THE COST OF WASTING ENERGY EFFICIENTLY

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Abstract

A SIGNIFICANT ADVANTAGE of cane sugar milling operations relative to sugar beet processing and most other industries is energy self-sufficiency. For typical cane fibre levels, the quantity of bagasse leaving a milling train exceeds the boiler station requirements for most factories. In the past surplus bagasse was universally perceived to have no value; factories were designed without emphasis on steam economy and inefficient and inefficiently run boilers were ubiquitous. This minimised the costs associated with storing and handling bagasse but has left the Australian industry with a legacy of high boiler maintenance costs, high replacement boiler capital costs and reduced reliability. This paper summarises calculations carried out to estimate the increase in boiler component wear due to different energy wasting techniques used in the boiler station.

Introduction

One of the competitive advantages of the cane sugar industry is the energy self-sufficiency of sugar milling operations. In most cases the heat energy released when burning the final bagasse residue from crushing operations is more than sufficient to produce enough steam and electricity to satisfy factory requirements.

Nearly all factories can export electricity during normal crushing operations (cogeneration) and it has long been recognised that a 'handsome profit' can be made if the electricity sale price is sufficiently high (Bell, 1931).

It is also well established that most mill areas produce surplus bagasse (Priestley, 1956) but past economic analyses have found that without incentives, large-scale electricity export would only be profitable if second hand equipment was used (Watts *et al.*, 1978).

Up until quite recently, there was little incentive for large scale electricity export from sugar factories because electricity prices were kept low due to the low costs of large scale coal fired electricity generation (Dixon and Burbidge, 2000).

This changed with the advent of the mandatory renewable energy target (MRET) in 2001 that made it possible for sugar factories to generate additional income through the sale of renewable energy certificates (RECs) (Hodgson and Hocking, 2006). This was one of the main drivers for the recent cogeneration projects at Australian sugar factories (Hodgson *et al.*, 2014; Palmer *et al.*, 2009; Trayner, 2008).

To maximise electricity export, extensive modifications are usually required to reduce the use of low and high pressure steam by the factory and increase the efficiency of the boiler station (Lavarack *et al.*, 2004; Trayner, 2008).

Most factories in the Australian sugar industry have not been modified in this way and are still set up to 'waste energy efficiently', which is another way of saying that energy is wasted without a lot of effort. This traditional mode of operation is not without its drawbacks. One of these is the accelerated wear of boiler components that becomes progressively more expensive to correct.

Background

Figure 1 and Figure 2 show the calculated effects of cane fibre content and factory steam on cane (SOC) on the rate of generation of a bagasse surplus or deficit (expressed as a percentage of the crushing rate) for boiler station efficiencies of 55% and 65% respectively. Note these boiler station efficiencies are based on the gross calorific value (GCV) of the bagasse, are averaged over the crushing season and take into account start-ups, stops, lost time and the reductions in efficiency due to load fluctuations. These calculations assume 50% bagasse moisture content, 9.5 MJ/kg bagasse gross calorific value and low pressure boilers (280 °C and 1800 kPag).

For the more typical boiler station efficiency of 55%, 50% SOC and a cane fibre content of 14%, a bagasse surplus of approximately 3.7% of the crushing rate would be expected (Figure 1).

Auxiliary fuel would not be required unless the cane fibre content fell below 12.3% or the SOC increased to above 57.5% (assuming the boiler station efficiency stayed constant at the higher steam output).

Previous studies (Hodgson and Hocking, 2006; Kent, 2007) confirmed that for most Australian factories that only have low pressure boilers and do not have condensing turbines, the costs associated with off season electricity export using this surplus bagasse as fuel exceed the revenue generated from electricity sales.

