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Energy production from biomass (part 3): gasification technologies

Peter McKendry [1,2]

Applied Environmental Research Centre Ltd, Tey Grove, Elm Lane, Feering, Colchester CO5 9ES, UK

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Abstract

The conversion of biomass by gasification into a fuel suitable for use in a gas engine increases greatly the potential usefulness of biomass as a renewable resource. Gasification is a robust proven technology that can be operated either as a simple, low technology system based on a fixed-bed gasifier, or as a more sophisticated system using fluidized-bed technology. The properties of the biomass feedstock and its preparation are key design parameters when selecting the gasifier system. Electricity generation using a gas engine operating on gas produced by the gasification of biomass is applicable equally to both the developed world (as a means of reducing greenhouse gas emissions by replacing fossil fuel) and to the developing world (by providing electricity in rural areas derived from traditional biomass). © 2002 Elsevier Science Ltd. All rights reserved.

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1. Introduction

Gasification is the conversion of biomass to a gaseous fuel by heating in a gasification medium such as air, oxygen or steam. Unlike combustion where oxidation is substantially complete in one process, gasification converts the intrinsic chemical energy of the carbon in the biomass into a combustible gas in two stages. The gas produced can be standardised in its quality and is easier and more versatile to use than the original biomass e.g. it be used to power gas engines and gas turbines, or used as a chemical feedstock to produce liquid fuels.

Strictly, gasification includes both biochemical and thermochemical processes, the former involving micro-organisms at ambient temperature under anaerobic conditions i.e. anaerobic digestion, while the latter uses air, oxygen or steam at temperatures >800 °C. In accordance with common practice, the term "gasification" in this study will refer only to the thermochemical conversion of biomass.

2. Basic chemistry

The reactions taking place in the gasifier can be summarised as indicated below:

Partial oxidation	$C + 1/2O_2 \leftrightarrow CO$	dH = −268 MJ/kg mole
Complete oxidation	$C + O_2 \leftrightarrow CO_2$	dH = −406 MJ/kg mole
Water gas reaction	$C + H_2O \leftrightarrow CO + H_2$	dH = +118 MJ/kg mole

The heats of reaction [3] for the three processes show that the greatest energy release is derived from the complete oxidation of carbon to carbon dioxide i.e. combustion, while the partial oxidation of carbon to carbon monoxide accounts for only about 65% of the energy released during complete oxidation. Unlike combustion that produces only a hot gas product, carbon monoxide, hydrogen and steam can undergo further reactions during gasification as follows:

Water gas shift reaction	$CO + H_2O \leftrightarrow CO_2 + H_2$	dH = −42 MJ/kg mole
Methane formation	$CO + 3H_2 \leftrightarrow CH_4 + H_2O$	dH = −88 MJ/kg mole

The arrows indicate that the reactions are in equilibrium and can proceed in either direction, depending on the temperature, pressure and concentration of the reacting species. It follows that the product gas from gasification

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[1] Present address: MSE Ltd, Arle Crt, Hatherley Lane, Cheltenham GL51 6PN, UK.

[2] Correspondence address: Green Acre, Dark Lane, Bristol BS40 8QD, UK. Tel.: +44-1242-269685.

[3] Heats of reaction are + for endothermic reactions and − for exothermic reactions.

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consists of a mixture of carbon monoxide, carbon dioxide, methane, hydrogen and water vapour.

Three product gas qualities can be produced from gasification by varying the gasifying agent, the method of operation and the process operating conditions. The main gasifying agent is usually air but oxygen/steam gasification and hydrogenation are also used. Catalytic steam gasification is another mode of operation that influences both the overall performance and efficiency.

The three types of product gas have different calorific values (CV):

Low CV	4–6 MJ/Nm^3	Using air and steam/air
Medium CV	12–18 MJ/Nm^3	Using oxygen and steam
High CV	40 MJ/Nm^3	Using hydrogen and hydrogenation

Low CV gas is used directly in combustion or as an engine fuel, while medium/high CV gases can be utilized as feedstock for subsequent conversion into basic chemicals, principally methane and methanol.

As the use of oxygen for gasification is expensive, air is normally used for processes up to about 50 MW$_{th}$. The disadvantage is that the nitrogen introduced with the air dilutes the product gas, giving gas with a net CV of 4–6 MJ/Nm^3 (compared with natural gas at 36 MJ/Nm^3). Gasification with oxygen gives a gas with a net CV of 10–15 MJ/Nm^3 and with steam, 13–20 MJ/Nm^3. It can be seen that while a range of product gas qualities can be produced, economic factors are a primary consideration. Unlike the reaction with air/oxygen, the reaction of carbon with steam (the water gas reaction) is endothermic, requiring heat to be transferred at temperatures around 700 °C, which is difficult to achieve. Gasifiers self-sufficient in heat are termed auto-thermal and if they require heat, allothermal: auto-thermal processes are the most common.

