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PENGEMBANGAN LISTRIK TENAGA BIOGAS SKALA KECIL MELALUI PROSES "DRY FERMENTATION" UNTUK MEMENUHI KEBUTUHAN LISTRIK MASYARAKAT TERPENCIL

Ketua Tim Peneliti

Dr. Ir. Agus Haryanto, M.P. (NIDN.0027056503)

Anggota Tim Peneliti

Dr. Ir. Udin Hasanudin, M.T. (NIDN. 0006016403)
Dr. Ir. Sugeng Triyono, M.Sc (NIDN. 0011126101)

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HALAMAN PENGESAHAN

Judul	: PENGEMBANGAN LISTRIK TENAGA BIOGAS SKALA KECIL MELALUI PROSES "DRY FERMENTATION" UNTUK MEMENUHI KEBUTUHAN LISTRIK MASYARAKAT TERPENCIL
Peneliti/Pelaksana	
Nama Lengkap	: Dr. Ir. AGUS HARYANTO M.P.
Perguruan Tinggi	: Universitas Lampung
NIDN	: 0027056503
Jabatan Fungsional	: Lektor Kepala
Program Studi	: Teknik Pertanian
Nomor HP	: 081379078674
Alamat surel (e-mail)	: agusharyid65@gmail.com
Anggota (1)	
Nama Lengkap	: Dr. Ir UDIN HASANUDDIN
NIDN	: 0006016403
Perguruan Tinggi	: Universitas Lampung
Anggota (2)	
Nama Lengkap	: Ir SUGENG TRIYONO
NIDN	: 0011126101
Perguruan Tinggi	: Universitas Lampung
Institusi Mitra (jika ada)	
Nama Institusi Mitra	: PD Semangat Jaya
Alamat	: Desa Sri Rejeki, Kec. Negeri Katon, Kab. Pesawaran, Lampung
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Wakil Dekan I

(Prof. Dr. Ir. Dermiyati, M.Agr.Sc)
NIP/NIK 196308041987032002

Bandar Lampung, 26 - 10 - 2016
Ketua,

(Dr. Ir. AGUS HARYANTO M.P.)
NIP/NIK 196505271993031002

Menyetujui,
Ketua LPPM

(Warsono, Ph.D.)
NIP/NIK 196302161987031003

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RINGKASAN

Biogas merupakan sumber energi terbarukan yang dapat menjadi solusi handal bagi pemenuhan listrik di daerah dan pulau-pulau terpencil. Biogas dapat diproduksi dari berbagai bahan organic baik melalui “fermentasi anaerobik basah” maupun “fermentasi anaerobik kering.” Setelah proses *clean up*, biogas dapat digunakan untuk menjalankan genset guna menghasilkan listrik.

Tujuan jangka panjang dari penelitian ini adalah untuk menghasilkan sistem pembangkitan listrik dengan bahan bakar biogas yang dihasilkan dari bahan organik padat melalui proses “fermentasi kering.” Target khusus yang ingin dicapai adalah memperoleh sistem pembangkit listrik tenaga biogas skala kecil yang dapat dioperasikan untuk memenuhi kebutuhan listrik rumah tangga di daerah atau pulau-pulau terpencil. Penelitian direncanakan selama tiga tahun dan dilakukan mulai dari laboratorium hingga skala aplikasi.

Pada tahun pertama telah dilakukan penelitian sebagai berikut:

1. Pengukuran potensi produksi biogas dari digester skala rumah tangga. Penelitian dilakukan menggunakan manometer air pipa U yang dipasang pada rangkaian pipa digester skala rumah tangga di Desa Pesawaran Indah.
2. Pengukuran konsumsi biogas untuk generator skala rumah tangga (kapasitas 750W). Penelitian dilakukan dengan menjalankan generator menggunakan 100% biogas pada berbagai pembebanan untuk mengetahui konsumsi biogas, daya yang dihasilkan dan efisiensi termal.
3. Produksi biogas dari campuran substrat kotoran sapi dan jerami atau rumput gajah. Penelitian dilakukan menggunakan digester drum berkapasitas 220 liter dan digester gallon kapasitas 36 L. Penelitian ini akan difokuskan pada upaya mengetahui kondisi yang optimum untuk menghasilkan biogas dari beberapa bahan organic segar dengan sumber bakteri dari kotoran sapi. Faktor-faktor penting yang mempengaruhi produksi biogas akan dikaji pada tahun ini seperti perbandingan substrate dengan inokulum (kotoran sapi), laju pembebanan, kandungan padatan total (TS), dan pengaruh pencampuran bahan (*co-digestion*). Parameter yang diamati meliputi produksi biogas, komposisi biogas, HRT, suhu, pH, kadar TS, kadar abu dan rasio C/N dari substrat. Substrat yang akan digunakan meliputi jerami padi dan rumput gajah.

Hasil yang sudah diperoleh dari 2 kegiatan di atas adalah:

(1) Digester skala rumah tangga dengan 5-6 ekor sapi menghasilkan biogas sebanyak 1582 L/hari atau 280 L/ekor/hari.

(2) Konsumsi biogas untuk generator kapasitas 750W adalah rata-rata 415 L/jam.

(3) Digester skala rumah tangga dengan 5-6 ekor sapi dapat melayani pengoperasian mesin generator kapasitas 750W selama 4 jam/hari.

(4) Hasil penelitian skala Lab menggunakan digester volume 36 L (volume kerja 25 L) dengan sistem pengumpanan semi mekanis menghasilkan produksi biogas sebesar 0,288 L/L substrat per hari. Jika volume kerja biogas 6 m^3, maka produksinya adalah setara dengan 1.728 L/hari, sedikit lebih tinggi dari produksi biogas di lapangan.

Kata kunci: listrik, biogas, limbah pertanian, rumput gajah, generator.

BAB I. PENDAHULUAN

1.1 Latar Belakang

Menurut laporan PLN, pada akhir tahun 2012 rasio elektrifikasi di Indonesia telah mencapai 73,37% (PLN, 2013). Hal ini berarti masih ada sekitar 26% msyarakat Indonesia yang belum memiliki akses terhadap listrik. Pada umumnya msyarakat ini tinggal di daerah terpencil dan pulau-pulau kecil. Daerah seperti ini dicirikan oleh tidak adanya aktivitas industri, lemahnya infrastruktur dan secara geografis tidak terjangkau oleh jaringan distribusi listrik PLN. Beberapa kelompok masyarakat membangkitkan listrik secara swadaya menggunakan genset berbahan bakar minyak. Tetapi pilihan ini tidak ramah lingkungan dan harga listrik menjadi jauh lebih mahal.

Biogas bisa menjadi salah satu solusi yang handal untuk menghasilkan listrik di daerah terpencil. Bahan baku biogas dapat dikembangkan secara lokal sehingga murah. Berdasarkan analisis parametrik secara menyeluruh, Chandra *et al*. (2012) menyimpulkan bahwa produksi metana (biogas) dari lignoselulosa biomassa limbah pertanian adalah lebih menguntungkan secara ekonomis maupun lingkungan dan merupakan cara pemanfaatan biomassa secara berkelanjutan untuk menghasilkan energi. Biogas merupakan salah sumber energi terbarukan yang telah memainkan peranan penting di berbagai negara, baik negara maju maupun berkembang (Abraham *et al*., 2007). Beberapa negara seperti Jerman (Federal Ministry of Food and Agriculture, 2014), China (Feng *et al*., 2012; Li, 2014), dan India (Ministry of New and Renewable Energy, 2014) telah memperoleh manfaat yang besar dari biogas. Tetapi, aplikasi biogas di Indonesia masih sangat terbatas.

Pada umumnya proses produksi biogas di Indonesia dilakukan menggunakan "fermentasi basah" (sistem konvensional) dengan substrat limbah cair agroindustri yang susah diperoleh di daerah terpencil. Proses basah juga memiliki beberapa keterbatasan, di antaranya: ukuran digester besar, *feedstock* terbatas pada bahan dengan kandungan padatan kering (TS) kurang dari 10%, perlu banyak air, dan masalah yang berkaitan dengan pengelolaan digestat (*slurry*). Proses kering dapat menggunakan bahan organik secara lebih luas karena TS bisa mencapai 25% sehingga bahan baku tidak perlu diencerkan.

Limbah organik padat hasil pertanian seperti jerami, batang jagung, bagase, kulit kopi, kulit kakao, dan limbah halaman rumah berupa dedaunan serta limbah pakan dan kotoran ternak merupakan bahan baku yang melimpah. Bahan-bahan ini dapat diproses melalui proses fermentasi kering untuk menghasilkan biogas yang selanjutnya dapat dikonversi menjadi listrik.

1.2 Perumusan Masalah

Biogas bisa menjadi salah satu solusi untuk menyediakan listrik bagi masyarakat di daerah terpencil yang belum terjangkau jaringan PLN belum. Biogas dapat dihasilkan dari substrat yang diproduksi secara lokal sehingga lebih sustainable. Oleh karena itu dikembangkan sistem pembangkitan listrik skala kecil berbasis biogas yang dapat dioperasikan secara mandiri.

1.3 Tujuan Khusus

Tujuan dari penelitian ini adalah untuk menghasilkan sistem pembangkitan listrik skala kecil dari konversi biogas yang diproduksi melalui fermentasi anaerobik bahan organik padat seperti limbah pertanian (jerami dan batang jagung), sampah dedaunan, limbah ternak dan rumput.

1.4 Manfaat Khusus

Manfaat khusus dari penelitian ini adalah tersedianya teknologi sistem pembangkitan listrik skala kecil berbahan baku lokal yang dapat memenuhi kebutuhan listrik masyarakat di daerah dan pulau-pulau terpencil.

1.5 Urgensi (keutamaan) Penelitian

Listrik merupakan kebutuhan primer masyarakat. Sekitar 26% masyarakat Indonesia yang tinggal di daerah dan pulau-pulau terpencil belum memperoleh akses listrik sehingga perlu dikembangkan system pembangkitan listrik berbasis sumberdaya lokal yang ramah lingkungan dan lestari (*sustainable*). Biogas merupakan suatu sistem yang lestari karena dapat memanfaatkan bahan biologi yang dihasilkan dari proses fotosintesis. Generai listrik skala kecil berbahan bakar biogas dapat mengatasi persoalan listrik bagi masyarakat di daerah terpencil. Limbah organik padat yang diproses melalui fermentasi anaerobik “kering” juga menghasilkan produk samping berupa kompos siap pakai. Pemanfaatan kompos digestat sebagai pupuk organik berarti mengembalikan produk fotosintesis ke tanah sehingga akan tercipta suatu siklus yang lestari. Secara teknis, kegiatan penelitian ini sangat sesuai karena selaras dengan kebutuhan riil di lapangan.

1.6 Luaran

Luaran yang diharapkan dari penelitian selama 3 tahun ini secara singkat diberikan dalam Tabel 1.

Tabel 1. Luaran penelitian selama 3 tahun

Luaran	**Tahun 1**	**Tahun 2**	**Tahun 3**
Publikasi Nasional (Non Akreditasi)	√√	√√	√√
Publikasi Nasional (Akreditasi)	√	√	√
Publikasi Internasional		√	√
Teknologi Tepat Guna			√
Buku Ajar			√

Produk yang dapat langsung dimanfaatkan adalah teknologi tepat guna berupa sistem pembangkitan listrik skala kecil berbahan bakar biogas yang dihasilkan dari fermentasi anaerobik bahan organik padat. Sistem ini dapat langsung diaplikasikan ke masyarakat. Produk samping dari sistem ini adalah kompos yang dapat diaplikasikan oleh masyarakat untuk mengganti atau mengurangi konsumsi pupuk kimia.

BAB II. STUDI PUSTAKA

2.1 Biogas sebagai Sumber Energi

Makin menipisnya cadangan energi fosil dan makin meningkatnya harga energi telah menempatkan Indonesia berada pada kondisi krisis energi. Azahari (2012) melaporkan bahwa cadangan energi fosil Indonesia hanya akan bertahan selama 11 tahun untuk minyak, 32 tahun untuk gas, dan 85 tahun untuk batubara. Oleh karena itu perlu dikembangan energi alternatif yang dapat diperbaharui. Limbah pertanian dan peternakan merupakan sumber biomassa yang melimpah yang dapat digunakan sebagai bahan baku untuk menghasilkan biogas karena memiliki kandungan bahan organik yang tinggi.

Proses fermentasi anaerobik biogas merupakan alternatif bagi pengomposan konvensional dan pengelolaan limbah organik lainnya, dan mengubah bahan organik oleh konsorsium mikroba dalam kondisi tanpa oksigen menjadi dua kategori produk berharga, yaitu biogas dan pupuk organik (Jingura dan Rutendo, 2009; Li *et al*., 2011; Lema dan Omil, 2001; Li dan Liew, 2011). Biogas telah menjadi salah satu teknologi konversi energi biomasa yang telah mapan dan terbukti dapat menyediakan energi listrik dan panas. Teknologi biogas dipercaya dapat menjadi salah satu sumber energi yang lestari (*sustainable*). Beberapa negara telah memperoleh keuntungan dari teknologi biogas, baik negara maju maupun berkembang, di antaranya adalah China, India, Vietnam, Nepal, dan Jerman. Pada akhir tahun 2012, di China terdapat 41,68 juta unit biogas skala rumah tangga, 24.000 unit biogas skala peternakan kecil, 80.500 unit biogas skala peternakan besar dan 3,691 unit biogas skala menengah-besar (Li, 2014). Di Jerman lebih dari 7000 unit biogas mampu menghasilkan listrik hingga 4000 MW (Federal Ministry of Food and Agriculture, 2014). Hingga tahun 2011, lebih dari 4 juta keluarga di India telah menggunakan biogas skala rumah tangga (Ministry of New and Renewable Energy, 2014). Aplikasi biogas di Indonesia baru mulai dan masih sangat terbatas jumlahnya. Salah satu alasan lambatnya perkembangan biogas di Indonesia adalah masih melimpahnya bahan bakar kayu di wilayah perdesaan (Marchaim, 1992). Program BIRU (Biogas Rumah), suatu program biogas rumah tangga Indonesia yang merupakan kerjasama pemerintah Indonesia dan Belanda, hanya menargetkan 10.000 unit biogas skala rumah tangga untuk periode 4 tahun (2009-2012) (SNV, 2012).

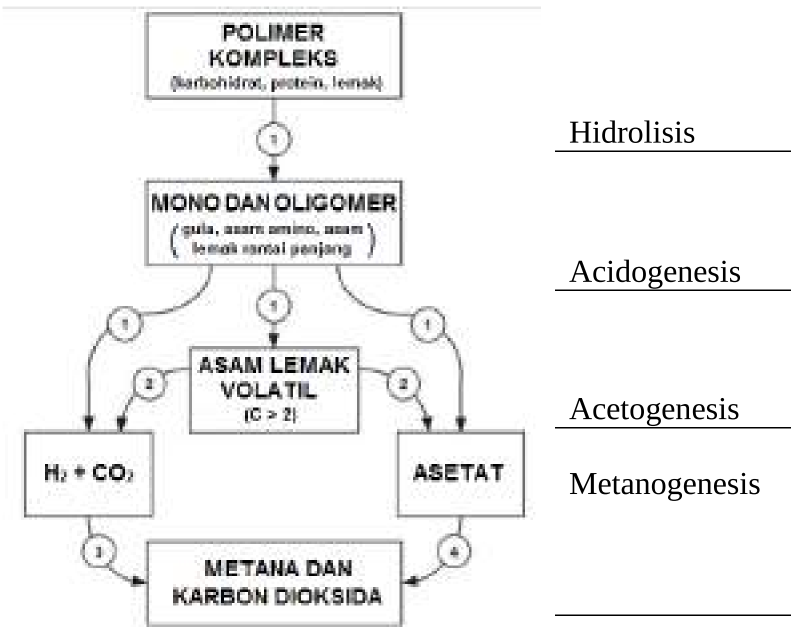
Saat ini mulai banyak industri yang memanfaatkan air limbah untuk produksi biogas, antara lain industri kelapa sawit, tapioka, dan etanol. Sekitar 10 industri di Lampung telah menginstal biogas untuk pembangkit listrik maupun panas. Hasanudin *et al*. (2011)

melaporkan, Lampung berpotensi menghasilkan biogas yang jika dimanfaatkan berpotensi menurunkan emisi GHG antara 1,49 hingga 1,57 ton CO_2 ekivalen per tahun.

2.2 Mekanisme Proses Biogas

Perombakan senyawa organik menjadi biogas dapat dianggap berlangsung dalam dua tahap. Pertama, kelompok bakteri fakultatif dan bakteri anaerobik mengubah senyawa organik kompleks menjadi material organik yang lebih sederhana (asam lemak volatil, CO_2 dan H_2). Kedua, asam organik dan H_2 dikonversi menjadi CH_4 dan CO_2. Proses produksi biogas dapat dirinci lagi berdasarkan lintasan metabolik seperti disajikan pada Gambar 1. Terlihat bahwa proses konversi substrat organik kompleks menjadi biogas melibatkan empat tahap, yaitu:

1. Hidrolisis polimer organik menjadi asam amino, gula, dan asam lemak (hidrolisis).
2. Fermentasi asam amino dan gula menjadi hidrogen, asetat dan asam lemak volatil rantai pendek, serta alkohol (acidogenesis).
3. Oksidasi anaerobik produk intermediet seperti asam-asam volatil (kecuali asetat) menjadi asam asetat (acetogenesis).
4. Konversi asetat menjadi metana oleh organism asetotrofik dan hidrogen menjadi metana (reduksi CO_2) oleh organism hidrogenotrofik (metanogenesis).



Gambar 1. Tahap-tahap dalam proses penguraian anaerobik (Lingkaran kecil menunjukkan jenis bakteri: 1. Bakteri hidrolisis (fermentatif), 2. Bakteri acetogenik, 3 dan 4. Bakteri metanogenik (Ahring, 2003).

Berdasarkan kandungan padatan kering (TS) dalam bahan baku, teknologi biogas dibedakan menjadi fermentasi anaerobik “basah” dan “kering.” Li *et al*. (2011) menggunakan batas TS kurang dari 15% untuk fermentasi basah dan lebih dari 15% untuk fermentasi kering. Sementara itu, de Baere (2000) membatasi TS untuk fermentasi basah kurang dari 10% dan fermentasi kering hingga 40%.

