OVERVIEW OF ENERGY EXPERIENCE AT C.G. SMITH SUGAR LTD.

G. Salt

C.G. Smith Sugar Limited
359 West Street, Durban 4001; South Africa

ABSTRACT

C.G. Smith Sugar operates six sugar factories in South Africa, of which three have back-end refineries, and two have associated by-product operations, which burn coal as supplementary fuel. The paper reviews energy conservation measures adopted over the past decade, including experiences in Mechanical Vapor Recompression, exercises in Process Integration or Pinch Technology, moves towards the use of falling film evaporators, cogeneration, and proposals for energy conservation designs in cane sugar factory complexes of the present day.

INTRODUCTION

"In this paper I have attempted to give an overview of our experience over the past decade or so, in the six C.G. Smith Sugar factories in South Africa; on how the energy issues has impacted on these factories; on what we have attempted to do, on how far we have succeeded, some of the limitations, and finally where we are going in the future."

We recently had the opportunity in a detailed design study to set out what we would do on a "greenfield" site, without the restrictions imposed by existing installation. We were unfortunately unable to implement this project, but the ground rules that were established will be applied to future factories and to the development of our existing ones.

It would be far beyond the scope of this paper to deal in any depth with the subjects raised, and there are many references to be found elsewhere on the subjects of Mechanical Vapor Recompression, Process Integration or Pinch Technology, and cogeneration, outlined in the paper.

THE C. G. SMITH SUGAR FACTORIES

C.G. Smith Sugar operates six sugar factories near the east coast of South Africa in subtropical conditions. They crush annually some 8 million tons of cane over
SYMPOSIA·PRESENTATIONS

a 34-38 week season. The factories presently comprise, from North to South:

1. PONGOLA
   (Located just outside the Natal border in Eastern Transvaal) Throughput 210 tch, by cane diffusion, with a back-end carbonatation refinery, producing 100% prepacked refined white sugar. It burns coals as supplementary fuel.

2. GLEDHOW
   Throughput 300 tch; having two extraction lines, one milling, one cane diffusion, with a back-end carbonatation refinery, producing 100% bulk conditioned refined white sugar, and supplying depithed bagasse to an associated paper plant, using coal substitution for supplementary fuel.

3. NOODSBERG
   Throughput 310 tch, with a single line milling plant, and with a back-end refinery, importing supplementary raw sugar from a nearby factory to produce the equivalent of 140% refined sugar by phosphatation, deep bed filtration and ion exchange. Essentially it is in an energy balance situation, occasionally burning coal as supplementary fuel.

4. ILLOVO
   Throughput 200 tch, by cane diffusion, producing VHP raw sugar and golden invert syrup for domestic use. It is capable of exporting fiber for paper production, but presently burns all its bagasse.

5. SEZELA
   Throughput 450 tch by cane diffusion in two parallel lines and with two parallel evaporator stations. It produces 100% bulk VHP raw sugar. It also supplies an associated chemical plant with some 60% of its bagasse as feedstock for furfural and furfuryl alcohol production, together with large quantities of HP steam and condensate. The furfural operation returns an equivalent quantity of residue for fuel, and also returns LP steam as exhaust from its reboilers. It burns coal as supplementary fuel.

6. UMZIMKULU MILL
   (The most southerly cane sugar factory in the world, at 31°S latitude) Throughput 235 tch, by cane diffusion, producing VHP raw and prepacked brown sugars. It is also capable of exporting surplus fiber. It supplies a small simultaneous distillation unit with coproducts and also receives some steam from a关联

IDENTIFICATION OF ENERGY SAVINGS

Over the past period of some 10-15 years, there has therefore emerged a need to develop energy strategies to meet the demands of the various coal burning
complexes. This has been in part achieved by energy management, by maintaining boiler efficiency, minimizing water addition to process, and the improvement in overall time efficiency - OTE. Our factories operate between 85-92% OTE for the season, including all stoppages based upon a 168 h week, evaporator cleaning generally every second week. *This paper will deal only with major design and equipment strategies.

DEVELOPMENT OF MECHANICAL VAPOR RECOMPRESSION (MVR)

Early in the 1980s the potential benefits of MVR to reduce process steam demand were recognized, and three installations were subsequently built.

The requirement for MVR to be able to reduce steam demand is firstly a substantial let-down margin, i.e. the difference between process demand and prime mover exhaust. The MVR recompresses vapor across part of the evaporator, reducing the process steam demand accordingly, but in turn creates its own prime mover demand which in turn produces further exhaust, with the let-down margin being the limiting factor. There is much greater scope for MVR with a diffusion factory than with mills, which have traditionally been driven by low efficiency turbines.