The overall efficiency of conversion of biomass to energy using gasification and pyrolysis is estimated as 75–80%.

3. Feedstock pre-treatment

The degree of pre-treatment of the biomass feedstock is dependent on the gasification technology used. The main problem areas are:

Drying. The biomass moisture content should be below 10–15% before gasification.

Particle size. In most gasifiers, gas has to pass through the biomass and the feed has to have sufficient compressive strength to withstand the weight of the feed above. Feed particle sizes in the range 20–80 mm are typical.

Fractionation. The nitrogen and alkali contents of the biomass are critical, as they are partially carried over into the gas-stream. Small particles tend to contain less nitrogen and alkalis, so fractionation into fine and coarse particles helps to produce a gas with fewer impurities.

Leaching. The nitrogen and alkali contents of the biomass can be reduced by prior leaching with water.

Drying wood from 50% to 60% (as-felled), or using air-dried wood with a moisture content of 20%, to the required level of 10–15% moisture requires the use of driers. The driers can be directly heated rotary driers using the flue gas or indirectly heated fluidised bed driers using steam to heat the feed material. The vapours emitted during drying contain a number of volatile organic compounds (VOCs), mainly terpenes, which require appropriate air pollution control systems.

4. Feedstock properties

The characteristics of the biomass feedstock have a significant effect on the performance of the gasifier, especially the following characteristics.

4.1. Moisture content

Fuel with moisture content above about 30% makes ignition difficult and reduces the CV of the product gas due to the need to evaporate the additional moisture before combustion/gasification can occur. A high moisture content reduces the temperature achieved in the oxidation zone, resulting in the incomplete cracking of the hydrocarbons released from the pyrolysis zone. Increased levels of moisture and the presence of CO produces H_2 by the water gas shift reaction and in turn the increased H_2 content of the gas produces more CH_4 by direct hydrogenation. The gain in H_2 and CH_4 of the product gas does not however compensate for the loss of energy due to the reduced CO content of the gas and therefore gives a product gas with a lower CV. Calculations based on a 2.7 MW$_{(e)}$ gas engine generator using a dryer with a retention time of one hour, indicate that sufficient waste heat is available from the engine oil and water cooling systems and the exhaust to dry 7.7 t/h of SRC willow feedstock at 35% moisture down to 15% for use in a gasifier (Stamford Consulting Gp., 1994).

4.2. Ash content

High mineral matter can make gasification impossible. The oxidation temperature is often above the melting point of the biomass ash, leading to clinkering/slagging problems in the hearth and subsequent feed blockages. Clinker is a problem for ash contents above 5%, especially if the ash is high in alkali oxides and salts which produces eutectic mixtures with low melting points.

4.3. Volatile compounds

The gasifier must be designed to destruct tars and the heavy hydrocarbons released during the pyrolysis stage of the gasification process.

4.4. Particle size

The particle size of the feedstock material depends on the hearth dimensions but is typically 10–20% of the hearth diameter. Larger particles can form bridges which prevent the feed moving down, while smaller particles tend to clog the available air voidage, leading to a high pressure drop and the subsequent shutdown of the gasifier.

5. Gasification types

Gasifiers are of main two types, fixed bed and fluidised bed, with variations within each type (Rampling, 1993; Rampling and Gill, 1993). A third type, the entrained suspension gasifier, has been developed for coal gasification but the need for a finely divided feed material (<0.1–0.4 mm) presents problems for fibrous materials such as wood, which make the process largely unsuitable for most biomass materials and therefore the process is not considered further.

5.1. Fixed bed gasification

The fixed bed gasifier has been the traditional process used for gasification, operated at temperatures around 1000 °C. Depending on the direction of airflow, the gasifiers are classified as updraft (Fig. 1), downdraft (Fig. 2), or cross-flow.

5.1.1. Updraft

In the updraft gasifier the feed is introduced at the top and the air at the bottom of the unit via a grate (Fig. 1). Immediately above the grate the solid char (the residual solid remaining after the release of volatiles) formed higher up the gasifier is combusted and the temperature reaches about 1000 °C. Ash falls through the grate at the bottom and the hot gases pass upwards and are reduced.

