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# Effect of sludge sewage quality on heating value: case study in Jakarta, Indonesia

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**ABSTRACT**

This study aimed to determine sludge sewage and its potential as a solid fuel with a case study of Jakarta City. It was conducted by taking the samples of fecal sludge for three consecutive days at peak hours. The age of the sludge used in this study was 0 d, which was taken at the wastewater treatment plant (WWTP), septic tank, and open defecation. The generation of fecal sludge in Jakarta in 2020 could reach 2,129 ton/d. The quality of fecal water discharged into the environment can improve from year to year, accompanied by poor treatment. Based on the quality standards of wastewater produced from WWTP, septic tanks and open defecation do not meet the quality standards of wastewater. If this condition continues, it will pollute the water bodies in Jakarta. One alternative that can be done is to use fecal sludge as fuel. The feces water content in this study reached 74.14% ± 4% (WWTP); 68.14% ± 3% (septic tank), and 82.49% ± 1%. The results of the measurement of the calorific value of WWTP, septic tank, and open defecation reached 2,620.67 ± 54 kkcal/kg; 2,853 ± 130 kkcal/kg; and 2,298.67 ± 99 kkcal/kg, respectively. The amount of energy used for Jakarta can reach 1,024,049 MJ/d. The 90% significance analysis of BOD, COD, and air content parameters affects the calorific value of feces sludge.

*Keywords:* Caloric value; DKI Jakarta; Fecal sludge; Open defecation; Septic tanks; Wastewater treatment plant

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## 1. Introduction

The management of basic service issues related to domestic wastewater needs to be a priority considering the 2019 universal access target and the need for safe and sustainable drinking water and sanitation management according to the sustainable development goals (SDGs) target in Jakarta. Furthermore, based on the SDGs agenda, the development of domestic wastewater is in line to ensure the availability of sanitation and water services for all, especially to improve water quality and achieve sanitation access for all and eliminate the practice of open defecation (OD). For this reason, an instrument for all stakeholders is needed in managing the direction and focus of domestic wastewater service development that can answer the realities and existing challenges. The conventional wastewater treatment technology in Jakarta still does not meet the standards of Ministry of Environment and Forestry of Indonesia Republic [1,2].

Treated wastewater and sludge are formed from wastewater treatment processes that have undergone physical, chemical and biological processes to achieve the removal of organic and inorganic solids. The resulting waste sludge is usually in the form of a liquid or a rather solid liquid depending on the operation and the process applied [3]. Sewage sludge can be described as solid or liquid waste that results from wastewater treatment. Wastewater can be sourced from municipal, commercial or industrial processes. Physical characteristics (low ratio of solids to liquids) require thickening and mechanical draining to facilitate transportation and logistics during processing [4]. As a consequence, it can be argued that the uncontrolled disposal of sludge waste into the environment can increase the risks to the health of the environment and society.

Domestic wastewater is composed mainly of water and the rest are the particles of dissolved solids and suspended solids. Water content in fecal sludge can usually reach 66% to 88% [5]. Most of the sludge originating from the sludge drying bed is biomass, which contains organic material, reaching 66.71% [6]. The organic material contained in the sludge from the remaining sludge can be used as a mixture of raw materials for making fuel [7]. The use of sludge and waste to energy applications also aims to attract water and form a dense texture or combine the two substrates being bonded. The nature of fecal sludge can also be used as an adhesive, and the content of organic elements in the sludge can help to increase the calorific value [8]. Fecal sludge in each city in Indonesia might have different characteristics. This can be caused by several factors, such as the local processing unit; culture and community behavior in fecal sludge management; and the use of clean water quantities [9]. Jakarta, as the capital of Indonesia, also has the different characteristics of fecal sludge.

The purpose of this research is to study the existing conditions of sludge management in Jakarta City and its opportunities to be used as alternative energy in the form of refuse-derived fuel. This research also studies the relationship between domestic wastewater parameters and the calorific value in the sludge.

## 2. Method

### 2.1. Sampling

Data were collected during peak hours in Jakarta at 9 am when all activities have started. Sampling was carried out for 3 consecutive days to obtain precise results. It was also carried out on a sunny day and it was not raining. The sampling location for each mud was in the Central Jakarta area. Sampling open defecation, septic tank, and WWTP had similarities to discharge to Kebon Melati Reservoir.

