Practical Aspects of the Operation of a Biomass-fired Boiler System

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ABSTRACT

Practical aspects of the operation of a sawdust-fuelled furnace/boiler unit are described. The system under discussion is rated at a thermal output of 170 kW and consists of a dual-chamber furnace, with primary and secondary air firing and a monotube boiler.

The overall boiler system, consists of the sawdust-fired furnace (including forced draft fan, cyclone and stack), monotube boiler, feedwater pump, and associated equipment. The unit uses sawdust as fuel and generates high quality steam, to be used as process heat or to drive a steam engine.

Attention is focused on aspects of boiler operation including furnace start-up, fuel conditioning and feeding, air control, feedwater control and system shut-down.

INTRODUCTION

Thousands of boilers of various sizes fired by biomass fuels have been designed, constructed and successfully used for several decades in many countries [1-6]. There have been many designs; and various types of biomass fuels have been used, with differing success. All such systems, however, operate on fundamentally similar principles.

A biomass-fired boiler installation requires several sub-systems for fuel conditioning (drying), storage and handling, conveying to combustion chamber; combustion control; feedwater treatment; air and water inlet control; steam generation and handling; control of undesirable emissions and pollutants and ash handling. Requirements for adequate safety devices and control over the wide range of variables must be included and add to the complexity and cost of boiler systems.

In this paper, a 'boiler' is the steam generation unit (irrespective of heat source) and 'furnace' refers to fuel handling and combustion, including emission control and flue gas handling.

Boiler performance is determined by many inter-related factors, and for biomass-fired boiler units, varies greatly with variations in the many parameters that determine output and efficiency [7].

A particular combustion system is necessarily designed for a given fuel, with specified fuel quality and rate, feedwater and air rates, and output. The major variables that determine boiler system performance include:

- type and quality of fuel,
- heating value of fuel,
- moisture content of fuel,
- air supply (draft) rate to the boiler,
- moisture content of air,

- dimensions and arrangement of boiler tubes,
- cleanliness of heat absorbing surfaces,
- rate of firing of furnace, and
- feedwater flowrate.

Many wood-fired boilers generating steam at rates of up to 500,000 pounds of steam per hour (equivalent to 50 MW of electrical output) are in current operation [8], and, in general, boilers range in thermal outputs from a few kilowatts to several hundred megawatts. Large commercial boilers are described in Babçock and Wilcox, 1978 [9], and biomass-fired boilers are well covered in the literature [4,8].

DESCRIPTION OF THE BIOMASS-FUELLED BOILER SYSTEM

Figure 1 shows a block diagram of a biomass-fired boiler system. The major components are the furnace and monotube boiler. Not all of the components are necessarily essential to the operation of a small boiler system. Small, simple and 'cheap' boiler units consist of a hopper, furnace and a steam generator. The boiler unit comprises two major parts; the furnace where the fuel is combusted; and the pressure vessel where the heat of the flue gases is transferred to the water in the pressure vessel, thus generating steam.

Good combustion of biomass requires a high temperature in the combustion zone, a high degree of turbulence or mixing of the fuel and air and sufficient time to ensure complete combustion. Two important variables which govern combustion efficiency are the fuel moisture content and amount of excess air. Both of these affect the combustion process, as well as the levels of particulate emissions from the furnace. Proper control of these and other variables can ensure a high performance from the boiler unit with acceptable emission products.

