Biogas for Development

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Presentation Outline

- Workshop objectives
- Background
- Benefits and limitations of biogas digesters
- Reactor types
- BGT diffusion status in developing countries
- Barriers to biogas
- Energy content
- Domestic biogas appliances
- Biological processes
- Reactor analysis
- Reactor sizing
- Estimation of methane production rate
- Life cycle cost
- A demonstration project in West Java

Workshop Objectives

- To be aware of the appropriateness of biogas digesters in developing countries
- To be aware of barriers to biogas in developing countries
- To be able to identify a suitable digester type for a particular application
- To have an overview of biogas technology diffusion in developing countries
- To understand the factors related to system design and operation of biogas digesters
- To be able to size a rector for particular conditions

Developing Countries

- Main energy requirements in the domestic sector for:
  - Cooking,
  - Water heating,
  - Lighting, and
  - Drinking water supply pump operation.
- Decentralised energy sources and systems offer an opportunity to supplement these energy needs.

Benefits of BGT

- Harnesses a renewable energy resource (biomass)
- Environmentally friendly
- No resource depletion involved
- Reduces deforestation and saves fuel wood
- Positive effect on national economy and can be integrated with rural development by providing
  - Cleaner fuel
  - Valued added fertiliser
  - Positive effects on healths (pathogens and parasites are destroyed)
  - Cleaner surroundings
  - Employment

Benefits of BGT (cont'd.)

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- Within the capabilities of users.
- Digesters can be constructed with local resources.
- Community scale digesters can provide electricity.
- Can reduce the extension of grids.
- Can contribute at least 10% of national energy requirements and about 50% of rural energy requirements.

Limitations

- Lack of optimum design appropriate for the variety of local conditions.
- Initial costs of biogas systems are high.
- Construction skill needed.
- Operational problems:
  - Pinhole leakages,
  - Water condensation in gas lines,
  - Scum formation,
  - Blockage, and
  - Burner problems.

Limitations (cont'd.)

- Low gas production in winter
- Water requirements
- Assured supply of animal wastes/feed stock
- Sharing benefits and obligations for community biogas plant
- Cultural resistance against the use of some wastes, compounded by resistance to change

Digester Reactor Types

- Floating cover/drum (Indian type)
- Fixed dome (Chinese type)
- Plastic bag reactor
- Prefabricated steel reactor
- Horizontal type

Floating Cover/drum (Indian type)

(http://mnes.nic.in/annualreport/2002_2003_English/ch3_pg4.htm)

