lab centrifuge at 10 000 rpm for 10 min. The process liquor and solid phase were separated by decanting and pH and electric conductivity determined in the process liquor. Subsequently, all samples were dried at 50 °C for one week to determine the total solids (TS). The low drying temperature was chosen to avoid evaporation of volatile fatty acids. Some samples were further analysed for their volatile solids (VS) content by heating them up to 550 °C for two hours.

All experiments were planned and evaluated with help of the experimental design software Umetrics MODDE 12.1. The experimental design is a full factorial design with four factors which are shown in Table 1. The experiments are conducted as a screening test to determine sweet spots and optimize the combination of the factors. For promising settings, further experiments with comprehensive analyses will be conducted. These analyses will include biomethane potential tests as well as elemental analyses on the process liquor. As well as elemental analyses and combustion experiments on the solid phase/hydrochar.

Table 1. Factors used in the experimental design and their type and tested range.

Factor	Type	Range
Temperature of HTC treatment	Quantitative	160-250 °C
Retention time of HTC treatment	Quantitative	30-120 min (+30 min heat up)
TS content of ingoing sludge	Quantitative	12-25% TS
Type of sludge	Qualitative	Fresh or stored (~4 yr.) sludge

2.2 System Perspective – LCA development

The data gained in the experimental part will be utilized in energy and mass balances of the treatment process. These balances will serve as a basis for the development of a lifecycle assessment process module in the software EASETECH for HTC as treatment for sewage sludge. The process module can be utilized in lifecycle assessments for various scenarios where HTC could be a potential treatment option. One of these scenarios will be Kiruna. The LCA methodology will help to evaluate environmental impacts of different treatments in combination with the prerequisites of Kiruna e.g. long distances to other treatment facilities.

3. PRELIMINARY RESULTS AND DISCUSSION

The HTC screening test is finished for all factors apart from “TS content of ingoing sludge”. First preliminary results can be presented and comparisons to literature can be made. In general, all experiments showed that higher temperatures can be utilized during HTC to shorten the retention times. Experiments with an HTC treatment at 230 °C for 120 min showed similar treatment results as treatments at 250 °C for only 30 min. These findings are supported by the semi-empirical coalification model developed by Ruyter (1982), which shows similar conversion factors for the two experimental settings.

The distribution of 1 g ingoing solids to the process liquor and the solid phase is shown in Figure 1 and Figure 2. The higher the temperature and the longer the retention time, the more solids are transferred to the process liquor. The plots also show that the mass balance of solids in process liquor and solid phase cannot be closed. This is especially the case at higher temperatures and longer retention time and indicates that more solids were transferred to the gas phase.

