Comparative study between conventional and mechanical technology on fecal sludge treatment plants (FSTP) in Indonesia

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Abstract. In pursuit of access to wastewater services to reach the target of 100%, it is undeniable that the non-sewer system/on-site system should continue to be developed. The non-sewer system provides low-cost options, making access to wastewater infrastructure more affordable. As a further treatment of the fecal sludge produced from on-site technology such as septic tank, FSTP (Faecal Sludge Treatment Plant) is needed. This study was conducted on 4 FSTPs in Java Island, namely 2 conventional system FSTPs (Keputih FSTP, Surabaya and Betoyoguci FSTP, Gresik) and 2 mechanical system FSTPs (Duri Kosambi FSTP, Jakarta and Sumur Batu FSTP, Bekasi). The research was conducted by comparing performance indicators which are collection, treatment, human resources, and cost-efficiency, representing development priority aspects. Analysis of the development strategy was carried out by SWOT analysis. Based on performance indicator comparison, Duri Kosambi FSTP has the highest collection efficiency among the others. Treatment efficiency ranging around 60%, and human resources efficiency in all FSTPs ranging at 80%. Duri Kosambi FSTP has an acceptable cost efficiency level, while the rest are still dissatisfactory. Development strategy derived from SWOT analysis should include an effort to do scheduled desludging, partial investment from government, adjusting tariff, and optimizing FSTP capacity.

1. Introduction

Sludge treatment at the FSTP is an advanced treatment because the fecal sludge that has been treated in the septic tank is not suitable for disposal into the environment or water bodies. In principle, the sludge accumulated in the pits and septic tanks needs to be regularly drained or emptied and then transported to the FSTP using a fecal desludging truck. Around 146 FSTPs built in Indonesia are still using the conventional system, which requires a relatively large area of about 2-3 Ha. Limited land availability in large and medium cities encourages the development of more compact mechanical technologies in FSTPs. Surabaya City and Gresik District, located in East Java Province, most citizens still use the decentralized wastewater management system. The presence of FSTP with optimal performance will support sanitation access to achieve the goals of sustainable development or SDGs. Keputih FSTP in Surabaya City and Betoyoguci FSTP in Gresik District are examples of two FSTPs still operationally with ongoing maintenance in Indonesia. FSTP conditions in Indonesia are still not yet optimal and can be improved by using mechanical technology. The two FSTPs can be developed because they are still
and residents in the city/district still use the FSTP as a final treatment facility for fecal sludge compared to communal WWTPs. Duri Kosambi FSTP in DKI Jakarta and Sumur Batu FSTP in Bekasi City are FSTPs that have applied mechanical technology to receive fecal sludge with Sludge Acceptance Plant and Screw Press for mechanical separation of solids and liquids from fecal sludge. However, the use of mechanical technology is one of the development strategies that can be carried out. The use of mechanical technology requires conditions, one of which is the fulfillment of the design capacity of the mechanical technology unit so that operational costs will become more effective. Analysis of the need for development is carried out by analyzing development and financing strategies and treatment capacity that can be implemented in conventional FSTP facilities. Relevant research for FSTP performance state that the priority of performance improvement strategy in Bawang FSTP Tangerang are improvement strategies of humanware, technoware, info was and or aware, meanwhile in Peck FSTP Indramayu are improvement strategies of techno were component, humanware, or aware and info were [1]. The need for development and improvement strategy can be done differently because each facility can have a different problem.

Several studies [2,3,4,5,6] state that in each developing country, fecal sludge management (FSM) still having issues. Some of the issues lacking fecal sludge management or FSTP are capital and operational cost to achieve financial stability, including policies or supporting regulation, treatment unit technology, and human resource requirement. In general, FSTP can operate optimally will not depend on financing efficiency but on collecting efficiency, fecal sludge treatment, and communities participation. Significant environmental pollution can be one of the results or consequences of the ineffectiveness of FSTP and fecal sludge management [7].

The objectives of this research are as follows: (i) analyze the performance of the FSTP that has been implemented; (ii) determine the effectiveness and efficiency of FSTP using conventional technology and mechanical technology; (iii) analyzing the comparison of the condition parameters for each FSTP; and (iv) analyzing the potential for the development of conventional FSTP using mechanical technology and its strategy with a SWOT analysis.

