Wood Residue Combustion and Gasification in a Fluidized Bed

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SUMMARY

Research into combustion and gasification of wood residues can result in reductions in the high cost of fossil fuels for timber seasoning and can improve the overall utilization of a diminishing resource of hardwoods.

The paper describes the firing of a high temperature kiln by replacing diesel fuel with combustible gases produced from green hardwood sawdust.

INTRODUCTION

In 1984 the Forests Department of Western Australia decided to embark on a program for the combustion and gasification of residue wood fuels. Consideration was given to two objectives.

Research into high temperature seasoning of jarrah in a diesel fired kiln had been technically successful. Commercial application of this research was dependent on reducing the high cost of diesel fuel which accounted for about \$30/m^3 of the seasoning cost. Replacing diesel fuel by the use of wood residues, presently costing money for disposal, was the first objective.

The second was to improve the utilization of the wood resource. Increasing demands on our forests for recreation and conservation, and inroads by disease and development have highlighted the need for greater productivity from production forests. Theoretical calculations indicate that only a small proportion of the energy available from wood residues could be utilized directly in the timber industry for seasoning and processing. Efficient combustion and controlled gasification appeared to be a useful starting point in the investigation of the products of wood pyrolysis. Such work envisages conversion of the residues into valuable products such as resins, carbon black, charcoal and activated carbon.

The slow growth of jarrah and the rapidly increasing world demand for high value fine red cabinet woods, such as jarrah, finally decided the issue.

During December 1984 to February 1985, wood combustion and gasification trials were conducted jointly by Pyrotherm Pty Ltd and the Forests Department's (now the Department of Conservation and Land Management) Wood Utilization Research Centre at Harvey. A fluidized bed pilot plant was designed and supplied by Pyrotherm. Mechanical modification, operating personnel and facilities were produced by the Department. The trials demonstrated the feasibility of using thermal energy from mill wastes to serve an existing distillate fuelled high temperature drying system. Green sawdust, chips, bark and shavings from both hardwoods and softwoods were tested during the trials.

Figure 1 shows the existing system which consisted of a distillate fired thermal oil heater and a high temperature drying kiln. The hot oil generated in the heater is pumped to a series of heat exchangers located inside the kiln where its thermal energy is transferred to the circulating air. The cooled thermal oil is then returned to the heater in a closed system ringmain. The thermal oil heater is served by a 1.25 MW distillate burner which was replaced by a simple gas burner and igniter during the gasification trials.

PRINCIPLES OF WOOD COMBUSTION AND GASIFICATION

Dry jarrah, a Western Australian hardwood, typically consists of:

carbon	50.4 per cent
oxygen	43.53 per cent
hydrogen	6.0 per cent
nitrogen (in combination)	0.03 per cent
ash	0.04 per cent

and has a dry calorific value of approximately 4 600 kcal/kg.

These figures were supplied by Unisearch at the University of NSW.

When dry wood is completely combusted in the presence of oxygen, the following overall chemical reactions take place:

$$C + O_2 = CO_2 + \text{heat}$$

$$H_2 + \tfrac{1}{2} O_2 = H_2O + \text{heat}$$

If, however, the oxygen supply is restricted, the above reactions do not reach completion and combustible gases are formed. The gases formed are mainly carbon monoxide and methane as shown in the following reactions:

