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Analysis of Faecal Sludge Treatment Alternatives to Enhance the Treatment Performance of Wastewater Treatment Plant (WWTP) Denpasar Sewerage Development Project (DSDP) Suwung Denpasar City

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Highlights:

- The existing wastewater treatment facilities at WWTP DSDP Suwung cannot accommodate treatment of all disposed faecal sludge, therefore additional treatment capacity needs to be provided.
- An alternative treatment method was selected based on technical design criteria and economic criteria using a weighting method. From the consideration of these technical aspects and non-technical aspects, the most prominent parameters were total suspended solid (TSS) removal efficiency and organic load removal efficiency.
- The selected treatment technology was Solid Separation Chamber (SSC) combined with Anaerobic Baffled Reactor (ABR) as a secondary treatment, after which the supernatant is treated by the aerated lagoon process.

Abstract. Most of the wastewater generated from domestic activities in Denpasar city is treated in an off-site treatment plant located in WWTP DSDP Suwung. This includes faecal sludge that originates from on-site treatment plants. The existing treatment facilities can only treat wastewater that has a maximum biochemical oxygen demand (BOD) concentration of around 225 mg/l while the disposed faecal sludge's BOD concentration reaches 3,394 mg/l. Therefore, an additional faecal sludge treatment plant needs to be established in order to separate the solid phase from the liquid phase. According to the treatment performance calculation, some alternative treatments can achieve BOD_5 and TSS removal of up to 97% and 98% respectively. The selection of the alternative treatment was decided from weighting results of several aspects, such as economic, land use, technological and environmental aspects. The weighting method that was used in this research was Simple Additive Weighting (SAW). The advantage of SAW is its ability to do the assessment highly precisely because it is based on predetermined criteria and preference weights. Based on the weighting result, the treatment technology selected was a Solid Separation Chamber as primary treatment, combined with an Anaerobic Baffled Reactor as a secondary treatment. A Belt Filter-Press was

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applied to reshape the sludge into a recyclable cake. The required cost is approximately 16 billion rupiahs.

Keywords: *ABR; BOD_5; faecal sludge treatment; imhoff tank; simple additive weighting; solid separation chamber; TSS; wastewater treatment plant.*

1 Introduction

According to the Republic Indonesia's Central Bureau of Statistics, Indonesia is one of the largest developing countries in Southeastern Asia, home to 270.2 million inhabitants in 2020 [1]. The World Bank has predicted that the Indonesian population will exceed 290 million inhabitants in 2045 [2]. This population increase will potentially also occur in the region, for example in Denpasar city. According to Ministry of Environmental and Forestry Law no. 68/2016, the total water usage per capita per day is up to 100 liter/capita/day [3]. Assuming that 80% of daily water usage will be converted into daily domestic wastewater discharge per person, a population increase will lead to significantly higher wastewater generation [4]. According to Abfertiawan, *et al*. [5] domestic wastewater treatment in Denpasar city relies heavily on an on-site system for over 96.8% of the total population. In contrast, as much as 3% of the population is served using an off-site system. Meanwhile, the remaining 0.2% of the population still practice open defecation.

The off-site wastewater treatment is carried out by the WWTP Denpasar Sewerage Development Project (DSDP). The on-site treatment sludge needs to be pulled out by a septic truck and disposed to WWTP DSDP Suwung. However, faecal sludge treatment is supposed to be separated from WWTP because faecal sludge possesses a considerable amount of pollutants, especially a high concentration of biochemical oxygen demand (BOD), chemical oxygen demand (COD) and total suspended solid (TSS).

The existing treatment using the aerated lagoon process is only able to treat a maximum organic pollutant load of around 225 mg/l and is unable to treat higher BOD loads. According to Mallory, *et al.*[6] failures in waste management cause contamination of natural resources, leading to deteriorating water quality, which is further stressed by the extraction of raw materials. Therefore, additional faecal sludge treatment can help treat faecal sludge from septic trucks to reduce the treatment load on the aerated lagoon process at WWTP DSDP Suwung. After being treated in the faecal sludge treatment plant, the supernatant effluent can be discharged into an existing treatment unit using the aerated lagoon method. The objective of this research was to study the most appropriate alternative faecal sludge treatments and select the most suitable one for application at WWTP

DSDP Suwung in order to reduce shock loading risk and enhance treatment capability.