2. Methodology

The framework of the research shows in Figure 1. Primary data was obtained through field observation in four selected FSTPs: Duri Kosambi FSTP Jakarta; Sumur Batu FSTP Bekasi; Keputih, FSTP Surabaya FSTP, and Betoyougci FSTP Gresik. Some of the other supporting data were obtained through online interviews due to the Covid-19 pandemic. The primary data was collected between March –April 2021.

**Figure 1.** Research framework.

The research was conducted by analyzing the FSTP performance with an evaluation approach on performance efficiency with indicators determined based on a literature study based on the results of research on Effective Faecal Sludge Management Practices in Decentralized Systems [8], FSTP Performance Diagnosis [9], and the Condition Map of the Sludge Treatment Plant (FSTP) [10]. The
performance indicators obtained by a modification with minimizing indicators influenced by community preference are collection efficiency, treatment efficiency, human resource efficiency, and cost efficiency—table 1 shown the performance indicators and influencing factors for FSTP.

**Table 1. Performance indicators and influencing factors for FSTP.**

| No | Indicator                  | Influencing Factor                              | Efficiency Level                                                                 |
|----|----------------------------|-------------------------------------------------|-----------------------------------------------------------------------------------|
| 1  | Collection efficiency      | Number of houses served                          | Between fecal sludge being collected and produced                                 |
|    |                            | Number of vacuum trucks service                 | - 80% = Satisfaction - 50-80% = Good - < 50% = Poor                               |
|    |                            | Suitability with planning criteria               | Between unit capacity and compliance with effluent quality standard               |
|    |                            | Treatment unit type                              | - 80% unit capacity is met, and the guideline effluent quality standard is met = Satisfaction |
|    |                            | Dry solid treatment                              | - 50-80% unit capacity is met, and the guideline effluent quality standard is met = Good |
|    |                            | Effluent quality standard                       | - Unit capacity <50% and quality standard are met = Good                         |
|    |                            | Number of operators each treatment unit         | - Unit capacity <50% and quality standard are not met = Poor                     |
|    |                            | Human resources competencies as structural from management lead to operators. Workload | Between the number of human resources and requirement                             |
|    |                            | Operational and maintenance cost (Rp/m$^3$)      | - 80% fulfilled or optimal performance = Satisfaction                             |
|    |                            | Collection and treatment fees paid (Rp/m$^3$)    | - 50-80% fulfilled or optimal performance = Good                                  |
|    | Benefit/cost ratio         |                                                  | - <50% fulfilled or optimal performance = Poor                                    |
| 2  | Treatment efficiency       |                                                  |                                                                                  |
| 3  | Human resources efficiency |                                                  |                                                                                  |
| 4  |                             |                                                  |                                                                                  |

1Modification of research in FSM indicators [8] and FSTP diagnosis [9].

The results of the analysis were determined with the performance comparison of each FSTP. It would be indicated the priority aspects to be developed and become the basis for the SWOT analysis so that the analysis could be categorized easily with quantitative data. The development strategy focused on research for conventional FSTP with the development of mechanical technology. The development of mechanical technology was carried out by analyzing financing and processing capacity by determining the efficiency of the performance of the mechanical technology unit if it was applied to the existing processing capacity. The development of the strategy was analyzed by SWOT and categorized as shown in Table 2 [11]

**Table 2. Development strategy by SWOT analysis.**

| Internal | External | Opportunity | Threats         |
|----------|----------|-------------|-----------------|
| Strength |          | Comparative advantage (SO) | Mobilization (ST) |
| Weakness |          | Divestment/Investment (WO)| Damage Controls (WT) |

SWOT analysis can determine a strategy that can be implemented in each facility. The possibility of development strategy obtained with SWOT matrix is SO (strength-opportunity), ST (strength-threat), WO (weakness-opportunity), or WT (weakness-threat). Position in the coordinate plane will show the
possible development strategy based on internal and external aspects in each facility. The equation used based on this qualitative approach [11]:

\[
\text{Strength Posture (X)} = S + (W) \\
\text{Competitive Posture (Y)} = O + (T)
\]

(1) (2)

For:
S = Strength; W = Weakness; O = Opportunity; T = Threat

3. Results and discussion
3.1 Overview of the study area
The research study area is determined based on the FSTP still operating and selected based on the technology. Sumur Batu FSTP with 100 m$^3$/day total capacity and idle capacity can reach 70%. Meanwhile, Duri Kosambi FSTP with 600 m$^3$/day total capacity and idle capacity can reach 75%. Both FSTP were chosen because they have applied mechanical technology to reception fecal sludge and unit for separation of solids-liquids using a sludge acceptance plant (SAP) and a screw press. The mechanical unit is shown in Figure 2.

