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DESIGN AND DEVELOPMENT OF BIOGAS REACTOR FOR FARMER GROUP SCALE

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ABSTRACT

Biogas technology has been introduced and developed for long time in Indonesia. However, its application as an alternative energy source is limited due to several constraints such as lack of technical expertise, misfunction of the reactor, non-user friendly design, manually handling, and highly investment for construction. A study was conducted to develop biogas reactor for farmer group scale. Reactor was designed with installed capacity of cattle dung from 10-12 heads or about 18 m^3 dung. Based on design calculation, digester was predicted to produce biogas up to 6 m^3/day. Production of methane gas depended on C/N ratio, hydraulic retention time, pH, temperature, and toxicity of cattle dung used. Temperature of slurry inside digester was around 25-27^{o}C and pH 7.0-7.8. Reactor produced biogas containing methane of about 77%. Results showed that mantle lamp needed biogas of 0.23 m^3/hour with pressure of 45 mm H_2O and gas stove required biogas of 0.30 m^3/hour with pressure of 75 mmH_2O. Analysis of environmental impact indicated that COD of effluent decreased about 90% compared to fresh dung. Moreover, BOD/COD ratio was 0.37, less than that of normal waste water of 0.5. Effluent components (N, P and K contents) were not different to compost as a reference.

[**Keywords**: renewable energy, biomass, cattle dung, biogas reactor]

INTRODUCTION

Fast population growth and industrial sector expansion cause increase in energy demand and decrease in environment quality. Although Indonesia is one of oil and gas producing countries, decrease in oil reserves and revocation of oil subsidy had increased oil price and decreased environment quality due to excessive utilization of fossil energy. Utilization of alternative renewable and environmentally-friendly energy resources, therefore, is required.

Biogas is a renewable energy that has highly prospect to be developed. Biogas can be produced from wastes such as household wastewater; liquid wastes from chicken, cow, swine farming; and organic wastes from market and food industry. Installed capacity of biogas utilization is less than 1% of existed biogas potential (685 MW). Ruminants (dairy cattle, beef cattle, buffalo) with population of 13.68 million heads (in 2004) with population structure of calf, young, adults and average cattle dung of 12 kg/head/day, produce cattle dung of 164.16 million tons per day or equal to 8.2 million liters of kerosene/day (Syamsuddin and Iskandar 2005).

The advantages of using biogas reactor system are reduce greenhouse gas effect, decrease unpleasant odor, prevent disease transmission, and produce heat, power (mechanic/electricity) and by-products such as solid and liquid fertilizers. Utilization of wastes as energy source will economically be competitive in line with increasing petroleum and inorganic fertilizer prices. Besides, this method is considered as environmentally-friendly and sustainable agricultural practices (United Nations 1984; Marchaim 1992).

Biogas technology has been introduced in 1980, hence it is not a new innovation in Indonesia. However, its development was stagnant due to several constraints such as lack of technical expertise, misfunction of biogas reactor due to construction fault, non-user friendly design, manually handling especially in enticing or expelling sludge from reactor, and highly investment for contruction. Therefore, indepth study technically and economically and new approaches for its development were highly required (Widodo and Nurhasanah 2004; Widodo *et al*. 2006). The study aimed to design and test biogas reactor for farmer group and analyzing its technical and economical development.

MATERIALS AND METHODS

Materials

Biogas reactor was constructed from cement, pebble, brick, sand, and waterproof coating materials. The strength of the reactor is highly depended on material quality,

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[1)] Article in bahasa Indonesia has been published in Jurnal Enjiniring Pertanian Vol. IV No. 1, 2006, p. 41-52.

technique, and accuracy of ferforming each construction working step. Construction steps of biogas reactor consist of building foundation, setting walls, and coating the walls. Coating was done repeatedly with a mixture of cement and waterproof materials. Manometer was made of transparent plastic pipe of 1 cm diameter and filled with colored water. One pipe tip was connected to bottle which functioned as safety seal. The difference in water surface levels from initial position (parallel) indicated the amount of pressure.

