

Mechanical Dewatering and Thermal Drying Characteristics of Pulp Mill Sludge Cake

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Abstract

Sludge cake is a type of solid waste in pulp and paper mills which may harm the environment if disposed without treatment. Its proximate analysis (adb) are: ash 26.74%; volatile matter 59.09%; fixed carbon 11.04%; moisture 3.13%, while its ultimate analysis (adb) are: C 33.46%; H 4.5%; N 1.14%; S 0.35%; O 33.81%. Having a calorific value of 3000 cal/g (adb), sludge cake may be used as renewable fuel. Unfortunately it has a high water content, so reduction of water content become a main concern in utilizing sludge cake. A combination of mechanical dewatering and thermal drying has been considered for water removal with a minimum energy consumption. Moreover, the application of pressurized mechanical dewatering may also play a role in formation of briquettes.

Experiments on mechanical dewatering and thermal drying were carried out using 50 g sludge cake with initial water content 73%. With a pressure of 400 kg/cm² for compression, water content at the end of mechanical dewatering was 57%. This dewatered sludge was subsequently treated using thermal drying to a moisture content of 15%. Calculated total energy for this combination of mechanical dewatering and thermal drying was about 1080 J/g. This value was lower than the energy consumption of 1520 J/g required for direct thermal drying from its moisture content of 73% down to 15%. Experiments on the use of coal powder as compression aid were also trial to improve sludge dewaterability and briquettes calorific value. Mechanical dewatering of sludge with addition of 20%-w/w coal powder resulting a briquette with moisture content of 38% at compression pressure of 400 kg/cm². The drying curves of briquette did not affected with its size if its diameter was less than 0.5 cm. Briquette with 1 cm thickness took significantly more time to remove its water content.

Keywords: Sludge cake; Dewatering; Drying; Briquette

1. Introduction

Sludge cake handling are not only requires high cost, but also become an environmentally sensitive issue. This problem is growing along with increased production of sludge cake and strict environmental quality standards set by the government. The challenge is to find innovative solutions and cost-effective, with due regard to environmental and applicable law [Hall, 2000]. Limited reserves of fossil fuel and rising of its prices pushed industrial sector to make conservation and diversification of energy resources. Several attempts have been made, including using sludge cake as renewable energy resource that available in the pulp mills plant. Some technologies had been developed to process the sludge cake into fuel. The common technology is processing sludge cake to biogas, but this technology has not been able to obtain high conversion of methane.

Sludge cake is produced from the pulp mill at 58 kg / ton pulp. On the basis of its calorific value and composition, pulp mill sludge cake has the potential to be used as briquettes. However, the high water content causes the sludge cake cannot be used directly. Pre-treatment are necessary prior sludge cake utilization as briquette. The problem arised as pulp mills sludge cake have high organic content. The presence of intracellular water in organic matter makes the mechanical dewatering process become difficult. Special treatment is required to reduce the effects of intracellular water in the sludge cake dewaterability and increase the rate of dewatering. Sludge cake treatment with char and carbon powder had been investigated and patented in recent years [Qi, 2007]. Reduction of water content can also be done by evaporative thermal drying. The thermal drying process need a very

large (hundreds times greater) energy than dewatering process [Chen, et al, 2006]. However, the mechanical dewatering has a limit value of moisture content that can be achieved, so combination of mechanical dewatering and drying processes is needed.

This study is intended to process pulp mills sludge cake into briquettes which can be used for boiler fuel or in gasification processes (at water content 10%). In particular, the purpose of this study are to (i) determine the optimum dewatering pressure so that the combination of dewatering and drying requires the most energy minimum, (ii) identify the effect of coal powder addition in dewatering characteristics, and (iii) identify the influence of briquettes dimensions in drying processes.

2. Experimental

Materials used in this experiment are (i) sludge cake from pulp mills in South Sumatra and (ii) coal powder that used as compression aid. Powdered coal have size of 32-60 mesh.