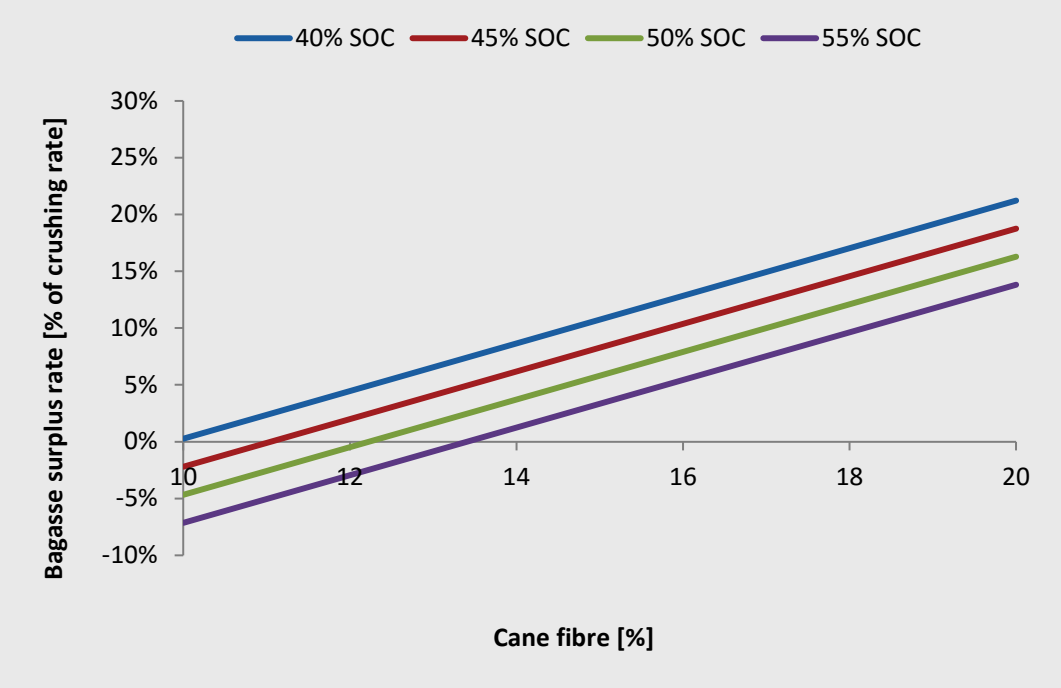

Fig. 1—Calculated effects of cane fibre content and factory steam requirements on bagasse surplus for a boiler station efficiency of 55% (GCV basis).

If the boiler station efficiency is increased towards the maximum that could be expected for bagasse fired boilers if start-ups, stops and lost time are taken into account (65%) then the calculated bagasse surplus for 50% SOC and 14% cane fibre content increases to approximately 7.5% of the crushing rate (Figure 2).

At this higher boiler station efficiency auxiliary fuel would not be required unless the cane fibre content fell below 10.4% or the SOC increased to above 68.0% (assuming the boiler station efficiency stayed constant at the higher steam output).

For virtually all the expected cane fibre contents and factory SOC in the Australian sugar industry, a large quantity of surplus bagasse would be produced that count not be burnt profitably in the off season.

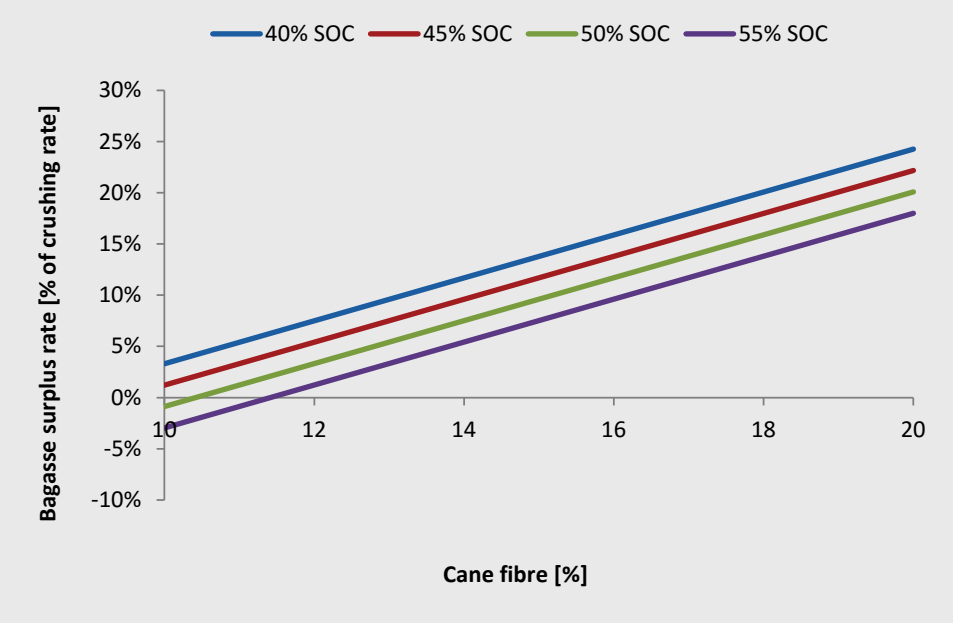

Fig. 2—Calculated effects of cane fibre content and factory steam requirements on bagasse surplus for a boiler station efficiency of 65% (GCV basis).

