SEWAGE SLUDGE DRYING AND HEATING VALORIZATION

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This study explores a sustainable method for converting sewage sludge with 80% water content into reusable biochar through drying and pyrolysis. The drying phase reduces water content to 12-15% using energy from pyrolysis-produced biochar, minimizing external energy requirements. Pyrolysis decomposes organic materials, producing biochar, gases, and oils, which are burned for energy recovery. The biochar can be reused up to eight times, enhancing resource efficiency and sustainability. Heat generated during both drying and pyrolysis is recycled within the system, further improving energy efficiency. The process demonstrates an innovative, closed-loop approach to waste management, minimizing waste and maximizing energy recovery, with significant potential for industrial applications.

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1 Introduction to Sewage Sludge Treatment

Sewage sludge is an inevitable byproduct of municipal and industrial wastewater treatment processes. As urban populations and industrial activities grow, the volume of sewage sludge generated also increases, presenting significant challenges for its management and disposal. Typically, sewage sludge consists of a mixture of water, organic materials, microorganisms, and inorganic solids. Its high moisture content, often around 80%, makes it heavy and voluminous, which complicates transportation and disposal. Additionally, the organic content can be a source of energy if properly processed, but it can also pose environmental hazards if not managed correctly.

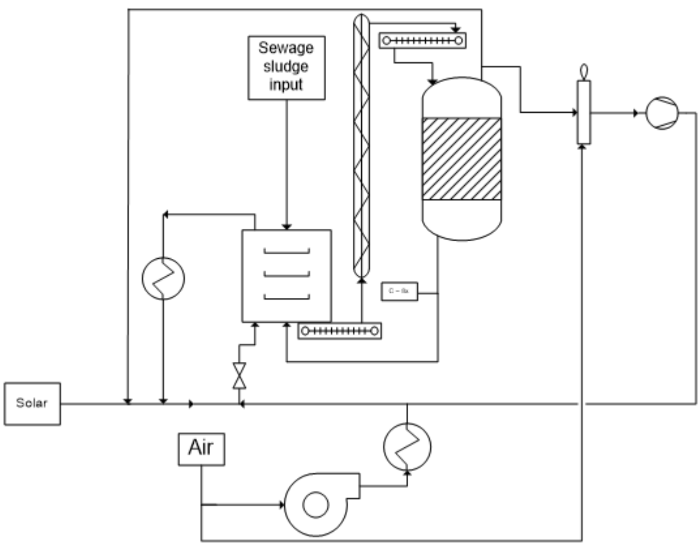

Figure 1: Process of drying and pyrolysis of sewage sludge

Conventional methods of sludge disposal, such as landfilling, incineration, and agricultural use, are facing increasing scrutiny and regulatory constraints due to concerns over environmental contamination, greenhouse gas emissions, and long-term sustainability. As a result, there is a growing interest in innovative treatment technologies that can reduce the volume of sludge, recover valuable resources, and minimize environmental impacts. One such promising approach involves the integrated process of drying sewage sludge followed by pyrolysis. This method not only reduces the moisture content and volume of the sludge but also converts it into valuable by-products like pyrolysis gas and biochar, thereby enhancing the overall sustainability and economic viability of sludge management.[1]

2 Drying Process

2.1 Characteristics of Sewage Sludge

The raw sewage sludge entering the drying process has an input flow rate of 1 tonne per hour (1000 kg/h) with an initial moisture content of 80%, equivalent to 800 kg of water and 200 kg of dry solids. The sludge's initial temperature is 20 °C. Given its high moisture content, substantial drying is required to reduce its weight and volume, making it more manageable for further processing and disposal.

2.1 Heating the Sewage Sludge

The first critical step in the drying process is to raise the temperature of the sewage sludge from 20 °C to 60 °C. This heating is essential to enhance the evaporation rate during the drying phase. The energy required for this temperature increase, considering the specific heat capacity of the sludge, amounts to 55.6 kWh. This heating process ensures that the sludge reaches an optimal temperature for effective moisture removal in the subsequent drying stage.

2.1.1 Air Used for Drying

In addition to heating the sludge, the drying process requires a significant amount of heated air to facilitate the evaporation of water content. The air must be heated from its ambient temperature to the required drying temperature of 60 °C. The input air flow rate is 3000 kg/h, and the final air flow rate after drying is 765 kg/h. The energy required for heating this air is 69 kWh. The moisture content of the air used for drying is 0.003 kg H_2O per kg of dry air. Heated air at 60 °C, with this moisture

[1] Dušan Klinar, 'Universal Model of Slow Pyrolysis Technology Producing Biochar and Heat from Standard Biomass Needed for the Techno-Economic Assessment', *Bioresource Technology*, 206 (2016), pp. 112–20, doi:10.1016/j.biortech.2016.01.053.

content, maximizes the drying process's efficiency by absorbing more moisture from the sludge, thereby accelerating the drying rate.

