INCREASING ENERGY EFFICIENCY BY CONSERVING BOILER FEEDWATER TEMPERATURE

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Abstract

For increased energy efficiency and cogeneration, the procedure is to maximise the production of high-pressure steam and minimise the factory requirements of low-pressure process steam. This takes maximum advantage of efficient fully condensing turboalternator systems. Factory configurations that reduce process steam requirements were examined in a paper at the 2000 Conference. The present paper addresses the production of more high-pressure steam by minimising heat losses presently occurring at the boiler feedwater tank and in the boiler blowdown. The examination quantifies the benefits of such schemes and should be helpful to technical staff faced with re-configuring their factories to meet the steam production and consumption targets necessary for profitable cogeneration, or by staff in factories that have a need to save bagasse fuel.

Introduction

The future economic viability of the cane sugar factory may well involve the cogeneration and export of electric power. There is a need for technologists to be aware of the modifications that can be made to an existing factory to reduce energy consumption and the costs and limits of those modifications. As well, some factories have a need to save fuel during seasons with low cane fibre (as was the 2000 season, especially in the Mackay region) or because they have a refinery or distillery that would otherwise use coal. Such factories need to review methods to increase their energy efficiency in the most economic manner.

The reasons for the present energy-inefficient configurations in Australian sugar factories were discussed in a previous paper (Wright, 2000). That paper indicated the need for greater energy efficiency when cogeneration is implemented. It focused on vapour bleeding as a method to achieve reductions in process steam consumption. In many cases, after including a small allowance for the effect of the extra use of power on the vacuum pan stirrers and the juice pumps, the reduction in process steam consumption would translate directly to increased cogeneration export or bagasse saving. In the high-bleed cases, the process steam saving is up to 16.3% on cane, which can give large benefits to power export to factories having a cogeneration facility.

The previous paper (Wright, 2000) also considered steam housekeeping measures. The operation of a raw sugar plant often presents a number of opportunities for minor economies in process steam. Broadfoot (1999) has identified items of pan stage practice that often can be improved. Other items in clarification and evaporation are:

- Evaporator calandria vent losses (use thermostatic vents, check valves, and piping of appropriate size).
- Flash loss from the juice flash tank. (Absorb this vapour by direct contact with a stream of cold mixed juice circulated from, and back to, the mixed juice tank).
- Substitution of clarified juice for water usually used in clarification additives and in vacuum pans. Attard (1989) has explored the opportunities for substitution in a typical factory.
- An additional item that should be included is the flash loss from condensates collected at the boiler feedwater tanks.

The last item can be associated with the largest vapour loss of all (estimated at 2% on cane), but it is often ignored as it takes place at the interface between the sugar processing

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section and the steam boiler station. The boiler feedwater tank flash loss can be reduced somewhat by flashing the #1 and #2 condensates to a lower pressure evaporator vapour space, and it can be economical to install such arrangements. However, such measures, while reducing the factory process steam consumption, do not increase the production of high-pressure steam from the boiler. Presented here is another option for conserving this condensate heat to produce more high-pressure steam; this gives benefits in both the high-pressure and process side of the factory steam balance.

Dissolved oxygen in boiler feedwater

For optimum steam boiler operation, it is necessary to control corrosive elements in the feedwater. Dissolved oxygen is one of several corrosive agents in sugar factory steam boiler systems, the other two being sugary materials and juice volatiles (acetic acid and ethanol). In high-pressure boilers, dissolved oxygen causes localised corrosion and pitting of the metal system components (Anon., 1970). With time, it can cause a scab of corrosion products to form over the point of the original attack, and the corrosion can continue even if the system conditions are corrected. Higher temperatures and pressures accelerate the dissolved oxygen corrosion rate.

Two techniques are traditionally used to control the oxygen levels, *viz.* deaeration and chemical treatment. Deaeration vents the gases including oxygen and any volatiles. Chemical treatments involve oxygen-scavenging chemicals added prior to the steam-generation process.

Hydrazine is preferred for high-pressure boiler installations because the products of its reaction with oxygen are inert. For low-pressure sugar mill boilers, deaerators are usually uneconomical, as the oxygen present in the feedwater can be removed chemically inside the boiler. This is normally achieved by the use of hydrazine or sodium sulphite (Anon., 1970), which absorbs oxygen to form sodium sulphate.

