Analysis of New Boiler Technologies

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Abstract

The thermodynamics of export cogeneration dictate that higher HP steam conditions result in more electricity produced, something which has driven the industry to achieve ever higher pressures and temperatures without considering the economics. In practice, as conditions are increased, the additional capital cost outstrips the additional electricity.

The higher HP conditions have also driven a second trend : to adopt single drum boilers instead of continuing to use bi-drum designs. Whilst this is the right approach at high conditions, care needs to be taken in selecting the details of the design.

Introduction

Export cogeneration – deliberately changing the energy balance of a cane sugar [in this instance] factory in order to be able to sell surplus energy as electricity – has substantially changed the engineering approach to the factory power station over the last 20 years. This paper will examine a couple of new approaches which are, of course, driven by economics or at least a perception of the economics.

In order to do that though, it is necessary to review the fundamentals of the technology behind export cogeneration.

Basic Thermodynamics

It is nature which dictates what can be done with the fuel energy in bagasse. One of the best ways of examining that is with a graph of temperature vs entropy :

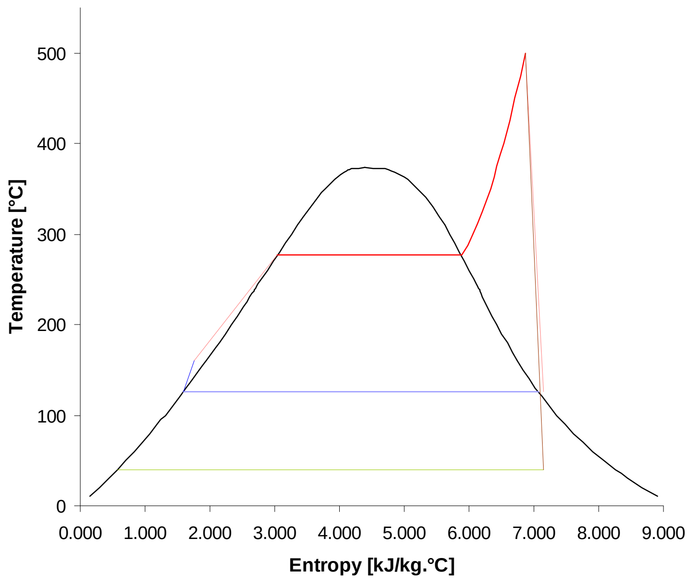

Fig. 1 Temperature vs Entropy Graph

The bell shape curve is the natural condition of water with liquid on the left and vapour on the right. In the power station the boiler feedwater is heated up in the boiler from the lower left until it boils to make saturated steam [upper horizontal line tracking to the right] which is then superheated before passing through the turbine to generate electricity as its temperature plummets. Where the horizontal saturated steam line is depends on the boiler operating pressure.

Two systems are shown on the curve, one for cogeneration [centre horizontal line] where the water vapour exits the turbine as exhaust steam at about 120 °C and is used for heating in the factory and the other for generating [lower horizontal line] where the vapour exits at about 40 °C and is immediately condensed using cooling water. In both cases it is the condensing which is represented by the horizontal part of the line tracking from right to left to start again.

The importance of the graph is that the amount of recoverable work [electricity produced] is proportional to the area bounded by the cycle. It therefore follows that the higher the saturated steam temperature [boiler operating pressure] the more that electricity is produced and, similarly, the lower the turbine exit temperature the more that electricity is produced. [It also partially explains why we use superheat : the area to the right of a line dropping from the saturated steam point on the bell curve is a substantial part of the total area bounded by the cycle.]

The problem is that a temperature vs entropy graph doesn't tell all of the story : it ignores what is called the 'utilisation factor'. The temperature of vapour leaving what is usually called a condensing turbine is so low that all the latent heat can only be dumped to atmosphere. By exhausting at say 120 °C we can use the latent heat usefully [to make sugar and/or alcohol] so the utilisation is much higher and the cycle efficiency is more than double that of a generation cycle.