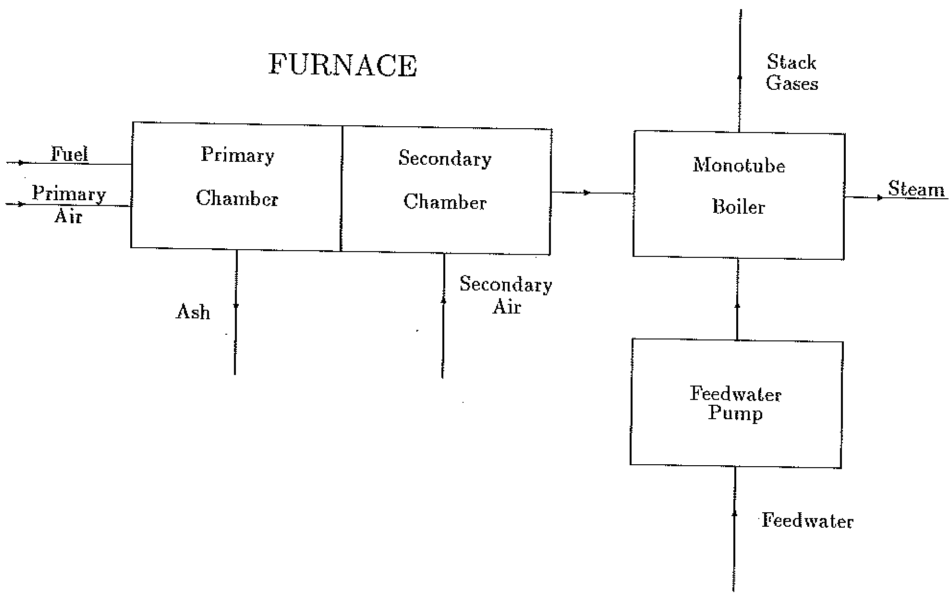

Fig. 1. Block diagram of a biomass-fired boiler system.

The monotube boiler system is relatively recent in its application. As the name implies, it comprises a coil of tube in which water is heated to steam in a single pass. This configuration is very simple, robust, cheap, and safe, since there is no large storage of hot water/steam. These and other advantages are detailed later. This type of boiler is used in this study to generate steam from the heat released in the biomass-fired furnace of the power generating system.

EXPERIMENTAL FURNACE/BOILER PERFORMANCE

The sawdust-fuelled 2-chambered furnace/boiler system was tested extensively at the laboratory of the Energy Research Center, Research School of Physical Sciences, Australian National University. The basic objective was to monitor performance for a range of variables, including inlet and outlet parameters, such as fuel moisture, fuel rate, air rates, flue gas composition, boiler feedwater flowrate and temperature and boiler steam outlet pressure and temperature, from which boiler output and efficiency were determined.

A photograph of the furnace/boiler unit is shown in Fig. 2. Figure 3 is a representation of the testing facility and Fig. 4 gives a more detailed functional diagram of the unit, with indications of approximate locations for measurement of the system. The major parts of the system are: primary chamber with ash pit, grate, primary air distribution plenum, and gas duct; secondary chamber with secondary air jets and gas passage; cyclone; boiler and stack.

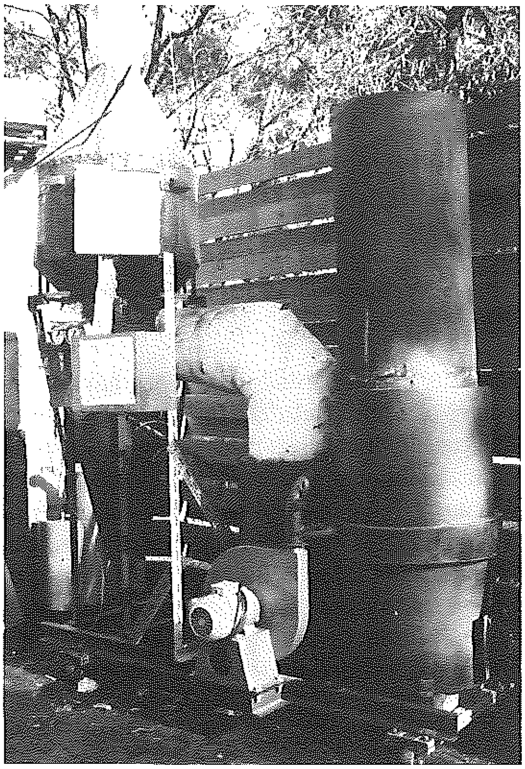

Fig. 2. Photograph of the furnace/boiler unit.

