Part 8. Examples for biomass utilization

8.1 Small-Scale Biomethanation

8.1.1. What are biomethane and biomethanation?

Biomethane (sometimes referred to as "Biogas) is generated from organic materials as they decay. The main component of biomethane is CH_4 (55%-70%) and CO_2 (25%-40%). Biomethane can be used for cooking, lighting, heating, generating electricity and so on.

Biomethanation is the process of conversion of organic matter in the waste (liquid or solid) to biomethane and manure by microbial action in the absence of air, known as "anaerobic digestion."

8.1.2. Situation of biomethane in China

The annual quantity of waste in China is more than 150 million tons. The production and disposal of large quantities of life and industrial waste without adequate or proper treatment result in widespread environmental pollution. While some of these wastes can be collected and biomethane is generated from anaerobic digesters where the manure decomposes. Especially in some far rural area where the transportation of electricity is expensive, biomethane is a good way to provide energy for cooking, lighting and heating, etc.

Since 1950s, Chinese governments encouraged small-scale biomethanation using animal and agricultural waste as feedstock. Table 1 shows the rural biomethane development in China. Till 2006, about 20 million families in rural area are using biomethane for cooking and lighting. Annual consumption reaches 5 million standard coal equivalent. Subsidy of 2.5 billion RMB from government is for small-scale biomethanation development, which means one small-scale biomethanation can get subsidy of 800-1200 RMB. China nation government plans to build 30 million biomethane digesters in 2010 and 45 million biomethane digesters in 2020.

Table 8.1.1. Survey of rural biomethane in China, 1991-2005.

Year	Biomethane digesters (million)	Annual output (billion m^3)
1991	4.75	1.11
1995	5.70	1.47
1999	7.63	2.25
2001	9.57	2.98
2002	11.10	3.70
2003	12.89	4.58
2004	15.41	5.57
2005	18.07	7.06

8.1.3. Characteristics of small-scale biomethanation

In China, the area of small-scale biomethane digester is about 6-8 m^2. Annual output is 300 m^3. Cost of each biomethane digester is 1500-2000 RMB.

In spite of providing energy, biomethane in China also has the following characteristics: 1) environment friendly. For an 8-10 m^3 biomethane digester, dejecta of 5-8 pigs or 2000-3000 chickens can be used. 2) The residues in the digester can also be used for fertilizer. 3) economically. It saves money of buying electricity or save labor of seeking firewood. And the woods can be saved.

8.1.4. Process of small-scale biomethanation

The process of small-scale biomethanation includes feedstock collecting, pretreatment, fermentation, treatment and purifying, storage and transportation, where the fermentation digester is the main equipment. The digesters are required to be airtight and impervious to make sure they are anaerobic. The temperature in the digester should be maintained at 20-40℃. There should be enough manure in the digester. Appropriate water (about 80%) content and pH (7-8.5) are required.

Batch fermentation and semi-continuous fermentation are usual technologies for small-scale biomethanation. In batch fermentation technology, all the feedstock is added at the first. The biomethane generates fast at the beginning and then decreases. This technology is easy for management, but the biomethane generation rates are different. In semi-continuous fermentation technology, 1/4 - 1/2 feedstock was added at the first. When the biomethane generation slows down, more feedstock is added to make the biomethane generation work in order.

8.1.5. Energy supply of small-scale biomethanation

Usually, the biomethane generation rate of digester is 0.2-0.25 $m^3/(m^3.d)$. So annual output of a 10 m^3 digester is about 600 m^3 biomethane. Usually, heat value of 1 m^3 biomethanol is equivalent to that of 3.3 kg raw coal. As mentioned in previous, annual consumption of biomethane reached 5 million standard coal equivalent in China. It is obvious that biomethane plays an important role in rural energy supply.

Further information

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8.2 Large Scale Biomethanation

8.2.1 Outline of large scale biomethanation

Anaerobic digestion has been in practical use for a long time. Its industrial installations had started as early as in around 1900. Since then, the anaerobic digestion systems have been continuously improved and enlarged to treat a wide range of biomass wastes such as food industry wastewater/waste, garbage, livestock waste, night soil and sewage sludge among others.