Meskipun proses fermentasi basah limbah organik untuk produksi biogas telah berkembang baik dan banyak digunakan, masih ada beberapa masalah yang harus diperhatikan. Fermentasi basah memiliki beberapa kekurangan yang akan memberikan pengaruh negatif terhadap kelayakan ekonominya. Sistem ini memerlukan beberapa persyaratan, di antaranya adalah: perlunya suplai dan pengelolaan air dalam jumlah besar; perlunya instalation digester atau reaktor berukuran besar; efluen digester (digestat) dalam jumlah besar perlu pengeringan dan penanganan; dan perlu energi besar untuk pemanasan digester, pemompaan slurry umpan, dan penanganan digestat atau slurry (Jha *et al*., 2010; Radwan *et al*., 1993).

Untuk mengatasi kekurangan-kekurangan di atas, fermentasi kering dapat digunakan. Proses fermentasi basah maupun kering bergantung pada prinsip dan proses yang sama untuk menguraikan bahan organik. Tetapi, proses kering menawarkan keuntungan: di antaranya dapat memanfaatkan limbah dalam bentuk apa adanya, tidak mensyaratkan sumber air, laju beban organik yang tinggi, ukuran digester kecil, tidak menghasilkan limbah cair, tidak perlu perlakuan untuk digestat (Pavan *et al*., 2000). Proses fermentasi kering menstabilkan limbah padat organik tanpa pengenceran atau menggunakan air terbatas. Oleh karena itu, biogas menggunakan fermentasi kering merupakan keuntungan bagi daerah-daerah dengan sumber air yang sulit (Köttner, 2002). Fermentasi anaerobik kering lebih dipilih dari fermentasi basah karena digestat dapat dengan mudah digunakan sebagai pupuk (Li dan Liew, 2011).

Selain itu, proses fermentasi kering mampu menghasilkan produksi biogas yang lebih tinggi per satuan volume reaktor. Brown (2012) melaporkan bahwa produktivitas biogas volumetrik dari fermentasi anaerobik kering sampah kertas adalah 70% hingga 88% lebih tinggi untuk proses kering dibandingkan proses basah. Chen *et al*. (2014) juga melaporkan bahwa produksi metana dari fermentasi anaerobik kering dengan kandungan TS 15–20% adalah lebih tinggi dibandingkan hasil pada fermentasi basah pada kandungan yang sama.

Melalui sistem fermentasi anaerobik kering, metana dari sampah organik dapat digunakan untuk energi sehingga fermentasi anaerobik kering menjadi alternatif bagi penumpukan sampah di TPA (*landfilling*) dan pengomposan konvensional (Li dan Liew, 2011).

2.3 Faktor-faktor Penting

Parameter pengoperasian digester harus diontrol untuk meningkatkan aktivitas mikrobial sehingga meningkatkan efisiensi degradasi sistem anaerobik. Beberapa faktor penting meliputi komposisi bahan, C/N ratio, kandungan TS, suhu, pH, dan SRT.

2.3.1 Komposisi Substrat

Bahan kompleks untuk biogas bisa memiliki komposisi yang berbeda-beda yang akan mempengaruhi produksi biogas dan kualitasnya, serta mempengaruhi kualitas kompos (kandungan CH_4 dalam biogas). Tabel 2 meringkaskan reaksi (stoikhiometri) dan komposisi metana dari berbagai substrat. Terlihat bahwa, kandungan metana (70%) tertinggi diperoleh dari substrat lemak.

Tabel 2. Komposisi teoritis metana dari beberapa jenis substrat (Harikishan, 2008)

Substrat	Reaksi	CH_4 (%)
Karbohidrat	$(C_6H_{10}O_5)_n + nH_2O \rightarrow 3nCH_4 + 3nCO_2$	50
Protein	$4C_{11}H_{24}O_5N_4 + 58H_2O \rightarrow 33CH_4 + 15CO_2 + 19NH^{+4} + 16HCO^{-3}$	69
Lemak	$4C_{15}H_{90}O_6 + 98H_2O \rightarrow 139CH_4 + 61CO_2$	70
Sludge primer	$C_{10}H_{19}O_3N + 4{,}5H_2O \rightarrow 6{,}25CH_4 + 3{,}75CO_2 + NH_3$	62,5
Limbah-aktif	$C_5H_7O_2N + 3H_2O \rightarrow 2{,}5CH_4 + 2{,}5CO_2 + NH_3$	50

2.3.2 Kandungan Padatan

Tchobanoglous (1993) membagi bahan baku untuk proses fermentasi anaerobik menjadi tiga golongan berdasarkan kandungan padatannya, yaitu bahan dengan kandungan padatan rendah (TS < 10%), medium (TS =15-20%), dan tinggi (TS = 22-40%). Makin tinggi kandungan TS berimplikasi pada penurunan volume reaktor (digester).

Li *et al*. (2011b) meneliti pengaruh kandungan TS pada proses produksi biogas sistem kering dari batang jagung pada suhu termofilik (55°C) dan mesofilik (37°C). Produksi biogas tertinggi (403,7 L/kg VS) diperoleh pada 55°C dengan kandungan TS bahan 22%. Mereka juga melaporkan bahwa peningkatan TS dari 22% menjadi 27% mengakibatkan penurunan produksi biogas sebesar 29,8% pada suhu 55°C. Digester dengan TS lebih dari 35% memiliki laju reaksi yang semakin lambat (Jewell *et al*., 1993). Menurut Chen *et al*. (2014), penurunan produksi biogas akibat peningkatan TS mungkin disebabkan oleh beban organik yang berlebihan dan kelebihan ammonia.

Pengoperasian digester pada kandungan TS hampir tiga kali lipat dari digester basah mengakibatkan produksi gas per unit volume yang meningkat secara signifikan sehingga meningkatkan efektivitas biaya. Secara hipotesis, pengoperasian digester kering dengan TS 30% akan meningkatkan tingkat produksi gas oleh tiga kali dibandingkan digester bash (TS 10%), dengan catatan semua variabel lainnya konstan dan bahwa densitas padatan bukanlah faktor pembatas. Namun, peningkatan konsentrasi padatan secara proporsional akan meningkatkan variabel lain (alkalinitas, konsentrasi amonia-N, dan massa mikroba). Sebagai contoh, jika alkalinitas dalam digester basah adalah 8 g/L (sebagai CaCO), maka pada digester kering nilai itu akan melebihi 20 g/L (Jewell, *et al*., 1993).

2.3.3 Rasio Karbon/Nitrogen **(*C/N*)**

Hubungan antara jumlah karbon dan nitrogen yang ada di dalam bahan organik disajikan oleh rasio C/N. Tabel 3 menyajikan rasio C/N beberapa bahan. Rasio C/N optimum dalam digester anaerobik berkisar antara 20 – 30 (Li *et al*., 2011). Rasio C/N yang tinggi menyebabkan konsumsi nitrogen yang cepat oleh bakteri metanogen dan mengakibatkan produksi gas yang rendah. Sebaliknya, rasio C/N yang rendah mengakibatkan akumulasi ammonia dan nilai pH melebihi 8,5, yang merupakan kondisi toksik bagi bakteri metanogen. Rasio C/N yang optimum dapat dicapai dengan mencampurkan bahan-bahan yang memiliki rasio C/N tinggi dan rendah, misalnya limbah padat organik dicampur dengan air limbah kota atau kotoran binatang. Digester anaerobik kering dioperasikan dengan kandungan TS antara 20 hingga 40% dan rasio C/N 20 sampai 30, dengan rasio optimal 25 (Li *et al*., 2011).

Tabel 3. Rasio C/N beberapa substrat untuk menghasilkan biogas

Material	Rasio C/N
Kotoran ayam	3-10
Limbah peternakan babi (cair)	5
Jerami	50-150
Rumput	12-26
Buah dan sayuran	7-35
Limbah makanan (tercampur)	15-32
Limbah rumah pemotongan hewan (jaringan lunak)	4
Limbah makanan	3-17

Sumber: Schnürer and Jarvis (2009)

2.3.4 Derajat Keasaman (pH)

Nilai pH untuk fermentasi anaerobik biogas terletak di antara 6,0 dan 8,5. Di luar kisaran ini akan terjadi ketidakseimbangan. Bakteri methanogen dan acetogen memiliki pH optimum sekitar 7, sedangkan pH optimum untuk bakteri acidogen sekitar 6. Nilai pH yang rendah akan menghambat acidogenesis dan pada pH kurang dari 6,4 dapat menjadi kondisi toksik bagi bakteri pembentuk metana. Kisaran pH optimum bagi bakteri metanogenesis adalah antara 6,6 hingga 7. Pada pH kurang dari 6,6 bakteri metanogen tumbuh sangat lambat. Kisaran pH yang optimal bagi proses fermentasi anaerobik berada pada rentang yang sempit, yaitu 6,4 hingga 7,2 (Monet, 2003).

2.3.5 Suhu

Suhu merupakan faktor lingkungan utama yang mempengaruhi pertumbuhan bakteri. Laju pertumbuhan bakteri meningkat dengan naiknya temperatur hingga suatu batas tertentu, tetapi pertumbuhan menurun tajam pada suhu mendekati batas atas di mana bakteri dapat bertahan. Selain itu, suhu juga mempengaruhi parameter-parameter fisik seperti viskositas, tegangan permukaan dan perpindahan masa. Berdasarkan suhu optimumnya, mikroorganisme dapat dibagi menjadi empat kelompok (Warner *et al*., 1989), yaitu psychrophilic (15–18°C), mesophilic (28–33°C), thermophilic (40–60°C), dan hipertermofilik (> 65°C).

Suhu memiliki efek positif pada laju dekomposisi bahan organik dan mengakibatkan volume produksi metana yang lebih tinggi. Vindis *et al*. (2009) melaporkan bahwa produksi biogas kumulatif dari batang jagung varietas NK PAKO mencapai 400 Nl/kg VS di hari ke-27 pada kondisi mesofilik dan 600 Nl/kg VS di hari ke-25 dengan kondisi termofilik.

2.3.6 Waktu Tinggal **(***Retention Time***)**

Waktu retensi adalah waktu rata-rata bahan baku menghabiskan waktu di dalam digester; untuk proses basah dinamakan waktu tinggal hidrolik atau HRT (*hydraulic retention time*) dan untuk proses kering dinamakan waktu tinggal padatan atau SRT (*solids retention time*). SRT adalah desain dasar dan parameter operasi untuk semua proses anaerobik. Tahap-tahap dalam proses fermentasi anaerobik secara langsung berhubungan dengan waktu tinggal. Penurunan waktu tinggal akan menurunkan tingkat reaksi, dan demikian sebaliknya.

Waktu tinggal bervariasi bergantung pada teknologi, suhu proses, dan komposisi bahan. Waktu tinggal untuk limbah kota yang diolah pada digester mesofilik berkisar antara 10 hingga 40 hari. Waktu tinggal untuk digester dengan kotoran sapi adalah antara 20 hingga 30 hari. Digester termofilik memerlukan waktu tinggal lebih cepat.

Hubungan antara produksi gas dan waktu tinggal dalam reaktor (semi-) CSTR (Appels *et al*., 2008) menunjukkan bahwa: (i) waktu retensi kurang dari 5 hari tidak mencukupi untuk penguraian yang stabil karena konsentrasi VFA meningkat akibat bakteri metanogen tercuci, (ii) konsentrasi VFA masih relatif tinggi untuk SRT 5-8 hari sehingga dekomposisi senyawa belum sempurna, terutama lipid, (iii) penguraian yang stabil diperoleh setelah 8-10 hari: konsentrasi VFA rendah, kerusakan lipid dimulai, dan (iv) kurva kerusakan stabil pada SRT 410 hari, semua senyawa lumpur berkurang secara signifikan.

2.4 Bahan Baku (*Substrat*)

Sebagaimana telah disampaikan sebelumnya, fermentasi anaerobik sistem kering dapat menggunakan bahan organik apa pun dengan kandungan TS hingga 40%. Limbah agro-industri, limbah rumah tangga, sampah halaman, dan tanaman energi merupakan bahan baku yang potensial bagi proses biogas fermentasi kering. Pemanfaatan limbah agro-industri sebagai substrat dalam proses anaerobik kering memberikan jalan alternatif dan nilai tambah pada limbah tersebut (Pandey, 2003). Di antara bahan-bahan tersebut, jerami padi, batang jagung, sampah halaman, dan rumput gajah perlu memperoleh perhatian.

2.4.1 Jerami Padi

Jerami padi sangat melimpah di negara kita sehingga layak dipertimbangkan potensinya sebagai feedstock untuk menghasilkan biogas sistem kering. Sarnklong *et al*. (2010) melaporkan bahwa jerami padi adalah 45% dari padi yang dihasilkan. Dengan luas panen 69,06 juta ton (BPS, 2013), potensi jerami Indonesia adalah 31,08 juta ton per tahun.

Jerami padi sangat potensial sebagai bahan baku biogas karena memiliki kandungan selulose 33,35% TS dan hemiselulose 31,42% TS. Shyam dan Sharma (1994) melaporkan fermentasi anaerobik dari jerami padi dan bahan organik lain yang dicampur dengan kotoran ternak dalam digester batch kecil, memberi hasil yang menggembirakan pada konsentrasi TS awal 16-19%. Produksi biogas bervariasi dari 202,2 hingga 499,3 liter/hari/m^3 untuk waktu tinggal 7 minggu dan 196,2 hingga 407,7 liter/hari/m^3 untuk waktu tinggal 10 minggu, lebih tinggi dibandingkan dengan 204-372 liter/hari/m^3 untuk kasus digester basah semi kontinyu menggunakan kotoran ternak yang diencerkan pada konsentrasi TS 8-9 % dan waktu tinggal 7 minggu. Song *et al*. (2013) melaporkan produksi metana sebesar 225,3 L/kg VS dari jerami padi dengan perlakuan alkali (9,81% $Ca(OH)_2$, w/w TS) dan proporsi inokulum 45,12%. Sementara itu, Teghammar *et al*. (2012) melaporkan bahwa produksi metana dari jerami padi meningkat dari 22 Nml/g bahan (tanpa perlakuan) dengan waktu tinggal 6 minggu. Dengan perlakuan NMMO atau N-methylmorpholine-N-oxide produksi metana meningkat tajam menjadi 157 Nml/g bahan, setara dengan 328 Nml CH4/g karbohidrat yang berarti 79% dari produksi teoritis 415 Nml CH4/g karbohidrat). Selain itu waktu tinggal dapat dipercepat menjadi hanya 1,5 minggu.

2.4.2 Batang Jagung

Menurut Prasetyo dkk. (2002) limbah batang dan daun jagung kering adalah 3,46 ton/ha. Dengan luas panen 3,9 juta ha (BPS, 2013) maka pada tahun 2013 limbah batang dan daun jagung diperkirakan mencapai 13,5 juta ton. Batang jagung tua memiliki TS sekitar 80% dengan TDN (*Total Digestable Nutrient*) 59 sampai 67%, sedangkan TS dan TDN untuk batang jagung muda berturut-turut adalah 26% dan 65% (Umiyasih dan Wina, 2008).

Fermentasi anaerobik kering campuran batang jagung dan kotoran ternak pada 55 - 35°C (Molnar and Bartha, 1989) dalam digester batch berisolasi termal juga telah dibuktikan keberhasilannya. Produksi biogas yang efektif melalui fermentasi kering batang jagung baik pada suhu mesofilik (37°C) maupun termofilik (55°C) juga dilaporkan Li *et al*. (2011b). Produksi biogas tertinggi (403,7 L/kg VS) diperoleh pada suhu 55°C dengan kandungan TS 22% dan inokulum (kotoran ternak) 29% berat bahan. Olugbemide *et al*. (2012) melaporkan produksi biogas dari campuran daun jagung dan daun rumput gajah menggunakan digester 2 L dengan volume isian setengahnya. Produksi biogas mencapai 520 ml untuk daun jagung dan 870 ml untuk campuran 90% daun jagung dengan 10% daun rumput gajah. Amon *et al*. (2007) mencoba mengoptimalkan pencernaan anaerobik jagung dan kotoran sapi perah. Produksi metana diukur selama 60 hari dalam 1 l digester batch pada 38^{o}C. Produksi metana spesifik tertinggi 166,3 Nl CH_4/kg VS. Produksi metana menurun ketika tanaman mendekati kematangan penuh. Produksi metana berkisar antara 312 dan 365 Nl CH_4/kg VS (matang susu) dan 268-286 Nl CH_4/kg VS (matang penuh). Produksi metana dari silase jagung meningkat sekitar 25 % dibandingkan dengan jagung segar.

Zheng *et al*. (2009), melaporkan perlakuan sodium hidroksida (NaOH) pada proses anaerobik basah menggunakan batang jagung dengan dosis NaOH 2% dan laju pembebanan 65 g/L menghasilkan biogas secara optimal. Produksi biogas 72,9% lebih banyak dibandingkan batang jagung tanpa perlakuan dengan produksi metana 73,4% lebih tinggi dan waktu tinggal 34,6% lebih pendek. Perlakuan NaOH basah memerlukan NaOH 66,7% lebih sedikit dibandingkan proses kering. Perlakuan alkaline dengan dosis NaOH antara 1 hingga 7,5% (w/w) juga dilaporkan oleh Zhu *et al*., (2010) pada proses fermentasi kering batang jagung dengan inokulum efluen cair digester anaerobik. Degradasi lignin meningkat dari 9.1% hingga 46.2% ketika dosis NaOH meningkat dari 1.0% menjadi 7.5%. Produksi biogas tertinggi 372.4 L/kg VS diperoleh pada batang jagung dengan perlakuan NaOH 5%. Hasil ini 37,0% lebih tinggi dari batang jagung tanpa perlakuan. Dosis NaOH 7,5% mengakibatkan produksi asam lebih volatil lebih cepat pada tahap hidrolisis dan acidogenesis, yang menghambat metanogenesis. Zhong *et al*. (2011) menemukan bahwa dengan perlakuan awal, komposisi jerami jagung seperti lignin, selulosa, dan hemiselulosa akan terdegradasi secara signifikan, dan bahwa struktur fisik dari matriks lignoselulosa juga akan berubah. Percobaannya menunjukkan bahwa produktivitas biogas meningkat oleh semua perlakuan (pemberian Jamur Pleurotus florida, NaOH, amonia, dan urea); dan bahwa produksi biogas setelah perlakuan NaOH 207,07% lebih tinggi dari jerami jagung tanpa perlakuan.

