Kode/namarumpunilmu: 163/TeknologiPertanian
Tema:EnergiBarudanTerbarukan
(*New and Renewable Energy)*

LAPORAN AKHIR TAHUN
PENELITIAN STRATEGIS NASIONAL

PENGEMBANGANLISTRIK TENAGA BIOGAS SKALA KECILMELALUI PROSES "DRY FERMENTATION"UNTUK MEMENUHI KEBUTUHAN LISTRIK MASYARAKAT TERPENCIL

Tahun ke-2 dari rencana 3 tahun

Dibiayai oleh:
Direktorat Riset dan Pengabdian Masyarakat
Direktorat Jenderal Penguatan Riset dan Pengembangan
Kementerian Riset, Teknologi, dan Pendidikan Tinggi
Sesuai dengan Kontrak Penelitian
Nomor: 071/SP2H/LT/DRPM/IV/2017585

Ketua Tim Peneliti

Dr. Ir. AgusHaryanto, M.P. (NIDN.0027056503)

AnggotaTim Peneliti

Dr. Ir. UdinHasanudin, M.T. (NIDN.0006016403)

UNIVERSITAS LAMPUNG
NOVEMBER, 2017

HALAMAN PENGESAHAN

Judul	: PENGEMBANGAN LISTRIK TENAGA BIOGAS SKALA KECIL MELALUI PROSES "DRY FERMENTATION" UNTUK MEMENUHI KEBUTUHAN LISTRIK MASYARAKAT TERPENCIL
Peneliti/Pelaksana	
Nama Lengkap	: 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
Institusi Mitra (jika ada)	
Nama Institusi Mitra	: Kelompok Tani Al-Hidayah
Alamat	: Desa Banjar Suri, Kecamatan Sidomulyo, Lampung Selatan
Penanggung Jawab	: Sujono
Tahun Pelaksanaan	: Tahun ke 2 dari rencana 3 tahun
Biaya Tahun Berjalan	: Rp 75,078,000
Biaya Keseluruhan	: Rp 280,000,000

Mengetahui, Wakil Dekan I, Fak. Pertanian	Kota Bandar Lampung, 13 - 11 - 2017 Ketua,
(Prof. Dr. Ir. Dermiyati, M.Agr. Sc) NIP/NIK 196308041987032002	(Ir AGUS HARYANTO, M.P) NIP/NIK 196505271993031002

Menyetujui,
Ketua LPPM Universitas Lampung

(Warsono, Ph.D)
NIP/NIK 196302161987031003

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 kedua telah dilakukan penelitian sebagai berikut:

1. Produksi biogas dari campuran rumput gajah dan kotoran sapi pada digester batch dan semi kontinyu.
2. Produksi biogas dari campuran jerami padi dan kotoran sapi pada digester semi kontinyu.
3. Persiapan uji generator skala rumah tangga (kapasitas 2500W). Pengujian akan dilakukan bekerjasama dengan PD Semangat Jaya di Negeri Katon, Kab. Pesawaran dan Prof. Tjokorda Nindhia dari Universitas Udayana, Bali.
4. Instalasi biogas skala rumah tangga dari tangka air kapasitas 2000 L.

Hasil yang sudah diperoleh dari kegiatan di atas adalah:

(1) Rumput gajah merupakan bahan yang potensial sebagai campuran substrat untuk produksi biogas. Produksi biogas menggunakan digester tipe batch mencapai 111,72 L/kg VS removal dengan kandungan metana 31,37%.

(2) Penambahan urea dapat meningkatkan produksi biogas dari campuran rumput gajah dan kotoran sapi, mencapai 167 L/kg VS removal. Tetapi kandungan metana masih rendah (22,35%).

(3) Masalah yang dihadapi adalah rendahnya kandungan metana pada biogas. Perlakuan awal (pretreatment) perlu dilakukan untuk rumput gajah.

(4) Jerami padi juga berpotensi menjadi bahan campuran produksi biogas. Produksi biogas dari campuran jerami padi dan kotoran sapi pada rasio 1:3 menggunakan digester semi kontinyu mencapai 885 L/VS removal. Kandungan metana cukup tinggi mencapai 50,12%.

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

PRAKTA

Puji syukur dipanjatkan ke hadirat Tuhan Yang Maha Kuasa, yang telah melimpahkan rahmat dan karunia-Nya sehingga memberikan kekuatan bagi kami untuk melaksanakan penelitian ini dengan sebaik-baiknya.

Laporan Akhir ini dibuat sebagai pertanggungjawaban kami atas hibah penelitian yang kami peroleh dari skim STRANAS yang berjudul PENGEMBANGANLISTRIK TENAGA BIOGAS SKALA KECILMELALUI PROSES "DRY FERMENTATION"UNTUK MEMENUHI KEBUTUHAN LISTRIK MASYARAKAT TERPENCIL. Hingga laporan ini dibuat, penelitian ini sudah menyelesaikan 100%. Meskipun demikian kami masih terus menyempurnakan beberapa makalah yang sudah diseminarkan untuk dipublikasi di jurnal terakreditasi atau internasional.

Kami berharap laporan ini bermanfaat baik bagi kami maupun institusi Universitas Lampung.

Bandar Lampung, 13 November 2017

Ketua Peneliti

Dr. Ir. Agus Haryanto, MP.

DAFTAR ISI

DAFTAR TABEL

DAFTAR GAMBAR

DAFTAR LAMPIRAN

Hal.

BAB I. PENDAHULUAN

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

Biogas bisa menjadi salah satu solusi untuk mengatasi masalah tersebut. Bahan baku biogas dapat dikembangkan secara lokal dan murah. Chandra *et al*. (2012) menyimpulkan bahwa produksi metana (biogas) dari biomassa limbah pertanian lebih menguntungkan dan merupakan cara pemanfaatan biomassa yang berkelanjutan untuk menghasilkan energi. Biogas telah memainkan peranan penting di berbagai negara, baik negara maju maupun berkembang (Abraham *et al*., 2007), 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).

Aplikasi biogas di Indonesia masih sangat terbatas. Pada umumnya proses produksi biogas di Indonesia dilakukan menggunakan “fermentasi basah” dengan substrat kotoran sapi atau limbah cair agroindustri. Proses basah memerlukan ukuran digester besar, *feedstock* terbatas pada bahan dengan kandungan padatan kering (TS) kurang dari 10%, dan perlu banyak air. 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, 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.

1.1 Perumusan Masalah

Biogas bisa menjadi salah satu solusi untuk menyediakan listrik bagi masyarakat di daerah terpencil. 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.

1.2 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 juga menghasilkan kompos. Pemanfaatan kompos 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.

1.3 Luaran

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

Tabel 1. Luaran penelitian selama 3 tahun

Luaran	Tahun 1	Tahun 2	Tahun 3
Publikasi Seminar Nasional	Dilaksanakan	Dilaksanakan	Dilaksanakan
Publikasi Seminar Internasional	Dilaksanakan	Dilaksanakan	Dilaksanakan
Publikasi Nasional (Akreditasi)	Draft	Diterima	Diterima
Publikasi Internasional	Dikirim	Direview	Diterima
Teknologi Tepat Guna	Uji Lab	Uji Lapang	Aplikasi
Buku Ajar	Draft	Dicetak	ISBN

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

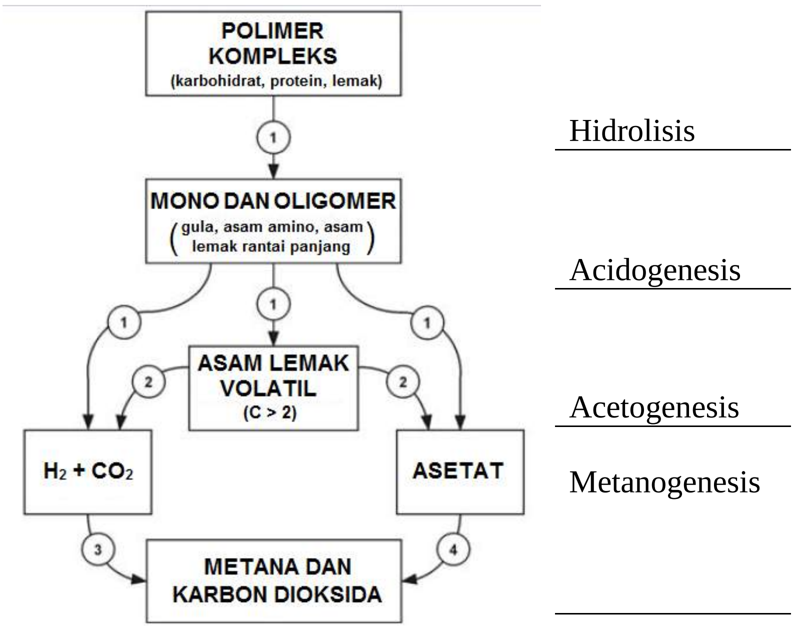
Makin menipisnya cadangan energi fosil dan makin meningkatnya harga energi telah menempatkan Indonesia berada pada kondisi krisis energi. Azahari (2012) melaporkan bahwa cadangan energi fosil Indonesia hanya akan bertahan selama 11 tahun untuk minyak, 32 tahun untuk gas, dan 85 tahun untuk batubara. 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.



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).

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).

Berdasarkan kandungan padatan kering (TS) dalam bahan baku, teknologi biogas dibedakan menjadi fermentasi anaerobik "basah" dan "kering." Li *et al*. (2011a) 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 (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 kandungan TS, C/N ratio, suhu, pH, dan SRT.

2.3.1 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).

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

Hubungan antara jumlah karbon dan nitrogen yang ada di dalam bahan organik disajikan oleh rasio C/N. Tabel 2 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 2. 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)

2.3.3 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).

2.3.4 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, 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.

2.3.5 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 Rumput Gajah

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 3) menunjukkan bahwa rumput gajah berpotensi untuk dikembangkan sebagai bahan baku produksi biogas melalui proses kering.

Tabel 3. 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. 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.

2.4.3 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.

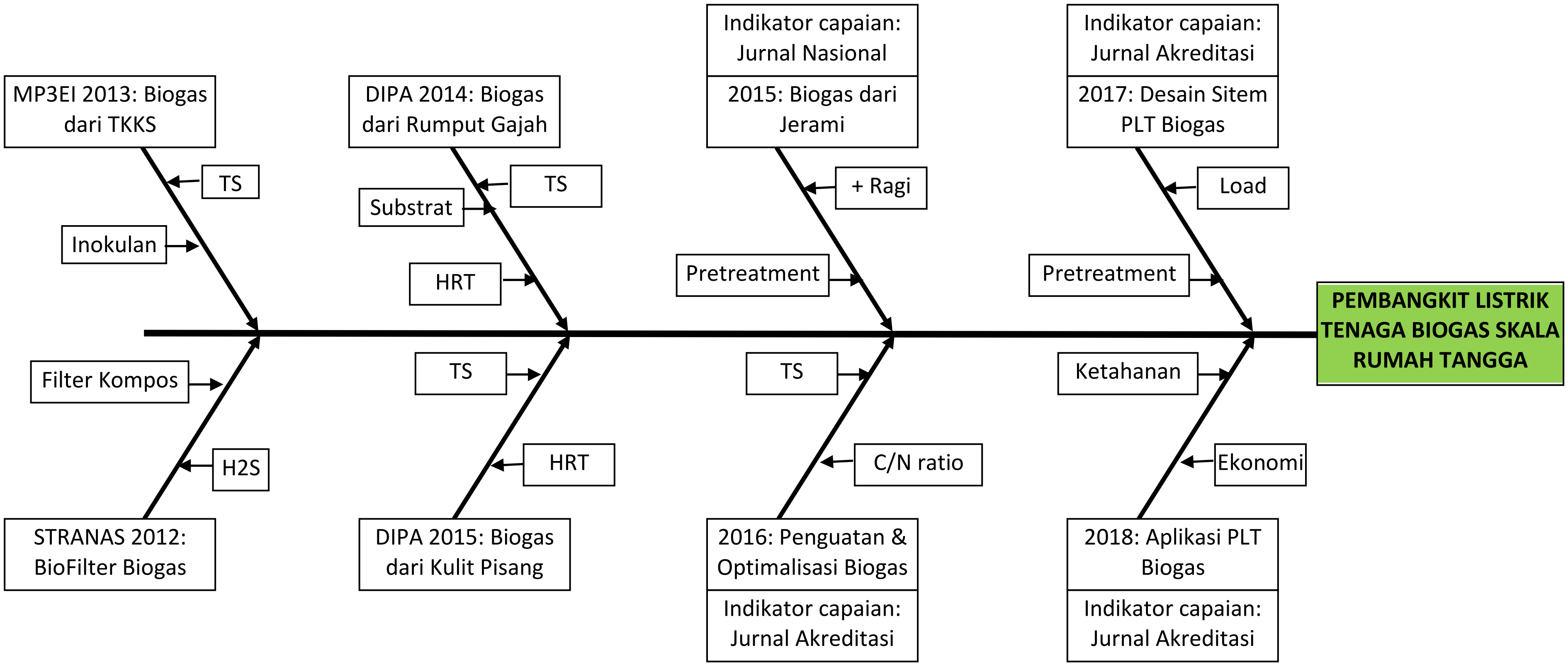
2.5 Peta Jalan Penelitian

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). Penelitian-penelitian tersebut menunjukkan bahwa bahan organik padat dapat menghasilkan biogas melalui proses fermentasi anaerobik. Penelitian mengenai pemurnian biogas menggunakan biofilter sudah dilakukan sejak 2012. Biofilter dapat menurunkan kadar H_2S menjadi <2 ppm (Indraningtyas *dkk*., 2012). Fadli *dkk*. (2015) mengkaji kinerja genset 700 W menggunakan biogas dari limbah cair industri kelapa sawit. Melalui pretreatment sederhana biogas dapat digunakan langsung untuk genset. Genset berkapasitas 700 W bekerja dengan baik hingga beban 600 W. Peta jalan (*roadmap*) penelitian produksi listrik skala kecil dari biogas diberikan dalam Tabel 4 dan Gambar 2.

Tabel 4. 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**
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. *JTEP Lampung 2015*)	
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	**2015**
Penguatan dan Optimalisasi Produksi Biogas dari Bahan Organik Padat	**2016**
Desain dan Uji Coba Sistem PLTBi Skala Kecil	**2017**
Aplikasi Sistem PLT Biogas Skala Kecil untuk Rumah Tangga	**2018**
PLT Biogas Skala Rumah Tangga	**…….**

Catatan: 2017 dan seterusnya akan dikerjakan



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

BAB 3. TUJUAN DAN MANFAAT PENELITIAN

3.1. Tujuan Penelitian

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

3.2. Manfaat Penelitian

Manfaat 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.

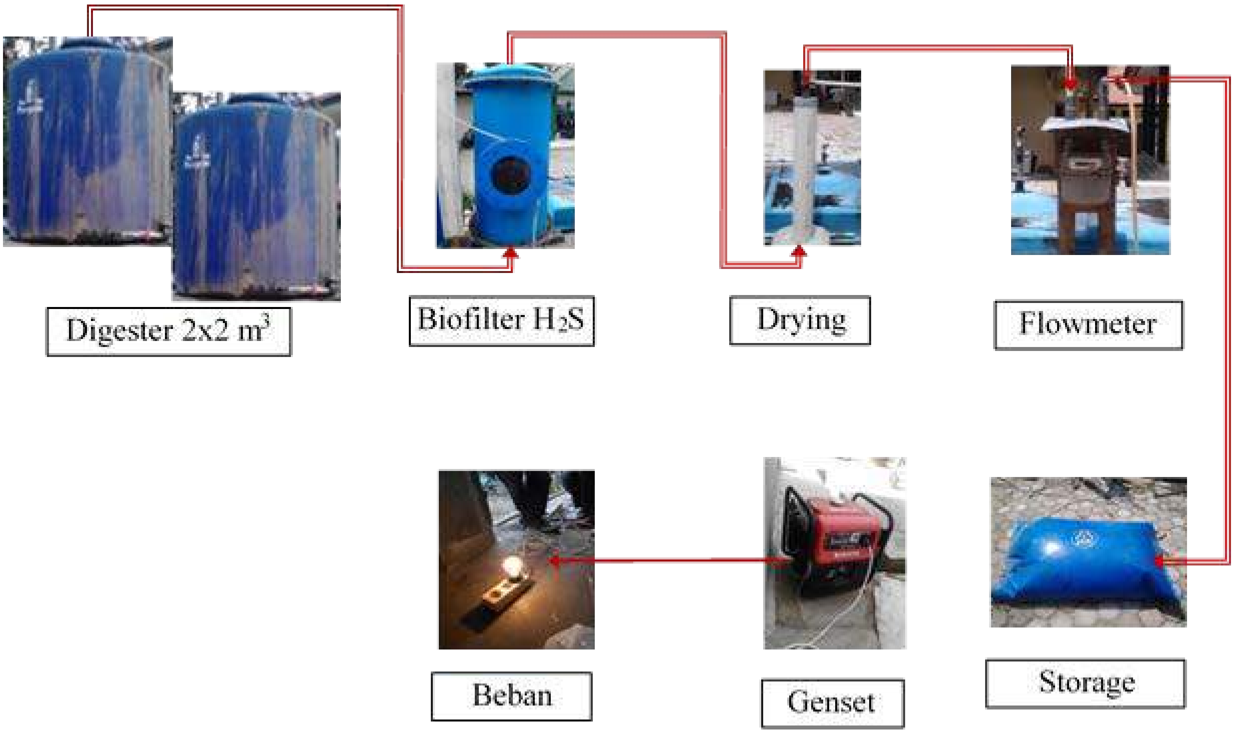
BAB 4. METODE PENELITIAN

Secara keseluruhan, penelitian ini dirancang selama 3 tahun (Gambar 3). Pada Tahun I telah dilakukan penelitian mengenai proses produksi biogas dari bahan organic padat dengan beragam substrat (kotoran sapi, jerami padi, dan rumput gajah) dan pengukuran produksi biogas dari digester skala rumah tangga. Pada tahun pertama juga telah dilakukan pengujian genset menggunakan biogas sebagai bahan bakarnya.

Pada tahun II, penelitian produksi biogas dari campuran kotoran sapi dengan bahan organik lain yang ketersediaannya melimpah seperti jerami dan rumput gajah masih akan dilakukan. Dalam hal ini aspek-aspek penting seperti loading rate dan penambahan urea akan diteliti. Penelitian meliputi:

1. Produksi biogas dari campuran rumput gajah dan kotoran sapi dengan digester tipe batch kapasitas 220 L. Rasio campuran rumput gajah dan kotoran sapi adalah 1:1. Campuran diencerkan dengan air sumur pada tiga tingkat pengenceran, yaitu P1 (50 L), P2 (75 L) dan P3 (100 L).
2. Produksi biogas dari campuran rumput gajah dan kotoran sapi dengan digester tipe semi kontinyu kapasitas 36 L (volume kerja 25 L) dengan empat perlakuan: P1 (loading rate 0,625 L/hari), P2 (loading rate 0,625 L/hari dengan penambahan Urea 1,25 g/L), P3 (loading rate 1,25 L/hari), P4 (loading rate 1,25 L/hari dengan penambahan Urea 1,25 g/L).
3. Produksi biogas dari campuran jerami padi dan kotoran sapi dengan digester tipe semi kontinyu kapasitas 36 L (volume kerja 30 L), loading rate 0,625 dengan empat perlakuan: P1 (tanpa urea), P2 (dengan penambahan urea 0,247 g/L), P3 (dengan penambahan urea 0,645 g/L), dan P4 (dengan penambahan urea 1,304 g/L).
4. Pengujian generator biogas kapasitas 2500 VA. Penelitian ini akan dilaksanakan bekerjasama dengan Prof. Tjokorda Nindhia (Universitas Udayana, Bali) dan pabrik tapioca skala rakyat PD Semangat Jaya di Negeri Katon, Kab. Pesawaran, Lampung. PD Semangat Jaya telah memiliki fasilitas biogas yang dapat digunakan sebagai bahan bakar genset. Selama ini biogas digunakan sebagai bahan bakar masak dan mengeringkan tapioca dan jagung.

Selain itu kami juga akan menginstal digester yang terbuat dari tangki dengan kapasitas 2×2 m^3. Digester diinstal di lokasi kandang sapi milik Bpk. Tulus, di Desa Sidosari, Kec. Natar, Lampung Selatan (jumlah sapi 3-20 ekor). Dengan kapasitas digester 4 m^3 diharapkan mampu menghasilkan biogas 2-3 m^2/hari. Dari hasil penelitian pada tahun I telah diketahui bahwa genset biogas dengan kapasitas rumah tangga (750 W) memerlukan bahan bakar biogas sekitar 400 L/jam sehingga digester ini mampu menghidupkan genset antara 6 hingga 7 jam.



Gambar 3. Komponen desain PLT Biogas skala kecil

Karena H_2S dalam biogas bersifat korosif, maka konsentrasinya harus diturunkan. Berdasarkan hasil penelitian kami sebelumnya, hal ini dapat dilakukan dengan menggunakan biofilter yang memanfaatkan kompos.

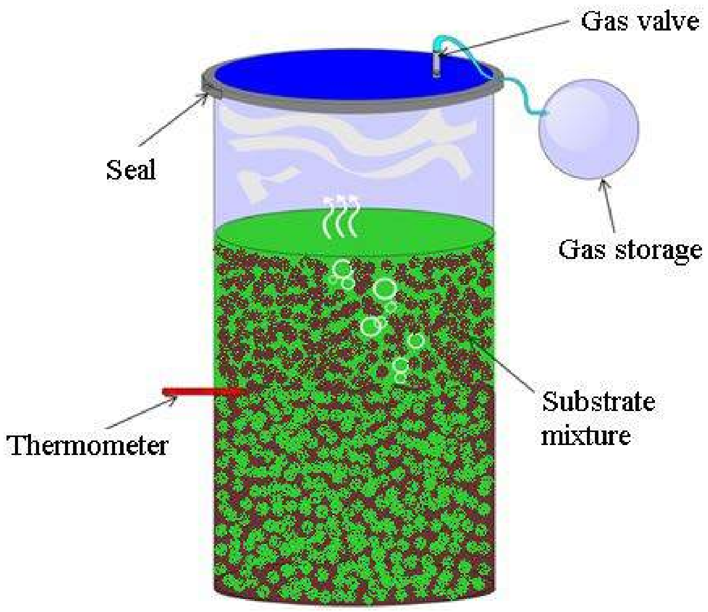
Pengujian genset lebih difokuskan untuk mengetahui keandalan sistem. Persoalan-persoalan yang dapat menyebabkan terganggunya pembangkitan listrik skala rumah tangga ini akan diamati dan dipecahkan sehingga dapat dilakukan optimasi. Parameter-parameter yang akan dikaji meliputi nilai ekonomi dan nilai tambah genset biogas skala rumah tangga serta keandalan sistem. Kualitas biogas (dicirikan oleh kandungan metana) juga akan tetap dipantau melalui analisis lab.

BAB 5. HASIL DAN LUARAN YANG DICAPAI

5.1. Hasil Penelitian

1. *Produksi Biogas dari Rumput Gajah*

Rumput gajah digunakan sebagai substrate tambahan (cosubstrate) pada produksi biogas dari kotoran sapi dengan digester batch kapasitas 220 L. Dalam hal ini 25 kg rumput gajah segar pada umur sekitar 2 bulan dicacah kasar (panjang 3 cm). Cacahan rumput dicampur rata dengan 25 kg kotoran sapi segar. Campuran substrat kemudian dimasukkan ke dalam digester lalu diencerkan dengan air sumur pada 3 level, yaitu 50 L, 75 L, dan 100 L. Produksi biogas diamati selama 70 hari. Gambar 4 menunjukkan sistem digester batch yang digunakan dalam eksperimen.



Gambar 4. Digester batch kapasitas 220 L dengan substrat campuran kotoran sapi dan rumput gajah (25:25).

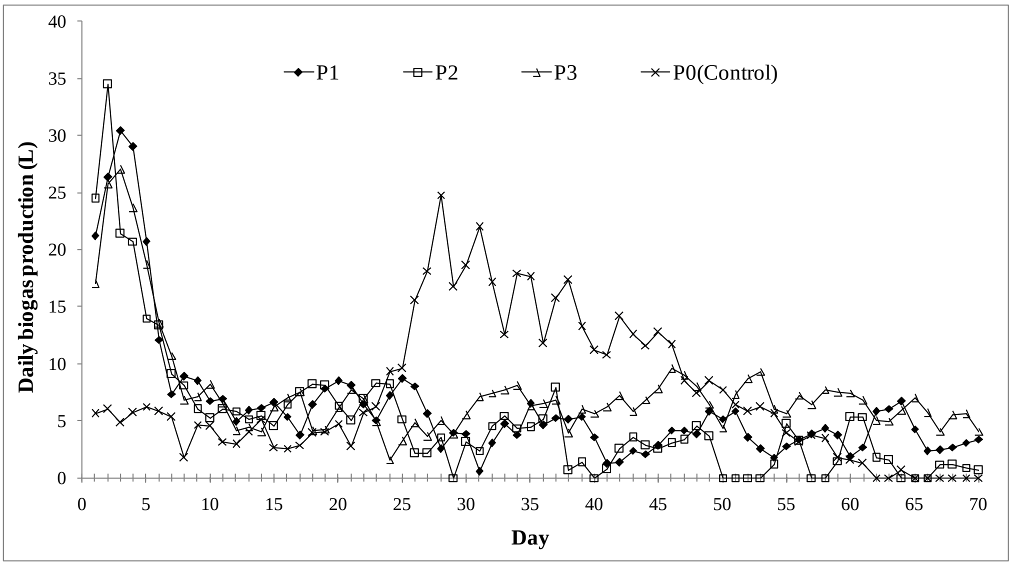
Hasil penelitian menunjukkan bahwa rumput memiliki karakteristik yang sesuai untuk produksi biogas seperti diberikan dalam Tabel 5. Hasil peelitian menunjukkan bahwa awalnya produksi biogas dari substrate yang dicampur rumput gajah lebih rendah dari perlakuan kontrol yang menggunakan kotoran sapi ditambah air dengan rasio 1:1. Tetapi, penambahan rumput memiliki efek positif seiring berjalannya waktu proses. Produksi biogas dari perlakuan kontrol sudah berhenti pada hari ke 66, sedangkan perlakuan dengan tambahan rumput masih berlanjut. Bahkan pada hari 70, akumulasi produksi biogas dari perlakuan P3 (pengenceran 100 L) sudah melampaui perlakuan kontrol. Oleh karena itu, penambahan rumput gajah dengan pengenceran yang sesuai akan sangat prospektif. Produksi biogas diberikan dalam Gambar 5 dan 6.

