BOILER PLANT AS AN INTEGRAL PART OF A CANE SUGAR FACTORY

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ABSTRACT

The nature of the load which a sugar factory imposes on the boiler plant is discussed. This load is shown to be relatively steady during continuous operation and only changes rapidly during transient conditions such as start up and shut down and when cane shortages occur. Boiler design characteristics to meet a factory’s specific requirements are discussed in detail as well as the design of the feed water system and the effect which the characteristics of this system have of ease of control. Ideas are put forward to simplify instrumentation and control circuits and also regarding fuel handling plant design and the effect which this has on controllability and ease of operation. Effluent disposal problems are discussed and basic parameters for the design of gas cleaning equipment to meet the ever increasingly stringent regulations governing stack emission are suggested. The performance of existing gas cleaning equipment is reviewed. Finally, the integration of the plant into the factory system as a whole is discussed and the relative cost of components reviewed. The paper stresses the need to simplify the design of the boiler plant and its auxiliaries to ensure maintenance free operation and so allow factory staff to concentrate on improving sugar extraction and quality and hence profitability.

FACTORY STEAM LOAD CHARACTERISTICS

Steam is used in a sugar factory primarily to:

a) generate power, and
b) concentrate sugar juices.

The pressure and temperature conditions normally encountered in a modern factory are scheduled in Table 1. Power generating conditions are usually determined by the size and type of prime mover employed, while process conditions are limited by a combination of factors, such as the temperature at which the juice will deteriorate, overall factory thermal balance considerations and the economics of pressure vessel manufacture.

The main steam consumers in a typical factory are shown in Fig. 1, and an approximate energy balance for this factory is given in Table 2.

When a factory is operating under steady load conditions, the most significant changes in energy demand are caused by varying milling conditions and the cyclic operation of the pans. Smaller changes are also induced by cyclic operation of the centrifuges and other minor items of plant. As the power load represents less than 10% of the total energy demand, a large change in power consumption, due to changes in milling of centrifuging loads, has only a small effect on the total steam demand; of the order of 2 to 3%. Changes in steam demand due to starting or striking pans heated with exhaust steam have a more significant effect. Their magnitude depends upon the number of pans installed and the way in which they are operated. Obviously,
### TABLE 1. Steam conditions in a cane sugar factory.

<table>
<thead>
<tr>
<th>Use</th>
<th>Equipment</th>
<th>Steam conditions</th>
<th>Remarks</th>
</tr>
</thead>
</table>
| Electric Power Generation | Turbo Alternator of:  
Back pressure, passout condensing or condensing design. | 1700-6200 kPa  
315-450 °C | Power is generated by expanding high pressure steam down to process conditions.  
Where condensing facilities are included these cater for balancing electrical and steam loads and/or meeting off crop power requirements. |
| Mill Drives       | a) Electrical  
b) Steam turbine  
c) Reciprocating steam engines | 1700-3 100 kPa  
315-400 °C  
700-1700 kPa  
Sat-285 °C | Power obtained from main turbo-alternator station.  
Relatively small powers preclude higher steam conditions. Due to high efficiencies, pressure reducing and desuperheating plant required to balance factory load.  
High capital cost of plant and foundations and oil entrainment in steam have tended to make this type of prime mover obsolete. |
| Process           | Evaporators, juice heaters, pans, etc. | Up to 275 kPa abs  
saturated | Since the heat transfer coefficient of saturated steam is about 10 times higher than that of superheated steam, superheated conditions should be avoided. Pressure is limited by deleterious effect which high temperatures have on juice. |
if pan cycles coincide, load fluctuations are compounded, whilst if they are evenly phased over the working day fluctuations are minimised.

The type of pan installed also has a bearing on the magnitude of the load swing. The steam demand of a coil pan is apparently steadier and less than that of a calandria pan. Wright and McDougall\textsuperscript{22} have shown, however, that with adequate instrumentation the quantity of "movement" water used in a calandria pan can be substantially reduced with consequent savings in steam and hence fuel consumption. In addition, steam demand is also steadier.

In the simplified 3 massecuite system upon which Fig. 1 is based, starting or striking a pan will impose a maximum load fluctuation of about 10% on the boiler station. In practice multiple pans are used (South African factories have on average 7 pans) which significantly reduce this load change so that even with the fluctuations due to changes in power demand, the overall change is still small: being of the order of ±5% at worst. Fig. 2 shows a steam flow chart taken from a modern factory served by a single boiler which illustrates this point. McGinn's\textsuperscript{16} figures also confirm this point.

The significant load swings frequently apparent in a multiple boiler station are in fact normally due to load swings between boilers caused by inadequate feedwater regulation or erratic firing conditions, rather than by factory load swings. The chart shown in Fig. 3 illustrates an exaggerated example of inter boiler load swing due to inadequate feedwater control. The station from which this chart was taken comprised three 45 th\textsuperscript{-1} capacity boilers supplied with water from a single common main served by two 155 th\textsuperscript{-1} capacity centrifugal feed pumps, only one of which was in operation at any one time.
TABLE 2. Approximate cane sugar factory energy balance. (For Basic Data refer Fig. 1.)

<table>
<thead>
<tr>
<th>Item</th>
<th>Energy balance based on total energy available to factory</th>
<th>Steam distribution in factory during steady crushing conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Without vapour bleeding</td>
<td>With vapour bleeding</td>
</tr>
<tr>
<td>1) Surplus Bagasse</td>
<td>6,6</td>
<td>29,5</td>
</tr>
<tr>
<td>2) Factory Power</td>
<td>6,2</td>
<td>6,2</td>
</tr>
<tr>
<td>3) Primary and Secondary Juice Heaters</td>
<td>18,4</td>
<td>11,1</td>
</tr>
<tr>
<td>4) Evaporator plus Tertiary Juice Heater</td>
<td>32,1</td>
<td>31,4</td>
</tr>
<tr>
<td>5) Pan station</td>
<td>18,8</td>
<td>14,6</td>
</tr>
<tr>
<td>6) Factory radiation and unaccounted losses</td>
<td>7,1</td>
<td>7,1</td>
</tr>
<tr>
<td>7) Start up, shutdown and time efficiency losses</td>
<td>10,8</td>
<td>9,1</td>
</tr>
<tr>
<td></td>
<td>100,0%</td>
<td>100,0%</td>
</tr>
</tbody>
</table>

Note: If all bagasse consumed and all low pressure factory steam requirements met by reducing through back pressure alternator sets, approximate export power available per 1 000 kg cane milled per hour = 39,80 kW without vapour bleeding and 46,25 kW with vapour bleeding.
FIGURE 2. Total steam flow/pressure chart, Sucoma, Malawi. This chart illustrates the total load characteristic normally imposed on boiler plant in the cane sugar industry. A single 30 th⁻¹ boiler served this factory at the time. The unit was fitted with self-feeding furnaces, single element proportional control feedwater regulator and master steam pressure controller with reset action coupled to the forced draught damper. While furnace pressure controls were fitted these were not operating on the day that this chart was recorded.

FIGURE 3. Steam flow chart no. 2 boiler, Jaagbaan, Natal. This chart illustrates load swing from no. 2 boiler to no. 3 boiler (no. 1 boiler not in operation) prior to the single element proportional control feedwater regulator being properly commissioned. Note: Load swing can also be induced by erratic firing conditions but this is not usually as severe as that illustrated above.

The boilers were fitted with single element proportional control feedwater regulators. The chart shown in Fig. 4 illustrates how this load swing was minimised by proper adjustment of the feedwater regulators. Even more stable conditions could have been achieved by controlling the pressure in the common feed line as well in order to improve feedwater control valve characteristics. Fig. 16 clearly illustrates the effect of feed pump characteristics on control valve operation.

During transient conditions, such as start up, shut down and when shortages of cane or bagasse occur, large changes in steam demand and load carrying capacity can occur. While these conditions are normal in a cane
sugar factory, there is no need to sophisticate control circuits to accurately follow them provided that plant operation is safe at all times; that is, minimum water level conditions are always maintained and water is not carried over to the turbines.

Off-crop steam demand is usually steady and does not normally present any problem.

**BOILERPLANT CHARACTERISTICS**

Different types of boilers have been developed to meet cane sugar factory requirements. Typical designs are illustrated in Figs. 5, 6 and 7. Their characteristics are scheduled in Table 3.

The unit illustrated in Fig. 5 is fitted with a hearth-type furnace having self-feeding characteristics. The unit has a large thermal inertia, contains a substantial amount of "ready to burn" fuel in the furnace and is extremely simple to operate. It is ideally suited to areas where skilled staff are at a premium. The unit must be de-ashed manually once a week.