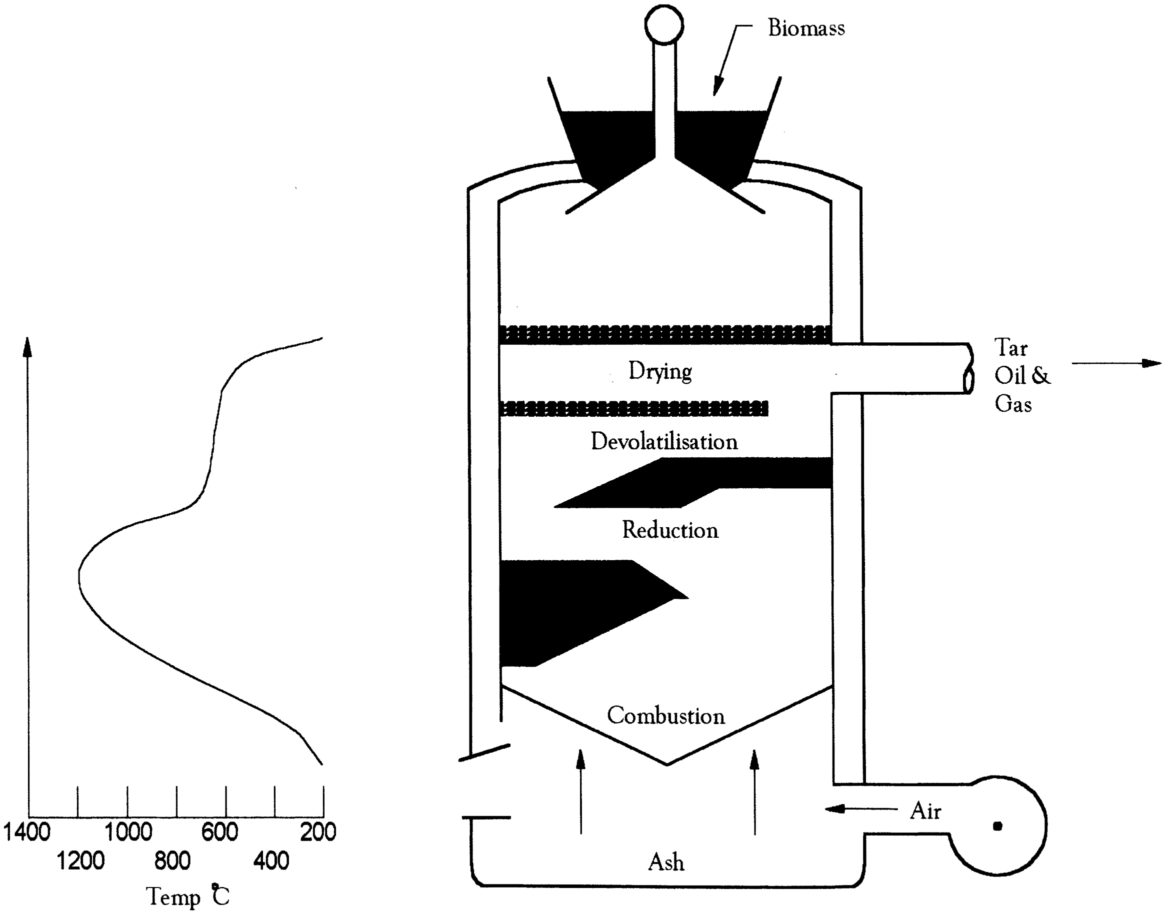

Fig. 1. Schematic of updraft gasifier.

