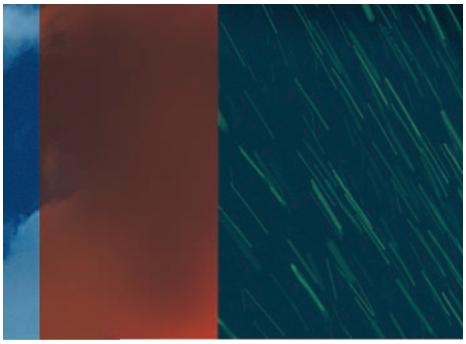
Chapter 17



SUGAR MILLING

Don Mackintosh

SUGAR mills are located within the cane lands and process cane supplied by the growers to produce raw sugar. A mill crushes and washes the juice from the cane. Then, over a series of operations, it separates as much as possible of the sucrose from the water, impurities, fibre and dirt that make up the balance of the cane juice.

The miller's responsibility for the process commences at the siding or loading pad where the harvested cane is left for collection. The cane is transported to the mill by rail (predominantly) but also by road (all cane in northern New South Wales, Maryborough district, on the Atherton Tableland, and Ord River irrigation region in Western Australia). There are 3600 km of purpose-built rail system in the Australian sugar industry. The system is predominantly 610 mm gauge.

In rail systems, cane is held at the mill in 'full yards' with several hours crushing capacity and at the district rail sidings. In road systems, storage is usually at the field pads with a just-in-time system governing arrival of cane at the mill. There are also systems in which road-delivered cane is transferred to rail bins for final transport to the mill. The Australian sugar industry tailors its harvesting, delivery and crushing operations to ensure that the time between cutting and crushing does not exceed 16 hours. It aims for the lowest possible delay to minimise cane deterioration and consequent sugar loss.

Weighbridges for rail systems are typically weighing tipplers introducing the cane to the mill. Standard weighbridges are used with road transport with subsequent tipping into a purpose-built cane carrier for milling.

A grower's parcel of harvested cane is maintained segregated in transit and at the mill prior to crushing. The size of a parcel is limited by the requirement that individual parcels are processed at the mill in less than 20 minutes of crushing time.

The cane is weighed prior to processing. Cane payment to growers depends on this weight and on quality measurements. Millers provide facilities for sugar cane analyses.

The analyses may be completed by the mill and audited for the miller and the grower by independent persons called cane auditors. Alternatively, independent cane analysts may carry out the analyses on behalf of the miller and grower.

The miller distributes those parts of the overall raw sugar return due to each supplier according to long-standing cane payment arrangements and advice from Queensland Sugar Limited on the sale price of the sugar.

The stages in the milling process are briefly described in this chapter.

CANE TO CLARIFIED JUICE

In the sugar milling process, cane is crushed and the juice undergoes a process of clarification, as shown in Figure 1.

Cane preparation

Australian cane is all harvested mechanically, and cane is presented to the mill in billets, 200–250 mm long. The tipped cane is levelled to a consistent depth and fed into a hammer-mill shredder which opens about 90% of the juice cells in the cane. This improves the efficiency of removal of the sugar from the fibre in subsequent processing.

The shredder contains a very large number of heavy hammers (100–200 each of about 20 kg mass) loaded on a shaft rotating at around 1000 r/min, and driven by one or two steam turbines. The hammers impact on the cane billets and are assisted by an opposing washboard-type grid bar. The design of the shredder, its hammers with appropriate hard facing, the grid bar and the power applied

