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Biothermal Gasification—A Critical Review

(Ms) T Bhowmik, *Non-member*

Dr G K Roy, *Associate Member*

Increase in production in the agricultural sector has posed a new problem in the disposal of the residues obtained during harvesting and downstream processing of the agro-products. In addition large quantities of municipal and sewage sludges from the cities are discharged in to adjoining waterways after undergoing costly systems of treatment. Biothermal gasification of the above-mentioned residues is an effective method of utilization. The process provides an alternative means for the production of usable energy in addition to solving the waste disposal problems. This paper reviews the various conversion processes of biomass in general and the biothermal gasification process in particular. Suitability of the process in the Indian context has also been discussed.

INTRODUCTION

The conversion of biomass into energy has received increased attention in recent years. The upward spiral in the price of fossil fuels coupled with impending shortages has made biomass attractive as a supplemental source of energy, Biomass represents a renewable, low-sulphur energy resource. Coal and nuclear energy are likely to create environmentalproblems, while production and use of biomass energy represents a balanced carbon cycle. This is because the amount of carbon dioxide released by its production is almost equivalent to the amount absorbed by plants from the atmosphere through photosynthesis. Also, conversion of biomass reduces environmental impact by conversion of organic mass residues. In view of these, biomass energy will become the most useful energy resource of future, especially in the tropical countries.

BIOMASS

Any source consisting of biodegradable component is a biomass. Apart from this, various kinds of agricultural and forest residues, sewage sludges, municipal solid waste, wastes from organic chemical industries like' sugar mills, breweries and -unwanted vegetation such as water hyacinth, kelp, algae and other marine vegetation can be used as sources for biomass.

BIOCONVERSION PROCESSES

Conventional processes for the conversion of biomass to produce usable energy forms are either thermal or biological. Thermal processes can either be of direct combustion or gasification types whereas the biological process is a case of an aerobic digestion (bio-gasification). Direct combustion of biomass is losing importance due to its low energy conversion efficiency and environmental impact. Further this method of exploitation of biomass energy also poses storage and handling problems.

Biogasification process is effective for the conversion of a wide variety of biomass to synthetic natural gas and medium calorific gases. The main advantages claimed of this process are:

(i) ability to process both dry and wet feeds

-(ii) methane and carbon dioxide are the product gases

(iii) process requires low temperature and pressure

(iv) relatively inexpensive and a simple reactor design and operating procedures.

However, there are two major limitations of biogasification. A desirable fraction of the biomass may be refractory to biological decomposition thus resulting in reduced conversion efficiencies and large quantities of unconverted material requiring end use or waste disposal. A second limitation is that many potentially attractive feedstocks are unsuitable to anaerobic digestion due to insufficient nitrogen and other-inorganic nutrients present therein. Many of these feedstocks need supplementary nutrient to bring the ratios of

carbon: nitrogen (|q-) and carbon:phosphorous (^-\

to less than 15 and 75, respectively—the generally recommended values for a good biological conversion. Table 1 lists the nutrient content of some common biomass.

Thermochemical gasification which converts biomass to synthetic natural gas and low-to-medium calorific gases, has high conversion efficiencies and rates. However, the process has several drawbacks, such as.

(i) requirement of low-moisture content feedstocks

(Ms) T Bhowmik and Dr G K Roy are with Regional Engineering College, Rourkela.

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TABLE 1 CARBON—NITROGEN AND CARBON—PHOSPHOROUS RATIOS OF VARIOUS COMMON BIOMASS

BIOMASS	$\frac{C}{N}$	$\frac{C}{P}$
Sewage Sludge	8	50
Municipal Solid Waste (MSW)	76	204
Bamboo	177	710
Bermuda Grass	40	194
Pine Tree	432	2595
Eucalyptus	490	446
Water Hyacinth	10	94

(ii) utilization of complex and expensive equipment

(iii) high temperature and high pressure operation

(iv) production of low quality gases

(v) less control on product gas composition.

Since a feed moisture content of less than 60 % is required for a positive energy balance from thermal conversion, biomass species like water hyacinth and sewage sludge are unsuitable for direct thermochemical gasification without pre-drying (Table 2).