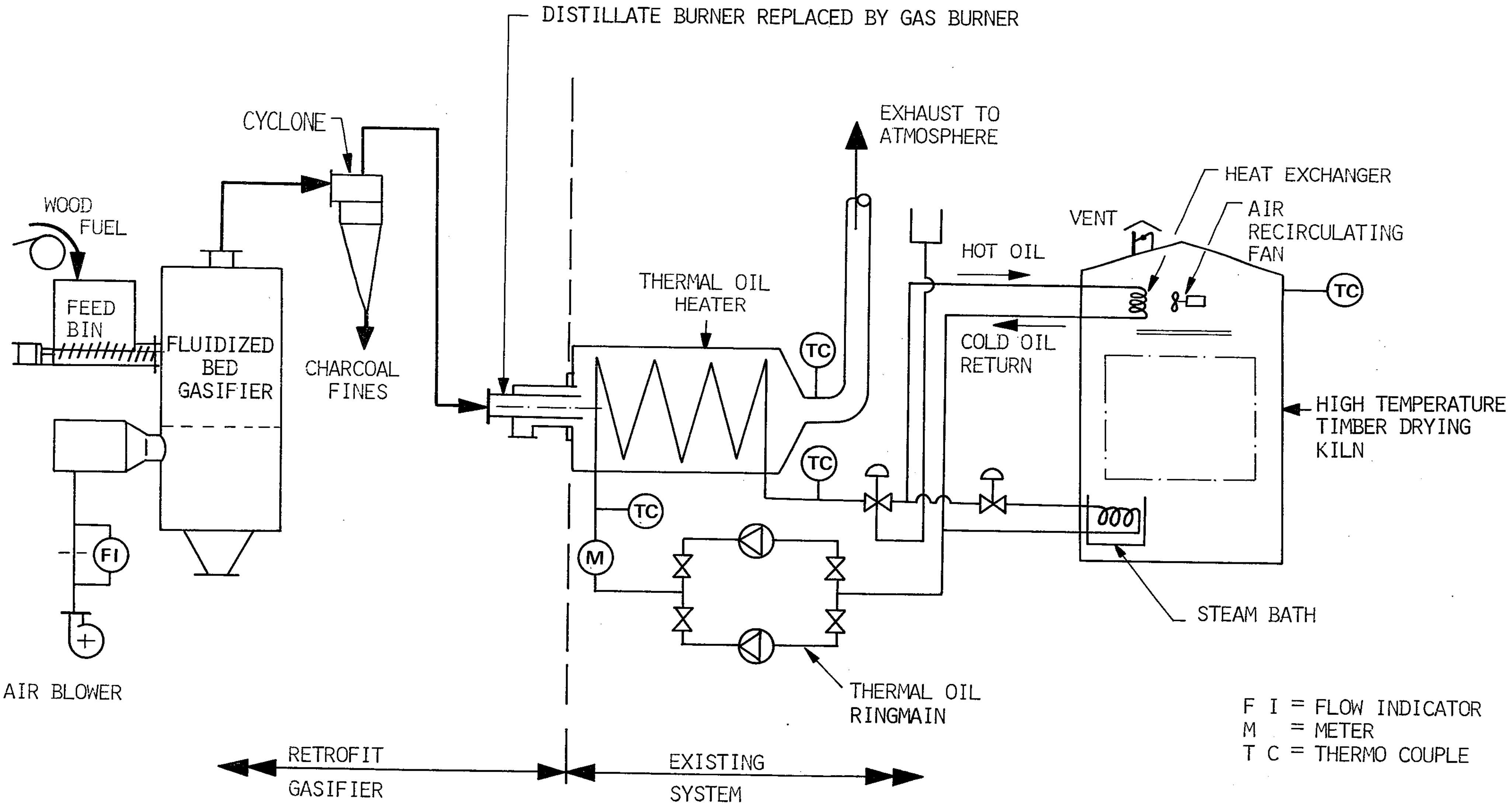

Figure 1 - **Flowchart of woodfired timber drying system.**

$$C + \frac{1}{2} O_2 = CO + \text{heat}$$
$$C + 2 H_2 = CH_4 + \text{heat}$$

If the gases so formed are ducted to a boiler or heat exchanger and additional oxygen is added, the reaction will be completed and more heat liberated as follows:

$$CO + \frac{1}{2} O_2 = CO_2 + \text{heat}$$
$$CH_4 + 2O_2 = CO_2 + 2H_2O + \text{heat}$$

The reactions shown above demonstrate the difference between combustion and gasification. The actual chemical reactions, however, are far more complex than those shown in the simplified example. All of the above reactions, and more, occur simultaneously to some degree depending on the ratio of wood to oxygen, temperature and pressure within the reaction vessel.

The amount of heat a unit mass of wood can liberate is fixed. It makes no difference whether the wood is completely combusted in one stage or whether it is first gasified and then combusted in a second stage. However, the combustion temperature that a wood firing system can attain does vary. This temperature will depend on heat losses. These losses are due to the moisture in the wood, the amount of excess air used in its combustion and the radiation losses to the atmosphere. The maximum temperature that is attainable is at or near stoichiometric conditions, that is, when there is just sufficient oxygen for complete combustion. If more air than is necessary is used, the temperature will be lower as some of the wood's available heat is absorbed by this excess air.