### 2.2. Sludge

The age of the sludge taken in this study was new or 0 d after discharge. The mud from the open defecation was taken directly from the residents' latrines. Meanwhile, the mud in the septic tank was taken from the top of the septic tank and the WWTP mud was taken from the sludge resulting from draining in the second deposition tank every day.

### 2.3. Sludge characterization

The measurement of sludge characteristics was based on the regulations of the Ministry of Environment of Indonesia Republic on the quality standards for domestic wastewater. The parameters tested included TSS, pH, BOD, COD, oil and grease, ammonia, and total coliform. Each of these parameters was tested based on Indonesia's applied standards, called as the Indonesian National Standard (SNI).

To test the feces sludge quality as fuel, it started by testing the moisture content, ash content, and calorific value. The calculation of water content used the gravimetric method that is a heating method by means of an oven with an optimal temperature of 105°C for 24 h following ASTM D-3173-03 standards. The calculation of the percentage of ash content (ash content), meanwhile, used the ASTM D3174-04 standard. The calorific value (heating value) of a fuel was obtained using a bomb calorimeter and this calorific value obtained through the bomb calorimeter was the lower heating value's calorific value (LHV). The calculation of gross calorific value was based on ASTM D240 standard.

### 2.4. Statistical analysis

In finding the interrelated parameters, correlation and ANOVA (2-tailed) were carried out. This statistical analysis was carried out with SPSS v24 software. To test the correlation, it used the Kendall parametric test.

## 3. Results and analysis

### 3.1. Feces sludge generation in Jakarta City

Most of the population in industrial countries use flush toilets and a connection to sewage systems, but most households in developing countries have on-site sanitation systems. Human excreta is the result of a process in the human body that causes the separation and disposal of substances not needed by the body. These unneeded substances are feces and urine, which usually run down in water bodies such as rivers [10]. The volume of stool is influenced by local conditions, physiological factors, and culture and beliefs. Humans excrete an average of 200 g of feces per day, but the excreted weight depends on a diet [11]. Based on data from the Jakarta Central Statistics Agency [12], the amount of sludge generated per day can be calculated in which in 2020 it appeared to have a value of 2,129 ton/d. The generation of feces in Jakarta City will continue to increase along with the growing population. Fig. 1 shows the appearance of fecal sludge.

Based on Jakarta report, access to domestic wastewater management services covers 5% processed using WWTP processing centrally or communally; 85% processed with a septic tank, and 10% through open defecation [13]. Fig. 2 shows the mass balance for feces sludge generation management in Jakarta. Feces usually smell bad and contain water, bacteria, nutrients, and food waste. They may also contain viruses such as pathogens, protozoan cysts and worm eggs. Research has shown that excreta generation rates may differ considerably in various regions. The observed variability

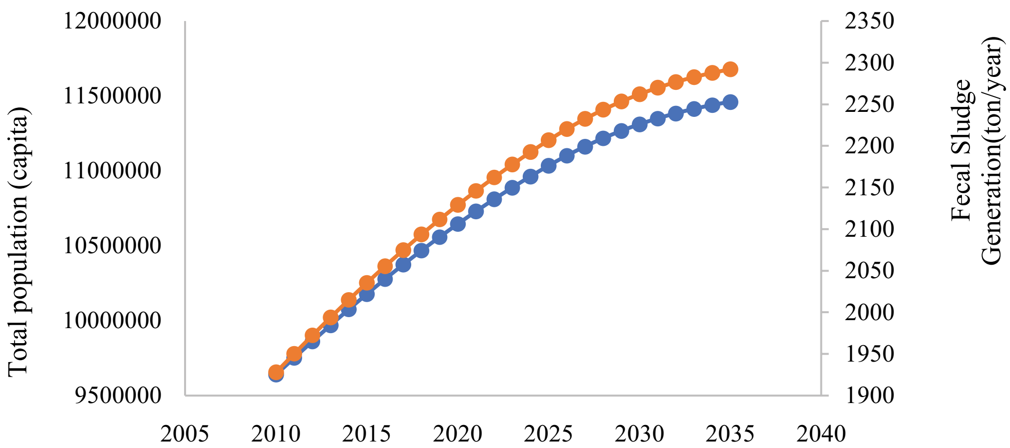


Fig. 1. Projection of Feces sludge generation in Jakarta City from 2010 to 2035.