Timber can be used as an auxiliary fuel in the form of logs measuring up to 150 mm diameter × 800 mm long. These can be fed manually through special doors in the bagasse chutes. Approximately 15 000 kg h⁻¹ of steam can be generated in this way, generating capacity being limited by the difficulty of man-handling sufficient fuel continuously into the furnace.

The units illustrated in Figs. 6 and 7 are fitted with suspension-firing equipment. The unit shown in Fig. 6 is fitted with a dump grate stoker and can be fired with oil and gas as auxiliary fuels. Coal can also be fired in this unit to generate up to 40% full load. The unit shown in Fig. 7 is fitted with a continuous ash discharge stoker and can be fired with coal, oil and gas as auxiliary fuels. Both units are highly susceptible to interruptions in bagasse supply and must be operated in conjunction with reliable mechanised reclaim systems. Both units can be de-ashed while in operation.
FIGURE 5. General arrangement of 2 drum bagasse and oil-fired water tube boiler fitted with hearth-type self-feeding furnaces.

When changing over from coal to bagasse-firing care must be taken not to smother the fuel bed with bagasse as this can lead to water gas generation with its consequent problems. Generally, if the change over is carefully controlled no load need be shed, conversely, when changing over from bagasse to coal load must be shed to enable ignition and a satisfactory fuel bed to be established. If the coal supply can be introduced 30 seconds before the bagasse supply fails, load will initially fall to about 30% MCR. This can then be increased to 100% MCR within 5-8 minutes.

On oil and gas no major change-over problems are likely to occur provided adequate purge and light up cycles are included in the control circuits.

All 3 units incorporate certain features which were developed specifically to meet cane sugar factory conditions. Where they apply these are:

a) Long Divergent Bagasse Feed Chutes

Bagasse is difficult, if not impossible to store in a bin. For it to flow satisfactorily it must be allowed to expand continuously along its path. This precludes storing an adequate fuel reserve where it is most required, that is, in a position where it can be fed directly to the boiler. For any control system to function satisfactorily, however, sufficient bagasse must always be available to respond to changes in load demand and the handling system must therefore cater for this requirement.

The amount of bagasse which can be transferred from a carrier to a feed chute is limited by the size of the feed chute opening. This in turn is dictated by the length of chute, the required divergency angle and the size of the opening into the feeder. These parameters must be fixed to give at least 30 seconds storage for satisfactory control results to be obtained.
FIGURE 6. General arrangement of 2 drum bagasse and oil-fired water tube boiler fitted with suspension firing equipment, dump grate stoker and mechanical grit collector.
### TABLE 3. Boiler plant comparative characteristics.

<table>
<thead>
<tr>
<th>Item</th>
<th>Characteristic</th>
<th>Hearth type</th>
<th>Suspension firing with dump grate stoker</th>
<th>Suspension firing with CAD stoker</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1)</td>
<td>Relative cost of 50 t/h unit with no auxiliary fuel firing equipment</td>
<td>1,00</td>
<td>1,05</td>
<td>1,22</td>
<td>Allows 6 m and 2 m clearance at front and rear of boiler respectively. Allows 2 m clearance around sides of boiler.</td>
</tr>
<tr>
<td>2)</td>
<td>Floor area occupied by boiler (assumes 1D fan and gas cleaning equipment outside building m²)</td>
<td>336</td>
<td>262</td>
<td>270</td>
<td></td>
</tr>
<tr>
<td>3)</td>
<td>Height of building required to eaves level (m).</td>
<td>12.25</td>
<td>19</td>
<td>19</td>
<td></td>
</tr>
<tr>
<td>4)</td>
<td>Relative building cost (assumed proportional to building volume).</td>
<td>1.00</td>
<td>1.21</td>
<td>1.25</td>
<td></td>
</tr>
<tr>
<td>5)</td>
<td>Approximate installed power without gas cleaning equipment (kW)</td>
<td>130</td>
<td>230</td>
<td>230</td>
<td></td>
</tr>
<tr>
<td>6)</td>
<td>Approximate installed power with gas cleaning equipment (kW)</td>
<td>170</td>
<td>270</td>
<td>270</td>
<td></td>
</tr>
<tr>
<td>7)</td>
<td>Approximate power consumption at MCR on bagasse without gas cleaning equipment (kW)</td>
<td>100</td>
<td>173</td>
<td>173</td>
<td></td>
</tr>
<tr>
<td>8)</td>
<td>Approximate power consumption at MCR on bagasse with gas cleaning equipment (kW)</td>
<td>137</td>
<td>218</td>
<td>218</td>
<td></td>
</tr>
<tr>
<td>9)</td>
<td>Possible auxiliary fuels</td>
<td>Oil, gas and wood (limited to 15 t/h on wood)</td>
<td>Oil, gas and coal (limited to 40% MCR on coal)</td>
<td>Coal, oil and gas (limited to 80% MCR on coal)</td>
<td>If bagasse is fired simultaneously with other fuels severe slagging problems can be encountered.</td>
</tr>
<tr>
<td>10)</td>
<td>Furnace</td>
<td>Large mass of “ready to burn” bagasse stored in furnace.</td>
<td>No thermal storage on bagasse, reasonable on coal.</td>
<td>Fully water-cooled combustion chamber requires very little maintenance.</td>
<td>Suspension fired units should preferably be fitted with clinker chills at grate level.</td>
</tr>
</tbody>
</table>
TABLE 3.—continued.

<table>
<thead>
<tr>
<th>Item</th>
<th>Characteristic</th>
<th>Hearth type</th>
<th>Suspension firing with dump grate stoker</th>
<th>Suspension firing with CAD stoker</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>3)</td>
<td></td>
<td>Self-feeding furnace</td>
<td>Insensitive to bagasse preparation. Turbulent furnace conditions.</td>
<td>Insensitive to bagasse preparation. Turbulent furnace conditions.</td>
<td>Coarse bagasse contains less than 40% minus 10 mm particles. Fine bagasse contains more than 55% minus 10 mm particles.</td>
</tr>
<tr>
<td>4)</td>
<td></td>
<td>Medium pressure secondary air required (1 500 Pa)</td>
<td>High pressure secondary air required (3 000-5 000 Pa)</td>
<td>High pressure secondary air required (3 000-5 000 Pa)</td>
<td>Pendant superheaters can also be fitted. Gas velocities must be limited to less than 15 m/s to avoid tube erosion with mechanically harvested or loaded cane. An airheater is preferred to an economiser as it stabilises combustion as well as improving efficiency. An economiser is required to achieve lower exhaust gas temperatures. Contra-flow airheaters without some form of protection not recommended due to inherent corrosion problems.</td>
</tr>
<tr>
<td>11)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12)</td>
<td></td>
<td>Furnace must be cleaned manually once a week</td>
<td>Crossflow drainable in separate pass. Vertical tube cross baffled.</td>
<td>Crossflow drainable in separate pass. Vertical tube cross baffled.</td>
<td></td>
</tr>
<tr>
<td>13)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15)</td>
<td></td>
<td>215 C-250 C</td>
<td>215 C-250 C</td>
<td>215 C-250 C</td>
<td></td>
</tr>
<tr>
<td>Item</td>
<td>Characteristic</td>
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<td>Remarks</td>
</tr>
<tr>
<td>------</td>
<td>----------------</td>
<td>-------------</td>
<td>----------------------------------------</td>
<td>----------------------------------</td>
<td>---------</td>
</tr>
<tr>
<td>16)</td>
<td>Factors limiting exhaust gas temperature</td>
<td>Expensive economiser required for small gain in efficiency. Dependant on local conditions.</td>
<td>Expensive economiser required for small gain in efficiency. Dependant on local conditions.</td>
<td>Expensive economiser required for small gain in efficiency. Dependant on local conditions.</td>
<td>Bigger fuel economies can be achieved by better utilization of steam on the factory side.</td>
</tr>
<tr>
<td>17)</td>
<td>Exhaust gas cleaning equipment</td>
<td>Due to self-feeding properties of furnace auto controls simplified. Only air flow and furnace pressure regulation required.</td>
<td>Fuel feed, air flow and furnace pressure regulation required.</td>
<td>Fuel feed, air flow and furnace pressure regulation required.</td>
<td></td>
</tr>
<tr>
<td>18)</td>
<td>Automatic Control</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19)</td>
<td>Ratio mass of water in boiler at normal working level to MCR evaporation.</td>
<td>0,72</td>
<td>0,57</td>
<td>0,58</td>
<td></td>
</tr>
</tbody>
</table>
Recommended dimensions are shown in Fig. 6 with a recommended design of carrier gate. Note that the chute is not fixed at both ends but is allowed to expand freely at its upper end. This feature prevents damage to the chute, feeder and carrier system in the event of a fire in the chute. Note also that 50 mm diameter holes are cut into the sides of the chute to enable the level of bagasse to be observed. These holes need not be covered with a transparent material as the matting properties of bagasse prevents spillage through them.