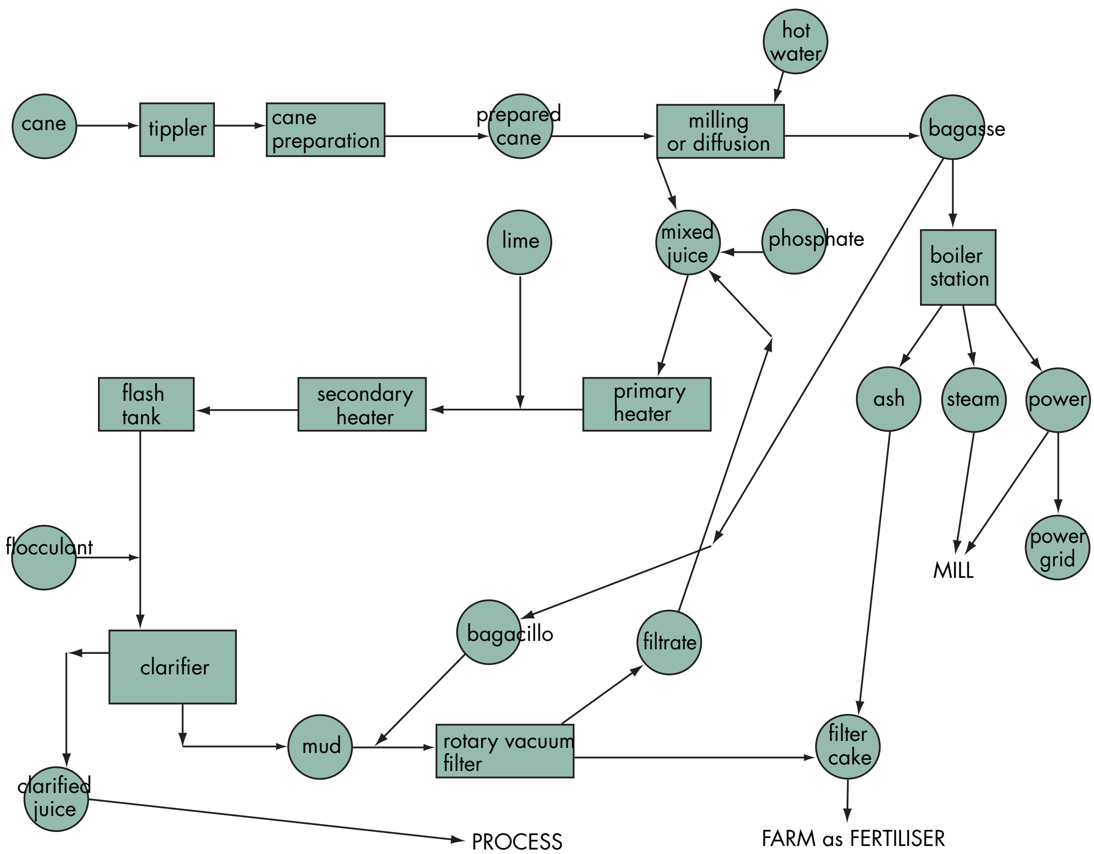


Figure 1. *A sugar mill—cane to clarified juice.*

are crucial for good cane preparation and must be matched to the fibre content and fibre characteristics of cane supplied.

Juice extraction

A single milling train can process up to about 800 tonnes of cane per hour. Some mills have more than one milling train. Crushing or grinding rollers are the predominant juice extraction equipment in Australian mills. These rollers are arranged in sets and three to five sets make up a 'milling train'. Rollers are sized to meet required throughput and may be up to 2.75 m wide.

A roller set in a conventional operation comprises three rollers arranged triangularly to ensure juice removal and to open further juice cells in the cane. These rollers are fed by two pressure feeder rollers which take prepared cane from a vertical chute and may be assisted by an under feed roller at the exit from the chute.

Cane exiting a roller set is called 'bagasse'. Maceration, which is hot water or juice from a following set, is doused on the bagasse as it leaves the set to refill the opened juice cells to help flush out the remaining juice at the next crushing set. The amount of added maceration water is typically controlled to about 200% of the amount of fibre moving through the sets. The balance between the level of maceration to achieve higher sugar extraction and the difficulties in subsequent processing of the water is an important issue in mill control.

A few mills employ an alternative technology, diffusers, in which the dissolved solids in bagasse or prepared cane are removed by a counter current leaching action of the passage of water or liquid from a suitable stage in the process. In this situation, a de-watering set or sets of rollers follow the diffuser to prepare the bagasse for use in the boilers as fuel, as moisture contents around 50% or less are required.