Table 1. Analys parameters of the materials

No	Analysis Parameters	Sludge Cake	Coal Powder
1	Proximate (adb)		
	- Moisture	3.13%	18.70%
	- Ash	26.74%	4.30%
	- Volatile matter	59.09%	42.09%
	- Fixed carbon	11.04%	34.90%
2	Ultimate (adb)		
	- Carbon	33.46%	51.71%
	- Hidrogen	4.50%	3.09%
	- Nitrogen	1.14%	0.57%
	- Sulphur	0.35%	0.45%
	- Oxigen	33.81%	21.22%
3	Calorific value	3055 cal/g	4860 cal/g

The experimental devices are presented in Figure 1. Mechanical dewatering and briquetting experiments were conduttet in a hydraulic press equipment, while drying experiments were carried out using an tubular reactor electrical furnace with 3 cm diameter and 40 cm high.

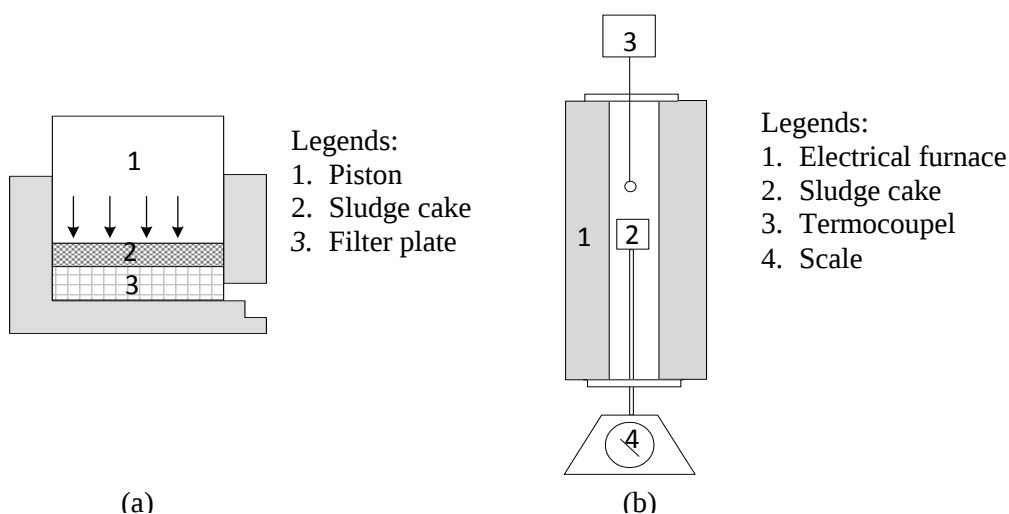


Figure 1. Experimental devices: (a) hydraulics press, (b) electrical furnace

Mechanical dewatering and briquetting can be assumed as one step experiment, as the product of the dewatering process is in the form of briquettes. 40 gram of wet sludge cake (with initial water content 73%) is inserted into the hidraulic press and pressed at bar, until the pressure gauge needle stops moving. Water discharged through the bottom of the clamp device housed in a beaker. The mass of dewatered sludge cake (briquette) are measured. The briquette then dried in an oven for 6 hours and after it recorded its mass. This experiment was repeated with pressure of 100, 150, 200, 250, 300, 350, and 400 bars.

The briquette were divided into three parts, the first 5 grams were crushed into powder, the second part were molded to produce briquettes with thickness of 0.5 cm and diameter of 1 cm, and the third part were molded to produce briquettes with thickness of 1 cm and diameter of 1 cm. Each part then dried in the electrical furnace at a temperature of 110°C while noting the time for each 0.01 gram mass reduction until constant mass was reached.

Sludge cake was mixed with 5% weight of coal powder. 50 grams of this mixture were dewatered at 50 and 400 bars. The briquettes produced were divided into three parts, the first 5 grams were crushed into powder, the second part were molded to produce briquettes with thickness of 0.5 cm and diameter of 1 cm, and the third part were molded to produce briquettes with thickness of 1 cm and diameter of 1 cm. Each part then is dried in an oven at a temperature of 110°C. The same procedure was performed with 10% and 20% weight of coal powder.

