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Research paper

Can biomass be satisfactorily gasified under pressure using an aqueous slurry feed? Examination by simulation

Brian Stanmore [a], Ange Nzihou [b, *]

[a] Formerly of the University of Queensland, Brisbane, QLD 4072, Australia
[b] Université de Toulouse, Mines Albi, CNRS, Centre RAPSODEE, Campus Jarlard, F-81013 Albi Cedex 09, France

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ABSTRACT

A major hurdle for the gasification of biomass under pressure is the need to introduce a fibrous biomass feed material such as straw, switchgrass or miscanthus into a pressure vessel. One proposed solution is to prepare a dense aqueous slurry from the biomass and then use a conventional high pressure pump. The production of syngas from wheat straw and subsequent power generation is examined theoretically in an Australian context. A slurry of concentration of 50% biomass by volume, which is regarded as the maximum pumpable value, is dried with superheated steam and the biomass gasified at 2 MPa with steam only in cyclones. It was found that the thermal deficiency of introducing excessive liquid water is considerable, rendering the process unsustainable. The problem can be overcome by employing a subsidiary fuel such as natural gas, but even with the minimal amount of water, the required energy input is equivalent to that of the straw. The net electrical efficiency of the process based on both fuels is 33.5%, so that the approach would be contemplated only if the over-riding consideration was the use of the straw for energy generation. The zero net present value cost of power production is 125 $ MWh-1 for 90 Gg of straw consumption per annum.

1. Introduction

The production of energy from biomass using thermal processes may follow the combustion, pyrolysis or gasification routes. Combustion is directed towards heat and electricity generation, while pyrolysis is employed for the production of liquid fuels. Gasification can satisfy either aim, but at the cost of greater process complexity and uncertainty. In the Australian context the process aims are generally less ambitious, and are confined to power generation. A preliminary study by the authors on the relative merits for power generation of combustion and gasification, both at atmospheric and elevated pressures, was undertaken [1]. The conclusion arrived at was that combustion is currently the only viable option, although pressure gasification is theoretically superior in terms of efficiency and cost.

The benefits of gasifying under elevated pressures rather than at atmospheric conditions have been repeatedly demonstrated e.g Bridgewater [2]. The process for carbonaceous fuels is more efficient when operated under a pressurised environment, with 2 MPa a typical figure. The advantage for power generation is that this shifts the equilibrium composition towards higher concentrations of hydrocarbons (methane) and hence higher syngas specific energy, but at the expense of somewhat diminishing amounts of hydrogen and carbon monoxide [3]. The configuration does not require energy to pressurise the syngas for subsequent combustion in a gas turbine. In addition the process density is enhanced, with comparatively smaller reaction vessels required.

In the previous paper [1] an economic analysis was carried out which showed that pressurised gasification should be a better option than combustion for electricity generation, as the overall efficiencies of the former are far higher, and the cost to generate power is lower. Unfortunately, there are some technical challenges which are still unresolved. The clean-up of the syngas to make it suitable for further processing is the study of considerable research, which is slowly developing solution [4,5]. The major hurdle is the need to introduce a cohesive and/or fibrous biomass feed material such as straw, switchgrass or miscanthus into a pressure vessel.

One feeding option which has been proposed is to pulverise the fuel, make it into a dense slurry, and pump it into the gasifier using conventional pumps. A literature search has not uncovered many examples of slurry feeding using water, which would be technically

* Corresponding author.
E-mail address: ange.nzihou@mines-albi.fr (A. Nzihou).

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the simplest. More emphasis has been placed on bio-oil produced by pyrolysis as the slurry medium. The gasification of this oil and the corresponding char has received some attention e.g. Refs. [6–9].

The process of producing a dense slurry of biomass involves a number of difficult steps. Most biomass is hard to handle and resists pulverisation to fine sizes. Dry materials will retain their inherent cell structures (see Fig. 1), which on water addition will be filled before free water will become available to mobilise the particle assembly. The only way to minimise overall slurry water content is to pulverise the biomass to a sufficiently small size which ensures destruction of the major cell walls.

The consequence of this is that a slurry produced from even a dry feed material will contain quantities of water which compromise the thermal conditions of a gasifier. In a conventional system air (or oxygen) is added in sufficient quantity to maintain the operating temperature at the required value, typically in the vicinity of 800 °C. The presence of water lowers the efficiency to such an extent that pre-drying is essential, which then transfers the thermal penalty to this operation. It must be addressed by adopting a suitable process configuration, typically with integration of the various steps.