In addition to the above parameters a factor termed the "instability volume" affects the size of chutes fitted to boilers having self-feeding furnaces. Unless the volume of bagasse in the chute is larger than the "instability volume" the furnace will not operate satisfactorily and severe cyclic fluctuations in performance will occur. A lack of appreciation of the significance of this factor was at the bottom of most of the problems encountered with older furnaces of this type developed in the West Indies in the late 1940's and in India in the 1950's.

b) Bagasse Feeders

For a bagasse feeder to operate satisfactorily the diverging chute concept must be carried through into its design. The method of application of this concept is shown in Fig. 7. The feeder drum is mounted eccentrically in the casing to provide a diverging passage. The rate of bagasse feed is regulated by varying the speed of the drum.

Unfortunately this device, while being very simple in concept, meters bagasse volume and not heat input \( M_b \times C_b \). The discrepancies due to density changes are not significant. More important are the discrepancies due to varying moisture content which has a marked effect on calorific value. This manifests itself as either a fall off in efficiency due to too lean a mixture of fuel and air, or a build-up of bagasse on the grate due to too rich a mixture. Fortunately, by means of a simple fuel/air ratio trimming device which can be incorporated in the control panel the operator can take care of this problem. Automating fuel/air trimming by measuring excess air is not recommended unless adequate maintenance facilities and staff are available to check the accuracy of the instrument daily. Gas sample probes are notoriously susceptible to failure on bagasse fired boilers.

The metering performance of the feeder shown in Fig. 7 should be linear with drum speed. Controller position can then be arranged to match this characteristic which simplifies setting up the auto controls.

c) Bagasse Distributors

From the analysis given in Table 4 it is obvious that bagasse is essentially a gaseous fuel, i.e. 50% water plus 37% volatiles. On suspension-fired boilers therefore it is best introduced as such into the furnace, that is with some of the combustion air supply. A typical pneumatic distributor is shown in Fig. 7 and it is made of 316 stainless steel. It is aircooled and has a deflector plate built into it to enable bagasse distribution in the furnace to be adjusted while the unit is in operation to cater for different fuel gradings. Normally, once a unit is commissioned in a particular factory, there is no need to alter the setting unless bagasse characteristics change radically.
d) Combustion Chambers

The moisture content of the bagasse fed to a boiler plays a significant role in the performance of the combustion chamber. In addition, in the case of boilers fitted with self-feeding furnaces, bagasse preparation has a marked effect on performance. While it is very difficult to quantify the effect of moisture content on excess air requirements, an approximate relationship, constructed from observations carried out over the last 10 years in South Africa, Australia and India, has been developed and is indicated in Fig. 8. Also shown in Fig. 8 is the effect which moisture content has on calorific value and the effect which both these factors have on overall boiler efficiency and fan power consumption.

For self-feeding furnaces to operate successfully combustion within the fuel bed must take place essentially under quiescent conditions. As with cane diffusers the permeability of bagasse, that is its ability to allow a fluid to pass...
through it, in this case air, is affected by preparation. The relationship between preparation and extraction power input and grading is even more complicated than the moisture content/excess air relationship. Here again, however, empirical data is available which enables performance to be predicted with reasonable confidence. Fundamental research is at present being carried out on this subject and it is hoped that in the near future additional basic data will become available.

The method of introducing primary and secondary air into the furnace plays an important role in the performance of boilerplant. For secondary air to penetrate the flame envelope it must be introduced at high pressure (2 500 to 5 000 Pa) through properly designed nozzles.

The position at which secondary air is introduced is also important as bagasse burns with a relatively short flame. The secondary air must therefore be introduced low down in the furnace at a position well within the flame zone. Small quantities of high pressure air introduced at between a third and half the height of the furnace will help reduce char carry-over by increasing bagasse particle residence time in the furnace. Fig. 20 indicates the effect which secondary air has on char carry-over.

Primary air should be introduced evenly over the full plan area of the furnace. As is explained later, it should preferably be heated. There is no need, however, to heat the secondary air as sufficient turbulence can be generated in the furnace with cold air. The extra fan power required to introduce hot secondary air is, therefore, not warranted.

Furnace geometry is dictated by:

i) The plan area of the furnace required to allow stable combustion to take place. In the case of self-feeding furnaces this is dictated by the permeability of the bagasse bed whilst in the case of suspension firing it is dictated by the ability of the furnace to burn the fuel without heaps forming on the grate. In both cases bagasse moisture content plays a significant role; the higher the moisture content the greater the plan area required. For example 17% more grate area is required to burn 52% moisture bagasse in suspension than is required to burn 48% moisture bagasse.

ii) The ability of the equipment to distribute the bagasse evenly over the full plan area of the furnace.

iii) The heating surface and volume required to reduce the gas temperature leaving the furnace to well below the ash deformation temperature and to contain the flame envelope. Furnace gas leaving temperatures of about 1 000 to 1 050 °C are preferred.

iv) By any special requirements imposed by the auxiliary fuel.

For suspension firing it is preferable to have some sort of clinker chill arrangement at grate level to avoid slag interfering with the operation of the grate and for coal firing this is vital. It is also advisable to eliminate protrusions in the furnace upon which ash can accumulate.

When burning a mixture of coal and bagasse there is a tendency for the coal ash deformation temperature to be suppressed. This condition manifests itself as a toffee-like substance forming on the grate and interfering with its operation. The mechanism causing this phenomenon is not yet understood but it is apparently related to the content of sucrose and other trace elements in
the bagasse. It appears that the higher the sucrose content the more likely it is that slag will occur. Dump grate stokers are particularly susceptible to this problem; hence one of the limits imposed on their rating on coal. Continuous ash discharge stokers are not as seriously affected but must nevertheless sometimes be derated if the problem is severe.

![Figure 9](image)

**FIGURE 9.** Graph showing effect of hot combustion air and moisture content of bagasse on combustion reaction temperature.

e) Superheater

Start up and shutdown occurs more frequently on bagasse-fired boilers than on utility boilers. Drainable superheaters which do not suffer from condensate locking are preferred, especially for steam temperatures in excess of 315 °C. In addition, for the higher temperatures preference is for crossflow superheaters, where the steam is made to pass across the width of the boiler, thus preventing uneven heating.

Irrespective of type, the superheater should be placed in a separate pass which is screened from direct combustion chamber radiation. No hoppers in which char can collect should be incorporated in this pass as fires can occur in them which can lead to gross overheating of tubing. No baffles or ledges should be incorporated upon which dust can accumulate as these very quickly lead to the pass choking. To avoid tube erosion gas velocities should be limited to 15 m/s.

Heating surfaces should be proportioned so that turbine stop valve conditions can be obtained at 80% MCR on bagasse. Tubes should be pitched to enable a flat characteristic over the range 50%-100% MCR to be obtained.¹³

The steam temperature when burning coal or oil will be lower than when burning bagasse. Rather than building steam temperature control circuits into the system, turbines should be chosen which can accommodate this difference which amounts to about 20-30 °C. At temperatures in excess of 430 °C control is warranted. Below this temperature, even though not strictly necessary the high temperature section should be made of chrome/molybdenum alloy tubes. Temperature controlled automatically operated drain valves should be installed on the more highly rated superheaters to ensure that steam temperatures do not rise above pre-set limits when load is changed suddenly.

f) Convection Surfaces

Vertical tube crossflow passes remain clean without sootblowing. Dust build-up on 15° baffles is minimal and does not affect performance. Gas velocities in this zone should be limited to 15 m/s to avoid tube erosion. At
these low gas velocities the pressure drop across the passes is low and leakage across baffles is therefore low and no local erosion problems should be experienced provided that the baffles are well placed and are at least 75 mm thick.

g) Heat Recovery Equipment

The extent of heat recovery equipment installed depends upon local mill conditions. In high fibre areas where only raw sugar is produced and there is no outside load, no heat recovery equipment is required. Where heat recovery equipment is required, only either an air heater or an economiser need be installed, provided that adequate convection heating surface is built into the boiler itself.