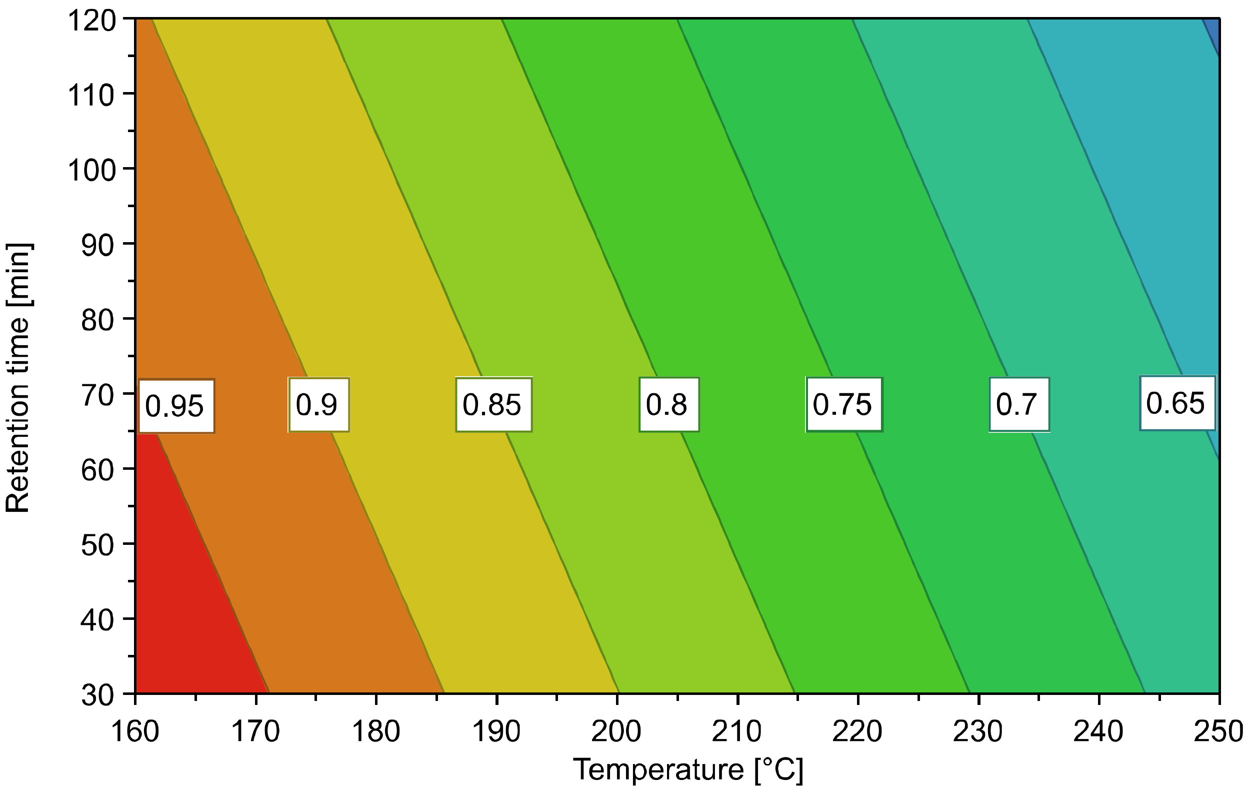

Figure 1. Contour response plot from MODDE showing how much of 1 g ingoing solids are transferred to the solid phase/hydrochar. The ingoing sludge before treatment had 12% TS and was fresh (not intermediately stored). Model quality: R2=0.96; Q2=0.94