8.2.2 Large-scale anaerobic digestion systems

A typical anaerobic digestion system in large-scale is depicted in Fig. 8.2.1. The function of each unit process is described below.

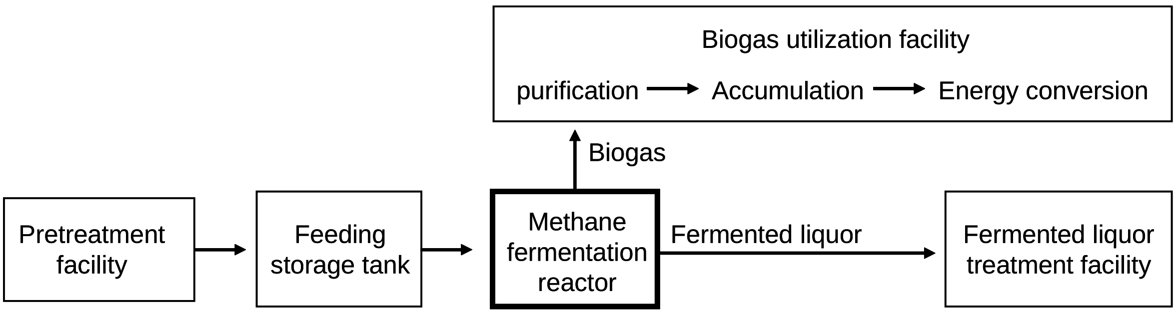

Fig. 8.2.1. A typical anaerobic digestion system in large-scale.

(a) Pre-treatment process

It is often required for an effective anaerobic digestion that the received biomass waste is conditioned in a pre-treatment process such as removal of foreign matters not suitable for anaerobic digestion, pulverization, dilution by water, thickening, and/or acid or alkali treatment. Some biomass wastes such as garbage, which is a mixture of various organic and inorganic matters, and, thus is not always consistent in its composition and properties, are subjected to mechanical and/or magnetic separation in order to get rid of indigestible materials such as metals and plastics. The separated biomass waste is pulverized and added with dilution water to prepare waste slurry for the next unit process.

(b) Slurry storage tank

Prepared slurry is temporarily stored in a slurry storage tank for leveling dairy fluctuations in both quality and quantity. If the ambient temperature is suitable, microbial activities of acidogens in the storage tank may increase. If this occurs, accumulation of organic acids in the slurry can cause a decrease in pH to as low as around 4. The slurry storage tank must be designed to resist corrosion due to such low pH conditions.

(c) Methane fermenter (anaerobic digester)

Three major functional microbial groups are active in the methane fermenter. These three functions that take place sequentially are; hydrolysis, acidogenesis and methanogenesis. The final products of the reactions are methane and carbon dioxide. The hydrolysis reaction is often the rate-limiting pathway of an anaerobic digestion process on not-readily biodegradable or recalcitrant biomass such as sewage sludge and ligneous biomass, whereas the methanogenesis is likely to be the rate-limiting pathway on readily biodegradable biomass such as garbage and starchy wastewater. In order to establish an efficient anaerobic digestion system, it is important to consider the rate-limiting pathway and to select the most suitable reactor design for the properties of anticipated biomass waste. For example, the overall rate of anaerobic digestion on readily biodegradable biomass waste heavily depends on the density of active methanogens in the reactor, thus the reactor should be designed to maximize the density or mass of the methanogens within the system.

(d) Fermentation wastewater treatment

Fermentation wastewater discharged from the anaerobic digester usually contains high concentrations of organic matters, nitrogen compounds and phosphorus compounds. The fermentation wastewater should be treated to reduce the concentrations of these pollutants to meet the standards for final discharge to a receiving body of water or sewer system. The most typical fermentation wastewater treatment system is the activated sludge process with tertiary treatment.

