# OPERATING EXPERIENCE ON SINGLE AND THREE PASS BOILERS IN THE CANE SUGAR INDUSTRY WITH PARTICULAR REFERENCE TO EROSION AND DRUM WATER LEVEL STABILITY

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## Abstract

Two boiler designs have recently emerged to suit the present requirements of the cane sugar industry, viz the single pass panel wall unit and the three pass, bottom supported boiler with an open pitch furnace tube construction. The former is less susceptible to erosion compared with the original concept of the three pass boiler. It is believed that the three pass unit in its present form as installed at Tongaat will be effective in reducing erosion in the tube bank. The effect of fuel properties on the performance of boiler plant is considered and it is shown that efficient operation, in addition to improving the utilisation of bagasse, can result in a significant reduction in tube erosion. A relationship is presented for determining dust loadings as a function of the grate heat release rate and the fuel ash content at the furnace and main bank exits. Circulation studies undertaken on both boiler types are presented indicating very similar circulation rates. Shrink and swell characteristics and hence the drum level stability can be related to the volume of water contained in the system and the water plan area in the drum at the steam – water interface. Finally the mechanical design features of the two boiler designs are compared to provide an insight into the design philosophies relating to the two units.

## Introduction

Two major developments during the 1970's have determined the direction in which boiler design will move during the 1980's. Mechanical harvesting and loading have had a profound effect on tube erosion and hence availability while the move to larger suspension fired units has affected water level stability and hence operational stability. Levy and Frost[3] and Moir and Mason[6] have documented the factors which affect tube wear. They have identified sand brought in with mechanically harvested and loaded cane as the most important; it acts as a blasting medium.

As boilers have become larger two design features have affected water level stability. Firstly, hearth burning has been

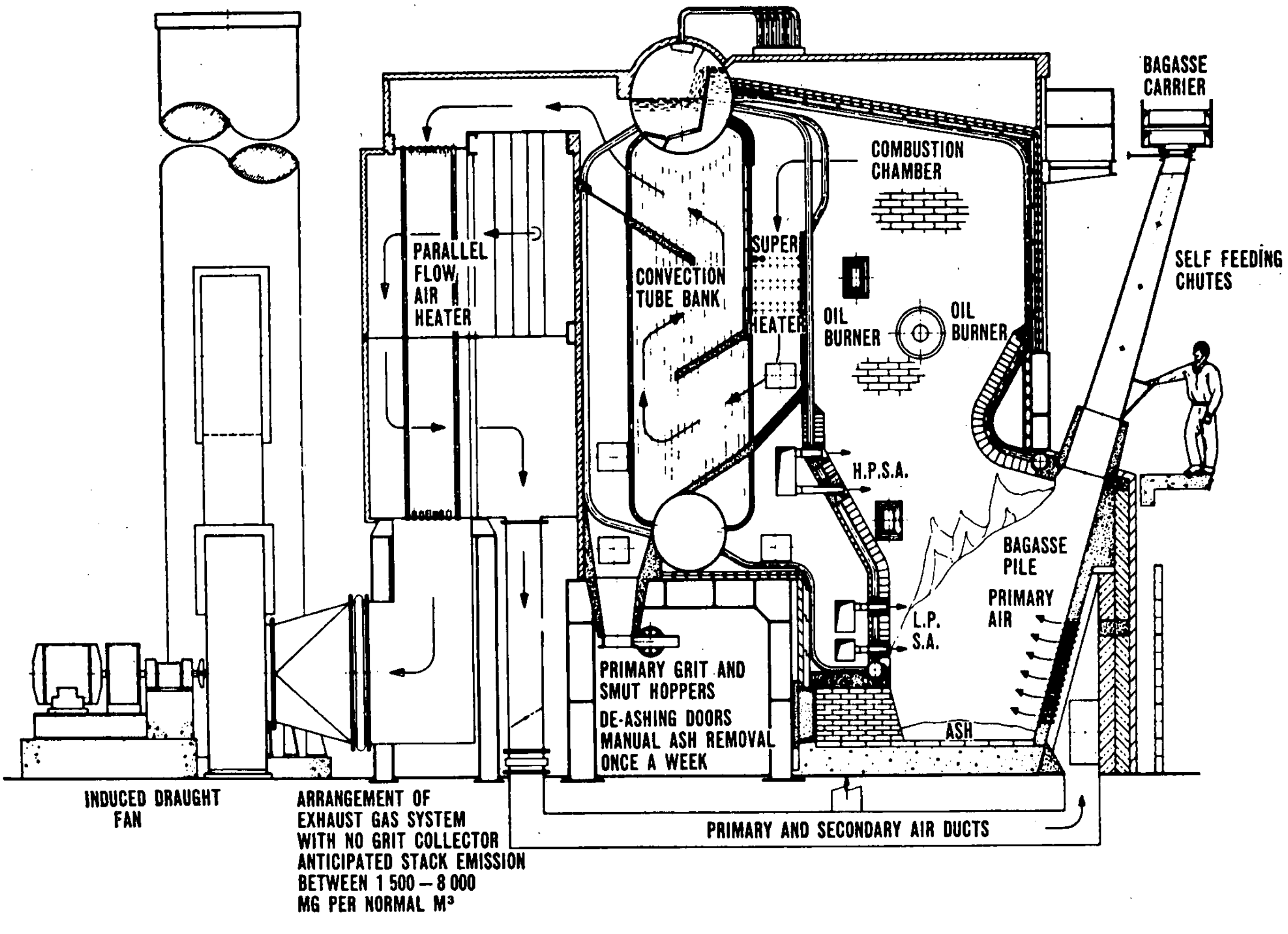

**FIGURE 1** General arrangement of two drum bagasse and oil fired watertube boiler fitted with hearth-type self-feeding furnaces