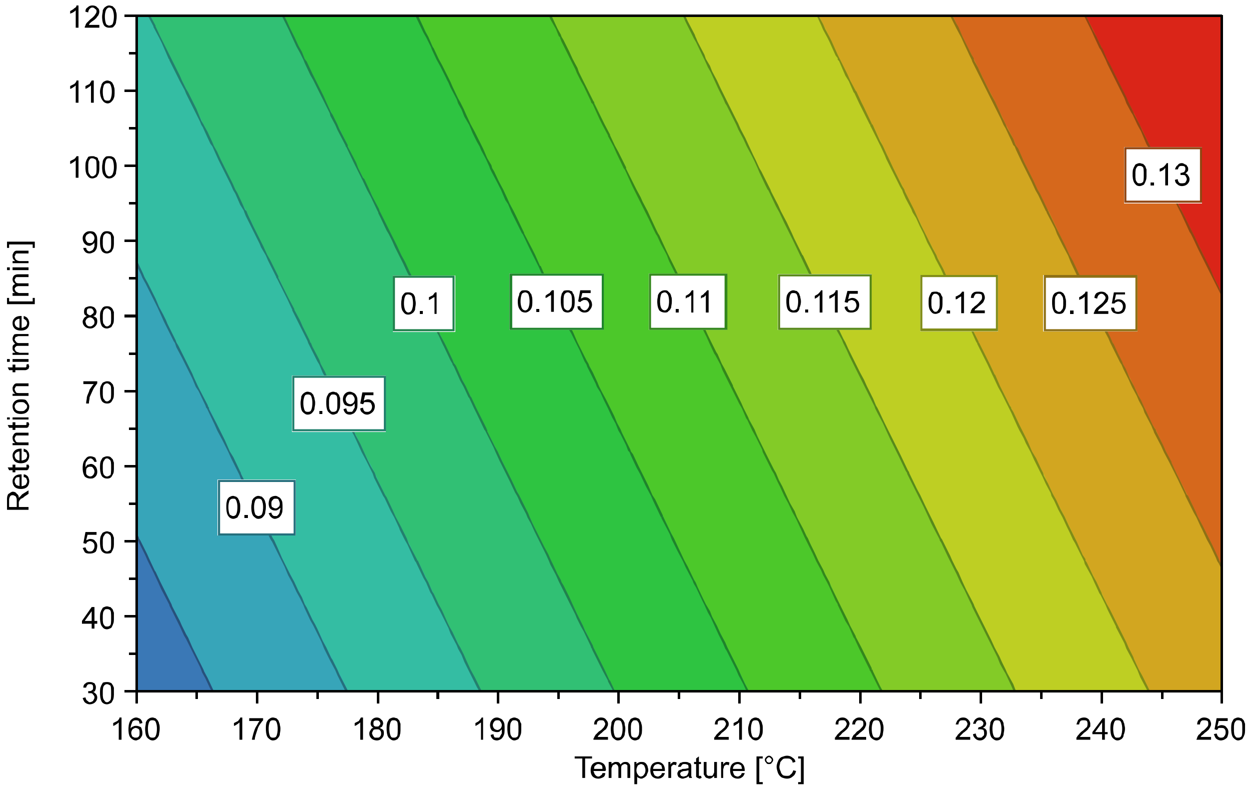

Figure 2. Contour response plot from MODDE showing how much of 1 g ingoing solids are transferred to the process liquor. The ingoing sludge before treatment had 12% TS and was fresh (not intermediately stored). Model quality: R2=0.98; Q2=0.96

Also, the dewaterability of the sludge is affected by the HTC treatment. Figure 3 shows the TS content of the solid phase/hydrochar after centrifugation. A better dewaterability was achieved at higher temperatures and longer retention times, with a bigger influence of temperature. The dewaterability results are comparable to the findings of Wang et al. (2019) and Yu et al. (2014).

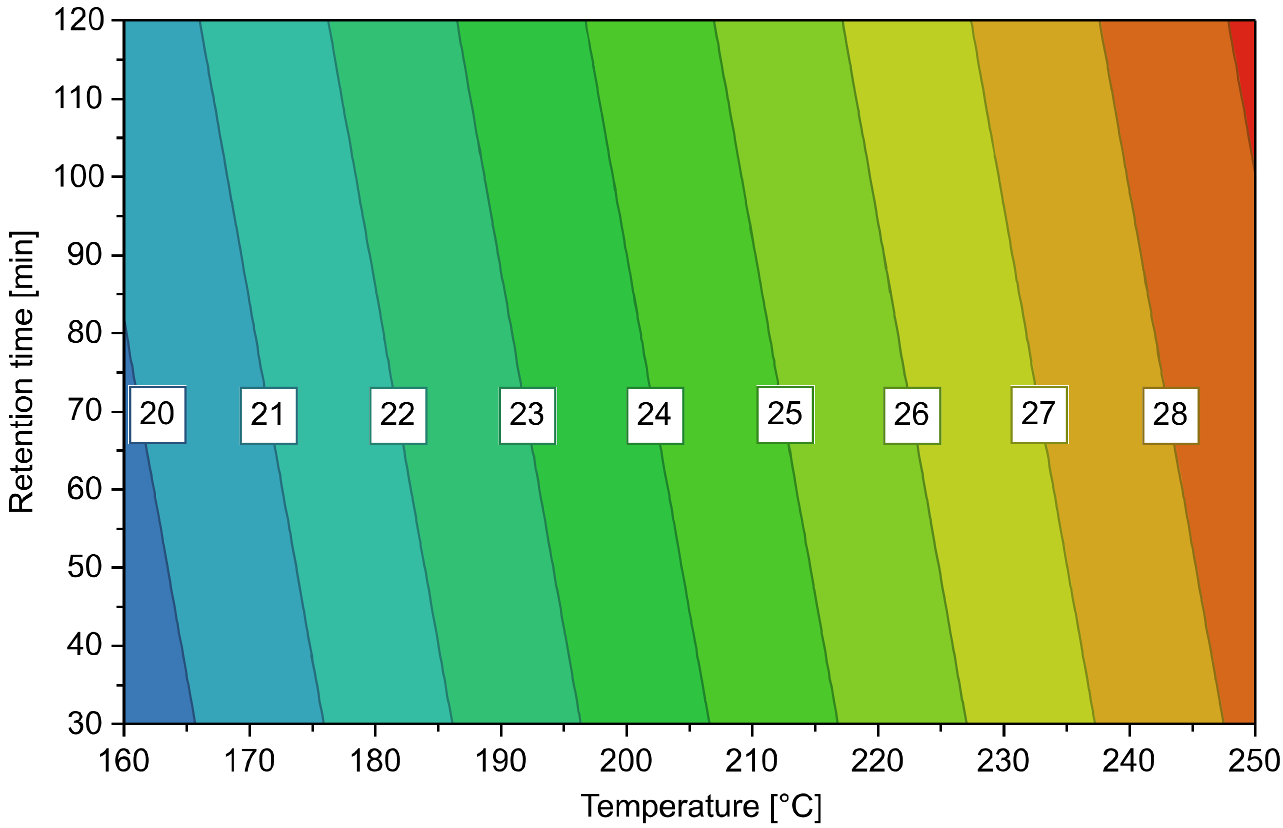

Figure 3. Contour response plot of the TS content in % in the solid phase/hydrochar after dewatering by centrifugation. The ingoing sludge before treatment had 12% TS and was fresh (not stored). Model quality: R2=0.71; Q2=0.60

