DEVELOPMENT OF FLUID BED COMBUSTION APPLICABLE TO THE SUGARCANE INDUSTRY

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Abstract

The fuels used in industry for the last two to three decades have become expensive; furthermore there are large quantities of coal in South Africa not readily burned by the conventional means. The application of the two stage fluid bed combustor and its ability to burn low grade fuels efficiently, are discussed.

Introduction

The application of a fluidised bed is not new to the sugar industry. It is used in the drying of refined sugar. The fluidised bed is also used by other industries in process applications, but it was not until the fuel crisis in the 1970's, coupled with a world wide increasing demand for energy that engineers associated with energy sources started to look further at the potential of using more readily available fuels.

From the 1970's, research has shown that fluid bed combustion of a wide range of fuels is a viable commercial application for the 1980's and areas where the system can be applied to the sugar industry in South Africa will be examined in this paper.

Many forms of fluid bed combustion are offered to the market but the atmospheric shallow bed with two stage combustion technique is worthy of further examination.

This system allows partial combustion in the fluid bed with burn-off of the generated gases above the bed and incorporates bed temperature control, without the use of submerged heating surfaces or the use of massive excess air and is ideal as a retrofit to existing boiler plant or for the drying of bagasse.

Design Concept

The basis of the design concept should be given as limitation of the heat release within the active fluid bed so that combustion of the fuel can be completed above the bed with the burn-off of generated gases in the second phase.

Supplementary features now well established are:

(1) Adoption of under bed firing for preheating the bed material to operating temperatures.

(2) Incorporation of trim heat facility to cater for excessive extraction of heat from the bed material as a transient effect of a slug of very wet fine fuel. This facility is provided by the light up burner as necessary.

(3) The provision of waste gas recycling into the bed as a means for modulated bed temperature.

The principle of fluidisation is based on the fact that above a critical velocity, the passage of gas through a bed of finely divided particles such as sand, can cause the bed material to expand in the same way as a fluid. The velocity of the gas through the bed should be in the order of 30 cm per second cold.

At this velocity the carry over of fines, low density fuels and bed material is limited.

Heat release within the bed can be substantially limited by operating to achieve sub-stoichiometric combustion; that is, to establish a semigasification process and to promote a secondary combustion zone above the freeboard of the bed to complete combustion. In this way, advantage can be taken of transferring heat release due to the calorific value of carbon monoxide into the secondary combustion zone above the freeboard.

Experience in operating the two stage technique indicates that, operating at full load, the primary air into the bed will be no greater than 80% of the stoichiometric air. This will permit 60% heat release in the bed and the balance of the heat (40%) will be released in the second phase. This is possible because of the natural slip of air within the bed allowing 25% of the air entering the bed to enter the second phase above the freeboard of the bed.

With the addition of secondary air above the bed, secondary combustion is completed over the bed utilising carbon monoxide and some hydrocarbons released from the bed. Temperatures significantly higher than the bed can thus be achieved.

Complete combustion is achieved with only 10% excess air. One of the factors contributing to the low excess air requirements is the fact that the combustible gases and the air that slips unreacted through the bed are both heated to the bed operating temperature. Furthermore, the close proximity of parallel streams of hot air and combustible gas entering the freeboard zone allows rapid mixing with secondary air in turbulent conditions.

Some recycle gas will also be passing through the bed under these conditions in order to provide the necessary heat extraction to maintain the bed at the desired temperature, usually 850 — 1 000°C.

At no time does the primary air to the bed reduce so that recycle attemperation gas takes over the bed dynamic motivation.

The horizontal sparge pipe air distributor is a standard feature of some bed designs. Experience has shown that this distribution system leads to further advantages beyond the dynamic gas distribution characteristic.

The sparge tubes can be welded into a simple tube plate to contain the difficult hot joint for the high temperature preheating fluidising gases at the relatively high pressure at bed entry.

The sparge pipes are the most suitable means for the introduction of these hot gases, being simple straight pipes of circular section, and therefore capable of withstanding the severe thermal shocks associated with this duty. This method is the most robust to accept the rapid variation of the temperature of the air, and air/waste gas mixtures passed into the bed with the "under bed" method of bed preheating and possible bed temperature regulation with supplementary heat addition.

