State-of-the-art of Utilizing Residues and Other Types of Biomass as an Energy Source

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ABSTRACT

Large quantities of agricultural and forestry residues are generated annually in the developing countries. A judicious use of these could play an important role in mitigating the environmental impacts of non-renewable energy use, particularly global warming and acid rain. This paper presents a review of different residue energy technologies with the emphasis on new developments in the thermo-chemical processes.

Traditional biomass combustion systems offer a great deal of scope for modernization and efficiency improvement. Owing to relatively new and emerging reactor designs, for example atmospheric and pressurized fluid beds, biomass combustion is poised to play a more important role in the future.

Although conventional charcoal gasification presents no particular operational problem, field acceptance of the technique is insignificant so far because of the low rate of return on investment. Moreover, in general, tar has remained an unresolved problem in uncarbonized biomass gasification. Integrated gasification-gas turbine systems may appear in the 1990s as an efficient alternative for power generation at the multi-megawatt scale.

Shortage of wood for charcoal production has led to an interest in residues as raw material for carbonization; a number of techniques for this now exist.

Densification of agricultural and forestry residues can potentially upgrade these as fuel. However, densified biomass normally cannot compete costwise with fuelwood although it is used in some situations.

INTRODUCTION

Following the oil shock of 1973, a great deal of effort was expended worldwide, during the period 1974-1985, to establish an understanding of renewable energy sources, estimate their potential, and develop engineering principles related to their use. A wide range of technologies were conceived and developed during this period. Although the interest in renewable energy declined after the fall of the oil price in the mid-1980s, the worldwide concern for the environment, particularly global warming, has currently rekindled interest in renewable energy. As a result, the contribution of renewable energy to global energy supply is expected to grow significantly during the next two decades. A large fraction of this will probably come from biomass.

In the developing countries, large quantities of residues are produced each year, the annual generation being equivalent to about 65% of energy use in these countries (Hall, 1991). At present however, the residues are normally under-utilized. Often these are left to decompose in huge heaps or are disposed of by burning. Thus, it has been reported that 90% of the straw produced in the Indian state of Punjab is disposed of by burning (Jenkins and Bhatnagar, 1991). Decomposition and combustion of residues result in the release of their carbon content to the atmosphere and contribute to global warming. According one estimate, the CO_2 emissions from unused residues amount to about 6.7% of total emission from the combustion of all fossil fuels (Bhattacharya, 1990). Thus CO_2 emission could be avoided significantly by utilizing normally unused residues in place of fossil fuels wherever possible.

Figure 1 shows the different methods of utilizing biomass as a source of energy. Primary biomass fuels, i.e. biomass as harvested from nature can be directly burned to produce heat. Biomass can also be upgraded to a variety of secondary fuels, solid, liquid or gas, by means of certain conversion processes. In general, the conversion processes can be either thermo-chemical or biological. This paper presents a review of the state-of-the-art of the different residue energy technologies, with the emphasis on thermo-chemical processes.

COMBUSTION

General

In the developing countries, biomass combustion provides the basic energy for cooking and heating in rural households and for production processes in a variety of traditional industries.

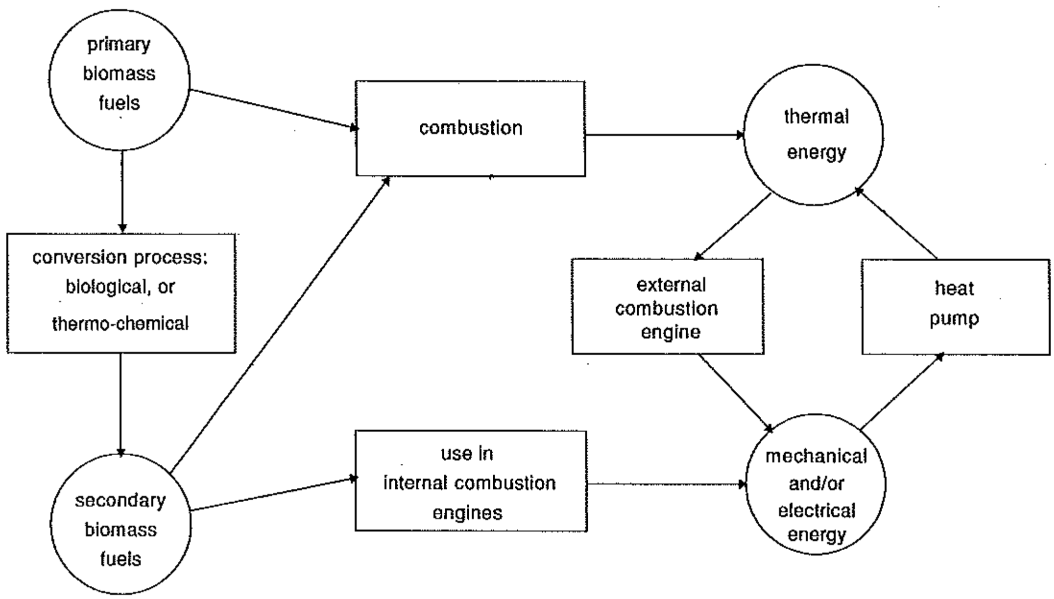


Fig. 1. Pathways for using biomass energy.

Potentially biomass fuels could provide a much more extensive energy service than at present if these were used efficiently. For example, new stove designs can improve the efficiency of biomass use for cooking by a factor of 2 to 3. Thus, the energy service provided by biomass in this case could be potentially provided by one third to half of the amount of biomass used currently.

An industrial biomass combustion system normally consists of fuel storage, feeding device, the combustor, ash removal device, heat recovery surface, flue gas cleaning facility and stack. The design of the combustor, the most important component of the system, depends on the characteristics of the biomass fuels. For lumps and big pieces having moisture content below 50%, the Dutch oven or a variety of grate firing designs can be used. Granular biomass, e.g. saw-dust, rice husk, can be more conveniently burned in a fluid bed combustor. For small and medium capacity applications, loose/granular biomass can be densified to produce pellets and then burned in auger-fed grate-firing systems. Straw, which is often burned in the fields for disposal in the developing countries, can be burned in special combustors, which have found increasing application in recent years.