TABLE 2 MOISTURE CONTENT OF VARIOUS BIOMASS

BIOMASS	MOISTURE, %
Sewage Sludge	89—97
Municipal Solid Waste	20—60
Bermuda Grass	20—60
Eucalyputus Tree	40—50
Bamboo Tree	40—50
Water Hyacinth	94—96

HYBRID BIOTHERMAL CONVERSION (BIOTHERM-GAS PROCESS)

This process developed by the Institute of Gas Technology, Chicago is a combination of biological and thermochemical processes in such a manner that total conversion of the organic component of biomass is accomplished and sufficient ammonia is produced to supply the needs of the biomethanation process. This process combination broadens the spectrum of feed suitable for single conversion scheme, reduces the quantity of undesirable liquid and solid process residues and enhances the overall thermal efficiency as compared to each of the separate processes.

Process Description

Fig 1 depicts a general process scheme for the biotherm-gas process. Chopped and ground biomass is first subjected to anaerobic digestion in slurry form. The digester effluent is then transferred to a thermochemical gasification process after reducing its water content to less than 60% by mechanical dewatering. Synthesis gas obtained from gasifier contains hydrogen, carbondioxide, carbon monoxide, hydrocarbons and ammonia (obtained from nitrogeneous matter of the solids). The synthesis gas is quenched and recycled to the digester to produce additional methane by the biomethanation reactions:

$$CO + 4\,H_2 \rightarrow CH_4 + 2\,H_2O$$
$$CO + 3\,H_2 \rightarrow CH_4 + H_2O$$
$$4\,CO + 2\,H_2O \rightarrow CH_4 + 3\,CO_2$$

Phosphorous and other inorganic nutrients necessary in the biological operation may also be recovered from the ash of the thermochemical gasifier and recycled to the feed as needed.

Biotherm-gas process has such advantages over biogasification as:

(i) results in high conversion of organic matter with high methane yield and low residue.

(ii) improves digestion kinetics.

(iii) feed-nutrients' requirement for biological conversion can be minimized by nutrient recycle.

(iv) thermochemical ash may improve digester effluent solids dewatering.

(v) heat integration results in increased process efficiencies.

Compared to thermochemical gasification, the following advantages are claimed by the biotherm-gas process:

(i) applicable to the processes of both dry and wet feed.

(ii) thermochemical process gases can be biomethanated thereby eliminating additional equipment and process steps.

(iii) heat integration results in high process efficiencies.

Biogasification and thermochemical gasification are the two important process steps in case of the biotherm-gas process.

BIOGASIFICATION

Biogasification or digestion, as it is called, is accomplished in bioreactors. Bioreactors used for digestion can be defined as a system of single or multiple vessels in which microbial or biochemical reactions are carried out employing free cells, immobilized cells, free enzymes or immobilized enzymes in batch, fed batch or continuous operations. Surface reactors, pneumatic reactors, fully filled reactors, cyclone reactors, fixed film reactor, deep shaft reactor, immobilized enzyme/cell reactors and membrane reactor are the common types of bioreactors. Out of these, the cyclone reactor is suitable for both anaerobic and aerobic digestion. In this reactor, the cells are circulated around a closed loop to effect mixing and homogeneous cultivation instead of agitation stirring in a tank. Special advantages are a high gas exchange; no use of antifoam and no wall growth. Based on biogasification a new type of biogas generator has been developed by the National Institute of Science and Technology, Manila, Phillipines, to produce methane from agricultural wastes and garbage. •

THERMOCHEMICAL GASIFICATION

In case of thermochemical gasification, a fluidized bed is ideal for the rapid processing of biomass naterial because continuous feeding and rapid heat transfer is possible. The biogasification processes can be classified according to how the heat is supplied to gasification as:

(i) heat carrier processes.

(ii) partial oxidation processes.

(iii) steam cracking processes.

The heat carrier process, which is essentially a gasification process with the necessary heat supplied by combustion of the residual char of the biomass material itself, has been found to be the most appropriate for the gasification of biomass in order to obtain a high calorific value, without the use of steam. In Japan gasification of biomass (Lauan wood chips and peanut shells) was carried out in a bed of microspherical alumina particles with nitrogen as the fluidizing medium in the temperature range of 400-1000°C. It was found that the total gas yield increased and the char yield decreased with the increase of bed temperature (Table 3).

TABLE 3 EFFECT OF FLUDIZED BED TEMPERATURE ON THE YIELD OF GAS AND CHAR

BD TEMPERATURE, °C	GAS, WEIGHT %	CHAR, WEIGHT %
600	31.0	24.5
700	49.7	22.9
800	63.8	18.8
900	75.6	13.9
1000	87.2	19.0

The composition of the product gas with a maximum calorific value of 3 870 kcal/Nm³ obtained at the gasification temperature of 900°C is given in Table 4.