Methods

Biogas reactor can be classified based on setting of gas collector construction, those are (1) combination of reactor/gas collector, consisted of fixed dome and flexible bag; (2) floating gas collector including without water insulation and with water insulation; and (3) separated gas collector (United Nations-Economic and Social Commission for Asia and The Pacific 1980). In this study, biogas reactor was designed and developed based on identification results with considering various factors of techniques, economic, operational ease, and work safety.

Parameters of Design and Capacity of Biogas Reactor

Designing biomass processing unit considered same important factors as follows: (1) number of cattle which will influence cattle dung and urine quantity, as well as amount of cleaning water; (2) reactor filling which was affected by reactor volume and amount of cattle dung used; (3) time of materials in reactor (hydraulic retention time); (4) estimation of methane gas pressure produced; and (5) estimation of methane gas volume production. Planning the establishment of biomass (cattle dung) processing unit considered four factors, those are: (1) availability of construction materials; (2) availability of organic wastes as filling materials; (3) amount of basic needs for energy of one family or community and kinds of their needs; and (4) utilization of effluent as organic fertilizers for plants or algae on fish ponds.

Parameters used in the biogas reactor design were based on literature study and consultation to some universities, research institutes, and related institutions to obtain data and information related to technical problems in utilizing biogas energy from cattle dung. The parameters were important in determinating of biogas reactor type and designing the biogas reactor.

Design activities

Biogas reactor capacity was estimated by using quotient (1), (2), (3) and (4) and data on: (1) highest methane gas production capacity per kg volatile solid added; (2) concentration of volatile solid in materials; and (3) hydraulic retention time. Whereas collector of sludge expelling from the reactor was estimated by using quotient (5). Based on this estimation, biogas reactor design can be drawn.

Performance testing

Performance test was done through several steps:

a. Reactor filling procedure. Results of chemicophysical properties testing of materials were used to know water requirement used in mixing materials, and if it is needed, cattle dung was mixed with other materials to obtain C/N content which suitable to required condition for digestion process (C/N content = 25:1).
b. Reactor filling. Reactor was filled with mixture of cattle dung and water with a ratio of 1:1. The filling was conducted until the reactor was full and remained until gas produced was stable. The filling was then carried out every day.

Some measuring tools were used in performance testing, such as water manometer to measure gas pressure, flowmeter gas, pH meter, and quicksilver thermometer.

Economic analysis of biogas reactor

Economic feasibility analysis of designing and developing biogas reactor included net present worth (NPW), net present cost (NPC), net present revenue (NPR), B/C ratio, simple payback, and internal rate of return (IRR).

Laboratory a nalysis

Laboratory analysis consisted of (1) cattle dung conditions including total solids, volatile solids, and C/N ratio, chemical oxygen demand (COD) and biological oxygen demand (BOD); (2) chemical composition of biogas (CH_4, CO_2, H_2S and NH_3); and (3) condition of sewage sludge from reactor (effluent) including COD, BOD, and main nutrient content (N, P, and K).

RESULTS AND DISCUSSION

Result of Problem Identification

Determination of biogas reactor type

Development of biogas technology faced many constraints, i.e. lack of technical expertise, misfunction of biogas reactor due to construction fault, non-user friendly design, manually handling (enticing/expelling sludge from the reactor), and high investment of construction. Therefore, technical and economical considerations were required in determining the type of reactor which will be developed.

Results of problem identification through literature study, technical consultation, and field visit indicated that biogas reactor of fixed dome type (China type) was selected to be developed. Some reasons were: (1) economic age reaching 20-25 years, (2) made of local materials, (3) dome construction was able to hold burden in or above soil surface, (4) construction was under soil surface so stability of material temperature in biogas reactor was secure, (5) saving land use, (6) ease to be operationalized, (7) ease and cheap maintenance (United Nations-Economic and Social Commission for Asia and The Pacific 1980; United Nations 1984; Chengdu Biogas Research Institute 1989; Marchaim 1992; Jan Lam 2005).

