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A review of recycling of human excreta to energy through biogas generation: Indonesia case

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Abstract

The use of waste to produce biogas not only limited to the waste from nature such as agricultural waste, food waste, or cattle manure; but can also use human waste hereinafter called human excreta. The use of human excreta for biogas generation considered beneficial either in the term of process or environment. It is at the same time produce energy and reducing environmental problem that caused by unmanaged human excreta disposal. In Indonesia, the main use of biogas itself is for cooking and generating electricity. The huge population and inequality deployment of electricity supply in Indonesia becomes a strong reason in developing biogas system from human excreta. This review paper will discuss utilization of human excreta to produce biogas as alternative energy source and the prospect of this technology in Indonesia.

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Keywords: biogas; human excreta; electricity; Indonesia

1. Introduction

Biogas, the methane rich gas, is the by-product of anaerobic digestion that breaking down the organic material in the absence of air. Anaerobic digesters convert the energy stored in organic materials present in manure into biogas. This gas can be used as a fuel for cooking, lighting and generating electricity. Cooking is the most convenient use of biogas. A biogas burner that burns with blue flame without odour is available in a wide ranging capacity from 8 cft to 100 cft biogas consumption per hour. The biogas lamp consumes 2-3 cft per hour having illumination capacity

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equivalent to 40 W electric bulbs at 220 volt [1]. Biogas also can be fed directly into a gas-fired combustion turbine. This combustion then converts the energy stored in the bonds of the molecules of the methane contained in the biogas into mechanical energy as it spins a turbine. The mechanical energy produced by biogas combustion in an engine, spins a turbine that produces electricity [2]. The biogas usability and its equivalent can be seen in Table 1 [3].

Table 1. Biogas usability and equivalent [3]

Application	1 m^3 biogas equivalent
Lighting	equal to 60 -100 watt bulb for 6 hours
Cooking	can cook 3 meals for a family of 5 - 6
Fuel replacement	0.7 kg of petroleum
Shaft power	can run a one horse power motor for 2 hours
Electricity generation	can generate 1.25 kilowatt hours of electricity

Biogas generation commonly utilize the organic waste such as cattle manure, food waste, agricultural waste, and human waste. This cause biogas considered as a potential waste-to-energy technology which greatly contribute in reducing environment pollution and the most important in reducing greenhouse gases effect caused by the waste. Utilization of raw material such as human waste (human excreta) considered beneficial in terms of the process because it does not require additional starter (microorganisms seed), and a supply of microorganisms occurs continuously during the feeding of raw materials. This directly supports the sustainability of the production of biogas.

In the case of Indonesia, the use of human excreta for biogas at the same time is a potential way in reducing environment problem and in supplying electricity. The 1.2% population growth rate per year in Indonesia in fact can be a promising raw material provider in biogas generation. Meanwhile, the 72.95% electrification ratio of Indonesia in 2012 and 80% of target electrification ratio year 2014 [4] lead the main use of biogas in Indonesia as electricity supply.

This review paper will discuss about utilization of human excreta, emphasizing on human faeces, to produce biogas as an alternative renewable energy. This paper will also discuss about sanitation condition in Indonesia which is a strong reason to develop human excreta-to-biogas technology and the prospect of developing this system.

2. Sanitary condition in Indonesia

In Indonesia, the data up to 2012 showed that the proportion of households with sustainable access to adequate sanitation only reached 57.35% [5]. It means that around 40% population do not have the access to a safe, hygienic, comfortable sanitation that can keep the user and the surrounding environment from contact with human faeces. Meanwhile in the communal/public infrastructure, at least 134 cities/counties have sludge treatment plants and in fact 37 plants have been rehabilitated, but less than 10% of the plants that function optimally [5]. Poor condition of sanitary in Indonesia (Fig. 1) might cause by limited facilities, lack of public awareness, and absence of proper Standard Operational Procedure (SOP). Improper management of human excreta definitely leads to environmental and health problems.

Basically, there are two systems of domestic wastewater and sludge management in Indonesia, on-site and off-site or sewerage system. In the on-site system, the addition of sludge treatment is needed. The example of on-site system is personal septic tank, and communal septic tank. Meanwhile, in the off-site system, the sludge treatment is separated from the source and the pipes are used to drain the sludge to the sludge treatment plants [7]. The plot of on-site system can be seen in the Fig. 2.