It is now possible to discuss the first of the modern boiler trends : increasing HP steam conditions.

Increasing HP Steam Conditions

In past decades the energy in bagasse was an embarrassment so factory energy efficiencies were deliberately de-rated to avoid a surplus. Part of that approach was to operate low pressure steam systems, typically at 20 or 30 bar. However, it is now over 20 years since the French island of Reunion paved the way forward with export cogeneration and systems with much higher HP steam conditions.

A bagasse fired boiler is really a plant in its own right, not a piece of equipment :

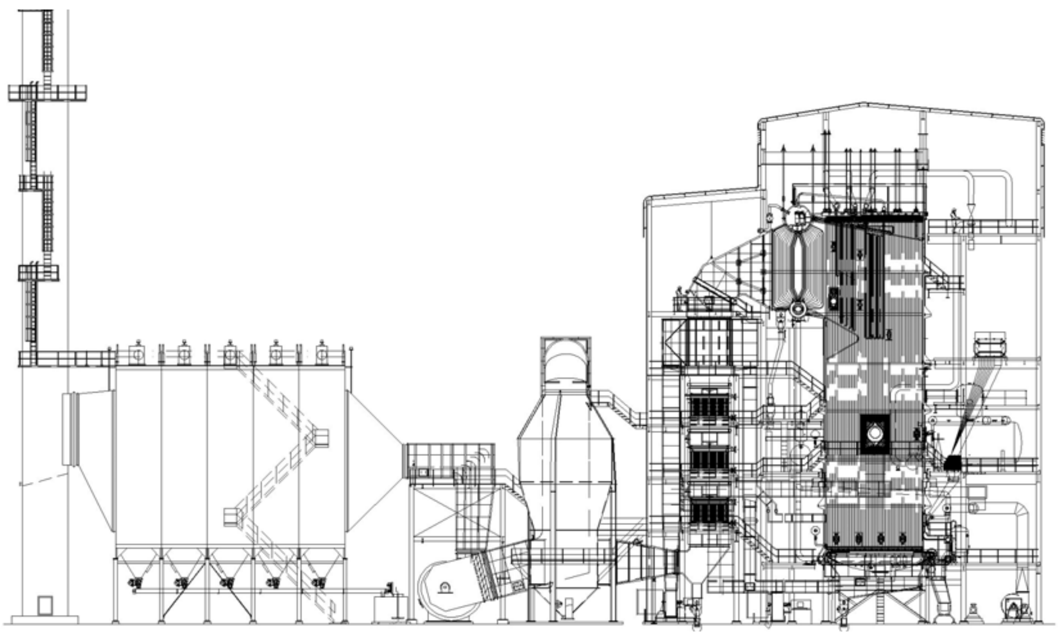

Fig. 2 Modern Boiler Arrangement

The pressure part envelope alone consists of the furnace, drum(s), the superheater(s) and the generating bank plus all of the connecting pipework and manifolds. In addition there is the economiser(s), another pressure part. To that have to be added the dearator, boiler feedwater pumps, water treatment plant and chemical dosing equipment in the pre-boiler plant, the fuel supply, metering and feeding trains, the grate, the FD, SA, DA and ID fans, the air pre-heaters, the gas and air ducting and the emissions control equipment.

HP Steam Pressure

Increasing the steam pressure has an impact on all of the pressure parts including the BFW pumps but it is not a simple relationship : there is a also an impact on the temperature at which most of the boiler operates [because the saturation temperature increases] and on the water quality requirements.

Higher pressures require thicker metal thicknesses to contain that pressure but the associated temperature increase reduces the strength of the steel so even more metal thickness is required.

The water quality issue is more of an operational issue and is therefore outside the scope of this discussion but it must not be overlooked.