Experiments with an ingoing sludge with a TS content of 25% show that the dewaterability after HTC treatment was even further improved. Next to this, the high TS content in the ingoing sludge leads to a higher concentrated process liquor. In literature it is stated that higher TS contents in the ingoing sludge also lead to a production of more hydrochar since less material is transferred to the process liquor (Wang et al., 2019). The experiments with high TS in the ingoing sludge also indicate this but further experiments are necessary to fully proof this.

Comparing the results of intermediately stored and fresh sludge, it can be stated that both types of sludge are similarly affected by variations of the factors of HTC treatment. The main difference can be found in the VS content of the hydrochar, which is significantly lower for the intermediately stored sludge, and in the transfer of solids to the process liquor, which is less for the intermediately stored sludge. These two effects can easily be explained by uncontrolled stabilization as well as uncontrolled leaching of the intermediately stored sludge. This resulted in already reduced VS content in the intermediately stored sludge before HTC treatment.

First tests with the büchiglasuster autoclave system show that the results are similar to ones of the microwave reactions system. Therefore, results from both equipment setups are equally presented. The usage of two different equipment setups helps to minimize possible influences of certain equipment characteristics.

In general, first results are promising and the models show a high validity and reproducibility (values given in each figure). The analysis of effects of temperature, retention time and TS content of the ingoing sludge at the same time are a novelty and have not been found in literature on HTC treatments of sewage sludge (Danso-Boateng et al., 2015; Wang et al., 2019).

4. CONCLUSIONS & OUTLOOK

The conducted experiments show promising results which also match with results from literature. The performed and upcoming tests increase the understanding of interactions between settings of HTC treatments and properties of the produced hydrochar and process liquor. This gives options for optimized treatment parameters which lead to a greatly increased efficiency and effectiveness of the treatment.

Results already show that the produced hydrochar is stabilized, easy to store and handle and strongly reduced in volume and water content. If applied by Kiruna city, the intermediate storage can be reduced in size and the risk for environmental pollution and health related issues by the sewage sludge can be drastically reduced. Apart from this HTC also gives the possibility to treat other organic waste streams in combination with the sludge (e.g. food waste) and by that facilitate treatment and transport of these waste streams as well. Further combustion experiments will show pathways for resource recovery from the hydrochar and experiments on process liquor will examine its biodegradability.

The results from the experimental stage will be directly applied in the LCA development. This will give possibilities to assess environmental impacts of sewage sludge treatment systems incorporating HTC in various scenarios including Kiruna's.

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REFERENCES

Danso-Boateng, E., Shama, G., Wheatley, A. D., Martin, S. J., & Holdich, R. G. (2015). Hydrothermal carbonisation of sewage sludge: Effect of process conditions on product characteristics and methane production. Bioresource Technology, 177, 318–327. https://doi.org/10.1016/j.biortech.2014.11.096

Escala, M., Zumbühl, T., Koller, C., Junge, R., & Krebs, R. (2013). Hydrothermal Carbonization as an Energy-Efficient Alternative to Established Drying Technologies for Sewage Sludge: A Feasibility Study on a Laboratory Scale. Energy & Fuels, 27(1), 454–460. https://doi.org/10.1021/ef3015266

Ruyter, H. P. (1982). Coalification model. Fuel, 61(12), 1182–1187. https://doi.org/10.1016/0016-2361(82)90017-5

Wang, L., Chang, Y., & Li, A. (2019, July 1). Hydrothermal carbonization for energy-efficient processing of sewage sludge: A review. Renewable and Sustainable Energy Reviews. Elsevier Ltd. https://doi.org/10.1016/j.rser.2019.04.011

Yu, J., Guo, M., Xu, X., & Guan, B. (2014). The role of temperature and CaCl2 in activated sludge dewatering under hydrothermal treatment. Water Research, 50, 10–17. https://doi.org/10.1016/j.watres.2013.11.034