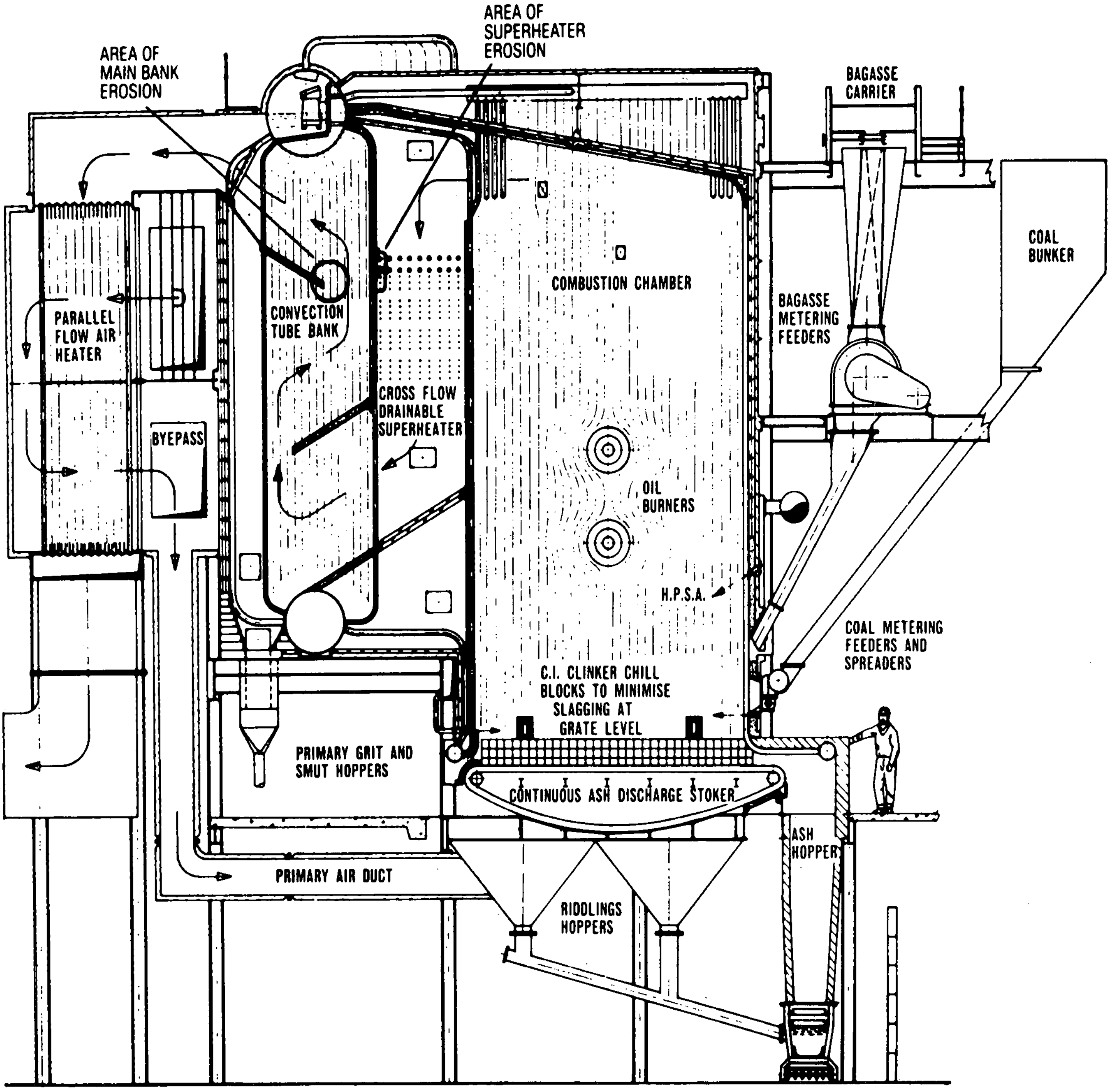

**FIGURE 2** General arrangement of two drum bagasse, oil and coal fired watertube boiler fitted with suspension firing equipment and a continuous ash discharge stoker

replaced by suspension firing which is inherently less stable. This adversely affects the swell and shrink characteristics of a boiler.

Secondly, cost factors have dictated that boilers should become narrower per unit of steam output as they get larger. The water level plan area in the steam drum has therefore become smaller per ton of steam evaporated and hence more sensitive to swell and shrink.