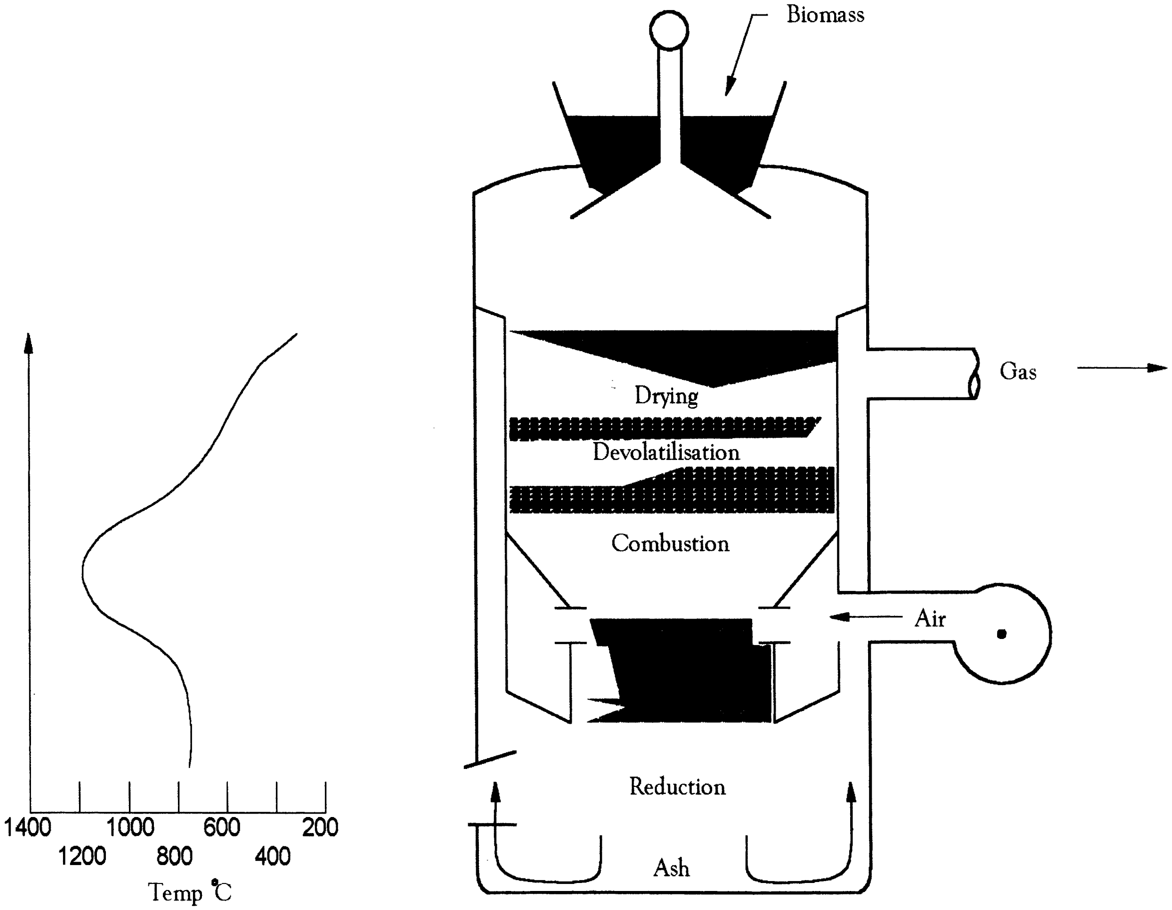

Fig. 2. Schematic of downdraft gasifier.

Higher up the gasifier again, the biomass is pyrolysed and in the top zone, the feed is dried, cooling the gases to around 200–300°. In the pyrolysis zone, where the volatile compounds are released, considerable quantities of tar are formed which condenses partly on the biomass higher up and partly leaves the gasifier with the product gas. The temperature in the gasification zone is controlled by adding steam to the air used for gasification, or by humidifying the air. Due to the low temperature of the gas leaving the gasifier, the overall energy efficiency of the process is high but so also is the tar content of the gas. The filtering effect of the feed helps to produce a gas with a low particulate content.

5.1.2. Downdraft

In the downdraft gasifier, the feed and the air move in the same direction (Fig. 2). The product gases leave the gasifier after passing through the hot zone, enabling the partial cracking of the tars formed during gasification and giving a gas with low tar content. Because the gases leave the gasifier unit at temperatures about 900–1000 °C, the overall energy efficiency of a downdraft gasifier is low, due to the high heat content carried over by the hot gas. The tar content of the product gas is lower than for an updraft gasifier but the particulates content of the gas is high.

5.1.3. Cross-flow

In a cross-flow gasifier the feed moves downwards while the air is introduced from the side, the gases being withdrawn from the opposite side of the unit at the same level. A hot combustion/gasification zone forms around the entrance of the air, with the pyrolysis and drying zones being formed higher up in the vessel. Ash is removed at the bottom and the temperature of the gas leaving the unit is about 800–900 °C: as a consequence this gives a low overall energy efficiency for the process and a gas with high tar content.

5.1.4. Operations and performance

In general fixed-bed gasifiers have the advantage of a simple design but the disadvantage of producing a low CV gas with a high tar content. The product gas composition is typically 40–50% N_2, 15–20% H_2, 10–15% CO, 10–15% CO_2 and 3–5% CH_4, with a net CV of 4–6 MJ/Nm^3. When using air as the gasifying medium, the resulting high N_2 content doubles the volume of the product gas and increases the size of the downstream gas cleaning equipment. To obtain a high CV gas the moisture content of the feed should be <15–20%, so that pre-drying of the biomass feedstock is usually required. Waste heat from the gasifer/engine system can be used to assist with pre-drying the feed material. The energy content of the product gas is up to 75% of the biomass energy content, the losses being accounted for by the sensible heat in the product gas, the heat content of the ashes and radiation losses.

In addition to the initial release of volatiles, a solid char residue is produced (termed charcoal if produced from wood or coal). The char can be reacted further to produce additional gas, making a high char content indicative of considerable gas producing potential. The char derived from straw and wood biomass is typically in the range 22–29 w/o but the reactivity of the char varies greatly. Good correlations exist between the yield of char and the C and N contents and also between the CaO content of the char and its reactivity. Char reaction rates at 240 and 260 °C generally increase with an increasing char yield but decrease as the C content in the char increases.