Parameters of design and capacity of biogas reactor

Small-scale farmers in Indonesia have 2-5 heads of cattle and spread in broad areas. Economically, number of cattle possession was 10-12 heads. Besides, centralized stall program was enhanced by government in region to prevent environmental pollution. With this consideration, capacity of biogas reactor was developed to carry cattle dung of 10-12 heads and produced biogas to fulfil energy requirement (cooking and lighting) for 5 families (Dinas Peternakan Provinsi Jawa Barat 2003; Kaltim Pos 2003).

The size of reactor was designed with maximizing gas production per volume unit of reactor to minimize construction cost. This was related to anaerobic digestion which depends on biological activities of methanogenic bacteria which slowly developed, hence reactor size should met required performance and quite big to avoid leaching of those bacteria out of reactor (washed out). At tropic areas which generally the temperature in the reactor is about 25-30°C, retention time ranges from 40 to 50 days (United Nations-Economic and Social Commission for Asia and The Pacific 1980; United Nations 1984; Gunnerson and Stuckey 1986).

From identification result, parameters obtained were as follows: (1) production of cattle dung per head per day was 15-25 kg; (2) 1 kg total solid produced biogas of 250 liters; (3) weight of total solid was 0.18 wet cattle dung weight; (4) calor values of biogas were 5.6-7.2 kwh/m^3; (5) optimum pH for methane gas production were 7.0-7.2; and (6) optimal digestion temperature was 35°C.

Location setting

Based on problem identification results, Agricultural Islamic Private School (*Pondok Pesantren*) of Darul Fallah at Bogor, West Java, was chosen as location for establishing biomass (cattle dung) processing unit into biogas. Dairy cattle farming with number of cattle 23-40 heads is a cooperative business unit under auspices of *Pondok Pesantren* Darul Fallah. *Pondok Pesantren* Darul Fallah has established institution, qualified human resources, wide farmland, integrated farming system such as processing composts as fertilizers, having grass land and forage land, other agricultural practices such as plant nurseries, and as a place for student practices of the *Pesantren* and universities in Bogor and its adjacent. Hence, establishment of biomass (cattle dung) processing unit into biogas can be as show window of biogas technology development in Indonesia. Other factors considered were willingness to manage the processing unit continuously, having considerable cattle number, and its location which is near the Indonesian Center for Agricultural Engineering Research and Development (ICAERD) so supervision and operational handling can be done easily. Memorandum of understanding (MOU) of collaboration between ICAERD and *Pondok Pesantren* Darul Fallah was held on 4 October 2005.

Design Activities

Estimation of biogas reactor design

Biogas reactor was designed by using quotient (1), (2), (3), (4) and (5). Volumetric capacity of methane gas production (specific yield) was estimated by following quotient (Gunnerson and Stuckey 1986):

$$Vs = \frac{Bo \times So}{HRT} \cdot \left[1 - \frac{K}{(HRT \times \mu m - 1 + K)} \right] \quad \text{..... (1)}$$

$$K = 0.8 + 0.0016 \times e^{0,06 \times So} \quad \text{...................... (2)}$$

$$\mu m = 0.013\,(T) - 0.129 \quad \text{....................(3)}$$

Vs : specific yield (volumetric capacity of methane gas production, m^3/day/m^3 reactor)
Bo : highest capacity of methane gas production, in m^3 methane gas/kg volatile solid added.
So : concentration of volatile solid in material input, kg/m^3
HRT : hydraulic retention time, day
K : kinetic coefficient, undimension
µm : maximum specific growth rate of microorganism, per day.

Reactor volume:

$$V_{reactor} = \frac{\pi}{2R^3} + \frac{\pi}{3R^2t} \quad \ldots\ldots(4)$$

Volume of effluent collector of reactor (*Vpl*) was calculated as follows :

$$V_{pl} = \frac{\pi}{2R^3} \quad \ldots\ldots(5)$$

R : radius of reactor dome
t : height of cone of reactor floor

Bo = 0.2 m^3 methane gas/kg volatile solid added, So = 100 kg/m^3, HRT = 45 days.

With knowing volumetric capacity of methane gas production (Vs) and reactor volume, quantity of biogas produced can be measured.