Air heaters are preferred to economisers as not only do they recover heat from the exhaust gases but they also assist the combustion process by elevating the combustion temperature. The magnitude of this effect is illustrated in Fig. 9. Whether economisers or air heaters are installed, extended heating surfaces should be avoided as these are susceptible to chokage due to char and dust accumulating between the fins. To avoid corrosion minimum metal temperatures at 80% load should not be less than 125°C when firing bagasse only. When firing auxiliary fuels having a high sulphur content the metal temperature must be higher than this and should be fixed in relation to the magnitude of the sulphur content. For example, with fuels containing 3% sulphur, metal temperatures should exceed 143°C.

h) Circulation

Natural circulation boilers perform perfectly adequately under cane sugar factory conditions.

To ensure rapid circulation and minimum scale formation, tubes should be placed vertically whenever possible. At least one of the combustion chamber circuits should be fed from the lower drum to ensure even heating of the unit on light-up and hence rapid steamraising characteristics.

i) Draught Plant

Of the 3 fans normally fitted to bagasse-fired boilers the induced draught fan is the largest and requires the most maintenance. It handles a dust laden gas which can also be corrosive if the fan follows a wet scrubber or if a high sulphur content auxiliary fuel is burnt.

To minimise the effect of erosion, replaceable liners are sometimes fitted. Hard surfacing techniques are also employed. As wet gas scrubbers have only recently been introduced it is too early yet to establish the long-term effect of the corrosiveness of the exhaust gases from these units. Preliminary indications are that a low carbon steel might very well be suitable without any special pre-treatment. Low carbon steels containing copper, chrome and nickel alloys such as Corten, which do not require any special welding or fabricating techniques should almost certainly be suitable. Stress corrosion problems have been encountered in fans fabricated from 316 stainless steel and where high sulphur content auxiliary fuels are used positive precautions against corrosion must be taken.

The induced draught fan is the first major item of plant to be started in a factory after the weekend shutdown. If no connection to the local grid is available the factory’s own auxiliary power source has to be used. To minimise
the starting load and hence the size of the auxiliary power unit, the fan can be driven through a fluid coupling, which can also serve to regulate its speed and hence its output. The fan can also be turbine driven, in which case the boiler must be lit up on natural draught and the fan then started as soon as sufficient pressure is available to turn it. Turbine driven fans can also be speed regulated. Turbines should be sized to generate full power when operating at 80% of their design pressure rating to ensure quick boiler recovery response from a low pressure condition. If steam economy is important the extra nozzles required to meet this condition can be manually operated when the need arises.

The high inertia characteristics of the induced draught fan makes response to speed control sluggish. If the induced draught fan is used to control furnace pressure puffing can occur which makes for messy boilerhouse conditions. Damper-controlled fixed speed fans follow furnace pressure fluctuations more rapidly and this method of control is preferred if it can be accommodated within the overall factory parameters. Unfortunately fixed speed operation leads to maximum impeller erosion and power consumption, so these two factors must be weighed against ease of control. The best of both worlds can sometimes be obtained by controlling boiler pressure with a variable speed induced draught fan and furnace draught with a damper controlled fixed speed forced draught fan. In this case the forced draught fan is still linked to the fuel feeders through a proportioning relay to control the air/fuel ratio.

The forced draught fan is a simple low head unit the design of which does not present any special problems. The secondary air fan is a high head unit which unless carefully designed can be noisy.

Where damper controls are used on the induced draught and forced draught fans contra rotating dampers should be employed to improve controlability. Fig. 10 illustrates the characteristics of these dampers compared to conventional parallel rotating dampers.

The response rate of a boiler to load change when operating near its maximum capacity depends upon the surplus fan power or “design margin” available. If the fans have been sized to cater for exactly MCR conditions

![Figure 10](image-url)
response will be sluggish. If, on the other hand, a reasonable fan design margin has been incorporated, response to load change will be more rapid. The effect of the magnitude of the design margin on response rate is shown in Fig. 11. The ID fan margin should always be slightly greater than the FD fan margin to ensure that the gases generated in the furnace under most conditions can be removed without the furnace being pressurised. No SA fan margin is required.

**FIGURE 11.** Effect of fan design margin on pressure recovery rate of a typical boiler operating at full load and having a working pressure of 3 000 kPa.

**FEED WATER SYSTEM**

There are 3 sources of uncontaminated boiler feed water in a cane sugar factory:

a) First evaporator effect condensate,

b) Turbo alternator condenser condensate, and

c) Softened or demineralised water make-up.

In a factory where all the exhaust is fed from turbine drives and a pressure reducing station to the evaporator the boiler feed water will consist mostly of condensate return with only about 5% make-up being required.

While second effect condensate is also usually uncontaminated it can on occasion be “sweet” if sugar is carried over from the first effect. Unfortunately it is very difficult to continuously monitor its quality as sucrose is not readily detected by conventional conductivity meters. Batch collecting and chemical testing second effect condensate before returning it to the boiler feed system can be employed to save using softened or demineralised make-up. This is a tedious procedure and does not always guarantee sufficient water being made available to the boilers. In factories where a surplus of bagasse is available first or second vapour can be used instead to produce distilled water in an auxiliary feed water evaporator thus ensuring 100% pure condensate return.

Second effect condensate flash can also be condensed for return to the hotwell as boiler feed. This circuit must of course be kept separate from second vapour as this can be “sweet”.
### Table 4. Typical chemical and physical properties of major fuels used in the cane sugar industry and their effect on plant performance.

<table>
<thead>
<tr>
<th>Property</th>
<th>Bagasse From Mill</th>
<th>Oil Medium/heavy</th>
<th>Wood Logs or chips</th>
<th>Coal Bituminous</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Chemical Properties</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1) Proximate analysis “as fired”</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fixed carbon %</td>
<td>11.5</td>
<td>—</td>
<td>16.7</td>
<td>56.1</td>
<td>Note similarity between bagasse and wood, also their high volatile and moisture content in relation to their solids contents.</td>
</tr>
<tr>
<td>Volatiles %</td>
<td>37.0</td>
<td>99.5</td>
<td>43.0</td>
<td>25.0</td>
<td></td>
</tr>
<tr>
<td>Moisture %</td>
<td>50.0</td>
<td>0.4</td>
<td>40.0</td>
<td>4.0</td>
<td></td>
</tr>
<tr>
<td>Ash %</td>
<td>1.5</td>
<td>0.1</td>
<td>0.3</td>
<td>14.9</td>
<td></td>
</tr>
<tr>
<td>2) Ultimate analysis “as fired”</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon %</td>
<td>22.5</td>
<td>85.6</td>
<td>30.2</td>
<td>65.8</td>
<td>Fibrous fuels while differing radically in physical properties have very similar chemical characteristics on a “dry basis”.</td>
</tr>
<tr>
<td>Hydrogen %</td>
<td>3.0</td>
<td>10.9</td>
<td>3.7</td>
<td>5.6</td>
<td></td>
</tr>
<tr>
<td>Sulphur %</td>
<td>—</td>
<td>2.8</td>
<td>—</td>
<td>1.4</td>
<td></td>
</tr>
<tr>
<td>Nitrogen %</td>
<td>—</td>
<td>0.2</td>
<td>—</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>Oxygen %</td>
<td>23.0</td>
<td>—</td>
<td>25.8</td>
<td>5.1</td>
<td></td>
</tr>
<tr>
<td>Water %</td>
<td>50.0</td>
<td>0.4</td>
<td>40.0</td>
<td>7.4</td>
<td></td>
</tr>
<tr>
<td>Ash %</td>
<td>1.5</td>
<td>0.1</td>
<td>0.3</td>
<td>14.9</td>
<td></td>
</tr>
<tr>
<td>3) Gross Calorific Value (kJ kg⁻¹)</td>
<td>9 540</td>
<td>43 800</td>
<td>11 670</td>
<td>26 880</td>
<td>Calorific value of bagasse calculated from Pritzlewitz van der Horst formulae: GCV = 19 050 — 41.9Bₐ — 188.4Bₐm; NCV = 17 800 — 41.9Bₐ — 201.3 Bₐm; NCV of other fuels calculated by deducting [(mass total moisture + mass moisture due to oxidation of hydrogen in fuel) x 2 453.1] kJ kg⁻¹ from GCV.</td>
</tr>
<tr>
<td>4) Nett Calorific Value (kJ kg⁻¹)</td>
<td>7 650</td>
<td>41 383</td>
<td>9 871</td>
<td>25 903</td>
<td></td>
</tr>
<tr>
<td>5) Mass air required to achieve Stoichometric combustion per 10 000 kJ (kg)</td>
<td>2 718</td>
<td>3 137</td>
<td>3 059</td>
<td>3 091</td>
<td></td>
</tr>
<tr>
<td>6) CO₂ in flue gas as measured by ORSAT under Stoichometric conditions (%)</td>
<td>20.64</td>
<td>15.91</td>
<td>20.12</td>
<td>18.63</td>
<td></td>
</tr>
<tr>
<td>7) Practical excess air requirements to complete combustion (%)</td>
<td>22</td>
<td>20</td>
<td>15</td>
<td>35</td>
<td></td>
</tr>
</tbody>
</table>
**TABLE 4.—continued.**