For example, the most prominent proponent of aqueous slurry feeding is de Souza-Santos, who with co-workers has published a series of detailed papers, of which the latest are [10–13]. At this stage, they are desk-top studies which examine a similar concept with different conditions and fuels. The last of the series, which considers operation at a very high pressure to produce a net mechanical output of ~106 MW [12], will be examined as typical of the approach.

The fuel considered is a hypothetical biomass with 50% as-received moisture and a comparatively large particle size (82% > 1.68 mm). This feed is slurried with water, pumped, dried in a fluidised bed at 10 MPa using flue gas from a gas turbine, and the dry solid then passed to a fluidised bed gasifier operating at a similar pressure.

There are a number of assumptions in the proposal which need closer examination. The core of the process is the production of an aqueous slurry containing 40% solid biomass by weight. The 60% of water is comprised of 40% inherent in the biomass and an extra 20% of added free water. Since the particles are comparatively large, the cellular plant structures would remain, and retain the inherent water. The added water does not appear to offer enough volume to fill interstices such that the particles would be mobilised. On a volume basis assuming the inherent water is retained, the slurry is likely to be 80% solids. The feed system would then be more of an extrusion rather than a pumping operation. The authors nominate a manufacturer who would supply such a device, which needs to be confirmed in practice. The complicated flowsheet incorporates two gas turbines, five steam turbines and three gas compressors, all of the latter with an intercooling stage.

It is hard to regard the process as practical when it relies on such an arrangement. For instance, when considering the steam turbines, the mechanical outputs range from lows of 0.7, 3, 15 and 25 MW up to 104 MW. Of the gas turbines, one has an output of 222 MW, and the other 25 MW during which the working gas decreases in entropy. The larger turbine operates at 9.9 MPa, which is beyond the range of conventional machines.

A major flaw in all the processes is the venting direct to the atmosphere of large quantities of wet gas from the driers at high pressures e.g. 83 kg s^{-1} at 0.9 MPa [12], 70 kg s^{-1} at 2.2 MPa [11]. This is inconceivable. The other configurations detailed in companion papers suffer from similar defects, meaning that the plants described are unrealistic in concept.

In the present simulation, an assumption has been made that the amount of water required for such a process will be determined by slurry rheology. As a consequence the principal disadvantage of this method is the large quantity of water introduced, and the subsequent need to dry the biomass before the gasification reaction. Application of the simulation software used here quickly revealed that the water deemed necessary to produce a slurry made the system unfeasible. As a result a supplementary fuel, in this case natural gas, was required to support the drying/gasification reaction. The quantity of NG was varied until a satisfactory energy balance was obtained. It was found to be roughly equivalent, in energy terms, to the amount of straw processed.

This paper proposes the use of superheated steam, rather than air as the drying agent, and then employing the generated steam as the only gasifying medium. It also proposes the use of a pressurised cyclone as the gasifier, thus simplifying the operation of pressure vessels.

The advantages of this system are as follows.

- Conventional feeding equipment is employed.
- The steam drying process is equally as efficient as, or more efficient than with air.
- High energy syngas is generated as nitrogen is excluded from the gasifier.
- The cyclone can act as an efficient, compact gas-solid contacting reactor.

The simulation is applied to wheat straw from central Western Australia, one of the major cereal-producing regions of the world.

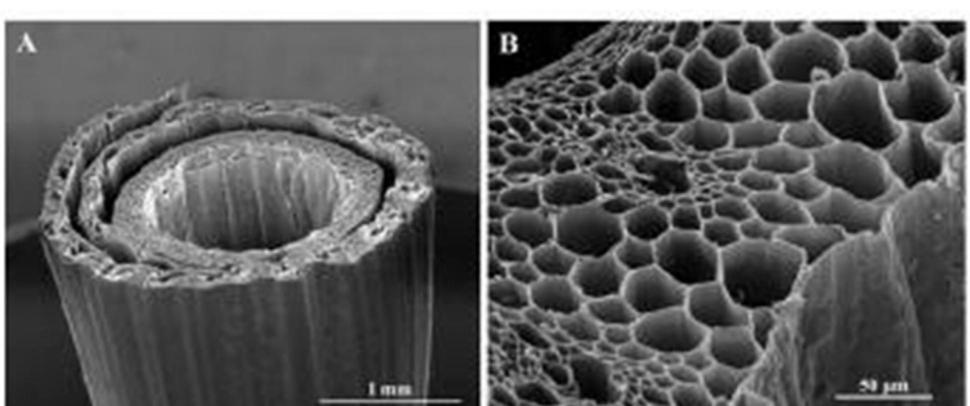

Fig. 1. Micrographs of a stalk of straw [22].