Design and construction

Biogas reactor of fixed dome type consisted of three parts, those are mixing unit, main part of reactor, and outlet of effluents (Figure 1). Mixing unit functioned to receive cattle dung collected from the stall and mix them with water with ratio of solid/water of 1:1. The mixture was then put into main digester.

Main part of reactor was a place where cattle dung was fermented anaerobically to produce biogas. Upper part of reactor had shape of dome with diameter of 4.2 m, whereas its floor was cone with length of side line 2.1 m and cone height 0.75 m. The estimation with quotient (4) obtained reactor volume of 18 m^3. The reactor was designed to be able to hold cattle dung from 10 heads (with cattle dung of 20 kg/day/head and retention time of 45 days). Estimation of biogas produced was 6 m^3/day (for average biogas production of 30 liters of gas/kg cattle dung). The main part of reactor was equipped with maintain hole (manhole)

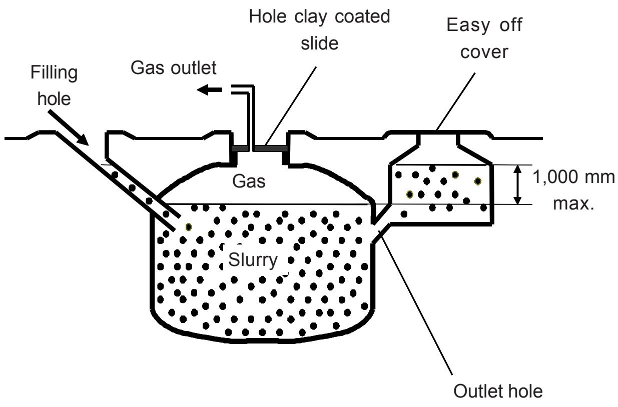


Figure 1. Biogas reactor of fixed dome type.

which covered with reinforced concrete plate, clay soil and filled with water. Other function of this part was as safeguard when there is a huge pressure from biogas formed, so reactor construction was not damaged.

Sludge outlet functioned to receive effluent temporarely expelling from main reactor after anaerobic fermentation process. This part also had shape dome with volume of 5 m^3 (3 m diameter).

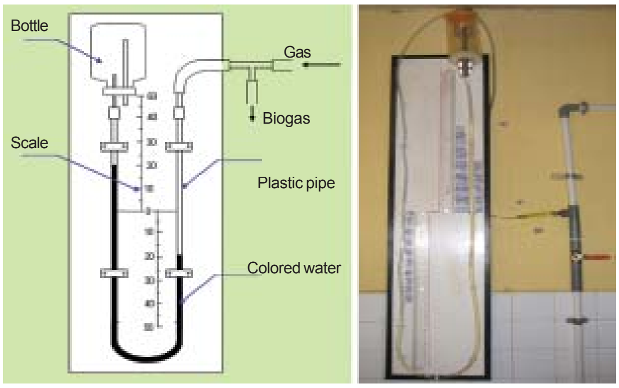
The strength of the reactor construction was highly influenced by material quality (cement, brick, sand and waterproof coating materials) and accuracy of performing each construction working step. Design and construction working steps were presented in Figure 2 and 3. To measure pressure at biogas installation, water manometer equipped with safety valve was used as presented at Figure 4.

In 2005, ICAERD has conducted design and development of biogas reactor at *Pondok Pesantren* Darul Fallah. Biogas reactor of fixed dome type was designed for 10 heads of cattle (with cattle dung of 20 kg/day/head and retention time 45 days), and reactor capacity was 18 m^3 (Widodo and Hendriadi 2005).

Methane gas produced depends on C/N ratio, hydraulic retention time, pH, temperature, and toxicity of cattle dung. Results showed that material temperature in reactor was 25-27°C and pH 7.0-7.8. Based on theory, this condition was favorable for methane gas producing-microorganism activities. This was supported by methane gas content of 77%, which was more than reference data. Biogas production was 6 m^3/day (for average biogas production of 30 liters/kg cattle dung). Measurement result without burden showed gas flow rate of 1.5 m^3/hour with pressure of 490 mmH_2O. Biogas produced from reactor can be utilized for gas stove and mantle lamp (Table 1 and Figure 5).