(e) Biogas utilization

Since most of the biomass wastes contain proteins (a source of nitrogen and sulfur) and sulfate salts, the biogas contains certain concentrations of hydrogen sulfide and ammonia. The biogas produced from sewage sludge, which sometimes contains a considerable amount of silicones, may contain siloxanes as well. Since these impurities can possibly cause damage to biogas utilization facilities such as a gas engine, gas boiler, gas turbine and fuel cell, and/or cause secondary air pollution, a biogas utilization unit process is often equipped with a desulfurization device and/or siloxane remover prior to the gas holding tank.

8.2.3 Examples of large-scale anaerobic digestion systems

Some of the typical implementations of large-scale anaerobic digestion systems are described below.

(a) Sewage Sludge

Sewage sludge is a waste biomass which is discharged in large quantities from sewage treatment facilities. For a long time, anaerobic digestion has been one of the treatments on sewage sludge to stabilize the sludge and reduce its volume. The reactor design usually applied to sewage sludge digestion is a completely mixed reactor design (Fig. 8.2.2). A contemporary anaerobic digester for sewage sludge is as large as 10,000 m^3 in the effective volume. Typical design parameters include the operational temperatures of ambient (ca. 20 degC) to mesophilic (ca. 35 degC) range, and the relatively long retention time of 20 to 30 days.

(b) Industrial organic wastewater

Industrial wastewater containing readily biodegradable organic matters, but little solids, such as the wastewater discharge from a beer brewery, the UASB (up-flow, anaerobic sludge blanket) reactor design, which was originally developed in the Netherlands, is usually selected. The UASB reactor design maintains a high density of anaerobic microorganisms in the form of self-aggregated microbial "granules" that enables a high rate of anaerobic digestion.

(c) Organic wastes from food industries

Anaerobic digester designs which allow a high rate anaerobic digestion on readily biodegradable biomass containing high concentrations of organic solids are being developed, and some have already been in actual operation in recent years. An example of such a new design is the DAPR (down-flow anaerobic packed-bed reactor) design. Many high-rate anaerobic digestion facilities for food wastes and distillery wastes, incorporating the DAPR design, have been implemented in Japan. The largest facility as of writing has the design capacity of 400 tons/day (Fig. 8.2.3).

Fig. 8.2.2. Example of a large scale sewage sludge anaerobic digester.
(Northern second sewage treatment plant)

Fig. 8.2.3. Example of a large scale biomethanation plant of food waste.
(Distilled spirit processing waste recycling plant of Kirishima Shuzo co. LTD.)

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8.3 Jatropha Plantation

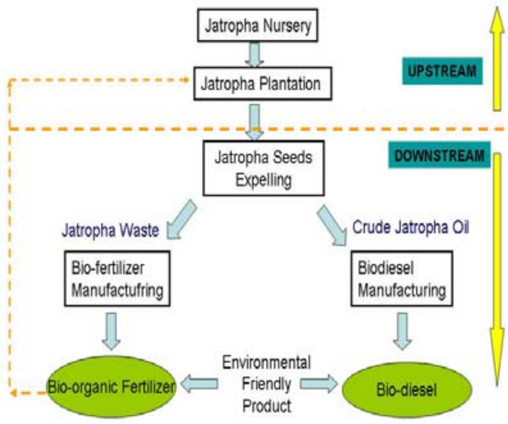

Fig. 8.3.1. Fully integrated jatropha business.

Jatropha integrated business consists of upstream and downstream activities. Upstream activity includes jatropha nursery and jatropha plantation. Down stream activity includes seeds expelling process where crude jatropha oil resulted can be used for biodiesel manufacturing, whereas jatropha by product/waste (i.e. seed cake, seed shell, glycerin) can be used to manufacture bio-fertilizer and other applications. Both activities are known as an environmental friendly products.

8.3.1 Jatropha cultivation

Fig. 8.3.2. Jatropha plantation. (Bambang P., 2007)

Cultivation of Jatropha is uncomplicated (Fig. 8.3.2). *Jatropha curcas* can grow in wastelands/marginal areas and grows almost anywhere, even on gravelly, sandy and saline soils. It can thrive on the poorest stony soil and grow in the crevices of rocks without competing with annual food crops, thus filling an ecological niche. Complete germination is achieved within 9 days. Adding manure during the germination has negative effects during that phase, but is favourable if applied after germination is achieved. However, it is usually multiplied by cuttings, because this gives faster results than multi-plication by seeds. The flowers only develop terminally, so a good ramification (plants presenting many branches) produces the greatest amount of fruits. Another productivity factor is the ratio between female and male flowers within an inflorescence (usually about 1 female to 10 male flowers - more female flowers mean more fruits).