The sparge tubes are manufactured from high grade heat resistant stainless steel welded to a tube plate of similar material. The tube plate is watercooled to prevent distor-

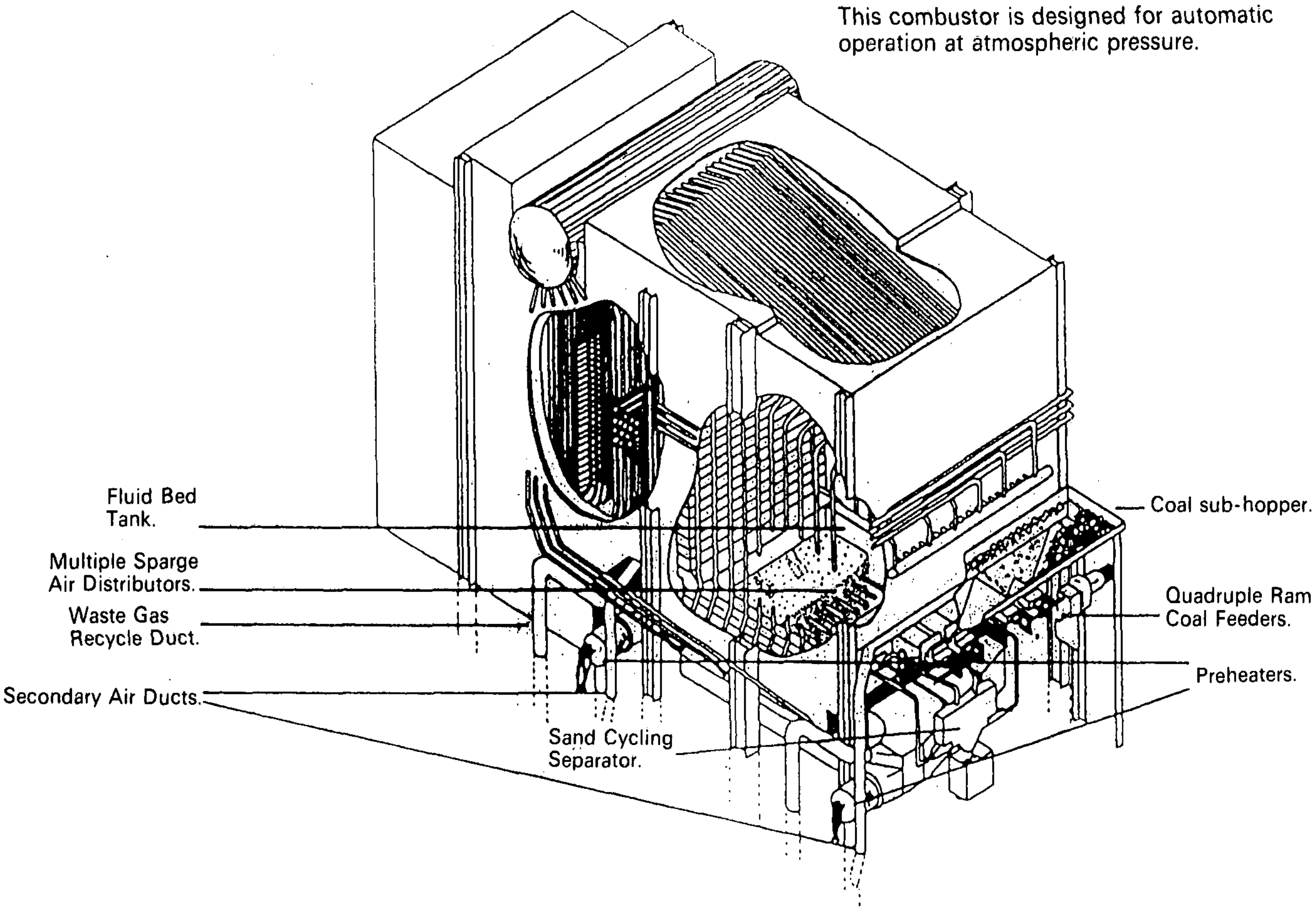


FIGURE 1 General arrangement drawing of fluidised combustion boiler

tion and the transmission of heat to the outer skin of the system.