2 Research Methodology

2.1 Fundamentals and Design Criteria

Faecal sludge is a type of sludge generated by on-site treatment facilities. Faecal sludge is specified as raw wastewater, slurry or semi solid, and the result of blackwater and excreta treatment from on-site sanitation [7]. The characteristics of septic sludge taken directly from a septic truck for examination are shown in Table 1. According to Tchobanoglous, *et al.*, the biochemical oxygen demand (BOD_5)/chemical oxygen demand (COD) ratio from septic sludge can reach 0.7, where if the ratio is above 0.5 the wastewater can be categorized as high-biodegradable wastewater [4].

Table 1 Septic sludge characteristics from septic trucks in WWTP DSDP Suwung.

Parameter	Unit	Value
BOD	mg/l	3394
COD	mg/l	4726
TSS	mg/l	3076
NH_3-N	mg/l	302.4
PO_4-P	mg/l	24.4
pH		7.1

Source: Vitraha Consultindo [9].

In order to define the biodegradability of the septic sludge wastewater, references about various sludge characteristics were obtained, as shown in Table 2. The discharge flow was calculated based on clean water requirements in the design area. Wastewater production ranges from around 65-85% of clean water usage [4]. Afterwards, in order to calculate the faecal sludge generated by the inhabitants in the service area, the sludge generation was assumed to be 0.5 L/inhabitant/day based on Technical Guideline No. CT/AL/Op-TC/003/98 on how to operate faecal sludge treatment plants [8].

Table 2 References for various sludge qualities.

Parameter	Type of septic sludge		WWTP	References
	Public toilet	Septic tank		
pH	6.55 – 9.34			[10]
Total solids, TS (mg/L)	52,500	12,000 – 35,000		[11]
				[11]
	30,000	22,000		[12]
		34,106		[12]
	≥ 3.5 %	<3%	<1%	[11]
Faecal coliform (cfu/100 mL)	1 x 10^5	1 x 10^5	6.3 x 10^4 – 6.6 x 10^5	[12]
BOD (mg/L)	7,600	840 – 26,400	-	[11]
	-	-	20 – 229	[12]
COD (mg/L)	49,000	1,200 – 7,800	-	[11]
	30,000	10.000	7 – 608	[12]
	20,000 – 50,000	<10.000	500 – 2,500	[13]

2.2 Population Projection and Selection of Treatment Units

The inhabitant population development in Denpasar city and Kuta district was projected using several popular and robust projecting methods, i.e. linear regression, logarithmic, arithmetic, geometric and exponential projecting. The best method was selected by comparing the correlation coefficient (R) that had the lowest standard deviation from the real condition. The data were taken from the Denpasar Central Bureau of Statistics [14] and the Badung Central Bureau of Statistics [15]. From the projection, the correlation coefficient and standard error for each method were obtained as listed in Table 3.

Table 3 Coefficient correlation (R) and standard deviation**.**

	Linear	Logarithmic	Arithmetic	Geo	Exp.
R^2	0.982	0.923	0.618	0.871	0.973
Standard deviation	10,009	20,542	12,7195	30,169	12,650

From comparison between the correlation coefficients and standard deviations it was found that the method that produce the population projection closest to the real condition was the linear regression method. Therefore, the future number of inhabitants in the service area was calculated using the linear regression method. After acquiring the population projection data, the faecal sludge wastewater flow rates were calculated. Then, several faecal sludge wastewater treatment alternatives were employed and arranged according to their ability to diminish the concentration of biochemical oxygen demand (BOD) and total suspended solid (TSS) so that at disposal to the existing treatment, the effluent wastewater does not contain a huge amount of pollutants that burden the existing treatment plant.

2.3 Simple Additive Weighting Method

In this research, the weighting method that was used for the selection process was Simple Additive Weighting (SAW). Score evaluation was done by multiplying the score of each criterion by the priority weight of each criterion relative to the other criteria. According to Haswan [16], the SAW method requires normalizing the decision matrix (X) to a scale comparable to all existing alternative ratings. The preference value for each alternative (Vi) is given as:

$$Vi = \sum_{j=1}^{n} W_j R_{ij} \tag{1}$$

Symbols information:

V_i	:	the final score of the alternative
Wj	:	the specified weight
Rij	:	normalization of the matrix

A high Vi score indicates that the alternative meets most standard criteria. According to Dede, *et al.*, the advantages of the SAW method compared with other decision-making models lies in its ability to perform judgments more precisely because it is based on pre-defined values and preference weight [17].