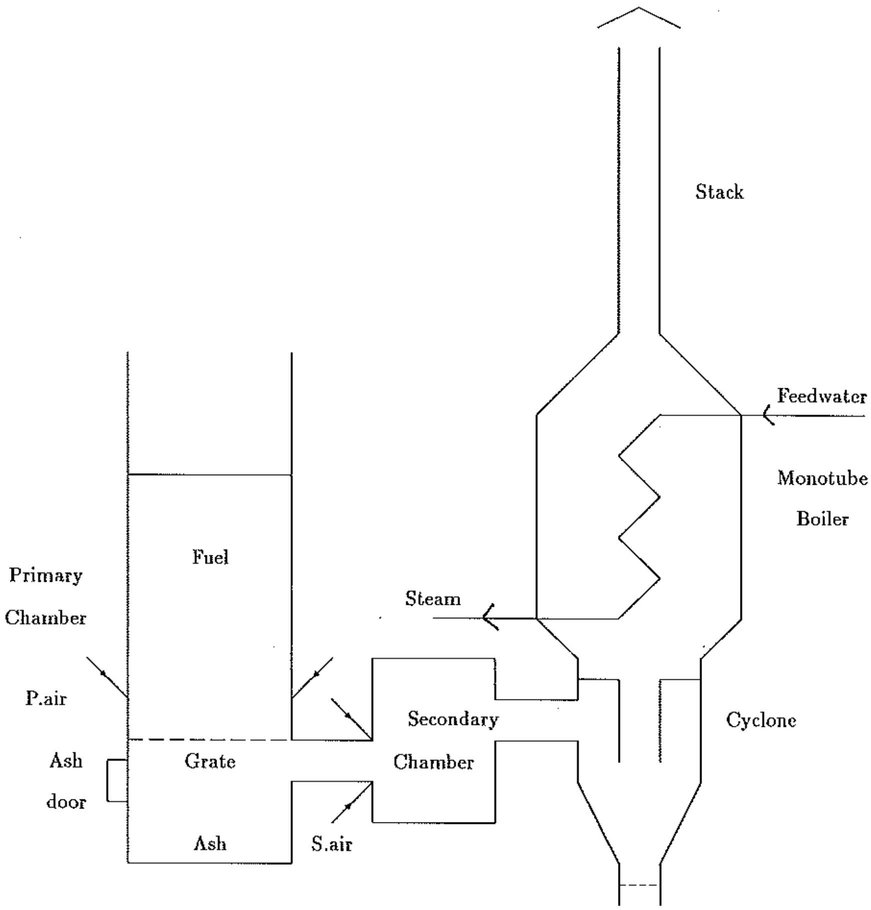

Fig. 3. Representation of furnace/boiler test facility.

The primary and secondary chambers and the cyclone have an inner layer of cast refectory (firebricks) and an outer layer of fibre insulation; the boiler consists of pancake-shaped coils of mild steel and stainless steel casing; the stack is made out of galvanised iron sheets.

Briefly, the unit operates as follows: Fuel is partially burned in the primary chamber, releasing gaseous products which are fully combusted in the secondary chamber and cyclone; combustion products then pass through a tube in the cyclone which traps solid, heavy particles and the gases then pass across water-carrying tubes in the boiler in which steam is generated, and finally flow through the stack into the atmosphere. Each combustion chamber has its own (adjustable) air supply, primary air being admitted through holes in a plenum (60 cm above the furnace bottom) around the primary chamber and secondary air delivered through angled openings to the secondary chamber from a plenum.

