Proximate, ultimate and calorific value analyses of paper industry sludge at different moisture content

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Abstract. Paper industry has a big potency of energy that can be reused in its sludge. However, the water content of the sludge is still high and need to be dried. In this study, the characteristics of the sludge at different water content are explored. The sludge is collected from paper industry in Sumatera Utara province of Indonesia mainly at 70% water content. The experiments are carried out at lower water content that is from 10% to 60%. The proximate and ultimate analyses are carried out and the calorific values are discussed. The objective is to explore the potency of the sludge if it is employed as solid fuel. The results show that reducing water content of the sludge affects the characteristics of the sludge. The lower water content increases fixed carbon value, calorific value and volatile matter.

1. Introduction
The global warming, if is not controlled, can be a catastrophe in the future. In order to save the human being from catastrophe, emission of Greenhouse Gases (GHGs) must be reduced. Reducing fossil fuel consumption is a significant mitigation action to reduce the GHGs emission. This can be done by enhancing the utilization renewable energy and increase the energy efficiency [1]. Increasing the energy efficiency include improvement the process and also recovery system [2]. Here the strategy include reuse the waste [3]. There many industries can implement the reuse strategy, one of those is paper industry. The industry has a big potency of energy that can be reused in its sludge. However, the water content of the sludge is still high and need to be reduced. Many researchers have proposed strategy and innovation to reuse the sludge of paper industry. Chen et al. [4] reported a study on recycling of paper sludge powder for achieving sustainable and energy-saving building materials. The effects of paper sludge powder on properties of Calcium silicate board materials (CSBM) were reported. The experimental results indicate that single addition of 30% paper sludge ash of 20% alkali recovery paper sludge can improve the flexural strength of CSBM effectively. The conclusion of the study is that the utilization of paper sludge powder presents a great potential to develop sustainable and energy-saving CSBM with enhanced flexural strength and reduced water absorption. Azevedo et al. [5] reported a study on the evaluation the effect of partial substitution of paper sludge, up to 20 wt%, for lime in cementitious mortars. The results reveals that for use in wall and ceiling mortar coatings, the level of incorporation should not exceed 10%. The reason is that higher levels yield lower values of mechanical strength resistance and will incompatible with market requirement. An et al. [6] reported the study on the
performance and energy recovery of a single and two stage biogas production from paper sludge. The study suggests that the potential application of the established two-stage process in valorization of low-value waste biomass. Azevedo et al. [7] assess the potential of sludge generated by the pulp and paper in assembling locking blocks. The objective is to analyze the feasibility of incorporating sludge from the pulp and paper industry in soil-cement block using 10% cement and 90% compensated soil. The energy saving in the process of bioethanol production from paper mill sludge examined by Salameh et al. [8]. In specific the objective is to reuse the wastewater produced during the de-ashing step as a substitute for freshwater addition during the conversion of paper mill sludge into ethanol. The results showed that wastewater recycling minimized the energy demands in the distillation and evaporation units by 1206 kJ/kg. The energy reduction due to the increase of metals and total soluble solids in both stream after fermentation. Glinska et al. [9] studied the recovery and characterization of cellulose from industrial paper mill sludge using tetrakris and imidazolium based ionic liquids. It was shown that the recovery cellulose from paper industry sludge is feasible with ionic liquid. However, improvement of the performance is needed to allow scale-up of the technology. Recently, Azevedo et al. [10] make comparison of the processing of primary sludge waste from paper industry for mortar from technological and environmental aspects. The conclusion is that the beneficiation process, which produces the thin liquid is the most efficient for the incorporation of waste into mortars when compared to the dry method.

Those literature show that mainly the sludge of the paper industry is recycled to produce building materials. A few study uses the strategy converting the waste into energy. The used method is converting the waste into ethanol production. Our work focuses on how to convert the sludge into energy. The used method is by reducing its water content and becoming biomass. In this work the characteristics of the sludge at lower water content will be explored. The results are expected to support the necessary information to convert sludge into energy.

2. Experimental method

![Experimental equipment](image)

**Figure 1.** Experimental equipment

In this section sample preparation and experimental method are explored. The experimental setup consists of oven, bomb calorimeter, digital balance and desiccant. These components are depicted in
3. Results and Discussions
In the experiment the sludge is then divided into six groups. Each group is dried to a certain number of water content. The water content is dry based. The target of the water contents are 10%, 20%, 30%, 40%, 50% and 60%. To each component the proximate analysis, ultimate analysis and calorific value analyses are carried out. The results are presented in the below section.