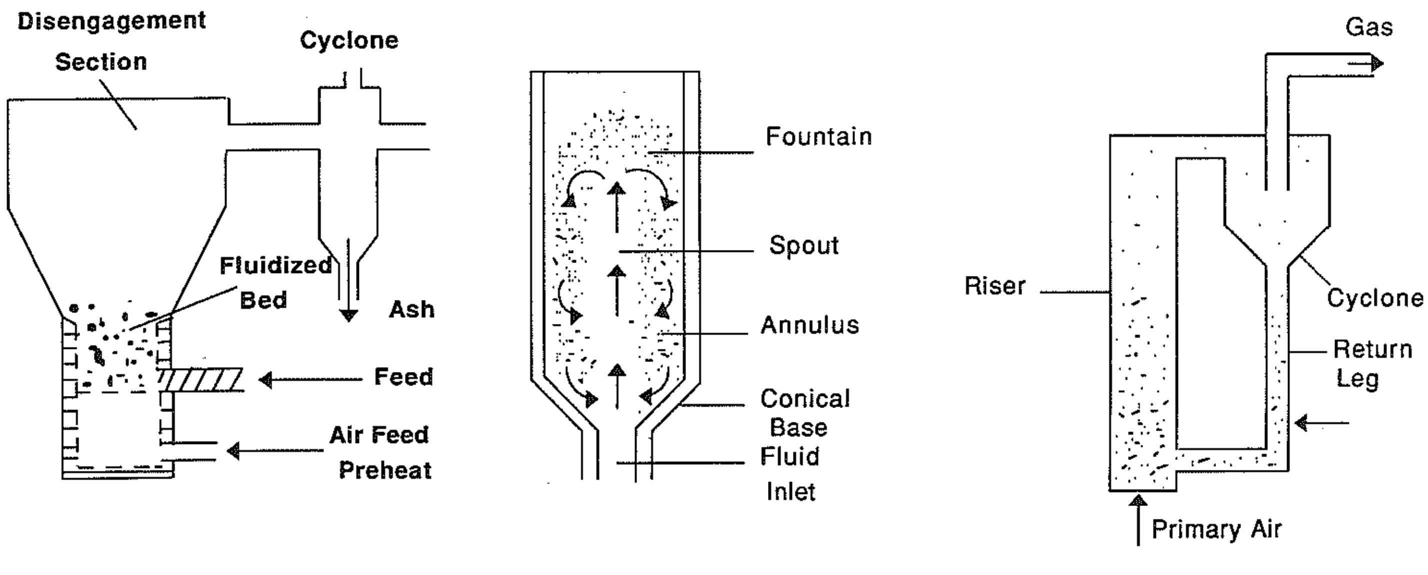
Selected Combustion Technologies

Some of the relatively recent developments in the field of biomass combustion are briefly described in the following paragraphs.

In fluid bed combustion, the fuel particles, normally below 6 mm in size, remain suspended/entrained in the combustion air. The fuel particles amount to only a small fraction, around 1%, of the total solid particles in the bed, the remaining being inert particles. The particles in such beds are often regarded as well-mixed. In the case of coal combustion, the inert particles are ash, limestone, dolomite, or sand, while for biomass combustion, these are normally sand particles. Fig. 2 shows the schematic diagram of common fluid beds.

In a bubbling fluidized bed (BFB) combustor, the primary combustion air flows from the bottom, up the bed of particles and then through a distributor. The particles remain suspended in the combustion air due to the balance of downward gravity force and the upward drag force due to gas flow. A part of the combustion air passes through the bed as voids or ***"bubbles"*** and creates vigorous stirring of the bed. The fuel to be burned is fed into the bed either above or below its upper surface, and gets quickly heated to the bed temperature as well as devolatilized. Most of the volatile burns above the surface of the bed in the ***"freeboard"*** while the char burns inside the bed. The important advantages of bubbling fluidized beds include low NO_x formation due to low operating temperature, (normally 800-900°C), high heat transfer coefficient in case of surfaces immersed in the bed, and ability to burn even low grade fuels with high efficiency. For example, rice husk, which cannot be burned efficiently in conventional furnaces, has been burned with 95-99% efficiency in such beds (Bhattacharya and Weizhang, 1988). According to one study, there were about 110 fluidized bed boilers utilizing biomass as fuel worldwide in the mid-1980s (La Nauze, 1986). At present, the number of such boilers appears to be much higher.

In a circulating fluidized bed (CFB) combustor, the fuel particles burn in an entrained bed of mostly inert particles inside a riser column. The solid particles at the exit of the riser are separated from the gas stream using cyclones and returned to the bottom of the riser. The first commercial CFB combustor was established in 1979. A total of 223 CFB combustor units were reported to be in operation in the early 1990s (Engstrom and Lee, 1991). A number of these are for biomass burning.



a) Fluidized bed

b) Spouted bed

c) Circulating fluidized bed

Fig. 2. Schematic diagram of different fluid bed reactors.

Flue gas produced by burning biomass under pressure can be used to run a gas turbine. A 3 MW sawdust burning plant was installed in Red Boiling Springs, USA in 1985; it was the first plant in the world of this type. Figure 3 shows the schematic diagram of a pressurized fluidized bed combined cycle, in which the exhaust from the turbine is used to produce steam for additional power generation by means of a steam turbine. In 1990, the first three PFB coal combustion plants were installed in different parts of the world. Future PFB combustion plants are expected to produce electricity at an efficiency approaching 50%. It should be possible to adopt PFB coal combustion technology for electricity production from biomass in the future.

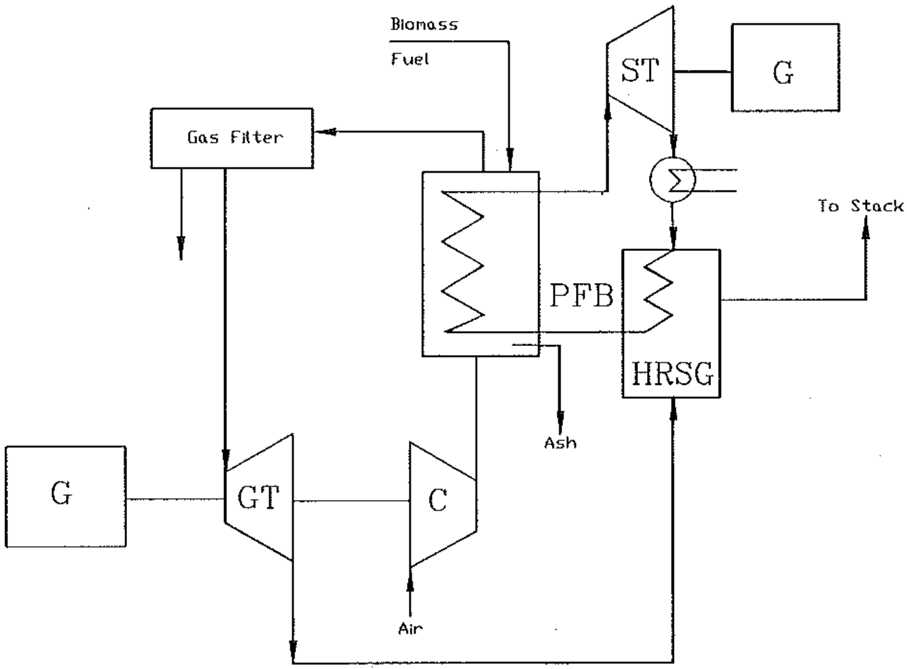


Fig. 3. Pressurized fluidized bed combustion combined cycle.

Application of another fluid bed technique, the spouted bed, for combustion is now in the initial stages of development and demonstration. The relative advantages of this technique over BFB include the ability to burn larger fuel particles, lower pressure drop of combustion air, and design simplicity.

An interesting technique for burning biomass of small size employs auger-fed automatic combustion systems (Fig. 4). These systems are easy to operate and have fuel storage for one to seven days as well as automatic sprinkle fire protection. Wood chips and biomass pellets are normally burned in such systems.

Industrial Applications

Such applications of residue combustion include process heat production, electricity production, and cogeneration.