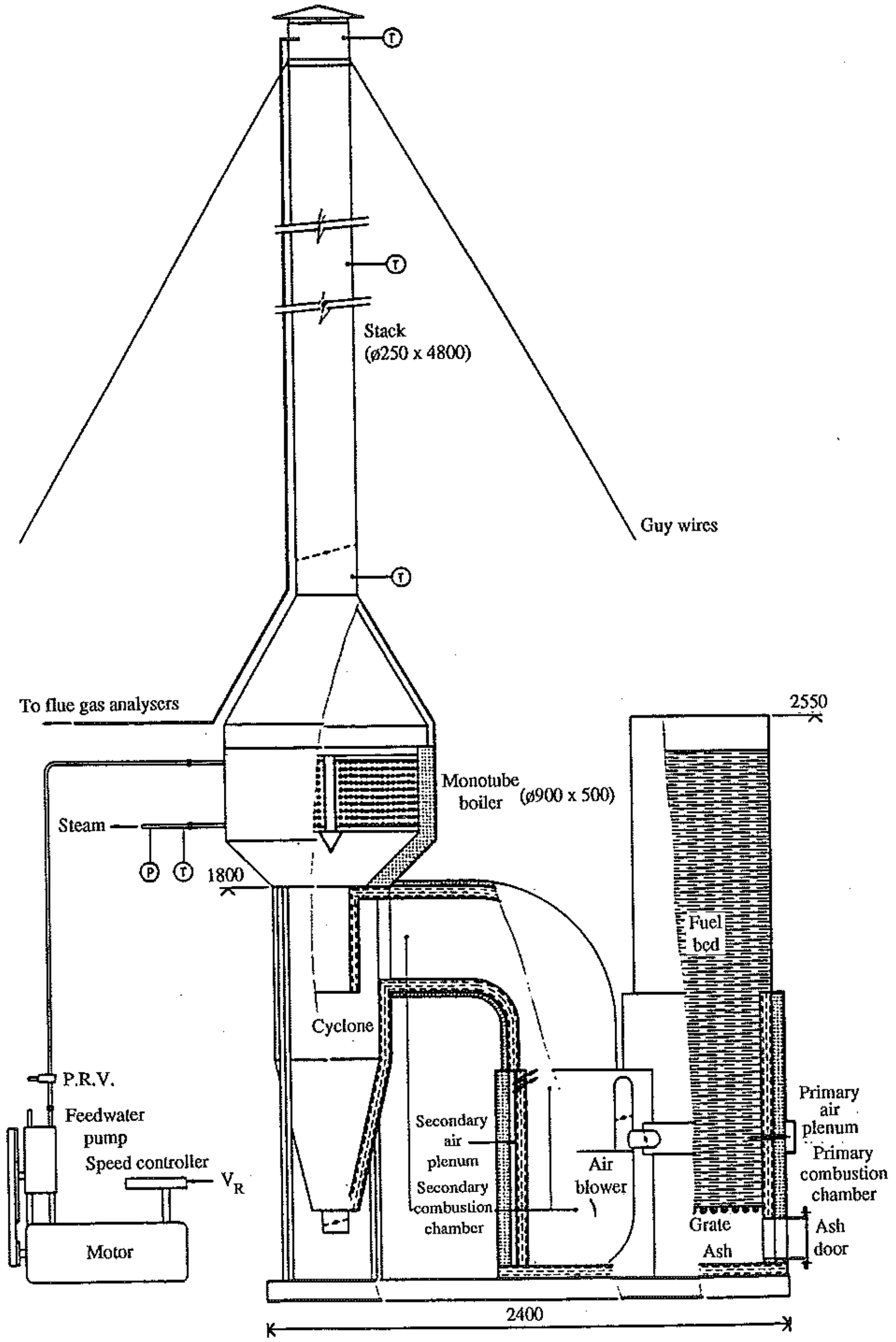

Fig. 4. Functional diagram of the system.

Practical Operation of the Unit

Hardwood sawdust was burned in the furnace, the burning process taking place in 2 stages: 1) primary combustion (or gasification) takes place in the fuel bed over the grate, volatiles being driven off to the secondary chamber and 2) secondary combustion inside the combustion tube and cyclone, during which volatiles and unburnt fuel are burned at a high temperature.

A forced draft fan provides both the primary and secondary air. Primary air is introduced through holes in a 150 mm wide plenum around the gasifier, the top of the plenum being two feet above the grate. Secondary air is forced through openings from an air plenum surrounding the secondary tube.

The primary chamber, sometimes referred to as a downdraft, co-current gasifier (indicating that both fuel and air travel down to the grate where fuel combustion takes place), has a volume above the grate of 0.29 m^3 with an additional volume of 0.33 m^3 given by an extension cylinder, allowing a maximum of some 180 kg of sawdust to be loaded into the furnace.

The hot combustion products pass into a cyclone, which traps most of the flyash in the gas. This is done by the ceramic tube suspended from the top of the cyclone to a height of 200 mm, which forces gas flow downwards around the tube and then through it. As the gas inlet into the cyclone is about 50 mm below the top of the cyclone, the change in velocity of the gas flings the heavier flyash particles to the bottom of the cyclone.