(a) (b) (c) (d)

Fig. 1. Poor sanitary condition in Indonesia; (a) Poor quality latrine; (b) improper faeces disposal; (c) septic tank leakage and; (d) illegally sludge dumping [6]

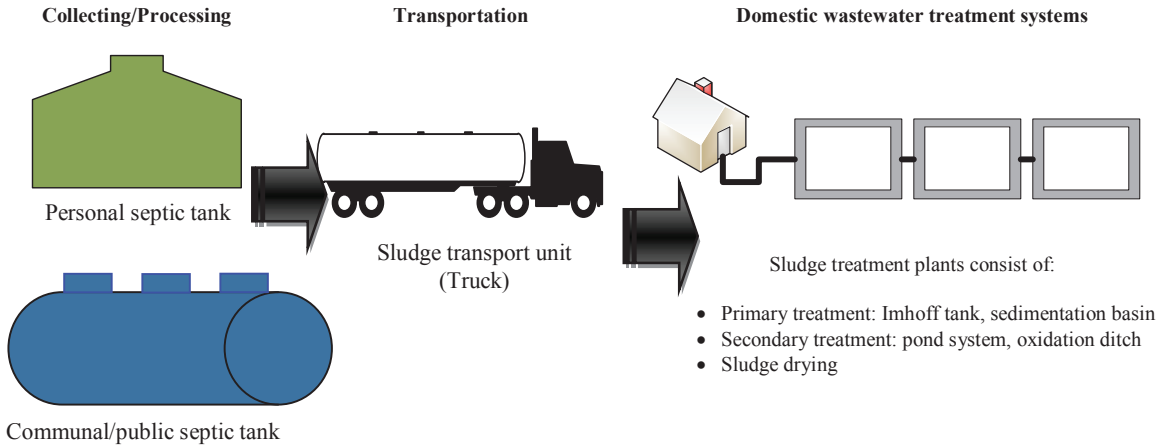

Fig. 2. The plot of on-site system of domestic wastewater and sludge management in Indonesia

Other fact regarding sanitation in Indonesia is 80% of household in Indonesia accommodate their final disposal in a septic tank. Of these, 60% of septic tank is have the distance less than 10 meters from the household wells. This condition induce high content of Bacteria *Eschericia coli* (*E. coli*) in the wells. The sanitary condition describes above become strong reason for the goverment to support the utilization of human excreta to produce energy.

3. The use of human excreta for biogas generation

Considering the ease of the process and no starter (microorganism seed) needed in the process, human excreta (in this term is human faeces) have similar potential in biogas generation compare to the cattle manure. Those advantages might due to the human faeces and cattle manure are derived from the anaerobic degradation in the gastrointestinal tract, so it is possible to contain high faecal anaerobic bacteria anaerobic. The component of human excreta as can be seen in Table 1 [8].

Based on the data on Tabel 2 [9], there is a possibility of potential biogas per kg human faeces becomes equal or higher than the manure, and the levels of methane in the biogas can reach 70% [10]. Other fact that makes human excreta a beneficial raw material is its pH which is about 7.3[11], the optimum pH range for biogas production.

The process of biogas generation using human excreta basically similar with cattle manure-biogas system (Fig. 3). The human excreta are fed into digester every day, while the produced gas and sludge also simultaneously will be

out from the digester with certain amount based on hydraulic retention time (HRT) of the slurry in the digester. The sludge itself can be streamed to the fish pond or further processed into fertilizer.

Table 2. The content of human excreta (human faeces)

Component	Unit (per wet mass)	Amount
Dry mass (at excretion)	g/kg	216
Total nitrogen (TN)	g/kg	11
Total phosphorus (TP)	g/kg	4
Potassium	g/kg	8
Moisture content	%	78
Dry matter content (at excretion)	%	22
pH	-	7 – 9

Table 3. Comparison of raw material and yielded biogas

Source	Waste amount/day/kg	% Water	Dry matter	Biogas m^3/kg dry waste
Cow	20-30 (28)	80	20	0.023-0.040
Dairy cow	20-30 (28)	80	20	0.023-0.040
Buffalo	30-40 (35)	83	20	0.023-0.040
Roaster/Hen	0.15-0.20 (0.18)	72	28	0.065-0.116
Pig	3.00-4.00 (3.40)	67	9	0.04-0.059
Human	0.10-0.40 (0.15)	77	23	0.02-0.028

