

## GASIFICATION - THE PROCESS AND THE TECHNOLOGY

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### ABSTRACT

Thermochemical gasification of biomass can produce low, medium and high calorific value gases. The characteristics, applications and potential of the different processes and reactor types are discussed. The introduction of biomass gasification on a large or intermediate scale for the production of power, synthetic natural gas (SNG), methanol etc. will depend on developments in coal and (municipal) solid waste gasification and on the price of biomass. Biomass - and especially wood - is a clean fuel and, therefore, its direct combustion using modern equipment will be a strong competitor for energy generation via gasification. Gasification is also attractive for small scale, power and power-heat generation and developments necessary for its widespread acceptance are discussed. It is further concluded that, on the small and intermediate scale, new processes which require minimum feedstock preparation and preferentially producing medium calorific value gas without the use of oxygen, should be developed.

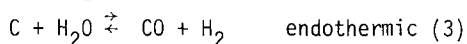
### INTRODUCTION

Thermochemical gasification of solid fuels such as biomass, peat and coals has been studied and applied for about 140 years (1). A complete review would easily fill several textbooks. Therefore, the discussion will be restricted to some of the fundamentals and the different types of technology used in the field of biomass gasification and will then concentrate on some applications which are expected to penetrate the energy market in the near future.

The aim of a gasification process is to transfer the combustion value of the solid fuel to a gaseous energy carrier, preferably in the form of chemical energy and not in the form of sensible heat. Gasification is performed because of the advantages of a gas over a solid fuel: gases are easy to clean, to transport and to combust efficiently with a low excess of air and little resulting pollution. Further, gases can be burned in an internal combustion engine (gasturbine, reciprocating engines) and can be easily applied in combined cycles.

Certainly biomass gasification can be carried out by means of biological processes. Thermochemical processes have the advantages of more compact equipment due to the relatively short residence times required (1-10,000 s), easy start-up and stable operation and there are no requirements on the nutrient value of the feedstock. Its disadvantages are that relatively dry feedstocks are required and that the ash produced has little value as fertilizer. Nonetheless, only thermochemical routes are discussed further.

In a gasification process the biomass is successively heated, dried and pyrolysed to produce gases and char. These products react further in a complex way with a gasification agent which can be air, oxygen, CO<sub>2</sub>, steam, mixtures of these gases or hydrogen to produce the final product. The reactions that take place between the char and the gasification agents can be described broadly speaking by the following equilibrium reactions:



The composition of the product gas is determined by the biomass feedstock and gasification agent used, and by process conditions such as pressure, temperature, residence time and heat loss or external heat input. The external heat source can be a nuclear plant (2), concentrated solar radiation or another chemical reaction (e.g. external combustion of part of the fuel, CO<sub>2</sub>-acceptor process (3) etc.). Most gasification processes are autothermic, however, and only those cases are considered here. Gasification produces several types of gases and these can be roughly divided into three categories, according to their heat of combustion per unit volume at ambient conditions (see Table 1).

TABLE 1  
Typical compositions of dry clean product gases

	CO	H <sub>2</sub>	CO <sub>2</sub>	CH <sub>4</sub>	C <sub>n</sub> H <sub>m</sub>	N <sub>2</sub>	Calorific value
	volume	volume	volume	volume	volume	volume	MJ/m <sup>3</sup>
	%	%	%	%	%	%	
Low calorific value gas	17	18	14	2	-	49	4.8
Medium calorific value gas	61	28	2	8	-	1	13.6
High calorific value gas	-	-	0.9	81.2	3.4	14.5	31.7

### Low calorific value gas (3.5 - 7 MJ/m<sup>3</sup>)

A typical production and application scheme is given in Fig. 1.