The gas then flows across tubes of the monotube boiler where it loses heat to water flowing inside the tubes, and eventually leaves the boiler passing through the stack into the atmosphere. Due to the various pressure drops in the furnace and boiler – across fuel bed, through gas passages and ducts, across cyclone and boiler tubes – the chimmney must have adequate height and diameter to provide good draught. Sufficient air to both the chambers must also be provided to ensure complete combustion and thereby to minimise air pollution.

Furnace Firing: "Cold" Start

Before firing, the ash pit should be cleaned out, the air control dampers closed and the stack damper opened fully. Fuel is fed from the top of the primary chamber and sits on the grate which may allow sawdust to fall through if the grate bars are widely spaced or if sawdust is too loose. In this case paper or cardboard should be spread on the grate before loading fuel which can be done right up to the top of the fuel hopper. The mass and density of fuel should be measured before filling in the furnace.

A fire, using dry sticks and wood, is then lit under the grate, all air supplied from the open ash door, and maintained while regular monitoring of the cyclone and stack temperatures is undertaken. Depending on ambient conditions and on the moisture in the sawdust, the furnace is warmed up for over half an hour until cyclone temperatures exceed 500°C. The forced draught fan is then turned on and the primary and secondary air ports opened fractionally to allow sawdust to burn. All measurements are then commenced and the primary and secondary air flows are continuously "tuned", using oxygen and carbon dioxide contents in the flue gas, as well as the cyclone and stack temperatures.

The fuel (sawdust) is ignited from under the grate by the wood fire. As the sawdust is higher in moisture content than the dry wood a great deal of smoke may be emitted from the stack during the initial burning of the sawdust. This signifies a low temperature inside the secondary chamber and also a high percentage of unburnt fuel, and would be reflected in a high CO and low CO_2

reading. As the temperature builds up, and with the gradual increase of secondary air, smoke levels diminish and CO level quickly falls to zero.

The air and gas circulation system is a forced draft one, where combustion air is forced into the furnace and the difference in the densities of the combustion products and the outside air provides the draft for the flow of gases up the stack. Stack dimensions were carefully chosen to enable proper flow of combustion gases. A galvanised iron stack of length 4.8 m, wall thickness 1.6 mm and inner diameter of 25 cm was used.

Diagnostic and Safety Aspects

To ensure safe operation of the boiler system, various diagnostic and warning systems were employed. Firstly, the tests were conducted with at least two people present all the time. This was necessary as most of the data were read manually from the various instruments. Furthermore, sawdust was fed manually into the furnace. Parameters such as feedwater flowrate, air rates, steam pressure and temperature were constantly monitored, both visually and by instruments to ensure safe operation. The feedwater line had a safety valve which was set to relieve pressure in excess of 7 MPa. In the event of feedwater pump failure, a by-pass feedwater line run from mains water supply could be turned on to maintain flow through the boiler. If a dangerously high temperature in the secondary chamber or cyclone is indicated, combustion air flow is increased until these temperatures are lowered to safe values. Steam temperature is controlled by controlling the feedwater flowrate and the level of both primary and secondary combustion air. The temperature of the flue gases is constantly monitored and used to assist in the control of furnace output and efficiency. Boiler steam pressure can be manually released in the event of high pressures.

SOME PROBLEMS WITH BIOMASS-FIRED BOILERS

Although the pollution problem is relatively small compared to coal and oil-fired power stations, especially with regard to the emission of sulphur compounds, the biomass-fired power plant does have a few problems and disadvantages. These include:

i) Particulate emissions with the stack gases. These include char, ash and other particles. The rate of such emissions depend mainly on the moisture content and chemical composition of the fuel – being high if the moisture content is high. Adequate safety measures can all but eliminate this problem, but at some expense.
ii) There can be problems with ash handling, particularly with fuels having significant amounts (>2 %) of ash. The problem arises from the ash covering walls and tubes that transfer heat, reducing heat transfer rates.
iii) Variations in the fuel type (energy content), fuel size and moisture content can lead to changes in the combustion temperature and thus steam quality. Where a constant steam quality is required, this can be a problem, especially with a diversity of fuel.
iv) Biomass may pick up impurities such as sand and salt during transportation to site of end-use. At high temperatures, these impurities can cause the fluxing of refractory and furnace walls and fouling and erosion of boiler tubes. For this reason, there is a need to limit furnace temperatures and water-cooling of furnaces could be necessary.
v) There may be some smoking problems with high moisture content fuels.
vi) Such operations as fuel storage, handling, drying and metering can be expensive.