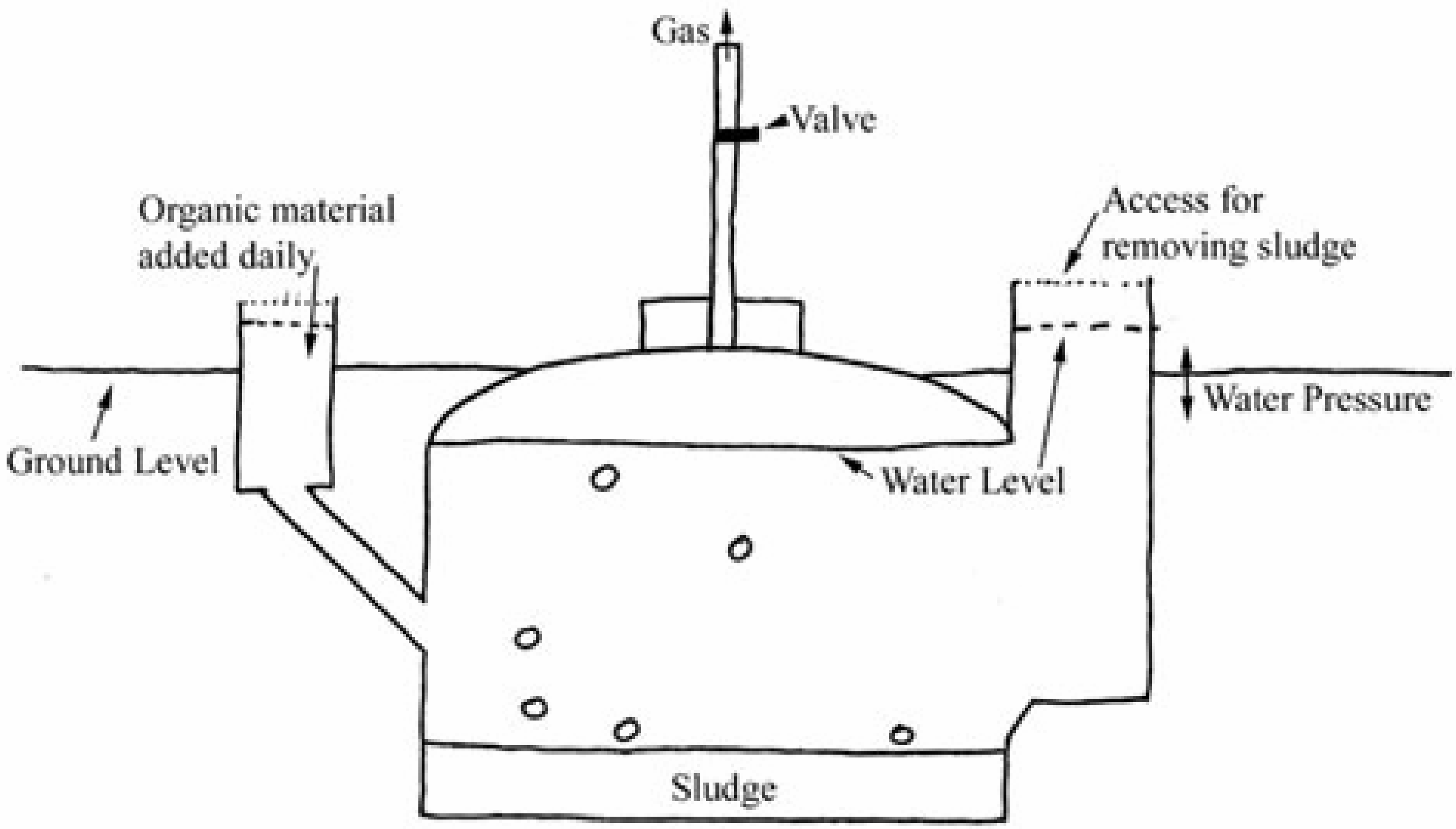
(http://teenet.chiangmai.ac.th/btc/introbiogas.php)

An Indian Stamp

(http://www.plantbio.uga.edu/courses/pbio1220/hainesmaterial/Lecture01-18-05_files/image002.jpg)

Fixed Dome (Chinese type)

(Source: http://www.csudh.edu/coe/chaut2005/Image%20Pages/simpleDigister.html)



A rural biogas plant under construction (Usher & Wang 2002)

(http://www.ashdenawards.org/all_finalists04.html)

Plastic Tubular

(http://www.solarengineering.co.za/Update%20-%20Dec%2012,03/gallery_biogas_plastic_htm1.htm)

Low Cost Plastic Reactor

(http://www.fao.org/WAICENT/FAOINFO/AGRICULT/AGA/AGAP/FRG/Recycle/biodig/manual.htm)

High Yield Bio-reactors

- Relatively cost and energy intensive and complex
- Work on thermophilic phase in additional to mesophilic phase
- Conversion efficiency 50 – 80 %
- Gas yield per m^3 of digester volume > 1 m^3/day
- Use of heating, insulation, stirring and pumping auxiliaries
- Suitable for large scale applications
- Short retention time is used (5 – 25 days)

Low Yield Bio-reactors

- Constant gas volume (FD) or constant gas pressure (FC) or plug flow type.
- Manually operated, unheated and uninsulated
- Work generally in mesophilic phase
- Conversion efficiency 20 – 35 %
- Simple & mostly used in developing countries.
- Typical yield per m^3 of digester volume 0.3 to 0.4 m^3/day, with a maximum value of 0.7 m^3/day.
- Long retention time is required (30 – 150 days).