Improvements to gas quality have been proposed by operating a two-stage, two-reactor process. Pyrolysis of the biomass takes place in the first stage using external heating at 600 °C. The gases formed in the first stage are then reacted with steam to crack the tars. In the second stage the gases react with the char from the first stage to produce the final product gas. After clean-up the gas quality is sufficient for use in a spark ignition gas engine (Warren et al., 1995).

5.2. Fluidised bed gasification

Fluidised bed (FB) gasification has been used extensively for coal gasification for many years, its advantage over fixed bed gasifiers being the uniform temperature distribution achieved in the gasification zone. The uniformity of temperature is achieved using a bed of fine-grained material into which air is introduced, fluidising the bed material and ensuring intimate mixing of the hot bed material, the hot combustion gas and the biomass feed.

Two main types of FB gasifier are in use:

- circulating fluidised bed,
- bubbling bed.

A third type of FB is currently being developed, termed a fast, internally circulating gasifier, which combines the design features of the other two types. The reactor is still at the pilot-stage of development.

5.2.1. Circulating FB

Circulating FB gasifiers are able to cope with high capacity throughputs and are used in the paper industry for the gasification of bark and other forestry residues. The bed material is circulated between the reaction vessel and a cyclone separator, where the ash is removed and the bed material and char returned to the reaction vessel. Gasifiers can be operated at elevated pressures, the advantage being for those end-use applications where the gas is required to be compressed afterwards, as in a gas turbine.

5.2.2. Bubbling bed

Bubbling bed FB gasifiers consist of a vessel with a grate at the bottom through which air is introduced. Above the grate is the moving bed of fine-grained material into which the prepared biomass feed is introduced. Regulation of the bed temperature to 700–900 °C is maintained by controlling the air/biomass ratio. The biomass is pyrolysed in the hot bed to form a char with gaseous compounds, the high molecular weight compounds being cracked by contact with the hot bed material, giving a product gas with a low tar content, typically <1–3 $\mathrm{g/Nm^3}$.

5.2.3. Operations and performance

The major operational difficulty experienced with FB gasifiers is the potential for the slagging of the bed material due to the ash content of the biomass. Of particular importance is the alkali metal content of the biomass, which is a problem with biomass derived from herbaceous annual plants. To avoid slagging, the bed temperature can be lowered but this results in an increased loss of char with the ash removed. The gas formed in the gasifier contains a number of impurities:

- particulates,
- tar,
- nitrogen compounds,
- sulphur compounds,
- alkali compounds.

The end-use of the gas determines the degree of clean-up required and can be achieved by either hot or cold gas cleaning. The benefit of hot-gas cleaning is that more energy is gained from the gas but the process poses significant technical challenges, while cold-gas cleaning is technically simpler but produces a wastewater contaminated with tar, which is likely to pose a disposal problem.

5.2.4. Particulates

Particulates consist principally of ash and char, with the quantity of particulate material produced depending on the gasification technology used. Fixed bed gasifiers generally produce a lower particulate load than FB gasifiers. Particles above 10 μm can be removed using conventional cyclones, with the material removed being recycled to the gasifier if necessary. Removal of finer particles requires the use of filtering devices, filter bags or sintered ceramic/metallic candles. These devices have overall removal efficiencies of +99.8% but clogging due to soot and tar adhering to the ash/char particles is a problem. Operating the filter at a temperature >500 °C can reduce clogging, while at lower temperatures condensed tars on the filter surface can only be efficiently removed by controlled combustion.

5.2.5. Tar removal

High molecular weight compounds in the gas downstream of the gasifier begin to condense at temperatures <450 °C. The condensed material, termed tar is partly deposited on the walls of the piping and partly remaining as an aerosol in the gas. The tar content hinders the removal of particulates from the gas and also causes problems with the subsequent utilisation of the product gas.

The type of biomass largely determines the nature of the tar produced, which is also influenced by the gasification process and the operating conditions. Air gasification produces a low viscosity/low reactivity tar, while steam gasification produces a liquid tar with a low molecular weight. High temperature gasification gives a tar with low oxygen content, consisting mostly of hydrocarbons. Research has shown the fixed-bed, downdraft gasifier to be most capable of producing a low tar/tar-free gas.

Two strategies can be applied to the removal of tar:

- improvement of the gasification technology so that no/little tar is produced,
- development of tar removal processes.