Tabel 5. Karakteristik kotoran sapi dan rumput gajah

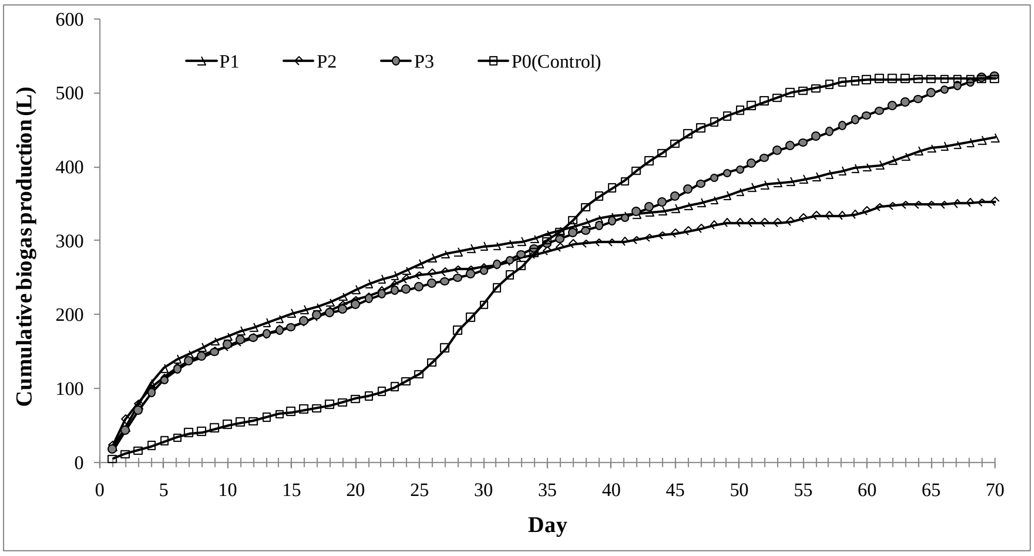
Karakteristik	Kotoran sapi	Rumput gajah
Kadar air (%, wet basis)	71,32	87,03
Total solid (TS) (%, wet basis)	28,68	12,97
Ash (% TS)	25,04	14,41
Volatile solid (VS) (% TS)	74,96	85,59
C (%)	39,87	55,51
N (%)	1,42	1,81
C/N Ratio	28,08	30,62

Masalah yang dihadapi adalah masih rendahnya kandungan metana yang dihasilkan dari campuran rumput gajah dan kotoran sapi. Gambar 7 menunjukkan bahwa kandungan metana tertinggi pada sistem batch hanya mencapai 31,34%.

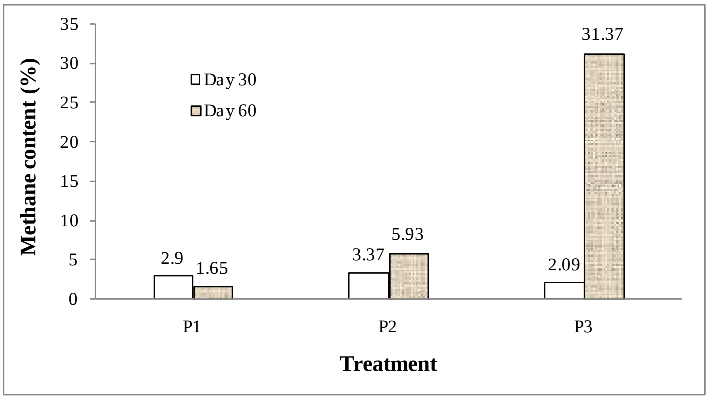
Produksi biogas dari campuran rumput gajah dan kotoran sapi juga kami teliti dengan menggunakan digester semi kontinyu kapasitas 36 L (volume kerja 25 L) seperti diberikan pada Gambar 8.



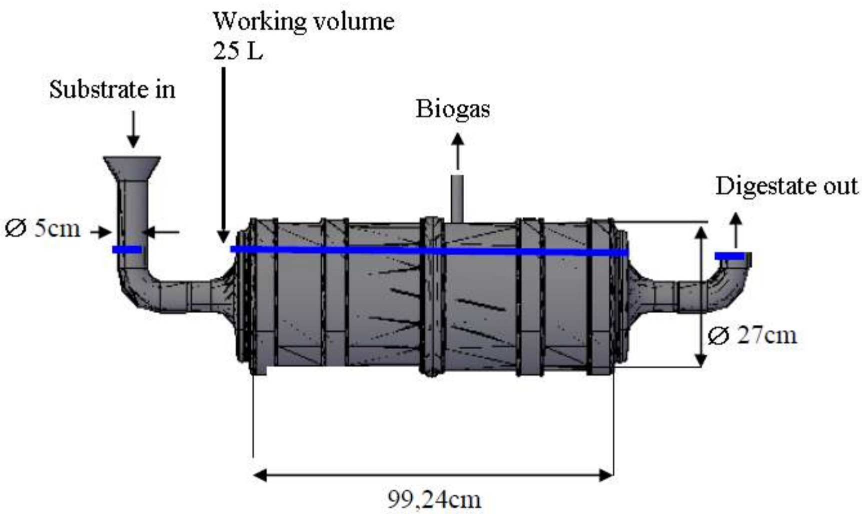
Gambar 5. Produksi biogas harian dari campuran kotoran sapi dan rumput gajah pada 3 tingkat pengenceran. P0 adalah control (kotoran sapi ditambah air dengan rasio 1:1)



Gambar 6. Produksi biogas kumulatif dari campuran kotoran sapi dan rumput gajah pada 3 tingkat pengenceran. P0 adalah kontrol (kotoran sapi ditambah air dengan rasio 1:1)

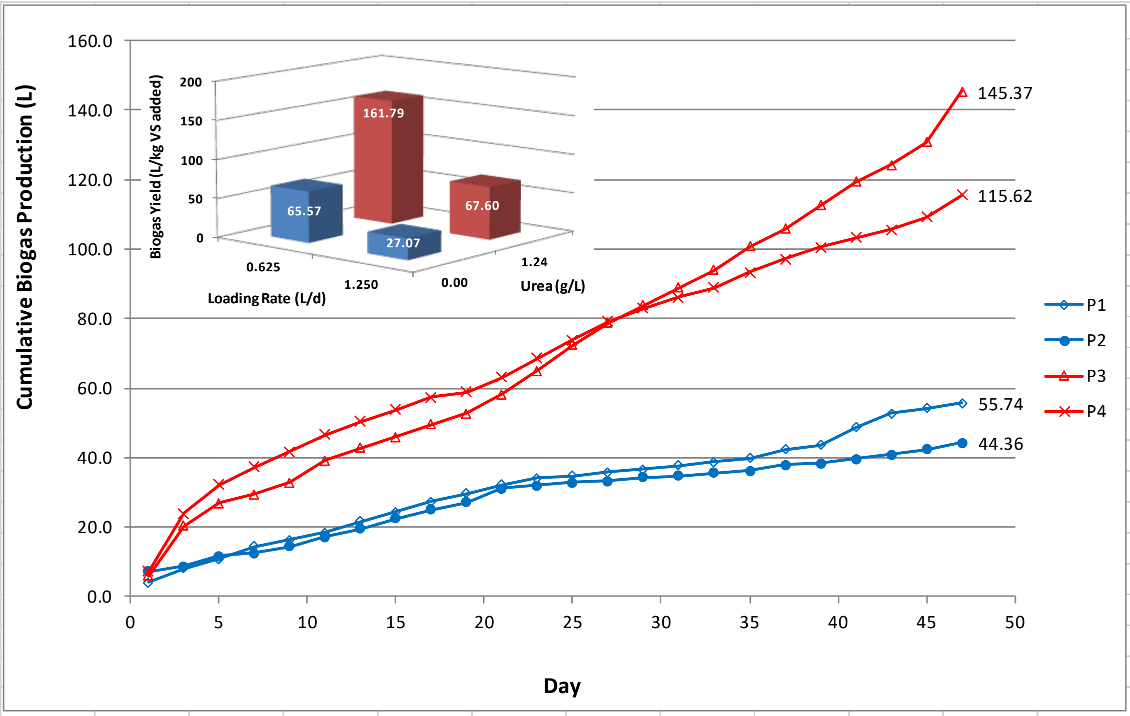


Gambar 7. Kandungan metana pada biogas dari campuran rumput gajah dan kotoran sapi

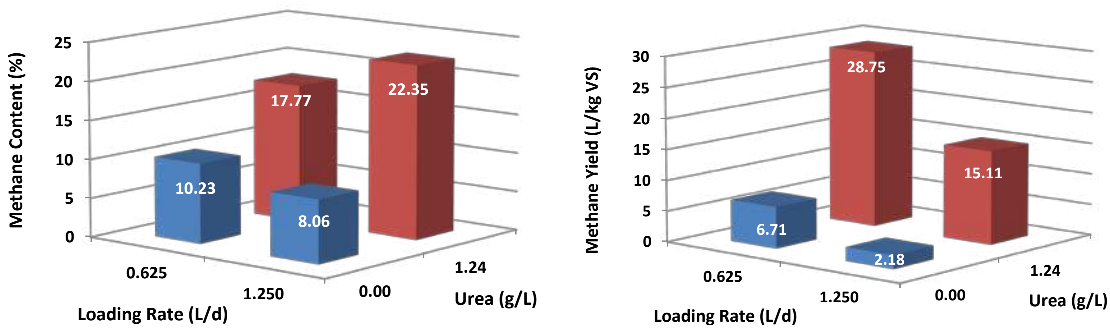


Gambar 8. Produksi biogas dari campuran rumput gajah dan kotoran sapi menggunakan digester semi kontinyu.

Hasil penelitian ditunjukkan oleh Gambar 9. Terlihat bahwa perlakuan P3 (loading rate 0,625 L/hari dengan penambahan urea) menghasilkan produksi biogas tertinggi (161,8 L/kg VS removal). Tetapi, biogas yang dihasilkan dari digester semi kontinyu juga memiliki kandungan metana yang masih rendah (Gambar 10). Hal ini semakin menguatkan bahwa rumput gajah perlu mendapatkan perlakuan awal seperti hidrolisis menggunakan soda api atau perlakuan mekanis untuk menghancurkan partikel dan serat rumput untuk mempercepat proses hidrolisis.

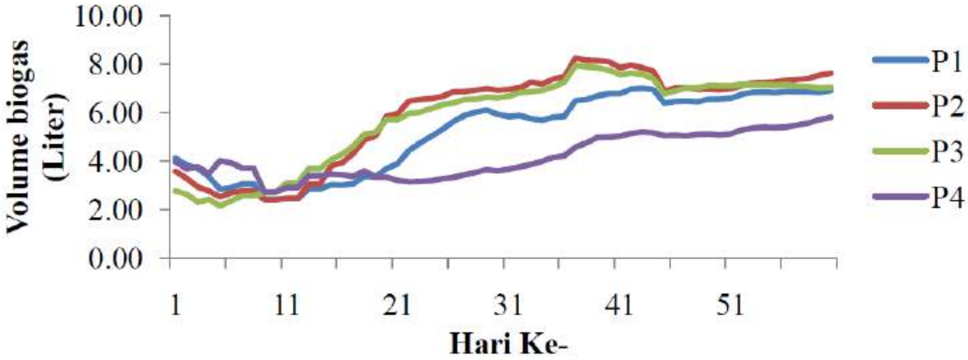


Gambar 9. Produksi biogas kumulatif dari campuran kotoran sapi dan rumput gajah dengan digester semi kontinyu.

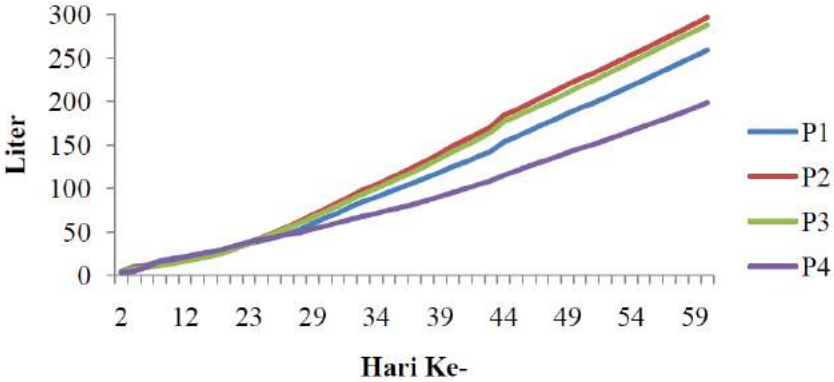


Gambar 10. Kandungan metana pada biogas dari campuran kotoran sapi dan rumput gajah dengan digester semi kontinyu.

Jerami padi juga menjadi bahan baku biogas yang menarik karena jumlahnya yang melimpah. Hasil penelitian menggunakan digester semi kontinyu menunjukkan bahwa campuran substrat dengan perbandingan 3:1 (kotoran sapi : jerami) mampu menghasilkan biogas hingga 8 L/hari dan 297 L selama 60 hari pengamatan (Gambar 11-12). Kandungan metana juga cukup tinggi mencapai 50,12% seperti diberikan pada Tabel 6.



Gambar 11. Produksi gas harian menggunakan metode moving average 8 harian



Gambar 12. Produksi gas kumulatif

Tabel 6. Kandungan metana dalam biogas dari campuran jerami padi dan kotoran sapi

Perlakuan	**CH4 (%)**	**CO2(%)**	**N2(%)**
P1 (tanpa urea)	49.817	40.431	9.752
P2 (0,247 g urea/liter)	50.121	39.966	9.914
P3 (0,645 g urea/liter)	46.489	43.150	10.361
P4 (1,304 g urea/liter)	37.037	35.405	27.559

2. Instalasi Biogas Skala Rumah Tangga

Instalasi biogas skala rumah tangga kapasitas 2 x 2 m3 telah berhasil dilakukan di Desa Sidosari, Natar (Gambar 13). Hingga saat ini biogas sudah mulai dihasilkan tetapi dalam jumlah yang masih terbatas sehingga belum cukup untuk pengujian genset. Hal ini disebabkan karena pada saat instalasi, pas bertepatan dengan musim kemarau. Sepanjang hapi sapi digembalakan di kebun sawit, sehingga jumlah kotoran sedikit karena hanya kotoran yang dihasilkan sapi pada malam hari saja yang dimasukkan ke dalam digester. Selain itu, kotoran sapi cenderung kering sehingga produktivitasnya berkurang. Diharapkan tidak lama lagi digester sudah bisa digunakan.

Gambar 13. Instalasi biogas rumah tangga 2 x 2 m^3 untuk pengujian genset

3. Uji Kinerja Genset Biogas

Gambar 14 menunjukkan genset yang akan diuji kinerjanya menggunakan bahan bakar biogas. Pengujian akan dilakukan bekerja sama dengan PD. Semangat Jaya, sebuah industri tapioka rakyat yang telah memiliki fasilitas biogas. Pada saat ini masih dilakukan persiapan instalasinya.

Gambar 14. Genset biogas kapasitas 2500 VA kerjasama dengan Prof. Tjokorda Nindhia

5.2. Luaran Penelitian

Luaran yang telah dicapai meliputi:

1. Paper berjudul **Developing A Family-Size Biogas-Fueled Electricity Generating System** telah dipublikasi pada Internasional Journal of Renewable Energy Development (IJRED), vol. 6 (2) 2017: 111-118.
2. Makalah berjudul **Biogas Production from Anaerobic Codigestion of Cowdung and Elephant Grass (*Pennisetum purpureum*) Using Batch Digester** telah dipresentasikan pada 2nd International Conference on Biomass, Bogor 24 Juli 2017.
3. Makalah berjudul **Effect of Loading Rate and Urea Addition on Biogas Yield Using Semi-Continuous Flow Anaerobic Codigestion of Cowdung and Elephant Grass (*Penisetum purpuerum*)** telah dipresentasikan pada International Conference on Food Security Innovation yang akan dilaksanakan pada 18-20 Oktober , 2017 di Serang, Banten.
4. Makalah berjudul **Anaerobic codigestion of cow dung and rice straw to produce biogas using semi-continuous flow digester: Effect of urea addition** telah dipresentasikan pada 2nd International Conference on Agricultural Engineering for Sustainable Production yang akan dilaksanakan pada 23-25 Oktober 2017 di IPB, Bogor.
5. Presentasi pada Seminar Nasional PERTETA Aceh 2-5 November 2017 berjudul **Pengaruh frekwensi pengumpanan pada produksi biogas dari campuran kotoran sapi dan rumput gajah (*Penisetum purpuerum*) menggunakan digester semi-kontinyu.**

BAB 6. RENCANA TAHAPAN BERIKUTNYA

Dalam waktu dekat akan dilakukan isntalasi genset biogas kapasitas 2500 VA bekerjasama dengan Prof. Tjokorda Nindhia (Universitas Udayana) dan industri tapioka rakyat PD Semangat Jaya di Desa Negeri Sakti, Kec. Negeri Katon, Kab. Pesawaran, Lampung. Selanjutnya genset akan diuji kinerjanya dengan menggunakan bahan bakar biogas. Kualitas biogas, tingkat beban dan daya output genset akan diamati dan dievaluasi.

Sebagai kewajiban penting juga akan dilakukan untuk menulis makalah berbahasa Inggris mengenai produksi biogas dari rumput gajah dan jerami dan mengirimkannya ke IJRED (Internasional Journal of Renewable Energy Development) atau jurnal internasional lain yang relevan.

BAB 7. KESIMPULAN DAN SARAN

7.1. Kesimpulan

Bahan hasil pertanian seperti jerami padi dan rumput gajah sangat berpotensi untuk digunakan sebagai bahan baku pembuatan biogas. Penambahan bahan-bahan ini sebagai cosubstrate pada kotoran sapi mampu meningkatkan produksi biogas. Kandungan metana dalam biogas yang dihasilkan dari campuran jerami padi cukup tinggi. Tetapi kandungan metana dari bahan dengan campuran rumput gajah masih rendah sehingga diperlukan perlakuan awal khusus untuk rumput gajah.

7.1. Saran

Rumput gajah perlu mendapatkan perlakuan awal untuk memepercepat proses hidrolisis. Perlakuan awal yang disarankan adalah penghancuran secara mekanis hingga mencapai ukuran yang kecil.

DAFTAR PUSTAKA

Abraham, E.R., Ramachandran, S. and Ramalingam, V. 2007. Biogas: Can it be an important source of energy? *Env Sci Pollut Res* 14(1): 67 – 71

Ahn, H.K., Smith, M.C., Kondrad, S.L. and White, J.W. 2010. Evaluation of biogas production potential by dry anaerobic digestion of switchgrass–animal manure mixtures. *Appl Biochem Biotechnol* **160**: 965–975.

Ahring, B.K. 2003. Perspectives for anaerobic digestion. *Advances in Biochemical Engineering/Biotechnology* **81**: 1-30.

Appels, L., Baeyens, J., Degrèvea, J., Dewil, R. 2008. Principles and potential of the anaerobic digestion of waste-activated sludge. *Progress in Energy and Combustion Science* **34**: 755–781

Azahari, H.L. 2012. New and Renewable Energy Policies. Presentation at *Conference and Exhibition EBTKE 2012*. Jakarta, July 18th, 2012

BPS. 2013. Produksi Padi, Jagung, dan Kedelai (Angka Ramalan I Tahun 2013). *Berita Resmi Statistik*. No. 45/07/ Th. XVI, 1 Juli 2013. 10 hal.

Brown, D. 2012. Comparison of Solid-State to Liquid Phase Anaerobic Digestion of Lignocellulosic Biomass for Biogas Production. Master Thesis. Graduate Program in Food, Agricultural, and Biological Engineering. The Ohio State University.

Chandra, R., Takeuchib, H., and Hasegawa, T. 2012. Methane production from lignocellulosic agricultural crop wastes: A review in context to second generation of biofuel production. *Renewable and Sustainable Energy Reviews* 16: 1462–1476.

Chen, X., Yan, W., Sheng, K. and Sanati, M. 2014. Comparison of high-solids to liquid anaerobic co-digestion of food waste and green waste. *Bioresource Technology* 154: 215–221

de Baere, L., 2000. Anaerobic digestion of solid waste: state-of-the-art. *Water Science and Technology*. **41(3)**: 283–290. (CARI)

Duke, J.A. 1983. *Handbook of Energy Crops*. Diakses pada 06 March 2014 dari https://www.hort.purdue.edu/newcrop/duke_energy/Pennisetum_purpureum.html

Ekpenyong, K.I., Arawo, J.D.E., Melaiye, A., Ekwenchi, M.M. and Abdullahi, H.A. 1995. Biogas production potential of unextracted, nutrient-rich elephant-grass lignocelluloses. *Fuel*. **74(7)**: 108-1082.

Federal Ministry of Food and Agriculture. 2014. *Bioenergy in Germany: Facts and Figures*. http://international.fnr.de

Feng, Y., Guo, Y., Gaihe, Y., Qin, X., Song, Z. 2012. Household biogas development in rural China : On policy support and other macro conditions. *Renewable and Sustainable Energy Review*. **16**: 5617 – 5624.

GGL (Great Giant Livestock). 2013. Komunikasi pribadi pada tanggal 8 Januari 2014.

Gu, Y., Chen, X., Liu, Z., Zhou, X., Zhang, Y. 2014. Effect of inoculum sources on the anaerobic digestion of rice straw. *Bioresource Technology*. **158:** 149–155.

Hasanudin, U., Haryanto, A., Suroso, E. 2011. Mitigation of Green House Gases Emission in Cassava Mill: Case Study in Lampung, Indonesia. *Proceedings International Conference and Exhibition on Sustainable Energy and Advanced Materials* (ICE

SEAM 2011). Jurusan Teknik Mesin, Fakultas Teknik, Universitas Sebelas Maret, Solo.

Jewell, W.J., Cummings, R.O., and Richards, B.K. 1993. Methane fermentation of energy crops: maximum conversion kinetics and inxw biogas purification. *Biomass and Bioenergy* 5(3-4): 261-278.

Jha, A.K., Li, J., Zhang, L., Ban, Q. and Jin, Y. 2013. Komparison between wet and dry anaerobic digestions of cow dung under mesophilic and thermophilic conditions. *Advances in Water Resource and Protection* **1(2)**: 28-38

Jingura, R.M. and Rutendo, M. 2009. Optimization of biogas production by anaerobic digestion for sustainable energy development in Zimbabwe. *Renewable Sustainable Energy Reviews*.**13**:1116e20.

Köttner, M. 2002. Dry fermentation – a new method for biological treatment in ecological sanitation systems (ECOSAN) for biogas and fertilizer production from stackable biomass suitable for semiarid climates. In *Proc. 3rd International Conference on Environmental Management*, pp 16. Johannesburg, South Africa 2002.

Lema, J.M. and Omil, F. 2001. Anaerobic Treatment: A Key Technology for a Sustainable Management of Wastes in Europe. *Water Science and Technology*. **44**:133-140

Li, X. 2014. Biogas Production in China: current status and future development. http://www.epa.gov/agstar/documents/conf13 …..pdf (20 April 2014).

Li, Y. and Liew, L.N. 2011. Solid-state anaerobic digestion for energy production from organic waste. Fact Sheet. Agriculture and Natural Resources. The Ohio State University.

Li, Y., Park, S. Y., and Zhu, J. 2011a. Solid-state anaero-anaerobic digestion for methane production from organic waste. *Renewable and Sustainable Energy Reviews* (15): 821–826.

Li, Y., Zhu, J., Wan, C. and Park, S.Y. 2011b. Solid-state anaerobic digestion of corn stover for biogas production. *Transactions of the ASABE*. 54(4): 1415-1421.

Marchaim, U. 1992. *Biogas processes for sustainable development*. Food and Agriculture Organization (FAO), Viale delle Terme di Caracalla, 00100 Rome, Italy.

Ministry of New and Renewable Energy. 2014. *Family Type Biogas Plants Programme*. http://mnre.gov.in/schemes/decentralized-systems/schems-2/ (April 21, 2014)

Monet, F. 2003. An introduction to anaerobic digestion of organic wastes. http://www.biogasmax.co.uk/media/introanaerobicdigestion__073323000_1011_24042007.pdf (20 April 2014)

Pandey, A. 2003. Solid-state fermentation. *Biochemical Engineering Journal* 13: 81–84

Pavan, P., Battistoni, P., Mata-Alvarez, J. and Cecchi, F. (2000). Performance of thermophilic semi-dry anaerobic digestion process changing the feed biodegradability. *Wat. Sci. Technol*., **41(3)**: 75–81.

PLN (Perusahaan Listrik Negara). 2013. *PLN Statistics 2012*. ISSN: 0852-8179

Radwan, A.M., Sebak, H.A., Mitry, N.R., El-Zanati, E.A. and Hamad, M.A. 1993. dry anaerobic fermentation of agricultural residues. *Biomass and Bioenergy* 5(6): 495-499.

Sarnklong, C., Cone, J.W., Pellikaan, W., Hendriks, W.H. 2010. utilization of rice straw and different treatments to improve its feed value for ruminants: A review. *Asian-Aust. J. Anim. Sci*. **23**(**5**) : 680 – 692.

Schnürer, A. and Jarvis, Å. 2009. *Microbiological Handbook for Biogas Plants*. Swedish Waste Management, Malmö: 142 halaman.

Shyam, M. dan Sharma, P.K. 1994. Solid-state anaerobic digestion of cattle dung and agro-residues in small capacity field digesters. *Bioresource Technology*, 48(3): 203–207.

Singh, R. and Anand, R.C. 1994. Comparative performances of Indian small solid state and conventional anaerobic digesters. *Bioresource Technology* 47: 235-238.

SNV. 2012. Annual Report 2011: Indonesia Domestic Biogas Programme. http://www.snvworld.org/en/countries/indonesia/publications.

Song, Z., Yang, G., Han, X., Feng, Y., and Ren, G. 2013. optimization of the alkaline pretreatment of rice straw for enhanced methane yield. *BioMed Research International*. Vol. 2013: 9 pages.

Tchobanoglous, G., Theisen, H., and Vigil, S.1993. *Intergrated Solid Waste Management*. McGraw-Hill, New York.

Teghammar, A., Karimi, K., Horváth, I.S., Taherzadeh, M.J. 2012. Enhanced biogas production from rice straw, triticale straw and softwood spruce by NMMO pretreatment. *Biomass and Bioenergy* 36: 116-120.

Vindis, P., Mursec, B., Janzekovic, M., Cus, F. 2009. The impact of mesophilic and thermophilic anaerobic digestion on biogas production. *Journal of Achievements in Materials and Manufacturing Engineering* **36**(**2**): 192-198.

LAMPIRAN

Contents list available at IJRED website
Int. Journal of Renewable Energy Development (IJRED)
Journal homepage: http://ejournal.undip.ac.id/index.php/ijred

Developing A Family-Size Biogas-Fueled Electricity Generating System

Agus Haryanto[a,] Fadli Marotin[a], Sugeng Triyono[a], Udin Hasanudin[c]

[a] *Department of Agricultural Engineering, Faculty of Agriculture, the University of Lampung, Bandar Lampung, 35144, Indonesia.*

[b] *Department of Agro-industrial Technology, Faculty of Agriculture, the University of Lampung, Bandar Lampung, 35144, Indonesia.*

*

ABSTRACT. The purpose of this study is to develop a family-size biogas-fueled electricity generating system consisting of anaerobic digester, bio-filter scrubber, and power generating engine. Biogas was produced from a pilot scale wet anaerobic digester (5-m^3 capacity). The biogas was filtered using bio-scrubber column filled with locally made compost to reduce hydrogen sulfide (H_2S) content. Biogas composition was analysed using a gas chromatograph and its H_2S level was measured using a H_2S detector. A 750-W four stroke power generating engine was used with 100% biogas. Biogas consumed by the generator engine 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 1.91 m^3/day with methane content of 56.48% by volume. Bio-filter successfully reduced H_2S content in the biogas by 98% (from 400 ppm to 9 ppm). Generator engine showed good performance during the test with average biogas consumption of 415.3 L/h. Specific biogas consumption decreased from 5.05 L/Wh to 1.15 L/Wh at loads of 100 W to 700 W, respectively. Thermal efficiency increased with loads from 6.4% at 100 W to 28.1 at 700 W. The highest thermal efficiency of 30% was achieved at a load of 600 W (80% of the rated power) with specific biogas consumption of 1.07 L/Wh.

Keywords: biogas; family size; generator; electricity; bio-filter.