2.4.3 Rumput

Rumput gajah (*Penisetum purpuerum*) dalam beberapa tahun terakhir telah menarik perhatian dan telah menjadi salah satu fokus dari riset bioenergi. Tanaman perennial ini memiliki tampilan yang tinggi, dan daun lebar (3 cm) dengan panjang 30–90 cm (Duke, 1983). Rumput ini telah dibudidayakan di Indonesia untuk keperluan pakan sapi. Pengamatan lapangan di PT. Great Giant Livestock (GGL), Lampung Tengah menunjukkan bahwa rumput ini mampu mengasilkan biomasa segar antara 40 hingga 80 ton per panen dengan masa panen 70-80 hari. Rumput dapat diratoon 6-7 kali sebelum dibongkar. Rumput ini juga lebih toleran di tanah yang sedikit masam (GGL, 2014). Komposisi kimia rumput ini (Tabel 4) menunjukkan bahwa rumput gajah berpotensi untuk dikembangkan sebagai bahan baku produksi biogas melalui proses kering.

Tabel 4. Komposisi kimia rumput gajah (%)

Komposisi kimia	Silase	Segar
Kadar air	-	77.8
Protein	5.8	1.0
Lemak	4.9	0.5
Karbohidrat total	73.4	17.6
Abu	15.9	3.1

Sumber: Duke (1983)

Pemanfaatan rumput sebagai bahan baku untuk menghasilkan biogas telah dimulai oleh beberapa peneliti. Hidrolisis komponen dinding sel rumput gajah menghasilkan gula yang siap dikonversi menjadi metana melaui fermentasi anaerobik. Jewell *et al*. (1993) meneliti produksi biogas dari tanaman energi yang meliputi sorgum (*Sorghum bicolor*), rumput gajah (*Pennisetum purpureum*), dan jagung (*Zea maiz*) dengan kandungan TS 25-30% dan memperoleh tingkat produksi metana maksimal.

Ahn *et al*. (2010) meneliti kinerja fermentasi anaerobik kering rumput switchgrass yang dicampur kotoran ternak yang berbeda (babi, unggas, dan sapi perah) pada TS 15% dan suhu termofilik (55°C). Campuran dengan kotoran babi menghasilkan dekomposisi VS (volatile solids) sebesar 52,9%, lebih tinggi dari campuran kotoran unggas (9,3%) dan kotoran sapi perah (20,2%). Selama 62 hari waktu tinggal, campuran rumput dengan kotoran babi menghasilkan metana tertinggi (0,337 L CH_4/g VS), sedangkan campuran dengan kotoran sapi perah dan kotoran unggas berturut-turut menghasilkan metana 0,028 L CH_4/g VS dan 0,002 L CH_4/g VS.

Ekpenyong *et al*. (1995) melaporkan produksi biogas dari fermentasi anaerobik batang rumput gajah kering yang digiling mencapai sekitar 450 ml selama 5 hari dengan 4 g substrat. Peningkatan produksi biogas sebanyak 40% diperoleh dengan penambahan 0,01 g urea.

2.4.4 Kotoran Sapi

Digester biogas dari kotoran sapi biasanya dilakukan dengan menambahkan air dengan perbandingan 1:1. Selain memerlukan air dalam jumlah besar, hal ini akan memerlukan volume digester yang besar juga. Lumpur digestat yang banyak memerlukan tempat yang besar untuk pengeringan guna memudahkan pengangkutan ke lahan untuk digunakan sebagai kompos. Masalah inilah yang membatasi instalasi biogas sistem basah di daerah yang memiliki keterbatasan lahan dan air. Beberapa penelitian telah dilakukan untuk menghasilkan biogas dari limbah sapi dengan konsentrasi TS yang tinggi.

Singh dan Anand (1994) melaporkan bahwa produksi biogas dari kotoran sapi pada digester kering adalah 84% dari sistem konvensional (basah) dengan suhu ambient maksimum 40,2^{o}C dan minimum 24,9^{o}C. Sementara itu Jha *et al*. (2013) melaporkan digester menggunakan kotoran sapi pada suhu mesofilik (35^{o}C) dengan fermentasi sistem basah dan sistem kering, berturut-turut menghasilkan produksi CH_4 spesifik 0,333 dan 0,345 LCH_4/gVS, dekomposisi VS 50,01% dan 56,33%, serta COD removal 54,99% dan 61,35%. Pada fermentasi termofilik (55^{o}C), produksi CH_4 spesifik meningkat menjadi 0,351 dan 0,374 LCH_4/gVS, dengan dekomposisi VS 53,43% dan 60,52%, serta COD removal 58,37% dan 65,36%, berturut-turut untuk sistem basah dan sistem kering. Meskipun penambahan air dapat membantu proses start-up dan biodegradabilitas substrat, produksi metana melalui proses fermentasi anaerobik kering cukup sebanding dengan proses basah. Selain itu, volume reaktor untuk proses kering (15,18% TS) adalah separoh dari proses basah (7,68% TS) untuk bahan baku kotoran sapi. Oleh karena itu, fermentasi kering lebih baik dalam hal rekoveri energi, penghematan sumber daya, dan investasi teknik dibandingkan dengan proses fermentasi basah (Jha *et al*., 2013).

Produksi gas, secara umum, lebih tinggi untuk substrat yang terdiri dari campuran kotoran ternak dan limbah pertanian dibandingkan kotoran ternak saja. Gu et al. (2014) menunjukkan bahwa inokulum efluen dari digester dengan substrat kotoran sapi menghasilkan biogas terbaik dibandingkan efluen digester dengan kotoran babi, kotoran ayam, dan air limbah kota.

2.5 Peta Jalan Penelitian

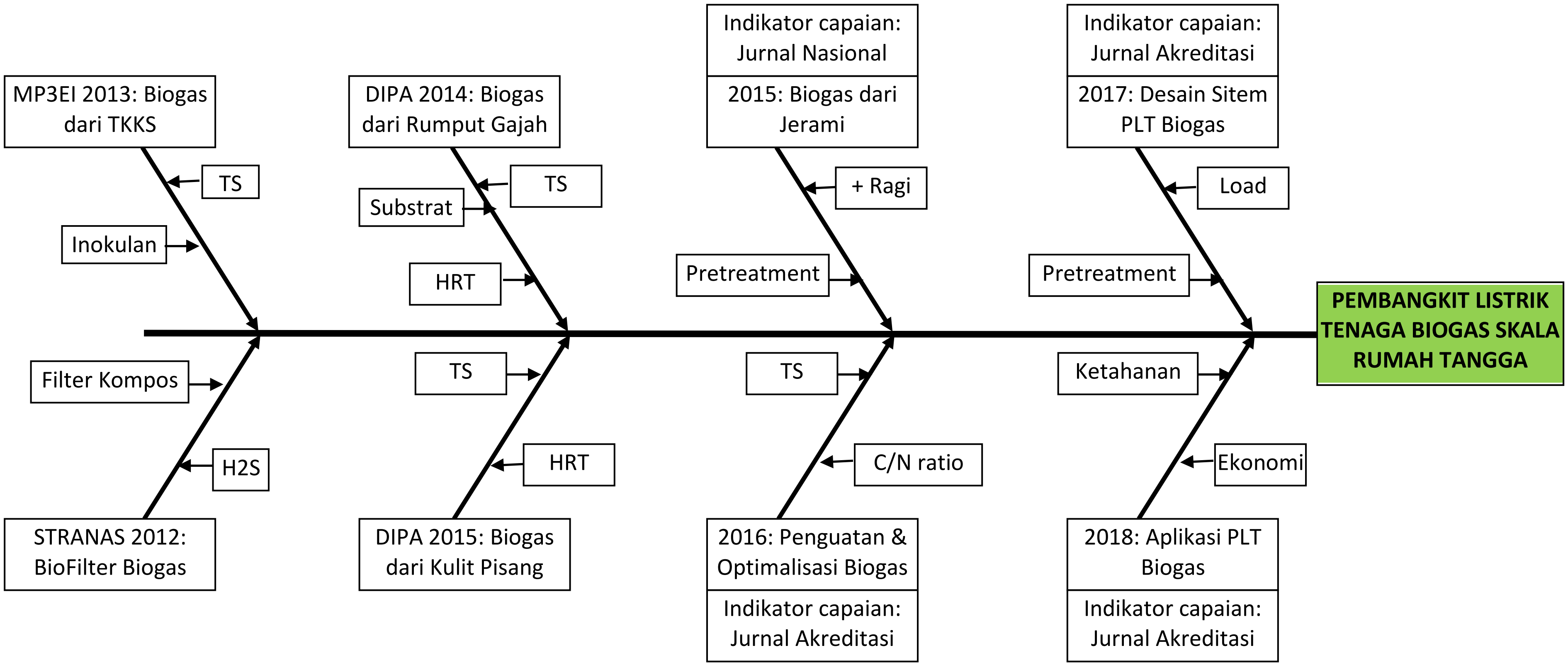
Dalam tiga tahun terakhir, pengusul telah melakukan penelitian terkait dengan biogas. Studi pendahuluan mengenai produksi biogas dari bahan organik padat telah kami lakukan menggunakan tandan kosong kelapa sawit (Haryanto *dkk*., 2014), rumput gajah (Ayub *dkk*., 2015), dan kulit pisang (Fairuz *dkk*., 2015). Penggunaan jerami padi untuk menghasilkan biogas saat ini sedang dalam proses. Penelitian-penelitian tersebut menunjukkan bahwa bahan organic padat dapat menghasilkan biogas melalui proses fermentasi kering. Tetapi hasilnya masih belum menggembirakan sehingga perlu dilakukan perbaikan proses. Penelitian mengenai pemurnian biogas menggunakan biofilter juga sudah kami lakukan sejak 2012. Hasilnya sangat memuaskan karena biofileter dapat menurunkan kadar H_2S menjadi <2 ppm (Indraningtyas *dkk*., 2012). Selanjutnya Fadli *dkk*. (2015) telah mengkaji kinerja genset 700 W menggunakan bahan bakar biogas yang dihasilkan dari limbah cair industri kelapa sawit dalam digester berkapasitas 5 m^3 substrat. Penelitian awal menunjukkan bahwa dengan pretreatment sederhana biogas dapat digunakan langsung sebagai bahan bakar genset. Genset berkapasitas puncak 700 W ini bekerja dengan baik hingga beban mendekati maksimum (600 W).

Secara ringkas, peta jalan (*roadmap*) penelitian produksi listrik skala kecil dari biogas adalah seperti diberikan dalam Tabel 5 dan Gambar 2.

Tabel 5. Roadmap penelitian produksi listrik skala kecil dari biogas.

Yang sudah/akan dikerjakan	**Tahun**
Peningkatan Kualitas Biogas Menggunakan Biofilter (Indraningtyas, L., Hasanudin, U., Haryanto, A., Triyono, S., Waluyo, S. 2012. Studi Reduksi Kadar H_2S pada Biogas Air Limbah Industri Tapioka Menggunakan Biofilter Kompos. *Seminar Nasional Asosiasi Profesi Teknologi Agroindustri* (APTA), Bali, 2-3 November 2012.)	**2012**
………	**2013**
Produksi Biogas dari Tandan Kosong Kelapa Sawit (Apria, N.E., **Haryanto**, A., Triyono, S. 2014. Produksi Biogas Dari Limbah Tandan Kosong Kelapa Sawit Melalui Proses Dry Fermentation. *Seminar BKS PTN Wilayah Barat.* UNILA 19-20 Agustus 2014.	**2014**
Produksi Biogas dari Rumput Gajah (Ayub, **Haryanto**, A., Prabawa, S. 2015. Produksi Biogas Dari Rumput Gajah Melalui Fermentasi Kering. Unpublished)	**2014**
Produksi Biogas dari Campuran Kulit Pisang dan Ampas Kelapa (Fairuz, A., **Haryanto**, A., Tusi, A. 2015. Produksi Biogas Dari Campuran Limbah Kulit Pisang dan Ampas Kelapa. *Jurnal Teknik Pertanian Lampung 2015 accepted***)**	
Kinerja Genset dengan Bahan Bakar Biogas (Marotin, F., **Haryanto, A.,** Kadir, M.Z. 2015. Studi Kinerja Genset Biogas Kapasitas 750 Watt Dengan Bahan Bakar Biogas Dari Limbah Kelapa Sawit. *Jurnal Teknik Pertanian Lampung*, submitted)	**2015**
***Produksi Biogas dari Jerami Padi* (on going)**	**2015**
Penguatan dan Optimalisasi Produksi Biogas dari Bahan Organik Padat	**2016**
Desain Sistem Pembangkitan Listrik Skala Kecil Menggunakan Biogas	**2017**
Aplikasi Sistem PLT Biogas Skala Kecil untuk Pengoperasian Kandang Ternak Sapi	**2018**
PLT Biogas Skala Rumah Tangga	**…….**

Catatan: 2016 dan seterusnya akan dikerjakan

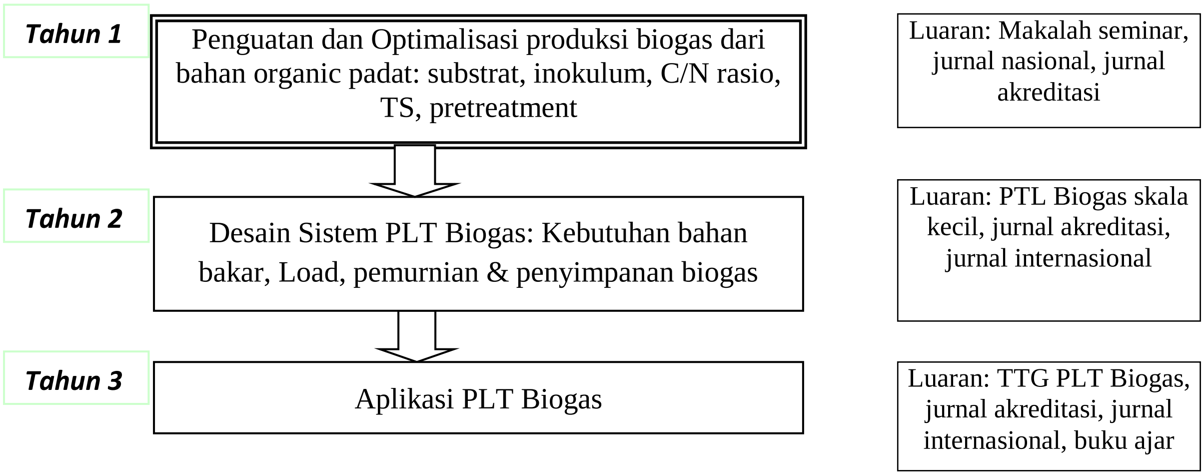


Gambar 2. Diagram *fish bone* tahapan penelitian hingga tahun 2018.

BAB 3. METODE PENELITIAN

Secara keseluruhan, penelitian ini dirancang selama 3 tahun (Gambar 3). Secara garis besar fokus pada tiap-tiap tahun adalah sbb:

* Tahun I: Penguatan dan Optimalisasi proses produksi biogas dari bahan organic padat dengan variable substrat, jenis (sumber) inokulant, perlakuan awal (pretreatment), kandungan TS, dan C/N ratio.
* Tahun II: Desain Sistem Pembangkit Listrik Tenaga Biogas Skala Kecil dengan variable kebutuhan bahan bakar, perlakuan awal biogas, kebutuhan dasar listrik rumah tangga.
* Aplikasi PLT Biogas skala kecil untuk mengoperasikan kandang sapi kapasitas 5 ekor.



Gambar 3. Diagram alir pelaksanaan penelitian selama 3 tahun (2016-2018)

3-1. Penelitian Tahun I (2016)

3.1.1. Bahan Baku

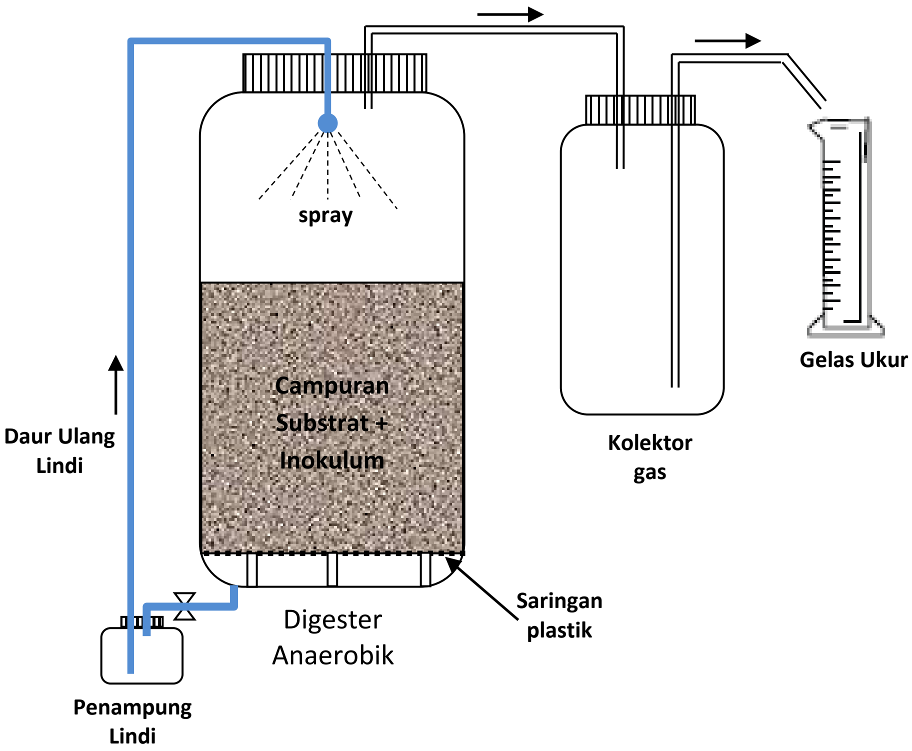
Bahan baku utama dalam penelitian ini terdiri dari:

* Limbah pertanian terpilih (jerami padi, jerami jagung) diperoleh dari kebun dan sawah petani terdekat.
* Sampah dedaunan dikumpulkan dari sekitar kampus Unila.
* Rumput gajah diperoleh dari kebun Lab. Lapang Terpadu, Fakultas Pertanian, Unila
* Starter yang akan digunakan adalah kotoran sapi yang akan diambil dari kandang sapi milik Jurusan Peternakan Fakultas Pertanian (UNILA) dan efluen dari digester pilot yang terdapat pada Jurusan Teknologi Hasil Pertanian (UNILA).