<table>
<thead>
<tr>
<th>Property</th>
<th>Bagasse</th>
<th>Oil</th>
<th>Wood</th>
<th>Coal</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>8) Corresponding CO₂ in flue gases as measured by ORSAT (%)</td>
<td>From Mill 16.92</td>
<td>Medium/heavy 13.26</td>
<td>Logs or chips 17.49</td>
<td>Bituminous 13.80</td>
<td></td>
</tr>
<tr>
<td>9) % moisture by mass in flue gases at above CO₂</td>
<td>19.55</td>
<td>6.88</td>
<td>15.41</td>
<td>4.51</td>
<td>Based on 60% humidity at 27°C when air contains 0.0132 kg water per kg air.</td>
</tr>
</tbody>
</table>

**Physical Properties**

1) Bulk density (kg m⁻³)

- **Range**: 110-190
- **Average**: 145

2) Heating value per unit volume (kJ m⁻³)

- **1.38 × 10⁶**

3) Ratio of bagasse burnt to auxiliary fuel burnt to produce same mass of steam

| a) by mass | 1 | 5.76 | 1.30 | 3.53 |
| b) by volume | 1 | 38.14 | 1.80 | 17.68 |

**Boiler Characteristics**

1) Practical output limitations with various boiler designs, (% MCR on bagasse)

| a) Self-feeding furnace — see Fig. 6 | 100% | (1) 60-100% | (2) 15% b⁻¹ | Nil |
| b) Pneumatic firing with dump grate stoker — see Fig. 7 | 100% | 100% | (3) 100% | (4) 33-55% |
| c) Pneumatic firing with CAD stoker — see Fig. 8 | 100% | 100% | 100% | (4) 60-100% |

1) Output on oil limited by furnace configuration which in turn is a function of boiler capacity.
2) Output limited by ability to feed logs manually into furnace.
3) With hogged wood belt type feeder must be used in place of rotary drum feeder.
4) Depends upon coal characteristics (in particular ash content and fusion temperature) grate rating chosen for bagasse which in turn is a function of bagasse moisture content.
<table>
<thead>
<tr>
<th>Property</th>
<th>Bagasse</th>
<th>Oil</th>
<th>Wood</th>
<th>Coal</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>From Mill</td>
<td>Medium/heavy</td>
<td>Logs or chips</td>
<td>Bituminous</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2) Comparative performance of typical 50 th\(^{-1}\) boiler fitted with CAD stoker when fired with fuels specified and at the excess air ratios scheduled above.

a) Working pressure (kPa)
   - Bagasse: 3000
   - Oil: 3000
   - Wood: 3000
   - Coal: 3000
   - Remarks: Assuming 50th\(^{-1}\) can be obtained on all fuels with final steam conditions of 3000 kPa and steam temperature as indicated below from feedwater at 105 C.

b) Final steam temperature (C)
   - Bagasse: 400
   - Oil: 370
   - Wood: 400
   - Coal: 400
   - Remarks: 

   i. Heat load ratio per kg steam generated.
   - Bagasse: 1.00
   - Oil: 0.975
   - Wood: 1.004
   - Coal: 0.983

   ii. Final gas temperature (C)
   - Bagasse: 250
   - Oil: (5)303
   - Wood: 249
   - Coal: 225

   iii. Efficiency
   i) unburnt carbon in ashes grits and stack discharge (%)
      - Bagasse: 1.50
      - Oil: 0.25
      - Wood: 2.00
      - Coal: 4.50
   ii) dry gas loss (%)
       - Bagasse: 8.24
       - Oil: 10.79
       - Wood: 8.73
       - Coal: 8.91
   iii) Wet gas loss (%)
       - Bagasse: 23.81
       - Oil: 6.86
       - Wood: 18.33
       - Coal: 4.30

   iv. Fan power consumption without grit collector (kW)
      - Bagasse: 168
      - Oil: 134
      - Wood: 166
      - Coal: 160
   v. Fan power consumption with medium efficiency grit collector (kW)
      - Bagasse: 213
      - Oil: 160
      - Wood: 196
      - Coal: 190
   vi. Fan power consumption with high efficiency grit collector (kW)
      - Bagasse: 146
      - Oil: 72
      - Wood: 121
      - Coal: 81

   v) Assumes air heater bypassed to minimise corrosion.
   Based on damper controlled fans.
   Based on speed controlled I.D. Fan.
   Based on damper controlled fans.
   Based on speed controlled I.D. Fan.

With the introduction of more stringent air pollution regulations greater attention is being paid to measuring these losses on bagasse-fired boilers. These measurements confirm that losses vary widely from one installation to the next. Figures range of 1.1% low through 1.9% average to 3.6% high.

\[
GCV = \frac{M_d \times C_p \times (T_f - T_a) \times 100}{GCV}
\]

\[
M_w \times (h_1 - h_2) \times 100
\]

From:

\[
GCV
\]
<table>
<thead>
<tr>
<th>Remarks</th>
<th>Coal</th>
<th>Wood</th>
<th>Oil</th>
<th>Grease</th>
</tr>
</thead>
<tbody>
<tr>
<td>TABLE 4—continued</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Boiler water quality and feedwater quality limits are scheduled in Tables 5 and 6. Deaerators are sometimes used in conjunction with boilers operating at pressures in excess of 2,000 kPa. At these pressures the saving in oxygen scavenging chemicals and reduced blowdown losses to maintain the TDS within required limits can warrant the extra capital outlay.

**TABLE 5.** Boiler water analytical control limits (ppm) applicable to watertube boilers in the sugar industry. (Phosphate residual conditioning.)

<table>
<thead>
<tr>
<th>Item</th>
<th>Working Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Up to 1,500 kPa</td>
</tr>
<tr>
<td>Total dissolved solids</td>
<td>3,000 max</td>
</tr>
<tr>
<td>Suspended solids</td>
<td>300 max</td>
</tr>
<tr>
<td>Hydroxide alkalinity (as CaCO₃)</td>
<td>Min 100</td>
</tr>
<tr>
<td>Preferably</td>
<td>Preferably</td>
</tr>
<tr>
<td>10% of TDS</td>
<td>10% of TDS</td>
</tr>
<tr>
<td>Soluble Silica (as SiO₂)</td>
<td>150 Max but</td>
</tr>
<tr>
<td>Preferably</td>
<td>Preferably</td>
</tr>
<tr>
<td>Hydroxide</td>
<td>Max less than</td>
</tr>
<tr>
<td>alkalinity</td>
<td>hydroxide alkalinity</td>
</tr>
<tr>
<td>Soluble Silica (as SiO₂)</td>
<td>40–80</td>
</tr>
<tr>
<td>Phosphate (as PO₄³⁻)</td>
<td>20–70</td>
</tr>
<tr>
<td>Sulphite (as Na₂SO₃)</td>
<td>Nil</td>
</tr>
<tr>
<td>Hardness (as CaCO₃)</td>
<td>Nil</td>
</tr>
<tr>
<td>Oil</td>
<td>Nil</td>
</tr>
<tr>
<td>Sugar</td>
<td>Nil</td>
</tr>
<tr>
<td>Oxygen plus carbon dioxide</td>
<td>0.03 ppm max</td>
</tr>
<tr>
<td>TDS</td>
<td>To suit blowdown economics</td>
</tr>
<tr>
<td>Silica</td>
<td>To suit blowdown economics</td>
</tr>
</tbody>
</table>

**TABLE 6.** Boiler feed-water analytical control limits.

<table>
<thead>
<tr>
<th>Item</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>8.5</td>
</tr>
<tr>
<td>Hardness</td>
<td>Nil</td>
</tr>
<tr>
<td>Organic suspended matter</td>
<td>Nil</td>
</tr>
<tr>
<td>Oil</td>
<td>Nil</td>
</tr>
<tr>
<td>Sugar</td>
<td>Nil</td>
</tr>
<tr>
<td>Oxygen plus carbon dioxide</td>
<td>0.03 ppm max</td>
</tr>
<tr>
<td>TDS</td>
<td>To suit blowdown economics</td>
</tr>
<tr>
<td>Silica</td>
<td>To suit blowdown economics</td>
</tr>
</tbody>
</table>

Fig. 12 gives a graphical representation of the percentage blowdown required to maintain a given TDS limit in a boiler for a given feedwater TDS concentration.