Typically, the crushing and/or diffusion processes remove 95–97% of the sucrose present in the cane sent to the mill.

The bagasse from the final mill is used for fuel in the boilers, producing high-pressure steam for driving the turbines for the mills, shredder and power generation. Spent steam from these processes is used for heating and evaporation in the process section of the mill. The ash from the boilers is high in potassium and is blended with filter mud from a later stage in the process. This is returned to the cane fields as fertiliser, called mill mud.

The throughput of milling equipment is related to the cane solids that can be processed. Increases in cane-fibre content, particularly because of higher extraneous matter (trash, tops and soil), reduces the crushing rate of the mill. This prolongs the crushing season. High dirt loadings cause severe wear to shredders, rollers, carriers and boiler station equipment. They reduce efficiency, increase maintenance costs, and lead to premature breakdown and maintenance shutdown.

Clarification

The juice from the crushing/extraction process is screened to remove fibrous matter, then heated, clarified, concentrated and crystallised to raw sugar with molasses as the major by-product.

Clarification with heat and lime is the first stage of the process. The juice is heated to about 75°C and limed with prepared saccharate (juice or syrup plus slaked lime) with lime solids at about 0.06% on cane. Naturally occurring phosphorus in the cane juice forms a precipitate of calcium phosphate. If appropriate, additional phosphorus may be added as superphosphate or phosphoric acid. The juice is further heated to about 102°C and let flash to atmosphere to remove air. Heat denatures interfering substances and kills bacteria.

Free of air, the juice enters settling vessels, called clarifiers, where the precipitate generated by the lime can settle out, taking with it dirt, cane fibre and the denatured protein and other organic material. The residence time should be as short as possible to avoid formation of colour. Flocculants are added to enhance the settling rate of the precipitate.

Clear juice, called 'clarified juice' or 'evaporator supply juice' (ESJ), overflows the clarifier, still well in excess of 80°C.

The precipitate is removed from the bottom of the clarifier with a proportion of the juice. The juice contains sugar and other dissolved solids which must be removed. The 'mud', as the precipitate is called, is concentrated or compacted and washed in a process called rotary vacuum filtration.

Clarification is adversely affected by fine soil particles, and stale and deteriorated juice from delayed or field-damaged cane, and is overloaded by excessive quantities of dirt in the incoming cane. Poor clarification lowers raw sugar quality, particularly in filterability and ash levels, and adversely affects crystal growth rates in crystallisation processes.

Australian cane-payment arrangements assume that the clarification process removes 25% of the dissolved impurities present in cane. Some impurities are removed to a lesser extent than others.

Filters

Rotary vacuum filters are slowly rotating screens with a vacuum applied behind them. This enables the pick-up of a layer of solids from a reservoir of mud. The liquid is separated from the solids and returned to the juice stream. Hot water sprays remove as much sugar as possible from the solids. The vacuum is broken and cake removed by a scraper. Fine bagasse, called bagacillo, may be added to the mud to enhance cake formation.

Filter area ranges from 50 to 100 m^2 per 100 tonnes of cane per hour depending on the crushing rate and the likely level of mud solids in the incoming cane. Insufficient capacity slows the clearance of mud from the clarifiers, and crushing ceases.

The product off the filters is called 'filter press' or 'filter cake', and contains 10–20% mud solids. It has a residue of about 0.5% of the sugar in the incoming cane. Hence, the more mud that is produced, the more sugar is lost from the process. The filter cake is mixed with ash from the boiler station and distributed back to the cane fields as a source of nutrients. It typically contains 0.24% nitrogen, 0.20% phosphorus, 0.13% potassium, 0.40% calcium, and 0.11% magnesium.

CLARIFIED JUICE TO RAW SUGAR

In the sugar milling process, clarified juice is further processed to produce raw sugar, as shown in Figure 2.