Article History: Received Janury 16th 2017; Received in revised form 2nd June 2017; Accepted 18th June 2017; Available online
How to Cite This Article: Haryanto, A., Marotin, F., Triyono, S., Hasanudin, U. (2017), Developing A Family-Size Biogas-Fueled Electricity Generating System. International Journal of Renewable Energy Development, 6(2), 111-118.
https://doi.org/10.14710/ijred.6.2.111-118

1. Introduction

In 2015 electrification ratio in Indonesia has reached 88.30%, increasing 3.94% from the previous year (Directorate General of Electricity, 2016). 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%) (Power in Indonesia, 2015). The implication of this condition is that around 12% of Indonesian people (about 29.8 million or around 7.46 million household) have no 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 a fact that Indonesia consists of about 13,000 islands. Assuming each unelectrified household requires electricity supply of 450 VA (the lowest of existing power rate from PLN's grid), and all power plants for supplying it operate at 80% of their name plate capacity, then it will require approximately 4.2 GW new additional power to cover just households in remote areas. The Power Supply Business Plan (RUPTL) 2015-2024 plans to develop 70,7 GW for the next 10 years (PLN, 2015). This means an average growth rate of 7 GW per annum.

Some communities (mostly in remote areas and on small islands) have generated their own electricity using small generator engines. This option, however, is not environmentally friendly. Oil fuels happen to more and more difficult and are not available in remote areas. Electricity price using this option is

* Corresponding author: agus.haryanto@fp.unila.ac.id

much more expensive. At a non-subsidized 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 (PLN, 2015).

Remote and sparsely populated areas in Indonesia will be best powered up by locally available renewable energy using economically efficient and proven technologies, such as: biomass, microhydro, or biogas power. 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 (Chynoweth *et al*., 2001). 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 (Kabir *et al*., 2013). 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. 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 (Chynoweth *et al*., 2001). Biogas has played an important role in many countries, both developed and developing countries (Abraham *et al*., 2007). Some countries such as Germany (Scheftelowitz and Thrän, 2016), China (Feng *et al*., 2012), and India (Schmidt and Dabur, 2014) have greatly gotten benefit 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 2014, BIRU had successfully installed 14,110 domestic digesters (BIRU, 2015). The biogas was used mainly for cooking. A 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 a small scale independent generator means that no grid is required. From ecological point of view, the engines fueled 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 (Mitianiec, 2012).

1.1. Biogas engine

A family size 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, power generator and irrigation pumps. Tippayawong *et al*. (2010) reported that biogas can potentially be utilized in a dual fuel operation and performed satisfactorily without any engine hardware modification and no significant problems were observed under long term engine operation. 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 frequent power black outages. 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. 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.

Spark ignited gasoline engines may be converted to be able 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, 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.

1.2. Biogas Desulfurization

Biogas contain a trace of compounds harmful for the engine, especially hydrogen sulfide (H_2S). This compound is so corrosive to metal parts in the engine, and 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 (Cherosky, 2012). Electric generation using ignition engine requires that biogas must be cleaned so that the H_2S content reaches less than 100 ppm (McKinsey-Zicari, 2003). Therefore, biogas treatment is necessary to reduce undesired compounds.

Kobayashi *et al.* (2012) noted some biological desulfurization including bio-filter processes, the bio-scrubber processes, and the process using headspace of the digesters (headspace process). McKinsey-Zicari (2003) used cow-manure compost to remove of hydrogen sulfide from biogas with H_2S removal efficiencies over 80%. Su *et al.* (2013) reported an average H_2S removal efficiency 93% in the livestock biogas using farm-scale bio-filter desulfurization system.

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 (Horikawa *et al.*, 2004):

$$H_2S\ (g) + H_2O \leftrightarrow H_2S\ (aq) \quad (4)$$

$$H_2S\ (aq) \leftrightarrow H^+ + HS^- \quad (5)$$

$$HS^- \leftrightarrow H^+ + S^{2-} \quad (6)$$

Biological desulfurization process begins with the dissociation of H_2S. In limited oxygen, the bacteria facilitates redox reactions to generate S^0 (Abatzoglou, 2009):

$$H_2S \leftrightarrow H^+ + HS^- \text{ (disosiation)} \quad (7)$$

$$HS^- + 0{,}5O_2 \rightarrow S^0 + OH^- \quad (8)$$

Utilization of biogas for electricity generation is not new technology. Family size electricity generation application using biogas, however, is hardly found. The objective of this research, therefore, is to develop a family size biogas-fueled power generation system for simple household utilization. The system should consist of at least three components, namely anaerobic digester to produce biogas, biofilter scrubber to reduce H_2S content in the biogas, and small power generating engine running with 100% biogas.

2. Materials and Methods

Figure 1 showed tools and equipment configuration used during the experiment. In short, biogas fuelled electricity power generating system consist of a digester unit to produce biogas, a desulfurization unit to reduce H_2S, and a power generating engine along with its load.

2.1. Biogas production and desulfurization

Biogas was produced from a pilot scale wet digester located at Wastewater Treatment Lab., Department of Agro-industrial Technology, the University of Lampung. The digester was locally made from fiberglass with a capacity of 5 m^3 and working volume of around 4.375 m^3. Digester base was slightly tilted in order to facilitate sludge sedimentation cleaning. Substrate used in this work was Palm oil mill effluent (POME) that was taken from cooling pond (second pond) of wastewater treatment plant of Bekri palm oil mill (Central Lampung) and was trucked to the laboratory and then stored in a 5-m^3 plastic water tank for substrate supply. Table 1 presented substrate characteristic. The substrate was circulated around for about one hour prior to loading into the digester. This step was conducted to make the substrate become homogenized. The substrate was introduced into the digester at a loading rate of 150 liter/day.

Table 1
Characteristic of substrate used in this experiment.

Characteristic	Value
Ph	4.65-4.98
COD (mg/L)	57,000-60,400
TSS (g/L)	0.23-5.44
VSS (g/L)	0.174-4.232

Biogas yield was measured using a flowmeter (ITRON ACD G1.6) and stored in a pouch (300 L capacity) for generator engine testing. Biogas piping was equipped with an expansion valve to dry the biogas. The biogas was flown through a bio-filter scrubber column filled with locally made compost to reduce H_2S content. The level of H_2S before and after purification was measured using a H_2S detector (Gastech). Main composition of biogas was analyzed using a gas chromatograph (Shimadzu GC2014) with TCD detector and zinc carbon column. Figure 1 showed tools and equipment configuration used during the experiment.

2.2. Biogas Desulfurization

Biogas was purified prior to utilization as engine fuel, using a scrubber filled with biofilter made from locally-produced compost, especially to remove H_2S. Biogas was flowed through the bottom of a vessel contained 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, we sent biofilter material to Graduate School of Environment and Information Sciences, Yokohama National University, for microbial quionone analysis. Isoprenoid quinones are lipid-soluble substances found in almost all species of organisms. Quinones play important biological role for their functions as electron carriers in respiratory chains and photosynthetic electron transport systems coupled to proton translocation (Hirashi *et al.*, 1999). Quinone analysis can be used to effectively quantify microbial community. Detailed procedure of quinone analysis has been described by Hasanudin *et al.* (2005).

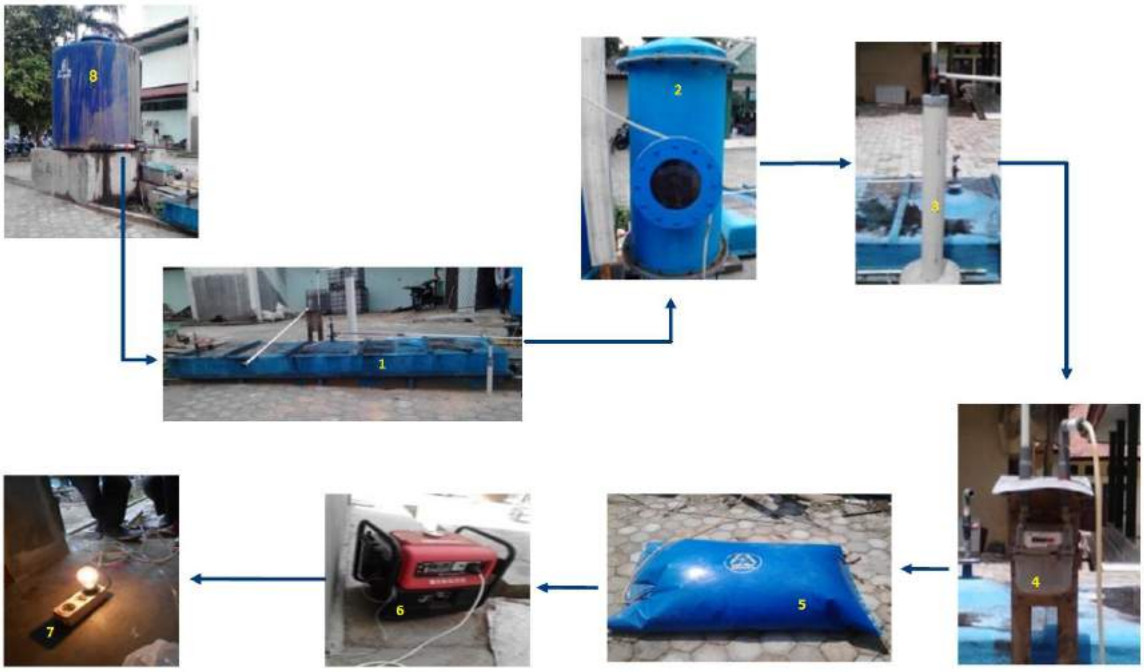


Figure 1. Tools and equipment used in the study, from biogas production to generator testing: 1. Wet anaerobic digester (5 m^3); 2. Bio-filter scrubber; 3. Pressure expansion (dryer); 4. Biogas flowmeter; 5. Biogas storage; 6. Generator engine 750-W; 7. Load; 8. Substrate storage tank (5 m^3).

2.3. Engine Testing

Generator engine was procured from PT. SWEN Bogor, Indonesia. It was a four-stroke spark ignition (SI)engine that has been modified to using biogas fuel with a capacity of 750 W (Table 2). As depicted in Figure 1, the biogas was stored in a pouch prior to using for the engine testing.

Table 2
Biogas engine specification used in the experiment.

Specification	Value
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

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 set in parallel arrangement were used as variable electric loads. 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 (Reddy *et al*., 2016):

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

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

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

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 the same gas flow meter.

3. Results and Discussion

3.1. Biogas production and desulfurization

The results showed that wet anaerobic digestion system was capable to produce biogas at a total of 1910 L/day (Table 3). Recently, Haryanto *et al*. (2017) also reported that a 6-m^3 fixed dome family size cowdung anaerobic digester with 6 head of cows was able to produce biogas at a rate of 2164 L/day. This implied that family size anaerobic digesters produce biogas at about the same amount, namely 361 L/day/m^3 to 382 L/day/m^3 of digester capacity.

Biogas composition (Table 4) 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 191.76 kcal/mole for methane or 35.82 MJ/Nm^3 (Capocelli and de Falco, 2016), the biogas has calorific value of 20.23 MJ/Nm^3.

Table 3
Biogas yield and H_2S content of biogas before and after bio-filtration.

Parameter	Unit	Value
Biogas yield	L/day	1910
H_2S content before filtration	ppm	400
H_2S content after filtration	ppm	9
H_2S removal	%	98

Table 4
Composition of biogas.

Composition	Value
Methane (CH_4)	56.48
Nitrogen (N_2)	3.33
Carbon Dioxide (CO_2)	39.31
Others	0.88

Biogas produced from anaerobic digestion mainly constituted of methane and carbon dioxide. Trace compounds in the biogas includes ammonia, water, nitrogen, and notably hydrogen sulphide (H_2S). Hydrogen sulphide is produced from the mineralization of organic compounds containing sulphur, such as proteins, by sulphate reducing bacteria. As presented in Table 3, biogas produced in this experiment had a relatively high H_2S content (400 ppm) which is harmful for the engine. Hydrogen sulfide is 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 ability to lubricate (Cherosky, 2012). Using bio-filter scrubber, the H_2S content was reduced to 9 ppm which is far below the minimum value for engine application (100 ppm). Our results showed that bio-filter scrubber effectively reduced H_2S level by 98%. This may be resulted from sulphur utilizing bacteria present in the compost used as bio-filter scrubber.

Results from quinone analysis of fresh compost used for biosrubber material is presented in Figure 2. The figure revealed that microorganisms in the compost contain quinone structures of menaquinone (MK) and ubiquinone (UQ). Menaquinone with 6 to 8 isoprene units, namely MK-6, MK-7 and MK-8 respectively, and ubiquinone with 8 and 10 isoprene units, namely UQ-8 and UQ-10, dominated quinone structure of the bacteria existing in the compost. These bacteria may take an important role in the desulfurization process through oxidation and reduction as well. Within anaerobic conditions, the MK-6 might correspond with sulfate reducing bacteria that derive energy by anaerobic respiration reducing sulfate compounds (Hasanudin *et al*., 2004). Some sulfur-reducing bacteria such as *Desulfovibrio desulfuricans, D. vulgaris* and *D. gigas* have been reported contain major menaquinone of MK-6 (Collins and Widell, 1986). Examples of sulfur-reducing bacteria with major menaquinone MK-7 include *Desulfococcus multivorans, Desulfobacter curvatus, Desulfosarcina variabilis,* and *Desulfonema limicofa* (Widdel and Bak, 1992); while *Desulfuromonas acetoxidans* and *Desulfuromonas acetexigens* having menaquinone MK-8 (Kuever *et al*., 2005). Ubiquinone with isoprene number of 8 (UQ-8) and 10 (UQ-10) may explained the existence of sulfur-oxidizing bacteria. Bacteria from *Thiobacillus* genera (*T. thioparus, T. denitrificans, T. aquaesulis*) are of sulfur-oxidizing groups those have been identified as containing major ubiquinone UQ-8; whilst *Thiobacillus novellus* and *T. perometabolis,* have quinone structure of UQ-10 (Robertson and Kuenen, 2006).

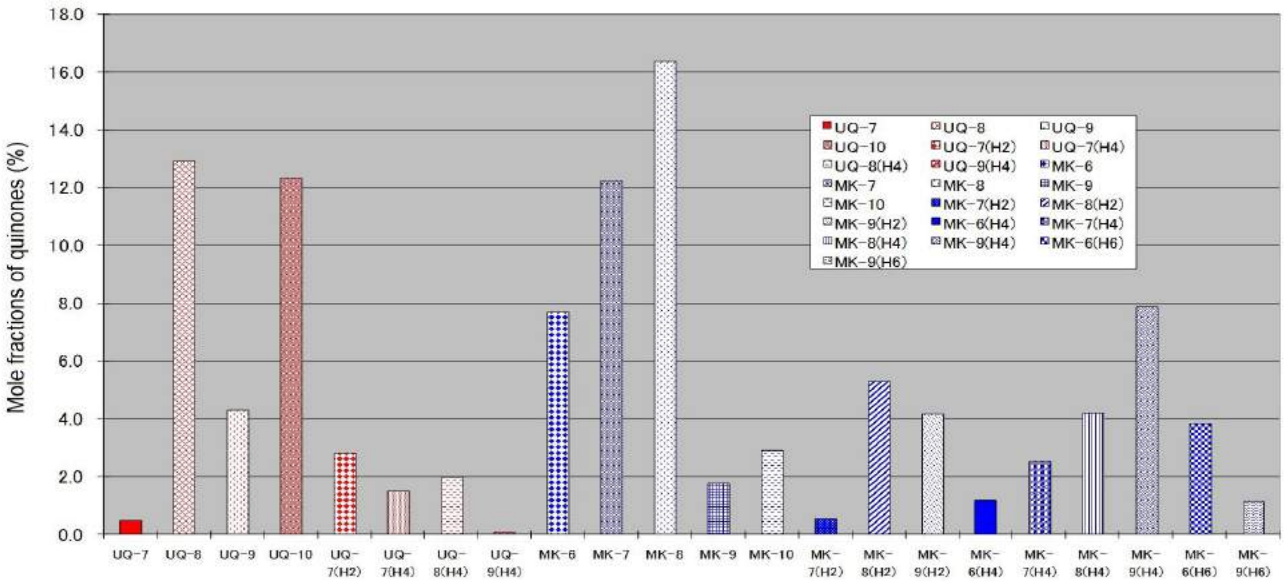


Figure 2. Microbial quinone distribution obtained from fresh compost used for biofilter scrubber.

3.2. Engine performance

Biogas utilization as fuel for generator engine 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 fuel consumption (*FC*) ranged from 400.8 L/h to 434.4 L/h biogas with average of 415.3 L (Figure 3). This implied that the digester in this experiment is able to serve for about 4-5 hours. Figure 3 also revealed that biogas consumption slightly increased linearly with load. The linear relation of biogas consumption towards load was also reported by Ehsan and Naznin (2005). They reported the biogas consumption of 1.5-kW engine was about 2.0 kg/h at a load of 800 W. Using biogas density of 1.12 kg/m^3 (Reddy *et al*., 2016), the figure corresponds to around 1786 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.

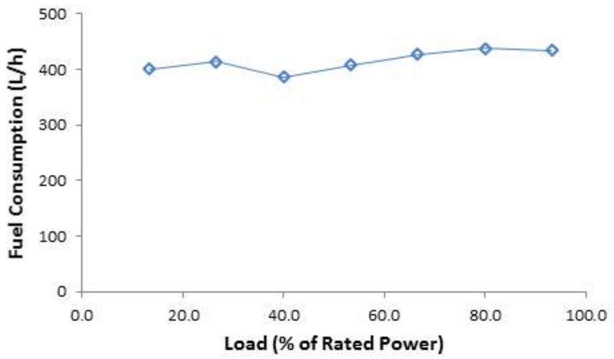


Figure 3. Relation of load and biogas consumption.

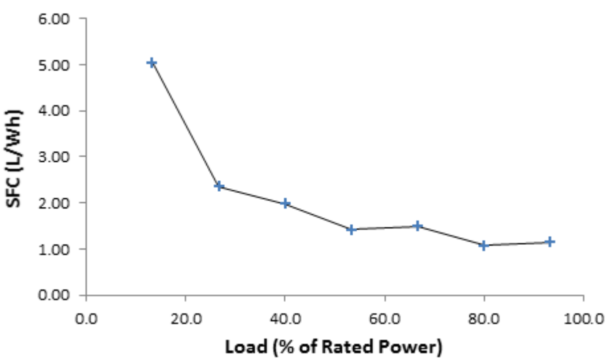


Figure 4. Effect of load on the specific biogas consumption.

Another useful parameter is the specific fuel consumption (*SFC*) which is fuel flow rate per unit of power output. It measures how efficiently an engine is using the fuel supplied to produce useful work. Figure 4 showed that *SFC* was high at low electricity load, then decreased sharply to a minimum near the rated capacity. It can also be observed that the magnitude of the electric load affected the *SFC*. Our results revealed *SFC* values ranged from 5.05 L/Wh at a load of 100 W (13.3%), sharply decreased 2.35 L/Wh at a load of 200 (26.7%) and gradually decreased to 1.15 L/Wh at a load of 700 W (93.3%). Similar pattern of the relationship between *SFC* of the engine generator and load applied to the generator was found in the work reported by others (Ehsan and Naznin, 2005; Reddy *et al*., 2016). Ehsan and Naznin (2005) studied the use of biogas with CH_4 content varies from 55% to 75% to run 1.4-kW four stroke spark ignited power generator engine. For biogas with 55% CH_4 (similar to our case), they reported specific fuel (biogas) consumption ranged from around 13900 g/kWh (around 12.4 L/Wh) at a load of 100 W (7.14%) decreased to 4034 g/kWh (around 3.36 L/kWh) at 370 W (26%) and to 2413 g/kWh (2.01 L/kWh) at 800 W (57%) of load. In general, increasing the 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%. This result was in close agreement with the work of Himabindu and Ravikhrisna (2014) which 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%.

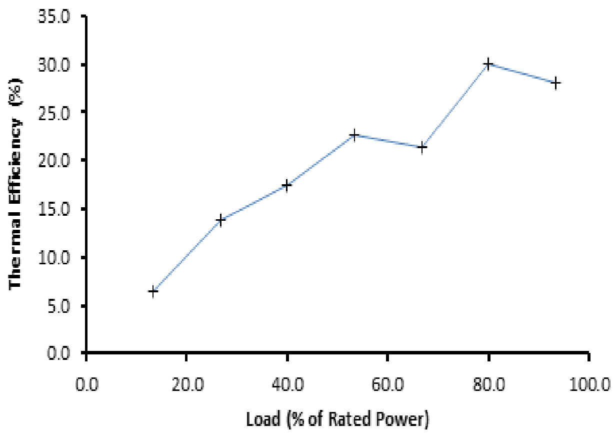


Figure 5. Effect of load on the thermal efficiency.

4. Conclusion

A family size biogas-fueled power generating system consisting of important units such as an anaerobic digester unit, a biofilter scrubber, and a four-stroke generator engine has been developed. The biofilter scrubber effectively reduced H_2S content with removal efficiency of 98%. The engine successfully ran using 100% biogas with CH_4 content of 56.48%. Average biogas consumption was 415.3 L/h in a range of 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 5.05 L/Wh at a load of 100 W and 1.15 L/Wh at a load of 700 W. The highest thermal efficiency was 30.0% and occurred at a load of 600 watt (80% load).

Acknowledgment

This work was supported by DGHE (Directorate General of Higher Education), Ministry of National Education through Strategis Nasional (STRANAS) research scheme. Contract: 419/UN26/8/LPPM/2016 (June 6, 2016). Quinone analysis was made possible thanks to the generosity of Prof. Koichi Fujie, Japan Graduate School of Environment and Information Sciences, Yokohama National University, Japan. The authors express their gratitude and appreciation to Prof. Fujie.

References

Abatzoglou, N. (2009) A review of biogas purification processes. *Biofuels, Bioproduct, Biorefinery*, **3**, 42–71.

Abraham, E.R., Ramachandran, S., Ramalingam, V. (2007) Biogas: Can it be an important source of energy? *Environmental Science and Pollution Research*, **14(1),** 67-71.

Ayade, M. and Latey, A.A. (2016) Performance and emission characteristics of biogas–petrol dual fuel in SI engine. *International Journal of Mechanical Engineering and Technology*, **7(2)**, 45-54.

BIRU (Biogas Rumah). (2015) Annual Report Indonesia Domestic Biogas Programme January – December 2014.

Capocelli, M. and de Falco, M. (2016) Enriched methane: A ready solution for the transition towards the hydrogen economy. In *Enriched Methane: The First Step Towards the Hydrogen Economy* (Editors: M. de Falco and A. Basile). Springer International Publishing, Switzerland, 1–21.

Chandra, R., Takeuchi, H., Hasegawa, T. (2012) Methane production from lignocellulosic agricultural crop wastes: a review in context to second generation of biofuel production. *Renewable Sustainable Energy Review*, **16,** 1462-1476.

Cherosky, P.B. (2012) Anaerobic digestion of yard waste and biogas purification by removal of hydrogen sulfide. *Master Thesis*. Graduate Program in Food, Agricultural and Biological Engineering, Ohio State University.

Chynoweth, D.P., Owens, J.M., Legrand, R. (2001) Renewable methane from anaerobic digestion of biomass. *Renewable Energy*, **22(3)**, 1-8.

Collins, M.D. and Widdel, F. (1986). Respiratory quinones of sulphate-reducing and sulphur-reducing bacteria: A systematic investigation. *Systematic and Applied Microbiology*, **8,** 8-18.

Directorate General of Electricity, (2016) *Statistik Ketegalistrikan 2015* (*2015 Electricity Statistic*). Ministry of Energy and Mineral Resources: 26.

Ehsan, M. and Naznin, N. (2005) Performance of a biogas run petrol engine for small scale power generation. *Journal of Energy & Environment*, **4**, 1-9.

Feng, Y., Guo, Y., Gaihe, Y., Qin, X., Song, Z. (2012) Household biogas development in rural China: On policy support and other macro conditions. *Renewable Sustainable Energy Review*, **16**, 5617-5624.

Haryanto, A., Cahyani, D., Triyono, S., Murdapa, F., and Haryono, D. Economic benefit and greenhouse gas emission reduction potential of a family-scale cowdung anaerobic biogas digester. *International Journal of Renewable Energy Development*, **6(1)**, 29-36.

Hasanudin, U., Fujita, M., Fujie, K., Koibuchi, Y. (2005) Dynamic changes in environment condition and microbial community structure in trench and flat seabed sediments of Tokyo bay, Japan. *Journal of Water Science and Technology*, **52(9)**, 107-114.

Hasanudin, U., Fujita, M., Kunihiro, T., Fujie, K., Suzuki, T. (2004) The effect of clams (*Tapes philippinarum*) on changes in microbial community structure in tidal flat sediment mesocosms, based on quinone profiles. *Journal of Ecological Engineering*, **22(3),** 185-196.

Himabindu, M. and Ravikhrisna, R.V. (2014) Performance assessment of a small biogas-fueled power generator prototype. *Journal of Scientific and Industrial Research*, **73**, 781-785.

Hiraishi, A. (1999) Isoprenoid quinones as biomarkers of microbial populations in the environment. Journal of Bioscience and Bioengineering, **88(5)**, 449-460.

Horikawa, M.S., Rossi, F., Gimenes, M.L., Costa, C.M.M., da Silva, M.G.C. (2004) Chemical absorption of H_2S for biogas purification. *Brazilian Journal of Chemical Engineering*, **21(03)**, 415 – 422.

Jawurek, H.H., Lane, N.W., Rallis, C.J. (1987) Biogas/petrol dual fuelling of SI engine for rural third world use. *Biomass*, **13(2)**, 87-103.

Kabir, H., Yegbemey, R.N., Bauer, S. (2013) Factors determinant of biogas adoption in Bangladesh. *Renewable Sustainable Energy Review*, **28**, 881-889.

Kobayashi, T., Li, Y-Y., Kubota, K., Harada, H., Maeda, T., Yu, H-Q. (2012) Characterization of sulfide-oxidizing microbial mats developed inside a full-scale anaerobic digester employing biological desulfurization. *Applied Microbiology and Biotechnology*, **93**, 847–857.

Kuever, J., Rainey, F.A. Widdel, F. Genus I. (2005) *Desulfuromonas Pfennig* and *Biebl* 1977, 306^{AL}. In *Bergey's Manual of Systematic Bacteriology. Vol. Two: The Proteobacteria. Part C: The Alpha-, Beta-, Delta-, and Epsilonproteobacteria*. (Editors: D.J. Brenner, N.R. Krieg, J.T. Staley). Springer Science+Business Media, Inc., 233 Spring Street, New York: 1005-1010.

McKinsey-Zicari, S. (2003) Removal of hydrogen sulphyde using cow manure compost. *Master Thesis*. Department of Biological and Environmental Engineering, Cornel University.

Mitianiec, W. (2012) Factors determining ignition and efficient combustion in modern engines operating on gaseous fuels. *Internal Combustion Engines* (Lejda, K. and Woś, P., editors). InTech, Janeza Trdine 9, 51000 Rijeka, Croatia: 3-34.

Power in Indonesia. (2015) *Investment and taxation guide*. 3rd edition. Available from www.pwc.com/id (January 11, 2016)

PLN. (2015) *Electricity Tariff Adjustment of December 2015*. www.pln.co.id/wp-content/uploads/2015/11/TA-Desember-2015.pdf (January 11, 2016)

Reddy, K.S., Aravindhan, S., Mallick, T.K. (2016) Investigation of performance and emission characteristics of a biogas fueled electric generator integrated with solar concentrated photovoltaic system. *Renewable Energy*, **92**, 233-243.

Robertson, L.A. and Kuenen, J.G. (2006) The Genus Thiobacillus. In *The Prokaryotes: A Handbook on the Biology of Bacteria. Vol. 5: Proteobacteria: Alpha and Beta Subclasses* (Editors: M. Dworkin, S. Falkow, E. Rosenberg, K.-H. Schleifer, E. Stackebrandt). Springer Science+Business Media, Inc., 233 Spring Street, New York. Third Edition: 812-827.