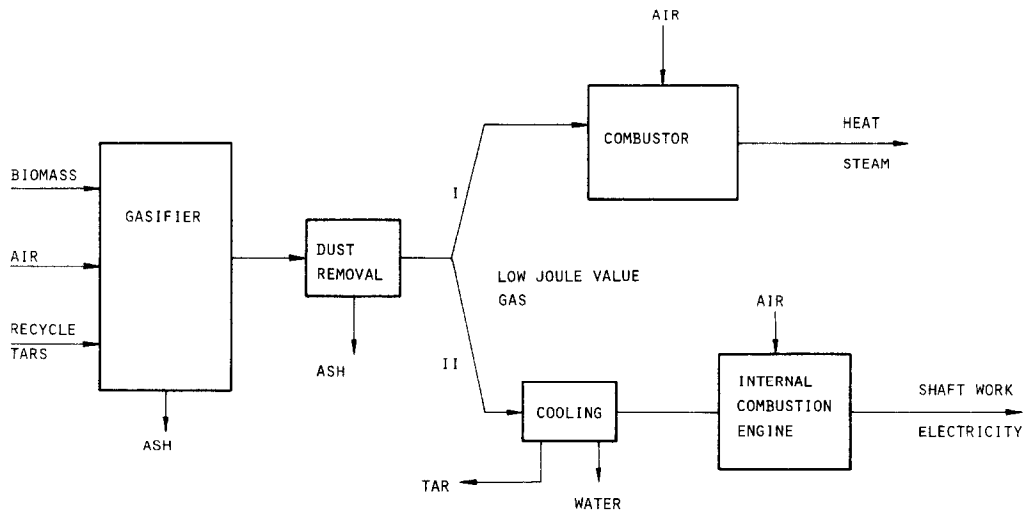
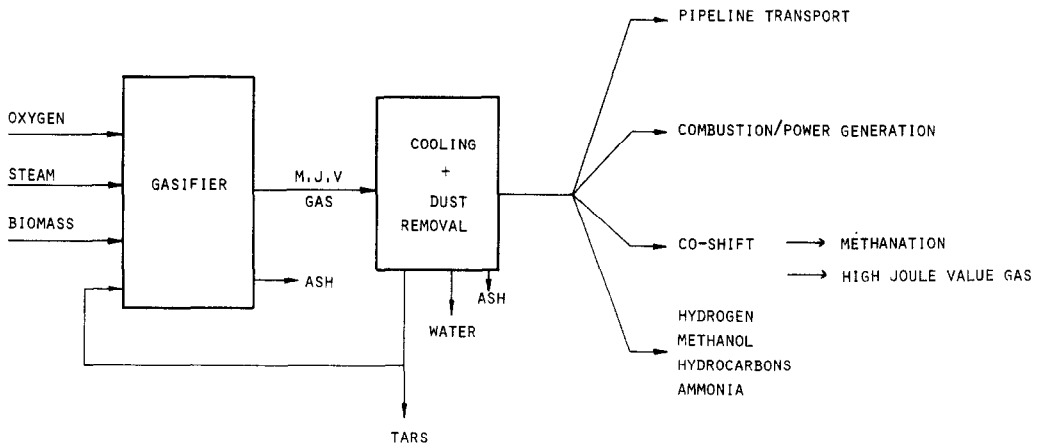


Fig. 1. Simplified scheme of the production and application of low calorific value gas

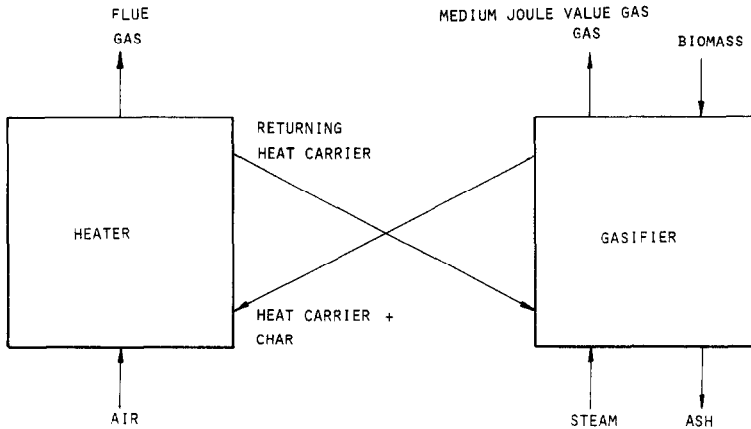
Air is the gasification agent. In most cases it is simply a two stage combustion process and sometimes the gasifier is retrofitted to an existing gas/oil boiler, kiln or motor. The lower scheme can also be replaced by a gas turbine and is especially attractive if electricity generation can be combined with a useful application of the sensible heat of the exhaust gases (drying, heating, etc.). Due to the low specific energy content the product gas cannot be transported over substantial distances or stored economically.