3. Results and Discussion

Dewatering energy at each pressure is presented in Figure 2. Residual water content is decreased linearly while dewatering energy is increased linearly with increasing pressure. Based on the observation, major change in piston step length occurs in the initial pressures and become smaller with increasing pressure. At initial pressures, the piston forced water and air out of the sludge cake. Changes of piston step length are decreased with increasing pressure because the sludge cake is already compressed and result in smaller air cavity. Noting that the pressure change is proportional to the reduction of water content, most of volume displaced by the piston movement is only used to reduce water in the sludge cake due to lack of air remain. From this behavior, it can be predicted that at a certain pressure, the addition of the pressure had no longer affects the length of the pistons move. This condition is achieved when no more water can be removed from the sludge cake.

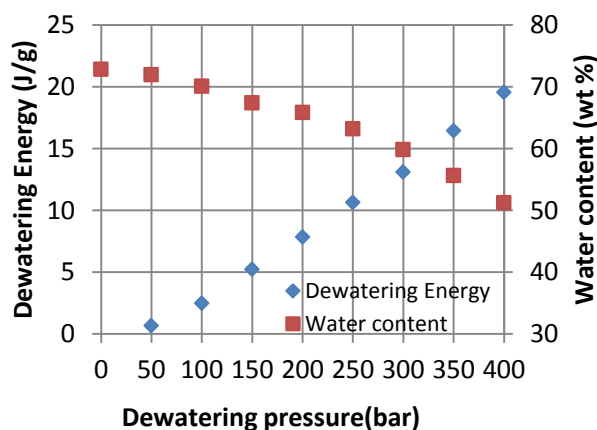


Figure 2. Dewatering energy curves

Mechanical dewatering can only remove free water and interstitial water. The remaining water content, the intracellular water and surface water can be removed by thermal drying. The drying energy calculations are based on water content at the end of the dewatering process at each pressure. The energy is the sum of the sensible heat required to raise the temperature of sludge cake to the drying temperature (110 °C) and latent heat to evaporate water. In the calculation, latent heat is much higher than sensible heat thus greatly affecting the total drying energy. The drying energy at each pressure dewatering is presented in Figure 3. Drying energy decreases with decreasing initial water content before drying. The slopes of the drying energy curve are sharper with increasing dewatering pressure.

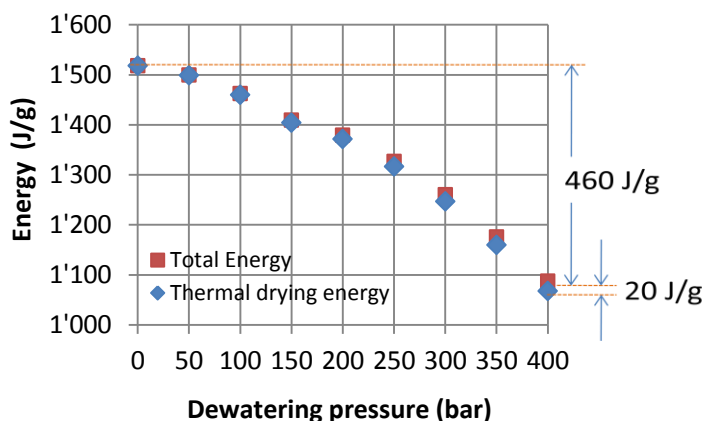


Figure 3. Total and drying energy curves

The lowest total energy is achieved at the largest dewatering pressure, which is 400 bar. If the water reduction is only performed by thermal drying without mechanical dewatering, the energy required to evaporate the water content of 72% reach 1520 J/g of sludge cake. If the mechanical dewatering are done on the same sample with pressure of 400 bar, the total energy required only 1080 J/g of sludge cake. The mechanical dewatering energy required at that pressure is 20 J/g of sludge cake, which resulting in energy savings of up to 460 J/g of sludge cake.