Scheftelowitz, M. and Thrän, D., 2016. Unlocking the energy potential of manure – An assessment of the biogas production potential at the farm level in Germany. *Agriculture*, **6**, 1-20.

Schmidt, T. S. and Dabur, S. (2014) Explaining the diffusion of biogas in India: a new functional approach considering national borders and technology transfer. *Environmental Economics and Policy Studies*, **16**, 171-199.

Su, J-J., Chang, Y-C., Chen, Y-J., Chang, K-C., Lee, S-Y. (2013) Hydrogen sulfide removal from livestock biogas by a farm-scale bio-filter desulfurization system. *Water Science and Technology*, **67(6)**, 1288-1293.

Surata, I.W., Nindhia, T.G.T., Atmika, I.K.A., Negara, D.N.K.P., Putra, I.W.E.P. (2014) Simple conversion method from gasoline to biogas fueled small engine to powered electric generator. *Energy Procedia*, **52**, 626-632.

Tippayawong, N., Promwungkwa, A., Rerkkriangkrai, P. (2010) Durability of a small agricultural engine on biogas/diesel dual fuel operation. *Iranian Journal of Science and Technology, Transactions B*, **34(B2)**, 167-177.

Vaghmashi, J.D., Shah, D.R., Gosai, D.C. (2014) An experimental study of petrol engine using compressed biogas as a fuel. *International Journal for Scientific Research & Development*, **2(04)**, 2321-0613.

Widdel, F. and Bak, F. (1992) Gram-negative mesophilic sulfate-reducing bacteria. In *The Prokaryotes: a handbook on the biology of bacteria: ecophysiology, isolation, identification, applications, Vol. 4.* (Editors: A. Balows, H.G. Triiper, M. Dworkin, W. Harder, and K.-H. Schleifer). 2nd ed. Springer Science+Business Media, Inc., 233 Spring Street, New York: 3370.

Biogas production from anaerobic codigestion of cowdung and elephant grass (*Pennisetum Purpureum*) using batch digester

Agus Haryanto[1,*], Udin Hasanudin[2], Chandra Afrian[1], Iskandar Zulkarnaen

[1] Agricultural Engineering Department, Faculty of Agriculture, The University of Lampung. Soemantri Brojonegoro Road, Bandar Lampung, Indonesia.
[2] Agricultural Product Technology Department, Faculty of Agriculture, The University of Lampung. Soemantri Brojonegoro Road, Bandar Lampung, Indonesia.

[*] E-mail: agus.haryanto@fp.unila.ac.id

Abstract. This study aimed at determining biogas production from codigestion of Elephant grass and cowdung using batch digester. Fresh grass was manually chopped with a maximum length of 3 cm. Chopped grass (25 kg) was perfectly mixed with fresh cowdung (25 kg). The mixture was introduced into a 220-liter batch drum digester. The substrate was diluted with water at different rates (P1 = 50 L, P2 = 75 L, and P3 = 100 L) and was stirred thoroughly. Six digesters were prepared as duplicate for each treatment. Two other digesters containing only 25 kg cowdung diluted with 25 L water were also provided as control treatment (P0). The digesters were air tightly sealed for 70 days. Observation was conducted on daily temperature, substrate pH (initial and final), TS and VS content, biogas yield and biogas composition. Results showed that final pH of grass containing substrate was in the acidic range, namely 4.50, 4.62, 6.82, whereas that of control (P0) was normal with pH of 7.30. Digester with substrate composition 25:25:100 (cowdung:grass:water) produced the highest biogas total (524.3 L). Biogas yield of codigestion, however, was much lower as compared to that of control, namely 7.35, 16.75, and 111.72 L/kg VS_r respectively for treatment P1, P2, P3. with dilution rate of 50, 75, and 100 L. Biogas produced from control digester had methane content of 53.88%. In contrast, biogas resulted from all treatments contained low methane (the highest was 31.37%). Methane yield of 39.3 L/kg TS removal was achieved from digester with dilution 100 L (P3). Mechanical pretreatment is suggested to break Elephant grass down into smaller particles prior to introducing it into the digestion process.

1. Introduction

Biogas is mixture of flammable gas produced through anaerobic digestion process of organic materials. During this process, complex organic matter such as protein, fats, and carbohydrate polymers (cellulose and starch) are first hydrolysed into monomer like amino acids, long-chain fatty acids, and sugars. These monomers are then fermented to form volatile fatty acids (lactic, propionic, and butyric acids) during acidogenesis (second step). In the third step (acetogenesis), bacteria consume these volatile fatty acids and generate acetic acid, carbon dioxide (CO_2), and hydrogen (H_2). Finally, methanogenic organisms consume the acetate, H_2, and some of the CO_2 to produce methane (CH_4) [1].

The biogas is mainly composed of CH_4 (45-70%) and CO_2 (30-45%) and traces of H_2, water vapour (H_2O), ammonia (NH_3), and hydrogen sulphide (H_2S) [1, 2]. Biogas can be used to fuel several applications, from cooking stove to generating electricity. Biogas technology is now an ecologically sound option to reduce environmental burden by decomposing organic material and producing not only energy but also good quality organic fertilizer [3, 4].

Grasses are efficient at cellulosic biomass production. Grasses give more benefit because of sequestering more carbon, requiring less tillage and consuming less fertilizers and pesticides [5], consuming less water and can be cultivated on non-arable soil [6]. In recent years, perennial grasses have been identified as leading candidates for bioenergy production including switchgrass (*Panicum virgatum* L.) in North America [7], giant miscanthus (*Miscanthus giganteus*) in Europe [8], and Elephant grass or Napier grass (*Pennisetum purpureum* Schumach) in Thailand [9–11].

Elephant grass, originating from Africa, has been successfully cultivated in Indonesia for cattle feed purposes. The plant has a high posture, wide (3 cm) and length (30-90 cm) leaves, and it is one of the highest-yielding tropical forage grasses [12]. Munasik *et al*. [13] reported that this grass can achieve a height of 259.6–289.2 cm and yield of 70–100 ton fresh biomass or 1.11–1.57 ton dry matter per hectare at 60 days old after planting. Biomass yield is influenced by age, the older the higher [11]. Field observation at PT. Great Giant Livestock, Central Lampung showed that the grass is able to be ratooned 6–7 times before replanting [14]. In addition to high yield, Elephant grass grows fast and is highly adaptive, and is easy in propagation and management [11]. The grass is also tolerant in acidic soil [13], copper [15], and drought condition [12].

Studies on biogas production by co-digestion of animal wastes with grass have attracted special interest. The grass has such high in organic substrate that it is good potential as co-substrate for biogas production. [11] Jewell *et al*. [16] examined the production of biogas from energy crops including Elephant grass with *TS* of 25-30% and obtained maximal methane production levels. Ekpenyong *et al*. [17] reported biogas production from anaerobic fermentation of ground dry elephant grass stems about 450 ml for 5 days with 4 g of substrate. An increase in biogas production by 40% was obtained by the addition of 0.01 g Urea. Ahn *et al*. [18] examined the anaerobic fermentation performance of dry grasses of switchgrass mixed with different livestock manure (pigs, poultry and dairy cattle) at 15% *TS* and thermophilic temperature (55°C). Mixture with pig manure resulted in a decomposition of VS (volatile solids) of 52.9%, higher than poultry manure mixture (9.3%) and dung cow dung (20.2%). For 62 days of residence time, the mixture of grass with pig manure produced the highest methane (0.337 L/g VS), whereas the mixture with dairy cow manure and poultry droppings respectively yielded 0.028 and 0.002 L CH_4/g VS.

Recently, Sinbuathong *et al*. [11] stated that cutting age affected methane yield with grass cut at 30 days after planting produced the highest, achieving 197 (L/kgTVS added). Total methane yield per hectare (6500 m^3/ha), however, was achieved at cutting age of 60 days. Sawanon *et al*. also reported that amount of the composition of substrate also influenced the biogas yield with the highest rate of 169 L/kg TVS added was achieved at a composition of 10:10:20 (grass:cowdung:water) [10]. Olugbemide *et al*. [19] noted that co-digestion of maize leaves and Elephant grass at a ratio of 60%:40% produced 67.3% higher biogas as compared to digestion of maize leaves alone. Evaluation of large scale biogas production using anaerobic co-digestion of pig manure and elephant grass silage for car transportation has been conducted in Thailand with a conclusion that co-digestion of pig manure and grass silage is a promising approach for improving biogas production [9].

The objective of our research is to determine the maximum biogas yield from anaerobic co-digestion of cowdung and fresh elephant grass by means of batch experiments.

2. Materials and Method

2.1. Digester preparation

Digester was prepared using plastic drum with a volume of 220 L. The lid was wrapped with rubber band as a seal to make the digester airtight. A hole on the lid of the drum was provided to deliver biogas into a storage balloon trough a plastic tube. The tube was facilitated with a stop valve to close the piping for biogas volume measurement and biogas sampling. Another hole was also made on the drum to insert a thermometer through a rubber cock.

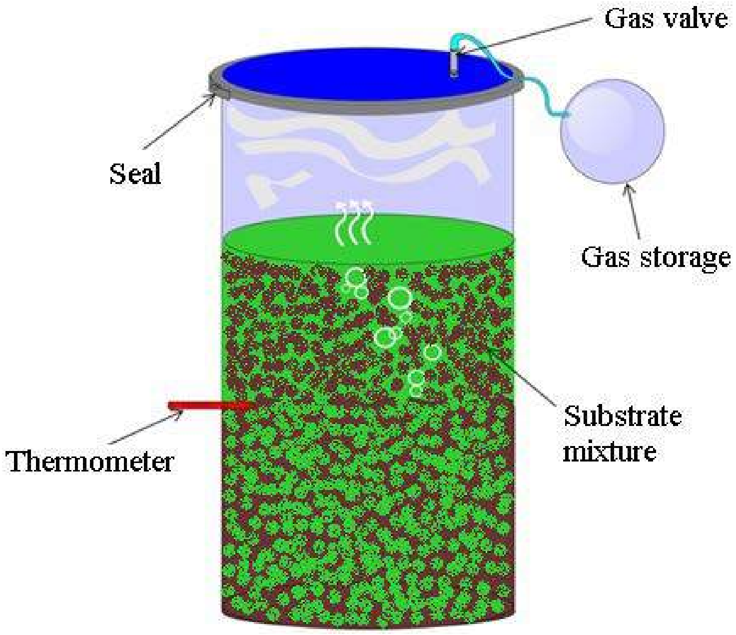


Fig. 1 A 220-L drum digester prepared for the experiment

2.2. Substrate preparation

Fresh cowdung was taken from the Department of Animal Husbandry, the University of Lampung. Elephant grass was cut at around 2 months of age from a farmer field in Pesawaran District, Lampung. Before starting the anaerobic digestion experiments, samples of grass and cowdung were analysed for total solids (*TS*), volatile solids (*VS*), and carbon (*C*) and nitrogen (*N*) contents. Table 1 shows characteristic of separate substrate.

Table 1. Fresh substrate characteristic

Characteristic	Cowdung	Elephant grass
Water content (%, wet basis)	71,32	87,03
Total solid (TS) (%, wet basis)	28,68	12,97
Ash (% TS)	25,04	14,41
Volatile solid (VS) (% TS)	74,96	85,59
C (%)	39,87	55,51
N (%)	1,42	1,81
C/N Ratio	28,08	30,62

2.3. Treatments

The fresh grass was chopped into maximum length of 3 cm. Twenty five kg of chopped grass were mixed thoroughly with cowdung at a mass ratio of 1:1. The mixture was introduced into 220-L drum digester and then diluted with water at three different levels, namely 50, 75, and 100 L. The mixture was manually stirred in order to homogenize the substrate. The lid of the drum was then closed with a rubber seal. Two drum digesters were provided for each treatment as duplicate. Two other digesters were also prepared for control treatment containing only cowdung and water with mass ratio of 1:1 and thoroughly mixed. Table 2 shows substrate composition of all treatments.

Table 2. Treatment and substrate composition

Treatment	Cowdung (kg)	Elephant grass (kg)	Water (L)	TS (%, wb)	TS (Kg)	VS (%, wb)	VS (Kg)
P0 (Control)	25	0	25	14.34	7.17	10.75	5.38
P1	25	25	50	10.41	10.41	8.15	8.15
P2	25	25	75	8.33	10.41	6.52	8.15
P3	25	25	100	6.94	10.41	5.43	8.15

2.4. Analysis and calculations

For determining the total solids (*TS*), samples with certain weight were placed in ceramic vessels and dried in a drying oven (Memmert, type UM 500, Germany) at 105 °C for 24 hours until constant weight. After cooling in the desiccators, the samples were weighed for *TS* measurement. The samples was then burnt in a furnace (Barnstead Thermolyne FB1300, USA) at 550 °C for 2 hours for volatile solids (*VS*) determination. The *VS* is determined by subtraction of the minerals content of the sample (residual ash after oxidation) from the total solids content. Total solid, *VS*, and removed VS_r are calculated by using Eq. (1) to (3), respectively:

$$TS\ (\%,\ \text{wb}) = \frac{W_2}{W_1} \times 100 \quad (1)$$

$$VS\ (\%\ \text{TS}) = \frac{W_3 - \text{Ash}}{W_3} \times 100 \quad (2)$$

$$VS_r\ (\%) = \frac{VS_{in} - VS_{out}}{VS_{in}} \times 100 \quad (3)$$

Carbon and nitrogen contents of each substrate were measured using element analyzer (Elementar Vario EL Cube, Germany). Carbon to nitrogen ratio (*C*:*N*) of the mixture is calculated using Eq. (4):

$$C:N = \frac{(C_c \times m_c) + (C_g \times m_g)}{(N_c \times m_c) + (N_g \times m_g)} \quad (4)$$

where *m* is dry mass and subscripts *c* and *g* denote cowdung and Elephant grass, respectively.

In order to evaluate process condition, temperature and pH of the substrate during experiment were also checked. Daily temperature was monitored from a thermometer inserted in the digester. The pH values were determined using pH meter (PHMETER, PH_009(I), China) for both fresh and spent substrates.

Biogas production was determined daily using simple water displacement method. Biogas composition was measured using gas chromatograph (Shimadzu GC 2014, Japan) with thermal conductivity detector (TCD) and 4-m length of shin-carbon column. Helium gas was used as carrier gas with flow rate 40 ml/min. Biogas yield (*BY*) was calculated from biogas productivity (*BP*) and VS_r by using Eq. (5):

$$BP\,(\text{L/kg}\,VS_r) = \frac{BY}{VS_r} \quad (5)$$

3. Results and Discussion

3.1. Operation condition

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.

Figure 2 shows daily temperature of the digesters. All digesters operated in the mesophilic temperature region with a range of 30.7 – 35.5 °C for P1, 28.6 – 30.5 °C for P2, 28.6 – 29.8 °C for P3, and 28.8 – 31.2 °C for P0 (control). These digesters worked at temperature higher than ambient temperature (26.4 – 28.6 °C) mainly due to exposure to sun rays. Different shading conditions also caused temperature differences among the treatments. Even though all digesters placed under the same roof overhang of a building, there were different shading conditions due to the existence of surrounding trees and buildings. This was confirmed by digester temperature in each treatment, which differed from morning to noon to afternoon. Digester temperatures at noon and afternoon are higher than that at morning. Digesters for treatment P1 showed the highest temperature than the other treatments. This was caused by digester position that was more exposed to sun radiation than the others especially during day and afternoon.

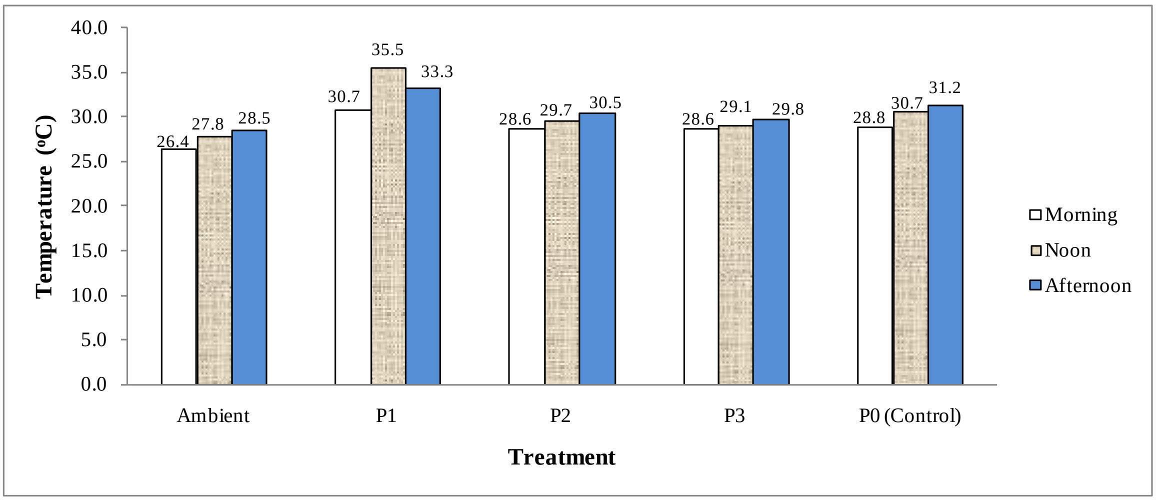


Fig. 2 Average working temperature of batch drum digesters

Figure 3 presents pH values of fresh and final substrates used in this experiment. Control treatment using only dilute cowdung shows ideal condition for anaerobic digestion process with pH values of 7.20 to 7.30, respectively from the beginning to the end. Stafford [20] reported the effects of pH upon methane production from anaerobic digestion of dairy cattle manure maintained at pH levels of 5.0 to 7.6 and found that biogas and methane production was highest at pH of 7.0. In our experiment, digesters for codigestion of cowdung and Elephant grass have initially basic pH (closes to 8) that actually in the range for good anaerobic digestion process. Abbasi *et al*. [1] noted that anaerobic degradation processes meet the requirement for both activities and cell growth of anaerobic microorganisms at pH of 5.5–8.5.

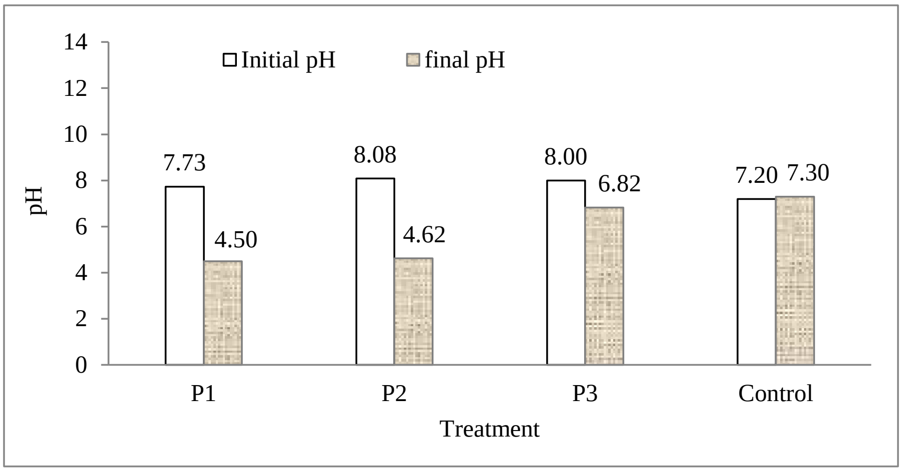


Fig. 3 Acidity of fresh and final substrate for different treatments

During the experiment lasted for 70 days, however, the pH decreases to acidic condition, especially for digesters with dilution rate of 50 L and 75 L. This indicates that dilution rate influences acidity of the substrate. More dilution resulted in better pH value in term of anaerobic process. At the end process, acidity value of digester P1 and P2 revealed acidic condition. Digester P3 showed final pH of 6.82 that closes to normal and meet the condition for anaerobic decomposition process. This asserted that dilution rate influences anaerobic decomposition process, the higher the better.

During anaerobic digestion process, substrate decomposition occurs. Table 3 presents characteristic of spent substrates for each treatment. Control digester has the highest decomposition of organic matter, achieving 50% (represented by VS_r). This value closes to the performance of family size digesters having average organic material removal of 51.32% [21]. The addition of fresh chopped Elephant grass resulted in the decrease in decomposition rate. The table showed that organic material degradation of substrate containing grass was in the range of 27.40% to 37.13%. Increase in dilution rate has improved organic material decomposition.

Table 3. Total solid (*TS*) and volatile solid (*VS*) of spent substrates

Treatment	*TS* (%, wb)	*TS* (Kg)	*VS* (%, wb)	*VS* (Kg)	VS_r (%)
P0 (Control)	13.51	6.76	5.31	2.66	49.91
P1	9.78	9.78	7.10	7.10	27.40
P2	7.50	9.38	5.27	6.59	29.74
P3	6.14	9.21	3.86	5.79	37.13

*) wet basis

3.2. Biogas production

Figure 4 presents daily biogas production resulted from different treatments. During first week the digesters showed decreasing trend of biogas production. Initially, gas was produced from respiration of the substrates due to the existence of air filling void space in the digester. The figure revealed that digesters with grass co-substrate have more extensive respiration process. Oxygen in the air has resulted oxidation reaction that produce CO_2 and H_2O. The produced gas was exerted out from the digester. By time, the amount of oxygen in the digester continuously decreased and finally vanished at which time the anaerobic process starts. The figure implies that anaerobic process started at the beginning of week two.

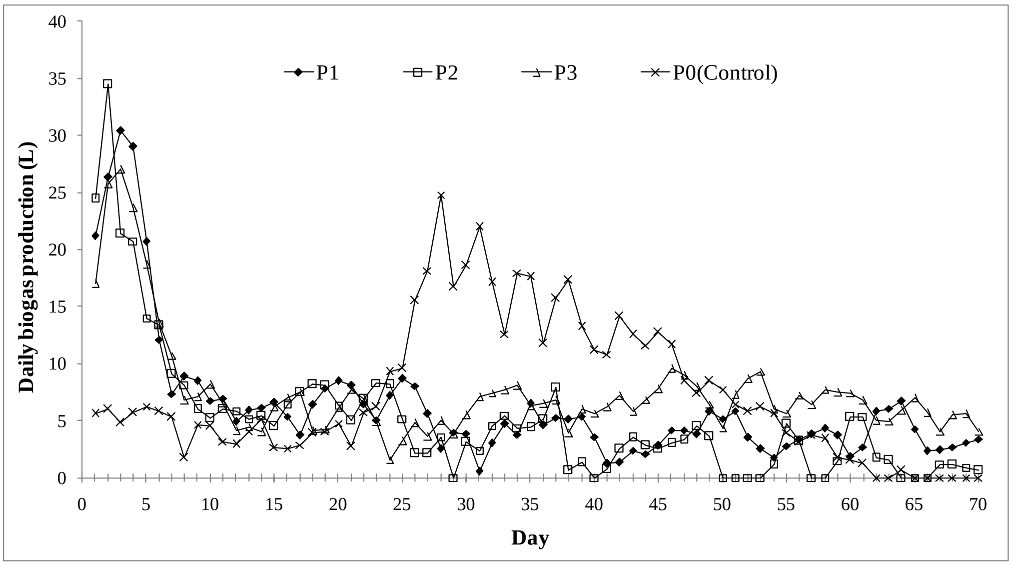


Figure 4. Daily biogas production from different treatments

Figure 4 also reveals that during anaerobic process, digester containing grass showed fluctuated biogas production at an average of 4.67 L/d for P1, 3.47 L/d for P1, and 6.16 L/d for P3. During week three, control digester (P0) demonstrated a significant increase of biogas production. From the beginning of week four, however, biogas production of P0 decreased until practically zero at day 60. On the other hand, digesters containing grass still produced biogas at significant amount, especially digester P1 and P3.

Figure 5 presents cumulative biogas production. During the first month, control digester showed the lowest cumulative biogas yield. This may related to low respiration during first week due to the absence of fresh grass in the substrate. Starting week fifth, biogas production from control digester lead but stuck at a total of 519 L after day 61. On the other hand, biogas production with grass co-digestion accumulatively increased for longer time. Digester P3 showed higher cumulative biogas yield than those of P1 and P2. Even by day 68, cumulative biogas yield of P3 (535 L) has surpassed that of P0. This indicates that addition of Elephant grass as a co-substrate is promising to improve total biogas yield. Digester P3 with dilution rate 100 L (twice of the substrate mixture) also produced higher total biogas than those of P1 (439 L) and P2 (353 L) with dilution rate 50 L and 75 L, respectively.

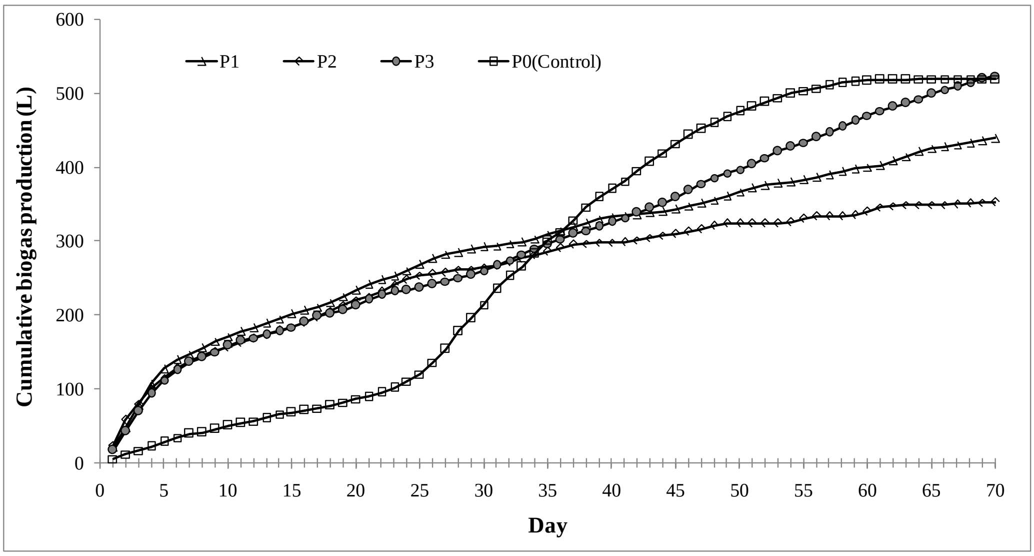


Figure 5. Cumulative biogas production from different treatment.

Figure 6 shows biogas yield on the basis of removed *VS*. Digester P0 demonstrated the highest biogas yield (422.58 L/kg VS_r). Biogas yield from grass containing digesters was substantially lower than that of P0. The figure also reveals that the degree of dilution affects the biogas yield, the higher the better. Increasing dilution (meaning reducing TS content) is possibly increase biogas yield.

3.3. Methane yield

The methane content of control digester (53.9%) was much higher as compared to those of grass containing digesters. Biogas produced from digesters containing grass had very low methane content. Methane content was measured twice, at day 30 and day 60. As depicted by Figure 7, at day 30, all digesters with grass had methane content lower than 4%. At day 60, significant increase in methane content was presented by digester P3 with 33%. No significant changes of methane content occurred at digesters P1 and P3 at day 60. This implies that acidification steps still dominate the decomposition process of organic materials. Methanogenesis step has not optimally gone on. This suggests that the presence of fresh grass has slowed down the methane formation and required longer time to favour decomposition.