In general, engineers tend to think of pressure in 10 or 20 bar stages so we have seen HP steam pressures increase to 40 then 60, 80 and even 100 bar. The latest projects in India are now selecting up to 110 bar. Taking the pressure alone, what does this mean in terms of additional electricity produced? Examination of the temperature vs entropy graph shows that the answer is, ‘not that much’ :

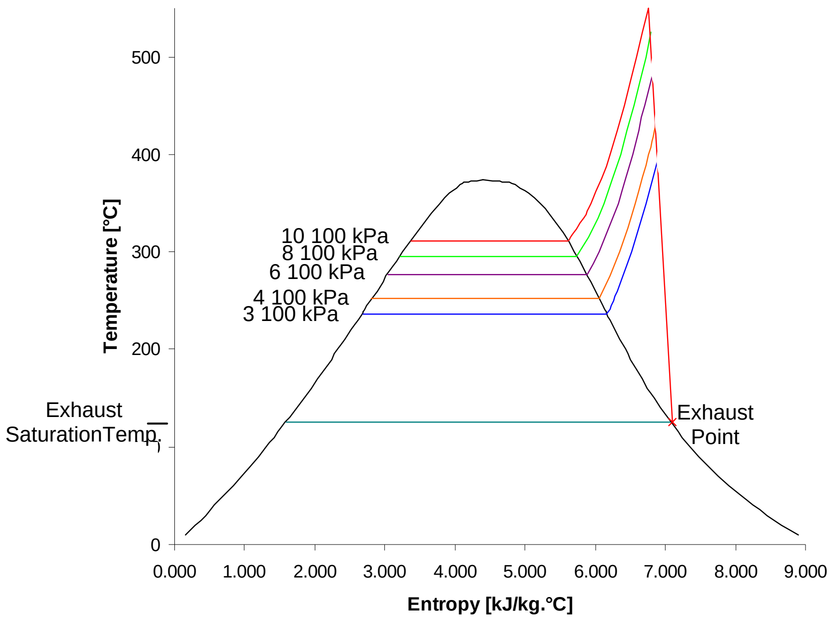

Fig. 3 HP Steam Pressure Effect

It can be seen that the law of diminishing returns is working in two ways. Not only does the saturation temperature increase per incremental increase in temperature fall but the liquid and vapour phase lines approach each other so there is a distinct fall in additional electricity production for each step increase in pressure.

Before analysing that, it is also necessary to discuss the HP steam temperature [as distinct from the saturation temperature].

HP Steam Temperature

Figure 3 shows that for any one exhaust steam condition and a particular turbine efficiency, there is an optimum HP steam temperature. For the conditions of the graph, the temperatures equivalent to the pressures shown are :

Steam Pressure	3 100	4 100	6 100	8 100	10 100	kPa a
Steam Temperature	388	423	475	513	545	°C

The difference between the impact of the HP steam pressure and the temperature is that the latter only affects the superheater(s) and beyond. Of course that does mean the turbine too.

As has been discussed, increased temperature reduces the strength of steels. Most industrial boiler engineers will switch to a [more expensive] high grade steel for all superheaters but above 480 °C they will switch again and at 510 °C or thereabouts they will switch to exotic metals for at least the hottest part of the superheater. Few will even consider an HP steam temperature above 525 °C.

Cost and Benefit Analysis

Clearly increasing the HP steam conditions does produce more electricity but at what cost? Applying the mathematics behind the statements and allowing for factors such as increasing parasitic load gives the effect of increasing conditions at optimum values :