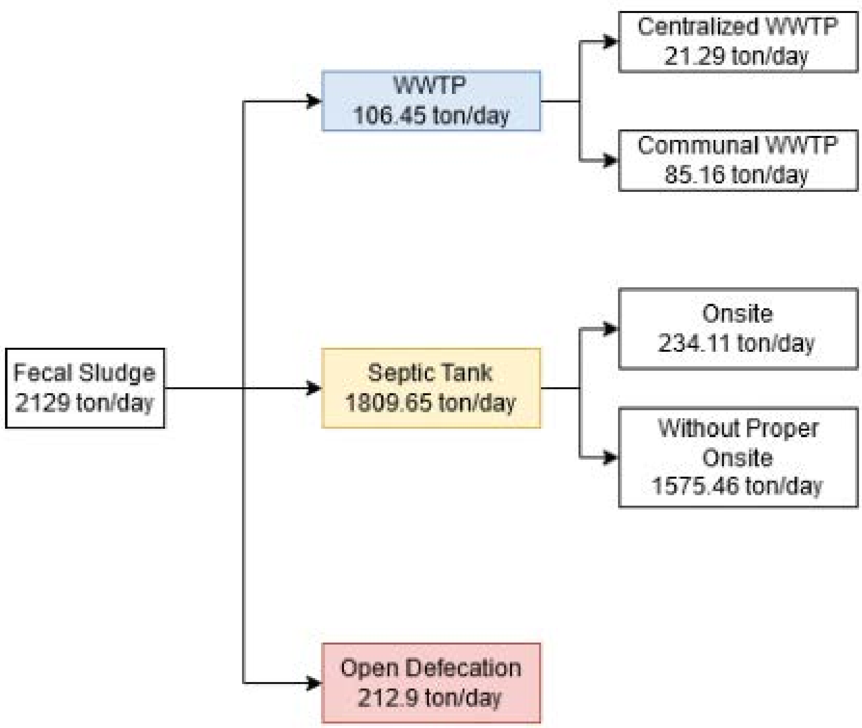


Fig. 2. Fecal Sludge Generation in Jakarta City by Treatment Method in 2020.

in the regions can reflect different dietary habits that result from various climatic, economic and cultural conditions [14].

Based on calculations in 2020, the 212.9 ton of feces/d were still discharged into water bodies. Three important factors in fecal management are wealth level, access to water, and respondents' perceptions of latrine ownership [15]. Reducing open defecation behavior requires various parties' efforts to increase knowledge through regular education and the use of health promotion media [16]. The factors that influence the selection of sanitation technology are population density, water sources, land topography, associated building capacity, and socio-economic conditions of the community [17]. However, stool processing in Jakarta must consider the convenience and sustainable economy.

### 3.2. Jakarta City fecal sludge quality

Table 1 shows the fecal sludge quality. Based on the standard TSS parameters, it was found that the fecal sludge did not meet the quality standards set by the Ministry of Environment of the Indonesia Republic (Fig. 3). The physical parameters of TSS in the measurement results had concentrations from 37,334 to 82,781 mg/L. The TSS concentration in the feces was very high. Research stated that the TSS concentration of 11,400 mg/L has been already very high [18]. The high TSS concentration can be caused by the high amount of organic substrates and nutrients in the feces.

The amount of organic material in fecal sludge can be seen through BOD and COD parameters. BOD indicated the amount of biodegradable organic compounds in the stool sample [19]. The BOD/COD values for each management, had different values. BOD/COD for WWTP and septic tank was lower than that of open defecation. This was because microorganisms have degraded organic pollutants in the WWTP and Septic tank processes. This finding is in line with the research on septic tanks and WWTP in Denpasar City, which had lower biodegradability than feces from fresh feces trucks [9]. Other findings also stated that feces' organic matter was at the value of 0.05–0.15 [20]. Processing in a physical, economically beneficial and sustainable way is the right solution in this case.