Conversely, if insufficient oxygen is available for combustion, combustible gases are formed which contain potential heat and the exothermic reaction does not reach completion thereby again resulting in a lower temperature.

THE FLUIDIZED BED GASIFIER

The term 'fluidized bed' usually refers to a bed of finely divided solids through which a gas is passing and which is in a state intermediate between that of a static bed and that where all the solids are suspended in a gas stream, as in pneumatic conveying.

This can be demonstrated by taking a cylindrical vessel with an open top and a porous bottom and partly filling it with ordinary sand. If a small flow of air is introduced through the porous base it will pass upwards through the bed of sand without producing any apparent change. This is a condition known as a 'fixed' or 'static' bed. The particles of sand are in contact with each other and the air is passing through the voids at a velocity which is too low to disturb the arrangement, and the entire bed is therefore motionless or static.

If the air flow is now increased at a slow and steady rate the bed will be seen to expand. At first there is no movement of particles within the bed, other than a few of the smaller ones near the surface but as the air flow continues to increase, the bed expands still further and all the particles begin to move.

This is the onset of fluidization. The particles move only slowly but the system is fluid. In fact the bed takes on many of the properties of a liquid. It exerts a hydrostatic head, and the material will flow steadily through a small hole in the side of the vessel or flow over and under a weir within the bed. With a still higher air flow the fluidization becomes more violent. Bubbles of air can be seen passing through the bed and there is a condition of rapid mixing. The bed has the appearance of a vigorously boiling liquid and although some particles are carried out of the bed into the air stream above, the upper surface is nevertheless quite clearly defined. It is this type of fluidization which has been employed in the design of the waste wood gasifier.

The fluidized bed principle was employed in the design because of the excellent contact between air and solids, thus ensuring efficient heat transfer, thorough mixing and uniform temperature conditions. Figure 2 shows the relationship between air and fuel ratio using the fluidized bed. Sized mineral sand with the ability to withstand high temperature without clinkering or attritioning was selected as the bed material. During operation, this bubbling red hot sand bed becomes an excellent heat sink enabling large fluctuations in feed rate or moisture content to be tolerated without noticeably affecting the bed and freeboard temperatures. It has the effect of averaging process fluctuations.