Jatropha curcas can grow at annual rainfall of 300 - 2,380 mm, with the optimum rain fall on 625 mm/year. The best time to start planting is in dry season or before the rainy season, with the annual average temperature is 20 - $28^{o}C$.

8.3.2 Propagation method

There are two propagation methods, i.e. Generative (seeding) and Vegetative propagation (cutting). For monoculer business, satisfactory planting widths are 2 x 2, 2.5 x 2.5 and 3 m x 3 m. This is equivalent to crop densities of 2,500, 1,600 and 1,111 plants/ha. However, plants propagated by cutting show a lower longevity and posses a lower drought and disease resistance than plants propagated by seeds. Only during its first two years does it need to be watered in the closing days of the dry season. Ploughing and planting are not needed regularly, as this shrub has a life expectancy of approximately forty years. The use of pesticides and other polluting substances are not necessary, due to the pesticidal and fungicidal properties of the plant.

Fig. 8.3.3. Jatropa fruits and seeds.

1 ha of jatropha plant normally will give yield to 2,250 kg of seeds (Fig 8.3.3 Jatropha fruits & seeds) and 750 kg of oil, hence the ratio of seed to oil is 3: 1. Seed oil can be extracted either hydraulically using a press or chemically using solvents, however, chemical extraction cannot be achieved on a small scale basis.

8.3.3 Jatropha biodiesel

Esterification – Transesterfication known as 'estrans' process (Fig. 8.3.4) has been developed and patented by Prof. R. Sudradjat (2003). There are two stages in this process :

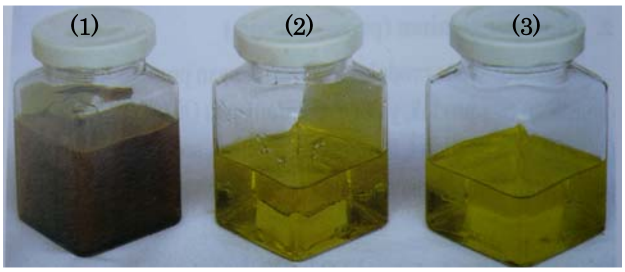

Fig 8.3.4. 3 grades estrans quality.

1. In this esterfication process, free fatty acid (the main cause for biodiesel acidity) is transformed to

biodiesel (methyl ester).

2. Triglyceride and fatty acid which are still bonded in triglyceride in the oil is converted to methyl ester via transesterification. By this process, oil conversion to biodiesel (without glyceroyl) of 99.75% can be achieved.

Other feature of this process is the usage of methanol/ethanol reactant can be reduced to < 20% and HCl catalyst can be substituted with solid catalyst from natural substance (FKS) which is much cheaper and can be recycled.

From a production cycle, three grades estrans quality (Fig. 8.3.4) can be obtained : 1) Crude Jatropha Oil (CJO) - as a substitution of kerosene or residue which can be used for direct combustion; 2) Jatropha Oil (JO) - as diesel oil (ADO) substitution for engines with have low rpm (such as portable generator set, tractor/bulldozer, etc.; 3) Biodiesel as fuel (automotive).

Fig. 8.3.5 shows the typical process diagram for jatropha biodiesel production from the seeds. It can be seen, it involves washing, blanching and drying of seeds before proceeding into peeling process. The resulted seed meat is grinded with a grinding machine, the grinded powder is pressed by a hydraulic pressing machine (manual or electric). The crude jatropha oil (CJO) then can be extracted and the residue seed cake can be utilized for animal feedstock, biopesticides, etc.