Using data on material temperature measurement in biogas reactor and using quotient (1) and (2), methane gas production can be estimated as presented at Figure 6.

Figure 2. Design of biogas reactor of *fixed dome* type.



Note: 1 kg/cm^2 =10,000 mmH_2O = 0.9678 atm

Figure 4. Combination of manometer and safety valve.

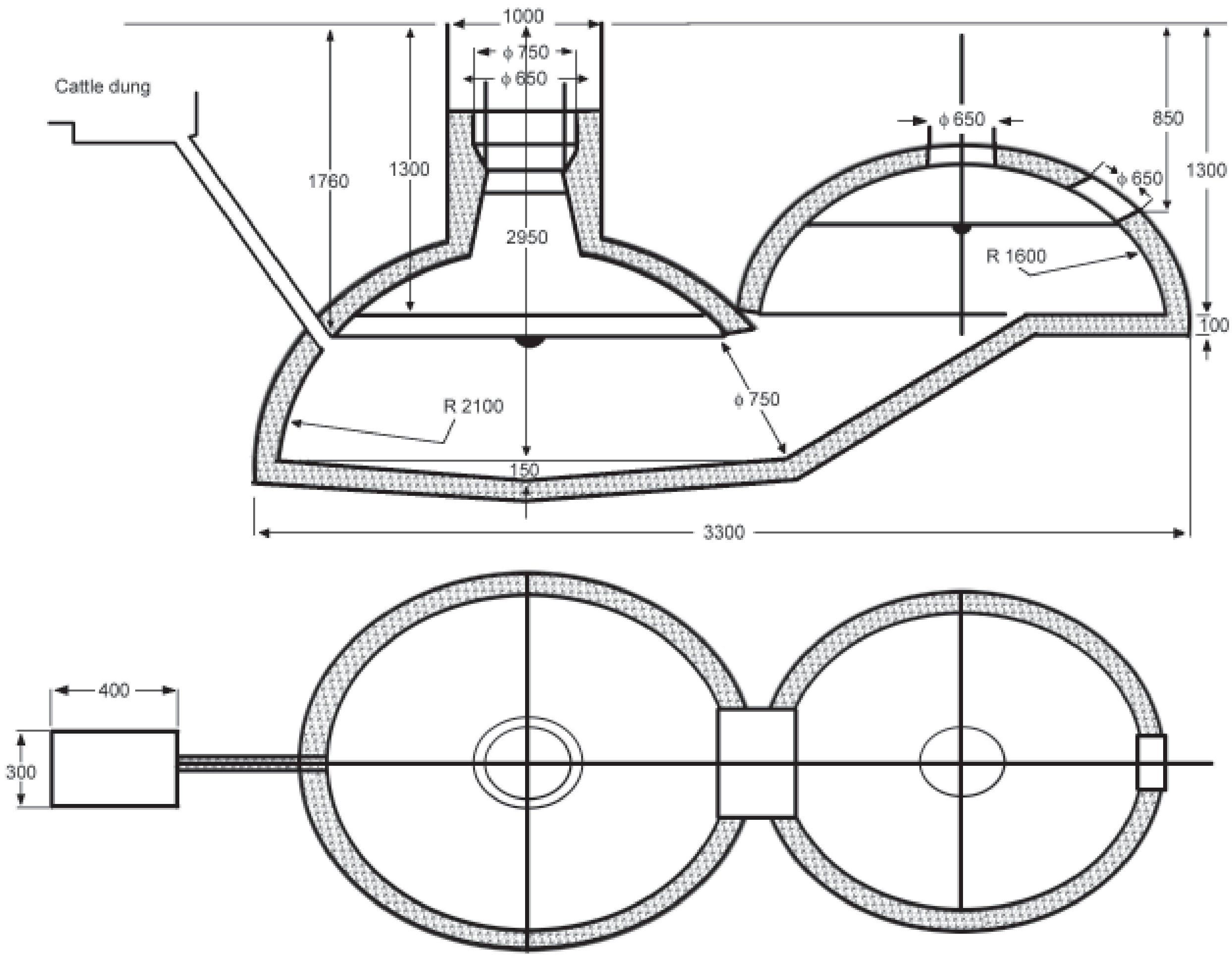


Figure 3. Working steps of development of biogas reactor.