TABLE 4 COMPOSITION OF THE PRODUCT GAS AS AT 900°C

CONSTITUENTS	AMOUNT ml/g (NET)	%
H_2	125	17.28
CO	310	42.87
CH_4	86	11.89
CO_2	158	21.85
C_2H_4	44	6.08

Thermochemical gasification of oak saw dust was conducted at 600-800°C in a synthesis gas from manure reactor operating as a counter-current fluidized bed in which the biomass (the saw dust) feedstock was fed to the top of the reactor and was fluidized by an air-steam mixture fed to the bottom. The heating value of the product gas was above 2 672 kcal/Nm³ and a typical composition is given in Table 5.

TABLE 5 COMPOSITION OF PRODUCT GAS FROM THE GASIFICATION OF OAK SAW DUST AT 700°C

CONSTITUENTS	AMOUNT, l/g, DRY ASH FREE DUST	VOLUME, %
H_2	0.180	15.65
CH_4	0.175	15.22
C_2H_4	0.060	5.22
C_2H_6	0.010	0.870
CO	0.465	40.44
CO_2	0.260	22.60
Total	1.150	100.00

APPLICATIONS OF BIOTHERMGAS PROCESS

Three applications of thei botherm-gas process have been investigated in the pilot plant scale, two with Bermuda grass and the third with municipal solid waste and sewage sludge.

Bermuda grass with its high moisture (60-70% w) and low nurient conttent $\left(\frac{C}{N} = 40 \text{ and } \frac{C}{P} = 194\right)$ is unsuitable to either thermochemical or biological gasification, but ideal for the combined biothermal process. Municipal solid waste, too, has low nutrient content $\left(\frac{C}{N} > 70 \text{ and } \frac{C}{P} > 200\right)$.

The biothermgas plant processing 10 000 dry t/day of Bermuda grass produces substitute natural gas of heat equivalent to about 28 × 10⁹ kcal. A temperature of 35°C is maintained in the digesters to undergo anaerobic digestion.

A two-stage reactor is utilized for thermal gasification. Temperature and pressure for the two stages were 800°C and 37.26 kg_f/cm^2(g) respectively for stage I and for stage II 925°C and 38.31 kg_f/cm^2 (g) respectively. The above process using biomethanation route has an overall plant efficiency of 76%.

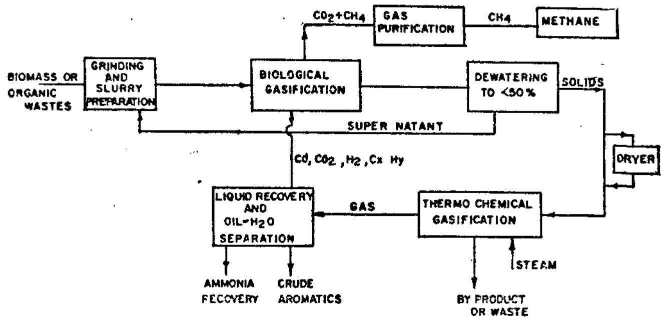

Fig 1 Biotherm-gas process

The biotherm gas process with biomethanation produces substitute natural gas of heat equivalent to 1.74 X 10^9 kcal from municipal sewage waste/sewage sludge blend (90:10) containing 1 OOO of municipal sewage waste. Analysis of the blend is given in Table 6.

TABLE 6 ANALYSIS OF MUNICIPAL SLUDGE WASTE/ SLUDGE BLEND

(90% MUNICIPAL SEWAGE WASTE + 10% SLUDGE, DRY WEIGHT)

Total moisture, total weight %	31.1
Total solids, total weight, %	68.9
Total carbon, dry weight, %	42.2
Total hydrogen, dry weight, %	5.6
Total oxygen, dry weight, %	31.9
Total nitrogen, dry weight, %	1.2

The total plant efficiency was found to be 71.6%. Temperature in anaerobic digester was maintained at 35°C. A single stage reactor with a temperature of 325°C and pressure of 24.6 kg/cm^2 (g) was used for thermal gasification. A carbon conversion of 95% was obtained.

