

FUELS AND FURNACES

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Scope

The subject matter of this paper, if treated in the general sense, covers an extremely wide field to which it is impossible to do justice in the time allocated. It is even difficult to cover the subject adequately if we confine ourselves only to the furnace design of bagasse fired sugar mill boilers.

I therefore intend to give a short summary of past and present bagasse furnace designs and cover the subject of auxiliary fuels and how the latter have affected basic boiler design considerations.

For the purposes of this paper I have assumed that the majority of you have been concerned, one way or the other, with the practical aspects of steam raising equipment in sugar mills.

Historical Background

Bagasse has been used as a fuel for the boiling processes of sugar production since the 18th century. With the introduction of steam boiler plant in the early 19th century and the growing mechanization of sugar mills, it became necessary to overcome the problems of burning this wet and rather unmanageable fuel in large quantities.

About 100 years ago the first Dutch ovens appeared, typically the Cook's Hearth furnace, which was the forerunner of many variations which are still in use up to the present day. However these variations took different forms in different parts of the world.

The original Cook's Hearth, which consisted of only one cell, with an approximately square grate on to which the fuel was fed in a conical pile, is still the basic form used in many parts of the world.

In this country over the years we have seen the development of this basic design with the introduction of forced draught, preheated air, flat suspended roofs and arches and the final refinements of secondary over-fire air and tertiary air into the secondary combustion chamber. With the rise in capacity of boiler plant, the number of cells was often increased to three, each cell maintaining the approximately square shape of the grate.

A parallel development, mainly in the Western hemisphere, was the Horseshoe Furnace, in which each cell was built up with refractories with a horseshoe shape in the plan view. The main difference from the Cook's Hearth was the elimination of the grate, the fuel burning in a conical pile on the floor. Primary air was introduced through cast iron tuyeres built into the first course of brickwork, with secondary air admitted higher up and all the way round the periphery of the horseshoe. These furnaces attained very high ratings indeed. With hot air, ratings of up to 1.5×10^6 BTU/hr. per sq. ft. of floor area were fairly common. This compares with the Cook's Hearth, where grate ratings seldom exceed 1.0×10^6 BTU/sq. ft./hr. with hot air.

The modern counterpart of the Horseshoe Furnace was developed in the 1930's in the West Indies and was known as the Ward Furnace. These furnaces eliminated the Dutch oven construction in front of the boiler and were placed directly below the main boiler furnace with an intervening refractory throat. The basic horseshoe shape was originally retained with later variations to oval and then rectangular cells. Although these furnaces have been introduced to many parts of the world, South Africa has been a notable exception.

Another parallel development was the inclined step grate originally introduced at the end of the 19th century. In its original Dutch oven form it still exists commonly in the East and West Indies. Particularly in more primitive areas these furnaces operate on natural draught without forced draught or airheaters.

In some cases the step grate has been brought in under the main furnace in a similar way to the Ward Furnace. In other cases preheated air and forced draught have been introduced.

A post war development has been the Eisner Furnace which started as a variation of the step grate Dutch oven. In its final form the furnace is also placed beneath the main combustion chamber, eliminating the typical Dutch oven contours, but the method of combustion and shape of fuel bed are similar to that of the step grate.

With the exception of the Eisner Furnace all the foregoing designs with their many variations were in use throughout the cane sugar milling industry until the late 1940's.

In the years immediately prior to the last war coal spreader fired boilers had become extremely popular in the United States both for power station and industrial use. It was found that this method of firing was extremely flexible and could be used for all varieties and sizings of bituminous coal. It could also be used for the auxiliary, or even main, firing of refuse fuels.

In the vast timber growing area of North America considerable quantities of electricity are generated from sawmill wood waste and it became common practice to fire this waste by spreader methods with coal or oil as the standby fuel.

It was therefore only logical that the American boiler and stoker companies should turn their minds to the possibility of burning bagasse on spreader stokers and developments were started in this direction very shortly after the second world war. The advantages of spreader firing were almost immediately apparent and the new system caught on very rapidly indeed.

In Southern Africa the first spreader fired units were installed in 1953/4 and by 1960 probably 90% of all new installations were of the spreader type. Many Dutch oven fired boilers were converted to the new system.