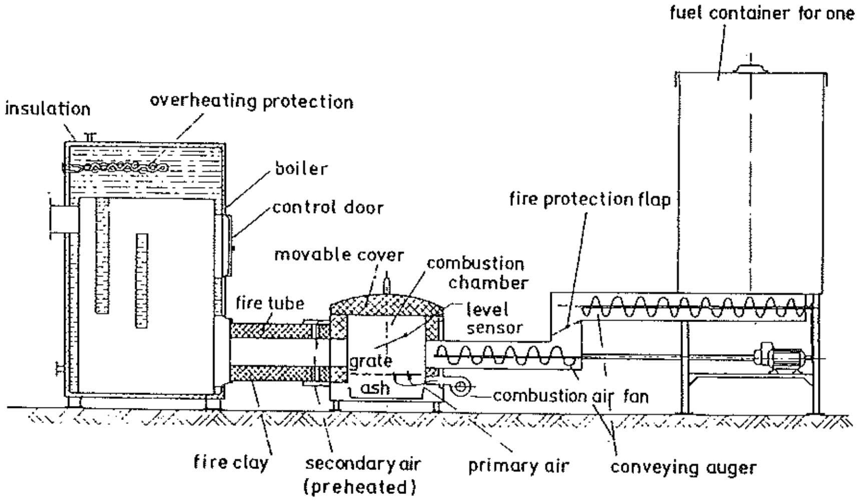


Fig. 4. An automaic auger-fed combustion system.

Hot gases produced by residue combustion can be used directly for **process heat**. Thus biomass combustion is used for heat in a variety of rural industries. Hot gases produced in fluidized bed combustors can be used directly for drying some products, e.g. tiles. Combustors for such applications are available commercially. Heat from residue combustion can also be used as energy input for running absorption refrigeration systems for producing ice or storing vaccines in remote areas.

In some drying applications, air is used as the heat transfer medium. Hot air for this purpose can be produced by heat exchange with flue gases. Fluidized bed combustors for hot air production for tea drying are currently available in India.

Electricity generation based on biomass combustion mostly employs steam turbine systems at present. Such electricity generation is well established in the developed countries in situations where relatively cheap/waste biomass is available. For example, the installed capacity of electricity generation from biomass in the U.S.A. is around 9,000 MW, more than half of which is based on cogeneration. About 3% of biomass power is produced from agricultural residues. The efficiency of these biomass power plants has been reported to be 20-25%.

An interesting program of electric power generation from a "dedicated plantation" was initiated by the National Electrification Administration of the Philippines. A typical 3 MW project required an area of 1500 hectares, including 1100 hectares for tree plantation. The original plan of a total generating capacity of 200 MW by the year 1990 was subsequently significantly scaled down. Seventeen plants with a total capacity of 46.07 MW were procured, eleven of which were French-made, while the remaining six were made in the United Kingdom. Some of these were never installed and practically all of those installed are currently inoperative. In spite of the failure of the wood power program in the Philippines, the option appears to be potentially viable in other countries. A recent study carried out shows that 30-50 MW wood power plants would be economically feasible in Thailand (Wibulswas, 1991).

Thermal energy produced by burning biomass and other low grade fuels can be used for small-scale power generation by means of an external combustion engine, e.g. a Stirling engine. In India, about 100 Stirling engines have been installed in recent years (Srivastava, 1990). Some time ago, the Stirling engine manufacturer, however, went out of business. The future of the Stirling engine program in India thus appears to be uncertain, although attempts to revive the program with government support appears to be under way at present. India's Stirling engines experience may prove to be of great interest to the other developing countries since the system has the potential to achieve higher efficiency compared to gasifier-engines or steam-based power plants of similar capacity.

As pointed out earlier, pressurized fluidized bed combustion systems are expected to allow utility-scale electricity generation with very high efficiency in the future.

Cogeneration is the process of producing two useful forms of energy, normally electricity and heat, utilizing the same fuel source. The process is well established in some industries, e.g. pulp and paper, sugar mills.

In an industrial plant where both heat/steam and electricity are needed, these requirements are normally met by using either 1) plant-made steam and purchased electricity or 2) steam and electricity produced in the plant in a cogeneration system. The second option results in significantly less overall fuel requirement, i.e. better fuel utilization efficiency.

Cogeneration systems based on residues are normally of topping steam cycle type, in which the heat produced from combustion is first used for steam generation to run a turbine-generator system and steam exhausted or extracted from the turbine provides heat for industrial processes. Figure 5 shows the schematic diagram of a number of steam cycles. The pure condensing cycle is used in conventional thermal power plants which produce electricity as the only useful energy output. The remaining cycles represent cogeneration systems in which both heat and electricity are produced.

Energy Conservation

Established energy conservation practices in the case of combustion systems include (1) control of excess air and (2) stack temperature control. Since biomass contains little or no sulfur, the flue gas can be cooled below dew point without the danger of corrosion. Recovery of latent heat may be an interesting option for energy conservation for wet biomass fuels although the hardware for this appears to be not yet available.

In the case of steam generation based on biomass combustion, additional energy conservation measures include (1) energy recovery from boiler blowdown, (2) steam leakage reduction by means of proper steam trap maintenance, (3) condensate recovery, (4) surface heat loss reduction by means of proper insulation, etc.

GASIFICATION

General

Gasification is the process of converting a solid fuel to a combustible gas by supplying a restricted amount of oxygen.