Design efforts during the 1970's were directed at reducing the effect of sand erosion and improving water level stability. The effect of rapidly escalating refractory material and placement costs played a secondary role. The two designs which emerged at the end of the 1970's to resolve these problems and which will no doubt be further refined during the 1980's are discussed in this paper. Figures 1 and 2 show the designs which dominated in the early 1970's. Figures 3 and 4 show the designs which have emerged in the early 1980's.

## Review of Design Parameters

The design of a boiler is dictated by the physical and chemical properties of the fuel to be burnt and the environment in which the unit will operate. The physical and chemical properties of bagasse are well documented. In recent years ash content has increased with the advent of diffusers and of mechanical harvesting and loading and fibre particle size has become smaller with increasing use of shredders. Don *et al*[1] have defined calorific value more accurately as follows:

$$GCV = 19\ 605\,(1 - a - m) - 3\ 114.b \quad . \ . \quad (1)$$

$$NCV = GCV - (1\ 296 + 1\ 155.m) \quad . \ . \ . \ . \quad (2)$$

(see Appendix 1 for list of symbols)

For suspension fired boilers, the effect of moisture content on grate heat release rate and the amount of excess air required to burn bagasse of a given moisture has been more accurately quantified. These relationships which are empirical are shown

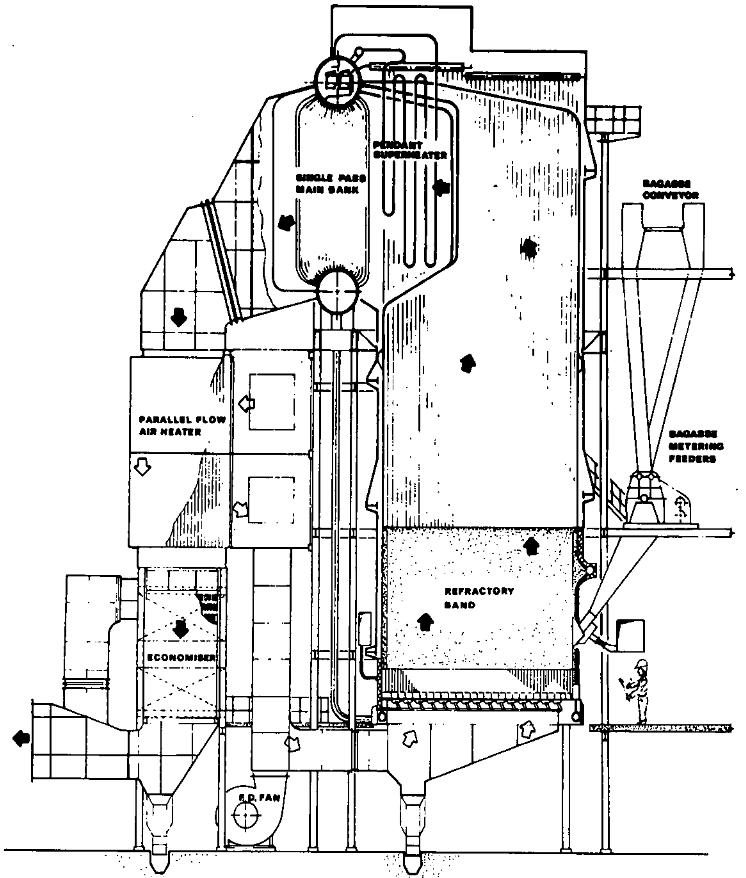

**FIGURE 3** General arrangement of the 204 t/h single pass boiler at Malelane Sugar Mill

in Figure 5. The grate heat release relationship limits carry over carbon loss to almost a constant figure. The carbon loss has been found to increase slightly with moisture content. With wetter fuels more excess air is needed to carry away the moisture.

The combination of a decreasing grate heat release rate with an increasing excess air ratio as the moisture content of the fuel increases, results in an almost constant gas mass flow rate. The effect of these relationships on boiler output is illustrated in Figure 6.

The relationship of bagasse moisture content, final flue gas temperature and carbon dioxide level on boilerplant efficiency is shown in Figure 7. When operating, plant excess air should be adjusted to meet the requirements shown in Figure 5. If more excess air is used, the carbon loss will be reduced slightly but erosion rates will increase substantially. On the other hand if too little air is used carbon losses will increase substantially while erosion rates will be reduced minimally. As most boilers are fitted with wet scrubbers it is impossible to determine the relative stack emission by observation. At Ubombo Ranches where a 74 t/h single pass panel wall boiler was commissioned in 1982 an extensive series of observations was carried out at varying $CO_2$ levels, McIntyre[5]. At a $CO_2$ level corresponding to Figure 5 and with secondary air correctly apportioned, optimal emission levels were attained.