Diffusion Status of BGT in Developing Countries

- Three main designs used in rural area:
  - Fixed dome (FD),
  - Floating cover (FC), and
  - Bag type.
- Three countries have installed a large number of units:
  - China (~7 millions units in 1982 , majority 6-10 m^3 family size FD design, main feed stock: pig manure)
  - India (~3.5 millions units in 2003, 8-10 m^3 and mainly FC design, feed stock: cattle dung)
  - South Korea (~30 thousands units in 1982).

Summary of Major Biogas Programs

Country	Number	Design	Priority	Strengths	Weakness
China	7×10^6	FD(95%), FC, Bag	E, N, S	Infra, R&D, Govt., Int.	Lack of materials
India	3.5×10^6	FC(95%), FD	E, N	Govt., Subsidy	Cost, Maintenance
S. Korea	30×10^3	FC	E	R&D	Temperature
Brazil	2 300	FC(60%), FD(40%)	E	Infra, Govt., Int, R&D	-
Nepal	1 200	FC(75%), FD(25%)	E	R&D, Comm	Temperature

Source: (Nijaguna 2002)

Barriers to Biogas (Ghana)

- Resource availability: seasonal dung availability and water shortages
- Absence of favourable promotion policies
- Absence of right financing schemes
- High cost
- Lack of market
- Lack of information

Barriers to Biogas (Philippines)

(Source: ARRPEEC 2005)

- Lack of access to information
- High adoption cost/transaction cost
- Lack of local expertise (manufacturing and maintenance)
- Lack of financing/risk coverage mechanism
- Lack of product standards
- Lack of financial/fiscal incentives
- Lack of coordination among government agencies
- Lack of biomass feedstock supply assurance
- Subsidy to fossil fuel

Yields (m^3/day per m^3) of Low Yielding Reactors

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Type	Range	Average
FC, Indian type	0.3 – 0.5	0.30
FD, Chinese type	0.1 – 0.3	0.15
Plastic bag	0.5 – 0.7	0.60
Prefab. steel	0.5 – 1.3	0.60
Horizontal	0.2 – 0.4	0.30
Source: (Nijaguna 2002)		