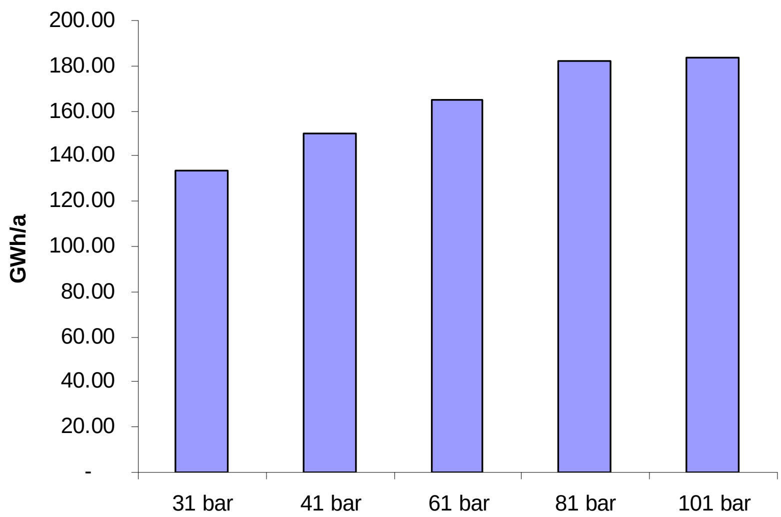

Fig. 4 Electrical Sales Figures

The figures are for a particular factory of course but they clearly show the reducing benefit at higher conditions.

The capital cost increase of reaching the higher conditions is less easy to determine as it varies around the world and to calculate the return on investment requires a knowledge of the selling price and operational costs. However, at a simplistic level the capital cost increases are broadly understood and can be compared with the increased return from selling more electricity as shown over the page :

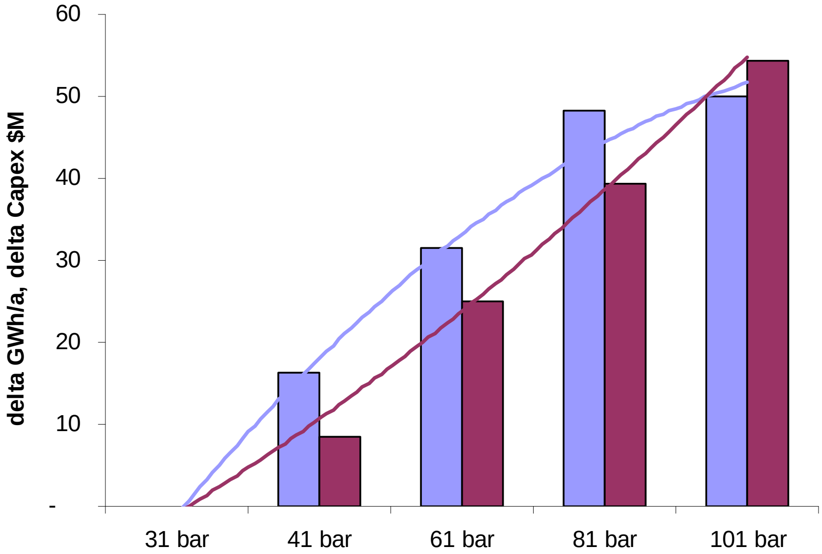

Fig. 5 Sales compared to Capex

It can clearly be seen that higher HP steam conditions – and remember that this graph does not go as far as the latest Indian stations have gone – cost relatively more and produce relatively less additional sales. The IRR on investment falls with increasing conditions.

Single Drum Boiler

Figure 2, discussed earlier, shows a conventional sugar industry bi-drum boiler. It has a steam drum and a mud drum with the generating bank between the two :