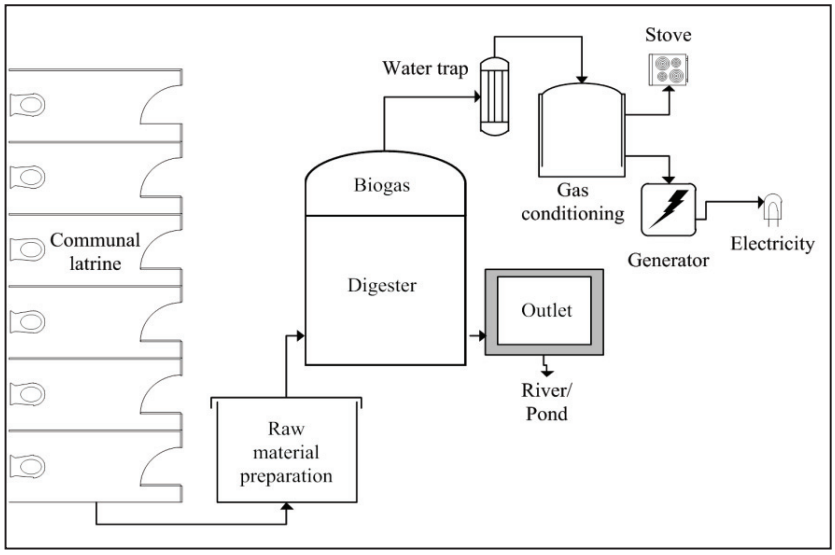

Fig. 3. Biogas generation using human excreta

The main shortcoming of human excreta is the low ratio C/N which about 6-10. It is lower than the ratio of C/N that is expected on biogas production by 25-30. This means that the amount of nitrogen is greater than the amount of

carbon, which resulted in a lot of ammonia formation from the decomposition process and further improves the system pH becomes alkaline. To overcome this shortcoming, the addition of high C/N ratio raw material is needed such as rice straw (C/N ratio 12.5-25), rice husk (C/N ratio 100-125), or corncob (C/N ratio 50) [12]. Other problem in using human excreta to produce biogas is the *E. coli* content in the waste to be disposal into the environment. However, Pramond and Michelle, 2011 [13] from their research showed that the percentage of survival colonies decreases with the length of time of incubation, as shown in Fig. 4. They also found that At thermophilic temperature, *E. coli* inactivation and biogas production were faster than that of at moderate and mesophilic temperatures.

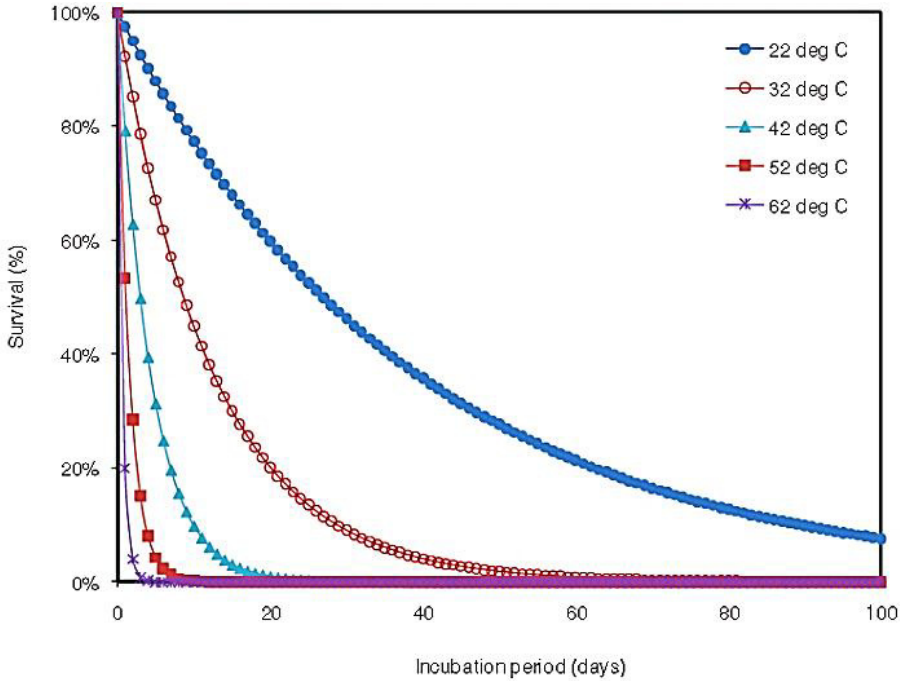

Fig. 4. Survival percentages of *E. coli* over incubation period for temperature range 22 - 62°C

4. Potency of human exctreta utilization for biogas generation in Indonesia

Considering the country with the high population growth rate, which is about 1.2% per year[14], Indonesia ought to be able to utilize any kind of waste that produced from human activities to generate alternative energy. Nowadays, the development of biogas technology can also utilize the human excreta (faeces). Therefore, the high population in Indonesia should be considered as something favourable.