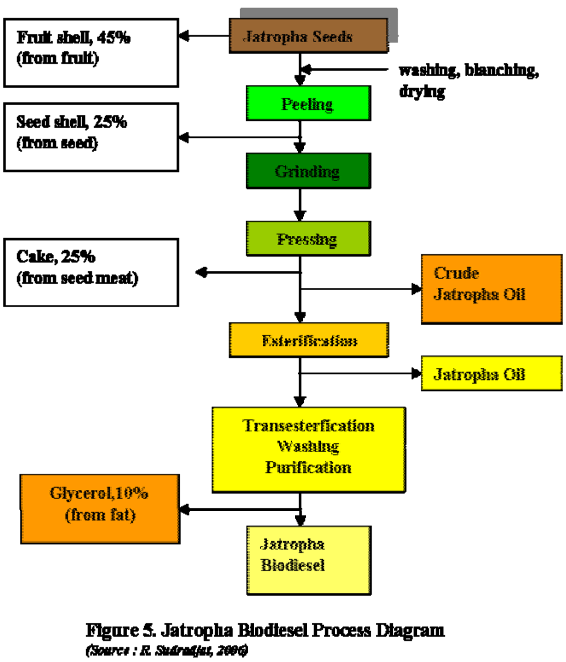

Fig. 8.3.5. Jatropha Biodiesel Process Diagram.
(*Source: R Sudradjat, 2006*)

The production of Jatropha Oil (JO) is carried out by using a estrans reactor where JO is heated at temperature between 50 – 60°C. Methanol as a solvent (5%) is used and HCl catalyst (10% v/v) is applied and then mixed them together. The esterification process will take 2 hours at 50°C. The mixture will direct to a glycerol separator where the aging process will take 4 hours. The glycerol (white paste) will stay at the bottom part whereas the top part JO can be extracted and feed to water separator and neutralization. In this water separator, JO is rinsed twice by using demineralization water, then neutralization is done by using 0.01% of $NaHCO_3$ and finally the deminineralization using water is carried out again. The final product will be pumped out to the storage tank.

Biodiesel production : JO is fed into an estran reactor with the temperature of 50 – 60°C. The mixture of methanol (10% v/v) and KOH catalyst (0.5% v/v) is then put into the reactor. Stir properly during transesterification process for 0.5 – 1 hour and keep the temperature at about 50°C. Separate the biodiesel from glycerol with the same procedure as JO making. Same procedure also for washing and neutralization process, but in here use 0.01% of CH_3COOH instead of $NaHCO_3$. Finally, the final product of Jatropha biodiesel is ready to be used as diesel fuel (ADO) substitution. The characteristic of Jatropha biodiesel is shown Table below.

Table 8.3.1. Characteristic comparison of Jatropa Oil, Biodiesel CPO & Diesel Oil.

(Source : Soerawidjaja, Tatang H, 2005)

Parameter	Jatropha Oil	Biodiesel CPO	Diesel Oil (ADO)
Density (g/cm3)	0.92	0.87	0.841
Viscosity (cSt)	52	-	6 – 11.75
Cetane number	51	64	51
Flash point (℃)	240	182	50
Sulfur (ppm)	0.13	0.0068	1.2
Iodin number (mg iodin/g)	105.2 ± 0.7	-	-
Acid number (mg KOH/g)	3.5 ± 0.1	0.5	-
Calorific value (kcal/kg)	9,720	8,783	10,200

8.4 Power Generation from Rice Husk

8.4.1 Power producer promotion in Thailand

In 2007, Ministry of Energy (Thailand) has strongly promoted SPP (Small Power Producer: 10-90 MW) and VSPP (Very Small Power Producer: < 10 MW), in particular those using biomass, with high grid buyback price of electricity and simple procedure for obtaining license permit in order to cope with the energy situation. As of October 2007, there are more than 77 SPP and VSPP with installed capacity over 1,100 MW, half of which are sold back to the grid.

8.4.2 Biomass power plant in Thailand

As shown in Fig. 8.4.1, biomass power plants are all distributed throughout the country, especially in the central and northeastern parts. In term of the electricity sold back to the grid, more than half of the power plants use bagasse as the feedstock fuel, followed by rice husk/Eucalytus bark of 31%, as shown in Fig. 8.4.2.