Evaporators (effets)

The clarified juice (ESJ) from the clarifiers is at 14°Bx (percentage dissolved solids on a weight/weight basis) and is concentrated to 65–70°Bx in multiple-effect evaporators. The output is referred to as syrup.

Several evaporator vessels are aligned in sequence. Steam and juice flow together from the first vessel under pressure to the final vessel under the highest vacuum. The vapour from stage one passes off to the calandria (or heating space) in vessel 2 to heat the juice in that vessel which had gravitated in from vessel 1 and so on. The multiple-effect evaporators are steam efficient, in that the steam is reused in each vessel down the line. There are four or five stages to a multiple-effect evaporator set, and there may be more than one vessel at each stage. Mills may have more than one set of evaporators.

Vapour is often bled from the first and second vessels for process use such as juice heating or vacuum pan boiling.

The area of heat transfer in the set, the inlet steam pressure, the final vacuum achieved, the heat transfer attained and the brix of the incoming juice all govern the rate of throughput of the evaporators. Cane juice contains substances which rapidly foul the evaporator heating surfaces, necessitating boil-out cleaning with chemicals at least every 2 weeks. The desire to remove as much as possible of the sugar in the process, while

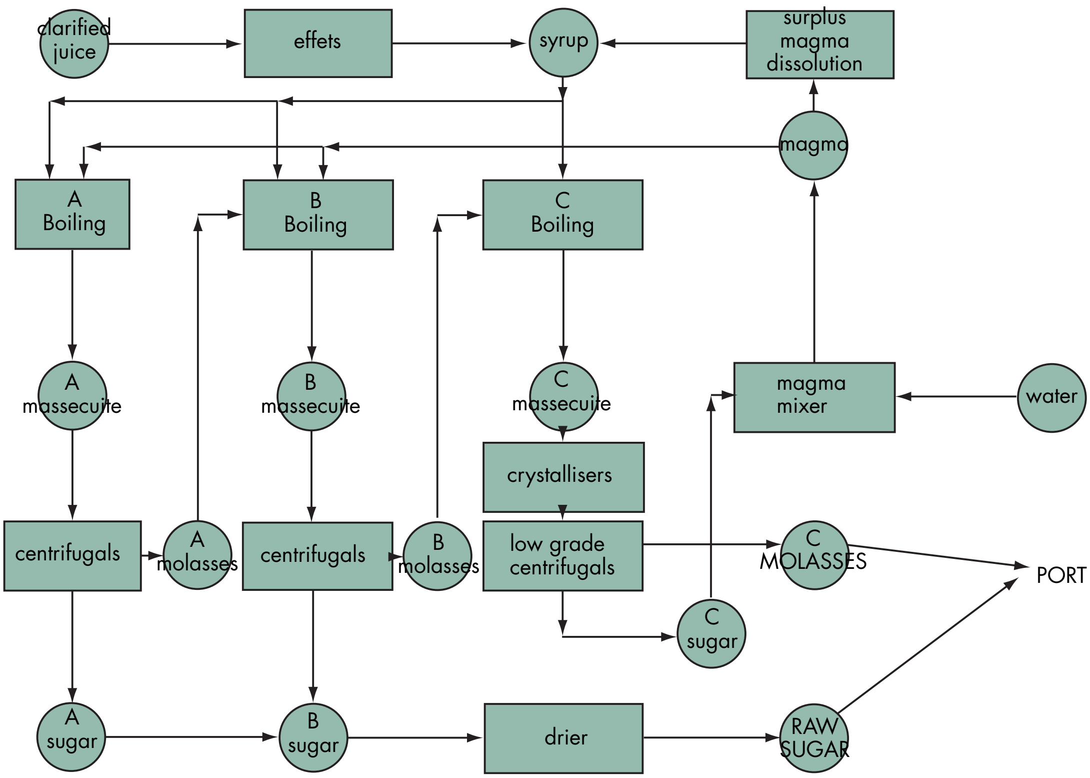


Figure 2. *A sugar mill—clarified juice to raw sugar.*

maintaining throughput at the effets, requires optimisation of maceration water usage in the milling train and filter spray water, both of which reduce ESJ brix.