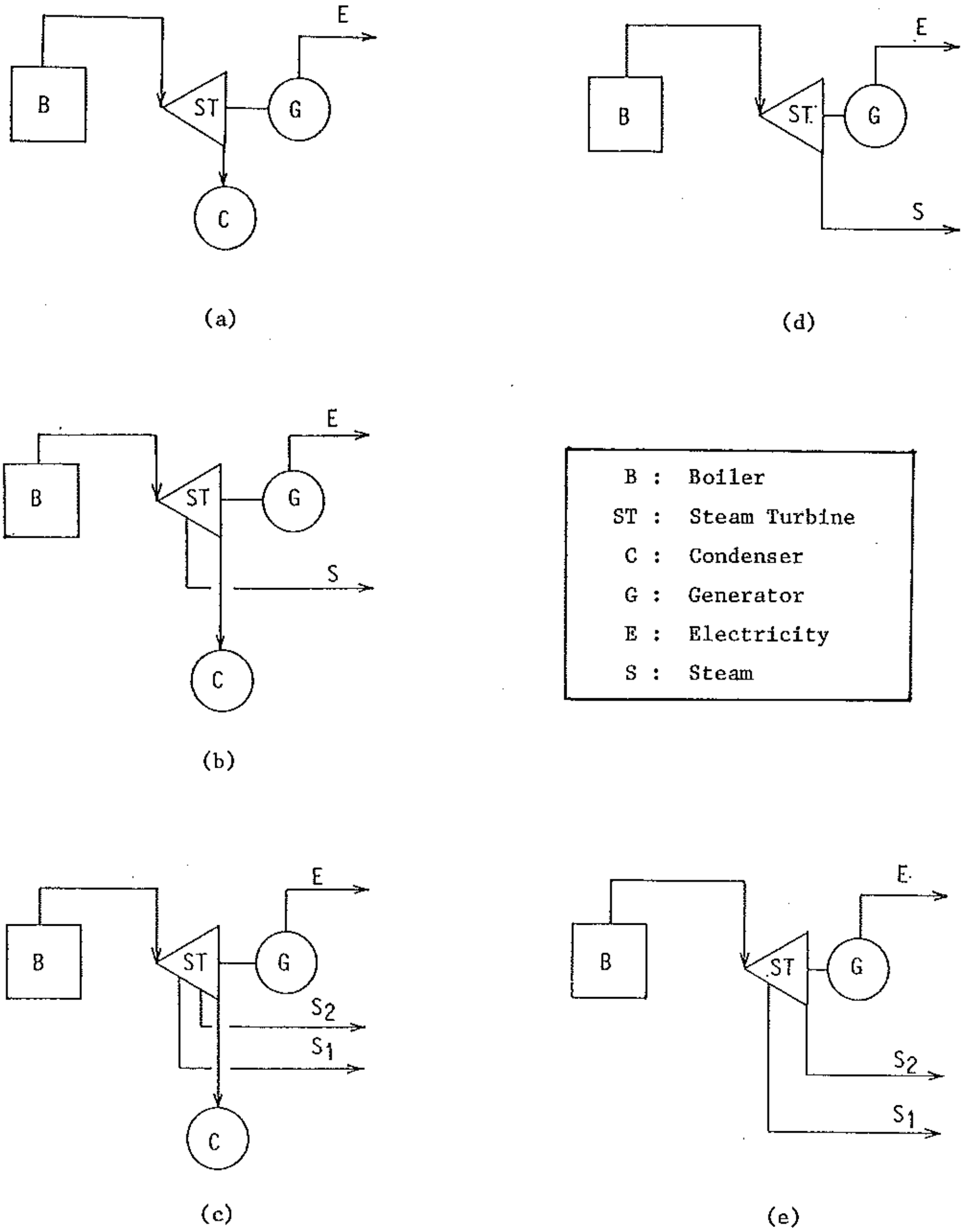


Fig. 5. Steam turbine cycles: (a) Pure condensing, (b) Single extraction condensing, (c) Double extraction condensing, (d) Pure back-pressure, (e) Single extraction back-pressure.

Air gasification of biomass has been used for producing a gas, the producer gas, that can fuel engines and furnaces. In Asia, machinery for this type of gasification is manufactured in numerous countries, e.g. China, India, Indonesia, Philippines, and Thailand. Gasification using pure oxygen can be used to produce synthesis gas, a mixture of H_2 and CO, which can be used to produce methanol.

The gasification technology is more than a century old and the use of gasifiers for operating engines was established by 1900. Gasifier-engine systems were used successfully during World War I. During World War II, more than one million gasifiers were in use for operating trucks, buses, taxis, boats, trains, etc. In Asia, gasifier-operated vehicles were used in China and India during World War II.

Figure 6 shows the schematic diagram of common fixed bed gasifier configurations. In updraft gasifiers, air enters at the bottom and the gases produced pass upwards and exit near the top. The exit stream contains combustible gases, water vapour, nitrogen from the air, and tar vapours produced in the pyrolysis zone.

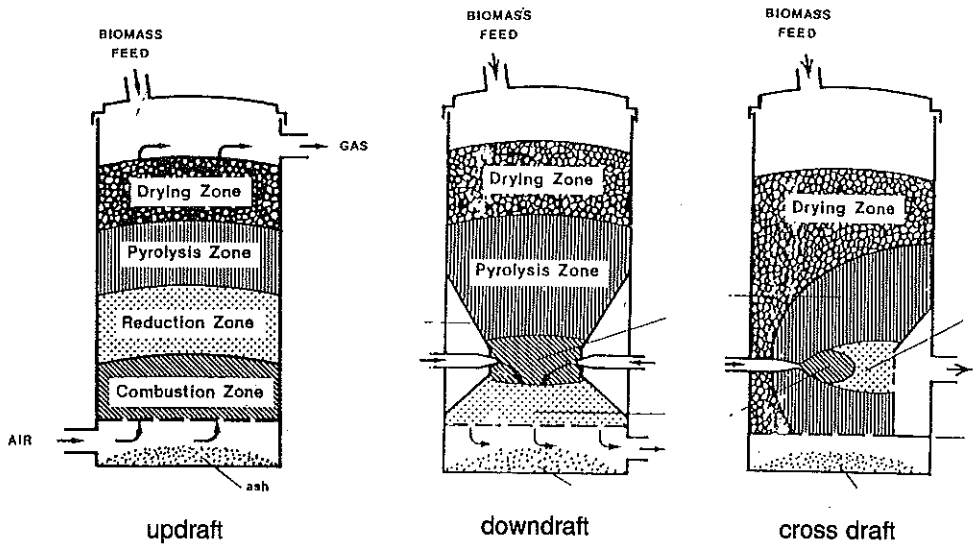


Fig. 6. Fixed bed gasifiers.

In downdraft gasifiers, air and the produced gases flow downwards. The tar vapours produced in the pyrolysis zone pass through the combustion zone and are mostly cracked to non-condensible gases. The downdraft gasifiers therefore produce much less tar than updraft gasifiers and are normally used for running internal combustion engines. Figure 7 shows some downdraft gasifier designs. Most of this type of gasifier have a constriction, called the throat, to create a high temperature zone for adequate tar cracking. The throat however causes a flow problem with most low density fuels. The throatless design is normally employed for such fuels.

In crossdraft gasifiers, air enters through a nozzle and the gas flow is nearly normal to the axis of the fuel bed.