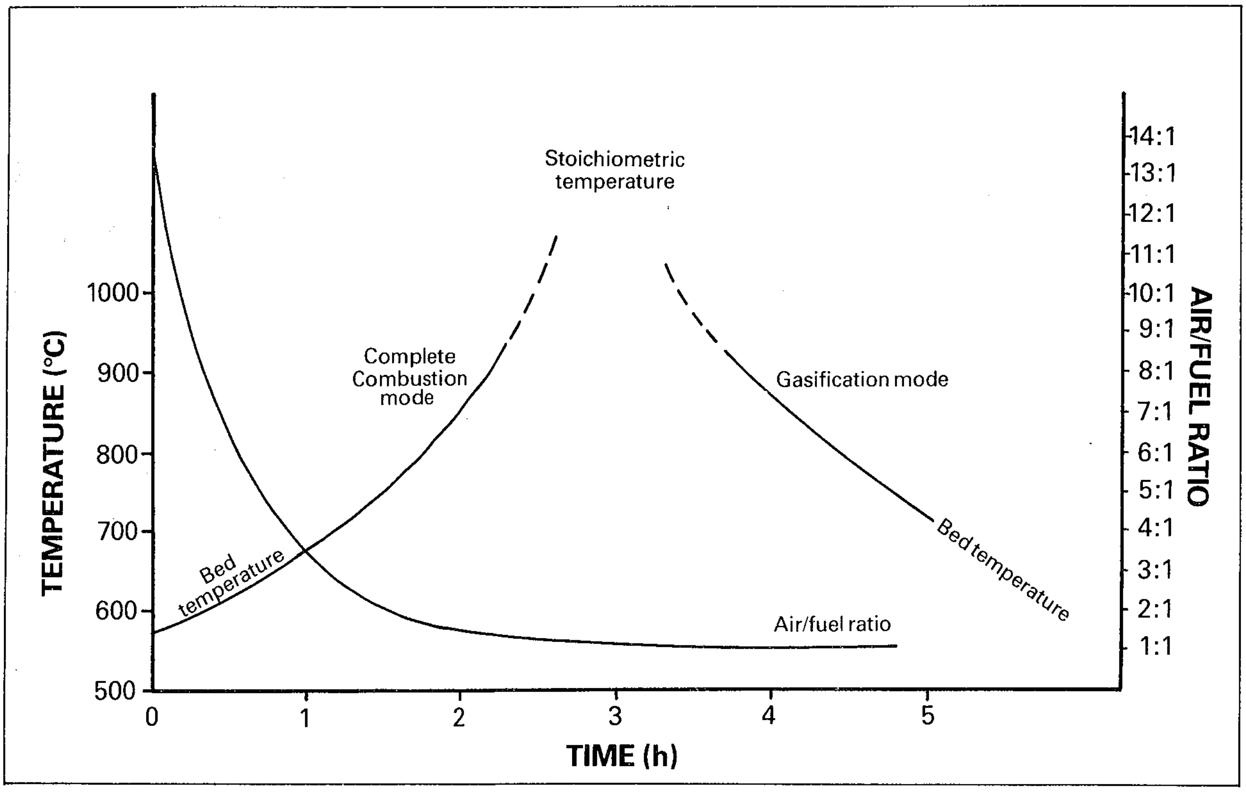

Figure 2 - Example of the relationship between temperature and air/fuel ratio (by mass) on the fluidized bed combustion of green jarrah sawdust.

The gasifier, shown in Figure 3, consisted of the basic fluidized bed reactor which was fed by a sealed variable speed screw feeder under a surge feed hopper. The rate of the variable speed feeder was governed by a temperature controller which maintained the bed at the required temperature. A liquid petroleum gas fired start-up heater was provided to heat the bed initially to wood ignition temperature. Once this temperature was attained, wood was fed into the bed to further raise it to operating temperature and the use of liquid petroleum gas was then discontinued.

Fluidizing or combustion air was provided by a positive displacement blower and was preheated by a bed heat exchanger. A high temperature cyclone served to collect elutriated fines from the reactor's exhaust gases.