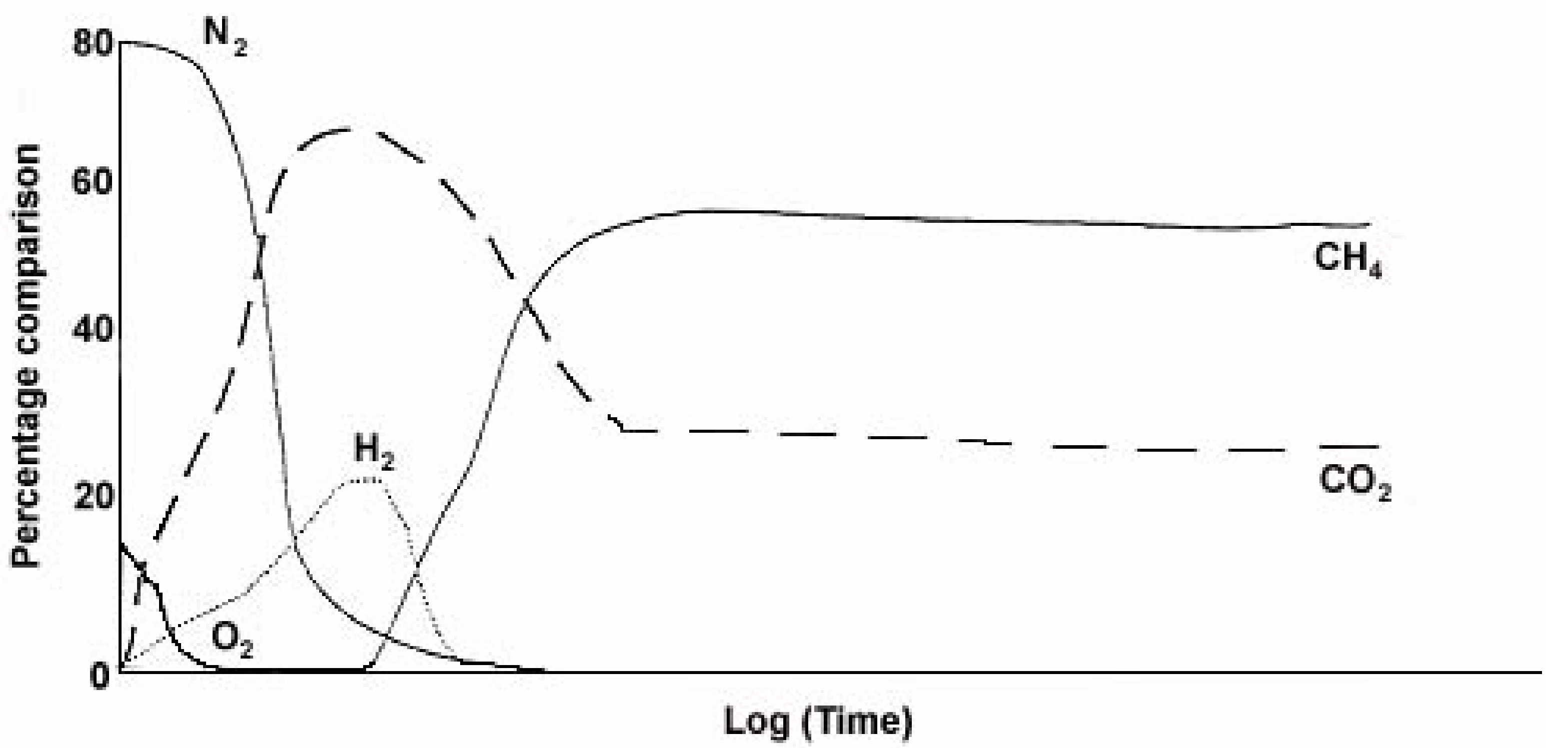
Typical Composition of Biogas

Compound	% Volume
CH_4	40 – 70
CO_2	30 – 60
H_2	0 – 1
H_2S	0 – 3
Other (NH_3)	0 – 2
Water vapour not included, Source: (Poulsen 2003)	

Biogas Cleaning

- Raw biogas is a wet gas containing a range of compounds.
- The gas must be cooled to condense the water vapour before the gas can be used.
- The gas transmission pipes should allow for draining.
- CO_2 is not normally removed.
- H_2S and SO_2 should be removed before used in boiler or engines.
- H_2S may be cleaned by adding a small amount of air (2 – 8 % by volume). Bacteria oxidise H_2S to S, H_2SO_3 or H_2SO_4.

Composition Changes for a Batch Reactor



(http://www.aeat.co.uk/mcpa/areas/software/facsimil/facsapps/app3.htm)

Energy Contents of Fuels

Fuel	LHV (MJ/kg)	(MJ/Litre) Liquid	MJ/N-m^3 Gas
Methanol	19.5	24.7	–
Ethanol	27	21	–
Diesel	43	36	–
Petrol	45	34	–
LPG	47	27	94.0
Natural gas	50	21	32.5
Methane	50	–	35.9
Hydrogen	120	8.5	10.8
Biogas	10 – 23	–	14.4 – 25.1

Biogas Domestic Appliances

(http://www.fao.org/WAICENT/FAOINFO/AGRICULT/AGA/AGAP/FRG/Recycle/biodig/manual.htm)

(http://www.topsaving.com/en/prod.html)

Biomass Feedstock

- Composition of biomass $C_aH_bO_cN_d$
- Which biomass feedstock is more suitable for anaerobic digestion (biogas production)?
  - Materials with high carbon content
  - Materials with high moisture content
  - Materials with high volatile solid
  - Materials with high biodegradable fraction or less lignin

Ultimate Methane Potential

$$C_aH_bO_cN_d + \left(\frac{4a-b-2c+3d}{4}\right)H_2O \rightarrow$$

$$\left(\frac{4a+b-2c-3d}{8}\right)CH_4 + \left(\frac{4a-b+2c+3d}{8}\right)CO_2 + dNH_3$$

$$B_{th} = 22.4\frac{\left(\frac{4a+b-2c-3d}{8}\right)}{12a+b+16c+14d} \quad (\text{Nm}^3\ \text{CH}_4\ \text{per kg VS})$$

Actual Methane Potential

- The actual methane yield from digester is always lower due to:
  - Part of organic input (substrate) is used for generation of bacteria (typical 5 – 10 % of input Volatile solid) [VS is defined as combustion loss at 550°C].
  - Part of substrate (lignin part of organic matter) exits the reactor without being degraded.