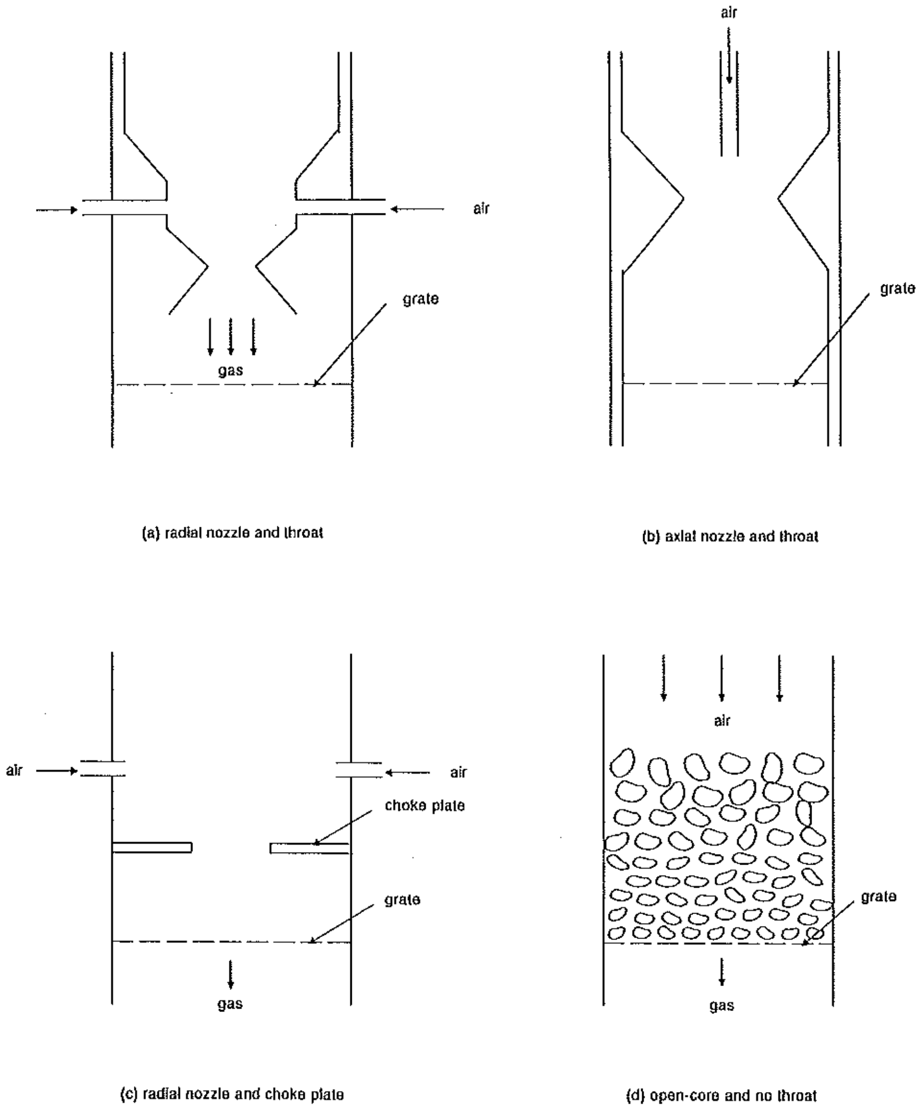


Fig. 7. Common downdraft gasifier designs

Charcoal Gasification

Air gasification of charcoal has been claimed to be a relatively simple option for small energy systems of size around 5 kW_e. Units of capacity 5-10 kW_e have been successfully operated in different parts of the world. In Vietnam, several gasoline-fuelled passenger buses converted to operate with charcoal gasifier are in use. In early 1992, about 40 such buses were reported as operating in one province. The power generation system in this case consists of (i) a gasifier, (ii) a gas conditioning device to separate particles and cool the gas, and (iii) an engine-generator unit fuelled by the gas (Tuyen, 1992). Although charcoal gasification presents no particular operational problem, the actual acceptance of the technology by potential users is rather insignificant at present mostly because of the low return on investment. Also, producer gas is less convenient as engine fuel compared with gasoline or diesel and the user has to have time and skill for maintaining the gasifier-engine system.

Gasification of Uncarbonized Biomass

Such gasification for power generation is feasible at a relatively big scale and the power systems require elaborate gas cleaning for removing tar, a complex and corrosive mixture of condensed liquid vapours produced along with the gas. Projects on such power generation have often been abandoned for a variety of reasons, the most important being the problem created by tar in the gas. Worldwide however, there are a number of units each of which has accumulated several thousand hours of operation. Gasification of rice husk, which is generated in rice mills where a demand for mechanical/electrical power also exists, has attracted a great deal of interest in recent years. A number of open-top rice husk gasifiers operate in rice mills in China. The plants require a regular maintenance schedule, the husk consumption being about 2 kg/kWh. The most well-known rice husk gasification system based on Chinese technology was installed in Mali in 1967.

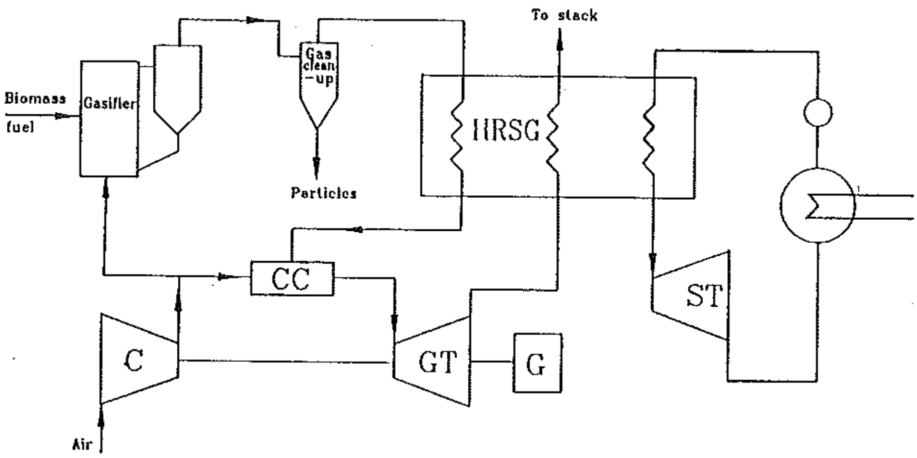
The plant normally operates at 80-85 kW_e and has operated for more than 55,000 hours. At 81 kW, the overall efficiency has been reported to be just under 8% (Mendis et al., 1989). A wood gasification plant at a rubber estate in Central java, Indonesia operated for more than 12,000 hours as of June, 1989. The world's largest successful downdraft wood gasifier power plant has been reported to be operating in Paraguay. It has three generator sets of capacity 420 kW each. Although a number of uncarbonized biomass gasifiers are reported to be operating successfully, the scrubber water from gasifier plants contains condensates from gas cleaning. Pollution caused by the scrubber water remains an unresolved environmental hazard.

Use of producer gas for heat production is relatively simpler and better established throughout the world. The gas in this case does not require tar removal or cooling before combustion.

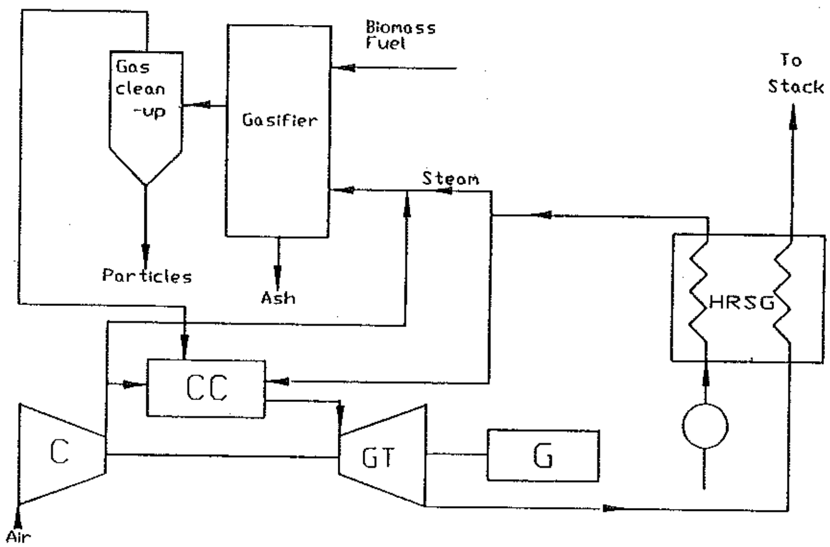
A survey identified 343 commercial/demonstration biomass and waste gasification plants in the industrialized world in the mid-1980s (Bridgwater, 1987). Less than 2% of the energy output was for power applications. The average size of the installations, about 60% of which were located in North America, was 8.3 MW_{th}, while the capacity of the largest plants was around 80 MW_{th}. In the developing countries, heat from the combustion of producer gas has found limited use for a variety of applications, e.g. cooking, drying and industrial furnaces.

New Developments

In the future, commercial electricity generation from biomass will probably utilize power plants in the capacity range 10-50 MW. For smaller sizes, the capital cost of the power plant per kW will be the constraining factor whereas for larger sizes it will be the cost of fuel collection from larger distances. For this size range, the steam cycle will be significantly less efficient and require a high investment cost per kW compared to modern utility scale plants. It appears that plants based on integrated gasification and gas turbine technologies (Fig. 8) would be particularly suitable for biomass (Elliot and Booth, 1990). Efficiency in excess of 40% has been predicted for such plants in the near future. A wood integrated gasification combined cycle (IGCC) demonstration plant is scheduled to be operational in Sweden in 1996. The cogeneration plant is expected to



Biomass Integrated Gasification Combined Cycle



Biomass-Gasifier Steam-Injected Gas Turbine System

Fig. 8. Biomass gasifier-gas turbine systems.

produce 60 MW net power and about 65 MJ/s district heat. The total efficiency and net efficiency for power generation are about 90% and 40%, respectively. A smaller wood waste/chip IGCC plant is scheduled to start operation in Sweden before summer this year. The rated fuel input, power output and district heat output of the plant are 18 MW, 6 MW, and 9 MW, respectively.