Normal boiler feedwater systems

In normal low-pressure sugar factory boilers the system is to divert almost all of the primary factory exhaust steam condensate (*viz.* from #1 evaporator stage, vacuum pans and secondary/tertiary juice heaters) to large capacity feedwater tanks vented to atmosphere. There is insufficient primary condensate to satisfy the boiler feedwater requirements, so the feedwater has to be supplemented with clean secondary condensate from the #2 or #3 evaporator stages. The selected condensate is monitored, and, if suitably clean, is passed to the feedwater reserve tanks. The primary condensate has a superheat up to 20°C above the atmospheric pressure boiling point, so a substantial flash loss takes place.

Conservation of energy in the boiler feedwater

The idea of reducing the energy loss in the boiler feedwater flash follows from the following considerations:

- With a steam boiler of relatively low operating pressure (below 35 bar), the need for deaeration of the feedwater is not overriding, and the deaeration can be handled by arranging a small flash off take (0.1% to 0.2% on cane). At present, the flash of condensates to atmosphere is around 2% on cane, much greater than required for deaeration of low-pressure sugar factory boiler feedwater.
- The flash loss can be reduced if the main #1 evaporator and vacuum pan condensate return flow (the primary condensate, produced by condensation of the process steam at a temperature of ~120°C to 124°C) is held in a small pressure tank. This can then be the major feed source for the main boiler feedwater pump. Only a small controlled deaeration flash is taken off this pressure tank.
- The secondary condensates selected for make-up can be flashed to atmosphere (to remove volatiles) and stored in the existing large feedwater tank system. A low-head (150 kPag) transfer pump is arranged to transfer this to the pressure tank whenever there is insufficient flow of primary condensate. This can be automatically regulated through level control on the pressure tank and an actuated control valve in the transfer line.
- The small deaeration flow from the pressure tank is directed into the make-up tank to assist in maintaining its temperature against heat losses.

Implementation of energy conservation

The conventional boiler feedwater tank arrangement is shown in Figure 1, and the arrangement modified for energy conservation is shown in Figure 2.

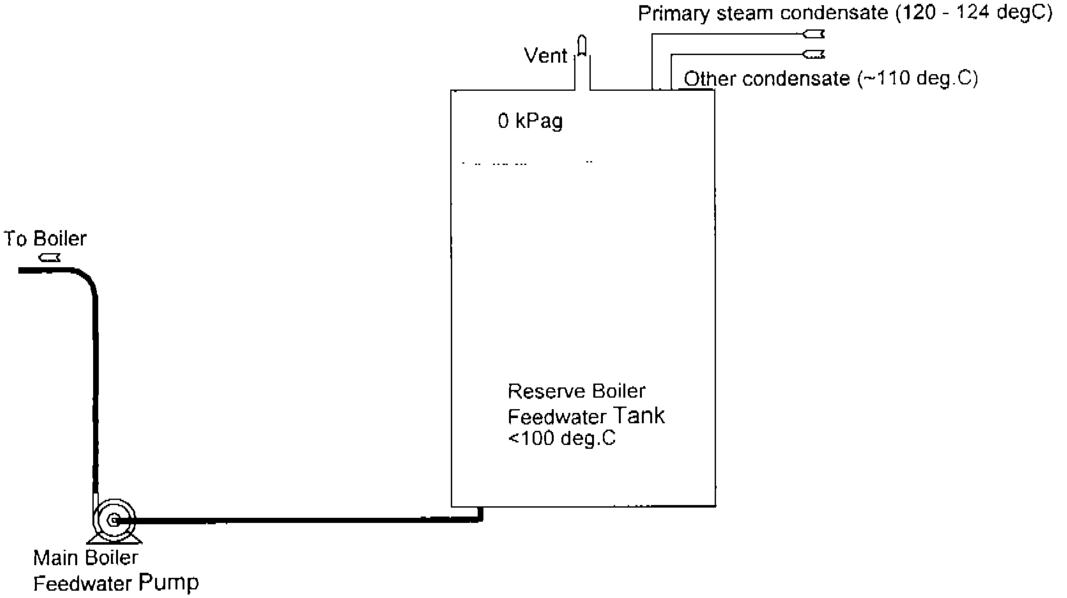

Fig. 1—Conventional boiler feedwater collection system.