Oil and grease, ammonia, total coliform are the parameters that are also regulated in Indonesian standards. Oil and grease in open defecation behaviour and septic tank processing had the values that did not meet standards (Fig. 3). Ammonia and total coliform did not meet the quality standards for the three types of sludge. Overall, this meant that the resulting sludge could not be discharged into water bodies, even if the sludge was treated with a WWTP or a septic tank. The main factor that contributed to the spread of acute watery diarrhea was open defecation and disposal of fecal sludge in public spaces, especially rivers and riverbanks [21]. Feces sludge is a combination of human waste that is more or less diluted with flush water and toilet paper, and sometimes other types of waste such as food scraps, tissue paper, wood particles, food scraps, sponges, bones, textiles, plant seeds, rocks, plastics and sand.

The fecal sludge's water content produced from each management had different values for open defecation, and the septic tank had a moisture content value of 74.14% ± 3.9% and 66.8% ± 3.2% (Fig. 4). The water content in the mud was identified due to the community's patterns and habits in flushing. The higher the water used, the greater the water content in the feces sludge. Each management's ash content was almost the same in the range 4.31%–5.91% for open defecation and septic tanks. In the waste sludge from WWTP processing, the ash content was slightly lower, that is, 2.71% ± 0.2%, this was the possibility of mineral processing in the WWTP process.

The total heating value of the WWTP can reach 2,298.67 kkcal/kg or 9.62 MJ/kg. The total heating value indicated that the raw material unsuitable for thermal process [22]. If calculated by the generation of sludge generated in Jakarta 106.45 ton/d, the total energy generated from sludge is 1,024.049 MJ/d. WWTP in Jakarta is higher than

Table 1
Fecal sludge quality for each management type in Jakarta City

| Parameters | Open defecation 1 | Open defecation 2 | Open defecation 3 | Septic tank 1 | Septic tank 2 | Septic tank 3 | WWTP 1 | WWTP 2 | WWTP 3 |
|---|---|---|---|---|---|---|---|---|---|
| TSS, mg/L | 74,219 | 68,143 | 82,781 | 74,219 | 68,143 | 37,334 | 8,521 | 6,437.00 | 7,391 |
| pH | 6.80 | 7.30 | 8.10 | 8.40 | 8.60 | 8.70 | 7.60 | 7.30 | 7.40 |
| BOD, mg/L | 24,585 | 25,314 | 29,153 | 36,563 | 14,764 | 17,851 | 874 | 1,009 | 984 |
| CO, mg/L d | 44,297 | 41,535 | 45,130 | 87,531 | 51,768 | 61,575 | 5,713 | 4,411 | 3,871 |
| Oil and grease, mg/L | 18.40 | 29.10 | 31.40 | 5.80 | 4.10 | 7.90 | 1.40 | 1.70 | 0.50 |
| Ammonia, mg/L | 25.49 | 24.78 | 48.19 | 21.89 | 18.19 | 22.34 | 18.71 | 21.77 | 19.85 |
| Total coliform, CFU/100 mL | 220,000 | 260,000 | 250,000 | 220,000 | 260,000 | 750,000 | 270,000 | 410,000 | 450,000 |
| BOD/COD | 0.56 | 0.61 | 0.65 | 0.42 | 0.29 | 0.29 | 0.15 | 0.23 | 0.25 |
| Water content, % | 78.56 | 71.04 | 72.81 | 68.54 | 68.75 | 63.11 | 82.56 | 83.04 | 81.86 |
| Ash content, % | 5.91 | 5.41 | 4.19 | 5.98 | 5.75 | 4.31 | 2.53 | 2.85 | 2.75 |
| Caloric value, kcal/kg | 2,571.00 | 2,613.00 | 2,678.00 | 2,875.00 | 2,713.00 | 2,971.00 | 2,356.00 | 2,184.00 | 2,356.00 |