DENSIFICATION

Utilization of agricultural and forestry residues is often difficult because of their uneven and troublesome characteristics. This drawback can be overcome by means of compaction of the residues into a product of high-density and regular shape. The process of compaction of residues into a product of higher bulk density than the original raw material is known as densification. Densification has aroused a great deal of interest in developing countries all over the world in recent years as a technique of beneficiation of residues for utilization as an energy source. The process, however, is not new. The first U.S. patent for densification was issued in 1880. Initially the technique was mostly used for producing animal feed (Reed and Bryant, 1978).

Converting residues into a densified form has the following advantages: (1) the process increases the net caloric content of material per unit volume, (2) the end product is easy to transport and store, (3) the fuel produced is uniform in size and quality, (4) the process often helps solve the problem of residue disposal, and (5) the process helps reduce deforestation by providing a substitute for fuelwood.

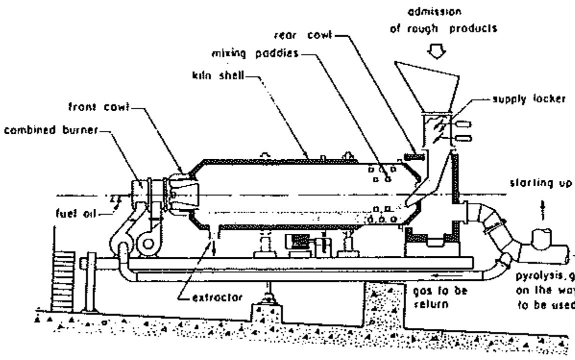
Densification is essentially a hot compaction process. Lignin, an important constituent of biomass, becomes soft at 130-190°C and is believed to act as an internal glue during the process (Bhattacharya and Shrestha, 1990). Depending on the type of equipment used, densification can be categorized into four main types: piston press densification, screw press densification, roll press densification, and pelletizing. Products from the first three types of densification are of relatively large size and are normally called briquettes. Figure 9 shows the schematic diagram of these presses.

A recent study (Bhattacharya et al, 1989) identified 152 manufacturers of densification machinery worldwide. In Asia, densification machinery is manufactured in India, Japan, Korea, Taiwan, and Thailand.

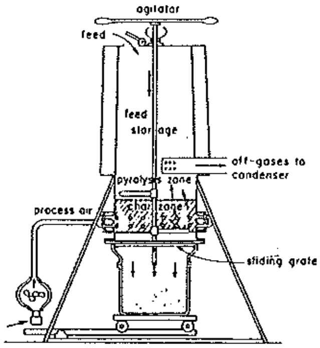
The process of briquetting agricultural and forestry residues normally involves high pressures exerted on the raw material in the compaction process. The pressure causes two problems, e.g., high electrical energy consumption in the driving motor and high wear rate of machine parts. It has been reported that the electricity cost amounts to 13.9 to 16.6% of the total production cost of sawdust briquettes in a heated-die screw press. Also, as a result of high wear, the screw of the press requires repairing after every 100 hours of operation and needs replacing after three repairs. The die requires replacing after 1000 hours of operation (Bhattacharya, 1988).

A recent study has shown that a considerable amount of energy could be saved by preheating biomass before densification (Aqa and Bhattacharya, 1992). The energy input to the briquetting system was reduced by about 40%. The decrease in the electrical energy requirement per kg of sawdust allows operation of the briquetting machine at higher throughput with the existing motor. Operating the briquetting machine at higher throughput further reduces the electrical energy requirement per kg of sawdust.

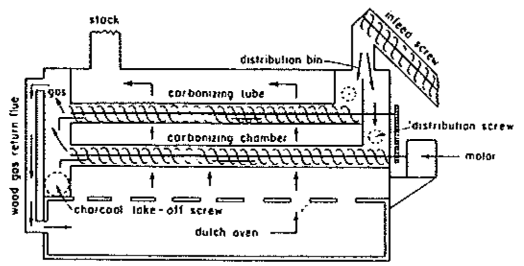
Binderless briquetting at low temperature and pressure is possible with decayed biomass. The raw material for this kind of briquetting may be in the form of unused residues accumulated and composted over years (e.g., *"mountains"* of waste bagasse).



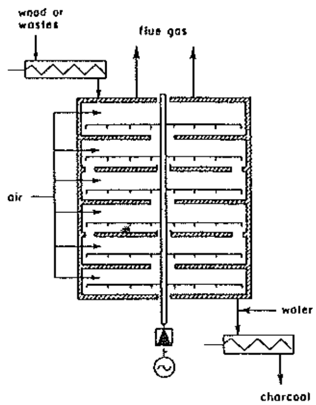
The pillard rotary carbonizer.



The vertical moving packed-bed pyrolyzer.



The Thompsen retort.



The Herreschoff carbonizer.

Fig. 9. Carbonization systems for small-size biomass.

One process of low temperature wet briquetting essentially consists of the following steps: (1) extrusion of the partially decayed material to obtain soft briquettes of high moisture content, and (2) drying of the soft briquettes. During the process of partial decay, the biomass structure and composition undergo change. Only a small amount of energy is needed to extrude the soft and decayed material, which emerges from the extruder with the consistency of potter's clay. This briquetting technique has been developed in Thailand (Stienswat and Buachanda, 1985), the Philippines (Gonzalo, 1982) and Indonesia (Eriksson and Prior, 1988).

Densified biomass is not cheap. Normally such a fuel cannot currently compete with fuelwood in developing countries, although increasing commercial energy prices up to the early 1980s generated a lot of interest in densification. Thus, during 1978-83, a large number of briquetting machines, about 300 according to one estimate, were installed in Thailand. Most of these were subsequently put out of operation due to lack of demand for the product. At present, there are some special situations in which densified biomass is used commercially. For example, a recent study identified a total of 53 briquetting machines operating commercially in 9 plants in Thailand; the briquettes were mostly carbonized to produce biocoal (i.e. briquetted charcoal from residues). Also, the cost of bagasse fuel blocks in Sudan has been reported to compare well with locally purchased fuelwood.

BIOMASS CARBONIZATION

Carbonization is the process in which biomass, by being heated in the absence of oxygen, is converted to a low volatile fuel, charcoal. Charcoal derived from wood is widely used in many developing countries for cooking. It has also a number of industrial applications. The process of making charcoal from wood is an established process and a variety of charcoal kiln designs exist.

It is, however, often difficult if not impossible to find a sufficient supply of firewood for making charcoal. Substitution of wood charcoal by biocoal, i.e., briquetted charcoal obtained from agricultural and forestry residues, appears to be an attractive means to alleviate the traditional fuel crisis faced in many developing countries. There are two technological routes for producing biocoal: the briquetting-carbonization (BC) option and the carbonization-briquetting (CB) option (Bhattacharya et al, 1990).

In the BC option, the raw material is first densified and the densified product is then carbonized to produce a charcoal briquette. In the CB option, the raw material is first carbonized and crushed if necessary to obtain powdered charcoal, which is then briquetted.

Briquetted charcoal is produced in a number of Asian countries, including Japan and Thailand, using the BC technique. The densification machine used is of the heated-die, screw-press type. Carbonization of the briquettes is carried out in conventional metal or brick kilns.

A number of reactor designs are available to carbonize granular biomass wastes and residues, e.g. the Pillard rotary carbonizer, Herreshoff carbonizer, vertical moving packed-bed reactor, Thompsen retort, and Carbonizing Gasifying Chamber (CGC). Some of these are shown in Fig. 10.

The Pillard rotary carbonizer consists of an inclined rotary furnace. A part of the off-gas is recycled and burned to provide the heat necessary for carbonization. The hot flue gases come in direct contact with the raw material that slowly moves down the inclined furnace. The raw material is carbonized by the time it traverses the full length of the converter. The capacity of the converter is in the range of 200-1500 kg/h.