Pertama-tama, bahan-bahan tersebut akan dikarakterisasi untuk memperoleh informasi yang diperlukan, seperti kadar air, kandungan bahan kering (TS), kandungan bahan organik (VS), kandungan Nitrogen total (N), karbon (C), dan rasio C-N. Kandungan TS, dan VS juga diukur untuk effluent dan kotoran sapi segar.

3.1.2. Rangkaian Percobaan

Drum dari bahan fiber dengan volume 220 liter digunakan sebagai digester anaerobik (Gambar 4). Di dalam drum diberi sarangan dari bahan plastik setinggi 10 cm dari dasar. Drum ditutup menggunakan tutup yang kedap udara. Pada tutup dilengkapi dengan port untuk mengeluarkan gas dan menyemprotkan air. Di bagian bawah toples dilengkapi dengan port untuk mengeluarkan lindi.



Gambar 4. Sketsa unit eksperimen produksi biogas melalui fermentasi kering

3.1.3. Prosedur Eksperimen

(1) Bahan-bahan baku dihancurkan atau dicacah untuk mendapatkan ukuran panjang maksimum 2 cm.

(2) Sampel bahan ditimbang sebelum dan sesudah proses.

(3) Kadar air setiap bahan (dan kandungan padatan kering, TS) dihitung dengan cara pengeringan di dalam oven pada suhu 105°C selama 24 jam.

(4) Kandungan bahan organik (VS) dihitung dengan cara pembakaran di dalam tanur pada suhu 550°C selama 30 menit.

(5) Kandungan C dan N substrat dianalisis menggunakan CN analyzer (Lab. Pengolahan Limbah, Jurusan THP).

(7) Produksi biogas diukur setiap hari hingga berakhirnya fermentasi menggunakan gas flow meter atau menggunakan metode pemindahan air.

(8) Biogas yang dihasilkan diukur menggunakan metode pemindahan air.

(9) Komposisi biogas diukur menggunakan GC (Simadzu GC 4514).

3.1.4. Potensi Produksi Biogas Skala Rumah Tangga

(1) Produksi biogas diukur dari digester skala rumah tangga berbentuk fixed dome di desa Pesawaran Indah menggunakan manometer air sederhana berbentuk pipa U.

(2) Pengukuran dilakukan pada dua digester kapasitas 6 m^3.

3.1.5. Kebutuhan Biogas Generator Skala Rumah Tangga

(1) Konsumsi biogas diukur dengan menguji mesin generator kapasitas 750W menggunakan 100% biogas.

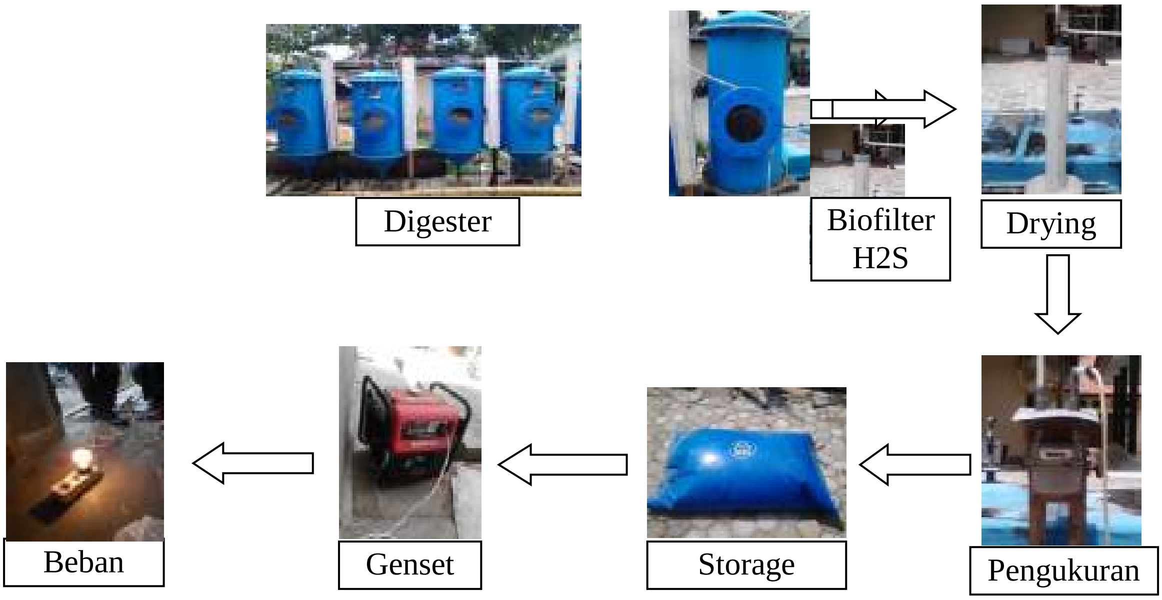
(2) Pengukuran dilakukan pada beban 100 – 700 W.

(3) Parameter yang diukur: voltase, arus, daya output, konsumsi biogas

3-2. Penelitian Tahun II (2017)

Penelitian pada tahun II dilakukan dengan membuat desain pembangkit listrik tenaga biogas (PLT Biogas) skala kecil yang memiliki komponen seperti diberikan dalam Gambar 5.

Pengujian dilakukan pada kebutuhan bahan bakar biogas, kualitas bahan bakar biogas yang mampu diterima genset, serta daya output dari genset. Pada tahap ini, sistem pembangkit listrik tenaga biogas juga akan diuji di lokasi Bapak Supar (Mitra) yang telah memiliki instalasi biogas skala besar tetapi belum dikonversi menjadi listrik.



Gambar 5. Komponen desain PLT Biogas skala kecil

3-2. Penelitian Tahun III (2018)

Pada tahun III, PLT Biogas skala kecil akan diaplikasikan pada pengoperasian kandang sapi kapasitas 5 ekor yang ada di Jurusan Peternakan (UNILA). Pengujian dilakukan pada aspek ketercukupan biogas, ketahanan (*durability*), serta ekonomi.

BAB 4. HASIL DAN PEMBAHASAN

4.1. Potensi Produksi Biogas Skala Rumah Tangga

Tabel 4-1 menunjukkan produksi biogas dari dua digester tipe fixed dome yang diperkirakan menggunakan perbedaan tinggi air pada kolom manometer U. Digester dengan 5 hingga 6 ekor sapi bisa menghasilkan biogas pada laju rata-rata 1582 L/hari atau 280 L/hari per ekor sapi. Hasil ini masih jauh dari produksi teoritis. Pathak *et al*. (2009) menghitung bahwa digester skala rumah tangga dengan 4 ekor sapi dapat menghasilkan biogas 2200 m^3/tahun atau 6 m^3/hari. Oleh karena itu, produksi biogas dari digester rumah tangga masih bisa ditingkatkan melalui operasi dan manajemen yang lebih baik.

Table 4-1. Produksi biogas dari digester skala rumah tangga

Digester	Jumlah sapi (ekor)	Produksi biogas (L/hari)	Produksi biogas (L/hari/ekor)
1	6	2164	360.7
2	5	1000	200.0
Rata-rata		1582	280.3

Komposisi biogas disajikan pada Tabel 4-2. Komposisi tersebut mengindikasikan bahwa biogas memiliki kualitas yang cukup baik dan mudah dibakar. Menggunakan nilai energi (low heating value, LHV) untuk metana sebesar 191.76 kcal/mole atau 35.82 MJ/Nm^3 maka biogas (dengan kandungan metana 51.4%) memiliki nilai kalori 20.23 MJ/Nm^3. Artinya, digester skala rumah tangga tipe fixed dome menghasilkan biogas dengan nilai energi 29.14 MJ/hari. Dengan mengambil nilai LHV bensin 44 MJ/kg atau 32 MJ/l, maka biogas yang dihasilkan setara dengan bensin 0,91 L/hari.

Table 4-2. Komposisi biogas yang dihasilkan dari digester rumah tangga

Digester	Komposisi		
	CH_4	CO_2	N_2
1	54.14	34.90	10.95
2	48.71	32.72	18.56
Rata-rata	51.42	33.81	14.76

Potensi produksi biogas dari bahan campuran kotoran sapi dengan bahan organik lain seperti rumput gajah dan jerami padi sedang dalam proses penelitian.

4.2. Konsumsi Biogas Generator Skala Rumah Tangga

Tabel 4-3 menunjukkan kinerja mesin generator menggunakan bahan bakar 100% biogas. Hasil tersebut menunjukkan bahwa pada beban 100 hingga 700 W, konsumsi biogas (BC) berkisar dari 400.8 hingga 434.4 L/jam dengan nilai rata-rata 415 L/jam.

Tabel 4-3. Kinerja mesin generator 750W dengan 100% biogas

Load (W)	BC (L/h)	Power out (W)	SBC (L/Wh)	η_{th} (%)
100	400.8	80	5.05	6
200	413.6	177	2.35	14
300	386.4	207	1.98	17
400	407.6	286	1.42	23
500	426.8	284	1.50	21
600	437.6	408	1.07	30
700	434.4	379	1.15	28

Parameter lain adalah konsumsi biogas spesifik (SBC), yaitu laju aliran bahan bakar yang digunakan per unit daya keluaran (power output). SBC merupakan ukuran seberapa efisien suatu mesin mengkonversi bahan bakar untuk menghasilkan kerja yang berguna. Hasil kami menunjukkan bahwa SBC menurun terhadap beban dan berkisar dari 5,05 L/Wh pada beban 100 W (13.3%) hingga 1,07 L/Wh pada beban 600 W (80%). Ini menunjukkan bahwa mesin bekerja makin efisien pada beban mendekati spesifikasinya.

Efisiensi termal (η_{TH}) bervariasi terhadap beban dari 6% pada beban 100 W hingga 30% pada beban 600 W. Ini membuktikan bahwa mesin menghasilkan kinerja terbaiknya pada beban mendekati kapasitas maksimum naanuggnep awhab itamagnem aguj imaK . apnat ,kiab gnay isarepo nakkujnunem rotareneg nisem rakab nahab iagabes sagoib .tinem 012 utkaw latot iapacnem gnay ,itrareb aladnek

Berdasarkan pada data produksi biogas skala rumah tangga sebelumnya, dapat kita tunjukkan bahwa biogas yang dihasilkan dari digester rumah tangga dengan 5 sampai 6 ekor sapi dapat melayani generator kapasitas 750W sekitar 4 jam per hari (jam 18.00 hingga 22.00). Jika manajemen dan pengoperasian digester diperbaiki, maka produksi biogas dapat ditingkatkan sehingga generator dapat dioperasikan dengan waktu lebih lama lagi.

4.3. Pengaruh laju pembebanan

Penelitian skala lab dilakukan menggunakan digester semi kontinyu rancangan sendiri. Digester terbuat dari dua gallon air minum yang disatukan di bagian pantatnya. Volume digester adalah 36 L dengan volume kerja (working volume) 25 L, karena ruang kosong harus disisakan untuk menampung biogas. Proses anaerobic digestion dilakukan menggunakan kotoran sapi segar yang diperoleh dari Jurusan Peternakan, Universitas Lampung. Karakteristik kotoran sapi diberikan pada Tabel 4-4.

Table 4-4. Karakteristik substrat kotoran sapi segar

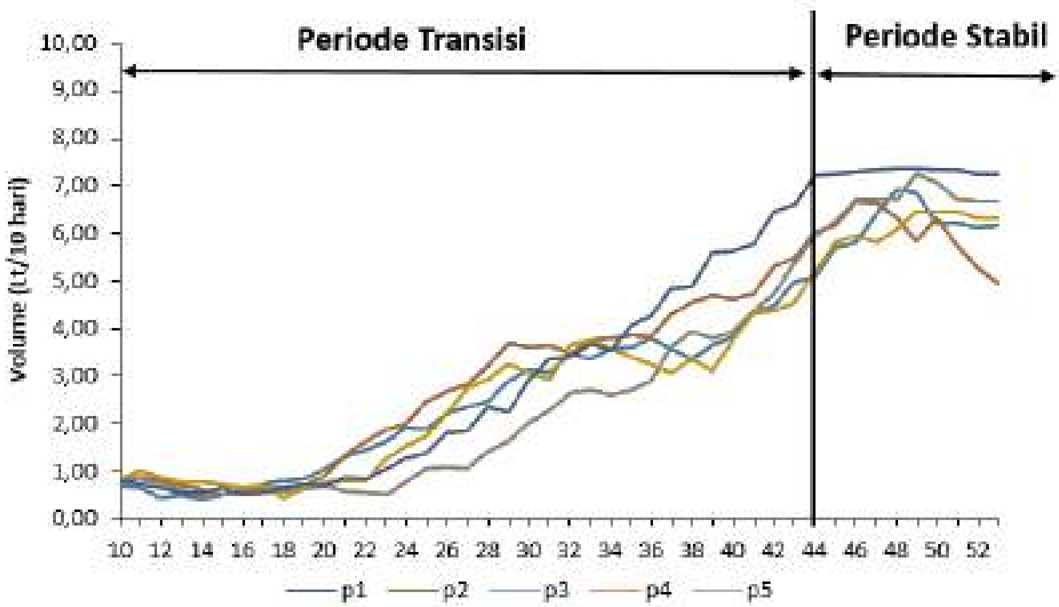
Karakteristik	Nilai rata-rata
Kadar Air (% wb)	80.12
Total solid, TS (% wb)	19.88
Abu (% TS)	30.58
Volatile solid, VS (% TS)	69.42
C	39.87
N	1.42
C/N ratio	28.1

Kotoran sapi diencerkan dengan air bersih pada perbandingan 1:1. Hal ini dilakukan untuk menurunkan kandungan TS hingga sekitar 10% agar proses biogas dapat berlangsung optimal (Ituen *et al*., 2007). Penelitian dilakukan untuk mengetahui efek laju pembenanan terhadap kinerja biogas. Pengisian awal dilakukan dengan volume 25 L. Selanjutnya, digester diisi setiap hari dengan volume pengisian bervariasi. Lima variasi laju pembebanan beserta waktu tinggal hidrolik atau HRT (hydraulic retention time) yang terkait diberikan pada Tabel 4-5.

Tabel 4-5. Variasi laju pembebanan dan HRT yang bersangkutan

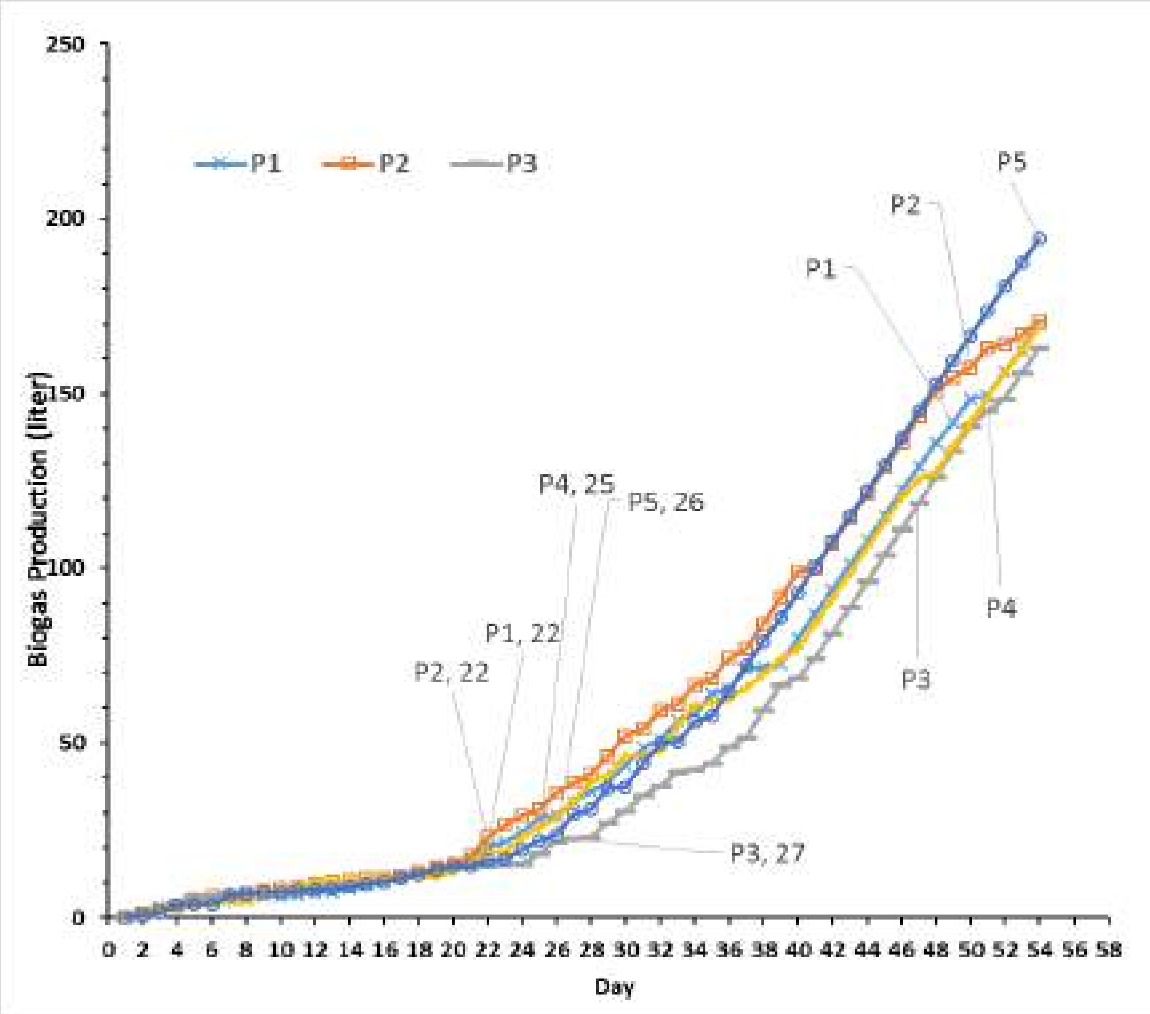
Volume (ℓ)	**Laju Pembebanan (ℓ/hari)**	**HRT (hari)**
25	2,5	10,0
25	2,0	12,5
25	1,5	16,7
25	1,0	25,0
25	0,5	50,0

Hasil penelitian diberikan dalam Gambar 4-1 dan 4-2. Gambar 4-2 memperlihatkan produksi biogas rata-rata harian dengan metode moving average 10-harian. Terlihat bahwa pada periode transisi produksi biogas meningkat dari rata-rata 0,6 L/hari menjadi sekitar antara 5 hingga 7 L/hari tergantung pada laju pembebanan. Periode stabil dimulai pada hari ke 44 yang ditandai dengan produksi biogas yang stabil.