### Medium calorific value gas (9 - 15 MJ/m<sup>3</sup>)

Two typical production schemes are given in Fig. 2 together with possible applications. Scheme A is well known. However, oxygen is usually expensive and scheme B avoids its use. The endothermic biomass steam reaction is separated in location from the exothermic reaction (combustion with air). Solid reactants and heat carriers are circulated between the gasifier and the heater in the same way as in fluid bed catalytic cracking. To some extent it can be considered as a continuous variant of the old intermittent water gas process. This scheme B (4, 5) has not yet been proven commercially for biomass. In Tokyo it is used for municipal waste. The medium calorific value gas can be economically transported over larger distances and used for (combined) power/heat purposes. Furthermore, the product gas (also called synthesis gas) can be used to produce a wide variety of chemicals and energy carriers such as methanol, H<sub>2</sub>, gasoline, SNG, etc.



2A. Production of medium calorific value gas from oxygen and steam.



2B. Production and application of medium calorific value gas  
 Fig. 2. Production and application of medium calorific value gas

High calorific value gas (20 - 36 MJ/m<sup>3</sup>)

Mostly, these gases are used to substitute for or supplement natural gas. They are usually produced from medium calorific value gas (see Fig. 2) but in a few schemes direct production is being developed (see Fig. 3).

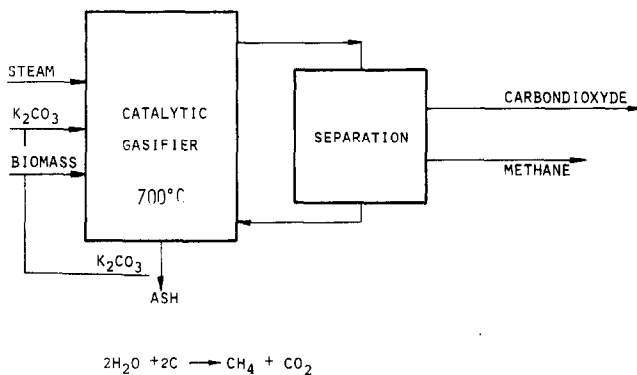
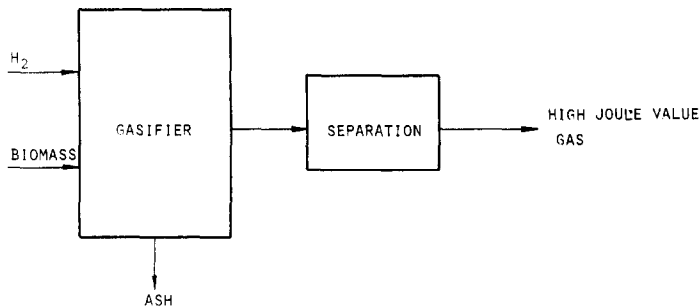


Fig. 3. Direct high calorific value gas production by gasification.

Apart from gasification at high pressure with hydrogen (A), the Exxon (6) process for coal looks promising. The almost thermally neutral reaction:  $2 H_2O + C \rightarrow CH_4 + CO_2$  is realized at approximately 600-700°C utilizing  $K_2CO_3$  as a catalyst. Methane is continuously separated from the recycle system by cryogenic distillation. However, such processes are not yet commercially available. Most of these type of processes have been developed for coal or peat but some have also been tested for biomass or municipal waste. Biomass contains much more oxygen and hydrogen than coal, reducing the amount of steam necessary to effect gasification. Furthermore, its sulphur content is usually low. On the other hand, as produced, biomass often contains large amounts of water and after drying will retain water if not properly stored. Apart from energy losses in drying, this adds to the complexity of the process. The biomass is often in an inconvenient form and unless the gasifier is specially adapted, extensive feedstock preparation may be required, such as grinding or pelletizing. The cost of these operations can be considerable (up to \$ 25 per ton (7)) and consume up to 10% of the

heat of combustion of the biomass. Another important property of biomass is the dispersed nature of its production giving rise to important collection and transportation costs, especially for large scale conversion processes.