The fluid bed combustor consists of a refractory lined steel tank with the sparge pipe system presented horizontally at or near the bottom of the fluid bed. The sparge tubes are immersed in sand which forms the bed.

Dependent on the size of the plant under consideration, there may be one or more sparge tube assemblies submerged within the fluid bed. The maximum length of any sparge tube is 2 metres and the number of tubes is dependent on the dimensions of the plant.

Before the introduction of fuel into the bed, the bed temperature has to be raised by using a light-up burner, either gas or oil fired, giving up its heat to the fluidising air before it passes into the bed.

The light-up burner is attached to a refractory lined plenum chamber, which is firmly bolted to the water cooled sparge tube plate.

Air for the light-up burner, fluidising air and secondary air is provided by a combustion air fan.

The third feature of the two stage technique is the recycling of low temperature inert waste gases down from the outlet gas duct of the plant for bed attemperation. The waste gases are handled by a separate recycle gas fan.

Application to Boilers

Figure 1 illustrates a retrofit fluid bed combustor to an existing water tube boiler.

The fluid bed in this boiler is arranged with two zones which are completely independent in terms of combustion, air supply and recycle gas supply, with individual preheat burners.

A number of fuel feeding methods have been investigated, i.e. a ram type feeder with independently driven rotary spreader and two air jet systems, one termed the "Mexican Shovel" and the other an "Air Ejector".

The Mexican Shovel is the most versatile and is used for feeding coal, peat, waste materials, bark and bagasse, etc.

Should a fuel such as waste paper or similar low density fuel need to be burned, then a separate air ejector system to handle this fuel would be added.

If a fluid bed is required to burn, for example, coal and bagasse, feeders at a height in the order of 800 mm above the slumped bed surface for feeding the coal and 250 mm above the slumped bed surface for feeding the bagasse would be incorporated in the designs.

Figure 2 illustrates the flow pattern of the gases from a two stage fluid bed combustor and the role of the various inputs to the fluid bed. The combustion air fan will supply air for fluidisation, heated by the ignition burner until ignition temperature is reached. During this period the fan will provide air for the burner. Once ignition is established, it will provide the primary air to support combustion within the bed and secondary air to burn off the gases above the bed.

It is important to note that in all fluid bed combustion systems, the bed temperature must be controlled below the ash fusion temperature of the fuel. It is therefore essential to maintain a temperature in the bed between 850 — 1 000°C.

Some of the facts established using the two stage system are :

(1) A fluid bed combustor will operate at higher combustion effiicency than can be obtained by currently con-