In this country it is indeed remarkable that, in the short space of less than 15 years, spreader firing has taken over almost entirely from the older methods.

Fuels for Sugar Mills

Bagasse always has been, and for the foreseeable future must be, the primary fuel of a sugar mill.

In the average modern mill, having a cane input of over 200 tons per hour, the weight of bagasse produced per day is approximately 1,800 tons and, with its low bulk density, the volume is prodigious.

Although there have been many schemes to make better use of this fibrous substance, particularly in paper and cardboard manufacture, these have not been of any particular economic significance. It must therefore be stressed that bagasse must remain the primary fuel of all cane sugar mills.

With the increase of refining facilities in larger mills and the necessity to generate electricity for irrigation, the problem often arises of a certain shortage of bagasse and the engineering designer must either economise in his use of steam or increase his boiler efficiency to overcome the shortfall of this fuel.

Only too frequently, and usually to minimise capital expenditure, recourse is made to the use of auxiliary fuels such as wood, coal and, in countries where coal is not as cheap as it is in South Africa, oil, rather than increase the efficiency of the bagasse firing equipment.

Auxiliary fuels, of course, have their advantages from the point of view of shutting down and starting up procedures and in the event of temporary mill outages. They obviate, to a large extent, the necessity to store very large quantities of bagasse, which is so awkward to handle mechanically.

Of course, with the generation of electricity for irrigation purposes, it is necessary to fire boiler plant with such auxiliary fuels during mill shutdown and off-crop periods.

A nice solution from the boiler designers point of view would be to install the highest possible efficiency boiler plant so that an excess of bagasse is produced and the fuel stored for periods of mill shutdown. Unfortunately nobody has yet come forward with a really practical solution to the problems of bagasse storage.

In this country we have the factor of probably the cheapest coal supplies in the world and this is the main reason for the very rapid development of spreader fired boilers in Southern Africa with their adaptability to coal/bagasse dual firing.

In most other sugar producing countries, particularly the West Indies, oil is cheap and hearth type furnaces, such as the Ward, with oil burners in the secondary furnace are able, by dint of lower capital costs, to hold their own against the spreader stoker.

Due to clinkering difficulties with high furnace temperatures it is, of course, not practical to fire high ash coal in Dutch oven furnaces.

On the other hand wood, with very similar burning qualities to bagasse, can be burnt either in hearth furnaces, or for that matter, on spreader stokers.

I have often wondered why so much labour is expended on bringing large quantities of wood logs to the boilerhouse and manhandling them into the furnaces for lighting up purposes. If this fuel were put through a simple hogging machine it could so easily be fed to the boilers through the normal bagasse carrier system.

In the following table I give the approximate furnace gas quantities for a boiler steaming at 100,000 lb/hr. with the four different fuels that we have discussed above:

	Bagasse	Coal	Wood	Oil
% moisture in fuel	50	5	50	—
G.C.V. BTU/lb.	4,150	12,000	4,300	18,500
Furnace gas weight lb/hr.	205,000	150,000	200,000	120,000

Assuming that we have a hypothetical boiler that can fire all four of these fuels, obviously the fuel with the lowest gas weight will have the most heat removed from these gases in the course of their passage through the boiler. If we have designed the boiler for operating with an economiser, or airheater, outlet temperature of 400° F. on bagasse, the equivalent temperature on wood will probably be 390° F, on coal 350° F. and on oil 320° F.

Consequently, with dual firing and where we desire to install boilers of high efficiency, we came up against the problem of corrosion with the higher grade fuel.

Particularly with auxiliary oil firing in boilers specifically designed for bagasse, it is essential to bypass heating surfaces and/or provide parallel flow airheaters in order to prevent dew point corrosion in the airheaters and draught plant. This is only one of the many criteria for the design of modern high efficiency boilers for sugar mills.

Design Considerations—Hearth Type Furnaces

With the majority of hearth furnaces, such as the Horseshoe, Ward or designs best known in this country, the Vincent & Pullar and Murray type furnaces, the fuel bed is ostensibly in the form of a cone with the fuel fed from over-head on to either a grate or the floor of the cell.

With very high temperatures maintained in the hearth cell the moisture in the fuel is driven off and most of the fuel ignites from the bottom periphery of the cone upwards. With the fuel falling through the flames a limited proportion representing the smaller particles of fuel, are flash dried and readily ignite; sometimes before they reach the cone.