The Herreshoff carbonizer consists of four to six circular hearths, stacked one above the other inside a cylindrical refractory lined vertical steel shell. The raw material is fed to the uppermost hearth and falls from one hearth to the lower under the action of a rotating center shaft, which is fitted with a rabble arm at each hearth level. The normal operating temperature of the hearth is 900-1000°C, and air introduced for partial combustion passes upwards through the furnace. The charcoal leaves the furnace at the bottom and is cooled before storage. The capacity of this type of carbonizer is in the range of 4-10 ton of wood or other residues per hour.

Different versions of the basic design of a vertical moving, packed bed, partial-oxidation pyrolysis reactor that originated at the Georgia Institute of Technology have been developed and tested in Ghana, Thailand, Indonesia, Papua New Guinea, and the Philippines.

The Thompsen retort consists of a number of metal tubes heated externally. The raw material is conveyed through the heated tubes by means of screws and gets carbonized in the process. Once carbonization is well underway, the heat input for the process is obtained from combustion of the volatile gases so that the whole operation becomes self-sustained without any supplementary source of heat.

In a CGC type reactor, dried biomass is continuously fed into the reactor where at a temperature of 800-900°C it is converted to charcoal and pyrolysis gas which can be used as a gaseous fuel. The reactor has been developed by Carbotecnica-Sonerga of Portugal. A demonstration plant of capacity 9000 tons of wet biomass wastes per year and financed by the European Communities is currently being built in Portugal.

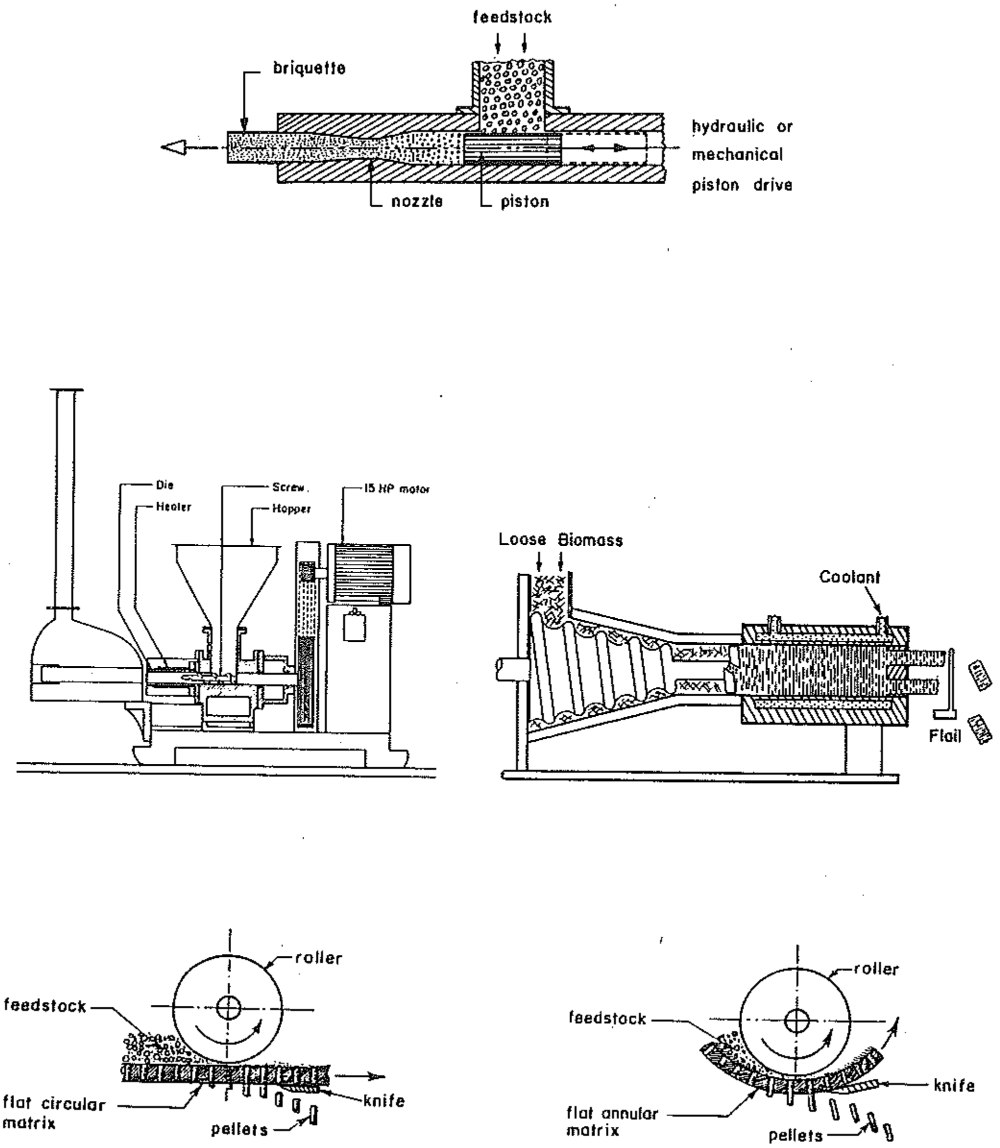


Fig. 10. Common densification presses.

In the developed countries, where a demand for barbecue fuel exists, biocoal production is an established practice. In the United States there were about 16 Herreshoff furnaces by 1980. Raw materials in the form of sawdust, shavings, wood waste and bark are normally carbonized in these furnaces. In Asia, commercial biocoal production is established in Japan, Korea, Taiwan, and Thailand. It is now in initial stages of commercialization in a number of developing countries around the world, e.g. Brazil, India, Jamaica, Nepal and Sudan.

In recent years, torrefaction or roasting, which is a variant of conventional carbonization, has been reported as attractive for certain applications (Bourgeois and Doat, 1985; Pentananunt et al., 1990). In torrefaction, biomass is subjected to a temperature of about 250°C. The product, torrefied biomass, retains 85-90% of the energy of the original biomass, and is hydrophobic. Potentially, torrefied biomass can substitute charcoal in a number of applications, e.g. barbecue fuel and gasifier fuel. Wood torrefaction was conceived in France, where most of the development work has been done so far. An industrial scale demonstration plant produced 10,000 tons of torrefied wood in 1988. Production and sale of torrefied wood were later suspended because of low profitability.

OTHER BIOMASS ENERGY TECHNOLOGIES

Liquid Fuel Production

The best known biomass-derived liquid fuel program in the world is the sugarcane-based ethyl alcohol (ethanol) program of Brazil which was established in 1975. Ethanol is produced from corn in the United States.

In 1988/89 about 12.3 billion litres of ethanol were produced in Brazil. Currently, however, the program appears to be facing an uncertain future because of the prevailing low oil price and rising domestic oil production. In 1990, only 50% of all new cars sold were fuelled by pure ethanol compared with 96% in 1985 (Hall et al, 1992).

Ethanol can also be produced from lignocellulosic raw materials, e.g. wood, and agricultural residues, although the process has not yet been commercially demonstrated.

Oil from certain plants, e.g. sunflower and coconut, can be used as a liquid fuel in engines and furnaces. Malaysia, the world's largest palm oil producer, has been reported to have succeeded in using palm oil as engine fuel; an experimental jeep has been reported to have run 200,000 km. without any problem.

Methanol is another liquid fuel that can be produced from biomass and is an excellent fuel for internal combustion engines.