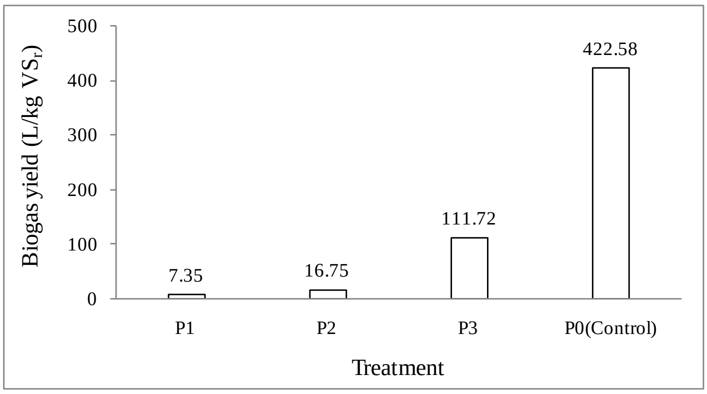


Figure 6. Biogas yield codigestion of cowdung and Elephant grass.

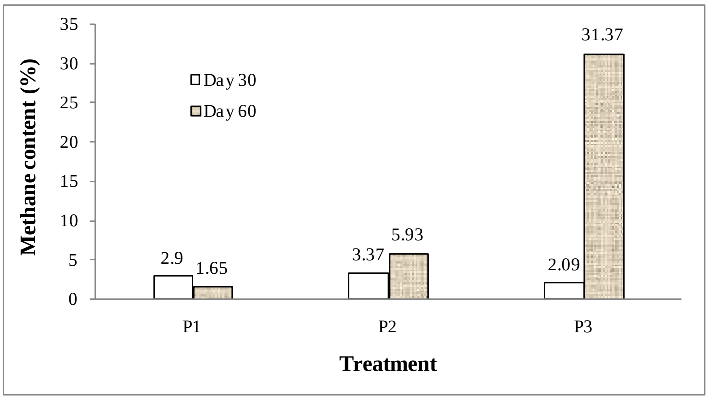


Figure 7. Methane content in the biogas produced from codigestion of cowdung and Elephant grass.

Total solid content of grass containing digesters can be a factor that causes low methane content. Figure 8 shows a relationship between *TS* and methane yield. In our experiment, the highest methane yield of 39.3 L/kg *TS* removal was achieved at *TS* content of 6.94% or 69.4 g/L. Sawannon *et al*. [10] reported high biogas yield of 116 LCH_4/kg TS_r was achieved from co-digestion of cowdung and Elephant grass at *TS* content of 22.72 g/L and 142 LCH_4/kg TS_r at *TS* content 33.08 g/L. This means that there is a room to increase methane yield by decreasing *TS* content or increasing dilution rate.

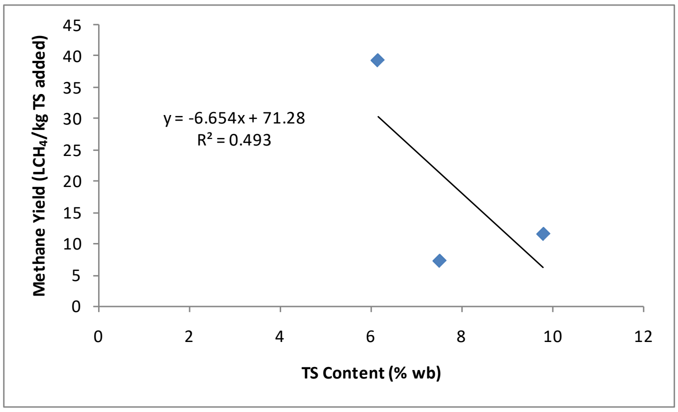


Figure 8. Effect of *TS* on the methane yield from codigestion of cowdung and Elephant grass.

The size of chopped grass can be an important key to be taken into consideration. The accessibility of microorganisms to the fermentable sugars is restricted because of complex structure of lignocellulosic materials. Reduction of particle size favours the contact between the enzymes with the substrate and reveals new zones which initially inaccessible. In this case, mechanical pretreatment to breakdown particle size of complex cellulose and to increase the substrate specific surface area available to the microorganisms, and therefore improve the biogas yield [22]. It was reported that the rate of biogas production is highly correlated to particle size and the highest biogas production from agricultural residues was obtained from raw materials of the smallest particles [23- 25]. Low biogas yield in our experiment could be resulted from particle size of grass that was barely chopped into a maximum length of 3 cm, longer than those reported sizes.

4. Conclusions

The addition of Elephant grass as co-substrate potentially improve total biogas yield. Dilution rate greatly influences biogas yield and its methane content. Digester with substrate composition 25:25:100 (cowdung:grass:water) produced the highest biogas (524.3 L) with methane content (31.37%). Methane content of biogas from co-digestion elephant grass and cowdung, however, substantially lower than that of only diluted cowdung which achieve 53.9%. Biogas yield of codigestion was 7.35, 16.75, and 111.72 L/kg VS_r respectively for treatment with dilution rate of 50, 75, and 100 L. Biogas yield from control digester 422.58 L/kg VS_r, much higher than those of grass containing digesters. Methane yield of codigestion process decreases with *TS* content. Mechanical pretreatment is suggested to break Elephant grass down into smaller particles prior to introducing it into the digestion process.

Acknowledgement

This work was financially supported by DGHE (Directorate General of Higher Education), Ministry of National Education though Strategis Nasional (STRANAS) research scheme. Contract number: 419/UN26/8/LPPM/2016 (June 6, 2016).

References

[1] Abbasi T, Tauseef S M and Abbasi S A. 2012. *Biogas Energy* (New York: Springer) pp 1–10.

[2] Gomez C D C. 2013. Biogas as an energy option: an overview. *The Biogas Handbook: Science, Production and Applications*, ed A Wellinger *et al*. (Cambridge: Woodhead Publishing Limited) pp 1–16.

[3] Higgins K T. 2008. Anaerobic gas and cash. *Food Engineering* **80(4)** 119–20.

[4] Petis M. 2006. Anaerobic digestion plant yields nutrients and power. *BioCycle* **47(12)** 61–62.

[5] Moore K J, Fales S L and Heaton E A. 2008. Biorenewable energy: new opportunities for grassland agriculture. *Multifunctional Grasslands in a Changing World*, Proc. XXI Int. Grassland Conf. vol. II, ed X Haining and H Jiehua (Guangzhou: Guangdong People's Publication House) pp 1023–30.

[6] Rodriguez C, Alaswad A, Benyounis K Y and Olabi A G. 2017. Pretreatment techniques used in biogas production from grass. *Renewable and Sustainable Energy Reviews* **68(2)** 1193-204.

[7] McLaughlin S B and Kszos L A. 2005. Development of switchgrass (*Panicum virgatum*) as a bioenergy feedstock in the United States. *Biomass Bioenerg.* **28** 515–35.

[8] Lewandowski I, Clifton-Brown J C, Scurlock J M O and Huisman W. 2000. Miscanthus: European experience with a novel energy crop. *Biomass Bioenerg.* **19** 209–27.

[9] Dussadee N, Reansuwan K and Ramaraj R. 2014. Potential development of compressed bio-methane gas production from pig farms and elephant grass silage for transportation in Thailand. *Bioresource Technol.* **155** 438-41.

[10] Sawanon S, Sangsri P, Leungprasert S and Sinbuathong N. 2017. Methane production from Napier grass by co-digestion with cow dung. *Energy Solutions to Combat Global Warming. Lecture Notes in Energy 33*, ed X-R Zhang and I Dincer (Switzerland: Springer International Publishing) chapter 7 pp 169–80.

[11] Sinbuathong N, Sangsil Y and Sawanon S. 2016. Biogas production from Napier prass at parious cutting intervals. *Energy, Transportation and Global Warming, Green Energy and Technology,* ed P Grammelis (Switzerland: Springer International Publishing) chapter 29 pp 375–85.
[12] El-Bassam N. 2010. Handbook of Bioenergy Crops: A Complete Reference to Species, Development and Applications, (London: Earthscan) pp 378–9.
[13] Munasik, Sutrisno C I, Anwar S and Prayitno C H. 2012. The growth, yield and quality of elephant grass (*Pennisetum purpureum*) specific tolerant of acid soils by mutagenesis with ethyl methane sulfonate. *Animal Production* **14(2)** 87–91.
[14] GGL (Great Giant Livestock). 2014. Personal communication, Januari 8, 2014.
[15] Liu X, Shen Y, Lou L, Ding C and Cai Q. 2009. Copper tolerance of the biomass crops Elephant grass (*Pennisetum purpureum* Schumach), Vetiver grass (*Vetiveria zizanioides*) and the upland reed (*Phragmites australis*) in soil culture. *Biotechnology Adv.* **27** 633–40.
[16] Jewell W J, Cummings R O and Richards B K. 1993. Methane fermentation of energy crops: maximum conversion kinetics and *in situ* biogas purification. *Biomass Bioenerg.* **5(3-4)** 261–78.
[17] Ekpenyong K I, Arawo J D E, Melaiye A, Ekwenchi M M and Abdullahi H A. 1995. Biogas production potential of unextracted, nutrient-rich Elephant-grass lignocelluloses. *Fuel* **74(7)** 1080–82.
[18] Ahn H K, Smith M C, Kondrad S L and White J W. 2010. Evaluation of biogas production potential by dry anaerobic digestion of switchgrass–animal manure mixtures. *Appl. Biochem. Biotechnol.* **160**: 965–75.
[19] Olugbemide A D, Imasuen A O, Oleghe P O and Efosa J O. 2012. Anaerobic co-digestion of fresh maize leaves with Elephant grass. *J. Appl. Sci. Environ. Manage*. **16(1)** 133–35.
[20] Stafford M G. 1982. *The Effect of pH on Methane Production from Dairy Cattle Manure,* Masters Thesis (USA: University of Central Florida).
[21] Haryanto A, Cahyani D, Triyono S, Murdapa F and Haryono D. 2017. Economic benefit and greenhouse gas emission reduction potential of a family-scale cowdung anaerobic biogas digester. *Int. Journal of Renewable Energy Development* **6(1)** 29–36.
[22] Rodriguez C, Alaswad A, El-Hassan Z and Olabi A G. 2017. Mechanical pretreatment of waste paper for biogas production. *Waste Management*. Inpress.
[23] Sharma S K, Mishra I M, Sharma M P, and Saini J S. 1988. Effect of particle size on biogas generation from biomass residues. *Biomass* **17** 251–63.
[24] Hills D J and Nakano K. 1984. Effects of particle size on anaerobic digestion of tomato solid wastes. *Agricultural Wastes* **10** 285–95.
[25] Xiao X, Zhang R, He Y, Li Y, Feng L, Chen C, and Liu G. 2012. Influence of particle size and alkaline pretreatment on the anaerobic digestion of corn stover. *BioResources* **8(4)** 5850–60.
[26] Hajji A and Rhachi M. 2013. The influence of particle size on the performance of anaerobic digestion of municipal solid waste. *Energy Procedia* **36** 515–20.

Organized by

ICB 2017

2nd INTERNATIONAL CONFERENCE ON BIOMASS

Toward Sustainable Biomass Utilization for Industrial and Energy Applications

CERTIFICATE

This is to certify that

Prof. Dr. Ir. Udin Hasanudin, M.T.

Has participate as the

PRESENTER

Bogor, July 24-25th 2017

Director of
Surfactant and Bioenergy Research Center
Bogor Agricultural University

Prof. Dr. Erliza Hambali

Chairman of
2nd International Conference on Biomass

Dr. Y. Aris Purwanto

Supported by

Effect of Loading Rate and Urea Addition on Biogas Yield Using Semi-Continuous Flow Anaerobic Codigestion of Cowdung and Elephant Grass (*Penisetum purpuerum*)

[1]Agus Haryanto, [1]Prasetya Adi Candra, [1]Siti Suharyatun, [1]Winda Rahmawati, [2]Udin Hasanudin, [1]Sugeng Triyono
[1] Agricultural Engineering Department, University of Lampung, Bandar Lampung, Indonesia
[2] Agro-Industrial Technology Department, University of Lampung, Bandar Lampung, Indonesia
Correspondence e-mail: agus.haryanto@fp.unila.ac.id

Abstract

The objective this research was to investigate the effect of loading rate and Urea addition on the biogas yield from anaerobic codigestion of cowdung and Elephant grass. Experiment was conducted using 25-L working volume semi-continuous digester. Elephant grass was minced to about 1 cm length and was mixed with cowdung at total solid ratio 3:1 (cowdung to grass). The substrate was then diluted with water to make a total solid content of the mixture around 10%. The experiment was conducted with four treatments, namely loading rate 0.625 L/d (P1), loading rate 1.25 L/d (P2), loading rate 0.625 L/d with Urea addition 1.25 g/L (P3), and loading rate 1.25 L/d with Urea addition 1.25 g/L (P2). Results showed that loading rate and Urea addition influence biogas yield. The highest biogas and methane yield (161.8 L_{biogas}/kg $VS_{removed}$ and 28.8 L_{CH4}/kg $VS_{removed}$) was collected from digester P3.

Keywords: biogas, cowdung, Elephan grass, loading rate, semi-continuous

INTRODUCTION

Biogas is a renewable fuel produced from anaerobic digestion process of organic materials which goes on through four steps, namely hydrolysis, acidogenesis, acetogenesis, and methanogenesis (Haryanto *et al*., 2017). Depending on the substrate type, the biogas is commonly composed of CH_4 (45-70%) and CO_2 (30-45%) and traces of H_2, water vapour (H_2O), ammonia (NH_3), and hydrogen sulphide (H_2S) (Abasi *et al*., 2012). Biogas can be used for several applications, from cooking stove to generating electricity.

Recently, perennial grasses such as switchgrass (Panicum virgatum L.), giant miscanthus (Miscanthus giganteus), and Elephant grass or Napier grass (Pennisetum purpureum Schumach) have been identified as good substrate for biogas (Lewandowski *et al*., 2000; Sawanon *et al*., 2017; Sinbuathong *et al*., 2016., Wilkie *et al*., 1986; Janejadkarn and Chavalparit, 2014). More than 50% of agricultural biogas plants in Germany and Austria used grass silage as their feedstock (Prochnow *et al*., 2009). Cadavid-Rodríguez and Bolaños-Valencia (2016), suggested that even though more research is required, fresh grass can be employed as feedstock for anaerobic digestion in a tropical countries by using an economical and simpler operation.

Elephant grass has a high posture and is one of the highest-yielding tropical forage grasses. Elephant grass can be harvested 5-6 times per year with a 45-60 days harvest period producing 375-635 tonne per hectare per year (Satjaritanun *et al*., 2016). In addition to high yield, Elephant grass grows fast and is highly adaptive, and is easy in propagation and management (Sinbuathong *et al*., 2016), tolerant in acidic soil (Munasik *et al*., 2013), copper (Liu *et al*., 2009), and drought condition (El-Bassam, 2010). Elephant grass has such high in organic substrate that it is good potential as co-substrate for biogas production.

Studies on producing biogas using E. grass have been reported long time back by Jewell *et al*. (1993) who obtained maximal methane production levels from energy crops including Elephant grass with TS of 25-30%. Recently, codigestion of E. grass with cowdung and other wastes has attracted special interests. For example the work of Sawanon *et al*. (2017) with cowdung reported that composition of substrate also influenced the biogas yield with the highest rate of 169 L/kg TVS added was achieved at a composition of 10:10:20 (grass:cowdung:water). Other works were also reported with chicken manure (Wilawan *et al*., 2014), food waste (Saitawee *et al*., 2014), and slaughterhouse waste water (Sittijunda, 2015).

Like other biomass, grass has high C/N ratio so that external nitrogen source is required to bring C/N ratio to the ideal values for anaerobic digestion. Ekpenyong *et al*. (1995) reported biogas production from anaerobic fermentation of ground dry elephant grass stems and noted that an increase in biogas production by 40% was obtained by the addition of 0.01 g Urea. For continuous fed anaerobic digesters, loading rate is important factor to be considered.

Most family scale biogas digesters in rural areas use cowdung as substrate with semi continuous loading mode. Therefore, the objective of our research is to determine the effect of loading rate and Urea addition on biogas yield from anaerobic co-digestion of cowdung and fresh Elephant grass using semi continuous fed digester.

RESEARCH METHOD

Digester preparation

Biogas production was carried out using lab scale self-designed 36-L semi continuous anaerobic digester. 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. A hole was made on the digester to deliver biogas into a storage balloon trough a plastic tube. The tube was facilitated with a stop valve to close the piping for biogas volume measurement and biogas sampling. Four digesters with working volume of 25-L each were set up for this experiment.

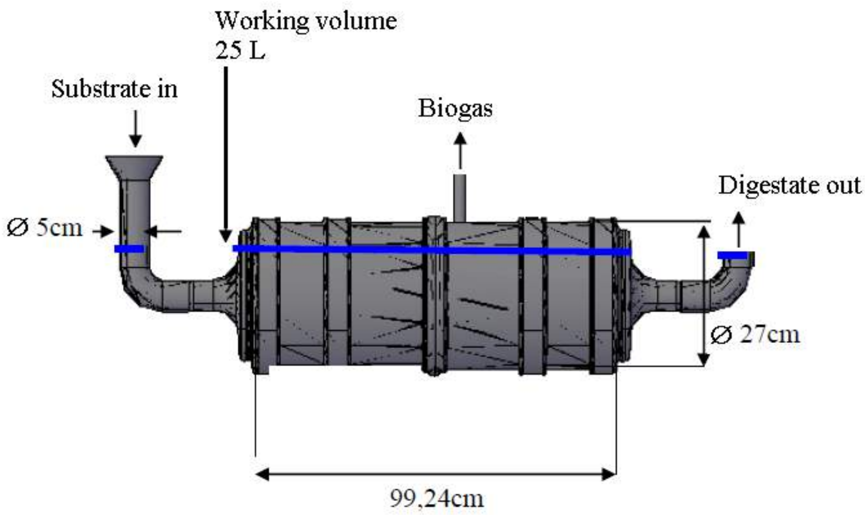


Figure 1: A Self-Designed Semi Continuous Digester Prepared for the Experiment

Substrate Preparation

Fresh cowdung, taken from the Department of Animal Husbandry, the University of Lampung, was used as microbial seed source. Elephant grass (Figure 2) was cut at around 2 months of age from a farmer field in Pesawaran District, Lampung. Fresh grass was chopped using a feed chopper into a maximum length of 1 cm. Before starting the anaerobic digestion experiments, samples of grass and cowdung were analysed for total solids (TS), volatile solids (VS), and carbon (C) and nitrogen (N) contents. Table 1 shows characteristic of each substrate. Urea granule with nitrogen content of 46% was purchased from local supplier and was used as external nitrogen source.

Figure 2: Elephant Grass: in thw field (left) and chopped (right)

Table 1. Fresh Substrate Characteristic

Characteristic	Cowdung	Elephant grass
Water content (%, wet basis)	83.02	82.71
Total solid (TS) (%, wet basis)	16.98	17.29
Ash (% TS)	20.83	11.76
Volatile solid (VS) (% TS)	79.17	88.24
C (%)	39.87	55.51
N (%)	1.42	1.81
C/N Ratio	28.08	30.62

Treatments and Loading

The experiment was designed with TS content of about 10% of substrate mixture and TS ratio of 1:3 (grass:dung). With digester working volume of 25 L, and referring to Table 1, then the composition of substrate for each digester is equivalent to 6.73 kg cow dung, 4.96 kg fresh grass, and the water (13.30 kg). Initially, chopped grass and cow dung were thoroughly mixed. For this experiment we prepared four packages of substrate mixture. Two packs of the substrate mixture were diluted with tap water until the total volume reaches 25 L. Both packets were introduced into the digester with a label P1 and P2. The other two packages were also mixed with the same water, but into the water it first has been diluted urea at a rate of 1.25 g/L (Malik *et al*., 1987). Substrate packages with additional urea were introduced into digester P3 and P4.

The four digesters were left for 3 days to stabilize. Starting from the fourth day, each digester was fed with matching substrate at a loading rate of 0.625 L/d for digesters P1 and P3, and a loading rate of 1.25 L/d for digesters P2 and P4. At the same time, an equal amount was removed from the digester outlet making the substrate volume in the digester remain constant 25 L. Table 2 shows substrate compositions along with their TS, VS, and C/N ratios. Substrate with a required composition was thoroughly stirred to homogenize the mixture.

Table 2. Treatment and Substrate Composition

Treatment	TS_{in} (% wb)	VS_{in} (% TS)	Urea (kg)	C/N Ratio	LR (kg/d)	OLR (kg VS/m^3.d)	HRT (d)
P1	10.2	81.4	0	28.7	0.625	2.082	40
P2	10.2	81.4	0	28.7	1.250	4.164	20
P3	10.2	81.4	0.031	20.9	0.625	2.082	40
P4	10.2	81.4	0.031	20.9	1.250	4.164	20

Analysis and Calculations

For determining the total solids (TS), sample with certain weight (W_1) was placed in ceramic vessels and dried in a drying oven (Memmert, type UM 500, Germany) at 105°C for 24 hours until constant weight. After cooling in the desiccators, the sample was weighed (W_2) for TS measurement. Some of this sample (W_3) was taken and burnt in a furnace (Barnstead International model FB1310M-33, USA) at 550°C for 3 hours for volatile solids (VS) determination. Total solid and VS are calculated by using Eq. (1) and (2), respectively:

$$TS\ (\%,\text{wb}) = \frac{W_2}{W_1}\times 100 \quad (1)$$

$$VS\ (\%\ \text{TS}) = \frac{W_3 - \text{Ash}}{W_3}\times 100 \quad (2)$$

In order to evaluate the digester efficiency, the destroyed or removed VS (VS_r) was calculated using equation developed by Koch (2015):

$$VS_r\ (\%) = \left[1 - \frac{VS_{out}(1 - VS_{in})}{VS_{in}(1 - VS_{out})}\right]\times 100 \quad (3)$$

Carbon and nitrogen contents of each substrate were measured using element analyzer (Elementar Vario EL Cube, Germany). Carbon to nitrogen (C:N) ratio of the mixture is calculated using Eq. (4):

$$C:N = \frac{(C_c \times m_c) + (C_g \times m_g)}{(N_c \times m_c) + (N_g \times m_g) + 0.46 \times m_{Urea}} \quad (4)$$

where m is dry mass and subscripts c and g denote for cowdung and Elephant grass, respectively.

In order to evaluate process condition, temperature and pH of the substrate during experiment were also checked. Daily temperature was monitored from a thermometer inserted in the digester. The pH values were determined using pH meter (PHMETER, PH_009(I), China) for both fresh and spent substrates.

Biogas production was determined daily using simple water displacement method. Biogas composition was measured using gas chromatograph (Shimadzu GC 2014, Japan) with thermal conductivity detector (TCD) and 4-m length of shin-carbon column. Helium gas was used as carrier gas with flow rate 40 ml/min. Biogas yield (BY) was calculated from biogas production (BP) and VS_r by using Eq. (5):

$$BY\,(\text{L/kg}\,VS_r) = \frac{BP}{VS_r} \quad (5)$$

RESULTS AND DISCUSSION

Process Condition

Process condition is evaluated from the substrate acidity (pH), working temperature, and degradation efficiency.

Substrate Acidity (pH)

Figure 3 showed daily pH of the four digesters with different treatment. The pH values decreased for the first four days and then increased till the day 20. Since then the pH values were almost stable for each treatment with average values of 6.3 for P1, 6.4 for P2, and 6.6 for P3 and P4. The Urea addition may cause the difference of the pH. Treatments with Urea addition (P3 and P4) resulted in a higher pH value than no Urea addition treatments (P1 and P2). The addition of Urea has increased the pH value. Urea contains 46% of nitrogen. The nitrogen will accumulate in form of ammonia (NH_4) that increasing substrate pH in the digester. The pH values of all treatments, however, are in the range of acceptable condition for anaerobic process. Abbasi *et al.* [1] noted that anaerobic degradation processes meet the requirement for both activities and cell growth of anaerobic microorganisms at pH of 5.5–8.5.

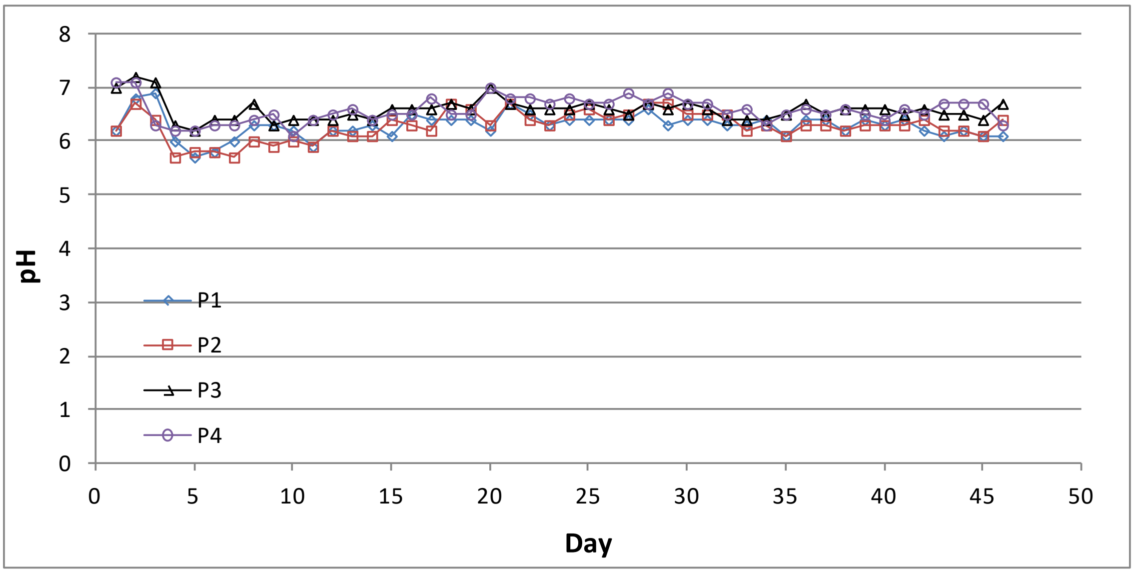


Figure 3: Daily pH values of biogas process for different treatments

Another factor affecting digester pH is loading rate. According to Babaee *et al.* (2011), high loading rate decreases pH and biogas production, but increases CO_2 content. Treatments P3 and P4 have pH that is close to the optimum pH requirement as compared to treatments P1 and P2.

Temperature

Digester temperature influnces the microorganism performance during decomposition process of organic materials. Specific microorganisms will not stand at a condition where the temperature is too high or to low. For mesophilic bacteri, the ideal temperatures are in the range of 25–40°C (Moset *et al.*, 2015). Figure 4 reveals that all digesters work with temperature range of 26–32°C with average temperature of 29.0 (P1 and P2), 29.3 (P3 and P4). This implies a good condition for mesophilic microorganisms in decomposing organic material. The average digester temperatures are little higher than average ambient temperature (28.9) because the overall biogas reaction is slightly exothermic (Marchaim, 1992).