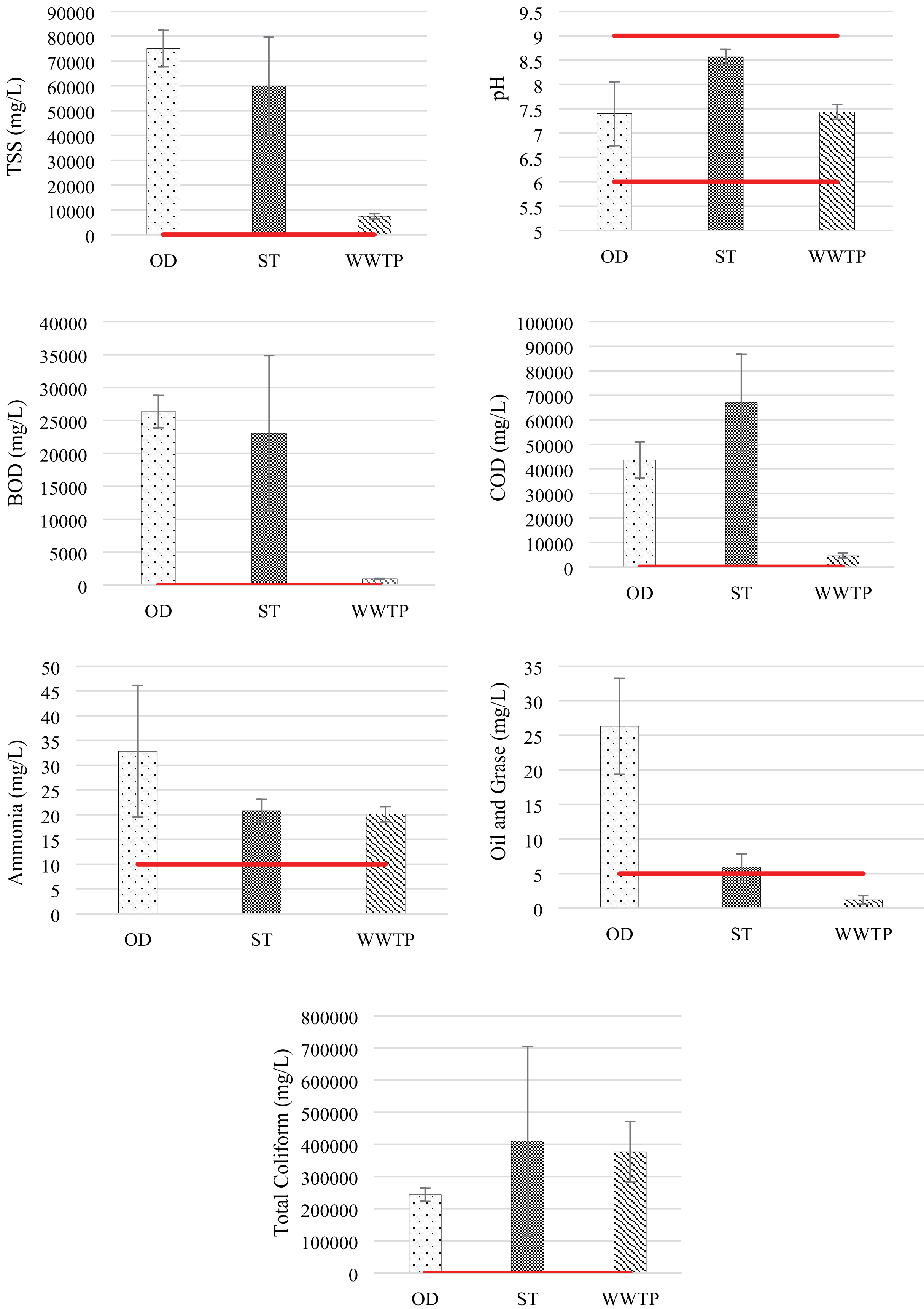


Fig. 3. Comparison of fecal sludge quality with wastewater quality standards in Indonesia.