The historical need to avoid end of season bagasse surpluses has meant that mills have had little incentive to install high efficiency boilers in sugar factories. In fact, boiler manufacturers have publicised how to make boilers consume more bagasse to accommodate the requirements of the sugar industry (Levy, 1981). Methods employed include:

- Full or partial bypassing of a boiler's heat transfer components. This could include flue gas bypassing of a convection bank, air heater or economiser, air bypassing of an air heater, or water bypassing of an economiser. The purpose in all cases is to reduce boiler efficiency by increasing the energy lost in the final flue gas.
- Increasing the quantity of air entering a boiler. This reduces boiler efficiency by increasing the energy lost in the final flue gas.
- Operate the boilers at higher loads to produce extra steam that is surplus to factory requirements. This surplus steam can be condensed externally to the boiler to recover the condensate.
- Increasing the bagasse moisture content using water sprays, sometimes referred to as 'bagasse moisture conditioning'. This reduces boiler efficiency by increasing the energy lost in the flue gas.

All the above options increase the flue gas flow rate through a boiler and will therefore increase wear of boiler components.

Convection bank tube wear is a serious problem, particularly in boilers with baffled convection banks (Levy and Frost, 1979; Plaza *et al.*, 1999) and erosion, along with dew point corrosion, has contributed to the failure of several economisers (Masotti, 2013). Erosion of dust collector components makes it difficult for boilers to comply with emission limits (Scott, 2009).

Raask (1969) found that the wear rate of boiler tubes due to an oncoming stream of particle was proportional to the particle velocity to the power of 3.5. More recent work (Novozhilov *et al.*, 2001) developed an expression for tube wear due a single bagasse ash particle impact that can be rearranged into the following form

$$\xi = C\eta^3\rho_p^{2.05}\left(\frac{|U|^2}{B}\right)^{1.05} \mathrm{G}\left(\frac{\mathrm{d}}{\eta}\right)\mathrm{H}(\alpha) \qquad \textbf{(1)}$$

where C is an empirical constant, η is the grain size of the tube material, ρ_p is the particle density, U is the particle velocity, d is the particle diameter, B is the hardness of the tube material and α is impact angle (the angle between the particle direction of motion on impact and the tube surface). The functions $G\left(\frac{d}{\eta}\right)$ and $H(\alpha)$ take into account the effects of ash particle diameter and impact angle on the wear rate and are shown graphically in Figure 3 and Figure 4.

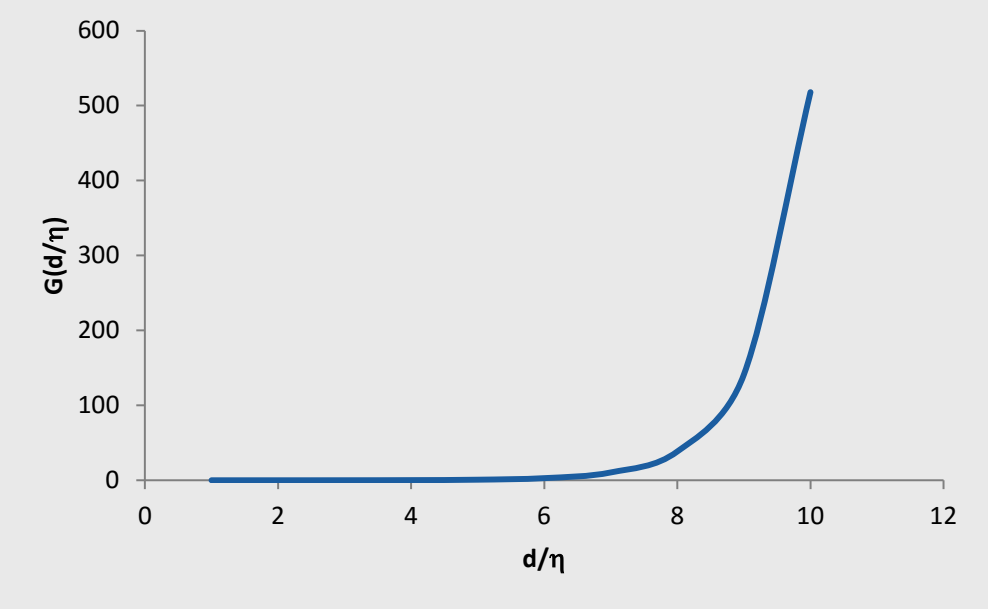

Fig. 3—Effect of particle size on wear rate.