Typical preboiler feed systems are shown in Figs. 13, 14 and 15, the system shown in Fig. 15 having particular merit for well integrated factories.

In an earlier section of this paper it was pointed out that for boiler operation to be stable the boiler water level control system must be carefully designed. Single element controls will function satisfactorily if control valves are correctly sized and given a fair chance of working by ensuring that upstream feedline pressure is reasonably constant. Fig. 16 illustrates the effect of feed pump characteristics on valve operation.

Water level fluctuations cannot be avoided during large rapid load swings. They are caused by changes in specific volume of the water/steam mixture in the boiler. As load increases so the ratio of steam to water increases, thus increasing the volume which the mixture occupies in the boiler. The water
FIGURE 12. Boiler blowdown rate as a function of feedwater dissolved solids concentration.

FIGURE 13. Basic feedwater station for boiler plant operating at up to 2000 kPa.

FIGURE 15. Basic feedwater station for well integrated boiler plant.
FIGURE 16. Effect of feed pump characteristics on operation of feed control valve.

Notes:  i) Valve type A will only work over about \( \frac{2}{3} \) of its full stroke. Reasonable control will be obtained with this arrangement.

ii) Valve type B will only work over about \( \frac{1}{2} \) of its full stroke. This is not acceptable.

iii) If feed line pressure is controlled valve type A will be more suitable than valve type B.

iv) If feed pump is sized to handle 2 or more boilers, problem will be magnified in proportion, e.g. valve type B will only operate over about 16% of its stroke if feed pump is sized for 2 boilers or about 10% of its stroke if feed pump is sized for 3 boilers. Feed line pressure control is essential under these conditions.

level therefore rises. Conversely as load decreases water level falls. These conditions are not serious provided prescribed safe limits are not exceeded. Large volume steam drums or cyclone separators fitted to smaller drums go a long way towards ensuring that safe conditions are maintained at all times. Operating at high TDS limits, that is, above those scheduled in Table 5 coupled with high alkalinity conditions are frequently the major cause of water level instability.

AUTOMATIC BOILER CONTROLS

Factory staff are most profitably employed making sure that the process plant operates efficiently. The boiler plant which provides only a service is of
secondary importance and must therefore be maintenance free and simple to operate and control. As far as factory staff are concerned, boiler plant must provide sufficient steam at constant pressure at all times.

Careful design and integration of the boiler station as a whole into the factory system is essential if these conditions are to be met. In addition plant characteristics must be stable and control circuits and components simple in concept. Controls must operate over their full modulating range.

Boilers fitted with self-feeding furnaces are the simplest to operate. To maintain constant steam pressure only the primary air supply need be regulated. Furnace pressure controls are not essential but improve efficiency and increase turndown performance. Boilers fitted with suspension-firing equipment are more difficult to control as primary air flow and fuel supply must be inter-related and furnace pressure controls are essential. Generally air flow and fuel supply are controlled in response to changes in steam pressure, with control of furnace pressure following, by regulating exhaust gas flow. Furnace puffing, which is a common characteristic of bagasse-fired boilers, can sometimes be reduced at the expense of a small loss in pressure holding characteristics by reversing this mode of control, i.e. by making exhaust gas flow follow steam pressure and air flow and fuel supply follow furnace pressure. This system is particularly useful when variable speed induced draught fans are installed which have a high inertia and hence are slow to respond.

Auto controls need not be designed to ensure that boilers operate at their maximum efficiency. Reasonable pressure holding characteristics and reliability are far more important. With simple controls thermal efficiencies within 2% of maximum can readily be achieved. Much larger changes in overall heat economy can be obtained by installing simple heat recovery equipment on the process side than can be obtained by complicating control circuits to maximise boiler efficiency.

Auxiliary fuels are burnt in bagasse-fired boilers for 3 reasons:

a) To start the plant up at the beginning of the crop and after an extended shutdown during which all surplus bagasse has been consumed.

b) To cater for a shortage of bagasse due to abnormally low fibre conditions, and

c) To meet offcrop loads.

To meet the requirements of (a) and (c) above air/fuel ratio control circuits can be made independent of, or partly integrated into, the main bagasse control circuits. To cater for (b) it is preferable to burn a fixed quantity of auxiliary fuel and to allow the boiler to follow load on bagasse. The quantity of auxiliary fuel being burnt can then be manually regulated to match the reserve of bagasse in the store.

As with control circuits, instrumentation should also be kept as simple as possible. Adequate information to operate and maintain a boiler can be obtained from the following:

a) locally Mounted Instruments

Two absolute water gauges.

One steam drum pressure gauge with inspecting authority’s test gauge connection.

One Superheater outlet pressure gauge.

One portable CO₂ measuring device.
b) *Panel Mounted Instruments*

- One remote water level indicator.
- One feed range pressure gauge.
- One superheater outlet pressure gauge.
- One combined steam flow and pressure recorder.
- One multipoint temperature indicator to measure:
  - Final steam temperature.
  - Feed water temperature.
  - Boiler gas outlet temperature.
  - Final gas temperature.
  - Air heater air outlet temperature.
- One set draught gauges. The number should preferably be restricted to a maximum of 4 to avoid logging meaningless figures.
- One set motor stop/start stations with ammeters.
- One set auto control equipment.

A mimic diagram mounted on the panel indicating the function of each instrument and control is useful to assist operators in taking an intelligent interest in the equipment.

**FUEL HANDLING FACILITIES**

Enormous quantities of bagasse, which is a low density low calorific value fuel, must be conveyed to the boiler station to provide the factory with steam. The volume of bagasse required to generate a given quantity of steam is about 38 times that of oil and 17 times that of coal. Belt or slat conveyors can be used to convey bagasse. Belt conveyors are preferred for all applications apart from feeding the boilers. Slat conveyors are preferred for feeding the boilers as transfer to feed chutes is effected automatically with these machines. Fairly sophisticated transfer equipment must be used when belt conveyors are employed.

Belts operate at speeds of up to 2,3 ms\(^{-1}\) and inclinations of up to 25° from the horizontal. Best results appear to be obtained from belts operating at 1,5 ms\(^{-1}\) and at inclinations of up to 22\(^{1/2}\). Belt widths are related not so much to their conveying capacity as to the need to avoid spillage. A 450 mm wide belt should be able to handle 100 th\(^{-1}\) bagasse, but spillage under these conditions would be excessive. A 1 200 mm wide belt would probably be chosen for the duty instead. As a rough practical guide 6,0 to 8,0 th\(^{-1}\) of bagasse can be carried per 100 mm of belt width. The lower figure would apply to capacities of 25 to 50 th\(^{-1}\) and the upper figure to capacities of 100 th\(^{-1}\) and over.

Slat conveyors operate at speeds of up to 0,75 ms\(^{-1}\). Best results appear to be obtained at speeds of 0,5 to 0,6 ms\(^{-1}\). At 0,6 ms\(^{-1}\) the carrying capacity per 100 mm of conveyor width is approximately 6,5 th\(^{-1}\). Slat conveyors are able to elevate at an inclination of up to 50° to the horizontal. For equal capacity slate conveyors cost about 1½-2 times more per unit length than do belt conveyors.

If burning an auxiliary fuel is to be avoided during start up or when a mill chokage or a temporary shortage of cane occurs, adequate storage and reliable reclaim facilities must be available. These facilities, if carefully designed, can very quickly pay for themselves by saving auxiliary fuel. Manual reclaim schemes are the simplest but are only suitable for mills situated in low labour
cost areas, crushing less than 75 th⁻¹. Mechanical reclaim systems can be justified for larger mills and for those situated in high labour cost areas.