3 Design Considerations

The faecal sludge generation per capita can be calculated as shown in Table 4. Nevertheless, the projected faecal sludge flow rate was lower than the amount of faecal sludge that was carried by incoming septic trucks. Consequently, the faecal sludge flow was then revised to 400 m^3/day based on the volume of the septic truck tanks of 4 m^3, and the fact that according to UPT PAL, the institution that manages WWTP DSDP Suwung, the incoming trucks are restricted to 100 trucks/day until 2030. In order to determine the expected effluent quality from IPAL in the service area, an approach using the effluent standard was applied.

Table 4 Sludge influent based on population projection.

	2018	2023	2028	2033	2038
Total inhabitants from projection	1,031,112	1,171,293	1,311,474	1,451,655	1,591,837
Percent of services (%)	50	50	50	50	50
Sludge production (l/inhabitant/day) [8]	0.5	0.5	0.5	0.5	0.5
Sludge flowrate (m^3/day)	258	293	328	363	398

This effluent standard quality refers to the water quality classification fromMinistry of Environment and Forestry Law No. 68/2016 about Effluent Standard of Domestic Wastewater [3]. The water quality standard is presented in detail in Table 5.

Table 5 Effluent standard for domestic wastewater.

Parameter	Unit	Concentration
pH	-	6 - 9
BOD	mg/L	30
COD	mg/L	100
TSS	mg/L	30
Oil and grease	mg/L	5
Ammonia	mg/L	10
Total coliform	Total amount/100 ml	3000
Flow	L/capita/day	100

Source: Ministry of Environment and Forestry Law No. 68/2016 [3]

To achieve the effluent standard of domestic wastewater in Table 6, especially for BOD and TSS, the existing wastewater treatment plant needs to be supported by an alternative faecal sludge treatment with the purpose of eliminating the high load of pollutants in the faecal sludge. Several faecal sludge treatment alternatives can be seen in Table 6. In this research, the supernatant from the faecal sludge treatment was directed into the existing wastewater treatment plant. From Table 7, alternative 3 showed the best performance in terms of TSS removal by removing approximately 98% of TSS, i.e. from 3076 mg/l in the influent to 60.69 mg/l in the effluent. Meanwhile, alternative 2 was estimated to exhibit the best performance in terms of BOD removal by 99%, i.e. from 3394 mg/l to 3.36 mg/l.

Table 6 Assumed BOD and TSS removal for each alternative treatment

Alternatives			Parameters	Faecal Sludge Influent Concentration	Removal Percentages Range	Reference	Assumed Removal Percentages	Expected Effluent	AL* Influent (Field data)	Mixing concentration	AL* Removal Efficiency in [24]	Expected Discharge Effluent
				mg/l	%		%	mg/l	mg/l	mg/l	%	mg/l
1	Primary Treatment	Imhoff Tank	BOD	3394	10%-40%	[18]	40%	2036.4	32.75	56.44	90%	5.64
			TSS	3076	30%-70%	[18]	70%	922.8	307	314.28	80%	62.86
2	Primary Treatment	Imhoff Tank	BOD	3394	10%-40%	[18]	40%	2036.4				
			TSS	3076	30%-70%	[18]	70%	922.8				
	Secondary Treatment	Upflow Anaerobic Sludge Blanket	BOD	2036.4	>90%	[19]	95%	101.82	32.75	33.57	90%	3.36
			TSS	922.8	88%	[20]	88%	110.736	307	304.68	80%	60.94
3	Primary Treatment	Solid Separation Chamber	BOD	3394	35%	[21]	35%	2206.1				
			TSS	3076	97%	[22]	97%	92.28				
	Secondary Treatment	Anaerobic Baffled Reactor	BOD	2206.1	89.5% - 94.5%	[23]	94%	132.366	32.75	33.93	90%	3.39
			TSS	92.28	93%-95%	[23]	95%	4.614	307	303.43	80%	60.69

4 Design Concept

4.1 Alternative Treatment 1

In the first alternative, the primary treatment is engaged by an Imhoff tank. The height of the Imhoff tank ranges around 7 to 9.5 m, while the detention time may be varied from 2 to 4 hours [4]. BOD removal in this tank reaches up to 40% and TSS removal reaches up to 70% [18]. The treatment scheme can be seen in Figure 1. According to Tilley, Imhoff tanks can treat high organic loads and are resistant to organic shock loads [25]. Low space requirements, low operating costs, and the fact that the unit can be used in warm and cold climates are reckoned as other advantages of using an Imhoff tank. There are also several drawbacks to using an Imhoff tank, such as higher construction costs, unsuitability for acidic influent, bad odor when improperly operated, and the tendency to form foam that can reduce effluent quality [26].