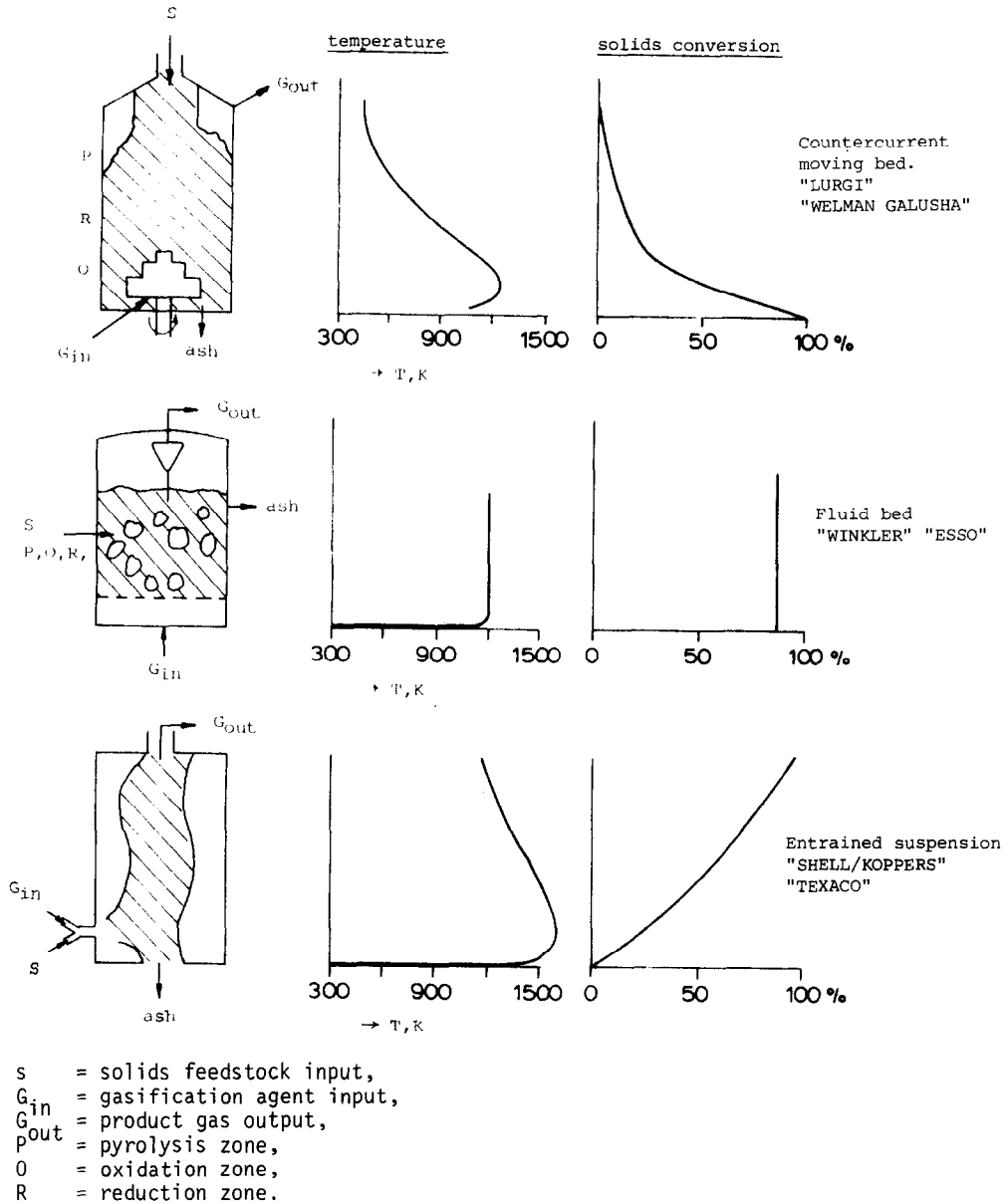


Fig. 4. Gasification reactor types with temperature and solid conversion profiles.

## REACTOR TYPES

Most of the reactor types have a long history. Fig. 4 gives the different principles together with temperature and conversion profiles. It should be realized that reactor properties do not necessarily reflect the process performance. Tars and heat can be recovered and recycled to the reactor. This complicates the overall process however. The countercurrent moving bed reactor has the longest history and is widely used (1, 8-10) both with solid and liquid (10, 11) ash removal. Its advantages are simplicity of operation, no solids flowrate control is necessary, and that there is internal heat exchange of the product gas with the biomass feedstock ( $T_{out} \approx 400^{\circ}\text{C}$ ). Its disadvantages are that large amounts of tars are produced, and that channeling due to sticking tarry particles may occur, necessitating the use of rotating grids. Pelletizing may be necessary depending on the feedstock. The co-current moving bed reactor (1, 12-14) is also simple to operate. Contrary to the countercurrent process it produces an almost tar-free product gas but it is more difficult to scale-up (see below). It has a higher product gas temperature ( $\sim 700^{\circ}\text{C}$ ) and may also require feedstock pelletization. The fluid bed reactor (15-17) can handle a wide range of feedstocks including those with high ash content and with a poor mechanical strength of the char. Disadvantages are a high product gas temperature ( $\sim 900^{\circ}\text{C}$ ), possible tar production, limited solids conversion, severe particle entrainment and a more complex solids flow rate control required.