![Figure 2](image)

Figure 2. Mechanical unit for Duri Kosambi FSTP and Sumur Batu FSTP (a) SAP at Duri Kosambi FSTP, (b) Duri Kosambi FSTP's screw press, (c) Sumur Batu FSTP's screw press.

Meanwhile, Keputih FSTP and Betoyoguci FSTP were chosen because they are still operating with a conventional unit. Keputih FSTP is a fecal sludge treatment plant in Surabaya with a design capacity of 400 m$^3$/day and idle capacity reach up to 75%. The principle of FSTP treatment is physical treatment through solids separation and biological treatment. Betoyoguci FSTP has a treatment capacity of up to 45 m$^3$/day. The significant difference between mechanical and conventional units is in the preliminary treatment and reception of fecal sludge. Mechanical units in field experiments have been proven can increase the efficiency of reducing the water content from fecal sludge in a shorter time. Here are the units separation of solids and liquids used in conventional FSTP in Figure 3.

![Figure 3](image)

Figure 3. Separation sludge chamber (SSC) unit in conventional FSTP (a) Keputih FSTP, (b) Betoyoguci FSTP.

3.2 Performance indicators comparative analysis
The comparative analysis of the performance indicators of each FSTP is based on the following indicators: (1) The collection efficiency is determined by looking at the percentage of management facility services based on the existing condition of treatment capacity, and the amount of sludge
generated in the study area; (2) The treatment efficiency of FSTP facilities in each study area is influenced by the suitability of the planning capacity with the capacity of the existing condition, the type of treatment unit carried out, the management and processing carried out for sludge drying and the adjustment of the effluent to the applicable quality standard, namely the Regulation of the Minister of Environment and Forestry Number 68 of 2016 concerning Domestic Wastewater Quality Standards [12]. The value of treatment efficiency is the average value of the efficiency of those factors; (3) Human resources efficiency can be determined by optimally employing human resources facilities according to resource requirements so that work will be carried out optimally; (4) Financing efficiency at the FSTP facility is based on the operational cost needs of the implementation of FSTP management and processing and its comparison with the retribution or revenue costs obtained by the FSTP for the treatment of fecal sludge from commercial, social or household. Table 3 shown the comparison result of the indicators of four different FSTPs.

The development that can be done based on the efficiency of the FSTP’s performance can be seen from the percentage of efficiency. Performance indicators with relatively low efficiency will be set as the development priority. The development that can be done, especially in conventional FSTP, which is the focus of this study, is the development of mechanical technology to increase the efficiency of fecal sludge treatment.

Table 3 shows that if a conventional FSTP will need development, the priority is on the collection and financing aspect, which is still in poor efficiency. One of the developments that can be done is the development using mechanical technology that has been applied in the Sumur Batu FSTP and Duri Kosambi FSTP. Cost estimates for the development of mechanical technology as one of the strategies for developing processing efficiency improvement solutions will be required and compared.

Table 3. The performance indicators of each FSTPs in Java Island.

| No | Indicator           | Keputih FSTP, Surabaya | Betoyoguci FSTP, Gresik | Sumur Batu FSTP, Bekasi | Duri Kosambi FSTP, DKI Jakarta |
|----|---------------------|------------------------|-------------------------|-------------------------|--------------------------------|
| 1  | Collection efficiency | 17.4%                  | 7.7%                    | 10.8%                   | 5.6%                           |
| 2  | Treatment efficiency | 63.75%                 | 43.5%                   | 60.8%                   | 60%                            |
| 3  | Human resources efficiency | 80%                    | 80%                     | 80%                     | 100%                           |
| 4  | Benefit/cost ratio  | 0.47                   | 0.054                   | 0.42                    | 0.64                           |