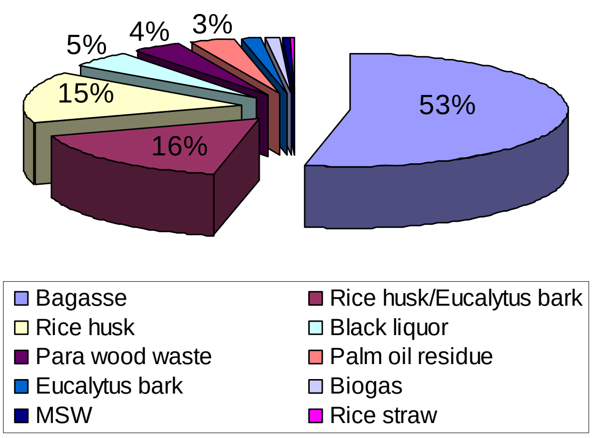

Fig. 8.4.2. Biomass Power Plants by Fuel (Grid).

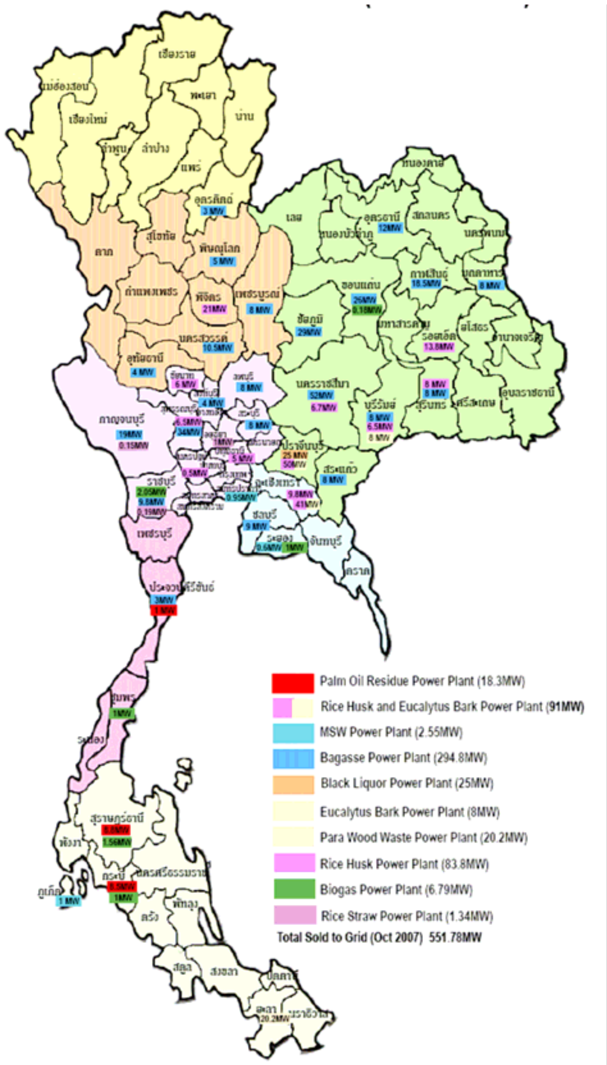

Fig. 8.4.1. Distribution of Biomass Power Plant in Thailand

Source: adapted from Energy for Environment Foundation (http://www.efe.or.th)

8.4.3 Gasification technology for rice husk

Despite many biomass power plants, some of them are still running at the low efficiency using conventional burning to produce a steam for power generation. Hence, thermo-mechanical conversion process like gasification technology can help solve the problem. Rice husk is another attractive feedstock for biomass power plant due to its plentiful availability from the rice mills, its small size and low moisture. Recently, Ministry of Energy has funded a project to demonstrate the feasibility of constructing the community biomass gasification system (using rice husk) to Kasetsart University and Great Agro Co., Ltd. This project was initiated to foster Sufficiency Economy philosophy by His Majesty the Kind of Thailand. The system produces not only 80kW electricity but also heat and biomass ash for fertilizer, as shown in Fig. 8.4.3. The system design uses three-stage fluidized bed pyrolysis and gasification, comprising of 5 main units: drying, pyrolysis, gasification, cooling system and engine/generator set, as shown in Fig. 8.4.4.