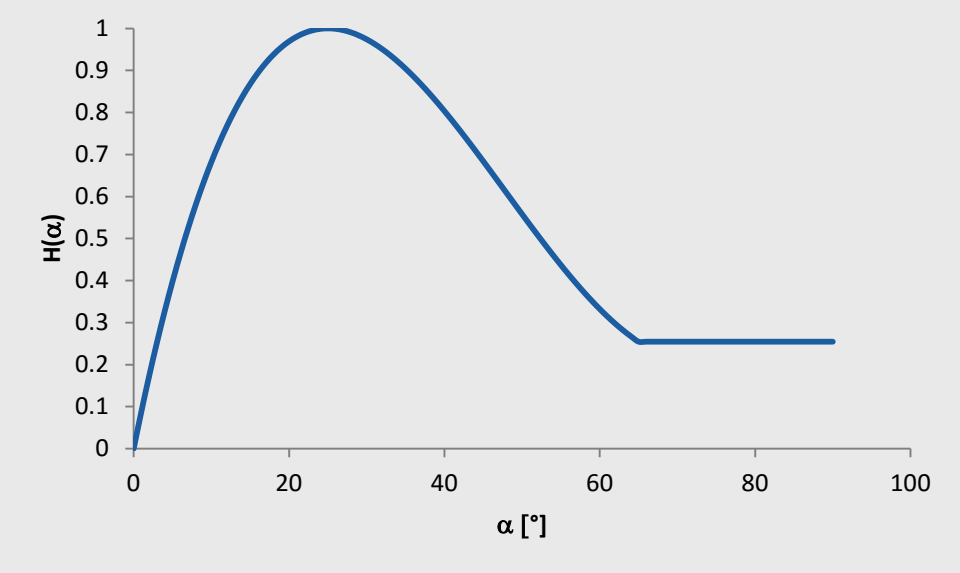

Fig. 4—Effect of impact angle on erosion rate.

From Equation 1 the mass of tube material removed in a single impact is proportional to the particle velocity to the power of 2.1.

To convert this to a wear rate (mass loss per unit time) ξ, the mass lost in a single impact, should be multiplied by the number of impacts per second which is proportional to the particle velocity and the particle concentration (number of particles per unit volume). Therefore using Equation 1 makes the wear rate proportional to the particle velocity to the power of 3.1.

Procedure

A previously developed BOILER model (Dixon *et al.*, 1998; Mann and Dephoff, 2006) was used to predict how different options for increasing boiler station bagasse usage to match the bagasse supplied by the milling train affect boiler tube wear. For the base case conditions, it was calculated that the bagasse rate from the milling train was 28.4% of the crushing rate for a cane fibre content of 14% and a final bagasse moisture content of 50%.

A boiler station efficiency of 65% GCV basis (taking into account start-ups, stops and lost time) was assumed which gives a boiler station bagasse usage of 20.9% of the crushing rate for a factory with 50% SOC and low pressure boilers (280°C and 1 800 kPag).

The modelled options for increasing the bagasse usage of the boiler station are:

- reducing the efficiency of the boiler station by bypassing and/or removing boiler heat transfer surfaces
- reducing the efficiency of the boilers by operating the boilers at higher excess air levels
- increasing the steam output of the boiler station
- increasing the moisture content of the bagasse sent to the boiler station by adding water.

For each of the above options incremental changes were modelled up to the point where the modelled boiler station bagasse usage matched the bagasse rate from the milling train (28.4% of the crushing rate). The BOILER model was used to predict the maximum convection bank gas velocity for the base case and each change.

The relationships of Raask (1969) and Novozhilov *et al.* (2001) were then used to estimate the wear ratio (wear at predicted flue gas velocity / wear for the base case) for each change from the maximum convection bank gas velocity ratio (maximum convection bank velocity / maximum convection bank velocity for the base case).

Results

Figure 5 shows the predicted increase in wear ratios as the boiler station efficiency is reduced by up to the 17.2 percentage points required for the rate of boiler station bagasse usage to match the bagasse rate from the milling train (28.4% of the crushing rate).