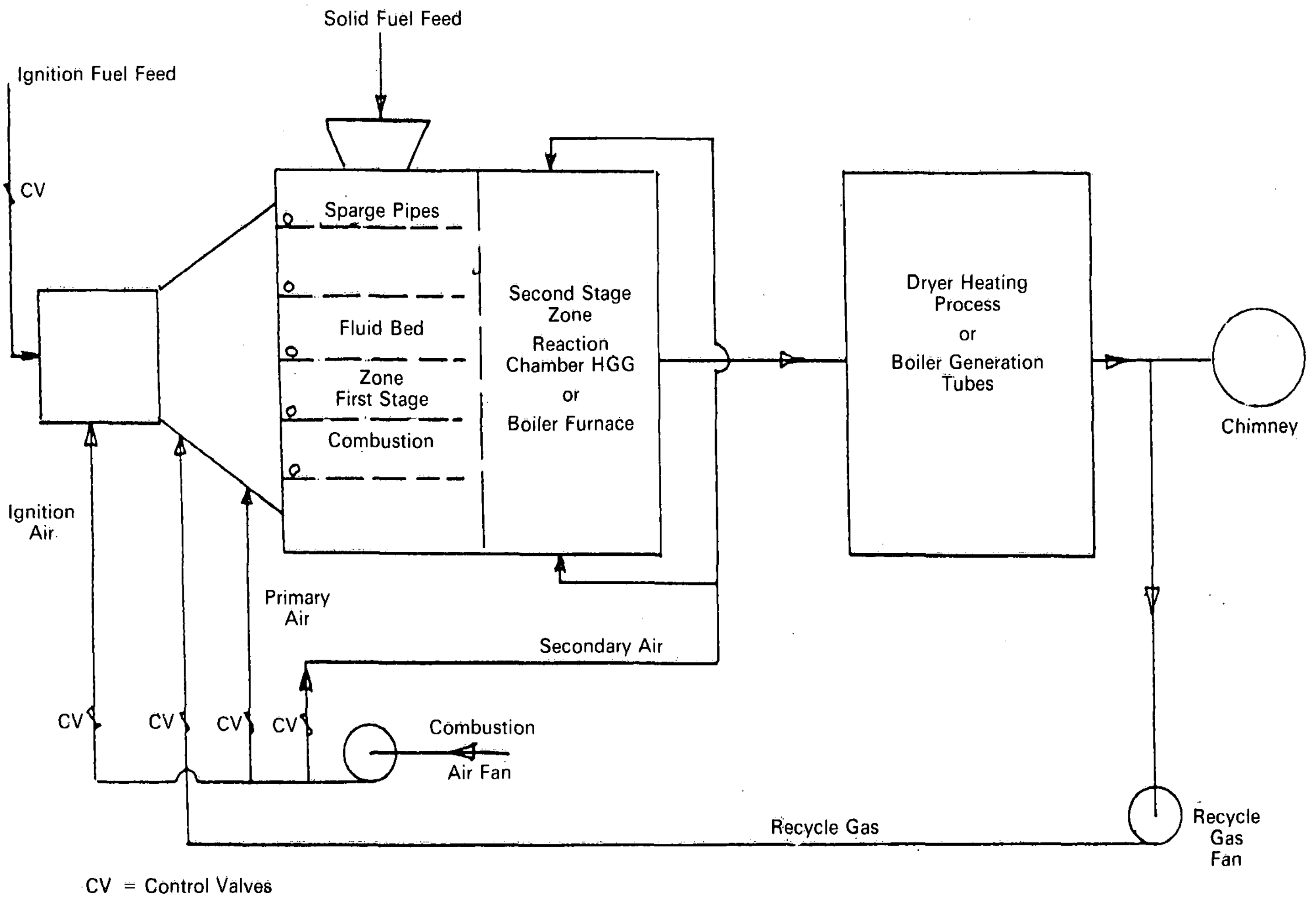


FIGURE 2 Flow pattern of gases in two stage fluid bed combustor system.

ventional oil or coal firing equipment. Operation of the combustor with only 10% excess air means an efficiency advantage of 3% compared to contemporary oil burners and an advantage of 6% compared to contemporary coal stokers.

(2) The fluid bed can be operated at this optimum high efficiency when burning high ash coals or waste of between 20% and 40% ash content.

(3) The fluid bed will operate as a genuine dual fuel unit, burning coal or waste separately with almost instantaneous changeover, or the two fuels burning concurrently, if required.

(4) In contrast to conventional solid fuel stokers, the fluid bed is able to accept small particle sizes of fuels, and give an even heat release from the total bed area, thus giving an even heat transfer to the whole of the boiler heating surfaces.

(5) High sulphur fuels can be burnt with acceptable exhaust conditions due to the reduction in sulphur levels that can be achieved by introducing lime or dolomite to the bed. Normal bed temperatures are ideal for converting lime to gypsum which can be discharged from the system along with the ash.

(6) Nitrogen oxides are greatly reduced at the operating temperatures employed.

(7) With efficiency improvement, the fuel consumption will reduce by up to 8%. Considering fuel cost saving with lower grade fuel and improved efficiency, the total fuel cost can be cut drastically.

(8) Analysis of many potential installations shows that capital repayment can be achieved in two years or less, even though the cost of the fluid bed combustors can be higher than conventional oil fired and coal fired systems.

Table 1 shows the results from a test run on the water tube boiler after conversion to fluid bed combustion as shown in Figure 1.

Application to Drying

From the development which has evolved as the present fluid bed system at Cadbury's, a range of process Hot Gas Generators which extends from a heat release of 10 GJ/h to a heat release of 100 GJ/h.

Currently four plants have been built and commissioned.

A typical Hot Gas Generator (HGG) is shown in Figure 3.

HGG's are often coupled to rotary dryers, drying crops or by-products of industries for the production of animal feed stock. The HGG could also be used to provide the heat for drying sludge, clays, aggregate, etc. and indirectly through an heat exchanger to provide clean air for drying where an uncontaminated heat source is required.