Gambar 4-1. Produksi biogas harian dengan metode moving average 10-harian

Kualitas biogas diuji dengan membakar biogas yang dihasilkan. Biogas baru dapat dibakar setelah memasuki minggu ke-4. Gambar 4-1 memperlihatkan bahwa perlakuan laju pembebanan 0,5 L/hari menghasilkan produksi biogas terbaik, mencapai 7,2 L/hari. Dengan volume kerja 25 L, maka hal ini sama dengan 0,288 L/hari per liter substrata tau sekitar 1.728 L/hari untuk digester dengan volume kerja 6 m^3. Hasil ini sedikit lebih tinggi dari data yang diperoleh dari lapangan sebagaimana dibahas pada bagian sebelumnya, yaitu rata-rata 1.582 L.



Gambar 4-1. Pengaruh laju pembebanan terhadap produksi biogas kumulatif. Angka yang mengikuti perlakuan menunjukkan hari dimana biogas dapat dibakar (misalnya P1, 22: Pada perlakuan P1, biogas dapat dibakar pada hari ke-22)

Gambar 4-2 memperlihatkan hubungan antara laju pembebanan terhadap volume produksi biogas kumulatif yang diamati selama 54 hari. Terlihat bahwa perlakuan laju pembebanan 0,5 L/hari menghasilkan produksi biogas terbanyak mencapai hampir 200 L.

BAB 5. KESIMPULAN

(1) Konsumsi biogas untuk generator kapasitas 750W adalah rata-rata 415 L/jam.

(2) Digester skala rumah tangga dengan 5-6 ekor sapi menghasilkan biogas sebanyak 1582 L/hari atau 280 L/ekor/hari.

(3) Digester skala rumah tangga dengan 5-6 ekor sapi dapat melayani pengoperasian mesin generator kapasitas 750W selama 4 jam/hari.

(4) Produksi biogas skala rumah tangga masih dapat ditingkatkan dengan mengatur laju pembebanan yang tepat.

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MESSAGE FROM THE CHAIRPERSON OF THE 2ND ISABE 2016

It is my honor to welcome you to the International Symposium on Agricultural and Biosystem Engineering 2016. Thank you all to be here today at the Jayakarta Lombok Beach Resort for attending this important meeting. The 2nd ISABE 2016 is held in August 9-11 organized by Department of Agricultural Engineering Faculty of Agricultural Technology Universitas Gadjah Mada, Department of Agricultural Engineering Faculty of Food Technology and Agro-Industry Mataram University and the Indonesian Society of Agricultural Engineer (PERTETA). The theme of the 2nd ISABE 2016 is “Recent Technology on Agricultural and Bio-system Engineering. The objectives of the symposium are to disseminate knowledge, to promote research and development, to obtain the latest information, as well as to exchange technical information in agricultural and biosystem engineering innovation. Moreover, the symposium will provide opportunity to strengthen networking among Indonesia and international academia, government and industries. The meeting will feature a serie of keynote speech in plenary sessions, presentations in technical sessions, cultural night, as well as excursion.

I am very pleased to welcome all the guest speakers: a. Prof. Sakae Shibusawa (TUAT, Japan), Prof. Chang-Hyun Choi (Korean Society of Agricultural Machinery, Korea), Prof. Ir. Dr. Azmi Dato' Yahya (Universiti Putra Malaysia, Malaysia), Prof. Mitsutoshi Nakajima (University of Tsukuba, Japan), Prof. Dipl.-Ing.Dr.nat.techn. Axel Mentler (Institute of Soil Research BOKU, Vienna), as well as Prof. Sigit Supadmo Arif (Universitas Gadjah Mada, Indonesia). And joining us to deliver a congratulatory speech Governor of West Nusa Tenggara Province. Thank you very much for all of you for your contribution in this symposium.

I am also pleased to greet participants of 61 selected papers, among them are 6 papers from Korea, 1 from Japan, 1 from Taiwan, 1 from Thailand, 1 from Malaysia,1 from Bangladesh and the remaining 56 papers are from Indonesia. For delegates who do not present papers, thank you for your participation. I hope you can enjoy all the agenda.

I would like to express my sincere gratitude to all colleagues, sponsors, organizing committee, steering committee for their support and cooperation for making this event succesfully performed.

Finally, thank you again for your participation and welcome to the 2nd ISABE 2016 meeting.

Chairperson of The 2nd ISABE 2016
Dr. Ngadisih

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Developing Family-Size Biogas-Fueled Electric Generator

Agus Haryanto*,1, Sugeng Triyono[1], and Udin Hasanudin[2]
[1]Department of Agricultural and Biosystem Engineering, Faculty of Agriculture
University of Lampung, Jl. Soemantri Brojonegoro No.1 Bandar Lampung 35145, Indonesia.
[2]Department of Agro-Industrial Technology, Faculty of Agriculture
University of Lampung, Jl. Soemantri Brojonegoro No.1 Bandar Lampung 35145, Indonesia.
Email: agus.haryanto@fp.unila.ac.id*

Abstract

Recently, electrification ratio in Indonesia has reached 84%. This means that there are still 16% (around 40 million peoples or 8 to 10 million household) have no access to national electricity grid (PLN). Most of these peoples live in isolated areas and remote islands that have not been facilitated by power grid (off grid). Family size power generation fueled by biogas can be a suitable solution for these areas. This paper discusses potential to develop small scale electricity generation using biogas produced from anaerobic digestion of cowdung. Results show that a family size anaerobic biogas digester with 6 heads of cows is able to serve 750W power generator engine operating for 4 hours per day. Therefore this technology is attractive to be developed to powering isolated areas with no access to PLN grid.

Keywords: *biogas, cowdung, electricity, remote areas.*

1. INTRODUCTION

Indonesia is covered by many small islands that are remote and out of national electric grid (PLN). By September 2014, electrification ratio in Indonesia has reached 84.3% in (PT. PLN, 2015). This number is still lower as compared to other ASEAN countries such as Malaysia (99.4%), Singapore (100%), Thailand (99.3%), the Philippines (89.7), or Vietnam (97.3%) (Power in Indonesia, 2015). The implication of this condition is that there are still around 16% of Indonesian people (about 40 million) who do not have access to the electricity. These people are living in remote and sparsely populated areas or small islands. Most of the unelectrified household (HH) live in and currently uneconomical to be reached by PLN.

Considering each unelectrified HH requires electricity supply of 450 VA at peak load (the lowest of existing power rate from PLN's grid) and all power plants to supply them operate at maximum 80% of their name plate capacity, then it will require approximately 5,6 MW new additional capacity to power up just the HHs in remote areas. The actual power capacity will be larger than just to cover the HH demand, likely reach 7–8 GW capacity due to increasing economic activity and other infrastructures, such as: schools, telecommunications, health clinic, village administration and police station, as well as other rural economic and retail activities.

Some communities have generated their own electricity using small diesel- or gasoline-generators. However, this option is expensive. At non subsidy diesel fuel price of 9.400 IDR/L and gasoline 8.600 IDR/L, and engine efficiency of 30%, then the cost of electricity is around 3,100 IDR/kwh (for diesel generator) and 2,900 IDR/kwh (for gasoline generator) just to cover fuel consumption. This is much expensive as compared to current electricity price of 1,509.38 IDR/kwh for R1-TR connection type (www.pln.co.id). In more remote areas the electricity price using diesel generators will likely be much higher due to fuel transportation cost.

Remote and sparsely populated areas will be best powered up by locally available renewable energy using economically efficient and proven technology, such as: biomass and hydro power, or biogas plant. Biogas can be one of the reliable solutions to generate electricity in remote areas. Raw materials or substrates for biogas can be developed locally and cheaply such as cow dung and agricultural wastes. In less developed countries, the biogas produced from renewable sources is the right option and could play a major role in meeting both energy and environmental problems (Kabir *et al*., 2013). Based on a thorough parametric analysis, Chandra *et al*. (2012) concluded that the production of methane (biogas) from lignocellulosic biomass agricultural waste is more economically and environmentally advantageous and is the utilization of biomass in a sustainable way to produce energy.

Application of family-sized biogas in Indonesia has a renewed attention since 2009 through a program popularly called BIRU (Biogas Rumah). By the end of 2014, the program a total of 14,110 domestic digesters (BIRU, 2015).

Small-scale electricity generation using biogas fuel can be one of the most suitable ways to overcome the electricity shortage problem for people in remote areas. Small generators (about 1 kW capacity) run on gasoline has been more and more applied in suburban areas by small shops, households or offices to cope up with the frequent power black outage. The generator can be operated completely using biogas to overcome electricity scarcity in remote areas. Vaghmashi *et al*. (2014) concluded that compressed biogas is having good potential to replace petrol. Ayade and Latey (2016) recently reported that blending biogas with petrol at a ratio of 60% petrol and 40% biogas (B40) resulted in the increase of thermal efficiency of the engine up to around 37% as compared to around 26% of engine with neat petrol. Ehsan and Naznin (2005) reported their work on power generation using small engine (1.5 kW) running with 100% biogas. Even though the brake specific fuel consumption (BSFC) using biogas was comparatively high but peak efficiency was comparable to that of engine using petrol.

Spark ignited gasoline engines may be converted to operate on biogas by changing the carburetor to one that operates on gaseous fuels. The conversion of SI engines to gas fuelling is a simple matter, requiring only the fitting of a simple gas-fuel adaptor and, possibly, hardened valves and valve seats (Jawurek *et al*., 1987). Recently, it was reported a simple conversion of gasoline-fueled single cylinder four stroke engines to run the electric generator using biogas without changing the compression ratio of original spark ignition engine. The engine run stable and was able to generate electricity using 100% biogas (Surata *et al*., 2014). Biogas treatment, however, may be necessary depending on the type of engine used. Electric generation using ignition engine requires that biogas must be cleaned so that the hydrogen sulfide (H_2S) content reaches less than 100 ppm (McKinsey-Zicari, 2003).

This paper discusses a prospect for developing family sized power generation using biogas, especially to electrify remote and sparsely populated areas.

2. MATERIALS AND METHOD

2.1. Biogas Consumption of Engine

Biogas consumed by power generator engine was evaluated by testing a 750W generator engine using pretreated biogas. The pretreatment was intended to reduce H_2S content to a level accepted by the internal spark engine. Pretreatment was conducted using locally fabricated compost. After pretreatment, the biogas has CH_4 content of 56.48% (calorific value of 20.23 MJ/N m^3) and H_2S content of 75 ppm. The engine testing was performed by varying the load from 100 to 700 W and was replicated 3 times for each load. Each experiment unit was run for 10 minutes. Parameter to be analyzed including biogas consumption, power production, and thermal efficiency. Power is equal to electric voltage (*V*) multiplied by electric current (I). Thermal efficiency (η_{th}) is calculated from:

$$\eta_{th} = V.I/(BC \times HV) \quad (1)$$

where *BC* is biogas consumption (L/s) and *HV* is heating value of biogas (MJ/L).

2.2. Biogas Production Potential

Biogas production potential from a family sized biogas digester was evaluated by measuring biogas yield of biogas digesters located in Pesawaran Indah village, District of Pesawaran, Lampung Province (Figure 1). The digesters were constructed in 2010 using concrete with fixed dome type and capacity of 6 m^3. Biogas yield was calculated by pressure difference measured using simple U-tube water manometer for a given period. Biogas composition was analyzed using a gas chromatograph (Shimadzu GC2014) with TCD detector and zinc carbon column.

Figure 1. Fixed dome biogas digester and simple water manometer.

3. RESULTS AND DISCUSSION

3.1. Biogas Consumption

Table 1 showed power generator engine performance using 100% biogas. The results showed that at load of 100 to 700 W, biogas consumption (BC) ranged from 400.8 to 434.4 L/h with an average value of 415 L/h.

A more useful parameter is the specific biogas consumption (SBC) which is fuel flow rate per unit power output. It measures how efficiently an engine converts the fuel to produce useful work. Our results showed that SBC decreased with load and ranged from 5.05 L/Wh at a load of 100 W (13.3%) to 1.07 L/Wh at a load of 600 W (80%).

Table 1. Performance of 750W power generator engine using 100% biogas

Load (W)	BC (L/h)	Power out (W)	SBC (L/Wh)	η_{th} (%)
100	400.8	80	5.05	6
200	413.6	177	2.35	14
300	386.4	207	1.98	17
400	407.6	286	1.42	23
500	426.8	284	1.50	21
600	437.6	408	1.07	30
700	434.4	379	1.15	28

Thermal efficiency (η_{TH}) varied from, increased with the load. This meant that the engine produce the best performance at load closes to the maximum capacity fo daol a tA . CBS htiw %03 saw ycneiciffe lamreht ,W 006 .hW/L 88.6 fo

It was also noted that biogas utilization as fuel for generator set showed a good performance during the test, which reached a total of 210 minutes.

3.2. Biogas Potential

Table 2 showed biogas yield of two biogas digester estimated by pressure difference of a U-tube manometer (indicated by difference of water column). Digesters with 5 to 6 heads of cow were capable of producing biogas at rate of 1582 L/day or 280 L/day per head of cow. Pathak *et al*. (2009) calculated that 2200 m^3/year (6 m^3/day) biogas can be produced from a family-sized digester with four cattle. Therefore, our result is much lower than the theoretical potential that can be improved through a better operation and management.

Table 2. Biogas yield of family size digester

Digester	Number of cow (head)	Biogas yield (L/day)	Biogas yield (L/head/day)
1	6	2164	360.7
2	5	1000	200.0
Average		1582	280.3

Biogas composition was presented in Table 3. The composition indicated that biogas has a fairly good quality and easy to burn. Using low heating value of 191.76 kcal/mole or 35.82 MJ/Nm^3 for methane (, the biogas has a calorific value of 20.23 MJ/N m^3. With an average CH_4 content of 51.4%, fixed dome family size digester produced biogas with energy value of 29.14 MJ/day. By taking low heating value (LHV) for gasoline as much as 44 MJ/kg or 32 MJ/l, the produced biogas is equivalent to 0.91 L of gasoline/day.

Table 2. Biogas composition

Digester	Composition		
	CH_4	CO_2	N_2
1	54.14	34.90	10.95
2	48.71	32.72	18.56
Average	51.42	33.81	14.76

Based on previous data on biogas consumption, it can be showed that biogas produced from a family digester with 5 to 6 heads of cow will be able to fuel 750W generator set for around 4 hours a day. Assuming that electricity consumption for lighting (a very basic need) of a simple family is 450W (the existing PLN grid connection for R1 type) for 4 hours a day (6:00 to 10:00 PM), it can be concluded that a family digester with 5-6 heads of cow is able to electrify a single family.

4. CONCLUSION

The power generator can be well operated using 100% biogas with methane content of 56.48%. Biogas consumption of 750W power generator engine ranged from 400.8 to 434.4 L/h. A family size anaerobic biogas digester with 5-6 heads of cow is able to serve 750W genset operating for 4 hour per day. More research is required to study the effect of biogas fuel on the engine performance as well as carbon deposit at the piston for much longer running time.

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PRELIMINARY RESULTS ON THE PERFORMANCE OF A FAMILY-SIZE BIOGAS-FUELED GENERATOR USING BIOGAS PRODUCED FROM PALM OIL MILL WASTES

Agus Haryanto[1,*], Fadli Marotin[1], Sugeng Triyono[1], Udin Hasanudin[2], Koichi Fujie[3].

1. Department of Agricultural Engineering, University of Lampung, Bandar Lampung, 35144, INDONESIA.

2. Department of Agroindustrial Technology, University of Lampung, Bandar Lampung, 35144, INDONESIA.

3. Graduate School of Environment and Information Sciences, Yokohama National University, 79-7 Tokiwadai, Hodogaya-ku, Yokohama 240-8501, JAPAN

*) Corresponding author: Agus Haryanto, Ph.D., research fields: biomass-based renewable energy. E-mail: agus.haryanto@fp.unila.ac.id.

Abstract

The purpose of this study was to evaluate biogas utilization to generate household electricity. Research was conducted by testing a 750-W generator set (genset). Biogas was produced from a wet digester (5-m^3 capacity) combined with 4 dry digesters (220-L, each). Palm oil mill effluent at a rate of 150 L/day was introduced into wet digester and its effluent was used as bacteria source for dry digesters which were loaded with 20 kg of empty bunches pressed for each dry digester. Biogas was filtered using bioscrubber and was analyzed using a gas chromatograph. Hydrogen sulfide (H_2S) level of biogas was measured using a H_2S detector. Biogas consumed by the genset was measured at different load from 100 to 700 W (13.3 to 93.3% of the rated power).

Three replications for each load experiment were taken. Results showed that the total biogas yield was 2.02 m^3/day with methane content of 56.48% by volume. Biofilter successfully reduced H_2S content in the biogas by 94% in average. Genset showed good performance during the test. Biogas specific consumption decreased with load, whilst thermal efficiency increased with load. At a load of 600 W, biogas consumption was 0.73 L/W/hour with a thermal efficiency of 30%.

Keywords: biogas, palm oil mill effluent, empty bunch pressed, biogas-fueled genset, electricity.