## Erosion in Boilers

Moir and Mason[6] developed the following equation to relate wear rate to abrasive particle concentration and velocity of the flue gases:

$$W = K_w . M_d . u^{3.5} \quad . \; . \; . \; . \; . \quad (3)$$

(See Appendix 1 for list of symbols)

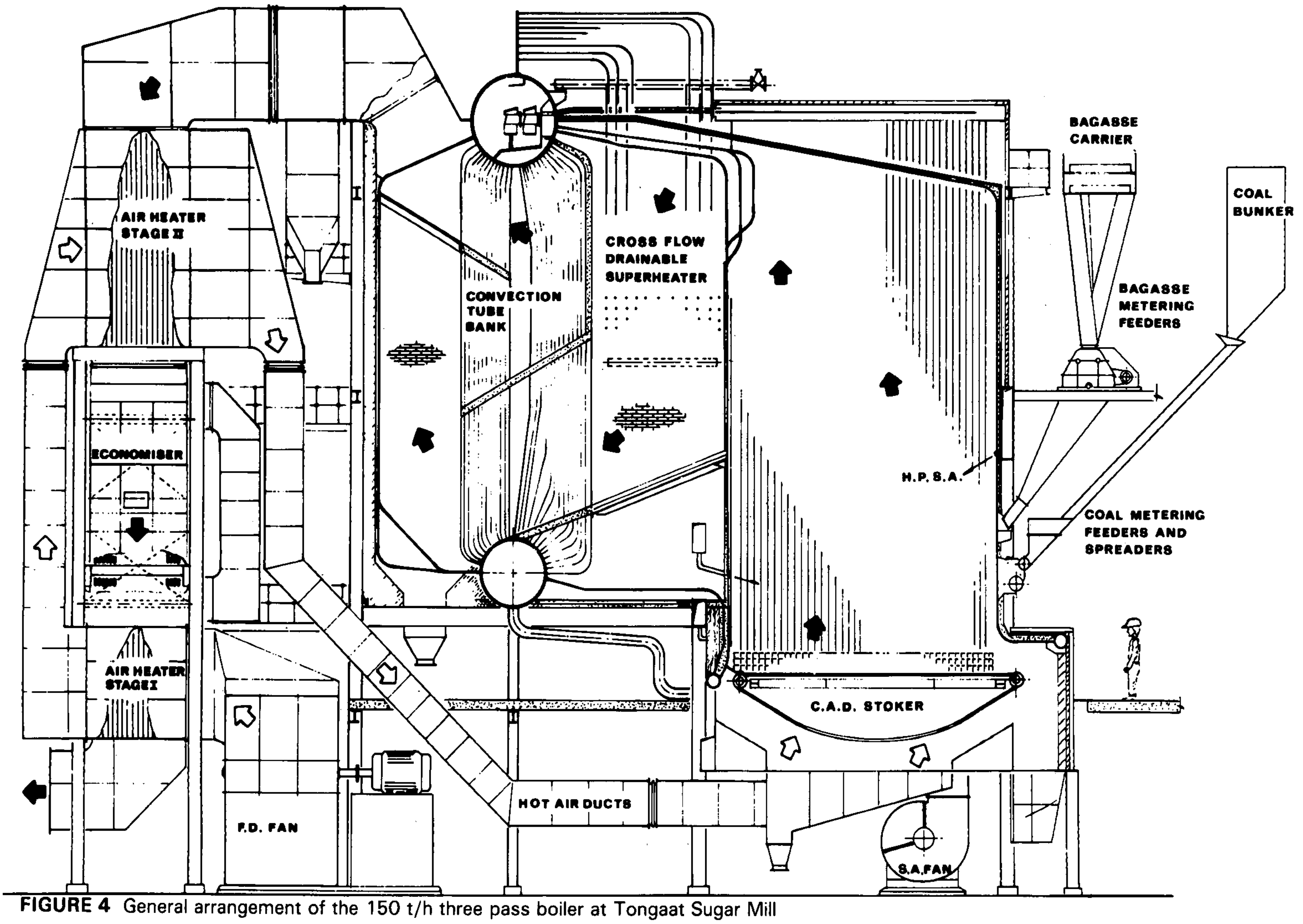

**FIGURE 4** General arrangement of the 150 t/h three pass boiler at Tongaat Sugar Mill

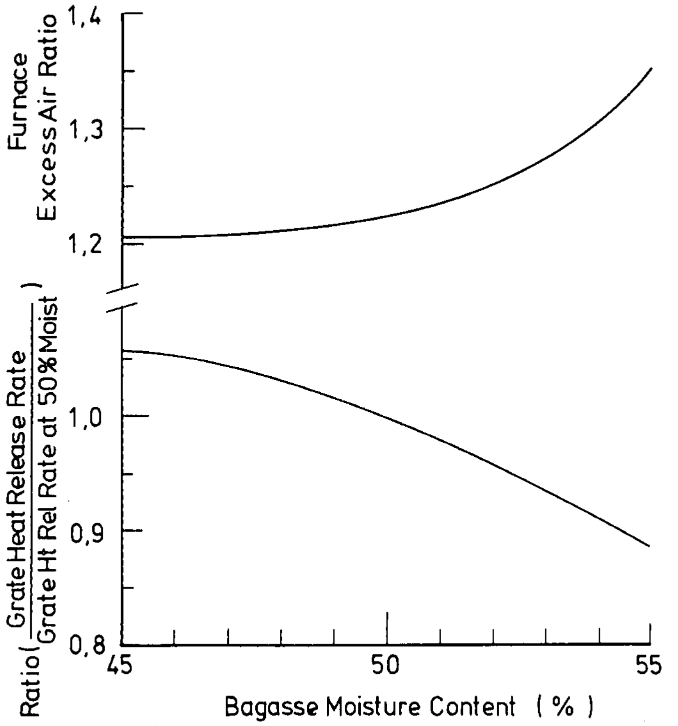

**FIGURE 5** Relationship of the furnace excess air ratio and grate heat release rate as a function of the bagasse moisture content