Tar can be cracked into lower molecular weight compounds using either catalytic or thermal processes: catalytic cracking takes place at 800–900 °C and thermal cracking at 900–1100 °C. As gasification is usually in the range 800–900 °C, thermal cracking requires additional energy to heat the gas, which is usually achieved by introducing a small volume of air to enable combustion of part of the gas to raise the temperature. While an effective method, thermal cracking reduces the overall efficiency of conversion of biomass-to-energy gasification process. Catalytic cracking is therefore preferred, using catalysts such as dolomite, olivine and nickel compounds. A uniform and high temperature has been found to be the ideal combination to achieve the total cracking of tar.

Production of a very low tar content gas is best achieved by cooling the gas to 60–80 °C with water and using electrostatic precipitators to capture any aerosols. However this approach also collects water condensed from the gas phase during cooling, resulting in a wastewater heavily contaminated with dissolved organic substances, which require appropriate treatment and/or disposal.

5.2.6. Trace impurities

The removal of N, S, Cl and other trace elements volatilised from the biomass during gasification is usually required for most end-uses of the gas. Nitrogen compounds are present mainly as ammonia, with some hydrogen cyanide being possible and cannot be removed by filtration but requires wet scrubbing with water or aqueous solutions, which cools the gas to about 50 °C. The alternative to wet scrubbing is to leave the N compounds and to use low-NO_x techniques during combustion, or selective catalytic reduction of the nitrogen oxides in the flue gas.

Chlorine contained in the biomass is present usually as HCl in the gas from the gasifier, the concentration depending on the feedstock and gasification conditions. The removal of HCl is typically undertaken by wet scrubbing or absorption on active materials such as CaO/MgO.

The alkali components in the biomass, particularly Na and K compounds, are volatile at high temperatures but it is uncertain which compounds are actually present in the gas. The alkali compounds cause corrosion of ceramic filters and turbine blades and the best way to reduce concentrations is to cool the gases to about 500 °C to condense the compounds and to then filter the gas.

5.3. Vehicle fuel

The use of gasification to provide a fuel for motor vehicles from biomass is well proven and documented. During World War 2, the shortages of petroleum products in Europe lead to the need to develop alternative technologies to provide fuel for motor vehicles. The technology chosen was gasification of wood, using a fixed bed gasifier unit attached to the front of the vehicle. However, the development of wood gasifiers to power motor vehicles had commenced earlier in the 1920s in Sweden, arising from the general lack of indigenous petroleum resources and the abundance of biomass resources in the form of wood. The Government undertook a development programme commencing in 1932 to promote car owners to convert to wood gasifiers. As a consequence by the outbreak of World War II the use of wood gas fuelled vehicles was well established in Sweden.

Extensive studies were undertaken over the period 1939–1945, further refining the design of the wood gasifier, gas cleaning and cooling systems and adapting engines to optimise their performance on wood gas. The work is well documented (Solar Research Institute, 1970) and it is advised that those interested in pursuing the technology and techniques of wood gasification in more detail consult the document. General findings from the research can be briefly summarised as follows:

- using wood gas in s.i.g.e's. presents no (insurmountable) technical difficulties,
- low CV wood–gas requires higher compression ratios to produce the same engine performance, necessitating that stronger built engines are utilised e.g. diesel-based engines,
- engines with large cylinder volumes and large valve areas, operating at constant load and at low rpm, give

optimum power output e.g. stationary, industrial engines,
- small high-speed engines drawing in the air/gas mixture (e.g. four stroke engines) do not perform as well as engines where the gas is injected into the combustion zone under pressure i.e. two stroke engines give better performance than four stroke engines.

The development and widespread use of cheap liquid hydrocarbon fuels after World War II led to the demise of wood–gas as a viable engine fuel. However, gas derived from renewable sources such as biomass has assumed renewed significance due to the issue of local air quality in urban areas and in terms of global warming.

6. Process summary

The advantages/disadvantages of the various generic types of gasifying reactor for the production of low/medium CV gases are summarized in Table 1.

The selection of the type of gasifier and its design will be dependent upon a number of factors; including the process attributes identified in Table 1; the influence of the properties of the feedstock (both chemical and physical); the characteristics of the required product gas; and the various operational variables involved. Listed below are key criteria that need to be addressed when selecting a gasifier reactor:
- capital costs of the gasifier and product gas cleaning unit should be as low as possible,
- operating and maintenance costs should be low,
- the gasifier should be robust, ideally without moving parts,
- feedstock preparation, such as drying, separation, size reduction or pelletisation, should be avoided.