1. PANGOLA

Our first venture consisted of a trial Brian Donkin compressor of 31 t steam/h capacity, turbine driven through an independent gearbox. This was installed in 1980, operating with a semi-Kestner rising film evaporator vessel. It had a relatively low compression ratio of about 1.33:1, and therefore needed a dedicated vessel to compress around, which limited its operational performance due to the effect of tube scaling which increased approach temperatures and thus required it to operate over a wider range of conditions than were originally specified, i.e. a higher compression ratio.

Whilst gaining experience, we incidentally found that we had overlooked the possibility of MVR driving the turbine, enabling the system, on one occasion, to run backwards at high speed, losing lubrication in the gearbox.

Although the unit has achieved coal savings of 0.86 t/h or 6 t/h HP steam, its operation was limited due to the low compression ratio and its integration within the evaporator, and it was subsequently taken out of service when the evaporator with its multitude of vessels was reconfigured due to being suspected as the major cause of a high undetermined loss (Allen et al.),

2. NOODSBERG

With the addition of the back-end refinery in 1982, an MVR was installed and became operational in 1984. It was dedicated to one evaporator vessel but
installed to operate either between vapor II to exhaust or to vapor I, depending on the degree of evaporator fouling. Operating over two effects the MVR would provide 6 tons of evaporation per ton of live steam used.

An Alsthom Rateau Type SM-67-1 compressor for 40 tons/h, running at 12,214 rpm, having a maximum compression ratio of 2.3:1 was selected. As the factory had adequate alternator capacity, a fixed speed electric drive of 2.2 MW through an integral gearbox was therefore chosen with inlet-vane control.

It operated well from day one and substantial fuel savings were achieved. However, ignorance of transient operating conditions led to failure of the compressor rotor by disintegration, some two seasons later.

The cause of failure was by no means obvious at the time, and we then entered into wide ranging and thorough investigations into every aspect of the theory and actual transient operating conditions of this MVR. It included an examination of the operational log sheets for trip occurrences, a dynamic stress analysis of the compressor rotor, an analysis of starting conditions, system characteristics, and a detailed investigation into surge protection and control. Surge is the term used to describe the breakdown of flow over the impeller blades, resulting in reverse flow taking place.

This investigation led to a complete vindication of the machine, with two major factors being identified:

i) One of the speed steps occurring during the resistance starter start-up profile coincided with the first blade harmonic frequency, and this step was unfortunately incorrectly held for 25 secs (the steps had been set up additively rather than from start).

ii) Surge protection was by means of blow-off to atmosphere with slow response digital controllers, of the order of 6 secs.

The machine was substantially rebuilt with the following changes:

i) Start-up settings were reset to avoid pauses close to blade harmonic frequencies.

ii) The compressor was fitted with a shroud ring at entry point as an additional precaution to dampen blade harmonics.

iii) High speed analogue anti-surge protection by the Compressor Control Corporation, operating within milliseconds, was installed together with vapor recycling.
iv) Pipework was modified to reduce losses and to allow for recycling over the compressor.

The results over the past five seasons have been excellent, meanwhile the refinery has been expanded to refine at the rate of 140% of raw sugar production. The resulting coal saving of 1.5-2.0 t/h has been consistently achieved.

The initial capital cost of R850,000 approved in 1983 has been repaid by an annual coal saving of some 7,500 tons. In addition concomitant changes to the evaporator configuration increased the total saving to 402 tons/week or 12,500 tons for the season, at a cost of R1,213,000 ($425,000) (Koster and Webb).

3. SEZELA

In 1982 when the Sezela factory was undergoing a major expansion in line with its chemical by-product operation, it became clear that MYR was economically justified. Two Alstom Rateau machines type TSM-82-1, similar to the Noodsberg machine, were selected, each 50 tons/h operating at 6,200-10,500 rpm and up to 2.3:1 compression ratio; and were initially installed in 1984. Due to limitations in electrical generating capacity we selected an integral high efficiency turbine drive (11,500-19,500 rpm), operating this time with variable speed control, operating range to range, between vapor I and exhaust. Some early problems were encountered and we benefitted from the experience at Noodsberg and were able to introduce the same anti-surge controllers before any damage was done.

We unfortunately have gained only limited operational experience with this installation due to the gradual expansion of the by-product operation, which has eaten into the let-down margin. As a result of returning more process steam this change has occurred despite attempts to improve the margin by electrification of the dewatering mill prime mover, by fitting variable speed DC drives in place of steam turbines, and expanding the generating capacity.

PROCESS INTEGRATION - "PINCH" TECHNOLOGY

The techniques of process integration, or "Pinch" technology as it is more generally known, were established during the 1970s by Linnhoff et al, and became well established in the following decade, as a systematic technique for the establishment of optimum energy designs in process plants, by achieving a balance between capital and energy costs.