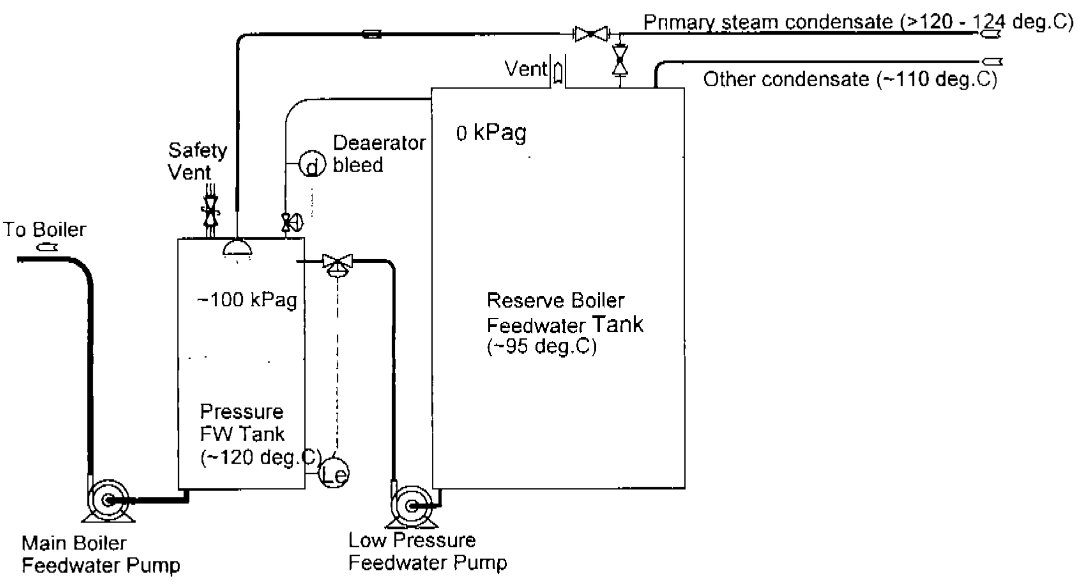

Fig. 2—Scheme for conserving boiler feedwater temperature.

Extra equipment items necessary for the modified system include:

- A small pressurised tank to maintain pressure on the primary condensate.
- A low-pressure feedwater pump, with a flow rating (against a 150 kPag head) set somewhat higher than that of the average total boiler feedwater flow. Note that at most times it will operate at less that 20% of this specification, at around the flow rate required to make-up any losses in the primary condensate circuit. Such losses can occur by leakages, boiler blowdown losses, and condensate flash.
- A flow control loop on the deaerator bleed valve to let out a nominated flash value (~ 0.5 t/h) to the reserve feedwater condensate tank. Mass and energy flows will then

dictate the operating pressure of the 'pressurised' tank and hence the temperature of the feedwater supplied to the main boiler feedwater pump.

- A level sensor in the pressurised tank, linked to a control loop that operates a valve in the line from the low-pressure feedwater pump, as well a valve in the return line to the reserve feedwater tank. The latter is necessary to provide relief if the pressurised tank becomes over-filled.

Benefits of the modified scheme

Among the benefits of maintaining the hot primary condensate under pressure are the following:

- The feedwater for the boiler is maintained at a significantly higher temperature. This means that, for a given heat release in the boiler there is more high-pressure steam generated, as the change in enthalpy for the feedwater to high- pressure steam is smaller.
- The limit on boiler capacity is commonly associated with a maximum combustion gas velocity across the boiler tubes, which is associated with the bagasse combustion rate. At the same combustion rate, the steam output will vary in inverse proportion to the enthalpy change from feedwater to boiler steam. Thus, if the feedwater is hotter the steam output of a boiler can be increased while maintaining the same bagasse combustion rate, and the steam generated per tonne of bagasse increased.
- Because there is less loss of flash from the primary condensate, there is reduced feedwater make-up from the secondary condensate source, thereby reducing the risk of contamination from sugar or volatiles.
- Because all the primary condensate is kept under pressure, there is reduced opportunity for it to contact air and to absorb oxygen, and the need for deaeration should be reduced.

Costs of the modifications

The estimated cost of the suggested modifications for a steam rate of 300 t/h, including a 30 t pressure tank, a 300 t/h low pressure feedwater pump, flow control and level control loops, has been estimated at around $125 000.

Modelling of the modified scheme

All steam generation and motive and electrical power production has been modelled in the proprietary HYSYS[1] process simulator, as well as with a spreadsheet model of the cane sugar factory. The appropriate data is transferred from HYSYS to the SRI spreadsheet model for analysis. Fully automated two-way data transfer between the two models is readily achievable to the extent that the HYSYS simulation can be an integrated component of any iterative process initiated in the spreadsheet model. The use of HYSYS adds a level of flexibility and sophistication to the HP steam analysis that would otherwise be difficult and expensive to achieve using 'home grown' spreadsheet based software.

The HYSYS steam boiler model has been modified to match 'low-pressure' steam boiler conditions (steam at 18 Bar pressure, 280°C temperature, base steam on cane 55%, base steam on bagasse 197%). It has then been used to test the effect of segregating and pressurising the feedwater/deaerator system. A series of results illustrating the effects of feedwater pressurisation has been produced. This is shown in Figure 3.