The limited dewaterability of sludge cake is associated with blinding phenomenon. Blinding is caused by migration or movement of small particles of sludge into cakepores which causes decrease of sludge cake porosity and increase of cake specific resistance. This phenomenon resulted in difficulties of free water in the sludge cake to diffuse during mechanical dewatering. Through chemical and electrostatic interactions, the aid particles (coal powder) will retain the porosity as well as the permeability of the sludge cake. In Figure 4 can be seen that increasing coal powder addition would result in greater water content reduction. Higher coal powder addition would increase the interaction between the particles, so sludge cake porosity could be maintained. At the same coal powder addition, increasing pressure also result greater water content reduction. The pressure acts as driving force in the interaction between the particles. At higher pressures, the interaction between the sludge cake and aid particles become more intense and result in increased permeability of the sludge cake.

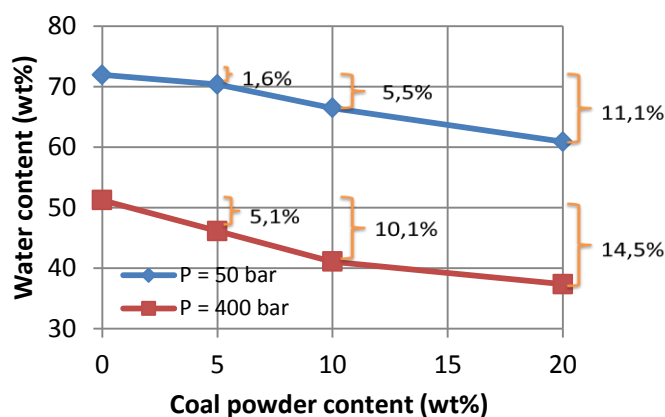


Figure 4. Effect of coal powder addition towards sludge cake dewaterability

The drying characteristics of 0.5 cm thick briquette, 1 cm thick briquette, and powder were compared each other. These characteristics were identified from the amount of water removed against time. Water content versus time curves for each dewatering pressure are presented in Figure 5. It can be observed the same behavioral tendency at different mechanical dewatering pressures. The drying characteristics of 0.5 cm thick briquette is very similar to the drying characteristics of powder sample, where the two curves are coincide at any pressures. The time required of 0.5 cm thick briquette and coal powder to evaporate its water content is almost the same in any point of water content. This is in contrast to the 1 cm thick briquette. At any pressures, its drying time is always greater than the other two samples.