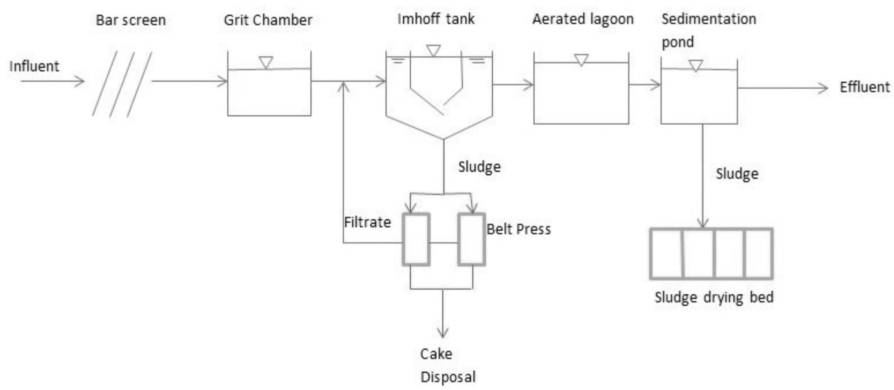

Figure 1 Flow diagram of alternative treatment 1.

4.2 Alternative Treatment 2

In this treatment, the faecal sludge is first treated in an Imhoff tank. The supernatant from the Imhoff tank is then discharged into an Upflow Anarobic Sludge Blanket (UASB) reactor as the secondary treatment. This alternative is shown in Figure 2. The UASB treatment was chosen as secondary treatment in the alternative treatment 2 because when compared to aerobic stabilization, UASB requires lower energy consumption, is efficient at higher loading rate and needs limited micro and macro-nutrients, producing a reduced amount of sludge that is characterized by an improved dewatering ability [27]. An UASB reactor can effectively remove organic pollutants from various industrial wastewaters characterized by high chemical oxygen demand (COD) [19]. The disadvantages of using UASB are sensitive response to organic shock load, restriction to nearly solid-free wastewater, and uncontrollable granulation process [28].

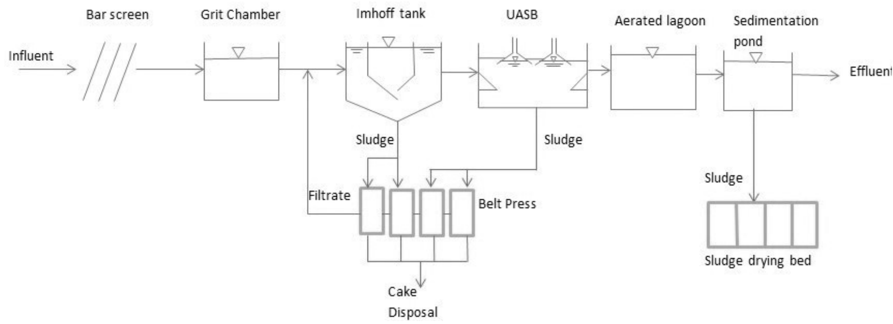

Figure 2 Flowchart of alternative treatment 2

4.3 Alternative Treatment 3

In this treatment, a solid separation chamber (SSC) was chosen as the primary treatment. The hydraulic retention time (HRT) is estimated to be as long as 1 day while the drying time is around 5 to 12 days. SSC has a shorter retention time but effectively removes TSS up to 90% [29] and removes BOD up to 35% [21]. The disadvantages of using SSC as primary treatment are difficulty to clean the filters from sludge, lack of reference and design clarity, and the unit demanding routine maintenance on a daily basis. Afterwards, the supernatant from the solid separation chamber is discharged into an Anaerobic Baffled Reactor (ABR) as secondary treatment. The ABR affords to treat BOD loads of up to 3000 mg/l and COD loads of up to 6000 mg/l, based on Barber and Stuckey in [30]. A flowchart of this alternative treatment can be seen in Figure 3.