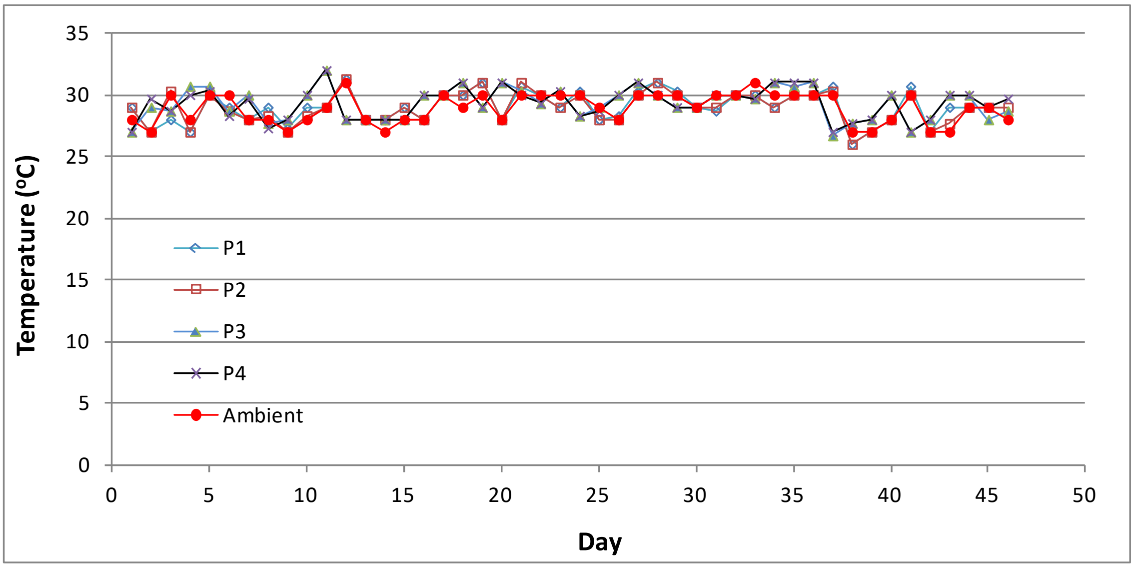


Figure 4: Daily temperature of digesters for different treatments and ambient

TS and VS Removal

During anaerobic digestion process, substrate decomposition occurs. Table 3 presents TS, VS of spent substrates and their removal efficiencies for each treatment. It can be observed that loading rate and urea addition influence digestion process efficiency.

Table 3. VS removal

Treatment	VS_{in} (% TS)	VS_{out} (% TS)	VS_r (%)
P1	81.4	74.4	33.76
P2	81.4	74.9	31.98
P3	81.4	74.6	33.06
P4	81.4	74.6	33.06

Biogas Yield

Figure 5 presents daily biogas production that is averaged using a 5-day moving average. We can observe that initially the daily gas production decreases with time. In the early period, biogas is more dominated by respiration reaction due to the presence of air occupying the empty space inside the digester. Oxygen in the air has resulted oxidation reaction that produce CO_2 and H_2O. The gas of this reaction gradually decreases with the depletion of oxygen in the digester, and finally exhausts at which anaerobic reaction predominates. We also observes that digesters with Urea addition requires a shorter period of decreasing biogas production (about 2 weeks), whereas digesters without Urea addition takes longer period (3 weeks). Kaur *et al.* (2016) noted that hydrolysis is the rate-limiting step in anaerobic digestion for high lignocellulosic substrates like Napier grass. Therefore, pretreatment process is required prior to anaerobic digestion of Napier grass to reduce structural and compositional impediments of lignocellulosic biomass and and to improve solubilization of the lignocellulosic biomass and subsequent enhancement in biogas productivity (Carvalho *et al.*, 2016; Rekha and Aniruddha, 2013).

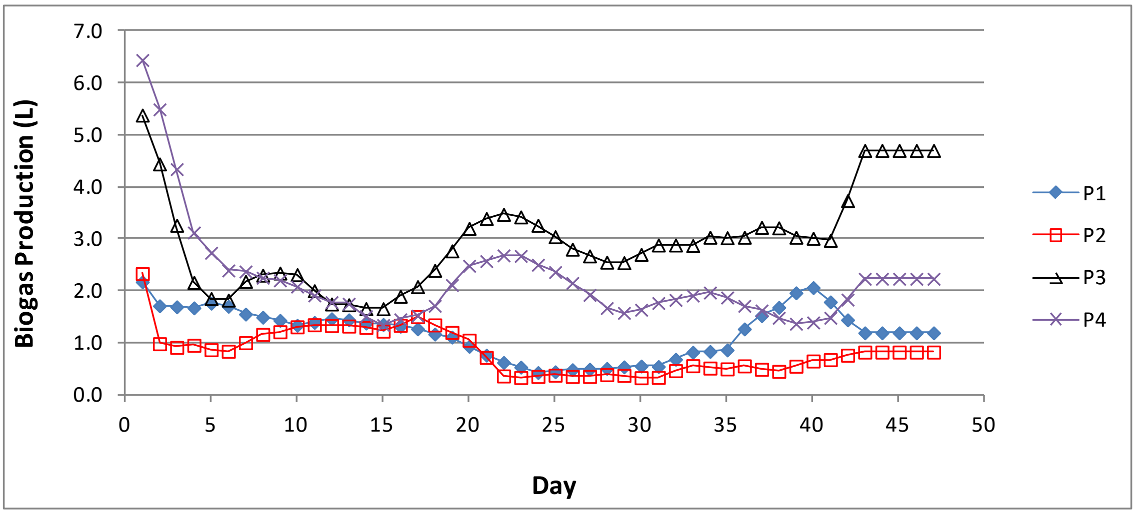


Figure 5: Biogas production for different treatments using 5-day moving average.

Figure 6 shows cumulative biogas production for 47 days of observation for all four treatments with a total value of 54.14, 42.36, 130.82, and 109.32 L respectively for treatment P1, P2, P3, and P4. We also calculate biogas yield as per kg VS added and the results are 65.57, 27.07, 161.79, and 67.60 L/kg VS_{in} respectively for P1, P2, P3, and P4. The results are also inserted in Figure 4. We can observe that both loading rate and Urea addition as well influence the total biogas yield. Increasing loading rate has resulted in lower biogas yield. This is in line with the findings of other researchers who concluded as the organic loading rate was increased, the degradation of organic material and biogas yield decreased (Babaee and Shayegan, 2011; Mel *et al.*, 2015; Adebayo *et al.*, 2015). The addition of Urea also resulted in positive effect on biogas yield. Liu *et al.* (2015) concluded that Urea addition of 2% was able to increase cumulative methane yield from giant reed grass ensilage by 18% higher as compared to that of fresh grass. Budiono *et al.* (2013) also reported that urea addition increased biogas formation by 52.47% greater than that of control treatment (without urea addition). In our experiment, the combination treatment of low loading rate and Urea addition (P3) produces the highest total biogas yield (130.82 L).

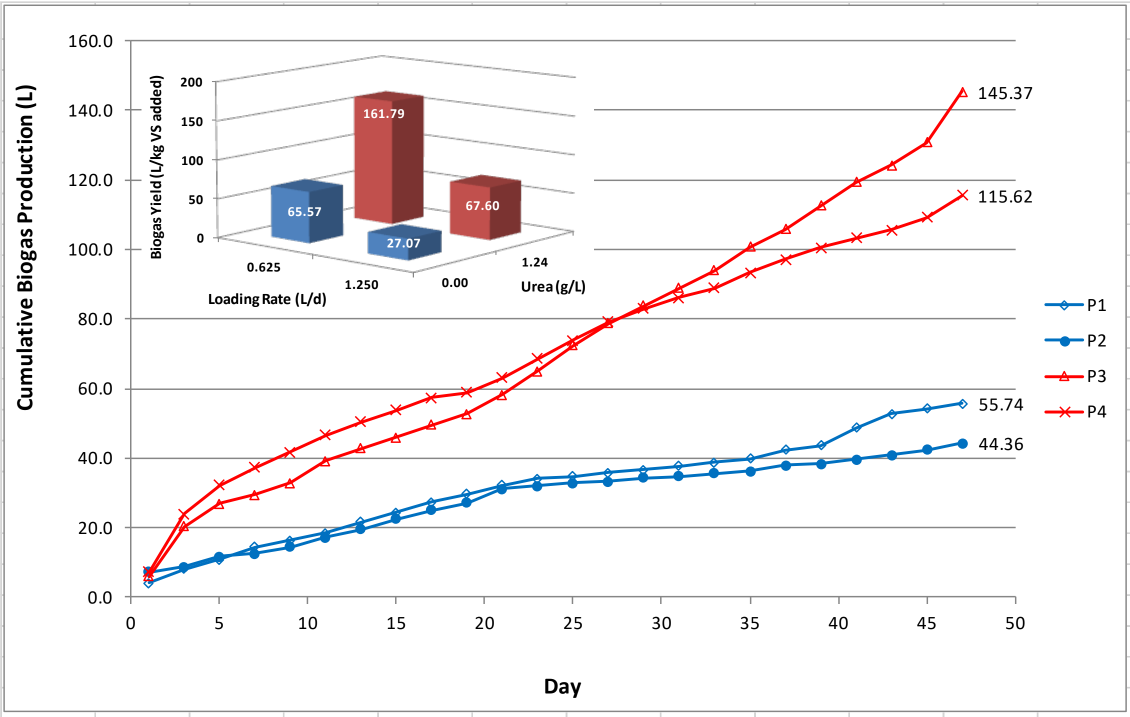


Figure 6: Accumulation of biogas production for different treatments (Effect of loading rate and Urea addition on biogas yield is inserted).

Methane Yield

Biogas analysis on day-39 revealed that methane content was relatively low, namely 10.23%, 8.06 %, 17.77%, and 22.35%, respectively for P1, P2, P3, and P4, as presented in Figure 7. The low methane content can be resulted of the presence Elephant grass that was mixed in fresh condition. According to Rekha and Aniruddha (2013), Elephant grass contains complex macromolecules that are dificult to be decomposed directly by microorganisms. Microorganisms need longer time to degrade the grass, especially at hydrolysis phase. This has caused a retardation on methane formation. As presented in Figure 7 we also calculate methane yield per kg VS added and the results are 6.71, 2.18, 28.75, and 15.11 L/kg $VS_{removed}$ respectively for P1, P2, P3, and P4.

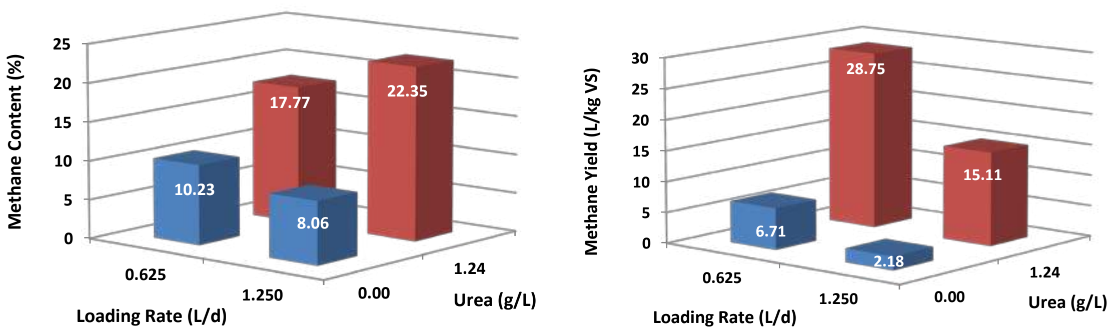


Figure 7: Effect of loading rate and urea addion on methane content (left) and methane yield (right).

When we compare our result on biogas yield with other value published in journals, we find that our result was very promising. Table 4 presents biogas yield we collected from some references. Different organic loading rate (OLR) can be a factor that make our result is substansially lower than other works. Our study used OLR of 2.08 kg VS/m^3.d, while they used only 0.5 kg VS/m^3.d Sawanon *et al*. (2017) and 0.57 kg VS/m^3.d (Janejadkarn *et al*., 2014).

Table 4. Comparison of Biogas and Methane Yield from Codigestion of E. grass in Semi Continuous Digester.

Substrate	**Biogas Yield (L/kg $VS_{removed}$)**	**CH_4 Yield (L/kg $VS_{removed}$)**	**Reference**
Cowdung and E. grass, TS ratio 75:25, total TS 10.23%, working volume 25 L, OLR 2.08 kg VS/m^3.d	161.8	28.8	This work
E. grass, cowdung, water (10:10:80), working volume 5 L, OLR 0.70 kg VS/m^3.d	169	252	Sawanon *et al*., 2017
E. grass with inoculum from anaerobic digester, working volume 5 L, OLR 0.57 kg VS/m^3.d	529	242	Janejadkarn *et al*., 2014

CONCLUSION

From the above discussion we can derive some conclusions that Elephant grass is promising as a co-substrate for producing biogas through anaerobic digestion using semi continuos digester. Loading rate as well as Urea addition influence biogas and methane yield. Urea addition positively improve biogas production as well as methane content fro codigestion of Elephant grass and cowdung using semi continous digester. On the other side, increasing loading rate of substrate mixture produce in lower biogas yield. Loading rate of 0.625 substrate mixture combined with Urea addition of 1.25 g/L substrate producing the highest biogas and methane yield (161.8 L_{biogas}/kg $VS_{removed}$ and 28.8 L_{CH4}/kg $VS_{removed}$). Pretreatment for fresh grass is required to accelerate hydrolysis step.

ACKNOWLEDGEMENT

This work was financially supported by DGHE (Directorate General of Higher Education), Ministry of National Education though Strategis Nasional (STRANAS) research scheme. Contract number: 419/UN26/8/LPPM/2016 (June 6, 2016).

REFERENCES

Abbasi, T., Tauseef, S. M. and Abbasi, S. A. (2012). *Biogas Energy*. New York: Springer.

Adebayo, A.O., Jekayinfa, S.O. and Linke, B. (2015). Effects of organic loading rate on biogas yield in a continuously stirred tank reactor experiment at mesophilic temperature. *British Journal of Applied Science & Technology*, Vol. 11(4), 1–9.

Babaee, A. and Shayegan, J. (2011). Effect of organic loading rates (OLR) on production of methane from anaerobic digestion of vegetables waste. *World Renewable Energy Congress*. 8–13 May, 2011, Linköping, Sweden, 411–417.

Budiyono, Syaichurrozi, I. and Sumardiono, S. (2013). Biogas production from bioethanol waste: the effect of pH and urea addition to biogas production rate. *Waste Technology*, Vol. 1(1), 1–5.

Cadavid-Rodríguez, L.S. and Bolaños-Valencia, I.V. (2016) Grass from public green spaces an alternative source of renewable energy in tropical countries. *Revista Ion*, Vol. 29(1), 109–116.

Carvalho, A.R., Fragoso, R., Gominho, J., Saraiva, A., Costa, R., and Duarte, E. (2016). Water-energy nexus: Anaerobic co-digestion with elephant grass hydrolyzate. *Journal of Environmental Management*, Vol. 181, 48–53.

El-Bassam, N. 2010. *Handbook of Bioenergy Crops: A Complete Reference to Species, Development and Applications*, (London: Earthscan), 378–379.

Haryanto, A., Marotin, F., Triyono, S., Hasanudin, U. (2017). Developing a family-size biogas-fueled electricity generating system. *International Journal of Renewable Energy Development*, Vol. 6(2), 111–118.

Janejadkarn, A. and Chavalparit, O. (2014). Biogas production from Napier grass (Pak Chong 1) (*Pennisetum purpureum* × *Pennisetum americanum*). *Advanced Materials Research*, Vol. 856, 327–332.

Jewell, W.J, Cummings, R.O. and Richards, B.K. (1993). Methane fermentation of energy crops: maximum conversion kinetics and in situ biogas purification. *Biomass & Bioenergy*, Vol. 5(3-4), 261–278.

Kaur, K., Urmila, G.P. and Milky, G. (2016). Comparative analysis of fodder beet and Napier grass PBN233 as a better substrate for biogas production. *Indian Journal of Science and Technology*, Vol. **9(3)**, 0974–5645.

Koch, K. (2015). Calculating the degree of degradation of the volatile solids in continuously operated bioreactors. *Biomass & Bioenergy*, Vol. 74, 79–83.

Lewandowski, I., Clifton-Brown, J.C, Scurlock, J.M.O. and Huisman, W. (2000). Miscanthus: European experience with a novel energy crop. *Biomass Bioenergy*, Vol. 19, 209–227.

Liu, S., Ge, X., Liew, L.N., Liu, Z., and Li, Y. (2015). Effect of urea addition on giant reed ensilage and subsequent methane production by anaerobic digestion. *Bioresource Technology*, Vol. 192, 682–688.

Liu, X., Shen, Y., Lou, L., Ding, C. and Cai, Q. (2009). Copper tolerance of the biomass crops Elephant grass (*Pennisetum purpureum* Schumach), Vetiver grass (*Vetiveria zizanioides*) and the upland reed (*Phragmites australis*) in soil culture. *Biotechnology Adv*., Vol. 27, 633–40.

Malik, R. K., Singh, R. and Tauro, P. (1987). Effect of Inorganic Nitrogen Supplementation on Biogas Production. *Biological Wastes*, Vol. 21, 139–142.

Marchaim, U. (1992). *Biogas Processes for Sustainable Development*. FAO (Food and Agriculture Organisation), Rome.

Mel, M., Suhuli, N.M., Avicenna, Ihsan, S.I., Ismai, A.F. and Yaacob, S. (2015). Effect of organic loading rate (OLR) of slurry on biogas production quality. *Advanced Materials Research*, Vol. 1115, 325–330.

Moset, V., Poulsen, M., Wahid, R., Højberg, O. and Møller, H.B. (2015). Mesophilic versus thermophilic anaerobic digestion of cattle manure: methane productivity and microbial ecology. *Microbial Biotechnology*, Vol. 8(5), 787–800.

Munasik, Sutrisno, C.I., Anwar, S. and Prayitno, C.H. (2012). The growth, yield and quality of elephant grass (*Pennisetum purpureum*) specific tolerant of acid soils by mutagenesis with ethyl methane sulfonate. *Animal Production*, Vol. 14, 87–91.

Prochnow, A., Heiermann, M., Plöchl, M., Linke, B., Idler, C., Amon, T., and Hobbs, P.J. (2009). Bioenergy from permanent grassland – A review: 1. Biogas. *Bioresource Technology*, Vol. 100, 4931–4944.

Rekha, B.N. and Aniruddha, B.P. 2013. Performance Enhancement of Batch Anaerobic Digestion of Napier Grass by Alkali Pre-Treatment. *International Journal of ChemTech Research*, Vol. 5(2), 558–564.

Saitawee, L., Hussaro, K., Teekasap, S. and Cheamsawat, N. (2014). Biogas proction from anaerobic co-digestion of cow dung and organic wastes (Napier Pak Chong I and food waste) in Thailand: temperature effect on biogas product. *American Journal of Environmental Science*, Vol. 10(2), 129–139.

Satjaritanun, P., Khunatorn, Y., Vorayos, N., Shimpalee, S., Bringley, E. (2016). Numerical analysis of the mixing characteristic for Napier grass in the continuous stirring tank reactor for biogas production. *Biomass and Bioenergy*, Vol. 86, 53–64.

Sawanon, S., Piyanee, S., Suchat, L. and Nusara, S. (2017). Methane production from Napier grass by co-digestion with cow dung. In *Energy Solutions To Combat Global Warming*, ed. X-R. Zhang and I. Dincer (Switzerland: Springer International Publishing), Vol. 33(7), 169–180.

Sawasdee, S. and Nipon, P. (2014). Feasibility of Biogas Production from Napier Grass. *Energy Procedia*. Vol. 61, 1229–1233.

Sinbuathong, N., Sangsil, Y. and Sawanon, S. (2016). Biogas production from Napier prass at parious cutting intervals. In *Energy, Transportation and Global Warming, Green Energy and Technology*, ed. P. Grammelis (Switzerland: Springer International Publishing), chapter 29, 375–385.

Sittijunda, S. (2015). Biogas production from hydrolysate Napier grass by co-digestion with slaughterhouse wastewater using anaerobic mixed cultures. *KKU Res. J.*, Vol. 20(3), 323–336.

Wilawan, W., Pholchan, P., Aggarangsi, P. (2014). Biogas production from co-digestion of *Pennisetum pururem* cv. Pakchong 1 grass and layer chicken manure using completely stirred tank. *Energy Procedia*, Vol. 52, 216–222

Wilkie, A., Goto, M., Bordeaux, F. M., Smith, P. H. (1986). Enhancement of anaerobic methanogenesis from Napier Grass by addition of micronutrients. *Biomass*, Vol. 11, 135–146.

CERTIFICATE *of* APPRECIATION

No: 525/UN43/TU/IDB/2017

International Conference on
Food Security Innovation
2017

This certificate is proudly presented to :

Agus Haryanto

as

Presenter

At the 1st International Conference on Food Security Innovation 2017
"Emerging Global Food Innovation for Future Quality of Life"

Date: October 18th - 20th, 2017

Head of PIC Research Consortia

Prof. Dr. Ir. Kartina AM, MP.
NIP. 196707042002122001

Rector of UNTIRTA

Prof. Dr. H. Sholeh Hidayat, M.Pd.
NIP. 195805091984031003

Anaerobic codigestion of cow dung and rice straw to produce biogas using semi-continuous flow digester: Effect of urea addition

Agus Haryanto[1,*], Badai Putra Sugara[1], Mareli Telaumbanuwa[1], R. A. Bustomi Rosadi[1]

[1] Agricultural Engineering Department, Faculty of Agriculture, The University of Lampung. Soemantri Brojonegoro Road, Bandar Lampung, Indonesia.

[*] E-mail: agus.haryanto@fp.unila.ac.id

Abstract. The objective this research was to investigate effect of urea addition on the biogas yield from codigestion of rice straw and cowdung using semi-continuous anaerobic digester. Experiment was conducted by using self-made semi-continuous anaerobic digester having working volume of 30 L. Cowdung was provided from Department of Animal Husbandry, University of Lampung; whilst rice straw was collected from farmer at Way Galih, Tanjung Bintang, South Lampung. Rice straw was sun dried to about 12% of moisture content and then ground into fine particles. Cowdung and ground straw was mixed at a dung-to-straw ratio of 3:1 based on total solid (TS) and four different urea additions (0, 0.25, 0.65, and 1.30) were applied to have a C/N ratio between 20 and 30. The mixture was diluted with water to create TS content of 10%. As much as 30 L of the substrate mixture was introduced into the digester as a starting load. The same substrate was added daily at a loading rate of 0.5 L/d. Experiment was made in triplicate and observation was performed for two months. Total and volatile solids of influent and effluent, and daily biogas production were observed. The biogas quality was observed by measuring its methane content was analyzed using gas chromatography. Results showed that urea addition influenced the biogas yield and its quality. Substrate mixture with urea addition of 0.25 g/L (C/N ratio of 25) was the best in term biogas yield (434.2 L/gVSr), methane content (50.12%), and methane yield (217.6 L/gVSr).

1. Introduction

Biogas is produced through anaerobic digestion process of organic substances. The biogas is mainly composed of CH_4 (45-70%) and CO_2 (30-45%) and traces of H_2, water vapour (H_2O), ammonia (NH_3), and hydrogen sulphide (H_2S) [1, 2]. Biogas can be used to fuel several applications, from cooking stove to generating electricity. Biogas technology is now an ecologically sound option to reduce environmental burden by decomposing organic material and producing not only energy but also good quality organic fertilizer [3, 4]. Application of small biogas digester provide economic and environmental benefits to the society [5]. Biogas is one of renewable fuel that can be an important source of Indonesia's energy in the near future. This is accentuated by a fact that Indonesia is bestowed with enormous biomass both fresh matters and as wastes from agro-industrials processing. During biogas process, which is carried out under anaerobic conditions, volatile solids are decomposed and converted into methane and carbon dioxide.

Rice straw can be a promising substrate for biogas production. Straw is produced during paddy harvesting. In the past time, when paddy was harvested manually simple cutter and then sickle, straw is left on the plant. Nowdays, rice straw is separated from the grains after the plants are threshed either manually or using stationary threshers. Recently, mechanical harvesting is conducted by using combine harvesters that is facilitated with threshing unit so that straw is produced just after harvesting. According to IRRI, the amount of straw is roughly 0.7–1.4 kg for every kg of milled rice, depending on varieties, cutting-height of the stubbles, and moisture content during harvest [6]. As one of the largest rice producing countries in the world, Indonesia has abundant rice straw. The potential of rice straw in Indonesia in 2012 was about 91.753 million tons which is equivalent to approximately 50.974 million tons of coal with potential energy around 382,305 GWh of electricity, and the electric power potential around 43,642 MW [7]. According to the report of the Agriculture Ministry of Indonesia, about 79.4 million tons of milled rice is produced in 2016 [8]. It can be calculated that Indonesian rice straw is 49.63–99.26 million ton. It is an abundant waste that can be used to generate energy to substitute fossil fuels [7, 9].

The most common utilization of rice straw in Indonesia is for animal feed, either directly or after fermentation, even though it is classified as a poor feed for the animals due to high silica content [10]. Rice straw is also used for fuel in brick, roof tile, and pottery industries. Very little amount is used for cooking fuels. Significant amounts, however, remain unused in the fields. One common managing practice of is incorporating the rice straw into the soil during ploughing to decompose and provide fertiliser for the next crop. Buresh and Sayre, however, noted that incorporation of rice straw in the soil may have detrimental effects because of the initial immobilization of soil N, decreasing Zn availability, and increasing methane emission [11]. This practice is supposed to reduce harvesting yields due to foliage diseases [12].

Other common practice is barely burning *in-situ* the straw on the fields. One of widely accepted reason of burning rice straw in the field is to accelerate soil preparation and to provide minerals. Research indicates, however, that open burning has negative effects such as nutrient loss, removal of soil organic matter, and reduction of beneficial soil insects and microorganisms [10]. Open burning has also been observed to contribute to emissions of harmful air pollutants. During uncontrolled burning, pollutants such as CO_2, nitrous oxide (N_2O), CH_4, CO, non-methane hydrocarbons, NO_x, SO_2, and particulate matter are emitted [13]. This emission not only does pollute the environment, but also causes serious impacts on human health due to polycyclic aromatic hydrocarbons [14] which have significant toxicological properties and are notably potential carcinogens. In addition, open burning of rice straw also threats security problems of fire disasters [15].

Anaerobic codigestion of animal manure and agricultural byproducts has drawn increased attention [16]. Studies on biogas production by co-digestion of animal wastes with rice straw have attracted special interest. Biogas production has shown to be one of the key technologies for sustainable utilization of rice straw as renewable energy source [15]. Rice straw has such high organic matter with cellulose content of 25.4–35.5%, hemicelluloses of 32.3–37.1%, and lignin of 6.4–10.4% [17].

Rice straw is potential for biogas production because of high organic matter. The problems encountered in biogasification of rice straw are mainly related with high C/N ratio or low hydrolysis performance and digestibility because of high lignin content and its complex, stable and recalcitrant lignocellulosic structure [18], which needs a further balance of nutrients and destructive pretreatments if rice straw is used as substrate for biogasification [17, 19]. The objective of our research is to evaluate effect of urea addition on biogas yield resulted from anaerobic co-digestion of cowdung and rice straw using semi continuous digester.

2. Materials and Method

2.1. Digester preparation

Biogas production was carried out using semi continuous anaerobic digester. The digester vessels were made of two 5-gallon 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. A hole was made on the digester to deliver biogas into a storage balloon trough a plastic tube. The tube was facilitated with a stop valve to close the piping for biogas volume measurement and biogas sampling.

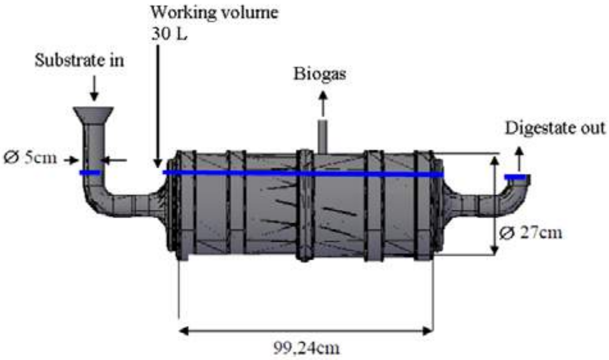


Figure 1: A self-designed semi continuous digester prepared for the experiment

2.2. Substrate Preparation

Fresh cowdung, taken from the Department of Animal Husbandry, the University of Lampung, was used as microbial seed source. Rice straw (Figure 2) was of Ciherang variety and was collected from farmer field in Way Galih, Tanjung Bintang, Regency of South Lampung. Straw was sundried until its moisture content is about 12% (wet basis). The dried straw was chopped and ground to fine particles. Biomass size reduction is important to enhance biogas production [20]. Samples of straw and cowdung were analysed for total solids (TS), volatile solids (VS), and carbon (C) and nitrogen (N) contents. Table 1 shows characteristic of each substrate. Urea granule with nitrogen content of 46% was purchased from local supplier and was used as external nitrogen source.