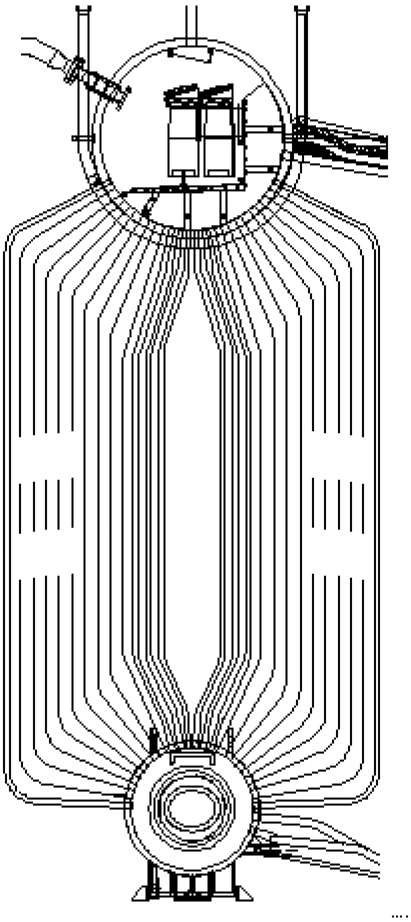

Fig. 6 Bi-drum Generating Bank

There might well be over 2 500 generating bank tubes, 25 at 5° intervals in the cross section shown and 100 or more along the length at 100 mm spacing. That in turn means over 2 500 quite closely packed holes in each of the drums, as can be seen in this picture of a mud drum just before installation :

Fig. 7 Mud Drum Erection

Any hole in a pressure part has to be carefully engineered, something which becomes more important with increasing pressure. In the case of drums it typically requires a thicker shell to compensate for the lack of metal but when there are long lines of holes an extra factor comes into play : the ligament efficiency. Put simply, lines of closely spaced holes introduce an extra weakness into the drum shell which has a propensity to open up rather like a zip fastener.

Single drum boilers, on the other hand, do not have a conventional generating bank – there is, after all, only one drum – so there are many fewer holes required in the drum. That substantially reduces the drum thickness and hence the cost and also the availability of the steel plate needed to fabricate the drum. Time can be as valuable as cost in boiler contracting.

Single drum boilers still need a generating bank however and the internal circulation within the boiler becomes more of an issue than with bi-drum units.

Generating Bank Arrangements

There are several types of generating bank and at least two locations for them. One solution that is frequently seen is the use of so called ‘flag’ style generating banks shown in Figure 8.

Ignoring the furnace shape [which is for wood waste firing], there is a two stage superheater behind the screen tubes and then a four pass zigzag generating bank. Multi-pass generating banks were phased out in the sugar industry during the 1980’s because of the localised erosion issues associated with baffling the gas flow but in this case the gas flow is once through, it is the water and steam side which is multi-pass, something not possible with a bi-drum boiler.

There are essentially two separate water wall chambers, the furnace and the main pass. Each generating bank tube starts at the lower end of the corresponding water wall tube of the main pass back wall and ends in a sloped 4th pass [counting on the water and steam side] which again connects with the corresponding water wall tube. The slope is to aid the circulation, particularly as the 4th pass contains a high proportion of steam which otherwise may cause phase separation and insufficient cooling of the tubes.