3.1. Proximate analysis
The proximate analysis has been carried out for all samples and the results are presented in Table 1. In the top line it is mentioned that there are six samples have been tested. The water content varied from 11.72% to 61.5%. The tested parameters are Ash, Volatile matter and Fixed Carbon. The ash content in the sludge is not affected by water content. On the other hand, volatile matter increase with decreasing water content in the sludge. Furthermore, the fixed carbon in the sludge increase with decreasing water content.

| Parameter          | Sample |       |       |       |       |       |
|--------------------|--------|-------|-------|-------|-------|-------|
| Water content      | A      | 61.5% | B      | 49.4% | C      | 39.64% |
|                    |        |       |        |       |        | 28.96% |
|                    |        |       |        |       |        | 19.28% |
|                    |        |       |        |       |        | 11.72% |
| Ash                | A      | 11.18%| B      | 11.47%| C      | 11.52% |
|                    |        |       |        |       |        | 10.94% |
|                    |        |       |        |       |        | 9.10%  |
|                    |        |       |        |       |        | 8.20%  |
| Volatile matter    | A      | 22.37%| B      | 28.48%| C      | 31.48% |
|                    |        |       |        |       |        | 35.64% |
|                    |        |       |        |       |        | 34.95% |
|                    |        |       |        |       |        | 33.29% |
| Fixed Carbon       | A      | 5.30% | B      | 10.71%| C      | 17.36% |
|                    |        |       |        |       |        | 24.46% |
|                    |        |       |        |       |        | 36.67% |
|                    |        |       |        |       |        | 46.79% |

3.2. Ultimate analysis
The results of the ultimate analysis is shown in Table 2. The tested parameters are Carbon, Hydrogen, Nitrogen and Sulphur. It can be seen that there is no effect of water content in the sludge to all those parameters.
Table 2 Ultimate Analysis

| Parameter      | Sample | A       | B       | C       | D       | E       | F       |
|----------------|--------|---------|---------|---------|---------|---------|---------|
| Water content  |        | 61.5%   | 49.4%   | 39.64%  | 28.96%  | 19.28%  | 11.72%  |
| Carbon         |        | 14.28%  | 16.12%  | 18.51%  | 21.57%  | 25.98%  | 29.42%  |
| Hydrogen       |        | 7.70%   | 7.62%   | 7.54%   | 7.46%   | 7.37%   | 7.29%   |
| Nitrogen       |        | 0.42%   | 0.45%   | 0.49%   | 0.53%   | 0.57%   | 0.61%   |
| Sulphur        |        | 0.11%   | 0.11%   | 0.12%   | 0.12%   | 0.12%   | 0.13%   |

3.3. Calorific value

The calorific value for all samples has been tested and shown in Table 3. In order to make comparison the theoretical Low Heating Value (LHV) and High Heating Value (HHV) of the samples are also presented in Table 3. It can be seen that those parameters show the same trend. The calorific value increase as water content decrease. In addition, the present calorific value drawn from experimental is within the range of LHV and HHV. Same for all samples.

Table 3 Calorific value

| Parameter | Sample | A       | B       | C       | D       | E       | F       |
|-----------|--------|---------|---------|---------|---------|---------|---------|
| LHV (Theoretical) [kcal/kg] |        | 1175.43 | 1288.62 | 1522.94 | 1786.65 | 2208.49 | 2478.46 |
| HHV (Theoretical) [kcal/kg] |        | 1215.43 | 1321.22 | 1549.13 | 1805.78 | 2221.23 | 2470.72 |
| Experimental [kcal/kg] |        | 1216.8  | 1304.3  | 1544.4  | 1782.6  | 2226.2  | 2438.10 |

4. Conclusions

In the present work the characteristics of sludge from the paper industry has been tested experimentally. There are six samples at different water content have been analyzed. The proximate analysis, ultimate analysis and calorific value analysis have been carried out. The main conclusion are as follows. The ash content in the sludge is not affected by water content. On the other hand, volatile matter increase with decreasing water content in the sludge. Furthermore, the fixed carbon in the sludge increase with decreasing water content. The calorific value increase as water content decrease. In addition, the present calorific value drawn from experimental is within the range of LHV and HHV. Same for all samples.

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