Biodegradable Fraction (*BF*)

- Chandler *et al*. (1980) formulated a mathematical correction for bioavailability of an organic substrate based on its lignin content.
- The data was collected from the anaerobic degradation of a range of lignocellulosic materials (40 day retention time).

$$BF = 0.83 - 0.28 \cdot PLC$$

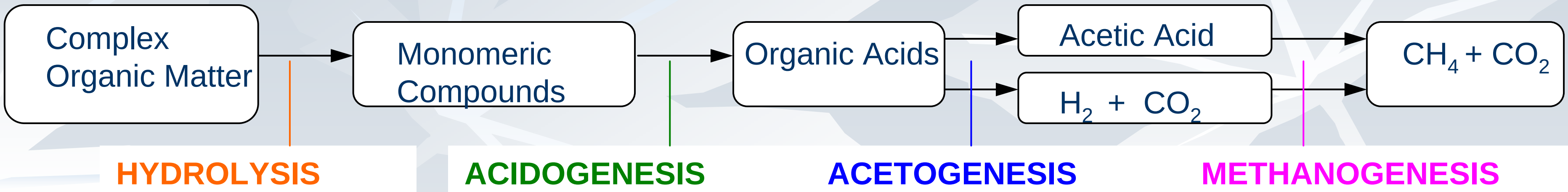
$$PLC = \text{The lignin content as a percentage of VS}$$

Substrate	Lignin %
Whey acid	0.0
Food wastes	0.4
Office paper	0.4
Pig manure	2.2
Chicken manure	3.4
Yard wastes	4.1
Ryegrass straw	5.0
Wheatgrass crest, Hay	6.0
Cow manure 1	8.1
Water hyacinth	8.7
Playboy magazine	9.0
Cow manure 2	10.1
Bagasse	11.0
Rice straw	12.5
Cardboard	12.9
Rice hulls	17.0
Sunflower hulls	19.0
Bamboo	20.0
Newspaper	21.9
Peanut hulls	23.0
Pine wood	27.8
Lignin content, Richard 1996	