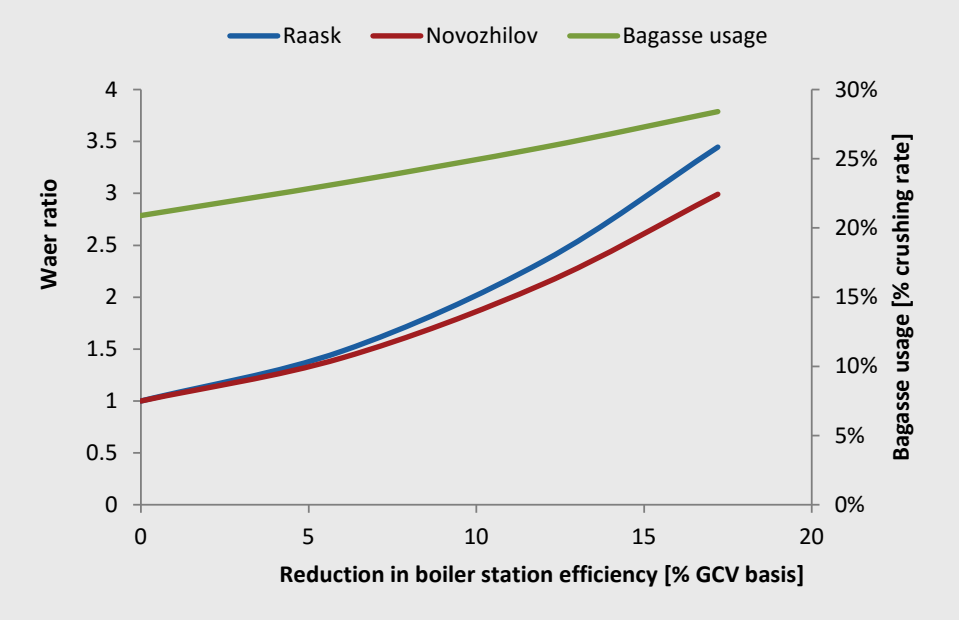

Fig. 5—Predicted effects of reducing boiler station efficiency by bypassing or removing boiler heat transfer surfaces on tube wear and boiler station bagasse usage.

The calculated bagasse usage, expressed as a percentage of the crushing rate, is also plotted against the reduction in boiler station efficiency. Reducing the boiler station efficiency from 65%, which is close to industry best practice, to 47.8%, which is close to the lowest boiler station efficiency in the industry, by removing and/or bypassing heat transfer surfaces is predicted to increase wear by a factor ranging from 3.00 to 3.45. This would cause a corresponding reduction in the life of the heat transfer surfaces affected by ash particle wear that are not bypassed.

Another option for increasing boiler station bagasse usage that is usually easier to implement than bypassing and/or removing heat transfer is to operate the boilers at higher excess air levels.

This can only be done if the boilers have sufficient fan capacity. However as Figure 6 shows, this approach has a dramatic effect on tube wear, with the predicted wear increasing by a factor of between 4.93 and 6.99 as the boiler station bagasse usage is increased from 20.9% to 28.4% of the crushing rate.

This significant increase in wear occurs because increasing the excess air level at which a boiler is operated causes a much greater proportional increase in flue gas flow than bagasse consumption. Note the calculations carried out to produce Figure 6 take into account the reduced particle concentrations at higher excess air levels.