Introduction

In 2014 the installed capacity of power plants in Indonesia was 43.46 GW, consisted of 33.5 GW in the Java-Bali, 6.17 GW in Sumatera and 3.84 in East Indonesia. The number has already taken into account the participation or contribution from Independent Power Producers (IPPs). With this capacity, electrification ratio in Indonesia has reached 84.3%, increasing 2.6% from the previous year [1, 2]. This number, however, is still lower as compared to other ASEAN countries such as Malaysia (99.4%), Singapore (100%), Thailand (99.3%), the Philippines (89.7), or Vietnam (97.3%) [3].

The implication of this condition is that there are still around 16% of Indonesian people (about 40 million or around 10 million household) who do not have access to electricity grid. In general, these people are living in remote and sparsely populated areas or small islands. Such areas are characterized by the absence of industrial activity, poor infrastructure and are geographically not covered by the electricity distribution network (off grid) from Government-owned Electricity Company or PLN. This problem is accentuated by the fact that Indonesia consists of about

13,000 populated islands. Considering each unelectrified household requires electricity supply of 450 VA (the lowest of existing power rate from PLN's grid), and all power plants to supply them operate at a maximum 80% of their name plate capacity, then it will require approximately 5.6 GW new additional capacity to power up just households in remote areas. The Power Supply Business Plan (RUPTL) 2015-2024 plans for PLN and IPPs to develop 70,7 GW for the next 10 years [1]. This means an average growth rate of 7 GW per annum.

Some communities (mostly in the remote areas and on Indonesia's small islands) have generated their own electricity using small diesel generators. This option, however, is not environmentally friendly. Fossil fuels, especially oil, happen to more and more difficult and are not available in remote areas. Electricity price using this option is much more expensive. At non subsidy diesel fuel price of 9.400 IDR/L and engine efficiency of 30%, the cost of electricity is around 3,100 IDR/kWh just to cover fuel consumption. In more remote areas the electricity price using diesel generators will be much more expensive as compared to current electricity price of 1,509.38 IDR/kWh for R1-TR connection type [4].

Remote and sparsely populated areas in Indonesia will be best powered up by locally available renewable energy using economically efficient and proven technology, such as: biomass, microhydro power, or biogas plant. Small gasification combined with internal combustion engine provides an efficient way of converting solid biomass into electricity because it uses renewable energy source, and presents a local fuel alternative [5]. Marginal, or even nil, economic profitability from small biomass gasifier plant, however, has resulted in difficulties of this plant to be developed. In the mid of ninety, Indonesia applied some small biomass power plants using gasification technology for heat and power generation. These power plants, however, collapsed and were no longer active. The reason of this faulty was mainly caused by economy aspect where most small gasifier projects are not economically profitable. In addition, some gasifiers, especially those using rice husk, faced problems related to high tar content (10 to 40 times higher than allowable) in the producer gas that corrosively damaged the gasifier [5].

Biogas can be one of the reliable solutions to generate electricity in remote areas. Raw materials or substrates for biogas can be developed locally and cheaply such as cow dung, agricultural wastes or dedicated crops. Production of biogas from renewable feedstock, such as energy crops and agro-industrial wastes through anaerobic digestion process could substitute fossil fuel-derived energy and reduce greenhouse gas emission [6]. Regarding the socio-economic features of villagers in less developed countries, the biogas produced from renewable sources is the right option and could play a major role in meeting both energy and environmental problems [7]. Based on a thorough parametric analysis, Chandra *et al*. (2012) concluded that the production of methane (biogas) from lignocellulosic biomass of agricultural waste is more economically and environmentally advantageous and is a sustainable way to produce energy from biomass [8]. Biogas produced from anaerobic digestion is competitive in term of costs and efficiencies as compared to other biomass energy forms including heat, synthesis gases, and ethanol [6]. Biogas has played an important role in many countries, both developed and developing countries [9]. Some countries such as Germany [10], China [11], and India [12] have benefited greatly from biogas.

Since 2009, Indonesia has received support from Netherlands Government to promote domestic biogas through a program that popularly called BIRU (Biogas Rumah). As a result, application of family-sized biogas is increasingly growing. In 2013, BIRU had successfully installed 11,249 domestic digesters [13] and by the end of 2014, BIRU had installed 2,861 more digesters [14], making a total of 14,110 domestic digesters. The biogas was used mainly for cooking. Small-scale electricity generation using biogas fuel is one of the most suitable ways to overcome the electricity shortage problem for people in remote areas. Using small scale independent generator means that no grid is required. From ecological point of view, the engines fuelled by the biogas emit much lower amount of CO_2 and decreases the global warming potential on our earth due to lower contents of the carbon in the fuel [15].

Family-sized power generation using biogas can be completed with small ignition engines by blending (dual mode) for diesel engines or completely (100%) running with biogas for gasoline or petrol engines. The power can be used to run some appliances as refrigerator, compressor, generator and irrigation pumps. Biogas can potentially be utilized in a dual fuel operation and performed satisfactorily without any engine hardware modification under long term engine operation. No significant problems were observed during the entire engine durability test [16]. Small generators (about 1 kW capacity) run on gasoline has been more and more applied in suburban areas by small shops, households or offices to cope up with the frequent power black outage. The generator can be operated completely using biogas to overcome electricity scarcity in remote areas. Vaghmashi *et al*. (2014) concluded that compressed biogas is having good potential to replace petrol [17]. Ayade and Latey (2016) recently reported that blending biogas with petrol at a ratio of 60% petrol and 40% biogas (B40) resulted in the increase of thermal efficiency of the engine up to around 37% as compared to around 26% of engine with neat petrol [18]. In addition, the B40 blending also decreased brake specific fuel consumption by 8% in comparison with neat petrol. Ehsan and Naznin (2005) reported their work on power generation using small engine (1.5 kW) running with 100% biogas. Even though the brake specific fuel consumption (BSFC) using biogas was comparatively high but peak efficiency was comparable to that of engine using petrol [19].

Spark ignited gasoline engines may be converted to operate on biogas by changing the carburetor to one that operates on gaseous fuels. The conversion of SI engines to gas fuelling is a simple matter, requiring only the fitting of a simple gas-fuel adaptor and, possibly, hardened valves and valve seats [20]. Recently, Surata *et al*., (2014) reported a simple conversion of gasoline-fueled single cylinder four stroke engines to run the electric generator using biogas without changing the compression ratio of original spark ignition engine. The engine run stable and was able to generate electricity using 100% biogas [21]. Biogas treatment, however, may be necessary depending on the type of engine used. Electric generation using ignition engine requires that biogas must be cleaned so that the hydrogen sulfide (H_2S) content reaches less than 100 ppm [22]. The objective of this research was to evaluate biogas utilization to generate household electricity through small generator set (genset) engine.

Materials and Method

Biogas Production

Biogas was produced from a combination of wet anaerobic digester and four dry anaerobic digesters. Wet digester system was made from fiberglass with a capacity of 5 m^3. About 4 m^3 of palm oil mill effluent (POME) was introduced into the digester as substrate. After stabilization phase was achieved, POME was delivered at a rate of 150 L/day. Dry digesters were a batch mode having a capacity of 220 L each. Dry digester used 20 kg of empty bunches pressed (EBP) of oil palm as substrate and using wet digester effluent as inoculum. Both POME and EBP was provided by Bekri palm oil mill of PTPN VII. Biogas produced from the digester system is passed through a flowmeter (Itron ACD G1.6), then to a biofilter scrubber, and to a storage pouch for generator set testing. Biogas piping was equipped with an expansion valve to dry the biogas. Biogas composition was analyzed using a gas chromatograph (Shimadzu GC2014) with TCD detector and zinc carbon column. The level of H_2S before and after passing through the biofilter was measured using a H_2S detector (Gastech). Figure 1 showed tools and equipment configuration used during the experiment.

Biogas Desulfurization

Prior to utilization as engine fuel biogas was purified using scrubber filled with biofilter made from locally-produced compost, especially to remove H_2S. Biogas was flowed into the bottom of a vessel containing biofilter, flowing out through the top. While the biogas is flowing up through the bed of biofilter, it is expected that chemotrophic bacteria separate the sulfur from the biogas. In order to elucidate the biological role of biofilter scrubber in the declining of H_2S content in the biogas, we performed microbial quionone analysis in the biofilter scrubber. The analysis can be used to effectively quantify microbial community structure. The detail procedure of quinone analysis has been previously described [23].

Engine Testing

The biogas-fueled genset was procured from PT. SWEN Bogor, Indonesia. It was a four stroke spark ignition engine modified to using biogas fuel with a capacity of 750 W (Table 1). As depicted in Figure 1, the biogas was stored in a pouch prior to using for the engine testing. Genset testing was performed by varying the load from 100 to 700 W and was replicated 3 times for each load. Several incandescent lamps and iron parallely arranged were used as variable electric loads.

The engine parameters to be evaluated are brake power (P_b), specific fuel consumption (*SFC*), and thermal efficiency (η_{TH}). All of these parameters are calculated as in the following [24]:

$$P_b = V \times I \quad (1)$$

$$SFC = FC/P_b \quad (2)$$

$$\eta_{TH} = \frac{3600 \times P_b}{FC \times LHV} \times 100 \quad (3)$$

where *V* is the voltage developed by the generator (V), *I* is the current produced by the generator (A), *FC* is the fuel (biogas) consumption rate (L/h), and *LHV* is the lower heating value of the biogas (MJ/L). The voltage is measured using a multitester Sanwa YX360TRF) and electric current is measured using a digital clamp meter (Kyoritsu 2007A). Biogas consumption rate was measured using gas flow meter (Itron ACD G1.6).

Results and Discussion

Biogas production and purification

The results showed that combination of dry and wet anaerobic digestion system was capable to produce biogas at a total of 2.02 m^3/day consisting of 1.91 m^3/day of wet digester and 0.11 m^3/day of dry digester (Table 2). Biogas composition (Table 3) showed a relatively normal value of methane (CH_4), which is 56.48% by volume. This value indicated that biogas has a fairly good quality and easy to burn. Using low heating value of 191.76 kcal/mole or 35.82 MJ/N m^3 for methane [25], the biogas has a calorific value of 20.23 MJ/N m^3.

The low biogas yield from dry digesters could be resulted from the substrate, that is EBP, characteristic which is relatively dry as compared to unpressed one. Previously, we have conducted an experiment of dry digestion using unpressed empty fruit bunches (EFB) and got high biogas yield [26]. We assumed that oil remnant attached at fibers of the EFB played major role in the biogas production. In EBP, a lot of liquid (water and oil) has been removed. As a comparison, our observation noted that water content of EFB was 64.2% [26] and was 46.9% for EBP used in this experiment.

Biogas produced from anaerobic digestion mainly constituted of methane and carbon dioxide. Trace compounds in the biogas includes ammonia, water, nitrogen, and notably hydrogen sulfide (H_2S). Hydrogen sulfide is produced from the mineralization of organic compounds containing sulfur, such as proteins, by sulfate reducing bacteria. Hydrogen sulfide is so corrosive to metal parts in the engine that must be removed. In addition, combustion of biogas containing H_2S produces poisonous sulfur dioxide (SO_2). When SO_2 reacts with water vapor it produces sulfuric acid that corrodes the engine and exhaust pipe. The SO_2 also dissolves in engine oil causing the oil to become acidic and lose its lubrication ability [27].

Biogas produced in this experiment had high H_2S content (400-800 ppm) which is harmful for the engine (Table 2). In this case, dry anaerobic digestion process of EBP produced biogas with higher H_2S content than that of wet process. In this case, we equipped biofilter scrubber to reduce H_2S content. Kobayashi noted some biological desulfurization including biofilter processes, the bioscrubber processes, and the process using headspace of the digesters (headspace process) [28]. Our results showed that biofilter scrubber effectively reduced H_2S level by 94% in average (Table 2). McKinsey-Zicari (2003) used cow-mansure compost to remove of hydrogen sulfide from biogas with H_2S removal efficiencies over 80% [22]. Su *et al*. (2013) reported an average H_2S removal efficiency exceeding 93% in the livestock biogas using farm-scale bio-filter desulfurization system [29].

Desulfurization of H_2S occur either physically through absorption by water or biologically by microbes. Hydrogen sulfide removal process through absorption is undergoing the dissociation according to following reactions [30]:

H_2S (g) + H_2O $\leftrightarrow$ H_2S (aq) (5)

H_2S (aq) $\leftrightarrow$ $H^+ + HS^-$ (6)

HS^- $\leftrightarrow$ $H^+ + S^{2-}$ (7)

Biological desulfurization process begins with the dissociation of H_2S (Equation 6). In limited oxygen, the bacteria facilitates redox reactions to generate S^0 (Equation 7) [31].

$H_2S \leftrightarrow H+ + HS^-$ (disosiation) (8)

$HS^- + 0{,}5O_2 \rightarrow S^0 + OH^-$ (9)

Quinone analysis revealed the existence of sulfur consuming microbes as presented in Figure 2. These bacteria playing role in the desulfurization process through oxidation and reduction as well. Reduction microbial was dominated by menaquinone MK-6, MK-7, and MK-8. The MK-6 during anaerobic conditions might correspond with sulfate reducing bacteria that derives energy by anaerobic respiration reducing sulfate compounds [32]. Microbial structure of sulfur-oxidizing bacteria was dominated by ubiquinone UQ-8 and UQ-10.

Engine testing

Biogas utilization as fuel for generator set showed a good performance during the test, which reached a total of 210 minutes. It was noted, however, that biogas should be utilized as soon as it is produced. The biogas that was stored in the pouch about five days resulted in unstable combustion which caused a problem for the generator. This was probably caused by diffusion of methane through the pouch skin.

The results also showed that hourly fuel consumption (*FC*) ranged from 400.8 to 434.4 L biogas (Figure 3). Pathak *et al*. [33] calculated that 2200 m^3/year (6 m^3/day) biogas is produced from a family-sized digester with four cattle. Giving that digester efficiency is 70%, then every single digester is able to serve a genset for about 10 hours duration, which is much more enough for primary lighting the house during night time. Figure 3 also revealed that biogas consumption slightly increased linearly with load. The relation between biogas consumption (BC) and load (W) can be presented mathematically as:

$$BC = 0.067\ W + 388.2 \qquad [R^2 = 0.608] \qquad (10)$$

The linear relation of biogas consumption towards load was also reported by Ehsan and Naznin [19]. Using 1.5 kW engine capacity, they reported the biogas consumption about 2.0 kg/h at a load of 800 W. Using biogas density of 1.2 kg/m³ [34], the figure corresponded to around 1667 L/h. Biogas consumption of our result was significantly lower. The different of engine capacity (750 W vs. 1500 W) might be the reason of this discrepancy.

A more useful parameter is the specific fuel consumption (*SFC*) the fuel flow rate per unit power output. It measures how efficiently an engine is using the fuel supplied to produce useful work. Our results (Figure 4) showed that *SFC* decreased with load and ranged from 30.3 L/Wh at a load of 100 W (13.3%) to 6.9 L/Wh at a load od 700 W (93.3%). It can also be observed that the magnitude of the electric load affected the *SFC* and can be presented mathematically as:

$$SFC = 914.8\ W^{-0.76} \qquad [R^2 = 0.959] \qquad (11)$$

Similar pattern of the relationship between *SFC* of the engine generator set and load applied to the generator was found in the work reported by others [19, 24]. Ehsan and Naznin reported specific fuel (biogas) consumption ranged from 4034 g/kWh (around 3362 L/kWh) at 370 W to about 2413 g/kWh (2010 L/kWh) at 800 W load for biogas with 55% methane content [19]. In general, increasing load close to the engine capacity resulted in the decreasing specific fuel consumption. Under low load the *SFC* is high because the mechanical efficiency is low. At high engine load (close to the rated power), the combustion is improved due to higher temperature (inside the cylinder) after successive working of engine at high load which improves fuel atomization and fuel-air mixing process as well.

Thermal efficiency (η_{TH}), on the contrary, increased with the load (Figure 5). This means that the engine produce the best performance at loads close to the maximum capacity. At a load of 600 W (80%), the hourly specific consumption of biogas was 0.73 L/W with an effective thermal efficiency of 30%. Thermal efficiency and load relationship can be presented mathematically as:

$$\eta_{TH} = 0.036\ W + 5.444 \qquad [R^2 = 0.910] \qquad (12)$$

Himabindu and Ravikhrisna reported a prototype of small power generator running on entirely biogas containing 65% methane. The prototype showed good performance in the power range of around 1 kW with maximum overall efficiency of 19% and approximated brake thermal efficiency between 25 to 37% [36].

Conclusion

We have successfully run four stroke spark ignited electric generator using 100% biogas. The generator run quite well using 100% biogas with methane content of 56.48%. Biogas consumption ranged from 400.8 to 434.4 L/h and increased with load. Load also affected specific fuel consumption and thermal efficiency. Specific fuel consumption was around 30 L/W/h at load of 100 W. The highest thermal efficiency was 30.0% and occurred at a load of 600 watt (80% load). More research is required to study the effect of biogas fuel on the engine performance as well as carbon deposit at the piston for much longer running time.

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TABLES

Table 1. Biogas engine specification used in the experiment

Engine type	air cooled, 4 stroke, single cylinder
Displacement	79.7 cm^3
Rated power output	750 VA
Maximum power output	850 VA
Voltage output	220 V
Frequency	50 Hz

Table 1. Biogas yield and H_2S content of biogas before and after biofiltration

Digester type	Biogas Yield (m^3/day)	H_2S content before filtration	H_2S content after filtration	H_2S removal
Wet	1.91	400 ppm	9 ppm	98 %
Dry	0.11	800 ppm	80 ppm	90 %
Average				94 %*

*) Average of H_2S removal was calculated from:

$$\text{Average } H_2S \text{ removal} = \frac{BW \times [H_2S]_W + BD \times [H_2S]_D}{BT} \quad (4)$$

where *BW* and *BD* are biogas amount produced from wet and dry digester, respectively; $[H_2S]_W$ and $[H_2S]_D$ are H_2S content of biogas produced from wet and dry digester, respectively; and *BT* is total amount of biogas.

Table 2. Biogas Composition (in % Vol.)

Composition	Value
Methane (CH_4)	56,48
Nitrogen (N_2)	3,33
Carbon Dioxide (CO_2)	39,31
Others	0,88

FIGURES

Fig. 1. Tools and equipment used in the study from biogas production to generator testing: 1. POME container (5 m^3); 2. Dry digester (220 L, each); 3. Wet digester (5 m^3); 4. Biofilter; 5. Pressure expansion (dryer); 6. Biogas flowmeter; 7. Biogas pouch; 8. Genset 750-W; 9. Load.