The features of a fluidised bed gasifier that make it appear less attractive are:
- complex design and operation,
- requires the particle size of the biomass feedstock to be reduced in size,

Table 1
Properties of gasification reactor types (Rampling, 1993)

Advantages	Disadvantages
Fixed/moving bed, updraft	
Simple, inexpensive process	Large tar production
Exit gas temperature about 250 °C	Potential channeling
Operates satisfactorily under pressure	Potential bridging
High carbon conversion efficiency	Small feed size
Low dust levels in gas	Potential clinkering
High thermal efficiency	
Fixed/moving bed, downdraft	
Simple process	Minimum feed size
Only traces of tar in product gas	Limited ash content allowable in feed
	Limits to scale up capacity
	Potential for bridging and clinkering
Fluidised bed	
Flexible feed rate and composition	Operating temperature limited by ash clinkering
High ash fuels acceptable	
Able to pressurize	High product gas temperature
High CH_4 in product gas	High tar and fines content in gas
High volumetric capacity	Possibility of high C content in fly ash
Easy temperature control	
Circulating fluidised bed	
Flexible process	Corrosion and attrition problems
Up to 850 °C operating temperature	Poor operational control using biomass
Double fluidised bed	
Oxygen not required	More tar due to lower bed temperature
High CH_4 due to low bed	
Temperature	Difficult to operate under pressure
Temperature limit in the oxidiser	
Entrained bed	
Very low in tar and CO_2	Low in CH_4
Flexible to feedstock	Extreme feedstock size reduction required
Exit gas temperature	Complex operational control
	Carbon loss with ash
	Ash slagging

- size reduction of the feed produces fines which are not suitable for fluidisation,
- product gas has high tar content requiring external gas cleaning.

In comparison to FB gasifiers, the fixed bed gasifier appears the most practicable option for the production of a low CV gas for use in small-scale power generation schemes using s.i.g.e's. or gas turbine engines. Fig. 3 shows a schematic flow sheet for the production of a fuel for a stationary gas engine. The gasifier plant is of simple construction, robust and has no/few moving parts.

The estimated capital cost of a fixed-bed gasifier plant to provide sufficient producer gas to generate 2.5 $\mathrm{MW_{(e)}}$ (i.e. about 7.5 $\mathrm{MW_{th}}$ at 30% conversion efficiency to electricity) is about £2.3 million (McKendry, 2000). The cost of the gas engine-generator set is additional, at about £500–600/$\mathrm{kW_{(e)}}$, or £1.2–1.5 million for a 2.5 $\mathrm{MW_{(e)}}$ system. Based on the above data, the total capital cost for a 2.5 $\mathrm{MW_{(e)}}$ biomass-to electricity plant would be between £3.5–3.8 million.

Operating costs for the plant would be about 1 p/$\mathrm{kWh_{(e)}}$. Based on a per unit produced costs basis, the significant unit cost elements are:

• production of biomass feedstock	5.7 p/$\mathrm{kWh_{(e)}}$
• gasifier/generator plant	4.3 p/$\mathrm{kWh_{(e)}}$
• operations and maintenance	1 p/$\mathrm{kWh_{(e)}}$
Total unit cost	11 p/$\mathrm{kWh_{(e)}}$

The two largest cost elements are the biomass feedstock and the gasifier/generator plant. While not much can be done to reduce the gasifier/generator cost if sources of waste biomass were available the impact on the total cost would be significant. Forestry and agricultural residues would inevitably result in additional processing and operating costs due to increased moisture content and contamination with soil and other sources of slag-forming materials. Allowing for the additional operating costs the overall saving in the unit cost is expected to be of the order 3–5 p/$\mathrm{kWh_{(e)}}$, dependent on the cost of transport and any sale price that may be paid for the residues.

7. Discussion

The simple financial assessment outlined in the previous section illustrates the sensitivity of any process to the various cost inputs. The potential of being paid to take biomass wastes greatly enhances the economics of power generation. The combined burden of increasing quantities of wastes and environmental legislation in Europe that limits the wastes that can be disposed to landfill has lead to an increase in the number of thermal treatment plants operating on biomass wastes. The greatest increase has been in the number of energy-from-waste plants (EfW) that treat municipal solid wastes (MSW). MSW is increasing at the rate of 3–5%/annum in the UK despite the current efforts to reduce/re-use/recycle such waste materials.