Table 2
Correlation and significance of each tested parameter in fecal sludge

| Correlations | | | TSS | BOD | COD | Oil and grease | Ammonia | Total coliform | BOD/COD | Water content | Ash content | Caloric value |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Kendall's tau_b | TSS | Correlation coefficient | 1 | 0.229 | –0.057 | 0.057 | 0.114 | –0.412 | 0.114 | 0.229 | –0.057 | –0.145 |
| | | Sig. (2-tailed) | 0. | 0.399 | 0.833 | 0.833 | 0.673 | 0.136 | 0.673 | 0.399 | 0.833 | 0.596 |
| | BOD | Correlation coefficient | 0.229 | 1 | 0.556* | 0.667* | 0.389 | –0.572* | 0.722** | –0.500 | 0.444 | 0.592* |
| | | Sig. (2-tailed) | 0.399 | 0. | ***0.037*** | ***0.012*** | 0.144 | 0.035 | ***0.007*** | 0.061 | ***0.095*** | ***0.028*** |
| | COD | Correlation coefficient | –0.057 | 0.556* | 1 | 0.333 | 0.167 | –0.400 | 0.278 | –0.722** | 0.556* | 0.817** |
| | | Sig. (2-tailed) | 0.833 | ***0.037*** | 0. | 0.211 | 0.532 | 0.140 | 0.297 | ***0.007*** | ***0.037*** | ***0.002*** |
| | Oil and grease | Correlation coefficient | 0.057 | 0.667* | 0.333 | 1 | 0.722** | –0.400 | 0.833** | –0.278 | 0.333 | 0.366 |
| | | Sig. (2-tailed) | 0.833 | ***0.012*** | 0.211 | 0. | ***0.007*** | 0.140 | ***0.002*** | 0.297 | 0.211 | 0.173 |
| | Ammonia | Correlation coefficient | 0.114 | 0.389 | 0.167 | 0.722** | 1 | –0.229 | 0.667* | –0.111 | 0.278 | 0.141 |
| | | Sig. (2-tailed) | 0.673 | 0.144 | 0.532 | ***0.007*** | 0. | 0.399 | ***0.012*** | 0.677 | 0.297 | 0.600 |
| | Total coliform | Correlation coefficient | –0.412 | –0.572* | –0.400 | –0.400 | –0.229 | 1 | –0.343 | 0.114 | –0.514 | –0.203 |
| | | Sig. (2-tailed) | 0.136 | 0.035 | 0.140 | 0.140 | 0.399 | 0. | 0.206 | 0.673 | ***0.058*** | 0.458 |
| | BOD/COD | Correlation coefficient | 0.114 | 0.722** | 0.278 | 0.833** | 0.667* | –0.343 | 1 | –0.333 | 0.389 | 0.366 |
| | | Sig. (2-tailed) | 0.673 | ***0.007*** | 0.297 | 0.002 | 0.012 | 0.206 | 0. | 0.211 | 0.144 | 0.173 |
| | Water content | Correlation coefficient | 0.229 | –0.500 | –0.722** | –0.278 | –0.111 | 0.114 | –0.333 | 1 | –0.500 | –0.930** |
| | | Sig. (2-tailed) | 0.399 | ***0.061*** | ***0.007*** | 0.297 | 0.677 | 0.673 | 0.211 | 0. | ***0.061*** | ***0.001*** |
| | Ash content | Correlation coefficient | –0.057 | 0.444 | 0.556* | 0.333 | 0.278 | –0.514 | 0.389 | –0.500 | 1 | 0.423 |
| | | Sig. (2-tailed) | 0.833 | 0.095 | ***0.037*** | 0.211 | 0.297 | ***0.058*** | 0.144 | ***0.061*** | 0. | 0.116 |
| | Caloric value | Correlation coefficient | –0.145 | 0.592* | 0.817** | 0.366 | 0.141 | –0.203 | 0.366 | –0.930** | 0.423 | 1 |
| | | Sig. (2-tailed) | 0.596 | ***0.028*** | ***0.002*** | 0.173 | 0.600 | ***0.458*** | 0.173 | ***0.001*** | ***0.116*** | 0. |