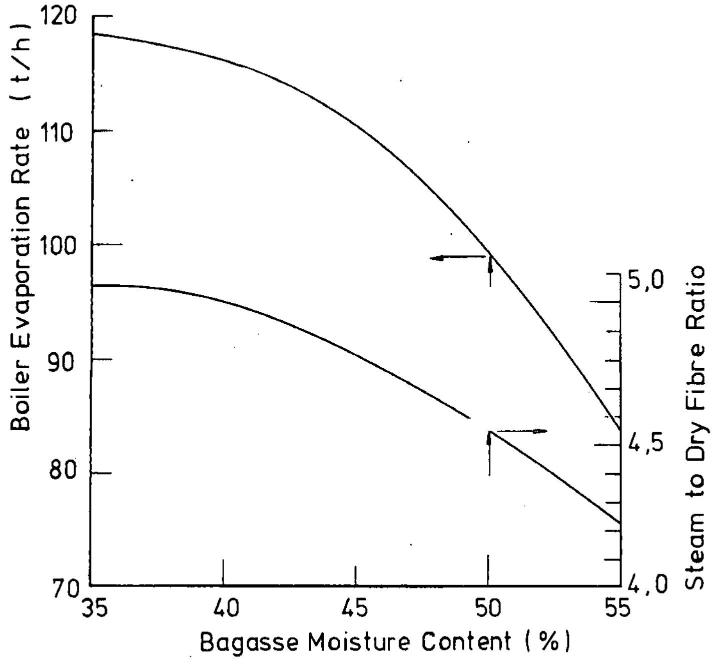

**FIGURE 6** Variation of the possible boiler evaporation rate and the steam to fibre ratio as a function of the bagasse moisture content for a unit nominally designed at 100 t/h when firing 50% moisture bagasse

The value of the wear constant '$K_w$' is about 1,68. $10^{-9}$ for the mainbank tubes of three pass boilers and about 0,40 . $10^{-9}$ for the mainbank tubes of single pass boilers.

As the firing rate is increased at constant excess air and bagasse quality, the erosion rate will be proportional to the flue gas velocity to the power 3,5. This is very nearly proportional to load to the power 3,5.

If too much excess air is used, four things will happen:

- the gas velocity for the given load will go up
- sand carry over will increase because there will be a higher upward velocity in the furnace
- carbon losses will be reduced very slightly and
- stack losses will be increased at a faster rate than carbon losses are reduced with the result that more fuel will have to be burnt to meet a given load. This will result in more gas being generated, more carry over and hence higher erosion rates.

When operating at 52% moisture i.e. 25% excess air at the furnace exit which corresponds to a $CO_2$ level of 16,5%, efficiency will fall by 1,2% if excess air is increased to 50% i.e. a $Co_2$ level of 13,8%. The erosion rate under these circumstances will increase by a factor of 1,80. This means that tube life is almost halved.

Moir and Mason[6] have also shown that the way in which the flue gases pass over the heating surfaces affects the rate of wear. Their findings are illustrated in Figure 8. Experience in Southern Africa has confirmed their results by the measurements taken by Field[2] illustrated in Figure 8. So far no erosion related failures have occurred on single pass mainbanks. The