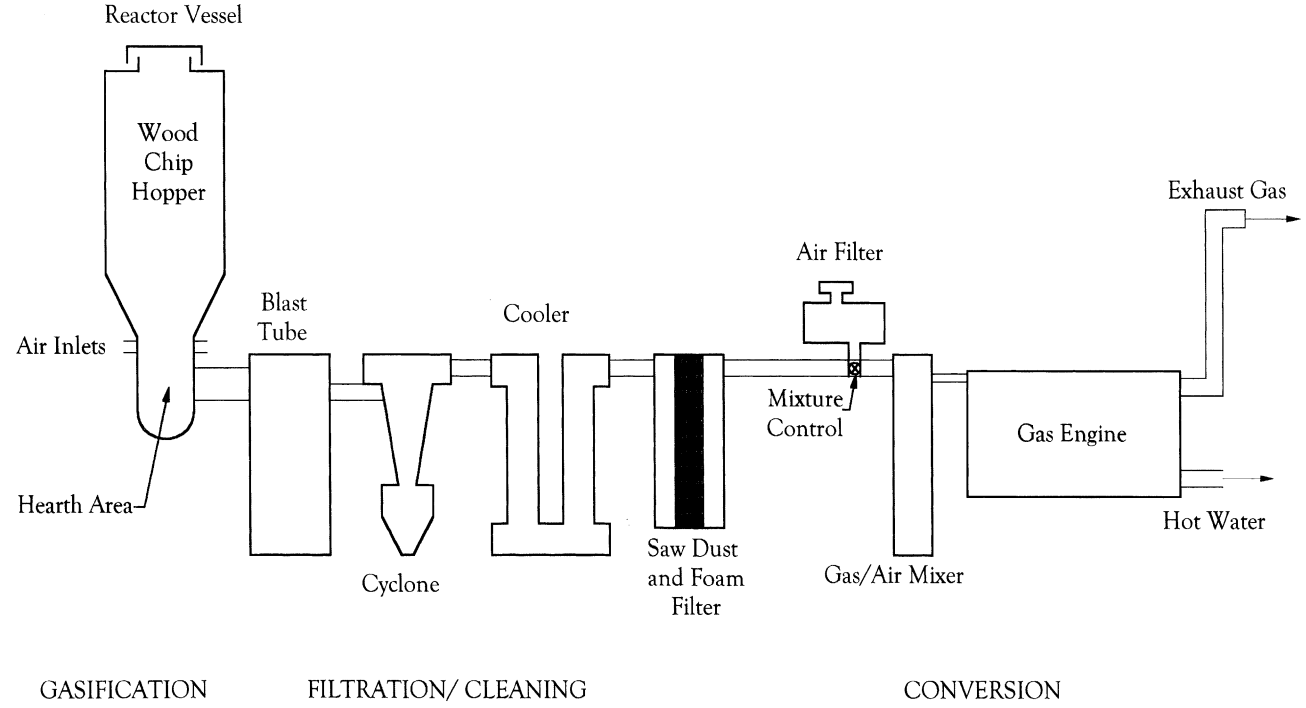

Fig. 3. Flow sheet for gasification to produce fuel of gas engine.

The large-scale of mass-burn EfW plants is not always acceptable to local communities, due both to the physical size of the plant and the perception that it hinders the potential for recycling due to the large tonnages that it can burn. A more sympathetic response is being given to smaller scale gasification plants where the scale of operation is seen to be more in keeping with the move towards encouraging recycling. Particular waste streams such as tyres will be banned from disposal to landfill in Europe in the next few years. While not biomass, tyres provide an ideal opportunity for gasification and pyrolysis processes to deal with what is perceived to be a difficult waste management issue and at the same time provide useful end products.

The thermal processing of biomass using gasification (and pyrolysis) has the potential to play many different roles in both the developed and the third world. In the third world where the availability of electricity is seen as a key factor in assisting development in rural areas, gasification can provide a local source of electricity using local biomass (Hislop and Hall, 1996). In the developed world gasification can both assist with the current crisis of global warming by providing a source of renewable energy and also deal with the environmental problem posed by the increasing quantities of waste produced by society.

8. Conclusions

- gasification is a versatile thermochemical conversion process which produces a gas mixture of CH_4, CO and H_2, the proportions being determined by the use of air, oxygen or steam as the gasification medium, with a concomitant range of CVs, low (4–6 MJ/Nm^3), medium (12–18 MJ/Nm^3) and high (40 MJ/Nm^3);
- key parameters for successful gasification are the feedstock properties (moisture, ash, alkalis and volatiles) and feedstock pre-treatment (drying, particle size, fractionation and leaching);
- gasifiers are of two main types, fixed bed and fluidised bed, with variations within each type and specific characteristics which determine the need for and extent of feedstock preparation/pre-treatment;
- for use in a s.i.g.e. gas produced from a fixed bed, downdraft gasifier provides a low tar gas, with a high particulates loading: as tar is a major contaminant for engine operation and particulates can be relatively easily removed, this system is considered best for fuelling s.i.g.e.;
- extensive development of wood gas-fuelled IC engines, suggests that diesel-based engines, with large cylinder volumes/valve areas, operating at constant load and low rpm, provide optimum power output;
- use of biomass from waste sources can influence the economics of plant operations in a positive manner and at the same time provide a means of assisting with the environmental problems posed by the disposal of wastes in the developed world;
- for the third world the use of a simple and robust technology represented by gasification can assist the development of rural economies by providing electricity produced from local sources of biomass.

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