Table 1. Performance test of biogas installation, Bogor, West Java, 2005.

Description	Reference	Result of test and analysis
Material condition (cattle dung)		
Total solid (kg/head/day)	4.8	4.2
Volatile solid (kg/head/day)	3.9	3.8
Moisture content (%)	7-9	13.59
C/N ratio	1:25 ~ 1:30	1:17
COD (mg/l)	-	19,800
BOD/COD	-	0.06
Condition in reactor (process)		
Temperature (°C)	35	25-27
pH	7.0-8.0	7-8.6
Chemical composition of biogas		
CH_4 (%)	50-60	77.13
CO_2 (%)	30-40	20.88
H_2S (mg/m^3)	< 1%	1,544.46
NH_3 (mg/m^3)	-	40.12
Condition of effluent		
COD	500-2,500	1,960
BOD/COD	0.5	0.37
Nutrient content, main (%)		
N	1.45	1.82
P	1.10	0.73
K	1.10	0.41
Performance test		
Mantle lamp (m^3/hour)	0.11-0.15 (lighting equal to 60 watt mantle lamp ≅100 candle power ≅ 620 lumen). Pressure: 70-85 mmH_2O	0.15-0.3 Pressure = 30-60 mmH_2O
Gas stove (m^3/hour)	0.2-0.45 0.3 m^3/person/day Pressure: 75-90 mmH_2O	0.2-0.4 Pressure = 60-85 mmH_2O

Source: United Nations-Economic and Social Commission for Asia and Pasific (1980); United Nations (1984); Gunnerson and Stuckey (1986); Marchaim (1992); Anonymous (1997); Schmidt (2005).

Observation with interval of 3 days for 2 months obtained pH of material 7.0-7.8 and temperature about 25-27°C. This condition was favorable for methanogenic bacteria growth and production of methane gas.

Economic Analysis of Biogas Reactor Performance

Biogas reactor was developed by investment of Rp18.45 million consisted of costs for materials and construction. Income obtained from biogas installation was Rp600,000/ month if it was converted with price and calor value of LPG. Using parameter and economic feasibility analysis as presented at Table 2, it was obtained B/C ratio of 1.35 which means that the investment was economically feasible. Simple payback analysis showed that investment of reactor construction will pay back at fourth year (economic age of digester 20 years). The income did not include by-products such as liquid/solid fertilizers. Other uses of sludge from reactor was put into fish ponds. Utilization of sewage sludge from reactor into ponds can stimulate growth of phytoplankton (algae) and zooplankton (daphia and crustaceans) as food sources for fish (United Nations-Economic and Social Commission for Asia and The Pacific 1980; United Nations 1984; Gunnerson and Stuckey 1986; Marchaim 1992).

Social and environmental factors until present have not been economically estimated yet, although biogas technology impacts have proven to be useful for

Figure 5. Utilization of biogas for mantle lamp and gas stove.

Table 2. Parameter and economic feasibility analysis of biogas reactor development, Bogor, West Java, 2005.

Description	Costs
Parameter	
Investment cost (Rp)	18,448,000
Operational and maintenance costs (Rp/year)	2,767,200
Income (Rp/year)	7,051,800
Profit (Rp/year)	4,284,600
Economic age (year)	20
Gas production (m^3/day)	6
Gas production (m^3/year)	2,190
Interest Rate (%/year)	12
Result of economic feasibility analysis	
Net present worth (NPW) (Rp)	13,555,578
Net present cost (NPC) (Rp)	39,117,444
Net present revenue (NPR) (Rp)	52,673,023
B/C Ratio	1.35
Simple Payback (year)	4.30
Internal Rate Return (IRR) (%)	23.70