In spite of the apparent lack of potential in the sugar industry we decided in 1988 to review the expertise then available, which was being offered commercially in the
U.K. The basic technique now forms part of chemical engineering curricula, and we were fortunate to be able to sponsor a chemical engineering graduate for a master degree, specializing on the evaporator and sucrose inversion effects.

Whilst the methodology is beyond the scope of this paper, the technique is based on a systematic analysis of a process plant into a number of process units connected by streams, cold streams which require heating and hot streams which require cooling. These analyses are set out as composite curves of temperature versus heat input (enthalpy), which can be combined into a grand composite curve. The balance of heating and cooling requirements must be met by hot (e.g. steam) and cold (e.g. cooling water) utilities.

Heating and cooling composite curves are closest at what has come to be known as the "Pinch" temperature, determining minimum energy targets, and setting out basic rules on heat transfer. The golden rule states that for minimum energy, heat transfer must not take place across the Pinch, which also means that energy should only be transferred between streams either lying above or below that temperature. It is therefore possible rigorously to examine designs which previously have only been determined by trial and error or by the instincts of experience.

Integration of the evaporator as a multiple level utility into the Grand Composite curve was first identified by MacDonald. For a typical South African Diffuser factory, the pinch temperature is around 85°C, and it follows that for minimum energy, the evaporator should lie completely above or below the pinch temperature. Whereas traditional evaporators straddle the pinch, they cannot therefore achieve minimum energy usage.

This minimum energy concept can only at present be achieved by the use of falling film evaporators, operating at low approach temperatures, and with low retention times to minimize inversion losses associated with the higher temperatures and brix levels. We have determined that a typical quadruple effect falling film design could operate between a temperature band of 130°C and 100°C. With this design process steam demand can be reduced to the order of 35% on cane (Brouckaert and Seillier) (Figure 1).

For the benefit of those conversant with pinch technology, Figures 2 and 3 show the way the falling film design can be fitted into the grand composite curve, compared with conventional design, typically on basis of steam % cane.
FIGURE 2. Conventional evaporator matched to grand composite curve.
FIGURE 3. Falling film evaporator integrated with grand composite curve.
Raising the back pressure of the steam turbines to achieve 130°C has an adverse effect on their specific steam consumption, increasing the exhaust production by about 10%, but also reducing the potential output.

We have prepared an alternative design that can operate in triple effect, using MVR, between 121°C and 100°C, at approximately the same steam consumption (Figure 4).

1. FALLING FILM EVAPORATORS

Whilst falling film evaporators are commonplace in many industries, and have more recently been introduced in beet sugar and refineries, their use in raw sugar has been held back as they were thought to be temperamental, difficult to operate, were prone to scaling, and the distributor had a tendency to block and cause drying out of tubes.

In view of the immense potential for energy savings within the C. G. Smith Sugar Group it was decided to move towards the use of falling film evaporators (Fitzgerald et al. ). Firstly to build a pilot but representative plant, to gain operational experience and to establish those factors specific to our industry, including heat transfer rates and the effect of fouling and scaling of tubes.

During the first season on standard first effect duty, the trial unit confirmed most of the reported characteristics of this type of evaporator, and exhibited a scaling rate which was much lower than that of conventional evaporators for a similar duty. Heat transfer coefficients of 3 kW/m²/°C have been maintained over several weeks of operation.

Trials at higher brixes are proceeding and we are presently starting to encounter problems with distributor fouling, but the test program for the last few weeks of the season will be covering the higher temperature profile. A program of two to three years development is envisaged to reach operation on a full production basis.

2. ELECTRIC POWER GENERATION

Although cogeneration of electricity is standard practice in many industries, including the U.K. beet industry, our national utility company, Eskom has been reluctant to purchase surplus power at other than coal-equivalent rates. This is certainly not attractive at South African pit-head prices, R52/ton ($ 18). However the situation is changing, in spite of Eskom having presently 2000 MW surplus generating capacity, and discussions are proceeding on the potential for cogeneration with them for supply of surplus power. Thus the
total process steam demand could then be used for power generation, completely eliminating the let-down margin. It would then be preferable to operate in parallel with the grid and control on the low pressure process team requirements, feeding surplus electrical power into the grid, rather than operating on a fixed load. At the present time, we could make a total of 20 MW available with existing plant, during the season, but without the restrictions imposed by existing equipment there is potential to achieve far more.

OPPORTUNITIES IN RAW SUGAR FACTORIES

"I was about to start this section with - The Sugar Mill of the Future, but it really refers to 'The Sugar Mill of Today', because what is proposed is what we would build in present-day circumstances; in fact the brief for the design for the new mill project included a requirement for "no untested or unproven technologies", a very important factor for a sound commercial venture."