The whole operation necessitates furnace temperatures of a very high order and this brings with it the following disadvantages:

Firstly, we have the difficulty of slag formation in the primary and secondary combustion chambers, although this will vary considerably with the type of cane and the area in which it is grown. Secondly, due to the high temperatures in the fuel

bed there is a tendency towards the production of gases which may pass through the boiler to the chimney in the unburnt state thus constituting a loss in boiler efficiency. For example, carbon dioxide will re-associate with carbon at high temperature levels to form carbon monoxide which may not all be burnt in the secondary combustion chamber. Admittedly, with modern furnace designs, secondary air blows directly on to the cone of fuel and tertiary air is introduced at the entrance to the secondary combustion chamber and the prevalence of unburnt gases in the flues is not very apparent.

Thirdly, the temperatures associated with hearth designs, with their large areas of brickwork, produce high radiation losses.

Fourthly, brickwork maintenance at these high temperatures is obviously a serious consideration.

There are, however, certain advantages in favour of the hearth type furnace and these can be summarised as follows:

The first and principal consideration is simplicity of operation. With comparatively primitive labour the fuel feed can be controlled easily as the level of the top of the cone is not critical. As long as this level is kept approximately constant, boiler output can be controlled by the simple manipulation of dampers.

Secondly there is the advantage of a fairly considerable reserve of mill in the furnaces in the event of fuel stoppage and cessation of supplies of bagasse.

It is when one comes to the question of the advance of boiler design over the last 20 years that one comes across the most serious objections to hearth type furnaces.

Up to comparatively recent times sugar mill boilers were very lowly rated, the evaporation seldom exceeding 5 lb./hr. per sq. ft. of boiler heating surface.

In most parts of the world 3- and 5-drum bent tube boilers were used although, in South Africa, preference was shown for the sectional header type longitudinal drum boiler.

The design of these two types of boilers was such that a maximum of approximately 3,000 lb./hr. of steam could be generated for each foot in width between boiler side walls. Thus a 50,000 lb./hr. boiler would be about 18 ft. wide.

The Horseshoe and Ward Furnaces with their comparatively high furnace rating, fitted in almost exactly with this criterion of boiler design. The more lowly rated furnaces such as the Cook's Hearth and Step Grate usually required a greater width than the boiler and the side walls of the latter were stepped out to accommodate the Dutch oven width.

With the advent of more highly rated boilers in recent years the permissible evaporation per unit width has increased rapidly until today the figure given above has very nearly doubled.

Obviously the more highly rated boilers of modern design have the advantage of reduced initial costs and furnace designs must fall into line. In the case of the

Cook's Hearth, the Horseshoe Furnace and the Step Grate Dutch oven we theoretically arrive at a furnace width nearly twice that of the boiler and this is obviously ridiculous.

At Mercedita Sugar Mill in the West Indies an attempt was made to overcome this problem with a Ward Furnace design having an individual cell width of 6 ft. and a length of 11 ft. Instead of having a cone of bagasse on the floor of the hearth a fuel bed shaped like the top of a grave was produced by means of an air spreader using a varying air pressure.

At Medine in Mauritius a similar idea was introduced only this was not a true Ward Furnace in that dumping grates were used and there were only two of them for a 35 tonnes/hour boiler. This design, was, in effect, a compromise between a hearth furnace and a full spreader design and can be classed under either category. Grate ratings for this design are midway between those employed for conventional spreader firing and those for typical hearth designs.

Design Considerations—Spreader Firing

With the spreader firing of bagasse, or any other wet vegetable fuel, intimate contact is made in suspension between the hot incoming air, flames and furnace gases on the one hand and the fuel on the other.

This results in flash drying of the fuel which loses a large proportion of its moisture before it lands on the grate. Bagacillo and smaller fibres actually burn in suspension. The fuel bed on the grate is relatively thin and most of the rest of the moisture is driven off by radiation from the furnace flames themselves rather than radiation from the refractories.

The grate itself is either of the stationary, dumping or travelling grate type. Due to difficulties of cleaning fires and ashing, the stationary grate can only be used for very small boilers and we will not consider it in this context.