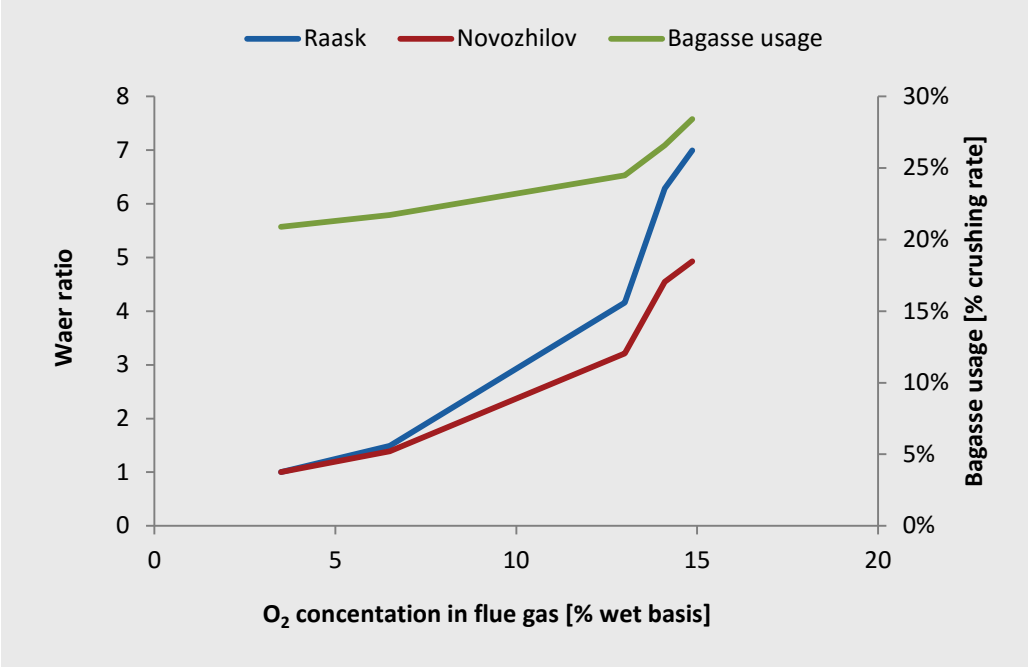

Fig. 6—Predicted effects of increasing excess air levels on boiler tube wear and boiler station bagasse usage.

The bagasse usage of the boiler station can also be increased by operating the boilers at higher loads, if they are able to do this, so that surplus steam is produced. If there is not enough turbo-alternator capacity to utilise this surplus steam, which is the case in a lot of factories, the surplus steam can be condensed so that the water can be re used by the boilers (Levy, 1981) or vented.

Figure 7 shows that the bagasse usage of the boiler station can be increased from 20.9% to 28.4% of the crushing rate by increasing the 'effective' SOC from 50% to 66.4% and tube wear is predicted to increase by a factor of between 2.92 and 3.36. This predicted increase in tube wear is slightly less than that predicted with the option of bypassing and/or removing heat transfer surfaces. Note the BOILER model simulations used to produce the data in Figure 7 take into account the reduction in boiler efficiency that occurs as boilers are operated at above maximum continuous rating steam loads.

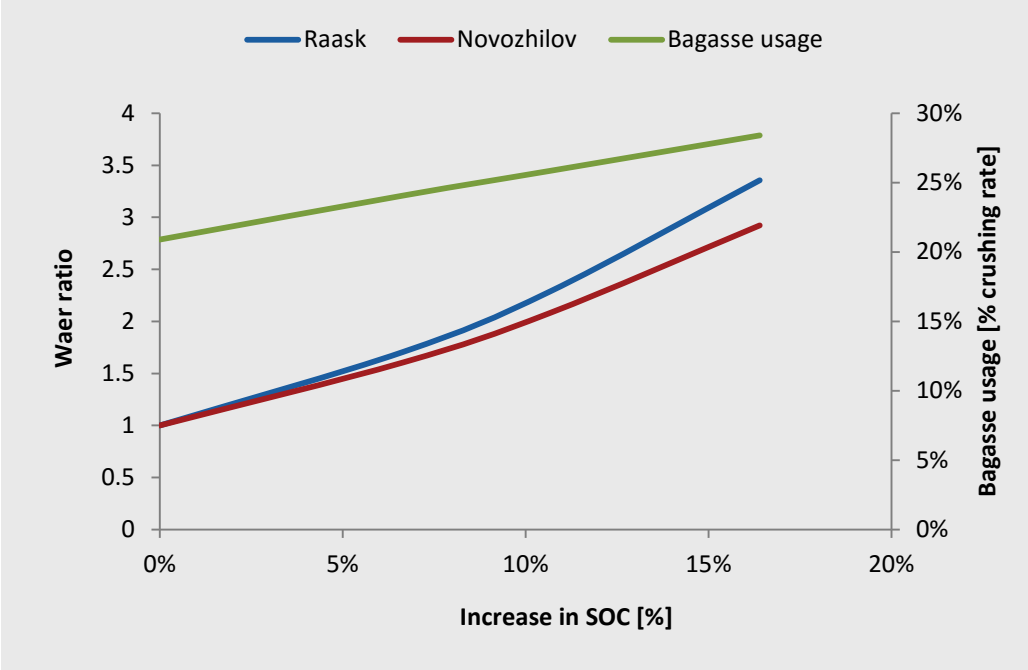

Fig. 7—Predicted effects of increasing boiler station steam generation on tube wear and boiler station bagasse usage.