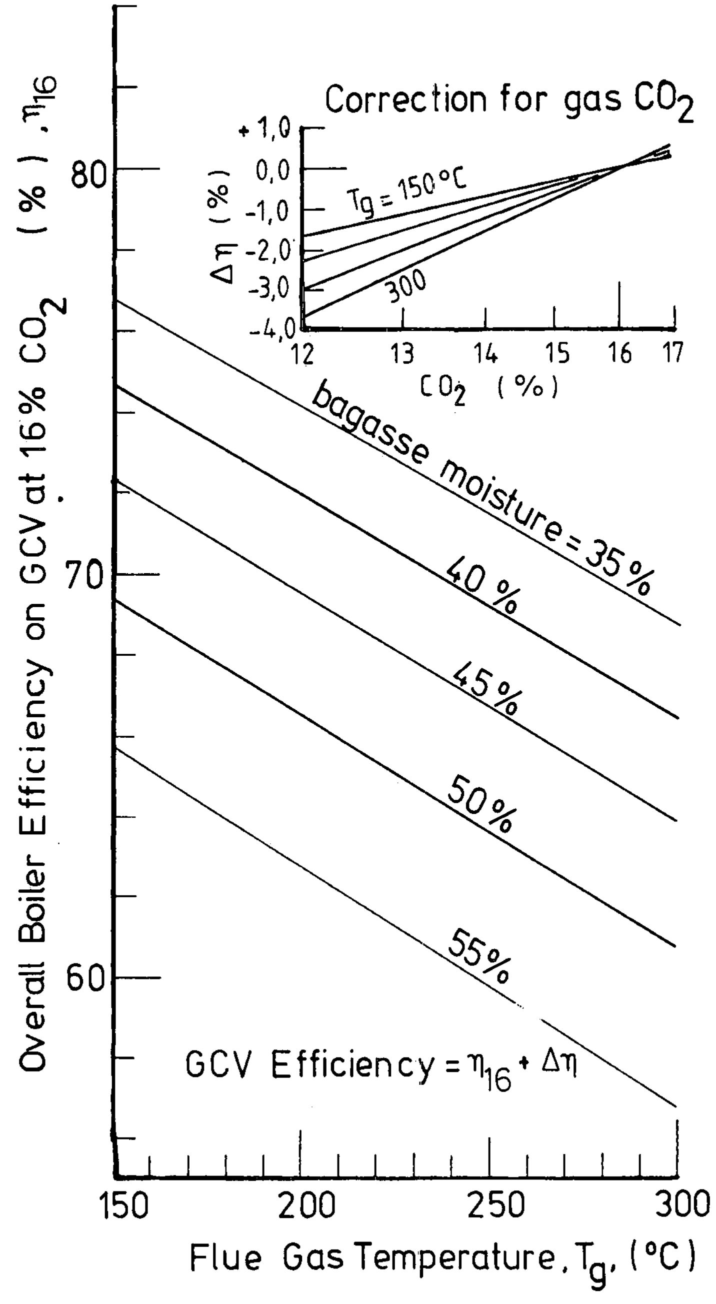

**FIGURE 7** Boiler efficiency as a function of the exhaust gas temperature, flue gas $CO_2$ and bagasse moisture content for bagasse containing 8% ash on a dry basis

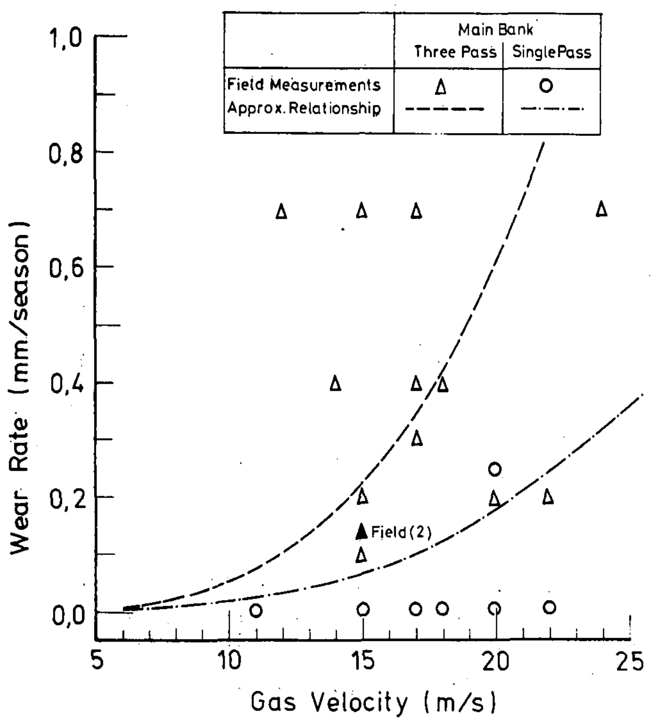

**FIGURE 8** Main bank tube wear rates as a function of flue gas velocity and boiler type as depicted by Moir and Mason[6] and including a single point from a South African mill. Approximate relationships for wear rates of the single and earlier three pass type mainbanks are illustrated.

failures which occur on three pass mainbanks are mostly concentrated in one zone. This is illustrated in Figure 2. The mechanism of this failure has been investigated at the University of Cape Town by Pryor.[7] Sand which is carried over into the third pass is deposited on the baffle and re-entrained in a reverse gas flow caused by a vortex at the baffle tip. The resulting heavy concentration of sand in this reverse flow pattern causes heavy erosion.

Superheater erosion on three pass boilers has been experienced in the areas indicated in Figure 2. Erosion of the rear row of superheater tubes is caused by sand concentrating in the gas stream because of centrifugal action as the gases pass over the rear wall screen tubes into the superheater pass. Neither the reason for nor the mechanism of excessive erosion rates of the superheater tube ends can be explained satisfactorily.

During 1978 a comprehensive series of tests were carried out on boiler No. 4 at Noodsberg. The boiler is similar to that illustrated in Figure 2 and burns coal as an auxiliary fuel. Measurements were taken of the quantities of ash and grit collected at various loads and for various fuel qualities. When burning bagasse, approximately one third of the sand and ash was collected in the stoker ash and riddlings hoppers; one third was collected in the mud drum hopper and the remainder was collected in the grit collector or discharged up the stack. The carry over could be related by the following equation:

$$M_d = C_d \, . \, a \, . \, q \quad . \; . \; . \; . \; . \; . \quad (4)$$

(See Appendix 1 for list of symbols)

The values for the dust burden characteristic constant '$C_d$' for different fuels and at different points in the boiler are contained in Table 1.