Whatever the scheme certain basic principles must be adhered to for them to be successful. These are:

a) Conveyors must be generously proportioned to cater for high short duration surge loads which can occur during reclaim operations.

b) With manual or partly mechanised reclaim systems the conveyor feeding the boilers must be sized to handle at least twice as much bagasse as the boilers require.

c) With mechanical reclaim systems bagasse must be reclaimed continuously at a rate greater than that required by the boilers.

d) Conveyor drives must be designed to start under full load conditions and must be sequence interlocked.

A scheme incorporating mechanical reclaim is shown in Fig. 17. Conventional manual reclaim schemes can be partly mechanised by using a front end loader modified to include a special engine air filter and a frame to protect the operator from avalanching bagasse.

**FIGURE 17.** Bagasse handling scheme for mechanical reclaim. *Note:* All conveyors can be belt conveyors in which case the boiler feed conveyor must be a 2 belt unit. To simplify bagasse feed to boilers this conveyor can be a slat conveyor.
Whatever scheme is employed operators in the boilerhouse and bagasse store must be kept informed of mill operating conditions by means of a suitable signalling system. This system must be sufficiently versatile to enable instructions and confirmation of receipt of instructions to be passed from one department to the other.

Capital expenditure on auxiliary fuel handling equipment should be kept as low as possible. Where coal is only used as a supplementary fuel, bucket elevators and "en masse" conveyors can be employed. Belt conveyors are preferred where coal is used as a major offcrop fuel.

**EFFLUENT CHARACTERISTICS AND DISPOSAL PROBLEMS**

There are 4 types of boiler plant effluent to be disposed of in a cane sugar factory:

a) Ash  
b) Fly ash and smut  
c) The gaseous products of combustion, and  
d) Boiler blowdown.

Fortunately the gaseous products of combustion contain only very small quantities of SO\textsubscript{2} and NO\textsubscript{x}. Their toxic effect is therefore minimal. They do, however, contain considerable quantities of fly ash and smut which, while apparently being non-toxic and non-respirable, are of considerable nuisance value and aesthetically offensive. Considerable work has been carried out recently in the USA, Australia and South Africa to arrive at a solution to this problem.

Fly ash and smut is a difficult material to collect. Illustrated in Fig. 18 are typical Australian and South African grading analyses. The grading of a typical fly ash produced when burning coal on a spreader stoker is also shown.

**TABLE 7.** Maximum allowable stack emission rates in Australia, South Africa, Hawaii and Louisiana.

<table>
<thead>
<tr>
<th></th>
<th>New plant</th>
<th>Existing plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>675 mg per normal m\textsuperscript{3}</td>
<td>788 mg per normal m\textsuperscript{3}</td>
</tr>
<tr>
<td>Note:</td>
<td>Concentrations to be referred to normal dry flue gas at 12% CO\textsubscript{2}</td>
<td></td>
</tr>
<tr>
<td>South Africa</td>
<td>400 mg per m\textsuperscript{3}. To be reviewed again in 1977 and again in 1987.</td>
<td>Installations with existing grit collectors not to exceed 1 000 mg per m\textsuperscript{3} by 1976. All existing installations not to exceed 450 mg per m\textsuperscript{3} by 1980. To be reviewed again in 1987.</td>
</tr>
<tr>
<td>Note:</td>
<td>Concentrations to be referred to dry flue gas at 12% CO\textsubscript{2}, 0\° C and local barometric pressure.</td>
<td></td>
</tr>
<tr>
<td>Hawaii</td>
<td>0.4 kg per 100 kg of Bagasse burned. As for new plant.</td>
<td>As for new plant.</td>
</tr>
<tr>
<td>Note:</td>
<td>This is equivalent to about 870 mg per normal m\textsuperscript{3} when referred to normal dry flue gas at 12% CO\textsubscript{2}.</td>
<td></td>
</tr>
<tr>
<td>Louisiana</td>
<td>0.258 kg per 10\textsuperscript{6} kJ heat input. As from May 1975 as for new plant.</td>
<td></td>
</tr>
<tr>
<td>Note:</td>
<td>This is equivalent to about 540 mg per normal m\textsuperscript{3} when referred to normal dry flue gas at 12% CO\textsubscript{2}.</td>
<td></td>
</tr>
</tbody>
</table>
for reference purposes. To facilitate comparison, all the gradings are referred to a density of 2 g cm\(^{-3}\). While this procedure is used extensively as a basis to compare the collecting properties of relatively homogeneous dusts it is not necessarily the best for the sugar industry. In the sugar industry emissions are not homogeneous but consist of 2 different materials, a high density fly ash and a low density char or smut, which have radically different collecting properties. To get a better feel of the problem there might very well be a case for reporting the grading analysis and density of these 2 components separately and then referring them individually to a standard density.

Typical maximum allowable stack emission rates are scheduled in Table 7. In Fig. 19 typical fractional efficiencies are plotted for dry cyclone type collectors and a wet scrubber collector.

Stack emission is not only a function of grit grading and collector efficiency but also of total dust burden to the collector. Measured figures vary widely from 1 500-12 500 mg per normal m\(^3\) with a reasonable mean being about 5 000 mg per normal m\(^3\). Combustion chamber design, moisture content of bagasse, quantity and method of application of secondary air and the quantity of excess air in the furnace all play a role in determining the dust burden. Fig. 20 illustrates the effect of reducing excess air in the furnace. A good deal more work will have to be done on this subject to establish the effect of the other parameters. At this stage it appears that dust burden increases with moisture content and is reduced by the correct application of secondary air and by reducing the furnace mean gas velocity.

Scheduled in Table 8 are typical characteristics of a number of different types of collectors. Included in the cost comparison is the cost of dewatering and dust conditioning equipment to bring the dust collected into a form which can be readily transported to a disposal point or into the fields to be ploughed back into the earth. The scrubber scheme includes recirculation of the scrubber
FIGURE 19. Typical fractional efficiencies for different types of collectors based on dust density of 2g cm⁻³.

FIGURE 20. Effect of excess air introduced as secondary air on dust burden in exhaust gases.

water. All schemes exclude treating blowdown water which it has been assumed can be treated with all other factory effluent.

In addition to the smuts collected from the exhaust gases, smuts are also deposited in the boiler passes. This material can be refired into the furnace but experience to date indicates that this is not a worthwhile exercise. The material collected is highly inflammable and has a tendency to rapidly abrade
TABLE 8. Typical fly ash and smut collector characteristics.

<table>
<thead>
<tr>
<th>Item</th>
<th>Single stage medium efficiency mechanical collector</th>
<th>Medium efficiency mechanical collector with secondary system</th>
<th>High efficiency mechanical collector</th>
<th>Impingement type wet scrubber</th>
</tr>
</thead>
<tbody>
<tr>
<td>Draught loss across main unit (Pa)</td>
<td>400</td>
<td>400</td>
<td>746</td>
<td>800</td>
</tr>
<tr>
<td>Draught loss across secondary unit (Pa)</td>
<td></td>
<td>746</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Approximate power consumption per 1 000 kg h⁻¹ of steam with:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) damper controlled fans (kW)</td>
<td>0.89</td>
<td>0.99</td>
<td>1.65</td>
<td>1.17</td>
</tr>
<tr>
<td>b) speed controlled fans (kW)</td>
<td>0.55</td>
<td>0.65</td>
<td>1.03</td>
<td>0.72</td>
</tr>
<tr>
<td>Efficiency on average dust grading on:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) Typical SA dust (%)</td>
<td>85</td>
<td>93</td>
<td>97</td>
<td>99.5 +</td>
</tr>
<tr>
<td>b) Typical Australian dust (%)</td>
<td>71</td>
<td>75</td>
<td>84</td>
<td>99.0 +</td>
</tr>
<tr>
<td>c) Typical coal dust (%)</td>
<td>83</td>
<td>90</td>
<td>93</td>
<td>99.3 +</td>
</tr>
<tr>
<td>Stack emission with inlet dust burden of 5 000 mg per normal m³</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) Typical SA dust (mg per normal m³)</td>
<td>750</td>
<td>350</td>
<td>150</td>
<td>25</td>
</tr>
<tr>
<td>b) Typical Australian dust (mg per normal m³)</td>
<td>1 450</td>
<td>1 250</td>
<td>800</td>
<td>50</td>
</tr>
<tr>
<td>c) Typical coal dust (mg per normal m³)</td>
<td>1 350</td>
<td>500</td>
<td>350</td>
<td>25</td>
</tr>
<tr>
<td>Relative Costs</td>
<td>1.00</td>
<td>1.27</td>
<td>1.45</td>
<td>1.46</td>
</tr>
</tbody>
</table>

and choke the refiring system. The increased dust burden carried through the boiler also increases the rate of erosion of the boiler tubes. Transporting the material hydraulically from the boiler appears to have the most chance of success.