1. NEW MILL CONCEPT

For a new sugar mill to be viable in today's world it needs to be integrated with a by-product venture. Therefore energy conservation is a major factor, if not the major factor in the design.

We tried to look as far ahead as possible so that we could anticipate as many as possible of the pitfalls that presently hold us back with retrofit operations. Furthermore as there was no clear cut route that the company would follow with by-product production, these decisions would be taken down the line according to market forces prevailing at the time - from experience, we have seen by-product markets fluctuate, and one must allow room to manoeuvre accordingly.

We therefore set about the basic decisions so as to leave as many options open as possible for any future stage in the development of the complex, even though the project did not call for by-product production from the start. Essentially the design allowed for fiber and/or energy (power, steam, etc.) export.

The possible stages in the development of the complex would be:

Stage 1  Raw sugar factory, with option for electricity export.
Stage 2  Addition of back-end refinery.
Stage 3  Addition of by-product plants, possible bagasse pulp, furfural, alcohol and/or single cell protein.
2. PRIME MOVER LOAD

We have seen from our "pinch" technology work that the practical minimum process steam demand could be as low as 35% on cane, therefore the prime mover total steam demand should be less than this. Despite using electric drives for all prime movers it is possible for a cane diffuser factory to operate with an electrical load of about 40-45 kW per tch, all of which can be generated efficiently. Meanwhile the total letdown margin is available for the generation of electricity for export or for irrigation.

3. PROCESS REQUIREMENTS

As we would initially be following the conventional evaporator route, we would retain our industry standard exhaust of 121°C, 205 kPa abs, but to be able to benefit from the potential of the falling film evaporator development, provision would be made to raise this to 131°C, 278 kPa in the future, and the turbine design should allow for this.

An important factor in maintaining these low process steam consumptions is continuous operation and in this respect one must include for continuous sugar boiling especially on "A" massecuite production.

4. STEAM CONDITIONS

It is obvious that the selection of the steam conditions required for any installation is generally a compromise, but the following are typical figures (Whittaker8) for turbine steam consumption:

i) With steam conditions of 31 bar abs, 380°C, and an exhaust pressure of 205 kPa abs, our present standards, a specific steam consumption of 7.4 kg/kWh can be obtained for a 10 MW turbo-generator rated at maximum output. There is an increase in specific steam consumption below its rated output,

ii) With steam conditions of 41 bar abs and 400°C, a fairly substantial saving in steam rate can be achieved to say 6.7 kg/kWh.

iii) However, with an increase in back pressure associated with 131°C 278 kPa, the 10% saving would be cancelled out.

iv) Under condensing conditions, with a dryness fraction of 0.92 anticipated in the exhaust of the turbine, the specific steam consumption would be 4.4 kg/kWh.
v) In recent years there has been a trend in the European sugar industry to increase the steam inlet conditions to typically 81 bar abs and 525°C. A check calculation shows that a specific steam consumption of 5 kg/kWh would be achievable.

We considered that there was no need drastically to uprate our steam conditions beyond 41 bar abs and 400°C, with its attendant greater sophistication of boilers, materials and water treatment, unless electric power generation became our primary objective, in which case condensing sets could be considered depending upon the final configuration. The prime mover steam demand would then become approximately 30-33% on cane.

The possible stages in the development of the complex would be:

i) Initially a 220 tce raw sugar factory, using quadruple effect evaporator and furnace capacity to use all the bagasse, but still capable of generating 20 MW surplus electrical power. The mill would have potential for expansion in stages to 350 tce or more.

ii) Addition of a back-end refinery, with conversion to quintuple effect evaporator with addition of an MVR, maintaining the potential for co-generation for export, and/or

iii) Addition of a by-product plant or plants, with conversion to falling film evaporation, either at 205 kPa or 278 kPa, with potential to release up to 100% of the bagasse, with minimum coal substitution, or to increase power generation with condensing sets.

CONCLUSIONS

The traditional cane sugar industry has been carrying the inheritance of a policy dictated by the need to balance process steam demand with total bagasse fuel supply. "I recall an early introduction to the industry" as "What better way of letting down steam than through a cheap inefficient steam turbine". Those days are gone, bagasse is an important raw material even as an energy producer, and we now have the tools to design for energy conservation. We would be failing our successors if we did not take the future into account in the sugar factories we are now building.

ACKNOWLEDGMENTS

The author would like to thank the management of C.G. Smith Sugar, and colleagues at Technical Services, the six sugar mills and the chemical division, for
the opportunity to work with them over the past ten years, to gain the experience which has been outlined in this paper.

REFERENCES