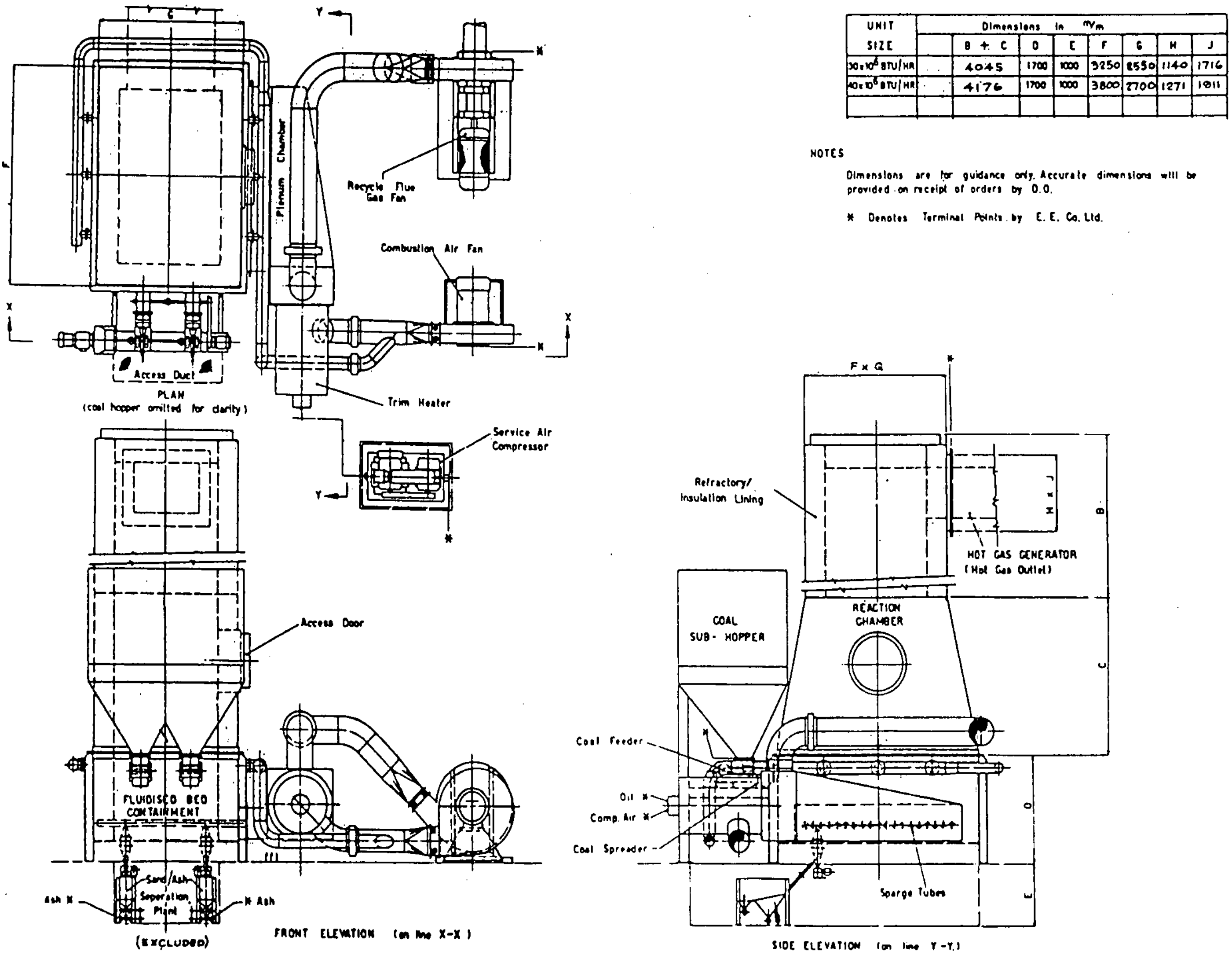
The HGG family have the same configuration of containment tank, submerged in sand sparge pipes and other equipment as would be fitted to a boiler.