SIGNIFICANCE OF THE BIOTHERMGAS PROCESS IN THE INDIAN CONTEXT

In order to produce energy from the biomass using the biothermgas process in India, it is essential to identify organic residues, which are abundantly available, eco-

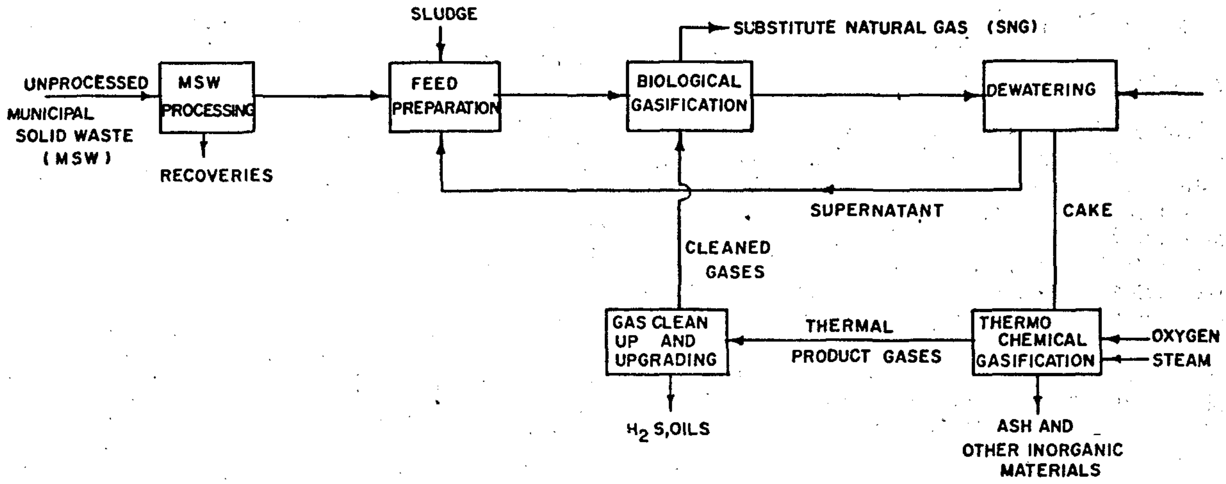

Fig 2 Flow diagram for the conversion of municipal solid waste-sludge blend to synthetic natural gas using biomethanation

nomical to collect or harvest and easily convertible. Table 7 lists some of the major biomass species which are available either as agricultural residues or agro-industrial bi-products. In addition there is excellent scope for the growth of aquatic plants like water hyacinth and algae with a high yield (154 t/ha for water hyacinth and 80 t/ha for algae) which are ideal feed stocks for the biotherm gas process.

TABLE 7 POTENTIAL BIOMASS RESOURCES OF INDIA

Biomass Species	Availability, Mt/year	Coal Equivalent Mt/year
Rice straw and husk	109.9	74.1
Jute sticks	2.5	2.3
Wheat straw	50.0	37.5
Cotton stalks	13.0	11.0
Bagasse	28.1	22.4
Molasses	2.1	0.8
Coconut husk and shell	1.0	1.1
Oil seed cakes	6.7	0.9
Saw dust	2.0	3.4
Cow dung	1335.0	128.0
Total	1550.3	281.5

Some attempts have already been made to find a suitable feed stock for biogasification. A 10 m^3 biogas plant working on banana stem has been devised at Jyoti Solar Energy Institute. A type of water hyacinth abundantly available in water logged areas of the country particularly in West Bengal, Assam and Kerala has been used as a feedstock for a plant designed by the Central Mechanical Engineering Research Institute, Durgapur with an installed capacity of 3 000 litres of gas per day. Research on methane fermentation of water hyacinth is also being conducted in the Regional Research Laboratory, Jorhat.

In view of the proven advantages, the biothermgas process can be employed effectively for the conversion of biomass available in India. To start with, the process can be employed for the gasification of garbage (approximately 40000 t/day) in the large metropolies of the country. Synthetic natural gas produced from the waste by the biothermgas process can be converted to methanol, an ideal base material for the Petro-chemicals. The garbage gas can also be synthesized to make gasoline, diesel or ammonia for the fertilizer industry. This will, no doubt, be an economic proposition. To quote an example, around 500 t/day of methanol produced from the Bombay city garbage(3 600 t/day) will earn an annual revenue of Rs 92 crores. Therefore, waste gasification by the biotherm gas route can not only reduce the disposal problem of the residues to maintain a cleaner environment -but can convert "waste to wealth" also.

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