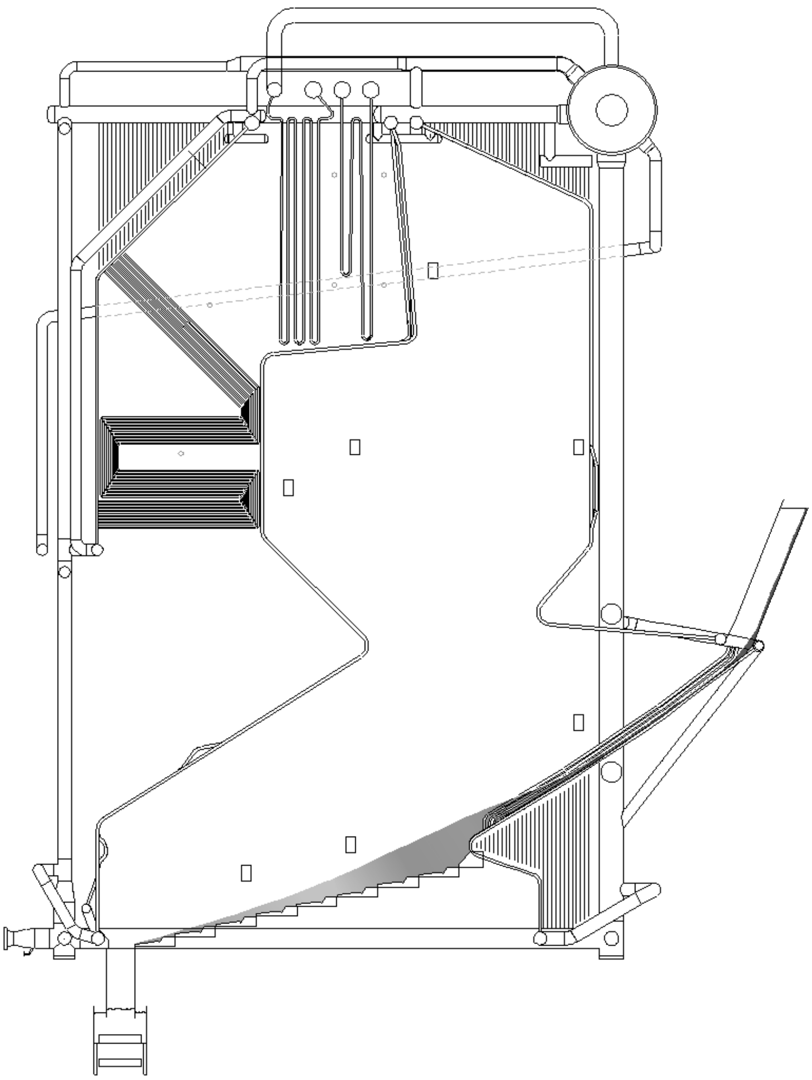

Fig. 8 'Flag' Style Generating Banks

The issue is the reliability and maintenance of this style of generating bank. The tube manipulations are all in the gas flow and hence exposed to erosion and at the back of the furnace rear wall have to be supported in some way without the full benefit water cooling and fighting gravity.

Should a tube fail, it cannot simply be plugged as is the case with a bi-drum arrangement. The short-term expedient is to abandon the leaking tube and weld up the stubs on the water wall tubes, a fiddly procedure when working from the wrong side of the water wall.

An alternative approach is to use bundles of tubes strung between upper and lower manifolds and somewhat mimicking a bi-drum generating bank :