The gases generated in the bed would be burned in a refractory lined secondary chamber forming a column above

TABLE 1

Results from Water Tube Boiler Test Run over 2 Days — Derived Quantities

Derived Quantities				
Average coal rate	kg/h	1 286,8	1 384,1	1 575,0
Steam meter correction	3,1 MPa & 370°C	0,995 × 0,97 = 0,965	0,995 × 0,97 = 0,965	1 × 0,97 = 0,97
Corrected steam flow rate	kg/h	10 941	11 488	12 889
Actual evaporation ratio	kg/kg	8,5	8,3	8,2
Heat to steam	kJ/kg	2 969,8	2 879,9	2 879,9
Load factor on 3,1 MPa × 382° × feed 80°C		1,02	1,01	1,01
Heat Balance per kg of Metered Coal				
Heat Losses				
To dry waste gas	kJ	3 430	3 250	3 186
To waste gas moisture	kJ	1 437	1 435	1 440
To unburnt carbon	kJ	252	252	252
To bed steam	kJ	150	150	150
Estimated radiation plus unaccounted	kJ	841	841	841
		6 110	5 928	5 879
Heat to steam (by difference)	kJ	21 923	22 105	22 155
By Loss Method				
Efficiency on gross C V	%	78,2	78,9	79,0
By Direct Method				
Steam evaporated/kg coal	kg	8,5	8,3	8,2
Heat added per kg steam	kJ	2 909,8	2 879,9	2 879,9
Heat added to steam per kg coal	kJ	24 741	23 903	23 615
Efficiency on gross C V	%	88,25	85,27	84,2



UNIT SIZE	Dimensions in m/m							
		B + C	D	E	F	G	H	J
30×10^6 BTU/HR		4045	1700	1000	3250	2550	1140	1716
40×10^6 BTU/HR		4176	1700	1000	3800	2700	1271	1911

NOTES

Dimensions are for guidance only. Accurate dimensions will be provided on receipt of orders by 0.0.

* Denotes Terminal Points by E. E. Co. Ltd.

FIGURE 3 A typical Hot Gas generator.

TABLE 2

Fuel	Milled Peat	Waste Derived	Lignite	Coal Washed Smalls	Coffee Waste	1/1 Coal Coffee Mix by Weight	Woodchips plus Bark
GCV-kJ/kg as fired	8 000	—	9 788	30 086	—	—	12 028
Dried	—	28 359	—	—	24 900	Coal 25 704 Coffee 24 900	—
Proximate Analysis — as fired							
% Volatiles	—	72,0	24,0	33,92	—	Coal 26,75	—
% F Carbon	—	9,0	13,0	53,84	—	49,84	—
% Ash	—	19,0	25,0	4,59	—	12,45	—
% Moisture	58,0	Nil	38,0	7,65	69,87	Coal 10,96 Mixed fuel 40,4	34,0
Bed Temp., Deg C	730-800	800-880	850-950	850-900	770	847	870
Outlet Temp. Deg C	1100	1160	1100	1150-1200	1100	1050	960
P of C at Outlet in GJ/h	11,8	11,0	8,96	11,0	15,9	12,6	8,54
Design of Plant in GJ/h on Coal	10,0	10,0	10,0	10,0	10,0	10,0	10,0
Gross EFF Percentage	76,6	93,0	84,2	92,4	72	87	86,6
Losses, Percentage	23,4	7,0	15,8	7,6	28	13	13,4
Radiation	3	3	3	3	3	3	3
Carbon in Ash %	3-5	3-5	3-5	3-5	3-5	3-5	3-5
Latent Heat %	16,4	—	8,8	0,6	21	6	6,4

the bed and hot gases would be ducted away from this column to the drying zone.

At the Research Centre in the UK, commercial size plant has been installed, providing test facilities for clients who have either usual fuels or unusual drying problems. A general view of the inside of the Research building is shown in Figure 4.