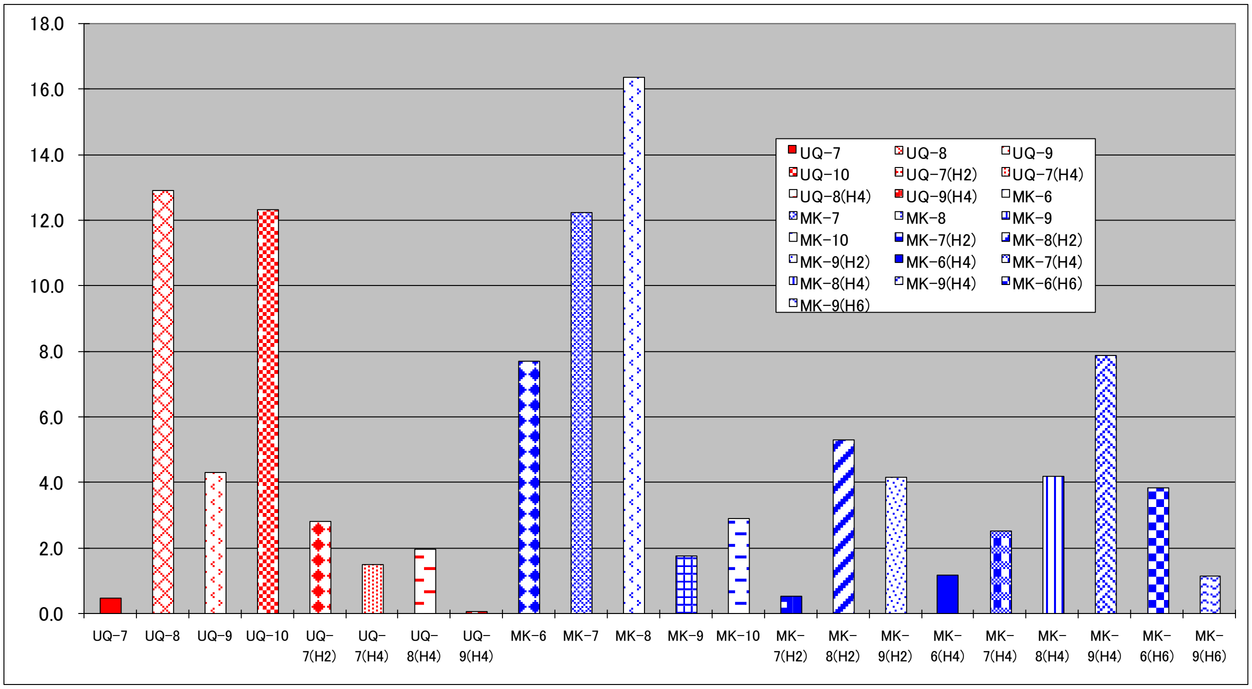

Figure 2. Microbial quinone distribution obtained from fresh biofilter scrubber.

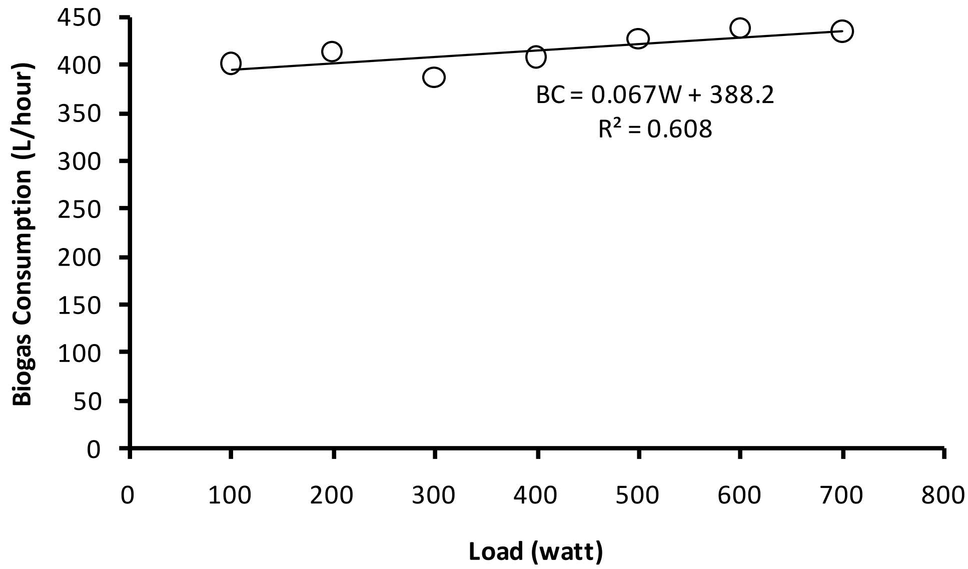

Fig. 3. Relation of load and biogas consumption.

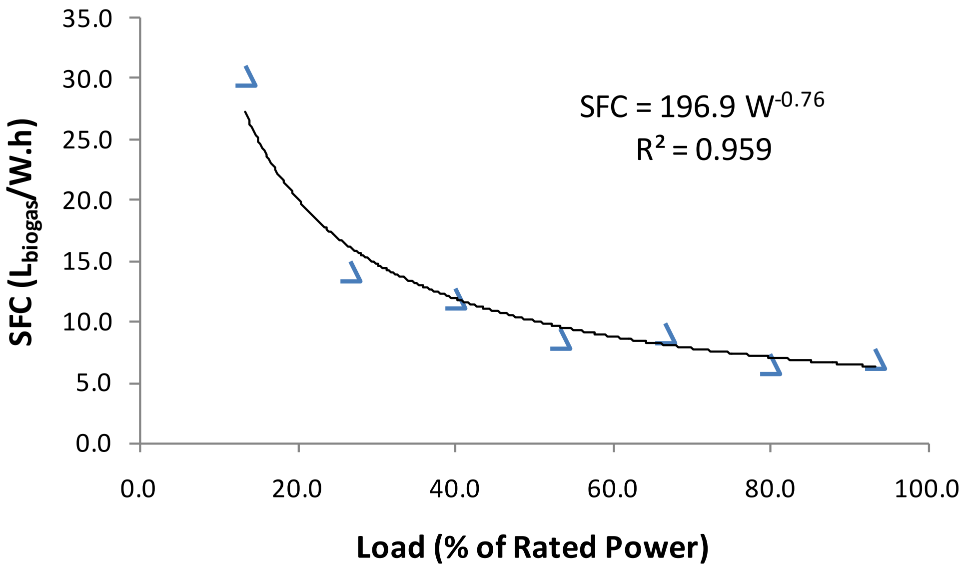

Fig. 4. Effect of load on the spscific biogas consumption.

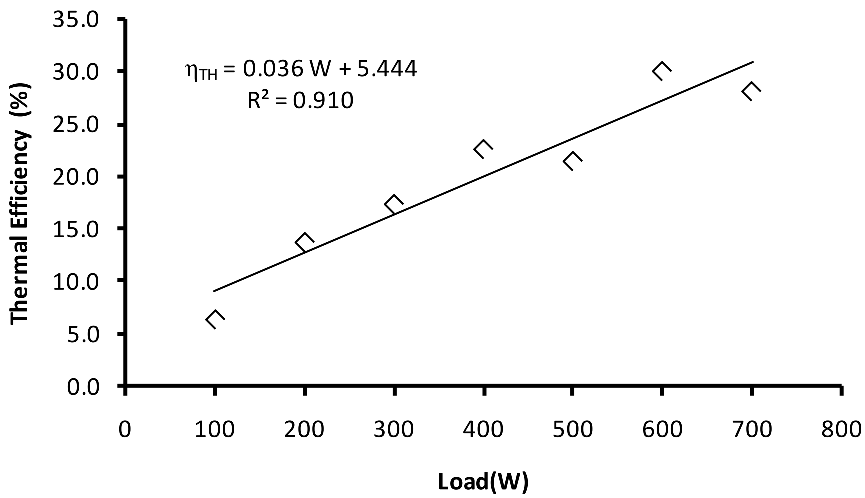

Fig. 5. Effect of load on the thermal efficiency.


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Dear **Mr. Agus Haryanto**

Your abstract entitled" **EFFECT OF LOADING RATE ON BIOGAS PRODUCTION FROM COW MANURE USING SEMI CONTINOUS ANAEROBIC DIGESTER"** was **accepted** as oral presentation in **The Seminar Nasional Perhimpunan Teknik Pertanian Indonesia** that will be held on 4th and 5th of November 2016, in Convention Hall, Andalas University, Padang, Indonesia**.**

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KETENTUAN

- Biaya registrasi harus DILUNASI selambat-lambatnya tanggal 31 Oktober 2016, agar peserta dapat mengikuti kegiatan seminar ini. Biaya yang sudah dibayarkan tidak dapat dikembalikan
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EFFECT OF LOADING RATE ON BIOGAS PRODUCTION FROM COW DUNG USING SEMI CONTINUOUS ANAEROBIC DIGESTER

Agus Haryanto*, Sugeng Triyono, Nugroho Hargo Wicaksono
Jurusan Teknik Pertanian, Fakuℓas Pertanian, Universitas Lampung
Jl. Soemantri Brojonegoro No. 1, Bandar Lampung 35145
*) Corresponding author: agus.haryanto@fp.unila.ac.id (081379078674)

ABSTRACT

The efficiency of biogas production on semi-continuous anaerobic digester is influenced by several factors, among other is loading rate. This research aimed to determine the effect of loading rate variation on the biogas productivity. Experiment was conducted using self-made anaerobic digester of 36-ℓ capacity with substrate of a mixture of fresh cow dung and water at a ratio of 1:1. Experiment was run with substrate initial amount of 25 ℓand five treatment variations of loading rate, namely3,33kg/hari/m^3 (P1), 2,67kg/hari/m^3 (P2), 1,90kg/hari/m^3 (P3), 1,23kg/hari/m^3 (P4) dan 0,65 kg/hari/m^3 (P5).Digester performance including pH, temperature, and biogas yield was measured every day. After stable condition was achieved, biogas composition was analyzed using a gas chromatograph (GC). A 10-day moving average analysis of biogas production was performed to compare biogas yield of each treatment. Results showed that the best productivity was found in P5 treatment (loading rate 0.65 kg/hari/m^3)with biogas yield of 7.23 ℓ/day. Biogas production showed a stable rate after the day of 44.

Keywords: *biogas, yield, cow manure, loading rate, semi-continuous digester*

Effect of Loading Rate on Biogas Production from Cow Dung Using Semi Continuous Anaerobic Digester

Agus Haryanto[#], Sugeng Triyono[#], Nugroho Hargo Wicaksono[#]

[#] Department of Agricultural Engineering, University of Lampung, Jl. Soemantri Brojonegoro No. 1, Bandar Lampung, 35145, Indonesia
E-mail: agus.haryanto@fp.unila.ac.id
E-mail: striyono2001@yahoo.com
E-mail: nugrohohargo17@gmail.com

***Abstract*— The efficiency of biogas production on semi-continuous anaerobic digester is influenced by several factors, among other is loading rate. This research aimed to determine the effect of loading rate variation on the biogas productivity. Experiment was conducted using lab scale self-designed anaerobic digester of 36-ℓ capacity with substrate of a mixture of fresh cow dung and water at a ratio of 1:1. Experiment was run with substrate initial amount of 25 ℓ and five treatment variations of organic loading rate, namely 1.31 kg/L/day (P1), 2.47 kg/L/day (P2), 3.82 kg/L/day (P3), 5.35 kg/L/day (P4) and 6.67 kg/L/day (P5). Digester performance including pH, temperature, and biogas yield was measured every day. After stable condition was achieved, biogas composition was analyzed using a gas chromatograph. A 10-day moving average analysis of biogas production was performed to compare biogas yield of each treatment. Results showed that digesters run quite well with pH of average 6.8-7.0 and average daily temperature 28.7-29.1. The biogas best productivity was found in P1 treatment (organic loading rate of 1.31 kg/L/day) with biogas yield of 7.23 ℓ/day. Biogas production showed a stable rate after the day of 44. Biogas contained methane at average of 53.88%.**

***Keywords*— biogas; yield; cow dung; loading rate; semi-continuous digester.**

I. Introduction

Along with economic growth at 5:02% during 2014, the energy needs of Indonesia also increased. During period of 2000-2014, the final energy consumption in Indonesia grew from 556 million to 962 million of oil equivalent, meaning an average annual growth of 3.99%. The growth is projected to increase into 4,3% under base scenario or into 5,1% under high scenario. The energy consumption was dominated by fossil fuels with a total of 76% including oil (32%), coal (23%), gas (18%) and fossil-based electricity (11%) [1].

On the other side, Indonesia is bestowed with enormous sources of renewable energy such as biomass, hydro, solar, wind, and geothermal. Biomass resource has a potential of 32,654 MWe, but only 1,626 MW (off grid) snd 91.1 MW (on grid) have been developed so far. Important biomass sources include a great number of solid and liquid wastes from agricultural, agro-industry, and livestock activities. Livestock in Indonesia is increasingly growing and by 2015 the number was as follows: dairy cattle (518,650), beef cattle (15,419,720), buffalo (1,346,920), goat (19,012,790), sheep (17,024,680), pig (7,808,090), horse (430,400), duck (45,321,960), native chiken (285,304,310), layer chiken (155,007,390), and broiler chicken (1,528,329,180) [2]. The waste produced from livestocks can be utilized to produce usable energy. Therefore, developing this potency in various ways is urgently required.

Biogas produced from anaerobic digestion is a promising way to convert agriculture waste and into energy especially in developing countries, including Indonesia. Biogas not only alleviates energy shortage in rural areas but also effectively reduces the environmental risk associated with agricultural waste management [3]. Various appliances can be fuelled by biogas, with stoves offering an application appropriate for deployment in developing countries. Other applications include the use of biogas as fuel heating, lighting or electricity generation. In addition, slurry digestate can be utilised as good compost. In fact, cow manure presents an important potential of renewable sources for energy and fertilizer. Regarding the socio-economic features of villagers in less developed countries, the biogas produced from renewable sources is the right option and could play a major role in meeting both energy and environmental problems [4].

Small scale biogas installations systems allow energy generation on site, thereby eliminating the need for energy intensive transport [5]. Small-scale biogas plants with no agitation and heating devices are most feasible because of convenience in management and maintenance [3]. In addition, the operation and maintenance of household bio-digesters are easier, and their environmental and economic performances are superior compared to those of medium and large scale. Household bio-digesters are suitable for undeveloped regions where the rural residents live far apart from each other [3]. Under correct and proper construction of the feeding process, small scale biogas digester is able to supply sufficient energy to the people but also provide digestate that can be used efficiently as fertilizer on tha farm, replacing chemical nitrogen and phosphorus [6]. Family size biogas technologies play a significant role to fulfil energy need in some countries such as China [7], India [8], Nepal [9], Bangladesh [10], and Vietnam [11].

Biogas digester performance is affected by many factors including microbial population, acidity (pH), carbon-to-nitrogen mass ratio (C/N ratio), operating temperature, substrate particle size, organic loading rate, hydraulic retention time, total solids content, reactor configuration (batch or continuous, single or two stage), oxidation-reduction potential, and the presence of inhibitory and toxic substances [5]. The process tends to fail if one or more of the environmental factors changes suddenly. Loading rate is a very important factor because it affects the stability of the anaerobic digestion and the biogas production rates. Because volatile solids represent the portion of organic-material solids that can be digested, then organic loading rate (OLR) indicates the amount of volatile solids to be fed into the digester each day [12]. Optimum organic loading rate is required to maximize biogas production; otherwise the productivity will be low. The purpose of this research was to investigate the effect of loading rate on the biogas yield produced from cow dung using semi continuous feeding anaerobic digester.

II. The Material and Method

Biogas production was carried out using lab scale self-designed 36-ℓ semi continuous anaerobic digester. Five digesters each of 25 litres working volume were set up for this experiment. The digester vessels were made of two 5-gallon transparent plastic drinking water containers as depicted in Figure 1. The two containers were cut at their bottom and then combined by using fiber resin and let to dry for 24 hours.

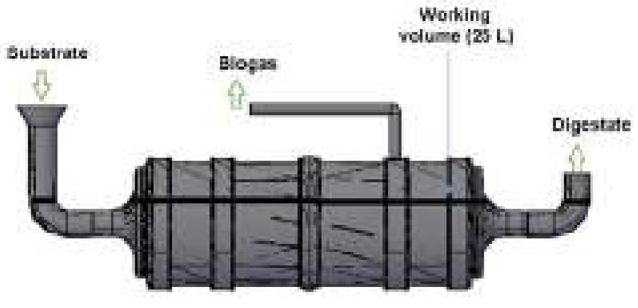

Fig. 1 Lab scale self-designed 36-L semi continuous anaerobic digester

Substrate used to produce biogas was fresh cow dung collected from the Department of Animal Husbandry, University of Lampung. In order to have a maximum biogas yield, fresh cow dung was diluted with tap water at a ratio of 1:1 [13, 14]. The analysis of fresh cow dung include moisture content, total solid (TS), volatile solid (VS), ash, carbon (C), and nitrogen (N) content. The moisture content of samples was obtained by sun drying followed by oven-drying (Memmert type UM 500) at 105ºC for 24 hours. Volatile solid was determined using a muffle furnace (Barnstead International model FB1310M-33) at 550ºC for at least two hours. Same sample was sent to Soil Science Lab. to determine the C and N content. Table 1 presented results of the analysis.

TABLE I
Characteristic of Fresh Cow Dung

Characteristic	Average Value
Water content (% wb)	80.12
Total solid, TS (% wb)	19.88
Ash (%TS)	30.58
Volatile solid, VS (% TS)	69.42
C	39.87
N	1.42
C/N ratio	28.1

Initially, 25 ℓ of substrate was loaded into the digester. The digester was refilled at five different loading rates. Table 2 presented five variations of loading rate application and the respected organic loading rate (OLR) and hydraulic residence time (HRT).