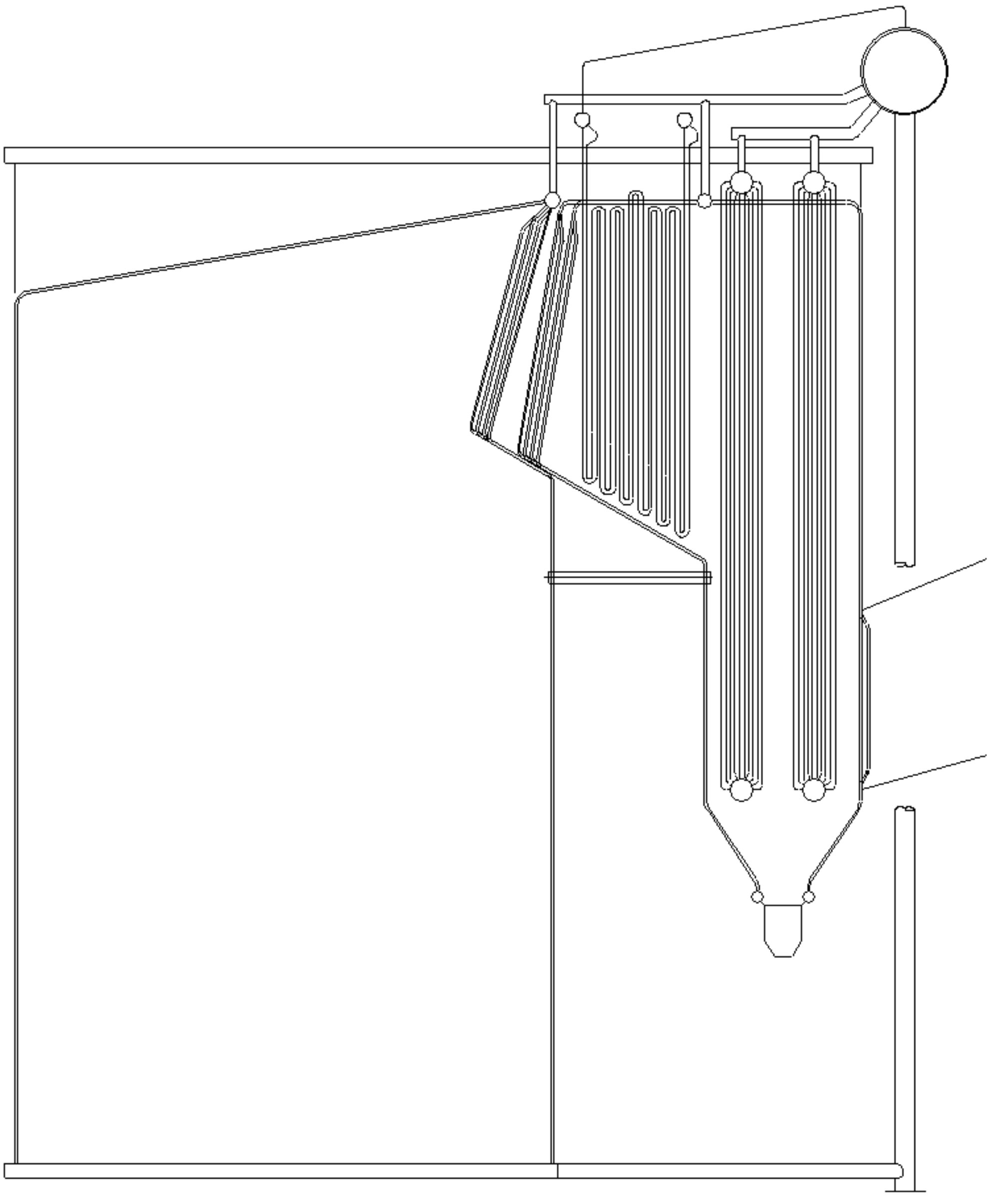

Fig. 9 'Pendent' Style Generating Banks

This style of generating bank is more robust than the flag style. The problem is that the gas flow is down the length of the tubes and not cross-flow, something which significantly reduces the heat transfer capability so more surface area is required to achieve the same result.

In general, it should also be noted that most styles of generating banks in single drum boilers currently on the market do not allow the use of internal non destructive measuring techniques for measuring remnant wall thickness, nor do they allow internal de-scaling, both of which are possible with bi-drum boilers.

Generating Bank Locations

Figures 8 and 9 both have a water cooled primary pass after the furnace because the gas temperature is still too hot for un-cooled walls. Of course that is true of any unit but if the generating bank could be in the same location as for a bi-drum boiler then it would be a less expensive option.

Cost and Benefit Analysis

The potential capital project benefits of a single drum design have already been discussed : a reduced capital cost due to having only one drum and a much thinner shell thickness for that. There may also be a time benefit to the design.

However, the capital project is only part of the equation – and a short-term one at that. Lifetime cost is more important than capital cost and in most electrical export scenarios reliability is a priceless commodity. It is therefore important to understand the implications for those factors when choosing a single drum design and particularly the detail of the generating bank and the emphasis placed on internal circulation studies.

Conclusions

Two current trends in modern bagasse fired electrical export power stations have been singled out for discussion : the ever higher HP steam conditions and single drum boilers.

There is no doubt that higher HP steam conditions deliver more electricity for sale but the cost of achieving those conditions is greater than the added revenue obtained so there is a reduction in the IRR of the project. It would be far better to concentrate on the fundamentals of the project, reducing the LP steam conditions, the factory steam on cane, the factory lost time and the bagasse moisture content.

Equally, there is no doubt that a single drum boiler will be of benefit provided always that the benefit is not overridden by poor details. All power station boilers need to be reliable and easy [and inexpensive] to maintain.