Biodegradable Fractions of Various Substrate

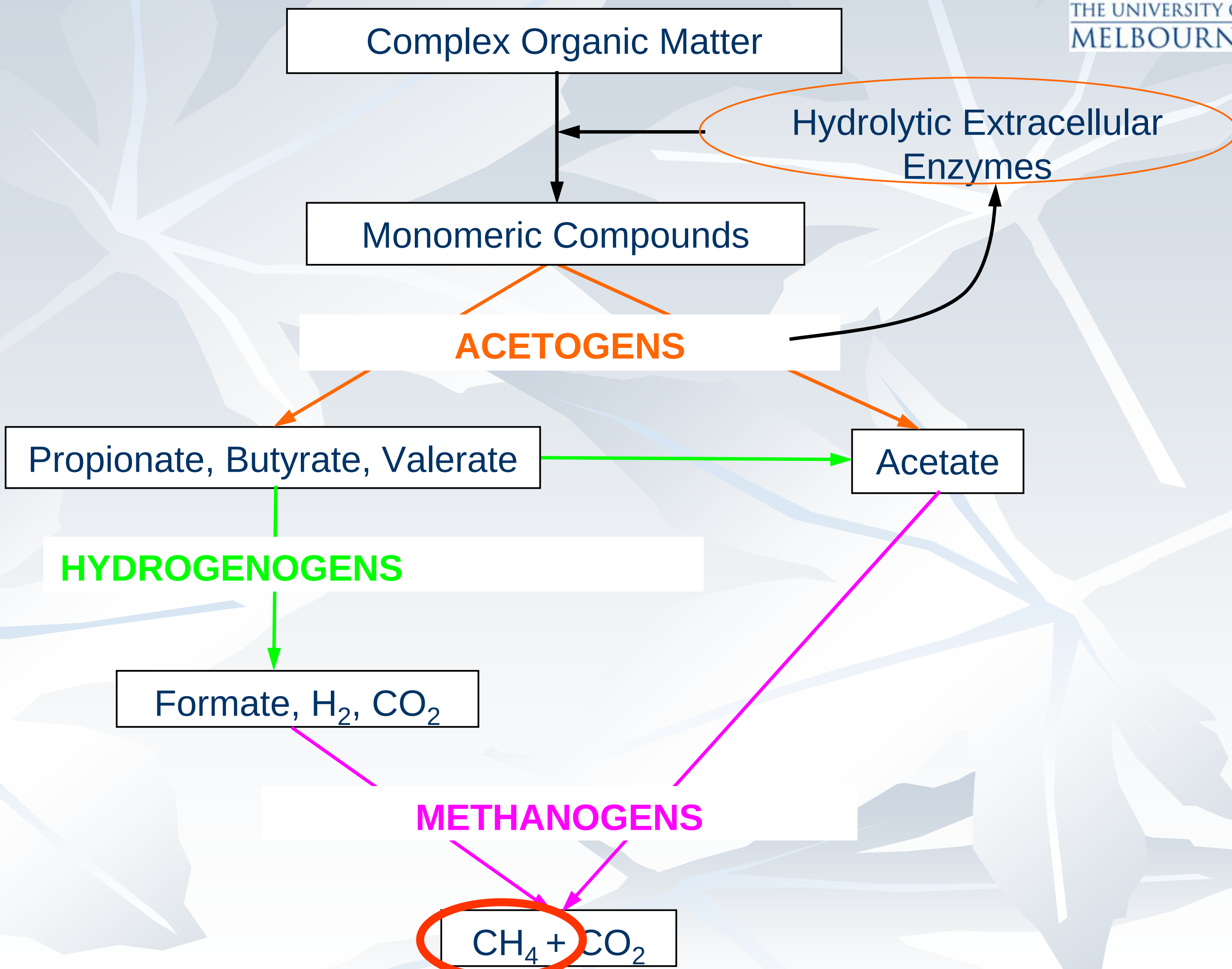
Substrate	BF
Food wastes	0.82
Office paper	0.82
Pig manure	0.77
Chicken manure	0.73
Yard wastes	0.72
Cow manure 1	0.60
Water hyacinth	0.59
Bagasse	0.52
Rice straw	0.48
Bamboo	0.27
Newspaper	0.22
Pine wood	0.05

Biological Processes



- Four phases
- Influencing factors:
  - Substrate properties (C/N-ratio, Particle size, Moisture content,..)
  - Retention time
  - Temperature (Mesophilic: 30-37°C; Thermophilic: 55-60°C)
  - Inhibitors (Fatty acids, Ammonia, CO_2, H_2S, H_2, O_2)

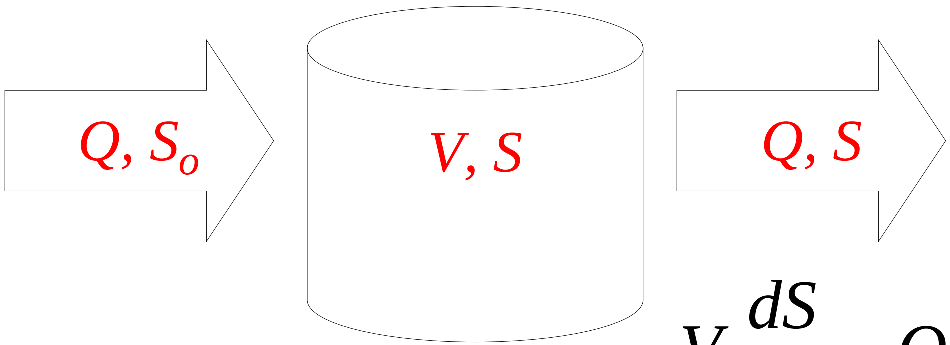
Biogas Digestion



Indicators of Process Performance

- Gas production
- Gas composition
- pH
- Alkalinity
- Total volatile fatty acids (VFA)
- Volatile solids (VS) reduction