3.3 SWOT analysis

The development strategy that will be applied to FSTP in the study area, especially to conventional FSTP analyzed based on internal and external factors of FSTP performance that have been previously reviewed with FSTP performance indicators. Analysis of internal and external factors on each FSTP performance indicator can be described for each study area. Internal factor analysis consists of several aspects based on performance indicators: management of FSTP facilities, existing treatment units, effluent, dry sludge quality, and availability of human resources. Meanwhile, the analysis of external factors consists of several aspects, namely financing, fecal sludge input flow, community participation in non-sewer/ decentralized system, institutional supervisory facilities, and regulations supporting the implementation of service facilities.

The position of the Keputih FSTP coordinates based on the results of the SWOT analysis are as follows:

Strength Posture (X) = S + (-W) = 4 + (-5) = -1
Competitive Posture (Y) = O + (-T) = 5 + (-3) = 2

So, the coordinates (X,Y) for determining the development strategy at Keputih FSTP are (-1,2).
The position of the coordinates of the Betoyoguci FSTP based on the results of the SWOT analysis is as follows:

- **Strength Posture (X)** = S + (-W) = 5 + (-2) = 2
- **Competitive Posture (Y)** = O + (-T) = 5 + (-3) = 2

So, the coordinates (X,Y) for determining the development strategy at Betoyoguci FSTP are (2,2).

The following are the coordinate locations for the development strategy with a SWOT analysis described, which can be seen in Figure 4.

![Figure 4. Coordinate position for development strategy from SWOT analysis.](image)

The coordinate position for the Betoyoguci FSTP is in quadrant I so that the SO strategy can be implemented, while the Keputih FSTP is in quadrant III so that the WO strategy can be implemented.

### 3.4 Development strategy

Keputih FSTP can implement a strategy with the Government of Surabaya to encourage the community to desegregate fecal sludge every 2-3 years, and operational maintenance costs are used for planning unit repairs. Supervisor institutional of Keputih FSTP, DKRTH, focuses on recruiting operators for more efficient human resources who will operate FSTP unit development. The implementation that can be done is procuring a new mechanical unit that can improve solid-liquid separation efficiency. The implementation that can be done so that the FSTP can operate effectively is to increase the scheduled service program for fecal sludge transportation so that the treatment capacity can be achieved.

Betoyoguci FSTP can implement strategies with supervisor institutional, which is UPTD PLCD continue to develop innovations to ensure the sustainability of FSTP and implement the results of the twinning program with Sumur Batu FSTP in Bekasi City. The strategy implementation that can be done is to continue the LLTT (scheduled desludging) program and the sanitation program that has been implemented.

### 3.5 Mechanical unit development for Keputih FSTP

The development strategy analysis carried out on conventional FSTP shows that the FSTP development strategy can be applied by developing mechanical technology in solid-liquid separation and fecal sludge reception. Guidelines for selecting alternative technologies for FSTP in Indonesia, especially in solid-liquid separation units and sludge drying, are described through simple illustrations in the Detailed Technical Planning Guidelines for Sludge Treatment Plants by the Ministry of Public Works and Public Housing [13]. The treatment capacity of FSTP facilities of more than 75 m$^3$/day, such as the Keputih FSTP, can use mechanical units such as SAP and screw press as alternative technology development. Solid and liquid separation units with mechanical technology are often not preceded by a sludge concentration unit or digestion. The mechanical unit will be effective in treatment costs per 1 m$^3$ processed if the treatment capacity is more than 75 m$^3$/day. Mechanical unit requirement analysis can be seen in Figure 5.
The cost requirement will decrease by optimizing the treatment capacity, but it can increase the SDB capacity requirement for the sludge dewatering unit. The point at which the volume of SDB capacity will be maximized when the maximum treatment capacity of the facility is 200 m$^3$/day, although the treatment cost/m$^3$ can be reduced to Rp 16,000/m$^3$ of treated fecal sludge. According to the Detailed Technical Planning Guidelines for Fecal Sludge Treatment Plants [13] stated that at a capacity of 200 m$^3$/day, alternative technologies that can be applied so that sludge drying will be effective is preceded by a mechanical unit for solids-liquid separation or with SAP and screw press with comparison units that have been applied in Sumur Batu FSTP and Duri Kosambi FSTP.