The entrained bed reactor (1, 18-20) is also omnivorous in that it operates tar-free and with molten ash due to the high temperatures. However, the process is complex to operate, requires powdered biomass and extensive heat exchange. Therefore, its application will be limited to large scale processes. The molten salt (21) and molten iron processes (22) are not considered here. The conversions and temperatures of these processes are somewhat similar to the fluid bed process. Also rotary kilns are used for co- and counter-current operation. Furthermore, intermediates between co- and counter-current operation have been operated in the past: double shaft and double fire gasifiers (see (1), (12)).

## PROSPECTS FOR BIOMASS GASIFICATION

The main factors determining the economics of biomass gasification processes apart from feedstock costs are the gasification agent, the operational pressure and the unit capacity. Fig. 5 gives a general picture of the prospects. With regard to large scale biomass units ( $>100 \text{ MW}_t$ ), if feasible at all, the criteria for process selection are not unlike those of the coal gasifiers and pressurized gasification with oxygen seems logical. Process pressures will be 3 MPa or higher in relation to the subsequent syntheses process (methanol, SNG, etc.). For coal gasification, only the LURGI process (8) has reached the commercial stage here but many others, e.g. Texaco (19), Shell/Koppers (18), are

in an advanced stage of development. For electricity production from coal, air gasification, at e.g. 3 MPa is often proposed (23). With biomass gasification, the problem of sulphur removal is far less important (or absent) and, therefore, direct combustion (e.g. in powder flames) seems more likely. The situation may change if high efficiency power units (combined cycles) based on gasification of coal will attract widespread use.

For the intermediate scale (10-100 MW<sub>t</sub>) the situation is not yet clear. Direct combustion in powder flames or (fast) fluid beds (24) are strong competitors to gasification. The preference for gasification depends much on the existing site facilities, feed preparation requirements and heat/work demands of the applications. It is very difficult to give general rules as yet because many more technical/economical data are required. Gasifiers for municipal waste based on oxygen (25) or air gasification (26, 27) are slowly finding application and similar biomass gasification processes may become more attractive.

Retrofitting existing boilers, kilns etc., previously fired by coal, gas or oil is widely discussed in the literature (28-30) especially in relation to wood. No de-rating is necessary if medium calorific value gas is produced. However, the system requires expensive oxygen or processes still to be made commercially available. De-rating may become important with air gasification if the heating value of the product gas is below 7.4 MJ/m<sup>3</sup> (28). An important factor in air-blown gasifiers can be the conservation of the sensible heat of the product gas by fitting the gasifier directly to the boiler. Increasing the calorific value of dual fuel firing may also counteract de-rating.

For small and medium scale power generation, 0.1 - 20 MW<sub>t</sub>, the set-up in Fig. 1, is attractive and likely that gasifiers in connection with dual fuel diesel engines or gas engines for combined power/heat generation will capture an important slice of the market in the near future. These plants have a relatively high efficiency at different loads and are basically simple. Several manufacturers are marketing such systems (31, 32) and some units are already operating or are in the construction phase. Some units operate in the countercurrent mode but for smaller plants, co-current operation seems to be particularly attractive because of its low tar production. These units will be discussed in more detail.

#### CO-CURRENT MOVING BED GASIFIERS

Although this type of gasifier has been known for more than 100 years, only approximative descriptions of the reactor and only purely empirical design rules are found in the literature. Groeneveld et al. (13, 33) recently studied the reactor mechanics in more detail (see Fig. 6). The solid feedstock enters the top of the gasifier and the pyrolysis zone is situated above the hottest zone, i.e. the oxidation zone. A critical requirement is that tars and other pyrolysis products pass the hottest zone and do not escape via the reduction zone into the product gas.