Complete Mix Reactor Analysis



$$V\frac{dS}{dt} = Q \cdot S_o - Q \cdot S - K \cdot V \cdot S$$

V = Volume (m^3)

S = Substrate concentration (kg/m^3)

t = Time (day)

Q = Volumetric flow rate (m^3/day)

K = Degradation constant (day^{-1})

Steady State Operations

$$\frac{dS}{dt} = 0 \quad \text{and} \quad \frac{V}{Q} = HRT \quad \Rightarrow$$

$$\frac{S}{S_o} = \frac{1}{1 + K \cdot HRT}$$

$$S_o - S = K \cdot S \cdot HRT$$

Steps for Reactor Sizing

- Determine the degradation constant K
- Choose the desired removal efficiency $\eta = (S_o - S)/S_o$
- Calculate exit substrate concentration for a given inlet substrate concentration $S = S_o(1-\eta)$
- Calculate the design hydraulic retention time

$$HRT = (S_o - S)/K \cdot S$$

- Calculate the reaction volume $V = HRT \cdot Q$

Volumetric Methane Production Rate

$$B = (B_o S_o / HRT)[1 - K/(HRT \cdot \mu_m - 1 + K)]$$

$$B_o = \text{Ultimate methane yield (m}^3\text{/kg)}$$

$$S_o = \text{Influence volitile solid concentration (kg/m}^3\text{)}$$

$$HRT = \text{Hydraulic retention time (day)}$$

$$\mu_m = \text{Maximum specific growth rate (day}^{-1}\text{)}$$

$$K = \text{Dimensionless kinetic parameters}$$

Reference: (Chen and Hashimoto 1978)

Ultimate Methane Yield m^3/kg VS

Source: Chen and Harshimoto 1980

Dairy cattle	0.20 ± 0.05
Beef cattle manure on grain ration dirt lot	0.25 ± 0.05
Beef cattle manure on grain ration concrete lot	0.37 ± 0.05
Pigs	0.50 ± 0.05