Fig. 8.4.3. Concept of Biomass Gasification System.

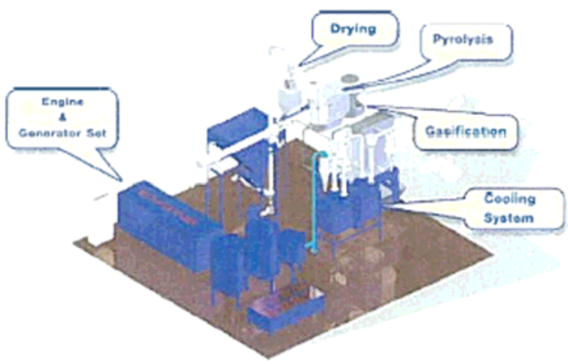

Fig. 8.4.4. Units of Gasification System.

As shown in Fig. 8.4.5 and 8.4.6, the system was installed at Lamlukka Cooperative Rice Mill & Paddy Center Market Co., Ltd for demonstration and test run for more than 360 hours. With gas flow rate of 240 m^3/hr (heating value at 4.5 MJ/m^3) and rice husk consumption of 85 kg/hr, the overall gasification system efficiency is 92%. In other words, 1.25 kg/hr consumption of rice husk generates 1 kW of electricity. Furthermore, the residue tar volume from the system is approximately 22 mg/m^3. On the economic analysis, this 80kW system requires a capital investment of ~3.9M Baht with the operating cost of ~1.79 Baht/unit. Assume that the system produces the electricity at 460,800 unit/year, which substitutes the electricity cost of 3 Baht/unit, the net profit is estimated to be 0.56M Baht/year with the payback period of 7 year. The next step would be the collaboration between MTEC and Great Agro Co., Ltd to scale up the system to 1MW capacity.

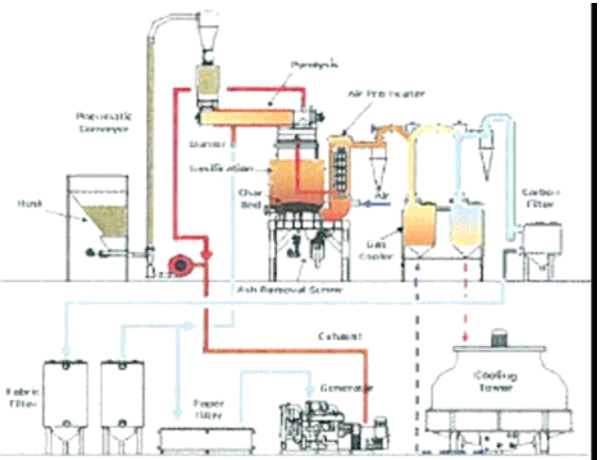

Fig. 8.4.5. Flow Diagram of Gasification System

Fig. 8.4.6. Test Run of the Complete Set

Further information

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8.5 Ethanol Production

8.5.1 What is a good source for ethanol production?

In Thailand, most existing commercial ethanol production plants use molasses as a feedstock but with increasing new facilities to use cassava in the near future. However, these two energy crops are still considered as food, which may interfere with the 'food vs. fuel' issue. As a result, more people are looking for alternative non-edible energy crops. Among many others, lignocellulose from various agricultural residues has received a great deal of attention, commencing the era of 2nd generation lignocellulosic bioethanol.

8.5.2 Lignocellulosic biomass feedstock for ethanol in Thailand

Each year in Thailand, agricultural industries generate millions of tons of various lignocellulosic biomass feedstock known as agricultural residues, including rice straw, sugar cane bagasse, corn stover/fiber and wood chip. Sugarcane and rice, mostly concentrated in the North and Northeastern provinces, are the first two largest national agricultural productions (in weight) as shown in the table below.

Table 8.5.1. The first four largest agricultural production in Thailand (2004).