The final option considered in this work for increasing boiler station bagasse usage was to increase its moisture content by adding water prior to the boiler station. To increase the boiler station's usage of 50% moisture content bagasse from 20.9% to 28.4% of the crushing rate the bagasse moisture content has to be increased from 50% to 69.45%. Figure 8 shows that when this is done the rate of tube wear is predicted to increase by a factor of between 2.93 and 3.37.

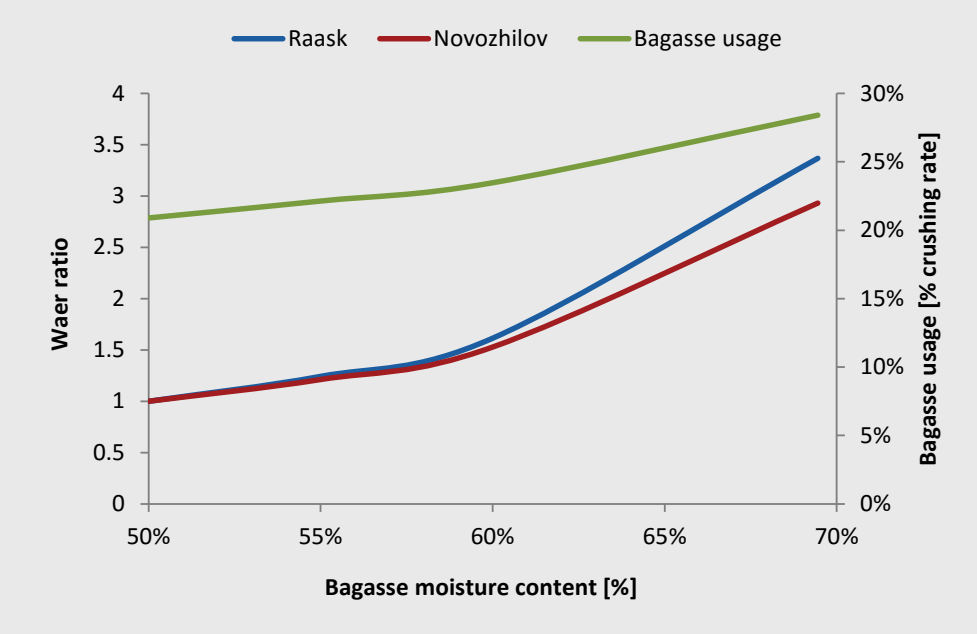

Fig. 8—Predicted effects of increasing bagasse moisture content on tube wear and boiler station bagasse usage.

This predicted increase in tube wear is comparable to that predicted with the option of increasing bagasse usage by increasing the boiler station steam output. However it is noted here that all bagasse boilers in Australia would require a major redesign for stable boiler operation at bagasse

moisture contents above 55%. This option is therefore not viable for significantly increasing the bagasse usage of an existing sugar factory boiler station.

Conclusions

The calculations carried out in this work have confirmed that increased tube wear is a significant drawback of all the main techniques used to increase the bagasse usage of the boiler station to balance the bagasse supplied by the milling train.

Increasing boiler station bagasse usage by increasing the excess air levels, while often the easiest to implement, is predicted to give the worst boiler component wear and is not recommended. Increasing the bagasse moisture content by water addition is also not practical because it would not be possible to operate the boilers stably with the quantity of water required to significantly increase boiler station bagasse consumption.

The other options of bypassing and/or removing boiler heat transfer surfaces and operating the boilers at increased steam output are also predicted to significantly increase boiler component wear but not by anywhere near as much as operating the boilers at increased excess air levels.

Given the current uncertainty associated with the pricing of electricity from renewable sources such as bagasse, sugar factories are understandably reluctant to commit to large cogeneration projects and in many cases will continue to 'waste energy efficiently' to avoid accumulating large bagasse surpluses and suffer the consequences of increased boiler component wear.

Looking forward, it appears that sizing the boiler station to burn all the available bagasse is preferable to sizing the boiler station to satisfy factory steam requirements, both to minimise boiler component wear and to reduce the costs of increasing electricity export when it becomes economically viable to do so. This will however increase capital costs.

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