CONCLUSIONS

Aspects of a biomass-fuelled steam generation system have been discussed. Direct combustion of biomass in a dual chamber furnace/boiler system yields high quality steam for use as process heat or as thermal input to a steam engine. It is essential to exercise good control over the furnace firing rate, feedwater flowrate, and emission of pollutants from the furnace. These aspects have been discussed in the previous sections.

Due to practical reasons, for example variable moisture content of sawdust and the difficulties of measuring primary and secondary air flowrates, operating conditions were somewhat restricted. Thus, for a particular run, sawdust of a fixed moisture content could not be fired, as it was impossible to dry all sawdust to an exact level because of time and weather limitations. In addition, because of the need to optimize secondary air for a 'fixed' rate of fuel burning, a wide range of primary and secondary air settings could not be used.

Overall furnace/boiler performance was found to be reasonably satisfactory, with system efficiency ranging from 55 to 71 %. Improvements in performance are possible by insulating the 'hot' areas of the cyclone and furnace, burning drier sawdust, operating the unit in better ambient conditions and by designing a more suitable boiler, as detailed in an earlier section.

Smoke and particle emissions were minimal, as indicated visually, by CO levels and by the small amounts of particles collected in the cyclone and tiny amounts scattered around the unit, pointing to the system being clean burning and thus environmentally sound.

The generation of electricity (and heat for crop drying, if needed), from biomass fuels, using a steam system, can be a viable alternative to electricity generation from diesel-fuelled generators. This is particularly true for many rural and remote locations in Fiji which do not have grid power and which have an abundance of cheaply available biomass fuels such as crop and sawmill wastes.

Technologically, economically, environmentally and socially, there would appear to be very few drawbacks to the utilization of biomass wastes and residues using small scale steam power systems to electrify off-grid, remote and isolated communities.

The boiler was tested on various fuels of various moisture contents in the engine research laboratory. The performance of the boiler and engine was monitored and later analysed. An overall system efficiency of 15% was achieved, from energy in the fuel to the electricity output.

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REFERENCES

1. Beenackers, A. A. C. M. and S. Ismail (1987). Power from Biomass via Gasification and Combustion, *Proceedings of the International Solar Energy Society's 'Solar World Congress'*, Hamburg, W. Germany, September 14-18, 1987, Pergamon Press, London.
2. Cheremisinoff, N. P., P. N. Cheremisinoff and F. Ellerbusch (1980), *Biomass: Applications, Technology and Production*, Marcel Dekker Inc.
3. Feinstein, Charles (1985), *Wood-fired Cogeneration for Rural Pacific Communities, Taveuni Case Study*, Resource Systems Institute, East West Centre, Honolulu, Hawaii.

4. Junge, D. C. (1975), *Combustion Systems for Wood and Bark Fired Boilers*, Forest Research Laboratory, Oregon State University, Oregon, U.S.A.
5. Koning, Jr., J. W. and K. E. Skog (1987), Use of Wood Energy in the United States - An Opportunity. *Biomass*, Vol. 12, No. 1, pp. 27-36.
6. Kranzler, G. A. and M. D. Stove (1982), Performance of a Direct Combustion Biomass Furnace, *Proceedings of the American Society of Agricultural Engineers.*
7. Prasad, S. B. (1988), *A Biomass-Fuelled Steam Power Generation System: Modelling, Performance and Control Aspects*, Unpublished PhD Thesis, Energy Research Center, Research School of Physical Sciences, Australian National University, Canberra, ACT, Australia.
8. US Dept. of Commerce (1976), *Comparison of Fossil and Wood Fuels.* Batelle Columbus Labs, prepared for Industrial Environmental Research Lab, March 1976.
9. Babcock and Wilcox (1978), *Steam - its generation and use.* The Babcock and Wilcox Company, New York.
10. Michelic-Bogdanic, A. (1987), Evaluation of Energy Generation from Biomass by Means of Gasification and Direct Combustion, *Proceedings of the International Solar Energy Society's 'Solar World Congress'*, Hamburg, W. Germany, September 14-18, 1987. Pergamon Press, London.