TABLE III
Loading Rate Variations and their Corresponding OLR and HRT

Treatment	VS in (% TS)	Loading Rate (L/day)	OLR (kg/L/day)	HRT (day)
P1	71.38	0.5	1.31	50.0
P2	70.44	1.0	2.47	25.0
P3	69.07	1.5	3.82	16.7
P4	73.45	2.0	5.35	12.5
P5	72.53	2.5	6.67	10.0

Important processing parameters include pH, temperature (digester and ambient), and biogas yield. The pH was measured daily for fresh inlet and spent substrate using portable digital pH-meter (PHMETER, PH_009(I)). Same analysis for TS and VS was also performed for spent slurry. Removed VS ($VS_{removal}$) was calculated using:

$$VS_{\text{removal}} = VS_{\text{in}} - VS_{\text{out}} \qquad \text{(g)} \qquad (1)$$

or,

$$VS_{\text{removal}} = \frac{VS_{in} - VS_{out}}{VS_{in}} \times 100\% \qquad (\%) \qquad (2)$$

Ambient as well as digester temperatures were monitored daily using digital thermocouple (Digi Sense, Cole Parmer, model No. 93410-00) equipped with K-type wire. Biogas production was measured daily using water displacement methode. Data were recorded for 55 days, by which time the digestion process was expected to already stable and the digesters were operating in practically steady conditions. After stable condition was achieved, biogas composition was analyzed using gas chromatography (Shimadzu GC 2014) with thermal conductivity detector (TCD) and 4 meter length of shin-carbon column. Helium gas was used as carrier gas with flow rate 40 ml/min. Biogas productivity was calculated from biogas yield at stable condition by using:

$$\text{Biogas Productivity} = \frac{\text{Biogas Yield}}{VS_{removal}} \qquad (3)$$

III. Result and Discussion

A. Process pH and Temperature

Biogas is produced during biological process involving a group of bacteria working in an anaerobic condition. The interaction of several factors affects the performance of biogas process. Temperature and pH are among the important factors. The bacteria optimally work at a certain pH value. Methanogenic bacteria work effectively at the pH range of 6.5 and 8. Hydrolysis and acidogenisis stages optimally go on at a pH range between 5.5 and 6.5 [15]. The overall process operates best at near of neutral pH. Anaerobic degradation processes meet the requirement for both activities and cell growth of anaerobic microorganisms at the acidity of 5.5–8.5 [16]. Reference [17] reported the effects of pH upon methane production from anaerobic digestion of dairy cattle manure maintained at pH levels of 7.6, 7.0, 6.0, 5.5, and 5.0. Active digestion was achieved at all pH levels except for pH 5.0. Biogas and methane production was highest at pH of 7.0.

Figure 2 showed daily pH values of the five different treatments for 55 days observation. It can be seen that the average pH values were not much different, between 6.8–7.0 with the maximum values between 7.5–7.8 and the minimum values of 5.8–6.4. The pH was observed changing overtime but the value was close to the initial. The pH value of fresh substrate was in the range of 6.5 – 7.7. This implied that the system was well buffered. Although there were some decreases in the pH, but overall, the values were still in the good range for biogas process. The values also indicated that biogas process was in good condition.

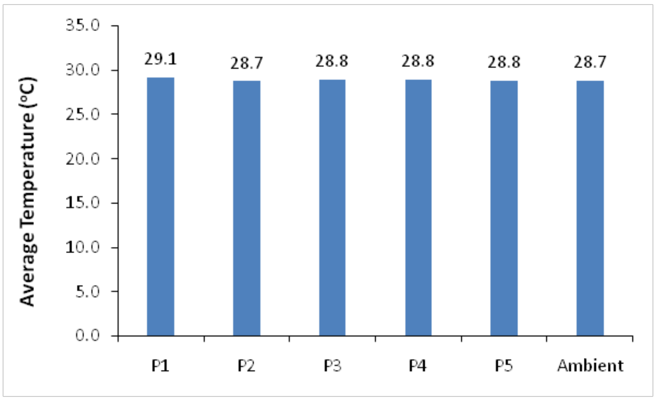

Fig. 3 Average digester temperature for different treatment and ambient air

Figure 3 showed daily temperatures of the five treatments as well as the ambient temperature averaged over 53 days observation. It was revealed that the temperature was almost same among the five treatments (ranging from 28.7 to 29.1 ºC). This meant that the digester working at mesophilic zone. Based on working temperature, anaerobic digestion process is classified into phsychrophilic (10–20 ºC), mesophilic (20–40 ºC), and thermophilic (40–60 ºC) [18, 19]. Digester temperatures, however, were slightly higher than the ambient. This was caused by a fact that. Some processes during anaerobic digestion are classified as endothermic, but the others are exothermic. Overall, anaerobic digestion process is very slightly exothermic reaction that producing heat [19]. However, the digesters or reactors were quite small with no such insulation that the heat produced during digestion process was easily transferred to the environment. As a consequence, the temperature of the digesters was just little higher than or in balance with environment temperature.

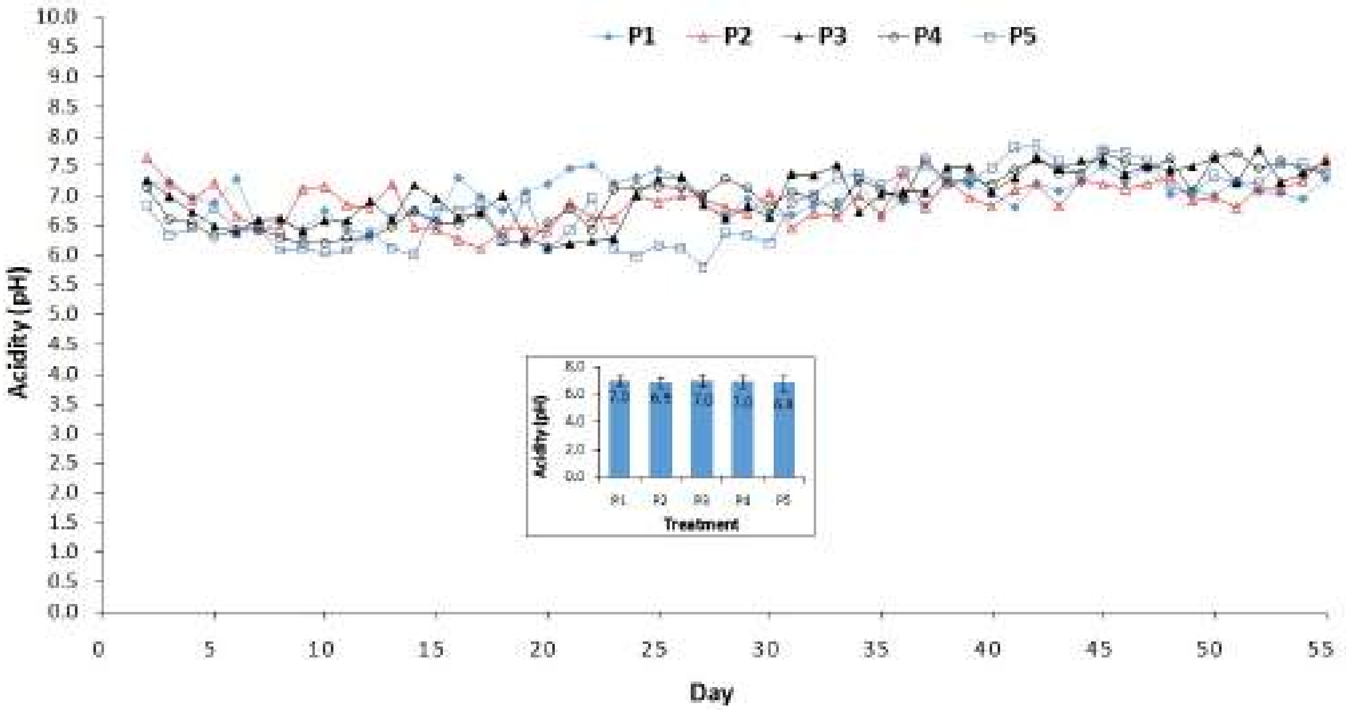

Fig. 2 Daily pH values of the anaerobic digestion process (small figure in the centre is average pH value during 53-day measurements)

B. VS removal

Anaerobic digestion process involves consortium of microorganisms that make use organic components within the substrate as building blocks. Therefore, efficiency of an anaerobic digestion system can be evaluated from the value of VS removal, which is a measure of anaerobic digestion system ability in decomposing organic material. For the purpose of evaluating the effect of loading rate on the process efficiency, VS reduction and biogas yield were both taken into account as the indicators to assess the reactor performance and efficiency of each loading rate.

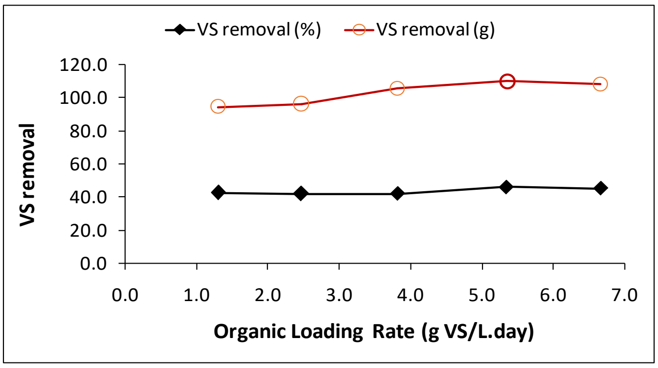

Fig. 4 Effect of loading rate on VS removal

Figure 4 showed the relationship of loading rate and VS removal. The digester efficiency (in term of VS removal) was in the range of 42.1% to 46.4%. It was revealed that elevating loading rate resulted in the increasing VS removal. But at an organic loading rate of 5.35 g VS/L/day, there was a tendency of VS removal to decrease. At an OLR range of 1.4-2.75, it was reported that VS removal decrease with increasing OLR [12]. On the other hand, Reference [21] reported an increase in the amount of organic matter biodegradation with increasing the OLR at a range of 3.4-5.0 g VS/L/day.

C. Biogas Yield

Figure 5 showed cumulative biogas production resulted from different treatments. The figure revealed that treatment P1 with loading rate of 0.5 L/day gave the highest cumulative biogas production, amounted to 194.4 L during 53 days consecutive measurement. In addition to biogas production measurement, the biogas was burnt to simply check if the biogas contains enough methane. It was observed that for the first three weeks the biogas could not be combusted, implying that the methane content was still low. In the figure we showed the day at which the biogas was able to be burnt and produce blue flame.

Biogas yield and biogas productivity were influenced by loading rate. Previously we showed that the increase in loading rate has resulted in the increase in VS removal (Figure 4). In contrast, Figure 6 showed that by increasing loading rate the biogas yield as well as biogas productivity decreased. This can be understood because the higher the loading rate (meaning the shorter HRT) the the process became uncomplete so that the biogas production was also low. This also implied that the decomposition process was not complete yet. Figure 6 also further strengthened the conclusion that treatment P1 with organic loading rate of 1.31 g VSL/day was the best for biogas production with biogas productivity of 0.08 L/g VS removal. Reference [22], however, reported higher productivity, like 0.358 LCH_4/gVS removal. This means that there is a challenge to improve the biogas productivity, for instance by apply agitation.

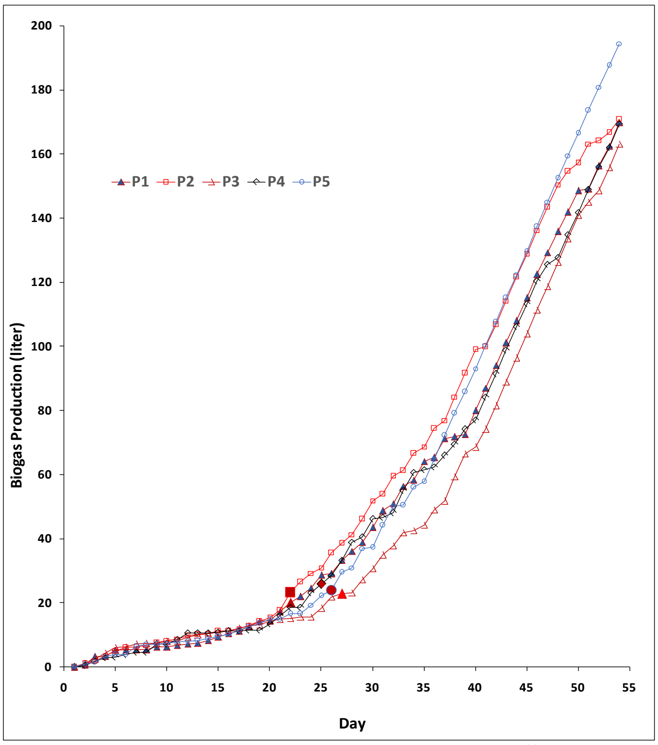

Fig. 5 Cumulative biogas production (solid symbols with different size and colour represent the day where biogas can be burnt).

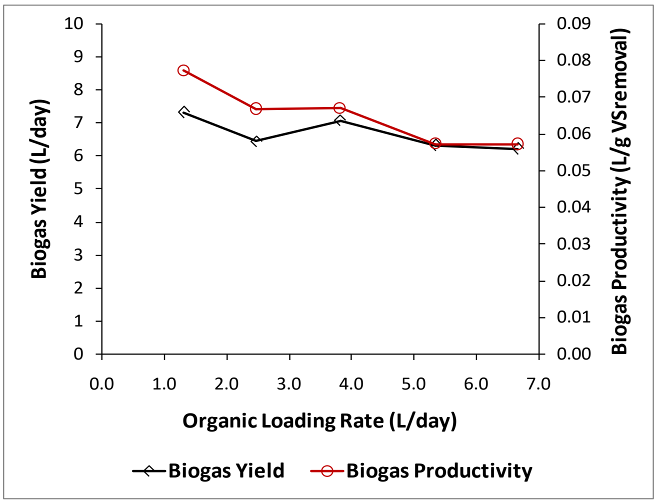

Fig. 6 Effect of loading rate on daily biogas yield and biogas productivity

By using 10-day moving average, the daily biogas yield is presented in Figure 5. In the figure we can differentiate two regions or periods, namely transition and stable periods. The transition period finished at around day 44 at which the stable period starts. It was revealed that during transition period the biogas yield gradually increases from around 0.6-0.9 to around 5-7 L/day. After stable period was achieved, biogas yield was stable at around 6 to 7. Again, treatment P1 with OLR of 1.33 g VS/L/day showed the best and gave the highest biogas yield with average of 7.23 L/day.

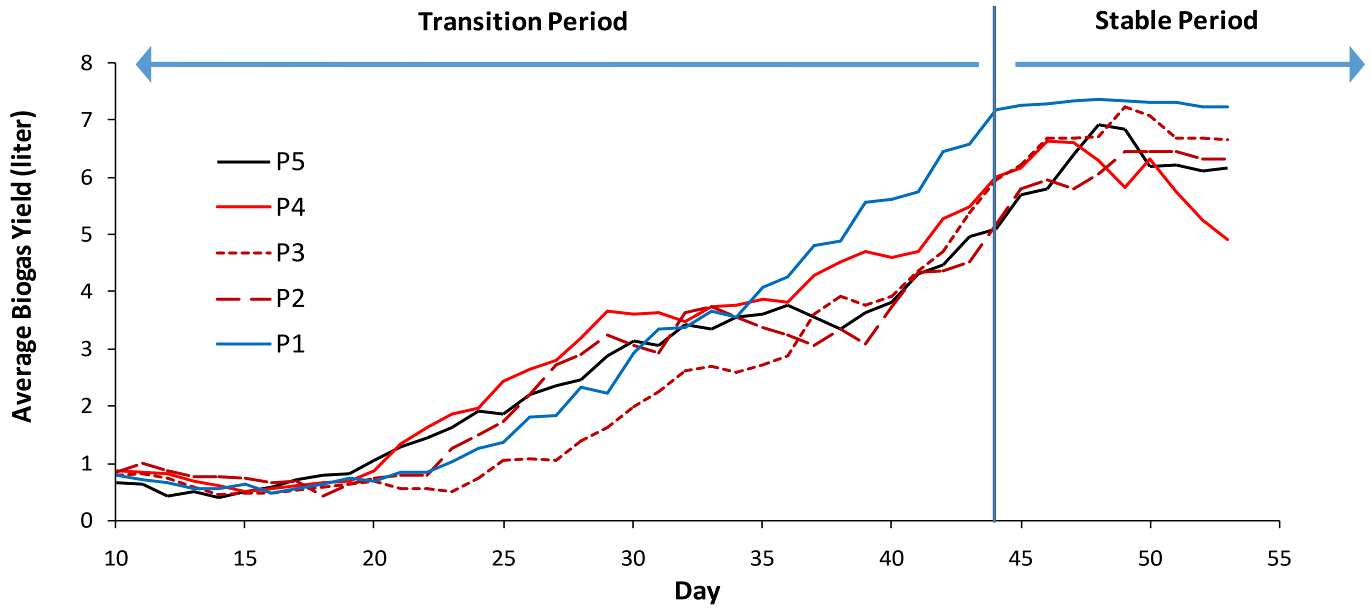

Fig. 5 The growth of daily biogas yield using 10-days moving average

D. Biogas Composition

Biogas is used as fuel. Therefore, its value is determined by combustible components. Good quality biogas mainly consists of methane (CH_4) gas at around 55-70% followed by carbon dioxide (CO_2) around 30-45%. Table III presented the composition of biogas collected from the best treatment (loading rate of 0.5 L/day). It was revealed that the biogas comprised of fairly high methane content (average 53.88 %) so that it was well burnt and can be used for fuel.

TABLE IIIII
BIOGAS COMPOSITION

Composition	Sample 1	Sample 2	Average
CH_4	32.91	31.13	32.02
CO_2	50.53	57.23	53.88
N_2	16.56	11.54	14.05

IV. CONCLUSIONS

Loading rate influenced biogas productivity and biogas yield of semi continuous digester. Increasing loading rate resulted in the decrease in both biogas yield and biogas productivity. Organic loading rate of 1.31 g VS/L/day gave the highest biogas yield (7.32 L/day) and biogas productivity (0.08 L/g $VS_{removal}$). The biogas produced from cow dung using semi continuous digester contained fairly good methane content (53.88%). Digester efficiency, in term of VS removal, was almost same for all treatments and was in the range of 42.1% and 46.4%.

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