Kinetic Parameters

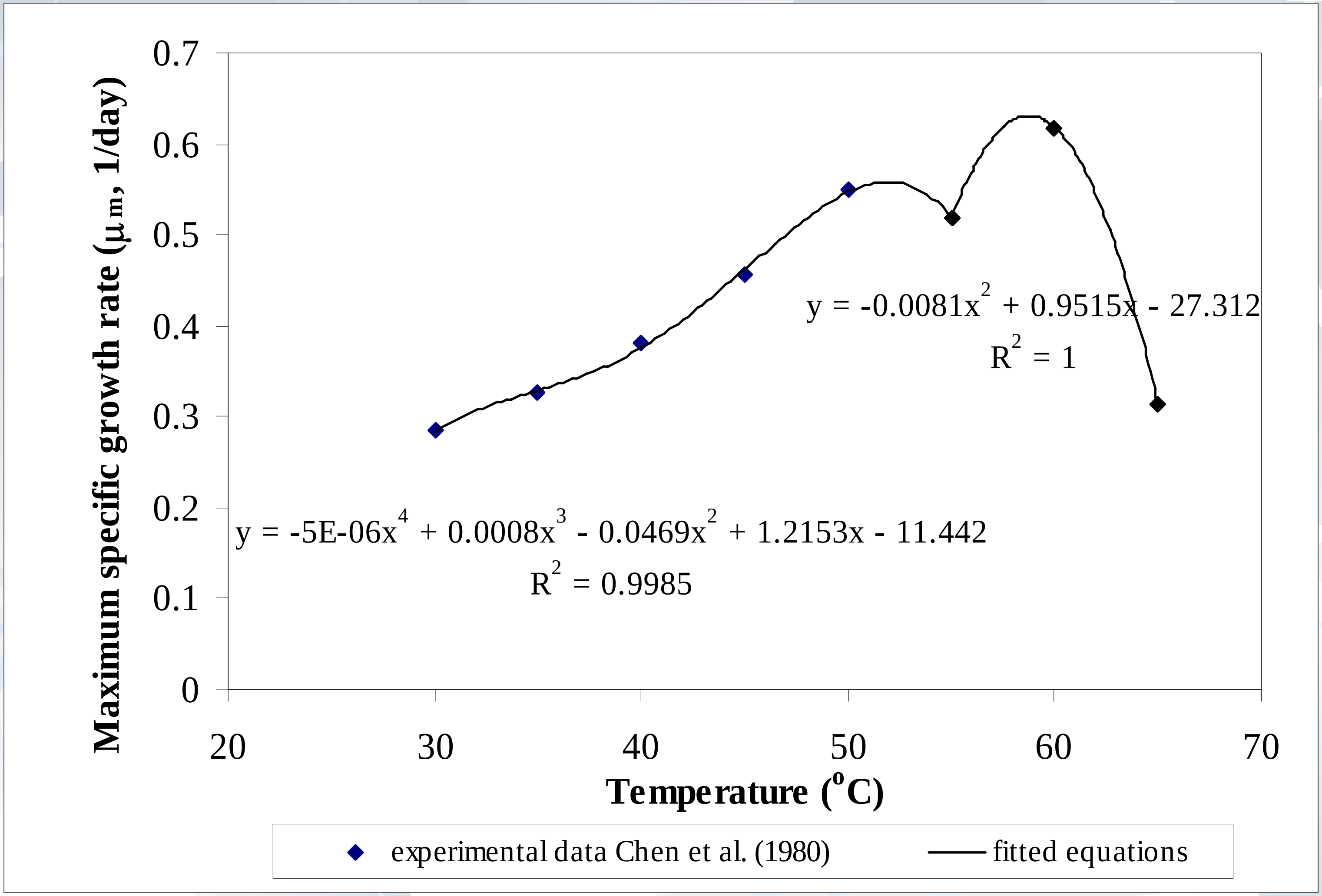
Source: Chen and Harshimoto 1980

$$K = 0.8 + 0.0016 \cdot \exp(0.06 \cdot S_o) \text{ for cattle manure}$$

$$K = 0.5 + 0.0043 \cdot \exp(0.051 \cdot S_o) \text{ for pig manure}$$

Growth Rate

(Source: Rifa'i 2002)



Life Cycle Costs

- Initial cost of digester with gas holder = US $ 50-60 per m^3 of digester volume
- 3 m3 per day biogas = 8.5 m^3 digester
- Typical life = 20 years
- Repair & maintenance ~2% of capital cost
- These would lead to a life cycle annual cost of US $ 50.

Technology Demonstration

- Location: Islamic School and Agriculture College of Darul Fallah (Pesantren Pertanian Darul Fallah), Bogor city, Province of West Java
- Owner: Indonesian Center of Agriculture Engineering Reseach and Development (ICAERD), Ministry of Agriculture, Indonesia
- Engineering team: Teguh W. Widodo, Elita Rahmarestia, Ana Nurhasanah, Ahmad Asari
- Capacity: 2 Nm^3/day of biogas production

Feedstock

- Type: A fixed dome digester made from clay bricks constructed under the ground level
- Feed source: 10 dairy cattle (milk producing cows)
- Feed: mixed slurry of cow dung and waste water from cattle cage (Note hot weather conditions made the farmer to shower the cattle three times a day)
- Trial stage, produced biogas and has been used for lighting and cooking
- More test results and seasonal data are expected

Construction

(Photo courtesy: Elita Rahmarestia, ICAERD)

Slurry Outlet

(Photo courtesy: Elita Rahmarestia, ICAERD)

Biogas Stove

(Photo courtesy: Elita Rahmarestia , ICAERD)

Biogas Lamp

(Photo courtesy: Elita Rahmarestia, ICAERD)

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