Bagasse has a low ash content; of the order of 1 to 2%. Removing the ash from a furnace continuously, however, presents a problem as the equipment required to do so is expensive and costly to maintain. In low labour cost areas the simplest way of solving the problem is to build a large furnace capable of operating without de-ashing from one week-end shutdown to the next. The unit illustrated in Fig. 5 is typical of this type of design. The furnaces are de-ashed manually once a week, which takes about 4 hours to complete after the unit has been allowed to cool down for about 8 hours.

Where labour costs are high some form of mechanical de-ashing equipment is required. Two alternative schemes are shown in Figs. 6 and 7. Where coal is burnt, which has a relatively high ash content compared with bagasse, the unit shown in Fig. 7, which is fitted with a continuous ash discharge stoker is preferred unless the load to be carried on coal does not exceed 40% of the maximum continuous rating of the plant. In all cases hydraulic ash
removal is preferred as this has the advantage of quenching the ash immediately it is discharged thus minimising the dust nuisance which is generated by dry de-ashing.

Because smuts are highly inflammable, pneumatic handling is not recommended. When installing hydraulic ash removal schemes cognizance must be taken of the fact that the ash and smuts contain solids which settle and solids which tend to float for a period of time until they become water-logged. Cognizance must also be taken of the relatively large volumes of material which must be handled compared to equivalent schemes for coal-fired boilers.

Apart from dissipating pressure, boiler blowdown does not present a problem as drains from blowdown vessels can be run to the fields with the condenser water or condenser cooling water blowdown system where closed cycles are used.

**GENERAL PLANT LAYOUT AND RELATIVE COSTS**

When siting and laying out boiler plant in a cane sugar factory, the following must be borne in mind:

a) The boiler plant, bagasse handling and reclaim facility, ash handling plant and exhaust gas cleaning and discharge equipment are all potentially messy components. To minimise their effect on the rest of the plant they should all be placed on the lee side of the factory and isolated from the rest of the plant as far as possible.

b) Large quantities of fuel and steam must be transported to and from the boiler station. Transport lines must therefore be kept as short as possible.

c) Provision must be made for readily extending the plant in the future.

Fig. 17 illustrates a suggested layout which meets these requirements. The boiler plant and bagasse store can be completely isolated from the rest of the factory while still retaining a communication link through the power house control room. The bagasse conveyor to the store, high pressure steam lines to power house and mill, and exhaust lines to the evaporator station are short and easy to accommodate. The bagasse store, boiler station and power house can all be readily extended.

In the introduction to this paper mention was made of the high proportional cost of the boiler station in relation to the cost of the factory as a whole. Any general analysis of costs must of necessity be hedged with all sorts of provisions. To give some idea of how costs would be divided a very approximate cost analysis of the station illustrated in Fig. 17 is given in Table 9. As a basis for analysis it has been assumed that the plant would serve a Natal mill crushing 250 th\(^{-1}\) cane and that the boilers would each generate 70000 kg h\(^{-1}\) at 3000 kPa, 400°C. No provision for burning an auxiliary fuel is included.

Relative boiler costs are illustrated in Fig. 21. These costs are based upon the same design of unit as has been incorporated in the analysis given in Table 9. The larger the unit the lower the specific cost.

**CONCLUSIONS**

The nature of the load imposed upon boiler plant installed in a cane sugar factory is usually steady. Provided the plant is well integrated into the factory complex and due care is taken to ensure a reliable fuel supply, good
TABLE 9. Approximate division of boiler station costs for a factory crushing 250 t cane per hour incorporating 2 x 70 th⁻¹ capacity 3 000 kPa 400 C boilers and mechanical reclaim bagasse handling scheme.

<table>
<thead>
<tr>
<th>Item no.</th>
<th>Item</th>
<th>% of Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1)</td>
<td>Fuel handling facility from last mill including bagasse storage and reclaim system and bagasse store</td>
<td>11,5</td>
</tr>
<tr>
<td>2)</td>
<td>Feedwater station including hotwell tank, deaerator, feed pumps, feed pressure control system, feed pipework and hotwell and deaerator staging</td>
<td>10,0</td>
</tr>
<tr>
<td>3)</td>
<td>Boiler plant including bagasse feeders, distributors, dump grates, superheaters, convection passes, airheaters, electrically driven fans, supporting steelwork, galleries and ladders and semi outdoor boiler house</td>
<td>55,5</td>
</tr>
<tr>
<td>4)</td>
<td>Instruments and automatic combustion controls</td>
<td>3,5</td>
</tr>
<tr>
<td>5)</td>
<td>Gas scrubbers and chimney</td>
<td>9,0</td>
</tr>
<tr>
<td>6)</td>
<td>Hydraulic ash and grit handling equipment</td>
<td>1,5</td>
</tr>
<tr>
<td>7)</td>
<td>Electrical wiring and starting gear</td>
<td>3,0</td>
</tr>
<tr>
<td>8)</td>
<td>Foundations and civil works</td>
<td>6,0</td>
</tr>
</tbody>
</table>

FIGURE 21. General indication of relative cost of boilers as a function of unit capacity.

Quality feedwater and adequate feedwater flow control, operation of the boiler station as a whole can be simplified and factory staff relieved of the necessity to devote valuable time to what is after all only one of the many, albeit vital, services required to produce sugar.

ACKNOWLEDGEMENTS

I would like to thank John Thompson Africa (Pty) Limited for allowing me to publish this paper and my colleagues, T. Kirkpatrick and B. Barclay for their assistance in its preparation.
LIST OF SYMBOLS

- $B_m$: Percentage moisture in Bagasse
- $B_s$: Percentage sucrose in Bagasse
- $C_g$: Gross calorific value of Bagasse
- $C_p$: Specific heat of dry gas at constant pressure
- $D_p$: Dust particle size
- $h_1$: Heat in water in exhaust gases at exhaust gas temperature
- $h_2$: Heat in water in exhaust gases at ambient temperature
- $M_b$: Mass of Bagasse
- $M_d$: Mass of dry exhaust gases
- $M_w$: Mass of water in exhaust gases
- $T_a$: Ambient air temperature
- $T_e$: Temperature of exhaust gases

REFERENCES

LA PLANTA DE VAPOR COMO UNA PARTE INTEGRAL DE UNA FABRICA DE AZUCAR

Norman Magasiner

RESUMEN

La posibilidad económica de la industria de la caña de azúcar depende en gran parte de la utilización eficiente del bagazo como fuente de energía. Las calderas se usan para convertir esta energía de tal forma que pueda ser usada en el proceso de extracción. El proceso de conversión de energía incluye usos múltiples, pero solamente es un medio para llegar a un fin que es la producción de azúcar. Por lo tanto, la planta de vapor usada deberá ser diseñada para operar con un mínimo de supervisión y mantenimiento. Para llegar a este objetivo el diseño de la caldera y sus equipos auxiliares deberán ser cuidadosamente integrados en el diseño de la fábrica como un conjunto. El artículo en principio discute la naturaleza de la carga con la cual una fábrica de azúcar impone a la planta de vapor. Muestra que esta carga es relativamente pareja durante operaciones continuas y solamente tiene cambios bruscos durante condiciones transitorias tales como paradas y arranques y cuando disminuye la entrada de caña. Las características de diseño de calderas para llegar a las necesidades específicas de una fábrica son discutidos en detalle así como el diseño de los sistemas de alimentación de agua y el efecto con el cual las características de este sistema tienen en la facilidad de control. Las ideas son enfocadas a simplificar la instrumentación y los circuitos de control. El diseño de la planta de manejo de combustible y el efecto que esto tiene en la controlabilidad y facilidad de operación son también discutidos. Se discute problemas de evacuación de desperdicios. Se sugieren parámetros básicos para el diseño de equipos de limpieza de gases que se acomoden a las más estrictas regulaciones gubernamentales relacionadas con la descarga de gases de las chimeneas. Se hace una revisión del funcionamiento de los actuales equipos de limpieza de gases. Finalmente se discute la integración de la planta de vapor dentro del conjunto total de la fábrica y se revisa el costo relativo de sus componentes. El artículo hace hincapié en la necesidad de simplificar el diseño de la planta de vapor y sus auxiliares para facilitar el mantenimiento y permitir que el personal de la fábrica se concentre en lograr mejores extracciones y calidad de azúcar y en consecuencia mayor rendimiento.