Other options currently being investigated for producing liquid fuels from biomass include (i) flash pyrolysis in which biomass is heated very rapidly to a high temperature and (ii) direct liquefaction by heating a biomass slurry in the presence of suitable catalysts.

Biogas Production

Certain wastes, for example animal manure, can be best utilized to produce biogas. The process is called anaerobic digestion and is carried out by groups of bacteria in a suitable reactor or ***"digester"*** in the absence of air. The digested material can be applied in the fields as fertilizer. In China, which has the biggest biogas program of the world, there were about 4.75 million family-size biogas digesters at the end of 1990. In addition, 64 thousand households were connected to pipeline biogas supply from biogas stations.

In India, about 1.29 million family size biogas plants were installed by the end of 1989. In addition, there were about 500 community and institutional type plants.

A survey carried out during 1986-88, identified 743 biogas plants in 12 countries of Europe (Tentscher and Shao Gong, 1992). About 67% of these were agricultural biogas plants.

UTILIZATION OF SOME SELECTED RESIDUES: A SUMMARY

Rice Husk

Rice husk production is about 20% by weight of the paddy milled. About 20% by weight of the husk is ash, more than 90% of which is silica.

Rice husk briquetting is a proven process with heated die densification machines. However, because of the high silica content of rice husk, wear of screw and die of the machines is high and the process requires regular repair/ replacement of these parts. Rice husk briquetting was reported to be commercially established in Thailand a few years ago to provide fuel for refugee camps and a few temples. These briquettes were normally more expensive than fuelwood.

Combustion of rice husk for process heat or steam generation is an established practice. Typically, the combustion process is inefficient due to unburned carbon retained in the ash and the efficiency of husk fired boilers is 50-60%.

Some rice mills in different countries have been using old steam engine technology to meet their power requirements. Husk requirement for such power generation is around 2.75 kg/kWh, i.e. 364 kWh/ton husk.

Relatively recent developments are the commercialization of fluidized bed combustors and high efficiency power plants. A power plant established in a rice mill in the Punjab state of India produces 36 tons per hour of steam at 71 bar and superheated to 505°C. Thirty to forty per cent of electricity production, amounting to 1060 kWh/ton of husk, is sold to the adjacent community (Mahajan and Mishra, 1992). The world's largest rice husk fired power plant (29 MW), with a gross output of about 1260 kWh/ton, is located at Williams, California.

Bagasse

Bagasse produced is about 30% by weight of the cane crushed and the moisture content of fresh bagasse is about 50%. Bagasse is traditionally used in sugar mills in cogeneration systems to produce steam and electrical power needed by the mills. Normally bagasse is used very inefficiently in such mills in order to avoid left-over bagasse, which would create a disposal problem.

A study (Larson et al., 1987) funded by USAID a few years ago assessed the feasibility of new technology in sugar mills. It was found that while a typical existing mill produced about 20 kWh of electricity per ton of cane (tc) crushed, a modern condensing extraction turbine would generate about 100 kWh/tc. Also, if the process steam demand were reduced, a gasifier steam-injected gas turbine system could be used to produce about 200 kWh/tc. It was also estimated that using cane tops and leaves, which are normally burned in the field, electricity production could continue after the normal milling season and a total of 460 kWh/tc could then be generated. Electricity exported from the sugar mills would then amount to a significant fraction of national electric utility generation in a number of developing countries. Using 1985 levels of cane production and 1982 levels of total electric utility generation, these values were India-24.4%, China-5.8%, Thailand-66.7%, Indonesia-63.9%, Philippines-42.5% and Pakistan-43%.

Apart from cogeneration, only limited attempts have been made to upgrade/use bagasse as a source of energy. Bagasse can be briquetted after drying and size reduction. An interesting technique of densifying composted bagasse has been used in Sudan to produce bagasse fuel-blocks using molasses as a binder (Paddon, 1988). The brick shaped fuel-blocks are produced using simple hand operated presses and sun-dried. As pointed out earlier, it is claimed that the bagasse blocks thus produced are competitive with fuelwood. In 1988, the fuel blocks produced consumed about 500 tonnes of bagasse annually, and were used as fuel in brick kilns. A GTZ funded project studied the feasibility of charcoal making from residues including bagasse. A market study showed very high market acceptance of the charcoal in Jamaica.

Straw

Straw is the most abundant and apparently the most under-utilized agricultural residue in Asia. Straw production is about two times the amount of paddy production by weight. Large amounts of the straw produced are normally burned in the field for disposal.

A number of systems for burning straw, are now available. The schematic diagram of such a system is shown in Fig. 11.

A straw power plant of capacity 10 MW has been recently commissioned in the Indian state of Punjab. It appears to be the first and largest straw power plant in the world.

The fluidized bed boiler of the plant was supplied by an Indian manufacturer. Such power generation appears to have great potential. For example, more than 8 million tons of straw produced every year in Punjab would be enough to produce 1000 MW of electricity.

Densification of straw to produce pellets is quite well established. A straw briquetting plant of capacity 30 tons per day started operation at Veszto, Hungary in 1988.

Straw can be used for biogas generation. The carbon to nitrogen ratio of straw is rather high, about 50, compared to an optimum value in the range of 20-30. For biogas production, straw therefore has to be mixed with a material rich in nitrogen, e.g. chicken manure.

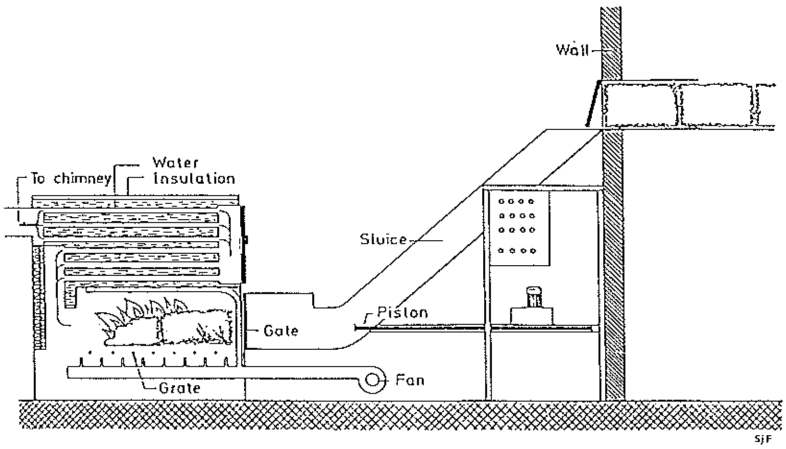


Fig. 11. A straw combustion system.

CONCLUDING REMARKS

Many modern residue energy technologies are fully or nearly mature at present. Some of these have been commercially demonstrated and are competitive. A number of residue energy technologies, however, are not commercially viable because of the prevailing low price of fossil fuels.

With the growing awareness of the environmental impacts of non-renewable energy use, some of the renewable sources, including biomass, currently appear to be set to stage a comeback. Considerations of the societal cost of energy use, e.g. a carbon tax is likely to significantly lower the price of biomass relative to fossil fuels. Modern technology and new techniques of wood production to achieve ultra-high yields may render biomass an important commercial energy source.

In the near-term future, efficient utilization of all biomass fuels in traditional combustion systems is likely to be particularly important. Also, using surplus residues for energy would allow avoiding use of an equivalent amount of fossil fuels and would have a net beneficial effect on the environment. In situations where demands for both electricity and thermal energy exist, cogeneration is expected to find increasing acceptance.

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