Investment costs that must be incurred to procure mechanical units are IDR 7,700,000,000. and maintenance costs are IDR 102,428,468/month or IDR 1,229,141,620/year, comparable to the maintenance costs that have been incurred every year at Keputih FSTP. The investment cost for mechanical unit development at Keputih FSTP can be concluded in Table 4.

### Table 4. Investment cost for Keputih FSTP.

| No | Unit Type                          | Unit price (IDR/1 unit)       |
|----|-----------------------------------|------------------------------|
| 1  | Sludge Acceptance Plant           | HUBER ROTAMAT Ro 3.3         | 3,850,000,000 |
| 2  | Screw Press                       | HUBER ROTAMAT RoS3           | 3,850,000,000 |
| **Total** |                          |                               | **IDR 7,700,000,000** |

Meanwhile, operational and maintenance costs for mechanical unit development at Keputih FSTP can be concluded in Table 5.

### Table 5. Estimated maintenance cost with mechanical unit implemented for Keputih FSTP.

| No | Description         | Requirement           | Unit price (IDR)            |
|----|---------------------|-----------------------|----------------------------|
| 1  | Maintenance         | Mechanical unit       | IDR 350,000,000/year       |
| 2  | Electricity cost    | 11.35 kW              | IDR 1,467.00/kWh × 11.35 × 10 hour × 30 day = Rp 4,995,135/month |
| 3  | Chemical cost       | Procurement 2000 kg   | IDR 200,000,000.00/year    |
| 4  | Operator            | IDR 4,300,000/month for a 12 person | IDR 46,400,000/month |
| **Total** |                     |                       | IDR 102,428,468/month | IDR 1,229,141,620/year |

### 3.6 Optimization of Betoyoguci FSTP

In 2020, Betoyoguci FSTP treated a total of 1,210 m$^3$ of fecal sludge, which indicates a treatment capacity of only 3.7 m$^3$/day. The use of mechanical technology at a capacity of $<75$ m$^3$/day will increase the treatment cost/m$^3$ of treated fecal sludge because the design capacity of the mechanical unit is not achieved. Constant optimization of capacity at 45 m$^3$/day can reduce processing costs significantly. The development that needs to be prioritized is increasing the supply of fecal sludge by optimizing existing units and utilizing the processing results, namely dry sludge, for purposes as compost or backfill. The
facility can consider the potential of compost as profit; however, as government policy stated, government facilities could not earn profit from selling products. The total treatment cost per m$^3$ that must be processed is calculated based on the operational and maintenance costs incurred, which is Rp. 335,000,000/year. The financing comparison can be seen in Figure 6.

![Figure 6](image-url)

**Figure 6.** Financing comparison of Betoyoguci FSTP between existing condition and optimization treatment capacity.

### 4. Conclusion

The conclusions of this research are as follows: analysis of each FSTP is carried out by determining performance indicators consisting of collection efficiency, treatment efficiency, human resource efficiency, and cost efficiency that indicates in each FSTP, collecting treatment and financing aspects need to be priorities in development. Comparison of conventional FSTP and mechanical technology-based FSTP can significantly describe financing needs where mechanical technology-based FSTP in principle will be higher treatment costs due to the need for electricity and chemical costs for operational of sludge acceptance plant (SAP) and screw press. Development of Mechanical unit in conventional FSTP needs to carefully analyze from the supply aspect that has directly influenced achieving its unit design capacity. Keputih FSTP can apply SAP and screw press with an average treatment capacity of 150 m$^3$/day; meanwhile, for Betoyoguci, FSTP needs to optimize its capacity design at 45 m$^3$/day before further development. The cost needed for transitioning in mechanical unit with the case of Keputih FSTP will need estimated of IDR 41,000 for 1 m$^3$ fecal sludge treated and IDR 1,229,000,000/year for O&M cost needed. Meanwhile, further research is conducted on the potential development of mechanical technology in the condition of the FSTP being built. There is a need for integrated data related to FSTP performance in Indonesia.

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