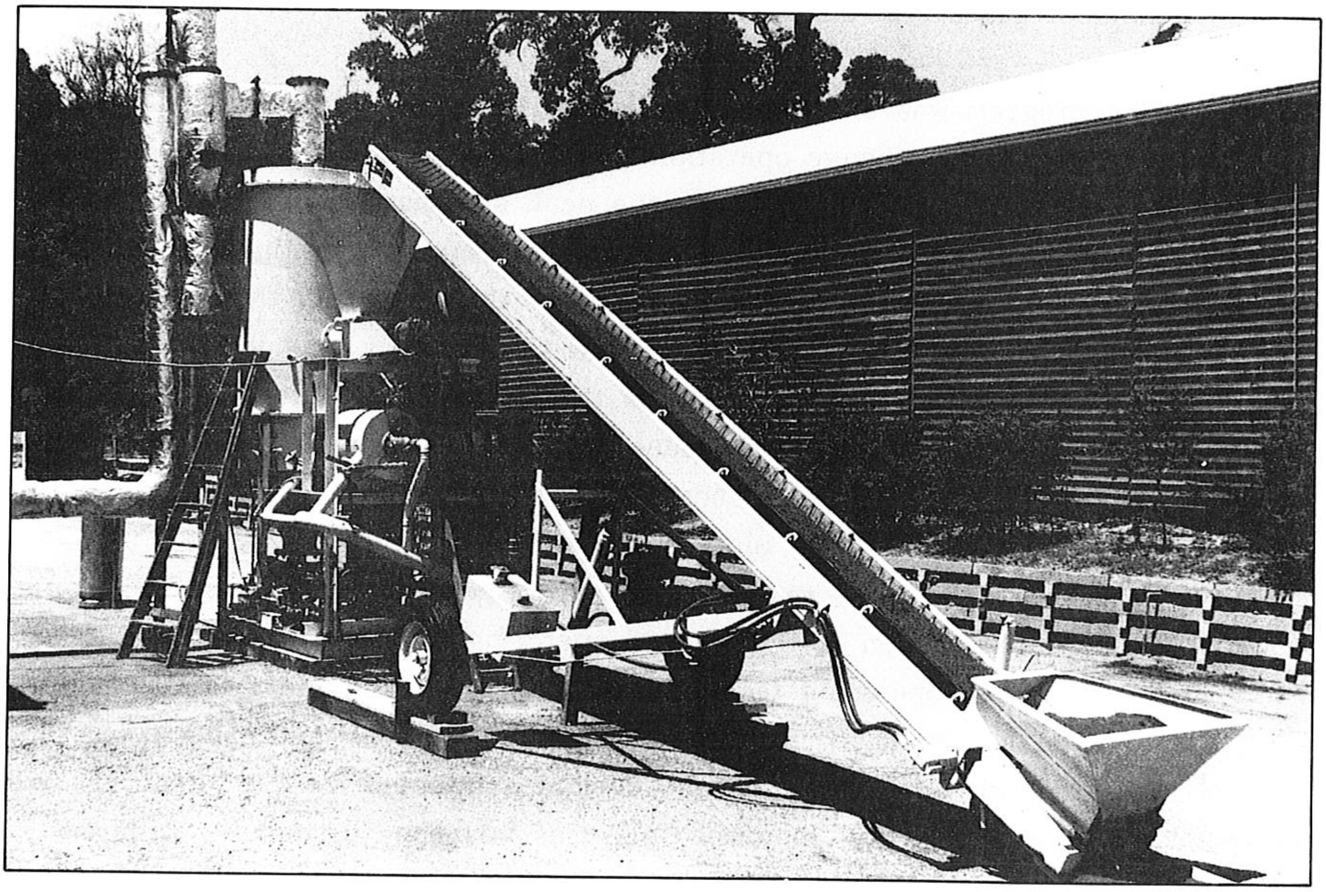

Figure 3 - Pyrotherm Waste Wood Gasifier
Located at the Department of Conservation and Land Management's mill at Harvey in Western Australia, the portable gasifier is shown with a sawdust feeding conveyor and a thermally lagged cyclone and exhaust gas ductwork.

TESTWORK

Initial testwork was based purely on green jarrah sawdust combustion. This was treated as a commissioning and training period for operators and to obtain experience on operating conditions. At this stage the cyclone exhaust was discharged to atmosphere and not ducted to the thermal oil heater. Combustion of green sawdust was fairly straightforward and predictable. Temperatures of combustion could readily be varied between 500°C and 1000°C by varying the feed rate.

Higher temperatures could probably have been attained, however, to protect the cyclone the maximum operating temperature was limited to 1000°C. Once sufficient confidence was gained on the operation it was decided to attempt a run on wood gasification with the cyclone exhaust gases still discharging to atmosphere.

The program was to start-up as normal for a combustion run and then instantaneously change operation to the gasification mode. The aim was to avoid operation through the peak stoichiometric temperature. As shown in Figure 2, this could be achieved by operating at a high excess air ratio on the left hand side of the curve and then suddenly increasing the feed rate to operate at the same temperature on the right hand side of the curve. As the air rate is constant in both the combustion and gasification modes, the air to fuel ratios vary with the feed rate. Unfortunately, however, we did not anticipate how much the feed rate had to be increased from one mode to the other. The feeder was set at its maximum feed rate, yet this proved insufficient to permit operation at the desired operating conditions. This resulted in very high operating temperatures which damaged the 3 mm thick 321 stainless steel cyclone beyond repair. The damaged cyclone was replaced with a new 5 mm thick cyclone fabricated from 253MA stainless steel. By this time Christmas was upon us and the program was postponed until the New Year.

On resumption of the test program, it was decided to operate at a lower fluidizing velocity. This allowed operation at a lower feed rate whilst still maintaining the sought after air to wood ratio in the gasification mode. Based on information gained from previous runs we were able to obtain the desired operating conditions at will. Although we were able to generate combustible gases and flare it to atmosphere, we were still unsure of the optimum operating conditions. Gases were generated under a wide range of bed and freeboard temperatures. Assistance was sought and gratefully received from the State Energy Commission of Western Australia for the analyses of various gas samples.