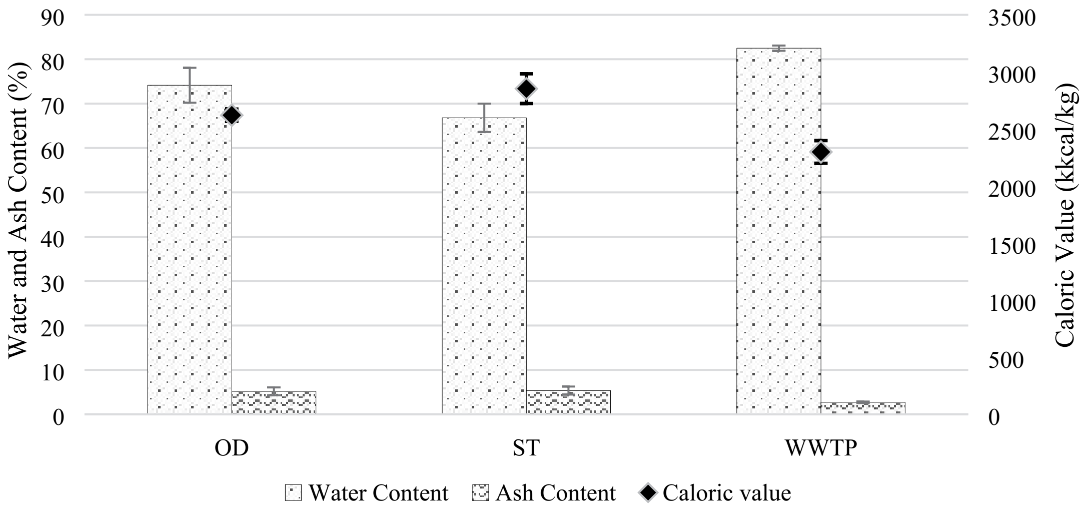


Fig. 4. Characteristics of sludge from various management based on moisture content, ash content, and calorific value.

that of WWTP in Minas Gerais – Brazil, with a value of 10,962 MJ/d [23]. Another study stated that the potential calorific value of sewage sludge can reach 150,000 MJ/d equivalent to 4,200 $m^3$/d of natural gas [24].

The calorific value for sludge from WWTP in India is between 8–21 MJ/kg under dry conditions. The potential for energy recovery of sewage sludge is 555–1,068 kWh/ton based on sludge dry matter [25]. For this reason, it is necessary to treat sludge with a physical process to remove moisture.

### *3.3. Statistical analysis on the effect of fecal sludge quality*

Table 2 shows the correlation coefficient data processing results, and the 2-tailed ANOVA analysis results of each parameter tested in this study. The feces sludge's COD and BOD parameters were seen to have quite high significance, namely, 0.028 and 0.002, respectively. This relationship was inseparable from the carbon value present in the organic elements of the sludge. Commonly, the secondary settling process mainly contains 60%–70% of organic material from organic with a heating value of 2,000–2,500 kcal/kg [26]. The strong relationship between BOD and COD parameters is also supported by other studies that stated calorific value as the main indicator in the conversion of fecal sludge or any organic compound containing electricity [27]. The sludge's energy recovery was limited to 14% regardless of how efficient high-temperature pyrolysis was to recover energy from sludge, where the calorific value was 14,226 kJ/kg COD [24]. Water content is one of the key parameters in getting a good calorific value for fuel. Many studies on the use of fecal sludge also showed a negative correlation where the calorific value increased when the water content decreased [28].

The sludge treatment plant uses heat energy to achieve bio-safety byproducts, and its design innovatively integrates nutrient recovery, water recovery and energy recovery during sludge treatment [29]. The generation of sewage sludge is a heavy burden on municipal management and an excellent source for bioenergy recovery [30], especially in Jakarta. Knowing that the BOD and COD factors are two of the key parameters in environmental pollution, this organic recovery becomes an opportunity for sludge treatment in several wastewater treatment plants such as leachate from landfills difficult to treat with conventional technology.

## 4. Conclusion

The current condition of Jakarta City can produce 2,129 tons/d of fecal sludge with a potential energy output of 1,024.049 MJ/d. By default, the sludge produced in each management is unsafe to be discharged into water bodies; as a consequence, so recovery efforts are needed from fecal sludge. Energy recovery from fecal sludge is very promising because of its high organic content. Organic content in the form of BOD and COD parameters is a parameter that affects the heating value.

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