**TABLE 1**

**Dust Burden Characteristic Constant '$C_d$' of Equation (4) obtained from tests conducted on the No 4 Three Pass Boiler at Noodsberg Sugar Mill**

| Fuel | Bagasse | Coal |
|---|---|---|
| Constant ex furnace | 115 000 | 24 500 |
| Constant ex main bank | 68 400 | 18 400 |

Very little erosion has been experienced on the type of boiler illustrated in Figure 1. This is due to the fact that the fuel is burnt in a quiescent condition in a hearth type furnace which minimises carry over.

Provided that boilers are operated within their design constraints, they should not suffer unduly from erosion. Single pass boilers are far more tolerant to maloperation than the earlier three pass units. These units can be made more tolerant to maloperation by rearranging the baffles and tubing in the main bank. The superheater can also be rearranged to minimise erosion problems. These improvements are all incorporated in the 150 t/h No 8 boiler installed at Tongaat which is illustrated in Figure 4.

## Drum Water Level Stability

Magasiner[4] has shown that the total demand for steam of a cane sugar factory operating under steady load conditions does not fluctuate by more than about 5%. When there are conditions such as a mill chokage or shortage of cane, large load fluctuations can occur. The load fluctuations, which are evident on individual boilers on a multiboiler installation under steady load conditions, are due to load swings from one boiler to the other. This is due to inadequate feedwater control.

Water level stability in a boiler can be characterised by the product of the volume of water in the boiler per unit of steam evaporated and the water plan area per unit evaporation at the water level. The larger this number the more stable will be the water level. The volume of water in a boiler is a function of the load on the unit at any instant in time and the circulation factor. The circulation factor is determined by boiler design.

The magnitude of the swell and shrink phenomenon in a boiler is determined by the characterising ratio mentioned above. The degree to which swell and shrink is damped and the rate at which it will decay is a function of a number of interacting factors such as the:

- rate at which load and hence pressure in the system changes
- actual load on the plant at the time
- circulating factor associated with this load
- rate at which the water level controls respond to changes in water level
- rate at which the firing rate is changed in response to load change
- quality of the water in the boiler

Operating experience on single pass boilers seems to indicate that they have more stable water level characteristics than three pass units. The reason for this is not readily apparent. The circulating factor characteristics of three typical units are given in Table 2. The swell and shrink characteristic ratios for these units, as well as the Noodsberg unit are as follows:

Noodsberg — 11,1 mm/kPa
Malelane — 12,6 mm/kPa
Tongaat — 10,3 mm/kPa
Amatikulu — 11,5 mm/kPa

This ratio measures the effective change in water level for a step change in pressure with all other parameters remaining constant. The characteristics are similar and do not lead to any definite conclusion. Perhaps the mills where single pass units are installed have paid greater attention to maintaining more uniform bagasse feed rates. Longer feed chutes are being utilized which provide a larger reservoir of bagasse and a better furnace seal. Irregular firing has a marked effect on water level stability. This factor has largely been ignored in the past.

The superheater tube failures experienced on a 70 t/h unit installed at Savannah Sugar Estates, Mauritius is a typical example of how irregular firing can affect water level stability. After careful investigation it was established that the failure was due to water carry over into the superheater tubes. This was due to a standing wave being formed in the drum opposite the bagasse feeder which was delivering more fuel than each of the remaining three feeders.

TABLE 2

Circulation Characteristics of Three Boilers installed in the Cane Sugar Industry

| | | Malelane | Tongaat | Amatikulu |
|---|---|---|---|---|
| Type of main bank | | Single Pass | Three Pass | Three Pass |
| Evaporation Rate | kg/h | 204 000 | 150 000 | 85 400 |
| Quantity circulated | t/h | 8 666 | 5 941 | 3 698 |
| Nett circulation factor | — | 35,0 | 31,8 | 33,4 |
| Water flow rate as a fraction of total quantity circulated: | | | | |
| Front wall risers | — | 0,139 | 0,064 | 0,065 |
| Rear wall risers | — | 0,188 | 0,114 | 0,132 |
| Side wall risers | — | 0,153 | 0,117 | 0,151 |
| Main bank risers | — | 0,520 | 0,705 | 0,652 |
| Circulation factor at: | | | | |
| Front wall exit | — | 24,6 | 17,3 | 18,7 |
| Rear wall exit | — | 29,6 | 22,0 | 25,4 |
| Side wall exit | — | 40,4 | 22,5 | 24,3 |
| Main bank exit | — | 37,9 | 40,7 | 43,3 |