Figure 2: Rice straw: sun dried (left) and ground (right)

Table 1. Fresh substrate characteristic

Characteristic	Cowdung	Rice straw
Water content (%, wet basis)	71.0	11.0
Total solid (TS) (%, wet basis)	29.0	89.0
Ash (% TS)	25.04	28.48
Volatile solid (VS) (% TS)	74.96	71.52
C (%)	39.87	38.55
N (%)	1.42	0.58
C/N Ratio	28.08	66.46

2.3. Treatments and Loading

The experiment was designed with TS content of about 10% of substrate mixture and TS ratio of 1:3 (straw:dung). With digester working volume of 30 L, and referring to Table 1, then the composition of substrate for each digester is equivalent to 8.03 kg cow dung, 0.83 kg ground straw, and 21.10 L tap water. Initially, fine grass and cow dung were thoroughly mixed. For this experiment we prepared four level of urea addition, namely 0 (P1), 0.25 g/L (P2), 0.65 g/L (P3), and 1.3 g/L (P4). Table 2 shows substrate compositions along with their TS, VS, and C/N ratios. The experiment was conducted with three replications.

Table 2. Treatment and substrate composition

Characteristic	P1	P2	P3	P4
Water content (%, wet basis)	89.48	89.49	89.51	89.50
Total solid (TS) (%, wet basis)	10.52	10.51	10.49	10.50
Ash (% TS)	25.66	25.69	25.70	25.61
Volatile solid (VS) (% TS)	74.34	74.31	74.30	74.39
C (%)*	39.75	39.75	39.75	39.75
N (%)*	1.34	1.59	1.98	2.64
C/N ratio*	30	27.3	24.3	20.5

*) Calculated based on Equation (4)

2.4. Analysis and Calculations

For determining the total solids (*TS*), sample with certain weight (W_1) was placed in ceramic vessels and dried in a drying oven (Memmert, type UM 500, Germany) at 105°C for 24 hours until constant weight. After cooling in the desiccators, the sample was weighed (W_2) for TS measurement. Some of this sample (W_3) was taken and burnt in a furnace (Barnstead International model FB1310M-33, USA) at 550°C for 3 hours for volatile solids (*VS*) determination. Total solid and *VS* are calculated by using Eq. (1) and (2), respectively:

$$TS\ (\%, \text{wb}) = \frac{W_2}{W_1} \times 100 \tag{1}$$

$$VS\ (\%\ \text{TS}) = \frac{W_3 - \text{Ash}}{W_3} \times 100 \tag{2}$$

In order to evaluate the digester efficiency, the destroyed or removed VS (*VSr*) was calculated using equation developed by Koch [22]:

$$VSr\ (\%) = \left[1 - \frac{VS_{\text{out}}(1 - VS_{\text{in}})}{VS_{\text{in}}(1 - VS_{\text{out}})}\right] \times 100 \tag{3}$$

Carbon and nitrogen contents of each substrate were measured using element analyzer (Elementar Vario EL Cube, Germany). Carbon to nitrogen (C:N) ratio of the mixture is calculated using Eq. (4):

$$C:N = \frac{(C_c \times m_c) + (C_s \times m_s)}{(N_c \times m_c) + (N_s \times m_s) + 0.46 \times m_{\text{Urea}}} \tag{4}$$

where *m* is dry mass and subscripts *c* and *s* denote for cowdung and rice straw, respectively.

In order to evaluate process condition, temperature and pH of the substrate during experiment were also checked daily. Temperature was monitored using a thermometer inserted in the digester. The pH values were determined using pH meter (PHMETER, PH_009(I), China).

Biogas production was determined using simple water displacement method. Biogas composition was measured using gas chromatograph (Shimadzu GC 2014, Japan) with thermal conductivity detector (TCD) and 4-m length of shin-carbon column. Helium gas was used as carrier gas with flow rate 40 ml/min. Biogas yield (BY) was calculated from biogas production (BP) and *VSr* :

$$\text{BY} = \text{BP/VSr} \qquad (\text{L/kg VSr}) \tag{5}$$

3. Results and Discussion

3.1. ANOVA test

Table 3 showed results from ANOVA test for some parameters to evaluate digester performance, including average pH, average temperature, total biogas yield, average daily biogas yield, and day at which biogas burnt. Explanation for each variable is incorporated in the following discussion.

Table 3. Summary of ANOVA test for six parameters to evaluate digester performance.

Treatment	Average pH	Average T (ºC)	Outlet VS (% TS)	Total Biogas (L)	Daily Biogas (L)	Day Biogas Burnt
P1	6.81 a	30.56 a	67.5 d	259.1 b	4.3 b	23.0 b
P2	6.84 a	30.42 a	67.1 c	297.0 **c**	**5.0 c**	**15.3 a**
P3	6.86 a	30.62 a	64.9 a	288.1 **c**	**4.8 c**	18.3 ab
P4	6.77 a	30.29 a	68.2 b	198.4 a	3.3 a	31.3 c

Note: numbers followed the same letter in the same column is not significantly different at α = 5%

3.2. Operation condition

Temperature and pH are among the important factors influencing digester performance. Figure 3 presents daily pH values of substrate from all treatments. Abbasi *et al*. [1] noted that optimum pH range for anaerobic degradation processes satisfying the requirement for both activities and cell growth of anaerobic microorganisms is 5.5–8.5. In our experiments, digesters for codigestion of cowdung and rice straw have initially basic pH value of 8.1 (P2 and P4) and 8.2 (P1 and P3). This actually was in the good range for anaerobic digestion process. During the first week, the pH decreased to a value of 6.5. In the second week the pH still fluctuated from around 6.5 to 7.0. Starting from the end of week two, the pH was practically stable between 6.7 and 7.0 with average value of 6.7 for P4 and 6.8 for the others. As presented in Table 3, there was no significant difference on average pH value of all treatments. According to de Mes *et al*., methanogenesis proceeds when the pH is close to neutral, and outside pH values of 6.5–7.5, the rate of methane production is low [24].

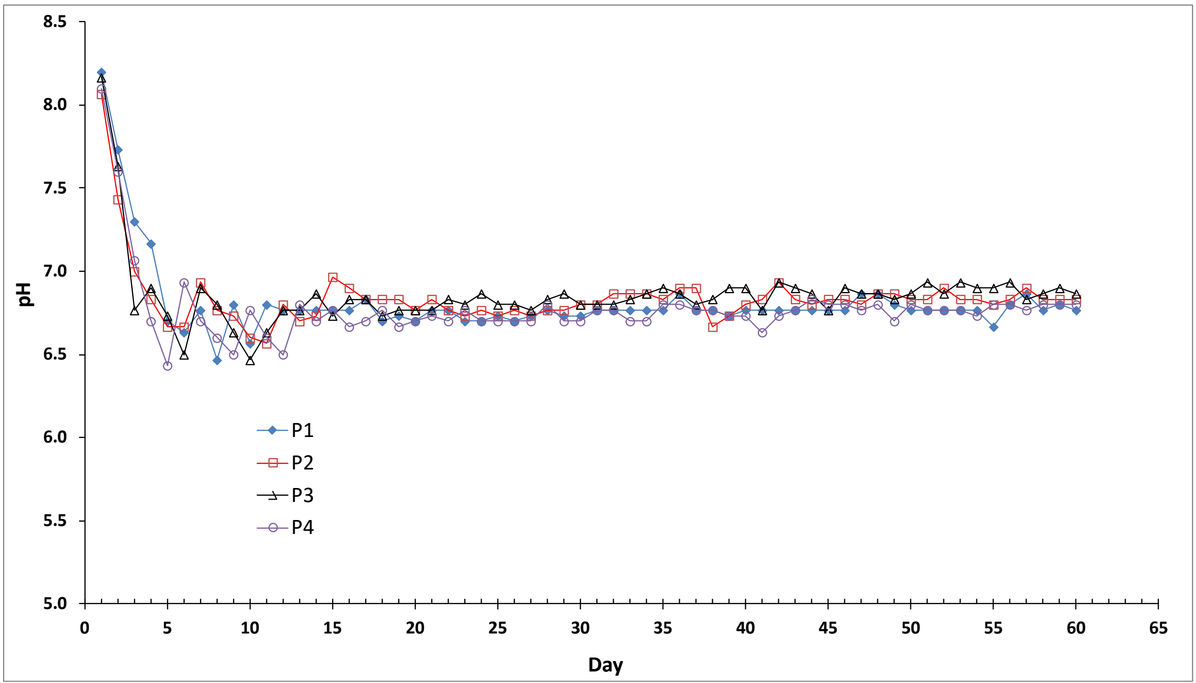


Figure 3 Change of daily pH of the substrate for different treatments

Figure 4 showed daily temperature of the digesters. All digesters operated in the mesophilic temperature region with average value of 30.56ºC (P1), 30.42ºC (P2), 30.62ºC (P3), and 30.29ºC (P4). It appears that the operating temperature of all digesters is very close to each other. There was no statistical different of average daily temperature between all treatments. Daily temperatures for all digesters had a pattern similar to ambient temperature. This indicates that the digester temperature is strongly influenced by environmental conditions. In general, all digesters work at temperatures slightly higher than ambient temperatures (28.61ºC). This is understandable because the overall reaction to the biogas process is a slightly exothermic, that is, producing heat [24]. Figure 4 shows that the digester temperature changed with time. During noon and afternoon, the digester temperature was higher than the temperature in the morning. The same was also observed for ambient temperature. It asserted that the working temperature of the digester is greatly influenced by the ambient temperature.

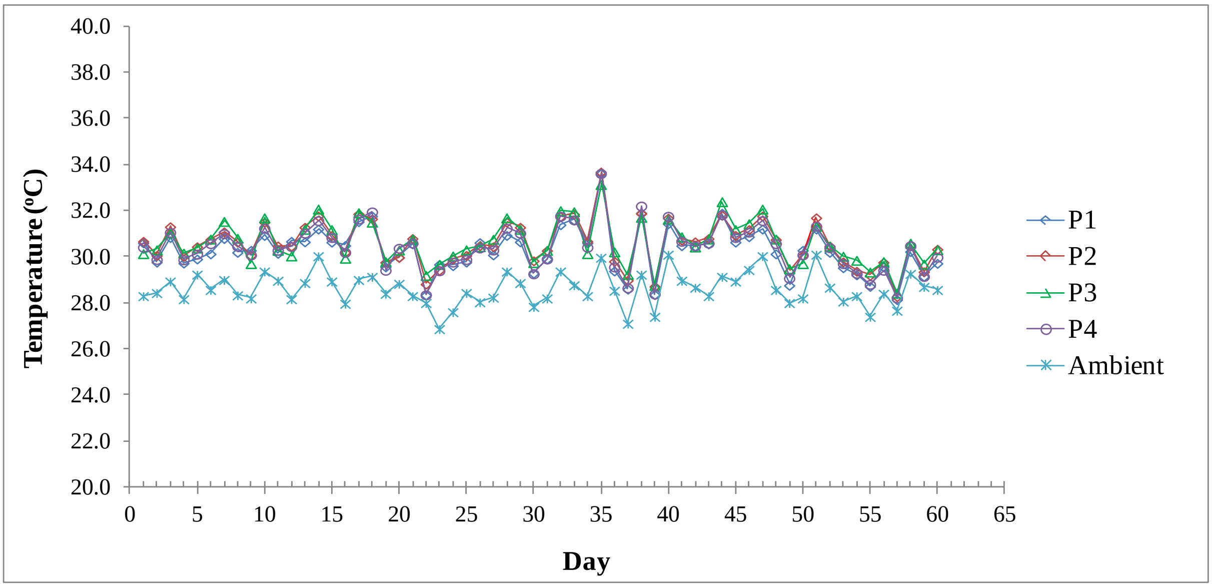


Figure 3 Comparison of daily digester temperature and ambient air.

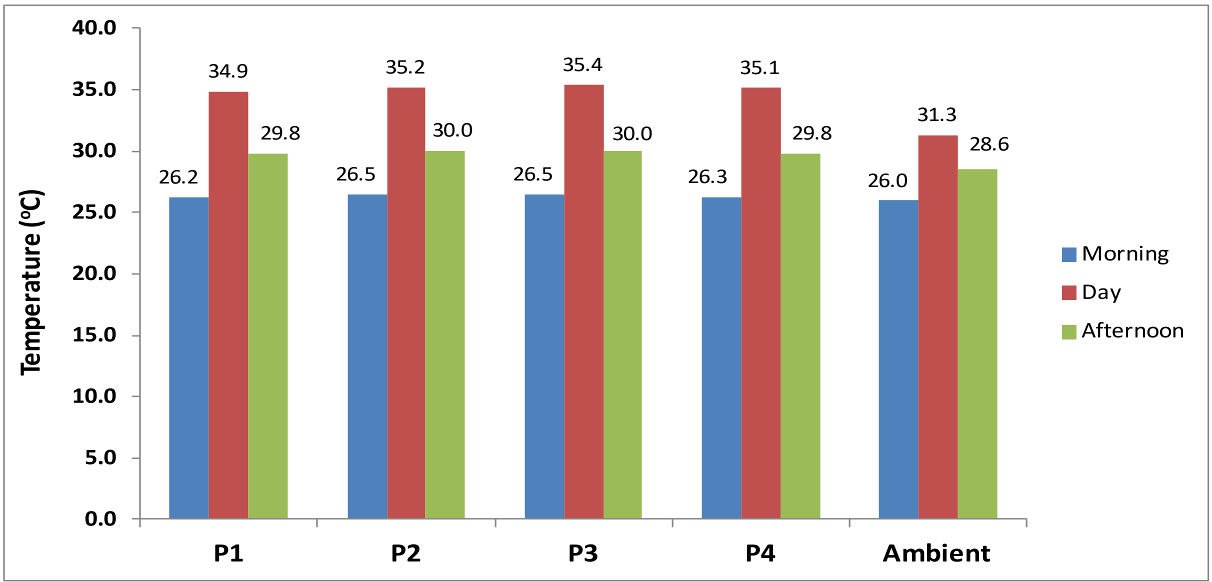


Figure 4 Average working temperature of digesters and ambient air: morning, noon, and afternoon

During anaerobic digestion process, substrate decomposition occurs. Table 4 presents characteristic of spent substrates for each treatment. The table also includes VS removal that is calculated from Eq. (3) and biogas yield calculated from Eq. (3). The addition of urea has resulted in significant difference on VS_{out} as well as *VS* removal. The VS removal increased with increasing urea addition and achived the highest (36% or 14 g VS/d) was achieved by P3 (urea addition 0.65 g/L), and then decreased with more increase in urea addition. Recently, family size digesters using cowdung substrate have been reported to have average organic material removal of 51.32% [5]. This meant that VS removal from our experiment is significantly lower than that of actual field practices. The addition of rice straw could be responsible for this low degradation. Therefore, other pretreatment should be applied to the straw prior to use for biogas substrate.

Table 4. Volatile solid (*VS*) removal

Treatment	VS_{in} (%, TS)	VS_{out} (%, TS)	*VSr* (%)	*VSr* (gVS)	*BY* (L/gVSr)
P1	74.34	67.5	28	11.1	388.4
P2	74.31	67.1	29	11.5	434.2
P3	74.30	64.9	36	14.0	341.7
P4	74.39	68.2	26	10.2	322.9

3.3. Biogas production

Figure 5 presents daily biogas production resulted from different treatments. During first week the digesters showed decreasing trend of biogas production. Initially, gas was produced from respiration of the substrates due to the existence of air filling void space in the digester. Starting day 6th digester with 0.65 g/L urea addition showed increase in biogas production; while other treatments practically start to increase by day 9th. As presented in Table 2, addition of urea had significantly influenced average daily biogas production. Treatment with urea addition 0.25 and 0.65 g/L produced the highest daily biogas production (5.0 L/d for P2 and 4.8 L/d for P3) compared to those of other treatments. Table 3, however, showed that P3 produced the highest biogas yield in term of biogas production per unit of degraded organic material (434.2 L/gVSr.d).

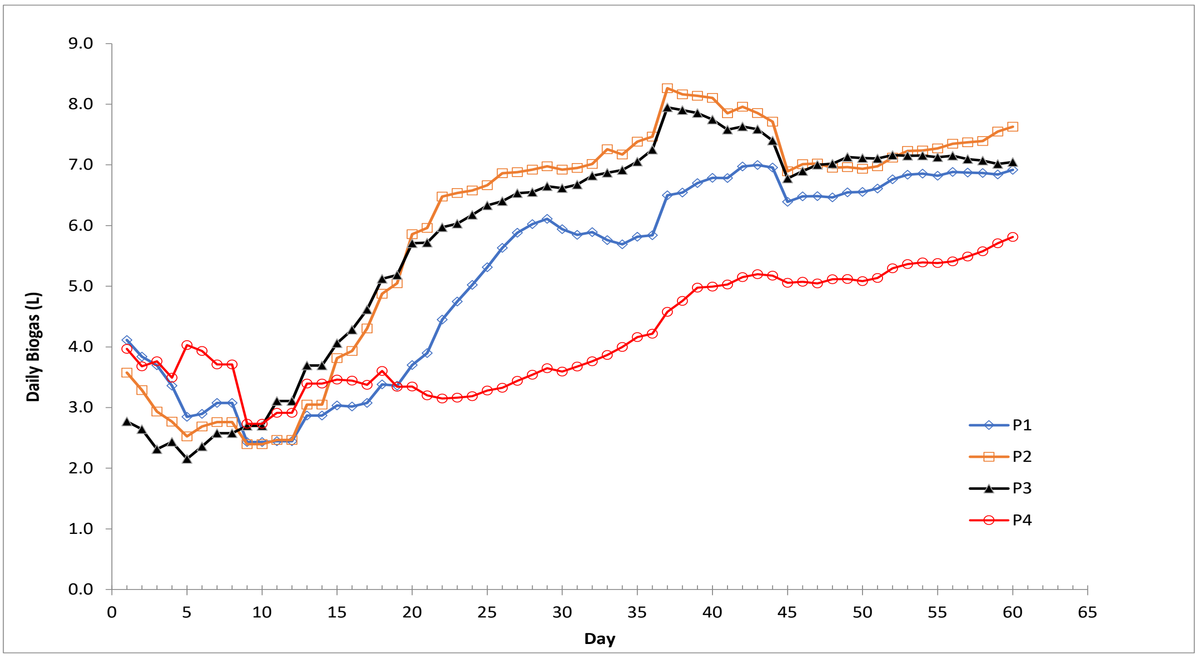


Figure 5. Daily biogas production from different treatments using 8-day moving average

Figure 6 presents cumulative biogas production. During the first three weeks, all digesters showed comparable cumulative biogas production. After that, the effect of urea addition appeared more clearly. Treatments P2 and P3 lead the biogas production with a total production of 297.0 L and 288.1 L. Addition more urea resulted in detrimental effect on biogas production. Treatment P4 with 1.3 g/L urea addition produced the lowest biogas production (198.4 L) with daily average of 3.3 L. This could be correlated to low C/N ratio (20.5) and the low VS removal (26%).

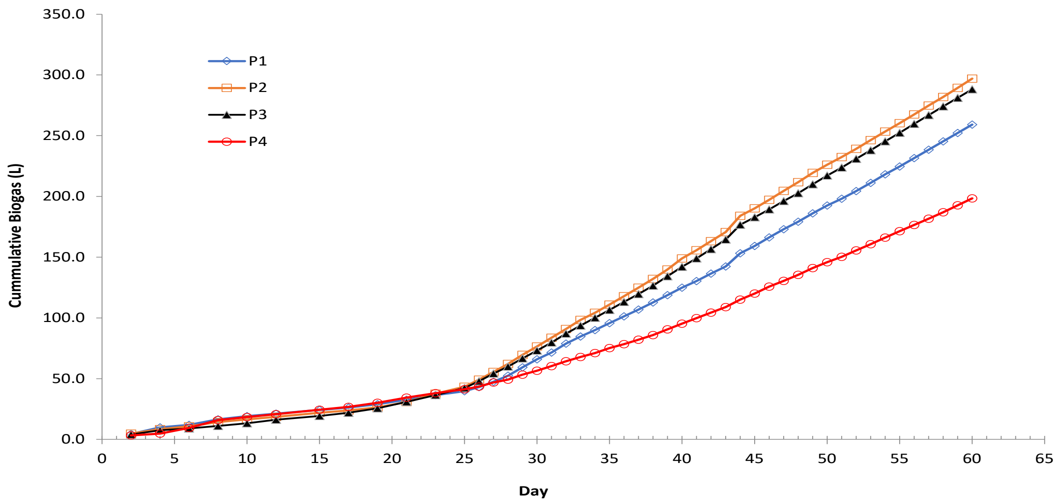


Figure 6. Cumulative biogas production from different treatment.

3.4. Methane yield

Table 5 presented biogas composition from different treatments. The methane content of P2 (urea addition 0.25 g/L) was the highest. Increasing more urea addition resulted in lower methane content. Treatment P4 with urea addition of 1.3 g/L produced biogas with lowest methane content (37.04%). Based on this composition we have calculated methane yield that was also presented in Table 4 (last column). It is obvious that treatment P2 with urea addition of 0.25 g/L gave the highest methane yield; whilst P4 with urea addition of 1.3 g/L produced the lowest methane yield. Table 6 compares methane yield of our work with the values already reported by other research. Our work is a half of the maximum value reported by Lei *et al*. (2010) [25]. This meant that there is possibilities to increase methane (biogas yield) by, for example adding other pretreatment.

Table 5. Biogas composition (%) and methane yield (L/gVSr)

Treatment	CH_4	CO_2	N_2	CH_4 Yield
P1	49.82	40.43	9.75	193.5
P2	**50.12**	**39.97**	**9.91**	217.6
P3	46.49	43.15	10.36	158.9
P4	37.04	35.45	27.56	119.6

4. Conclusions

Rice straw is promising for biogas co-substrate. The addition of rice straw as co-substrate potentially improve total biogas yield. Urea addition influenced biogas production and biogas quality from codigestion of rice straw and cowdung using semi continuous digester. Substrate mixture with urea addition of 0.25 g/L at which C/N ratio is 25 was the best treatment in term biogas yield (434.2 L/gVSr), day at which the biogas can burnt (day 15), as well as its methane content (50.12%) and methane yield (217.6 L/kg VSr).

Table 6. Biogas composition (%) and methane yield (L/gVSr)

Condition	CH_4 Yield (L/gVSr)	Reference
Cowdung 3: Straw 1, TS 10%, Urea 0.25 g/L; 30.6°C	217.6	This work
Batch, 37°C; hydrothermal pretreatment 5% NaOH	132.7	Chandra *et.al.* (2010) [26]
Phosphate addition 115 mg/L; 25°C	440.0	Lei *et al.* (2012) [25]
Batch, kitchen waste : pig manure : straw = (0.4) : (1.6) : (1); 37°C	383.9	Ye *et.al.* (2013) [27]
Straw 10 mm, preheat 110°C, ammonia 2%; 35°C	247.2	Zhang & Zhang (1999) [28]

Acknowledgement
This work was financially supported by DGHE (Directorate General of Higher Education), Ministry of National Education though Strategis Nasional (STRANAS) research scheme. Contract number: 071/SP2H/LT/DRPM/IV/2017585.

References

[1] Abbasi T, Tauseef S M and Abbasi S A. 2012. *Biogas Energy* (New York: Springer) pp 1–10.
[2] Gomez C D C. 2013. Biogas as an energy option: an overview. *The Biogas Handbook: Science, Production and Applications*, ed A Wellinger *et al.* (Cambridge: Woodhead Publishing Limited) pp 1–16.
[3] Higgins K T. 2008. Anaerobic gas and cash. *Food Engineering* **80(4)** 119–20.
[4] Petis M. 2006. Anaerobic digestion plant yields nutrients and power. *BioCycle* **47(12)** 61–62.
[5] Haryanto A, Cahyani D, Triyono S, Murdapa F and Haryono D. 2017. Economic benefit and greenhouse gas emission reduction potential of a family-scale cowdung anaerobic biogas digester. *Int. Journal of Renewable Energy Development* **6(1)** 29–36.
[6] IRRI (International Rice Research Institute). 2017. Rice Straw. http://ricestraw.irri.org/ (October 29, 2017)
[7] Makhrani. 2014. Potential analysis of rice straw as an alternative energy source for substitute coal in Indonesia. *Applied Mechanics and Materials* **554** 276-280.
[8] Sulaiman AA, Simatupang P, Las I, Jamal E, Hermanto, Kariyasa IK, Syahyuti, Sumaryanto S, Suwandi, and Subagyono K. 2017. Sukses Swasembada: Indonesia Menjadi Lumbung Pangan Dunia 2045. Ministry of Agriculture.
[9] Sidjabat O. 2011. Prospect of rice straw potential for bioenergy in indonesia as substituted gasoline and reducing of environmental problem. *Ketenagalistrikan dan Energi Terbarukan* 10(2) 113-122.
[10] Mandal KG, Misra AK, Hati KM, Bandyopadhyay KK, Ghosh PK. and Mohanty M. 2004. Rice residue- management options and effects on soil properties and crop productivity. *Food, Agriculture & Environment* **2(1)** 224-231.
[11] Buresh R and Sayre K. 2007. *Implications of Straw Removal on Soil Fertility and Sustainability*. Expert Consultation on Biofuels. IRRI, Los Banos, Philippines, p. 34.
[12] Zhang R and Zhang Z. 1999. Biogasification of rice straw with an anaerobic-phased solids digester system. *Bioresource Technology* **68** 235–245.
[13] Gadde B, Menke C, and Wassmann R. 2009. Rice straw as a renewable energy source in India, Thailand, and the Philippines: Overall potential and limitations for energy contribution and greenhouse gas mitigation. *Biomass and Bioenergy* **33** 1532–1546

[14] Korenaga T, Liu X, Huang Z. 2001. The influence of moisture content on polycyclic aromatic hydrocarbons emission during rice straw burning. *Chemosphere - Global Change Science* **3(1)** 117-122

[15] Lei Z, Chen J, Zhang Z, Sugiura N. 2010. Methane production from rice straw with acclimated anaerobic sludge: Effect of phosphate supplementation. *Bioresource Technology* **101** 4343–4348.

[16] Song Z, Yang G, Han X, Feng Y, and Ren G. 2013. Optimization of the alkaline pretreatment of rice straw for enhanced methane yield. *BioMed Research International* 1-9.

[17] Jin S and Chen H. 2006. Structural properties and enzymatic hydrolysis of rice straw. *Process Biochemistry* **41** 1261–1264.

[18] Chen Y, Cheng JJ, and Creamer KS. 2008. Inhibition of anaerobic digestion process: A review. *Bioresource Technology* **99** 4044–4064.

[19] Ward AJ, Hobbs PJ, Holliman PJ, and Jones DL. 2008. Optimisation of the anaerobic digestion of agricultural resources. *Bioresource Technology* **99** 7928–7940.

[20] Kratky L and Jirout T. 2011. Biomass size reduction machines for enhancing biogas production. *Chemical Engineering* & *Technology* **34(3)** 391–399.

[21] Malik, R. K., Singh, R. and Tauro, P. 1987. Effect of Inorganic Nitrogen Supplementation on Biogas Production. *Biological Wastes* **21** 139–142.