On 15 January 1985, a special trial was conducted in which operating conditions were purposely varied to enable comparisons to be made on the quality of the gases generated. Figure 4 shows the sawdust feed and air flow rates and their effect on the bed and freeboard temperatures. Five gas samples were collected during the trial and the times at which they were taken are also shown on the graph. The analyses of the corresponding gas samples are shown in Table 1.

Table 1: Analyses of dried gas samples produced from the test firing illustrated in Figure 4.

Sample No.	1	2	3	4	5
Time (Hours) (*a*)	2.4	3.4	4.3	4.6	5.1
Gas	%	%	%	%	%
Hydrogen	2.60	0.78	1.97	4.50	0.30
Methane	2.24	1.69	2.70	3.90	1.47
Carbon Monoxide	9.63	6.75	9.71	13.32	5.44
Carbon Dioxide	13.50	9.27	11.88	14.47	7.06
Ethylene	0.70	0.56	0.79	0.80	0.45
Ethane	0.05	0.03	0.08	0.18	0.13
Acetylene	0.24	0.14	0.12	0.02	0.07
Oxygen	2.89	8.30	5.09	0.98	11.16
Nitrogen	68.15	72.48	67.66	61.83	73.92

(*a*) Time of sampling is the number of hours after initial firing.

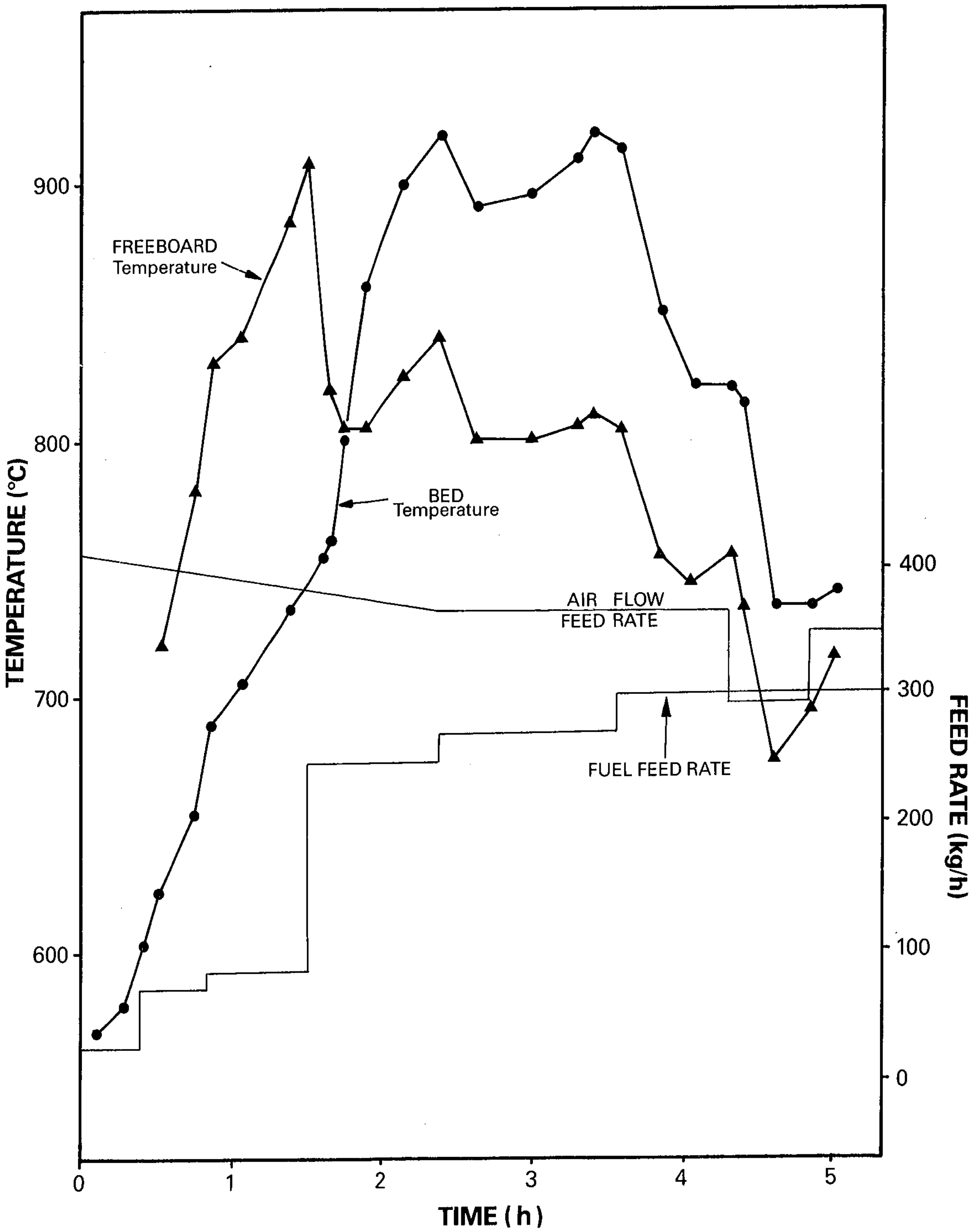

Figure 4 - Combustion chamber conditions during a typical test firing of the fluidized bed combustor with green jarrah sawdust.

For operation in the gasification mode, the sawdust feed rate was substantially increased from 85 kg/h to 251 kg/h. The freeboard temperature responded by rapidly decreasing in value. The bed temperature, however, responded much more slowly. In the gasification mode, the bed temperature was higher than the freeboard temperature. Further increase in the feed rate reduced both the bed and freeboard temperatures. As anticipated, the best results were obtained at the lower operating temperatures. This is entirely logical as it means that less energy is liberated inside the reactor thereby leaving more energy in the gases produced. Based on the results obtained, the optimum operating conditions were reproduced on another day and another gas sample taken for comparison. The results of the two samples correlated remarkably well and it was decided that we were now ready to duct the gases to the thermal oil heater for a full test on the timber drying kiln.

A simple concentric tube gas burner was fabricated and installed together with a pilot igniter onto the existing thermal oil heater. Gas produced in the gasifier was ducted to the inner tube of the burner whilst a fan blew combustion air tangentially into the outer tube. The resulting swirling air and gas mixture was then ignited inside the heater. On 7 February 1985, a demonstration trial