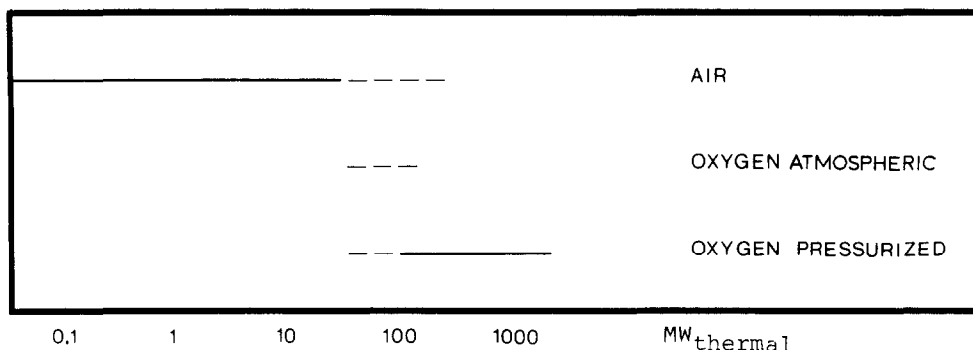


Fig. 5. Anticipated economical capacity range of Biomass gasification processes.

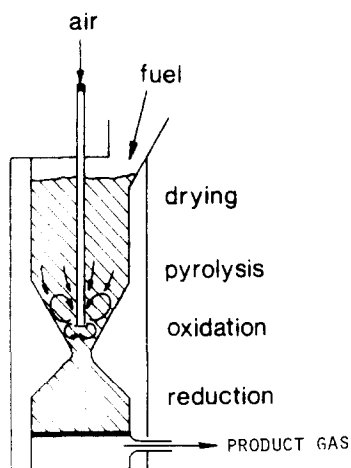


Fig. 6. Typical Co-current moving bed gasifier.

In the reduction zone oxygen is absent and due to the endothermic reactions (2) and (3), the temperature is relatively low. Therefore, the reaction time for the gas phase is not sufficient for tar conversion in this zone. It was found that for tar-free operation a double vortex, induced by the incoming airflow, should form the throat. With this in mind, and knowing the time required for complete pyrolysis of the particles, it is possible to understand to some extent the empirical rules for throat design found in the literature (13). The product gas composition and the temperature can be estimated by using simple heat and mass balances, the estimated methane formation (mainly in the pyrolyses zone (34)), and assumptions on heat loss and "equilibrium" temperature (see e.g. Schläpfer model (35)). Although the concept of equilibrium cannot strictly be applied to this process, these simple models give good results once fitted for a specific unit

Groeneveld et al. (13, 33) have made an approximate kinetic/transport model for the processes occurring in the reduction zone. From this model the relationship between reactor volume conversion, particle size, carbon conversion profile in the particle, solids flow, gas composition, and temperature can be understood (see Fig. 7). In the pyrolysis zone, the pyrolysis reaction takes place without change of particle size and the particle will enter the oxidation zone homogeneously converted. Because of the rapid reaction in the presence of oxygen, the particles react here essentially in a shrinking core mode and an outer layer of char will be burned off.

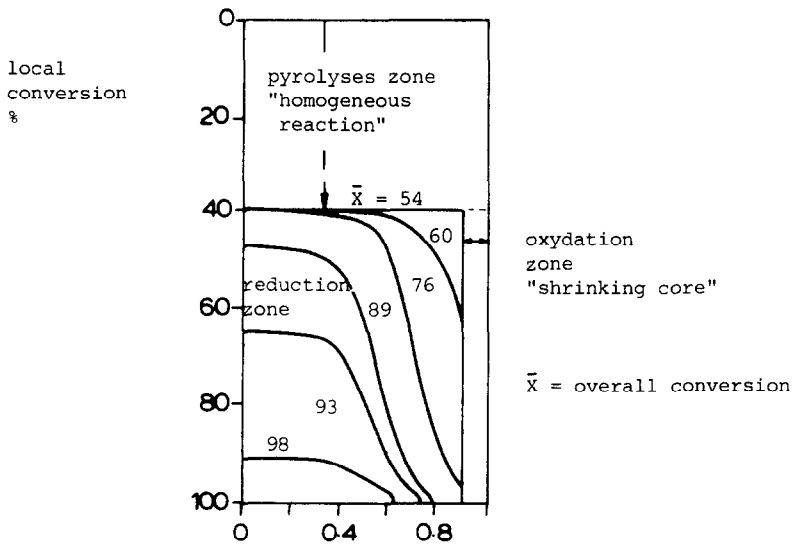


Fig. 7. Typical conversion behaviour of a particle during its gasification in a co-current gasifier as calculated from the reactor model of Groeneveld et al. (13) Initial radius of wood particle  $R_0 = 12.4 \times 10^{-3}$  m.