2.1.2 Detailed Drying Process

The primary objective of the drying process is to reduce the moisture content of the sewage sludge from 80% to 15%. This involves removing a substantial amount of water, which requires precise control of temperature and airflow. The output sewage sludge flow rate is 235.3 kg/h with a final moisture content of 15%, and the energy required for drying is 764.71 kWh. The drying phase involves several key steps:

- **Pre-Heating**: The pre-heated sludge is exposed to hot air, initiating the evaporation of surface moisture.
- **Moisture Removal**: As the process continues, moisture within the sludge gradually moves to the surface and evaporates.
- **Drying Rate**: The drying rate is governed by factors such as temperature, airflow, and the physical characteristics of the sludge.
- **End Point:** The process continues until the sludge reaches the desired final moisture content of 15%.

The enthalpy change associated with drying is critical, as it represents the energy required to evaporate the water content from the sludge. This process is energy-intensive, necessitating efficient energy use and recovery strategies.

2.1.3 Total Energy Requirements for the Drying Process

Summarizing the energy inputs required for the drying process, the energy for heating sewage sludge is 55.6 kWh, the energy for heating air is 69 kWh, and the energy for the drying process is 764.71 kWh, resulting in a total energy requirement of 889 kWh. This comprehensive energy requirement underscores the need for efficient energy recovery and supplementation methods to ensure the process's sustainability.

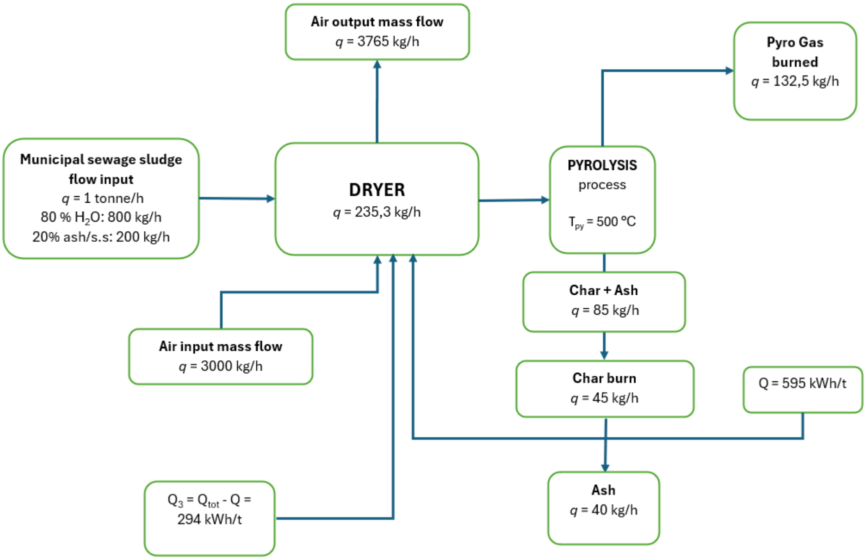

Figure 3: Process mass balances

3 Pyrolysis Process

Post-drying, the sewage sludge undergoes pyrolysis, a thermochemical decomposition process conducted in the absence of oxygen. The pyrolysis in this scenario is a slow pyrolysis method occurring at a temperature of 500 °C. Slow pyrolysis is characterized by a longer residence time, which maximizes the yield of solid char compared to faster pyrolysis processes that favour liquid and gas products.[2]

Pyrolysis transforms the organic components of the dried sludge into valuable by-products such as pyrolysis gas and biochar. The dried sewage sludge input is 235.3 kg/h, and the pyrolysis gas production is 132.5 kg/h, yielding 232 kWh of energy. Additionally, biochar production is 45 kg/h, which, when burned, provides 363 kWh of energy. Ash production is 47.1 kg/h. The pyrolysis process involves several stages:

[2] Aida Hosseinian and others, 'Life Cycle Assessment of Sewage Sludge Treatment: Comparison of Pyrolysis with Traditional Methods in Two Swedish Municipalities', *Journal of Cleaner Production*, 455 (2024), doi:10.1016/j.jclepro.2024.142375.

- **Dehydration:** Any remaining water in the dried sludge evaporates.
- **Decomposition**: Organic materials break down into gases, liquids, and solids (biochar).
- **Gas Collection:** The gases produced (pyrolysis gas) are collected and can be used as a fuel source.
- **Char Production:** The remaining solid fraction is converted into biochar, a carbon-rich product with potential energy and soil amendment applications

3.1 Energy Recovery from Pyrolysis

The energy produced from the pyrolysis process can be harnessed to offset the energy requirements of the drying process. The contributions from pyrolysis gas and biochar are substantial, amounting to a total of 595 kWh. This recovered energy plays a crucial role in making the overall process more energy efficient and reducing the reliance on external energy sources.