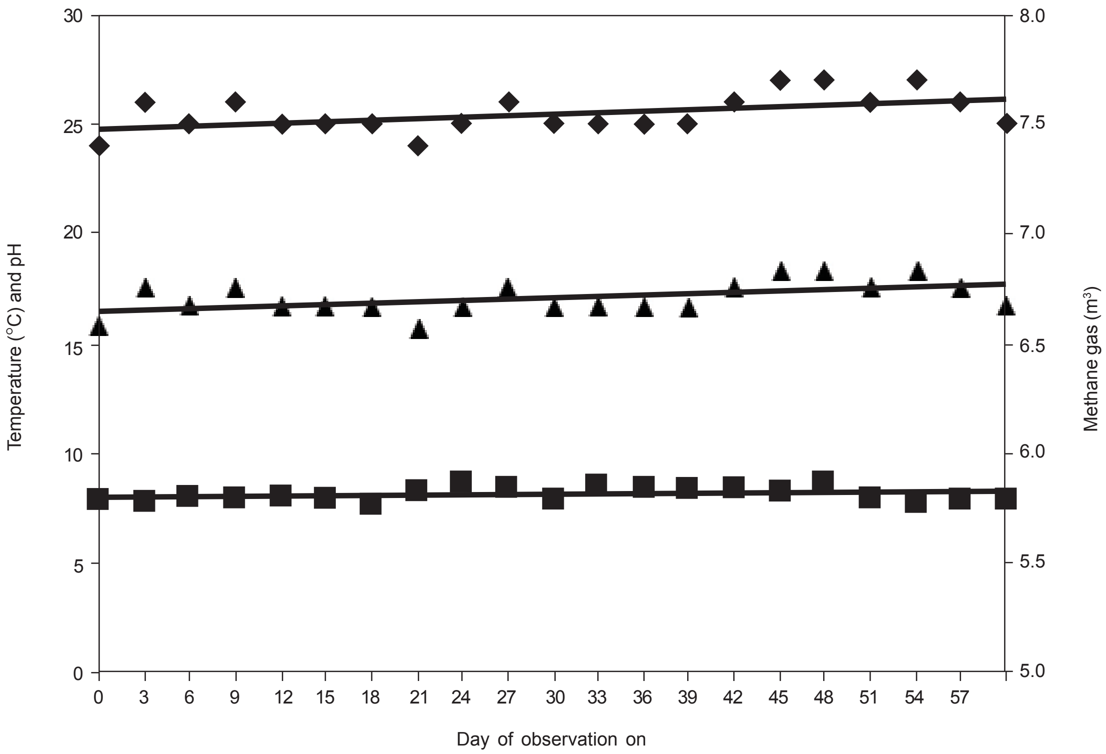


Figure 6. Graph of effect of temperature and pH on methane gas production of biogas reactor, Bogor, West Java, 2005.

communities. To enhance sustainable and environmentally-friendly agricultural practices, it should be considered to give award for person who pay attention to environment in form of tax withholding and sanction for person who ignoring environmetal pollution (United Nations 1984; Widodo and Tokumoto 2005). Based on technical and economic assessments, biogas technology was feasible to be developed.

CONCLUSION

Development of biomass (cattle dung) processing unit in form of biogas reactor of fixed dome type with capacity of 18 m^3 produced biogas of 6 m^3/day. Methane gas production was depended on C/N ratio , retention time, pH, temperature, and toxicity of cattle dung. Material temperature in reactor was 25-27°C and pH 7.0-7.8 producing biogas with methane gas content of 77%.

Utilization for mantle lamp required biogas of 0.23 m^3/hour with pressure of 45 mmH_2O and for gas stove needed biogas of 0.30 m^3/hour with pressure of 75 mmH_2O. Environmental impact analysis of effluent from biogas reactor showed that COD decreased by 90% from initial materials and ratio of BOD/COD was 0.37, less than normal condition of waste water (BOD/COD = 0.5). N, P and K nutrients of the effluent were similar with compost as reference.

Income obtained from biogas installation was Rp600,000/month. Economic feasibility analysis showed that investment was feasible with B/C ratio of 1.35 and capital was payback in fourth year (economic age of digester was 20 years). The income was not included by-products as liquid/solid fertilizers.

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