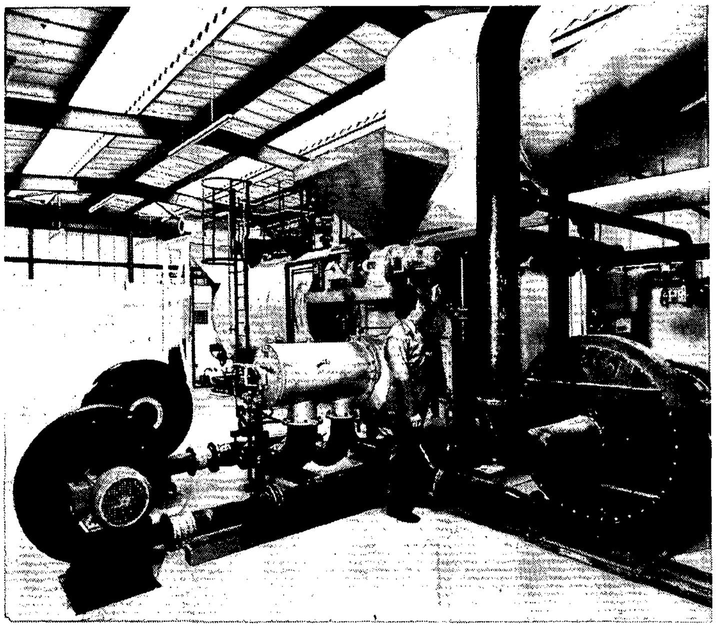


FIGURE 4 Inside the Reasearch Centre in the UK.

The HGG installed in this Research Centre is a 10 GJ/h unit and results of a number of tests undertaken from various clients are shown in Table 2.

The temperatures recorded at the outlet of the HGG in all these tests was deliberately depressed by recycling waste gas. When firing into a boiler, the above bed temperature is allowed to rise to 1 350 — 1 400°C. This has been shown for example in the water tube boiler at Cadbury Schweppes where the boiler has steamed for some 4 000 hours at 3,1 MPa and 370°C, supporting a portion of the factory steam load and has on occasions steamed at 15% overload conditions for up to 14 hours.

It will be seen that it could be expected when firing bagasse, having the following analysis, into a fluid bed combustor, similar results would be obtained as logged for milled peat or lignite.

GCV as fired	9 556,9 KJ/kg
Volatiles	37,0 %
Fixed carbon	11,5 %
Ash	1,5 %
Moisture	50,0 %

The larger size of HGG units will have more than one bed or zone and in every application the bed temperature will be regulated by recycling exhaust gas after it has passed through the dryer or other heat exchanger coupled to the HGG.

Conclusion

Although the two stage fluid bed combustors are operated with a low fluidising velocity, there is inevitably a carry over of gifts, degraded sand and ash and removal of debris from the bed.

This is removed to an acceptable level by one or a combination of the following :

(1) Dumping rocks and debris through the bottom of the containment tank.

(2) Hot grit cyclones at the outlet of the HGG before the process dryer.

(3) Weiring over the excess ash from the top of the fluid bed.

(4) Collecting the ash and grits after the process and before exhausting the final waste gas to atmosphere.

(5) Collecting carry over in the boiler passes.

In the sugar industry the two stage fluid bed combustor could be employed to provide hot gases or indirectly, hot air, for drying and the unit could be fired by coal of inferior grade or waste material providing that it has a calorific value, such as bagasse.

The more immediate application would be to replace existing Dutch oven fired boiler plant with a two stage fluid bed combustor, which is fitted without modifications to the furnace or generation tubes of the unit.

Comments that are frequently made on the potential use of South African coals with fluid bed combustion that it may well embarrass the user and the combustor, due to the differing nature of these coals compared to the well tested coals of the Northern hemisphere. Successful tests have been undertaken on the 60 GJ/h unit and on the test plant in the UK burning South African coals.

At present, a prolonged test run is being conducted on the test plant illustrated in Figure 4 burning SA coal having the following analysis.

15% Ash.
23% Volatiles.
0,6% Sulphur.
50% Fixed Carbon.
9% Moisture (inherent as delivered plus surface moisture).

Forty tons of this coal were delivered to the UK for this test.

The recent development of the fluid bed gasifier producing hot raw gas which can be either fired direct or can be cooled and cleaned to allow distribution through normal piping systems, will be progressed during this test run.

Acknowledgements

The presentation of this paper has been possible by making use of information recorded by the Energy Research Unit in the UK under the direction of Mr. P. B. Caplin and from records of commercial plant in the field and it is hoped that interest will be stimulated for the sugar industry in South Africa to make use of the techniques discussed.