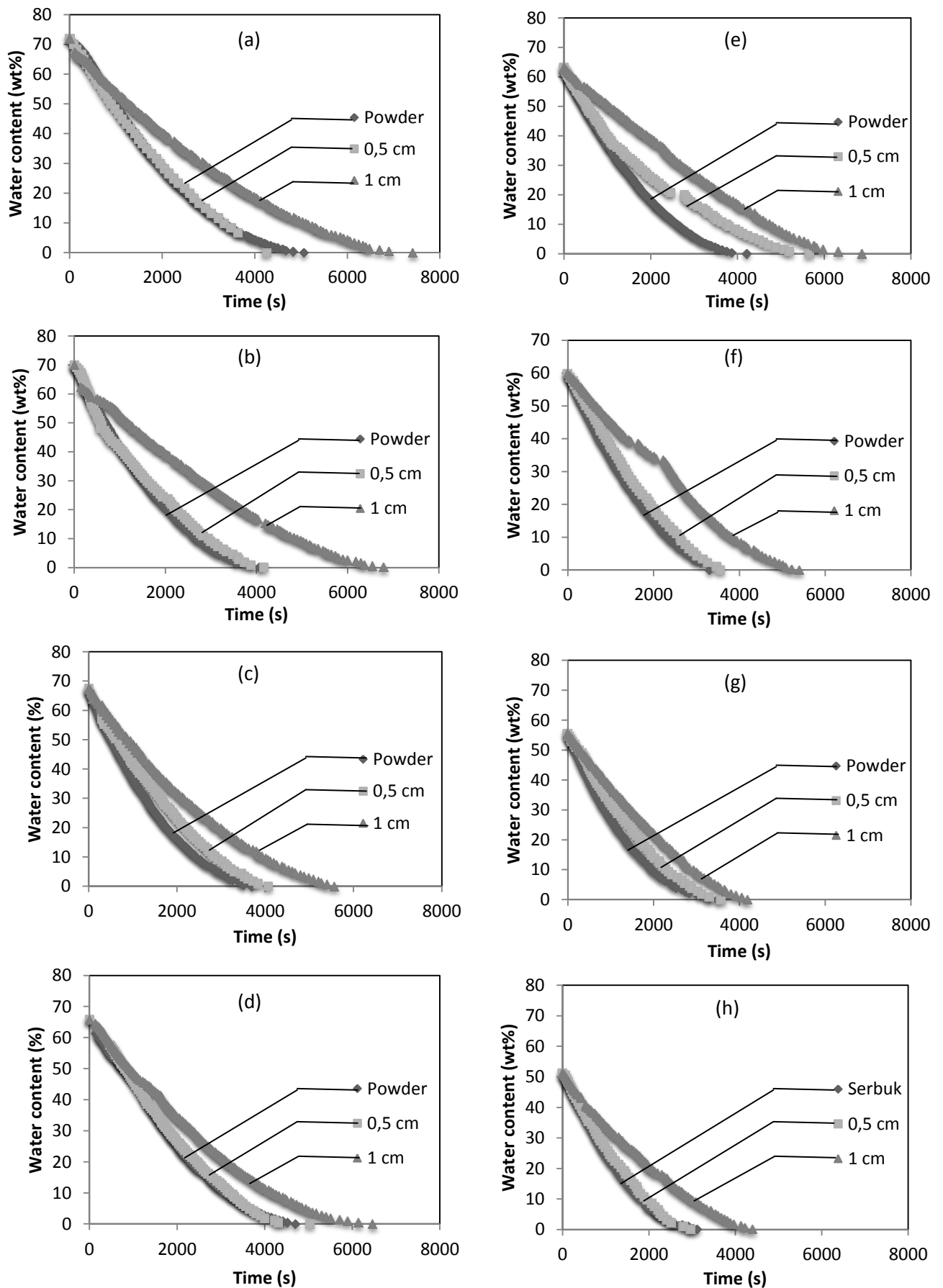


Figure 5. Drying curves at dewatering pressure: (a) 50 bar (b) 100 bar (c) 150 bar (d) 200 bar (e) 250 bar (f) 300 bar (g) 350 bar (h) 400 bar

Noting that mass transport driving force is concentration difference between two points, it can be interfere that the behavioral differences between samples are due to internal resistances in the sludge cake. These resistances cause difficulties of internal water to move toward sample surface. By forming the sample into powder, it is the same as removing internal resistances that exist in the sludge cake. The resistances only exist in briquettes samples. However, the briquettes with 0.5 cm thickness have not showed the existence of these resistances significantly. The internal resistances are more clearly seen in 1 cm thick briquettes. Hence, it can be concluded that the briquette dimension had an effect on briquette drying characteristics, as it will lead to the existence of internal resistances that hinder the water transport.

4. Conclusion

Higher pressure of mechanical dewatering would result in lower total energy of mechanical dewatering and thermal drying. The difference between total energy that involved mechanical dewatering and total energy without mechanical dewatering is addressed as energy saving. Lowest energy is obtained from pressure of 400 bars with energy savings up to 420 J/g of sludge cake. Addition of aid particles in term of coal powder is proven to increase the dewaterability of sludge cake. Higher coal powder addition would result in higher water content reduction. Dewaterability also increases with pressure, especially at high additon of coal powder. The dimensions of briquette greatly affect its drying characteristics. Briquettes of low thickness (0.5 cm thick is used) has drying characteristics that are almost similar to drying characterictics of powder sample. While higher briquette thickness (1 cm thick is used) requires a longer drying time than 0.5 cm thick briquettes and powder sample. This phenomenon are caused by difficulties of water diffusion in the sludge cake during thermal drying due to mass transfer resistance.

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