Discussion

The simulation results for the particular conditions modelled gave regression expressions for the effect of boiler feedwater temperature as given below.

$$Steam\%\ bagasse = 164.2 + 0.333*T$$

$$Steam\%\ cane = 46.0 + 0.093*T$$

where T = feedwater temperature, °C.

These expressions show that the mass of HP steam generated from a fixed bagasse flow increases by 2.3% on cane if the average feedwater temperature can be increased by 25°C (e.g. from 95°C to 120°C, the possible upper limit using he modifications suggested). The process steam quantity could increase in the same proportion. For a 600 tc/h factory this

1 AEA Technology provides HYSYS.Process Version 2.2 under licence to SRI. It is the process flow sheet simulation module of the HYSYS suite of engineering design, simulation and control software applications. It allows process flowsheets to be constructed in a diagrammatic way for automatic mathematical solution. HYSYS.Process comes with a host of fluid property databases (such as the ASME steam tables used in the models for this paper). Additional property data can be added if necessary. HYSYS.Process is also designed to interface very effectively with Windows applications such as Excel and Visual Basic to allow additional functionality to be added by the user.

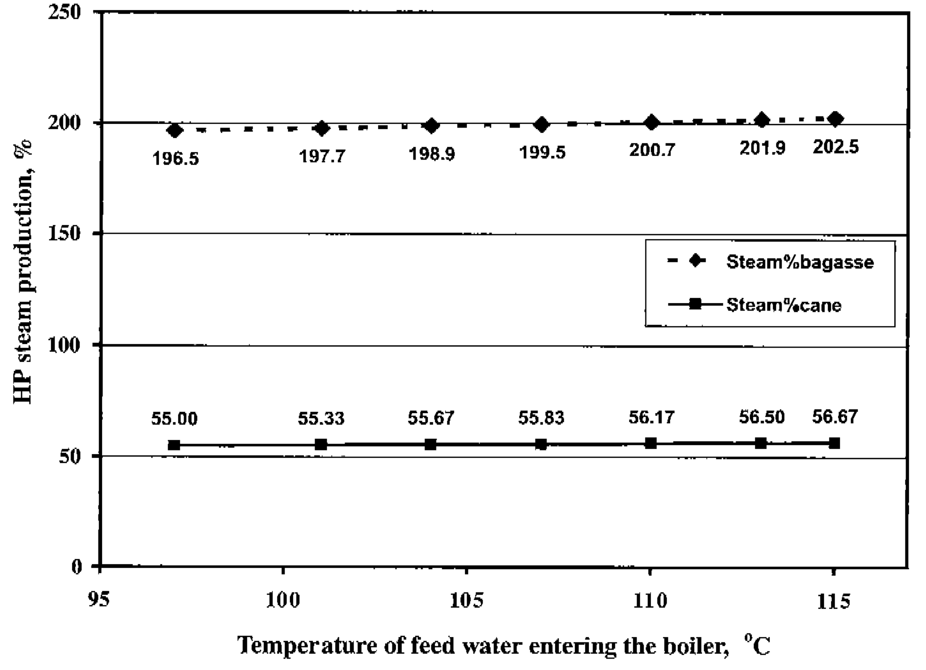

Fig. 3—The effect of energy conservation in the boiler feedwater on steam production.

would amount to approximately 14 t/h of extra steam. With a fixed steam demand, the bagasse requirement would reduce by 4.25%, or by about 7 t/h bagasse in a 600 tc/h factory. In certain circumstances, this would allow a saving in fuel supplements of over $500 000.

These benefits incur a capital cost corresponding to approximately $9000 per t/h of increased steam, or approximately $18 000 per t/h of bagasse saved. Such costs are an order of magnitude below the equivalent cost of adding efficiency-improving accessories such as air heaters and economisers to large steam boilers.

Conclusions

With the proposed scheme for conserving the energy in boiler feedwater, for a factory processing cane at 600 t/h up to 14 t/h of extra steam could be produced, or equivalently a saving of 7 t/h of bagasse could be made (amounting to 24 000 tonnes per season). The latter could save over $500 000 per season for the factory in fuel replacement for a once-only cost of around $125 000.

This simple low-cost strategy for producing extra high-pressure steam from existing steam boilers and the existing bagasse supplies can be recommended to factories that have a need to conserve fuel (such as during periods of low cane fibre or because they have a refinery or distillery that would otherwise use coal). As well, the scheme should be considered as a cost-effective method of increasing cogeneration power output in cane sugar factories.

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