Various calculation can be used in determining the biogas production, such as Formula according to Bousier equation, Buswell equation, equation according to Bouille and Bubois, model Hashimoto according to Nijaguna, equation according to Vedrenne, and equation according to Executive Board-CDM [15-21]. Buswell created an equation to estimate the products from the anaerobic breakdown of organic material of chemical composition $C_{450}H_{2050}O_{950}N_{12}S_1$. For the estimation of 10,000 people that produce faeces about 250 gram/person/day[10], the total faeces produced will be 2,500 kg/day. 100 – 400 gram human faeces equivalent to 30-60 gram dry matter [11], therefore 2,500 kg human faeces will have about 750 kg dry matter. In producing biogas, total of organic matter in faeces that could be degraded is approximately 50% of total solid (TS) or 60% volatile solid (VS) [11]. Estimated biogas generated from human excreta using Buswell equation is as follow [21]:

Carbon (24%) in 750 kg dry matter in human faeces: 750 kg dry matter x 0.24 kg C = 180 kg carbon. With the assumption % of carbon biodegraded is 60%, and then 180 kg x 0.6 = 108 kg carbon is converted to biogas. From

Buswell 53% CH_4 in biogas, then the weight of methane carbon (CH_4-C) = 108 kg x 0.53 = 57.24 kg carbon. Weight of methane therefore 57.24 kg x 16/12 = 76.32 kg CH_4. If 1 mole gas at STP is 22.4 litre and 16 g of CH_4 is 22.4 litre, then 57,240 g CH_4 contains 3,577.5 moles CH_4 and can be converted into 3,577.5 x 22.4 = 106,848 litre CH_4. So the estimated methane produced from 2,500 kg/day of human faeces is 106.85 m^3 CH_4, respectively. The calorific value of biogas is variable (depending on methane content) at 20-26 MJ/m^3 (5.6-7.2 kWh/m^3) [22]. By using the typically biogas calorific value of 22 MJ/m^3, the energy yield of 106.85 m^3 gas produced from human faeces is 2,350.7 MJ/day or 652.97 kWh/day.

The potency of biogas generated from human excreta is clearly advantageous considering the large number of Indonesian population and also high population growth as describe in the prediction of Indonesian population in the following few years ahead. The potency of biogas from human excreta that possible to be generated in Indonesia can be seen in Fig. 5. [23].

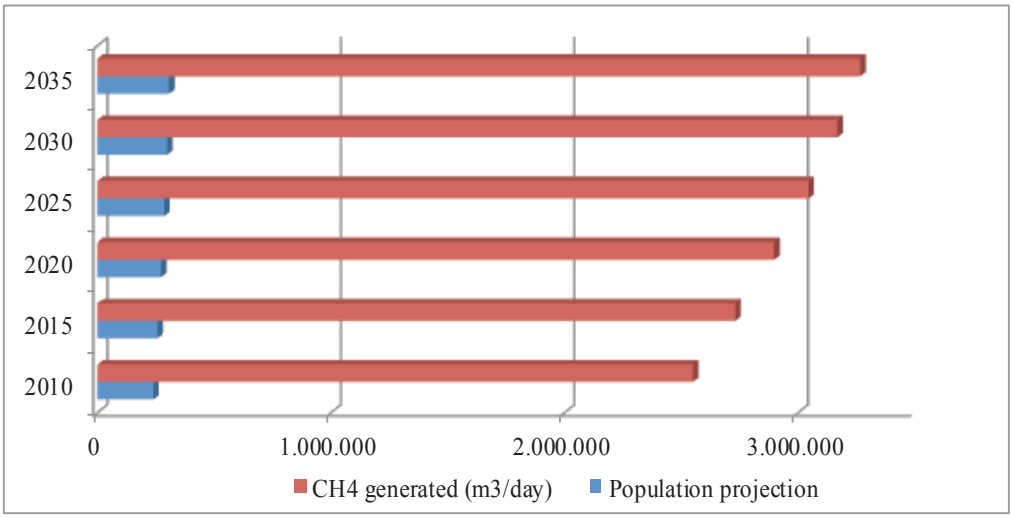

Fig. 5. Population projection in Indonesia from year 2015-2035 and potency gas generated (m^3/day)

The application of biogas from human excreta still limited in Indonesia. Nowadays this technology mostly applied in the (islamic) boarding school, because of the large number of students and the needs of proper waste management. The problems regarding human excretra-biogas system are including the technology itself and also the social economic problem. In the technology term, the difficulty is how to transfer the technology to the communities. The management of the communal latrines as the source of raw material is also important. The roadmap or strategy in investing in small-scale communal system that can be integrated with centralized piped in principle can provide economic benefits while in the same time support the waste-to-energy program. In this circumstance, the cooperation beetwen goverment (in the term of legal aspect) and the community is highly needed.

5. Conclusion

The application of biogas using human excreta can provide various benefits, both in the term of environment and providing the alternative energy source. Considering the high population in Indonesia with potency of gas production from human excreta/ human faeces 106.85 m3 gain 2,350.7 MJ/day or 652.97 kWh/day of energy, this technology should be developed and ensured its sustainability.

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