TABLE 3

Characteristics of the Single and Three Pass Boilers currently being supplied to the Cane Sugar Industry

| Item | Single Pass Boiler | Three Pass Boiler |
|---|---|---|
| 1. Combustion Equipment | (a) Dump grate, continuous ash discharge stoker, pinhole grate to suit application<br>(b) Hinged stainless steel seals at grate level | (a) Dump grate, continuous ash discharge stoker, pinhole grate to suit application |
| 2. Bagasse Feeders | Three drum low torque units | Three drum low torque units |
| 3. Bagasse Spreaders | Pneumatic distributors | Pneumatic distributors |
| 4. Coal Feeders | Self-cleaning drum type | Self-cleaning drum type |
| 5. Coal Spreaders | Mechanical or pneumatic | Mechanical or pneumatic |
| 6. Furnace Construction | Panel walls with re-fractory band to suit application | Open pitched tubing with refractory backing |
| 7. Furnace pressure | Balanced Draught | Balanced Draught |
| 8. Superheater | (a) Pendant non-drainable or inverted hairpin drainable type<br>(b) Heavy grits recycled back to the furnace through openings in superheater cavity floor | Cross flow drainable |
| 9. Main bank | (a) Single pass | (a) Three pass baffled<br>(b) Erosion rates reduced by including a gap in the bank |
| 10. Support | (a) Girt support at mud drum level | (a) Bottom supported<br>(b) Casings integral with boiler steelwork |
| 11. Heat recovery | Airheater and/or economiser to suit application. **Note:** On bagasse firing only an airheater is required.<br>As the convective heating surface is small the airheater is large and layout may dictate the use of a counterflow unit | Airheater and/or economiser to suit application. **Note:** On bagasse firing only an airheater is required.<br>The convective heating surface of the three pass main bank results in a smaller airheater and a parallel flow unit can almost always be used |

The converse of this situation can also arise. If fuel feeders are starved of bagasse a trough will be formed. If tramp air is allowed to enter the boiler through this feeder, the position will be aggravated. Low level bagasse feed chute trip switches should be installed to minimise this problem.

## Mechanical Design

The relative merits of the features of the two designs shown in Figures 3 and 4 are discussed in detail in Table 3. The temperature characteristics of the number 5 boiler installed at Noodsberg, which is typical of the single pass design are shown in Figure 9.

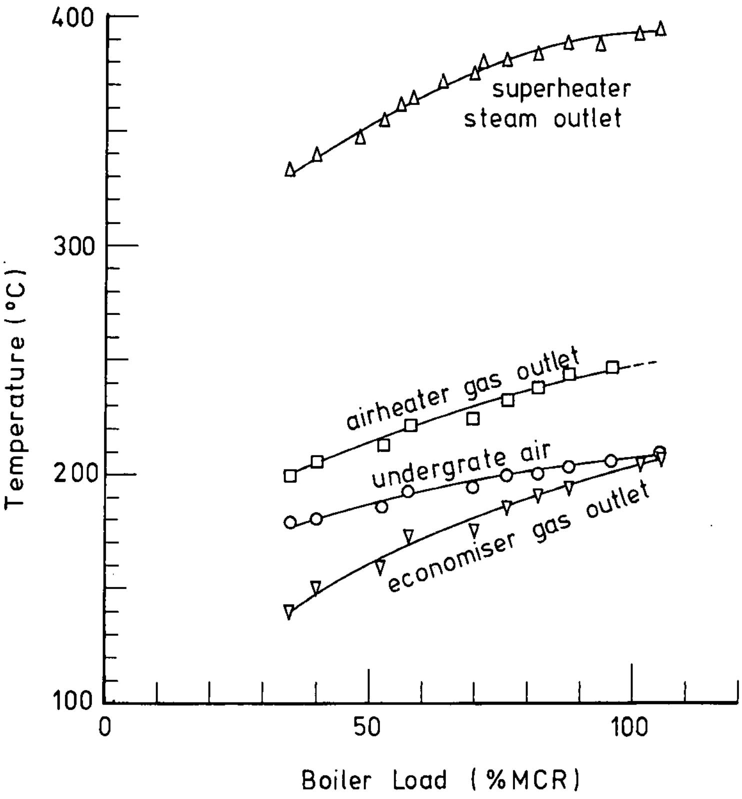

**FIGURE 9** Temperature characteristics of the single pass 86 t/h boiler at Noodsberg Sugar Mill

## Acknowledgements

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## APPENDIX 1

### LIST OF SYMBOLS

a — fraction of ash contained in the fuel
b — fraction of the fuel as brix
$C_d$ — dust burden characteristic constant
GCV — gross calorific value (kJ/kg)
$K_w$ — wear rate characteristic constant
m — fraction of moisture contained in the fuel
$M_d$ — dust burden (mg/m$^3_n$)
NCV — net calorific value (kJ/kg)
q — grate heat release rate (MW/m$^2$)
u — flue gas velocity (m/s)
w — wear rate (mm/season)

## APPENDIX 2

**Schedule of Single Pass Boilers**

| Sugar Mill | Year of Commissioning | Evaporation Rate kg/h | Final Steam | |
|---|---|---|---|---|
| | | | Temp. °C | Pressure kPa(g) |
| Ubombo Ranches | 1982 | 74 000 | 385 | 2 930 |
| Umzimkulu | 1982 | 86 000 | 390 | 3 100 |
| Noodsberg | 1982 | 86 000 | 390 | 3 100 |
| Malelane | 1983 | 204 000 | 400 | 3 100 |
| Sezela | 1984 | 130 000 | 390 | 3 100 |
| Nakambala | 1985 | 91 000 | 263 | 1 720 |