The dumping grate can be used for boilers up to about 60,000 lb./hr., a steam dumping mechanism usually being employed. This type of grate is perfectly suitable where bagasse is the main fuel and coal is only used for supplementary purposes or for limited periods on its own. Obviously dumping grates are also suitable where the auxiliary fuel is wood or oil.

The travelling grate design with the grate moving from rear to front, is essential where it is required to burn coal over extended periods. For coal firing alone boiler sizing may go as high as 300,000 lb./hr. although I believe the largest bagasse fired unit is only 150,000 lb./hr. This type of grate obviously has the advantage of bringing all ashes to the front of the boiler automatically whence they can be removed by a variety of mechanical means.

Regarding the methods of spreading the fuel over the grate, there are two principal means of accomplishing this.

The first method consists of a rotor, usually with four blades, on to which the fuel is fed and thrown into the furnace. Very much higher rotor speeds are

required to obtain a satisfactory spread with bagasse when compared with coal. It is therefore desirable to have means of varying over a wide range the speed of the rotors according to the fuel being burnt.

The second and rather simpler method of distributing bagasse over the length of the grate is by means of pneumatic air spreaders. These obviously have no moving parts and operate on an air supply from the boiler secondary air system. However they are unfortunately unsuitable for coal except in a special applications.

Consequently, and particularly in this country where the need is to burn coal and bagasse, the tendency has been towards the rotor type spreader which can handle either fuel.

Personally I am very much in favour of air spreading as it must increase the flash drying of bagasse especially when hot air is used in the spreaders themselves.

The main disadvantages of spreader firing can be summarised as follows:

Firstly, with spreader firing it is essential to meter the fuel in order to obtain a completely steady rate of feed. This means that we must provide some form of feeder with a variable speed drive and it is by no means easy to design a feeder which will handle such an awkward fuel as bagasse. However this problem has been reasonably well overcome with the drum type and the slat type conveyor feeders. The latter has been adapted to meter both the bagasse and coal in the same unit.

Secondly, and partly as a result of the first disadvantage, it is necessary to have more complicated controls and more skilled operators than is obtained with hearth furnace operation.

Thirdly, due to the relatively thin fuel bed, there is little reserve of fuel on the grate in the event of mill stoppage and it is necessary to change over to coal within a fairly short space of time. Operators have to be trained to carry out this operation without loss of steam pressure.

Fourthly, especially where travelling grate stokers are used, the cost of firing equipment is much higher with spreader stokers than with the older hearth designs. This is to a certain extent offset by the narrower and more highly rated boilers that can be used with spreader firing.

Fifthly, the very nature of spreader firing means that higher excess air is used in the furnace than is obtained with hearth furnaces. The basic figures are probably 40% and 30% respectively, in other words one third more excess air is used in the case of spreader firing and this increases the chimney losses. Again this feature is offset by the fact that furnace temperatures are very much lower with reduced radiation losses.

The advantages of spreader firing far outweigh the disadvantages and they can be summarised as follows:

Firstly, there is the intimate mixing of fuel and air in suspension with consequent flash drying. This brings with it the almost complete elimination of unburnt gases.

Secondly, we have comparatively low furnace temperatures with a consequent reduction in brickwork maintenance. Also under this heading should be mentioned the ability to use partially water cooled walls which again have the effect of reducing furnace maintenance.

Thirdly, the use of auxiliary fuels, such as coal or wood waste, on the stoker is facilitated. Also in the case of combined bagasse and oil firing, the heavy slagging which is experienced with Ward Furnaces is not here apparent due to lower furnace temperatures.

Fourthly, it is possible to mechanise ashing completely.

Fifthly, and as mentioned above, it is possible to obtain a considerable reduction in boiler width.

Sixthly, the spreader fired boiler is highly flexible and has "quick steaming" characteristics.

One can only come to the conclusion that, especially where larger boilers over 50,000 lb./hr. are concerned and where higher steam pressures and temperatures are to be used, the only possible economic solution lies with the spreader stoker. However it is my opinion that, where coal is only used to a limited extent or where the auxiliary fuel is oil, a compromise such as the Medine design described previously may be a better proposition.