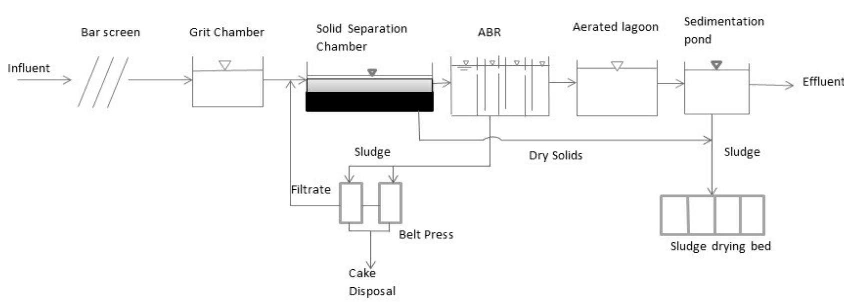

Figure 3 Flowchart of alternative treatment 3.

5 Weighting Results

The preferable faecal sludge treatment system was determined according to the technical design parameters and economic criteria. The parameters and weighting criteria that were considered in this research are shown in Table 7.

Table 7 Weighting value for each parameter.

Parameter		Weight									Total
		1	2	3	4	5	6	7	8	9	
Land requirements	1		0.5	1	0.5	0.5	0	0.5	0	0	3
Energy requirements	2	0.5		1	0.5	0.5	0	0.5	0	0	3
Chemical requirements	3	0	0		0	0	0	0.5	0.5	0.5	1.5
TSS removal efficiency	4	1	1	1		0.5	1	1	1	1	7.5
COD & BOD removal efficiency	5	1	1	1	0.5		1	1	1	1	7.5
Level of recycle difficulties	6	0.5	0.5	1	0	0		0	0.5	0.5	3
O&M	7	0.5	0.5	0.5	0	0	0.5		0	0	2
Initial Investments	8	1	1	0.5	0	0	1	0		0.5	4
O&M fee	9	1	1	0.5	0	0	1	0	0.5		4

Annotation: 0 = less important; 0.5 = quite important; 1 = very important

From Table 7, it can be seen that the weighting value for TSS removal and BOD removal efficiency was set as the highest priority due to the urgency of WWTP DSDP Suwung to meet the performance requirements and comply with the wastewater effluent standard. The second priority was the operation and maintenance (O&M) cost aspect. This aspect evaluates the cost of materials and resources required for each alternative. A priority that had the same weight as O&M was initial investment. Eventually, the weighting result from these non-technical and technical considerations, can be seen in Table 8.

Table 8 Weighting result of faecal sludge alternatives treatment.

Parameter	Weight Parameter	Alternative 1		Alternative 2		Alternative 3	
		Weight	Value	Weight	Value	Weight	Value
Land requirements	**3**	3	**9**	2	**6**	1	**3**
Energy requirements	**3**	3	**9**	1	**3**	2	**6**
Chemical requirements	**1.5**	3	**4.5**	1	**1.5**	2	**3**
TSS removal efficiency	**7.5**	1	**7.5**	3	**22.5**	2	**15**
COD & BOD removal efficiency	**7.5**	1	**7.5**	3	**22.5**	2	**15**
Recycle difficulties	**3**	1	**3**	2	**6**	3	**9**
O&M	**2**	2	**4**	1	**2**	3	**6**
Initial investment	**4**	3	**12**	1	**4**	2	**8**
O&M fee	**4**	3	**12**	1	**4**	2	**8**
Total			**68.5**		**71.5**		**73**

Annotation: 1 = fair; 2 = good; 3 = excellent

To calculate the investment feasibility, the present value of the annual cost of each alternative was calculated. The result showed that alternative treatment 1 was the cheapest in terms of investment and financially the most feasible both in construction and O&M, while alternative treatment 2 was the most expensive. From the consideration of both technical and non-technical aspect, it was concluded that alternative treatment 3 was the best alternative because according to the SAW method had the highest score among the alternatives.

6 Conclusion

Eventually, it can be concluded that the lack of faecal sludge treatment facilities in WWTP DSDP Suwung leads to the inability of the existing treatment to meet the discharge standard. Therefore, supporting faecal sludge treatment facilities need to be built. There are three alternatives that were feasible to treat faecal sludge wastewater properly. The first alternative is using an Imhoff tank for primary treatment, the second alternative is an Imhoff tank for primary treatment combined with UASB as secondary treatment, and the third alternative is using a Solid Separation Chamber as primary treatment and an Anaerobic Baffled Reactor as secondary treatment. In order to figure out the best alternative, a simple additive weighting method was used. From consideration of both technical and non-technical aspects, it was concluded that alternative 3 is the best alternative to be applied because according to the SAW method this alternative had the highest score. Alternative 3 consists of a Solid Separation Chamber (SSC) to remove total solids combined with an Anaerobic Baffled Reactor (ABR) to remove BOD_5.

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