	Sugarcane	Rice	Cassava	Maize
Production (thousand tons)	64,974	27,038	21,440	4,216
Harvested Area (thousand rai*)	7,009	63,709	6,608	6,810
Yield per rai (kilograms)	9,270	424	3,244	619

Source: Office of Agricultural Economics (2004) * 6.25 rai = 1 hectare

In general, these residues are inefficiently utilized, which most often, also causes environmental problems. Rice straw is considered wastes and disposed off through various methods such as open-air burning (as shown in Fig. 8.5.1 and 8.5.2), dumping or animal feeding. A rather more attractive method to mange these abundantly available rice straws is through cellulosic ethanol

Fig. 8.5.1. Open-air burning causes air pollution.

Fig. 8.5.2. Burning also causes soil pollution.

8.5.3 R&D pioneer work on processing

Since lignocellulose is mainly composed of cellulose, hemicellulose and lignin, it needs additional pretreatment in order to get sugar monomer ready for the fermentation process.

Typical process requires SHF (Separate Hydrolysis and Fermentation) of great complexity involving pretreatment, fractionation, delignification, hydrolysis and fermentation. Alternatively, pretreatment with proper steam explosion yields the hydrolysate, which can be enzymatically digested and fermented in a single reactor via SSF (Simultaneous Saccharification and Fermentation) method, as shown in Fig. 8.5.3, 8.5.4 and 8.5.5, involving only the pretreatment and hydrolysis/fermentation steps. The goal is to seek for the appropriate SSF that uses a commercially available cellulase enzyme and microorganism available in Thai market.

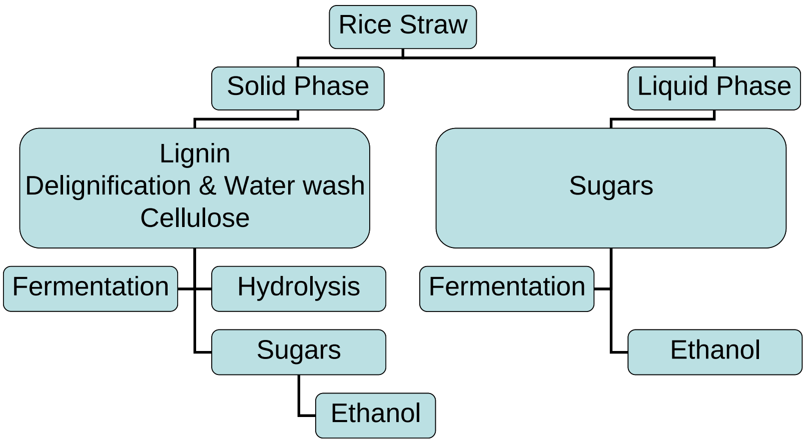

Fig. 8.5.3. Typical process of lignocellulosic ethanol production.

Fig. 8.5.4. Prototype of steam explosion unit.

Source: C. Pomchaitaward *et al*, MTEC report (2007)

The steam explosion was applied to rice straw Supunburi1™ showing good carbohydrate recovery and high ethanol concentrations obtained in a single reactor with minimal enzyme and yeast supplementation. A 150 g of dried rice straw was steamed with pressure between 10 to 25 bar (with corresponding temperature 185 and 210 ℃, respectively) for 5 minutes. Higher steam pressure (or higher temperature) favored hemicelluloses solubilization. However, the strong influence of steam pressure on the cellulose solubilization was not found. The optimum

Fig.8.5.5. Exploded rice straw.

pretreatment condition resulted in the production of a very small amount of sugar decomposition products, which enabled an effective fermentation of sugars to ethanol. In conclusion, mild steam pretreatment condition at 15 bars for 5 minutes results the highest hydrolysis yield.

This process substantially reduces the complexity of the overall rice straw to ethanol bioconversion, while simultaneously lowering the capital investment cost and time associated with the need for separate processes. Furthermore, it significantly lowers environmental impact due to less hazardous process chemicals and conditions involved. Last but not least, it provides an alternative for better energy efficiency in agricultural residue management.

Further information

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