Yet another variation, which has arisen in my experience, is the case of a boiler which is primarily coal fired for long offcrop periods for irrigation purposes and here we used a conventional backward moving chain grate stoker with air spreader firing of bagasse. In the actual case this method was adopted because the boiler was secondhand and had an existing chain grate stoker. For new plant the backward moving travelling grate stoker is slightly more expensive than the conventional spreader travelling stoker which operates in the opposite direction. It may therefore not be normally a very economic solution, but the point is that the combustion of coal on a conventional travelling grate or chain grate stoker is more efficient than spreader firing. The main reasons for this are lower excess air and lower grit emission, both giving reduced chimney losses.

Future Developments

The cane sugar mill of the future may well develop a steam demand in excess of 1,000,000 lb./hr. It will then be necessary to consider boiler unit sizes of the order of 300,000 to 400,000 lb./hr. of steam.

To the boiler designer this size of unit has no problems whatsoever as units of ten times this size are currently being installed in power stations all over the world.

However the real problem is how we are going to fire these larger units with bagasse and in my opinion, the only possible solution can lie with pulverizing of bagasse in milling equipment.

These mills would be swept with very high temperature air and the powdered fuel fed into a bin system.

The dry pulverized fuel would be led to special feeders which would distribute the fuel to burners set in completely water cooled boiler furnaces.

We should not get too enthusiastic about this system until such time as there is a call for much larger units. I say this because it is unlikely that such a system with its complicated controls and the necessary firing skills, will become economic until a boiler size of at least 250,000 lb./hr. is reached. I envisage here a minimum of three such boilers which would mean a sugar mill handling something over 600 tons of cane per hour.

A second development which I have in mind is the possibility of somebody solving the problem of bagasse storage. This would go a long way towards increasing the efficiency of the use of bagasse and effect a saving in the use of auxiliary fuels.

Thirdly and finally I would like to comment on the possibilities of higher efficiency boiler plant being employed. Quite a few mills are now using economisers as well as airheaters, particularly where higher boiler pressures have been employed, but in sugar mill practice we are still a long way off the order of efficiencies employed in power station practice. Especially where large quantities of coal are used, consideration should be given to back end temperatures of the order of 280° F. on coal, equivalent to say, 320° F. on bagasse.

With this order of low exit gas temperature it is probably better to place the Economiser after the main airheater with possibly a small primary cast iron airheater after the Economiser.

With these low outlet gas temperatures it will be necessary to go to concrete, brick or gunite lined mild steel chimneys.

Conclusion

I have by no means covered the whole field of this most absorbing subject and have probably done less than justice to some furnace designs. For any omissions in this direction I can only apologise.

Mr. Magasiner: What order of boiler capacity do you recommend for pulverised bagasse units?

Mr. Glennie: Definitely not below 250,000 lb./hr.

Mr. Hulett: It is mentioned in the paper that the new large boilers with which the industry may be equipped will require the bagasse to be further pulverised. Final bagasse is already being pulverised by about 5,000 h.p. before it reaches the boilers. How much more horse power does the author suggest would be required?

Mr. Glennie: It is extremely difficult to assess horse power requirements for pulverising bagasse at this stage. However, it should be borne in mind that the use of dry fuel in firing boiler plant will increase the efficiency to a very considerable extent and that this will more than compensate for the extra horse power requirements.

Mr. Hulett: The spreader stoker is recommended but it is very often the cause of breakdowns. With regard to furnace designs, I would like to mention that the Eisner furnace has a simple brick construction and requires very little maintenance.

Mr. Glennie: Returning to the question of future higher capacity boilers, it should be pointed out that if, for example, two 250,000 lb./hr. boilers are installed instead of ten 50,000 lb./hr. units, or five 100,000 lb./hr. units, the capital and amortisation charges will be considerably less. In the assumption I have made for mill steam requirements, I have not taken diffusion into account. However, I understand that there would be certain savings of steam requirements.

Mr. Hulett: High velocity secondary air in spreader-fired furnaces boosts the output of a boiler tremendously. A twenty per cent increase was obtained in a boiler at Darnall.

Mr. Glennie: When the bagasse spreader-fired units were first introduced in the early 1950's, it was the opinion of a number of people in the boiler industry that these units required adequate provision for secondary air. Subsequently, high pressure secondary air was introduced by most manufacturers.

Mr. Magasiner: There is a lot more horse power consumption if you use this high pressure, high velocity air.