In the reduction zone, the reaction can take place throughout the particle but close to the oxidation zone where the temperature is still preferentially high at the outer layers of the char. If the carbon concentration becomes too low the outer layer will be removed and entrained by the gas. This process causes the particles to shrink further until they finally collapse. The shrinking of the particles governs the solids flow in the gasifier.

Figure 8 gives typical conversion and temperature profiles in the reduction zone calculated from the model and observed in an experimental unit. This model can be used as an additional guide for design and gives some background information about the limits of the simple "thermodynamic" models.

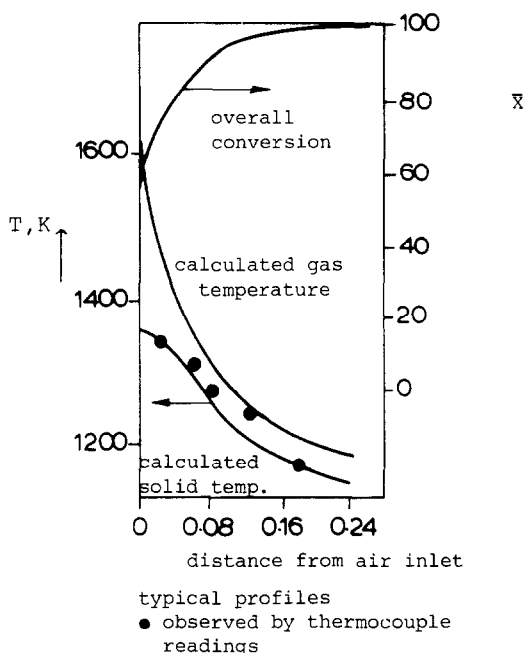


Fig. 8. Typical conversion and temperature profiles in the reduction zone of a co-current moving bed gasifier.

A critical design problem concerns the scaling-up of the throat without increasing tar production. A possible solution might be the use of a cylindrical annular throat (34). The problem might also be solved by recycling of pyrolysis gas over the top of the gasifier, possibly via an external combustion chamber prior to the air inlet. However, this increases the complexity of the system. Such systems have been in operation for some years (1, 12) and essentially are now applied in designs of "Moteur Duvant" (32). An additional advantage of this system could be a lowering of the highest oxidation zone temperature and thus reducing the risk of unwanted slagging. However, the exact description of the highest solid temperature in the oxidation zone, specially in relation to pyrolysis gas recycle, needs more investigation. Although the future for the small scale units appears bright, new demands concerning automation, safety, flexibility and environmental protection have been imposed on these units as compared to former applications. In designing modern units, the following must be considered: (a) automation of solid preparation and feeding, start up, stand by, turn down, control of dual fuel ratio and speed control; (b) problem-free heat exchangers and residual tar soot and ash removal; (c) safety with respect to CO and to the danger of explosions of gas/air mixtures; and (d) environmental acceptable solutions for the condenser water containing compounds such as sulfides, cyanides, ash, and traces of organic compounds (phenolic compounds, etc.).

Another important factor is the selling/buying policies of electricity companies which will influence the economics of all decentralized electricity generation units. Furthermore, feed preparation steps may be too expensive in some cases (drying, pelletizing). Drying should be integrated as far as possible with exhaust heat recovery and for extremely wet feedstocks, compression drying or other special upgrading processes may be required. Because feed-preparation is so costly (7), more complicated techniques (fluid bed reactors in combination with new type heat exchangers) may gain preference over the simple moving bed system. The application area can be extended to much larger capacities if integration with gas turbines can be realized. Also small scale units (30 - 50 kW<sub>t</sub>) might become economically attractive for individual energy provision for farms, homes and for villages in developing countries. In a Dutch-Tanzanian development co-operative program (12, 36), 40 kW<sub>t</sub> units running on maize cob spills and used for maize milling in the villages are being tested for the technical, economical, and social viability of this concept (see Fig. 9).

In the long term, even small scale production of pure H<sub>2</sub> via shifting and separation could become attractive depending on possible developments in, for example, fuel cell and hydrogen storage technology. Generally the production of syntheses gas from low calorific value gas deserves more attention in research programs.



Fig. 9. Application of biomass gasification in Tanzania. Maizepills are gasified to generate energy for maize milling.

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