[22] Koch K. 2015. Calculating the degree of degradation of the volatile solids in continuously operated bioreactors. *Biomass* & *Bioenergy* **74** 79–83.

[23] Marchaim, U. (1992). *Biogas Processes for Sustainable Development*. FAO (Food and Agriculture Organisation), Rome.

[24] de Mes TZD, Stams AJM, Reith JH, and Zeeman G. 2003. Methane production by anaerobic digestion of wastewater and solid wastes. In *Bio-methane & Bio-hydrogen*: *Status and Perspectives of Biological Methane and Hydrogen Production*. ECN. Dutch Biological Hydrogen Foundation - ISBN 9090171657 58–102.

[25] Lei Z, Chen J, Zhang Z, and Sugiura N. 2010. Methane Production from Rice straw with acclimated anaerobic sludge: Effect of phosphate supplementation. *Bioresource Technology* **101** 4343–4348.

[26] Chandra R, Takeuchi H, and Hasegawa T. 2012. Hydrothermal pretreatment of rice straw biomass: A potential and promising method for enhanced methane production. *Applied Energy* **94** 129–140.

[27] Ye J, Li D, Sun Y, Wang G, Yuan Z, Zhen F, and Wang Y. 2013. Improve biogas production from rice straw by co-digestion with kitchen waste and pig manure. *Waste Mangement* **33** 2653–2658.

[28] Zhang R and Zhang Z. 1999. Biogasification of rice straw with an aerobic-phased solids digester system. *Bioresource Technology* **68** 235–245.

AESAP 2017
Agricultural Engineering
for Sustainable
Agriculture Production

Certificate of Appreciation

AGUS HARYANTO

is recognized for outstanding contribution as presenter in

2nd International Conference

Agricultural Engineering for Sustainable Agriculture Production

PERTETA CHAPTER BOGOR

Department of
Mechanical and Biosystem Engineering
Faculty of Agricultural Engineering and Technology,
Bogor Agricultural University IPB

October, 23-25 2017

Organized and hosted by Bogor Agricultural University (IPB), Indonesia

Chairman of Committee

Dr. Ir. Desrial, M.Eng.

Pengaruh frekwensi pengumpanan pada produksi biogas dari campuran kotoran sapi dan rumput gajah (*Penisetum purpuerum*) menggunakan digester semi-kontinyu

Penelitian ini dibiayai DRPM Kemenristekdikti melalui skim Strategis Nasional (STRANAS). Kontrak Nomor : 071/SP2H/LT/DRPM//IV/2017585.

Agus Haryanto
Arif Junaedi
Triwahyu Saputra
Siti Suharyatun

INTRODUCTION

- Biogas (campuran CH_4 (45-70%) dan CO_2 (30-45%) yang dihasilkan dari dekomposisi biomassa melalui proses anaerobic digestion
- Rumput gajah (*Penisetum purpuerum*) merupakan bahan baku yang menjanjikan untuk menghasilkan biogas.

WHY GRASS?

- Mengapa rumput gajah?

  ► tumbuh cepat, umur panen 60-70.

  ► hasil tinggi 70 – 100 ton FM/ha.

  ► ratoon 6-7 sebelum replanting.

  ► sangat adaptit, dapat ditanam pada lahan non arable.

  ► sedikit olah tanah, sedikit air, pupuk, dan pestisida.

  ► propagasi dan managemen mudah.

  ► tolerant tanah sam. tembaga. Dan kondisi kekeringan.

PREVIOUS

- Penelitian sebelumnya:
- rumput gajah cacah kecil (1 cm), rasio kohe : rumput = 1:3 (TS), laju pengumpanan 0.625 L/D, TS = 10%.
- Hasil: biogas mengandung metana rendah, (22,35%, tidak bisa dibakar).
- Setelah dibiarkan 3-4 hari tanpa pengumpanan, biogas dapat dibakar dengan kandungan CH_4 50 %.

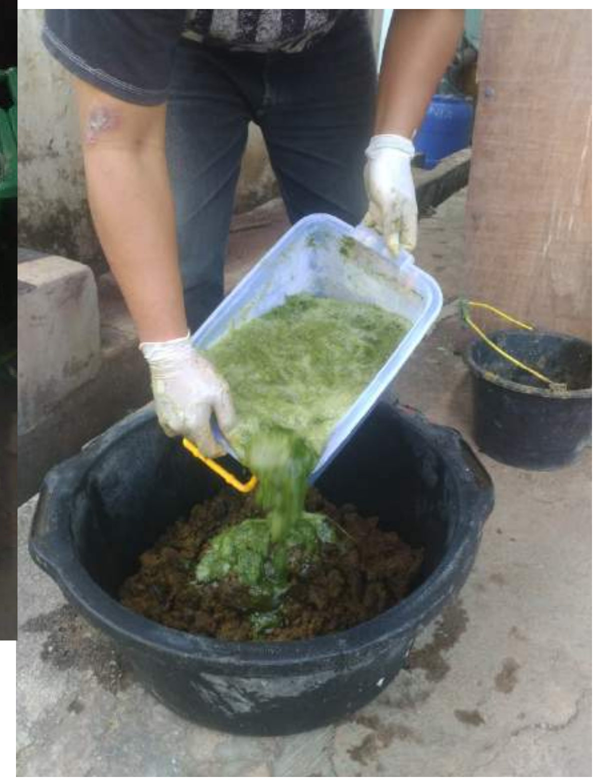
OBJECTIVE

- Evaluasi pengaruh frekuensi pengumpanan terhadap produksi dan kualitas biogas dari campuran kotoran sapi dan rumput gajah menggunakan digester semi kontinyu 30 L.

MATERIALS

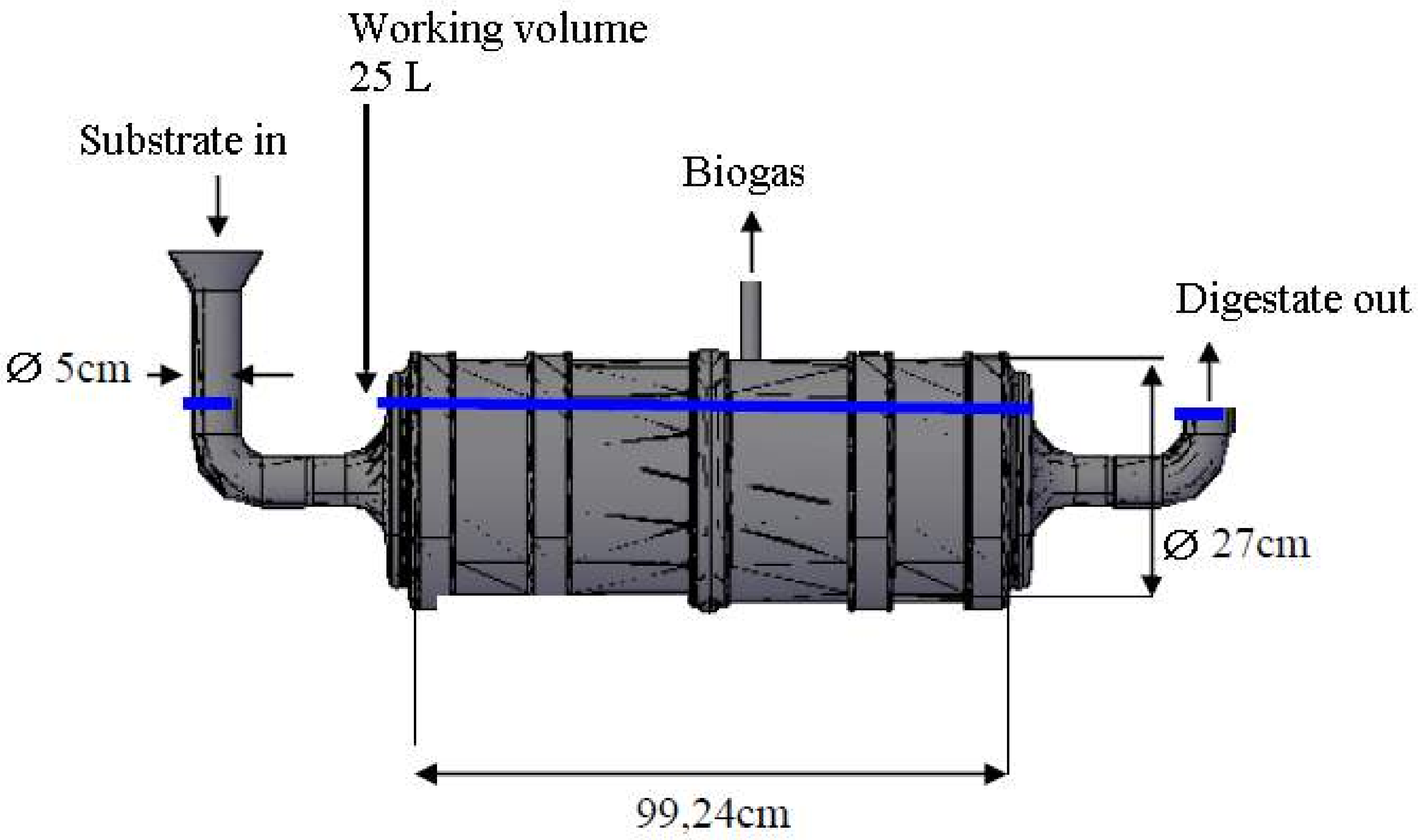
- Rumput gajah umur +/- 2 bulan.
- Kotoran sapi dari Jurusan PTK, UNILA.
- Rumpuh dicacah hingga panjang 1 cm, lalu diblender dengan ditambah air hingga lembut.
- Rumput dan kotoran sapi dicampur dengan rasio TS 1:3 (rumput:kohe).
- Campuran diencerkan hingga Total TS = 5%





METHODS

Semi-continuous digester



TREATMENTS

- Volume kerja digester 25 L
- Lima digester disiapkan dengan 30 L dandibiarkan mencapai kestabilan.
- Setelah stabil, digester diumpani dengan laju pembebanan 0,5 L/d dengan frekwensi yang berbeda (5 perlakuan):
  - P1: frekwensi tiap hari @0.5 L
  - P2: frekwensi tiap 2 hari @1.0 L
  - P3: frekwensi tiap 3 hari @1.5 L
  - P4: frekwensi tiap 4 hari @ 2.0 L
  - P4: frekwensi tiap 5 hari @ 2.5 L

ANALYSIS

- Analysis and observation:

1. pH Substrate
2. Temperature
3. TS and VS content (Gravimetri)
4. C and N content (Elemental analyzer)
5. VS removal
6. Daily biogas production
7. Biogas yield
8. Biogas composition (GC)
9. Methane yield

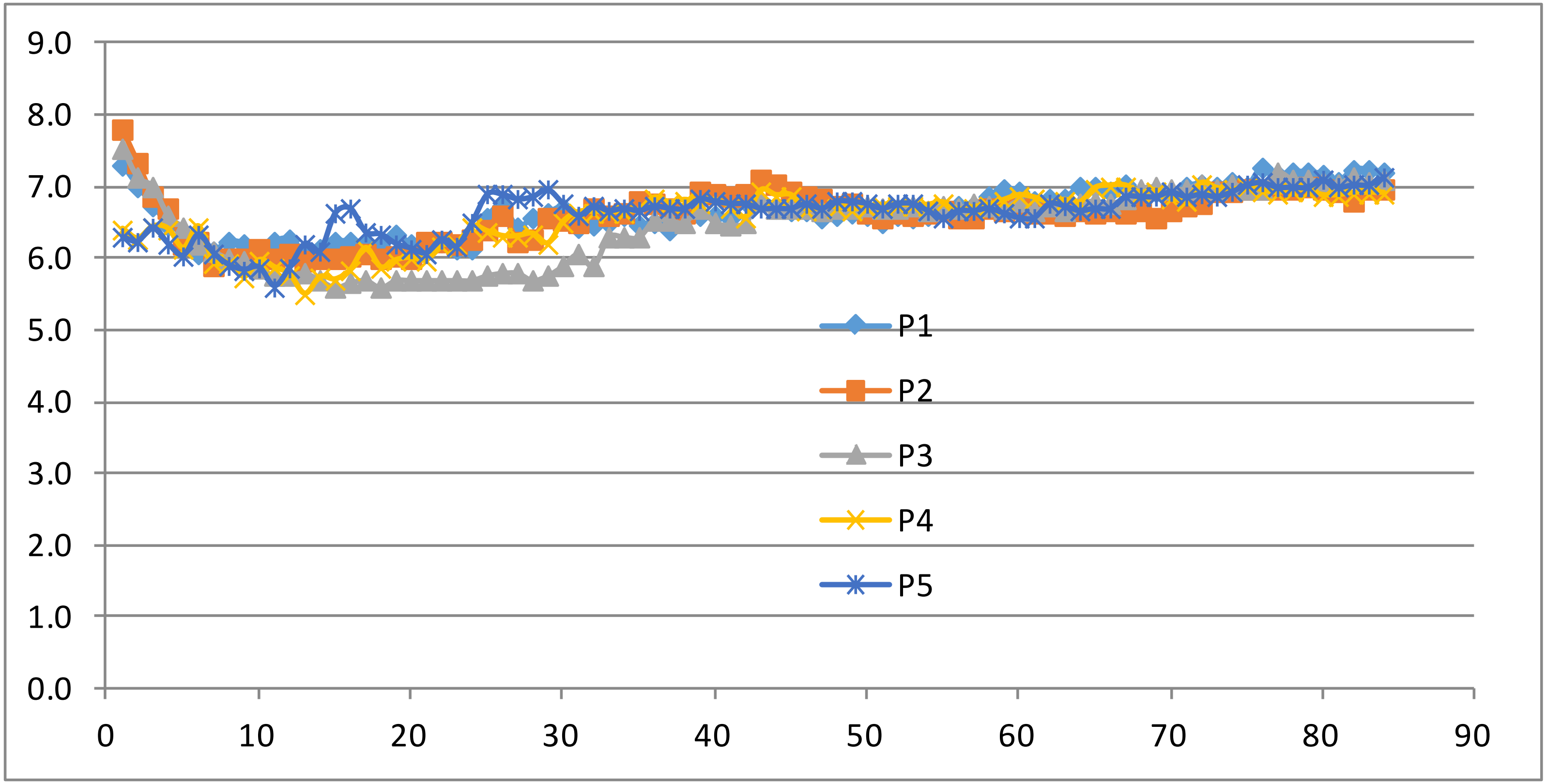
MATERIALS

Substrate Characteristic

Characteristic	Cowdung	E. grass
Water content (%, wb)	83.02	82.71
Total solid (TS) (%, wb)	16.98	17.29
Ash (% TS)	20.83	11.76
Volatile solid (VS) (% TS)	79.17	88.24
C (%)	39.87	55.51
N (%)	1.42	1.81
C/N Ratio	28.08	30.62

RESULTS

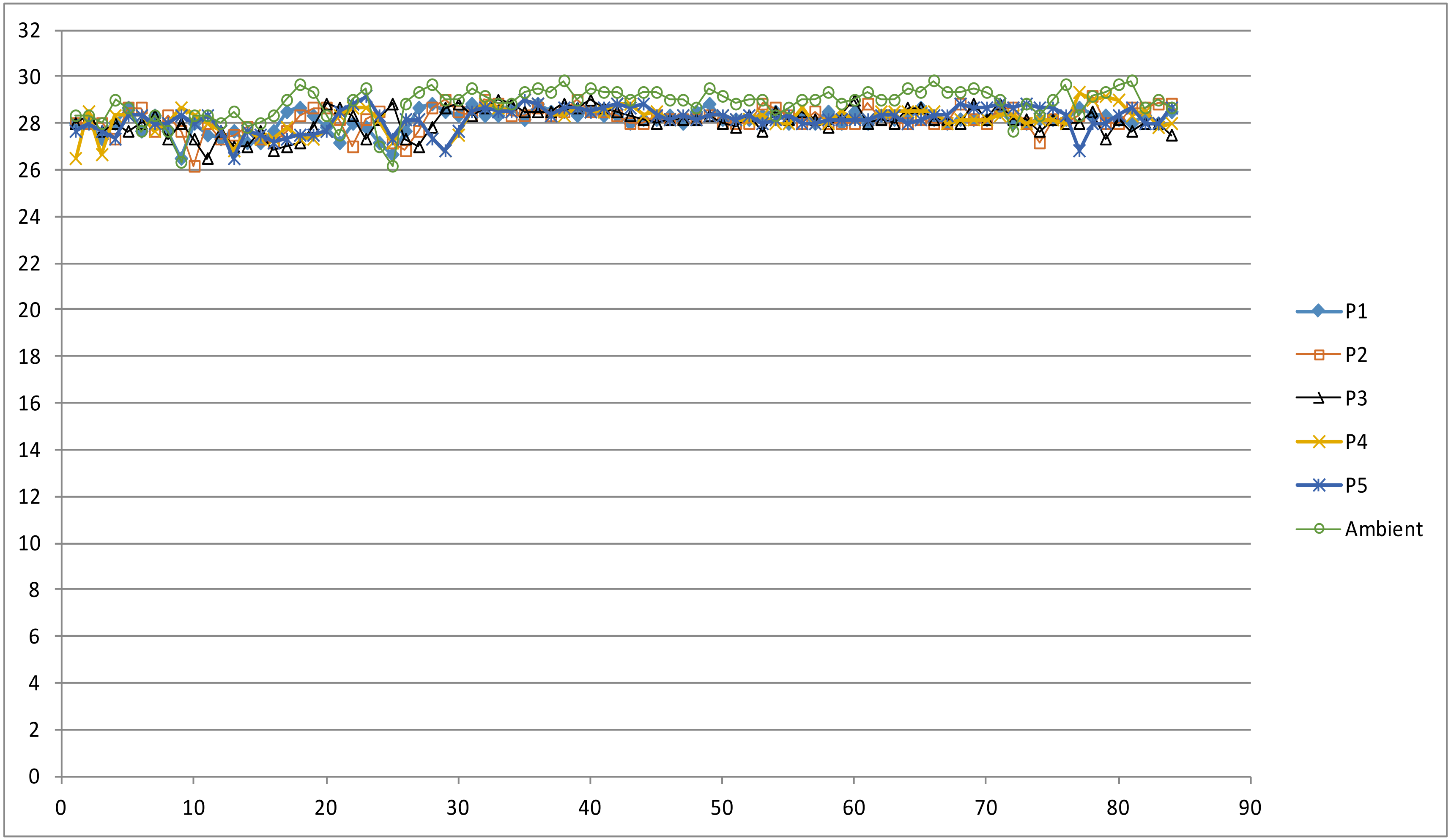
- **Process pH:**



Average: 6.3 for P1, 6.4 for P2, 6.6 for P3, 6.6 for P4.

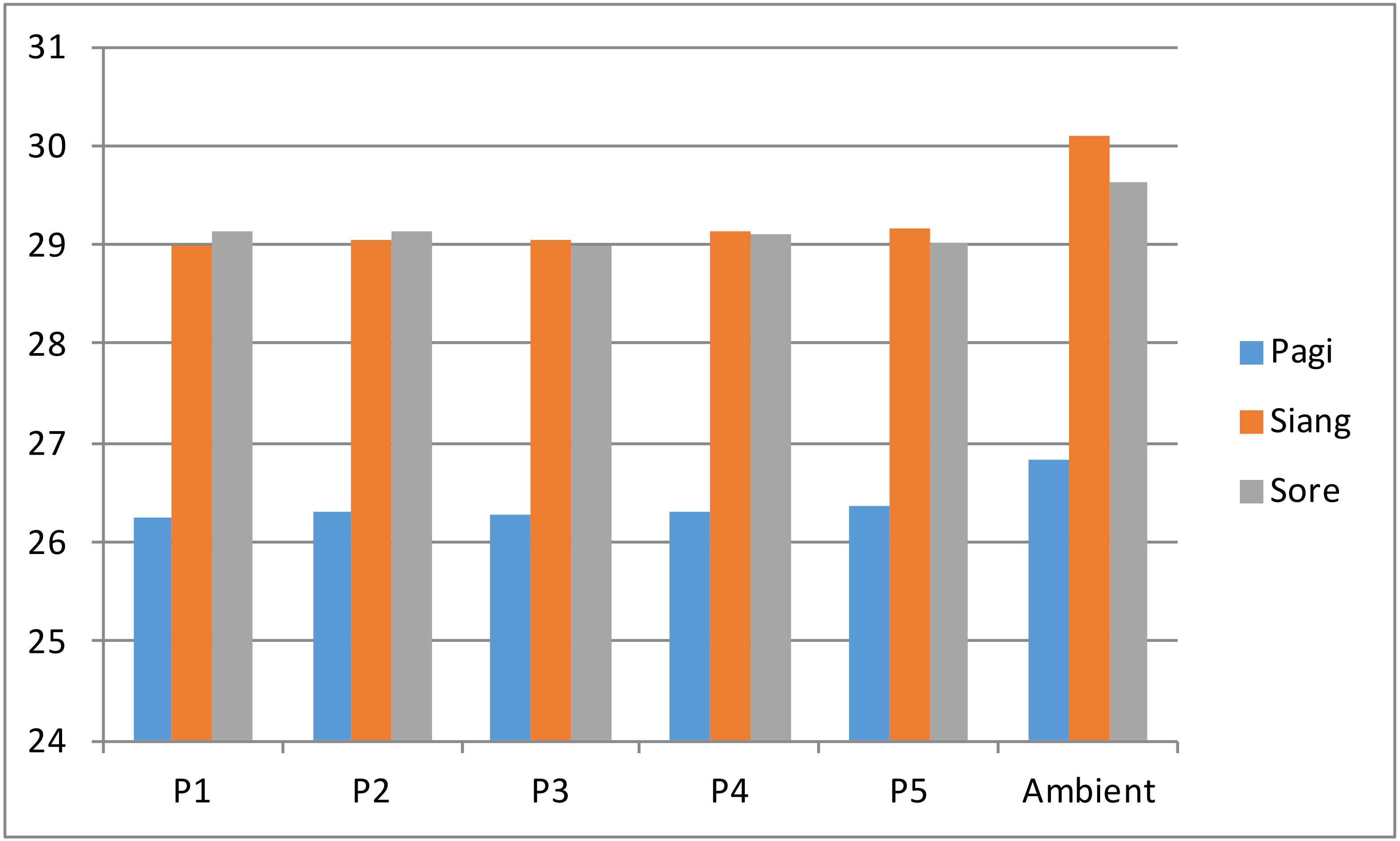
RESULTS

- Temperatur Harian



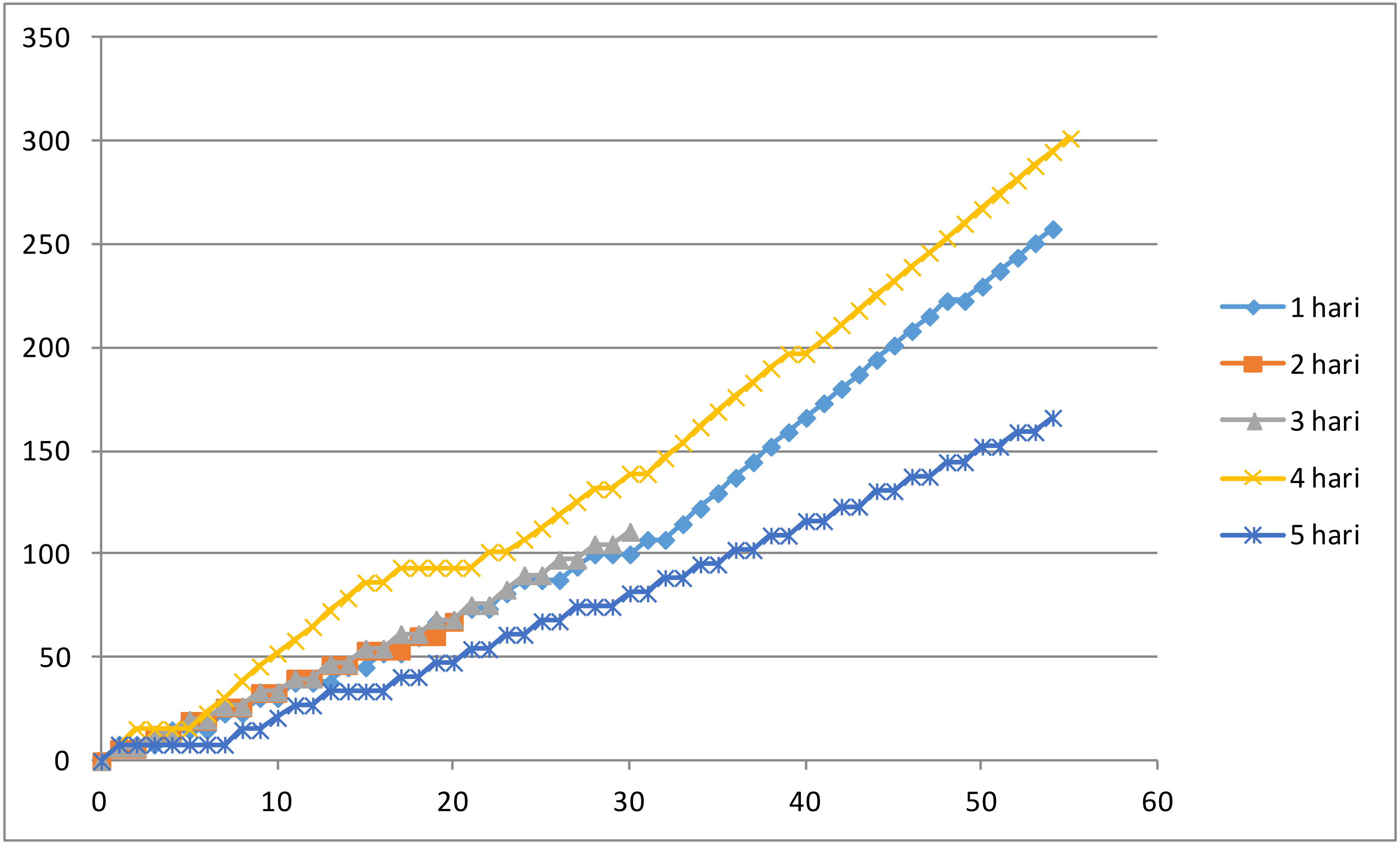
RESULTS

Suhu Rata-rata



RESULTS

- Cumulative bioas yield



RESULTS

Komposisi Biogas

Perlakuan	CH_4	CO_2	N_2
P1	41.73	39.04	19.23
P2	39.61	18.84	41.10
P3	36.75	29.91	33.11
P4	**51.80**	35.82	12.38
P5	41.13	22.24	36.55

CONCLUSIONS

- Rumput gajah merupakan ko-substrate biogas yang potensial
- Frekwnsi pembebanan mempengaruhi produksi dan kualitas biogas.
- Frekwensi pengumpanan 4 hari sekali menghasilkan biogas terbanyak dengan kandungan CH_4 tertinggi (51.80%).

Acknowledgement

Penelitian ini dibiayai DRPM Kemenristekdikti melalui skim Strategis Nasional (STRANAS). Kontrak Nomor : 071/SP2H/LT/DRPM//IV/2017585.

Thank You

Sertifikat

Diberikan Kepada :

Agus Haryanto

Sebagai

PEMAKALAH

SEMINAR NASIONAL

PAMERAN TEKNOLOGI PERTANIAN & KONGRES PERHIMPUNAN TEKNIK PERTANIAN INDONESIA (P E R T E T A)

Banda Aceh, 02 - 05 November 2017

KETUA PERTETA ACEH	KETUA PRODI TEKNIK PERTANIAN UNSYIAH	KETUA PANITIA
Dr. Ir. Syahrul, M.Sc	Dr. Ichwana, ST, MP	Dr. Kiman Siregar. S.TP, M.Si