3.2 Energy Deficit Analysis

Despite the significant energy recovery from pyrolysis, there remains an energy deficit that must be addressed to ensure the process's viability. The total energy required for drying is 889 kWh, while the energy produced from pyrolysis is 595 kWh, resulting in an energy deficit of 294 kWh (missing 33 %). This shortfall highlights the need for additional energy inputs to fully meet the drying process's energy demands.

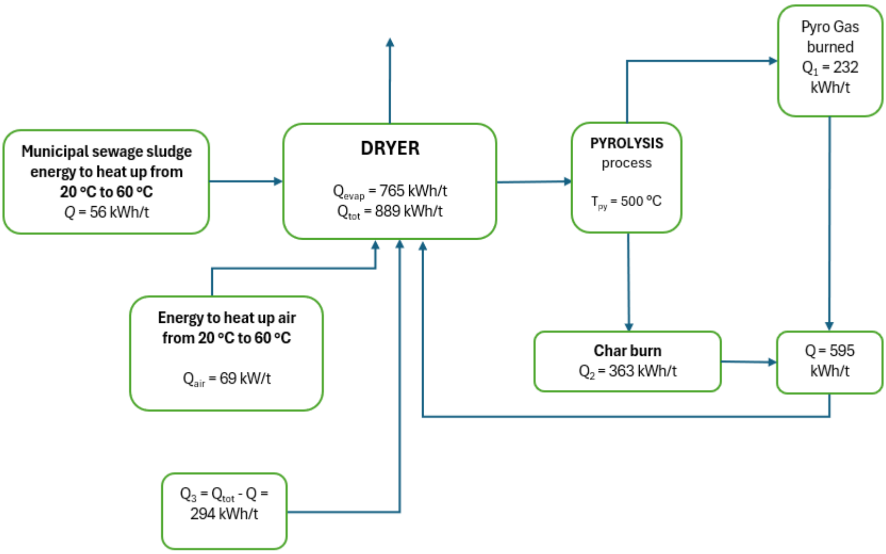

Figure 4: Process energy balances

4 Process Optimization and Reuse of Char

To enhance the efficiency of the drying process, biochar produced during pyrolysis can be reused multiple times. Char has excellent thermal properties and can be used as a heat transfer medium in the drying process. By incorporating biochar back into the drying system, it is possible to optimize the heat transfer rates, thereby reducing the overall energy consumption. Biochar can typically be reused about eight times in the drying process before it needs to be replaced, which contributes to a reduction in operational costs and energy use.

4.1 Environmental and Economic Benefits

The integrated process of sewage sludge drying with char and pyrolysis offers significant environmental and economic benefits:[3]

[3] Salman Raza Naqvi and others, 'Recent Developments on Sewage Sludge Pyrolysis and Its Kinetics: Resources Recovery, Thermogravimetric Platforms, and Innovative Prospects', *Computers and Chemical Engineering* (Elsevier Ltd, 2021), doi:10.1016/j.compchemeng.2021.107325.

- **Volume Reduction**: By reducing the moisture content and converting the organic matter into char and gas, the volume of sewage sludge is significantly reduced, lowering transportation and disposal costs.
- **Resource Recovery:** Pyrolysis gas can be used as a fuel source, and biochar has potential applications as a soil amendment, enhancing soil fertility and carbon sequestration.
- **Energy Efficiency:** The process maximizes energy recovery, reducing the reliance on external energy sources and contributing to a more sustainable operation.
- **Reduced Environmental Impact:** By minimizing the amount of sludge sent to landfills or incinerated, the process reduces greenhouse gas emissions and potential leachate issues.

5 Conclusion

The integrated process of sewage sludge drying with char and pyrolysis represents a forward-thinking approach to managing the complex challenge of sewage sludge disposal. By leveraging the combined benefits of drying and slow pyrolysis at 500°C, this method not only reduces the volume and moisture content of the sludge but also generates valuable by-products such as pyrolysis gas and biochar, which can be used as energy sources. This approach significantly enhances the sustainability and economic viability of sludge management by recovering energy and reducing environmental impact.[4]

Despite the process's efficiency, an energy deficit remains, necessitating the integration of additional renewable energy sources like solar panels or efficient systems such as heat pumps. These supplementary energy sources help bridge the gap, making the overall process more self-sufficient and environmentally friendly.

In summary, the drying and pyrolysis of sewage sludge offer a promising solution to the growing problem of sludge disposal. This integrated approach not only addresses the immediate need for effective sludge management but also contributes to broader

[4] Xiaoguang Liu and others, 'Pre-Drying Limitedly Affected the Yield, Fuel Properties, Pyrolysis and Combustion Behavior of Sewage Sludge Hydrochar', *Waste Management*, 184 (2024), pp. 63–71, doi:10.1016/j.wasman.2024.05.032.

environmental goals by minimizing waste, recovering energy, and producing useful by-products. As urbanization and industrial activities continue to expand, such innovative and sustainable methods will be essential for managing the by-products of human activity in an environmentally responsible manner.

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