was conducted for interested people in the timber industry. The flame produced burnt clearly and produced no visible smoke emissions. The trial was highly successful and the heat generated exceeded anticipation. It was more than adequate to attain and maintain oil temperature. For the trial, the kiln was not charged with timber, however, all the air vents were fully opened, the main door left open and a water hose played on the heat exchangers to dissipate the heat generated.

CONCLUSION

The fluidized bed principle is ideally suited to waste wood combustion or gasification as very high moisture content wood waste can easily be tolerated. Green sawdust with 60-74 per cent moisture content was utilized during the test and temperatures in excess of 1000°C were easily obtainable indicating that higher moisture content waste could still sustain combustion. Due to the heat sink effect of the fluidized bed, variations in the feed moisture content did not adversely affect operation. Process temperatures were controllable and the process is therefore suited to automatic operation. The combustion process is capable of a turn down ratio of approximately 3:1 by simply increasing or decreasing the feed rate as required. The gasification process however, has a limited turndown ratio unless the gas train is capable of withstanding temperatures of up to 1300°C or unless the air flow rate is varied, together with the feed rate. The latter would be limited by the range of fluidizing velocities the bed material is capable of withstanding. In both combustion and gasification modes, the limiting lower bed temperature is about 550°C.

Operation in the combustion mode resulted in higher freeboard than bed temperatures. The thermal duty on the bed material is therefore not as severe and the possibility of ash fusion occurring in the bed is reduced. A heat exchanger suspended in the freeboard space would also perform better in the higher temperature environment.

In the gasification mode the bed temperature was higher than or equal to the freeboard temperature. Both temperatures, however, were relatively low and certainly below ash fusion temperatures normally expected. Lower operating temperatures produced higher calorific value gases. Gas produced from wood waste burns cleanly with no visible smoke emission.

Utilization of a small percentage of wood waste generated by a timber mill is sufficient to meet the thermal needs of timber drying.

ACKNOWLEDGEMENTS

Gas analysis by the State Energy Commission of W.A. is gratefully acknowledged.