Pan boiling and centrifugals

The pan floor crystallises syrup into raw sugar with final or C molasses as the by-product.

Australian sugar mills typically use a three-stage sugar boiling system, producing A sugar and B sugar which are combined as raw sugar. C sugar is recovered in the lowest purity boiling and is typically used as the starting crystal (or seed) for the A and B sugar boilings. Alternatively, C sugar may be dissolved and treated as syrup at the start of the pan-boiling process. Twice as much A sugar as B sugar is produced. One Australian mill further purifies raw sugar by dissolution, further clarification and crystallisation, to produce very pure, almost refined-sugar crystals.

The pan boiling operation produces a mixture of sugar crystal and sugar syrup (called molasses). The whole is termed a massecuite. The molasses and crystal components are separated using high-speed spinning baskets in plant called centrifugals.

The quality of sugar is set to the desired level (e.g. VHP or Brand JA or Brand 1) by varying the time and speed of rotation of the centrifugal machine, the throughput, the quantity of wash water, or the purity (ratio of sucrose to sucrose plus impurities) of the massecuite produced by the pan boiling operation. The pan boiling schedule in most mills follows a similar process.

Syrup is produced by the evaporators at approximately 65–70°Bx and 85–90% purity, and passes to the crystallisation stage. Three massecuites are boiled, together with seed or magma preparation stages. The first or A massecuite is based on syrup, the others (B and C massecuite) on the molasses spun off the preceding massecuite. Massecuite purities decrease from A to C and the value of each is a major focus of the miller in maintaining control of the process. A massecuite typically comprises about 80–100% syrup or magma and up to 20% returned A molasses or 'boil back', depending on the process and the preferences of the production manager. B massecuite typically contains about 50% syrup or magma and 50% A molasses.

The correct amount of magma or seed crystal is introduced at a known size to reach the desired size crystal at the end of the massecuite stage. C sugar crystals are about 0.3 mm in size and are used as a starting crystal for the production of A and B massecuite where the final crystal size is 0.8 to 1 mm.

C massecuite is close to 100% B molasses. It carries all the impurities in the cane not incorporated into the raw sugar or removed in clarification. The quantity of C massecuite gives a very clear indication of the impurity loading in the factory. In contrast to A and B massecuite, crystal growth in C massecuite is initiated by the controlled addition of an appropriate number of crystal fragments in a slurry or fondant that quickly repair to tiny crystals, growing to about 0.3 mm at the end of the process.

C massecuite provides the last opportunity the mill has to maximise the retention of sucrose before discard of molasses. As a result, additional time is provided for the crystals to grow after the boiling process. The C massecuite passes to crystallisers which may be batch or continuous flow where the massecuite slowly cools with movement provided by the cooling coils to allow further crystal growth. The degree to which cooling takes place is carefully controlled. A measure of reheating is applied to the massecuite to promote flow and separation of crystal and C molasses in the centrifugals which follow, but also ensuring minimal crystal redissolution. This takes 15–20 hours.

C molasses discard has purity in the vicinity of 45%. The sugar is not economically recoverable with current technology. The molasses separated from C sugar is termed final molasses or C molasses and has uses such as in alcohol fermentation, stock-food supplements, nutrients in various fermentation processes, or as fertiliser for cane fields.

As purity decreases, viscosity increases. The level of increase is very much a function of the cane supply or cane supplying district, and has a large bearing on the efficiencies in sugar removal and rates that can be achieved in the process.

The crystallisation process is carried out in vessels called vacuum pans, which may be batch or continuous in operation, and into which is introduced the footing to be grown to full size crystals. The contents are boiled under vacuum at around 60°C, and syrup or molasses is concurrently added to the vessel. The rates of feed addition and heating steam flow are balanced to ensure that the concentration of the solution surrounding the growing crystals is below that at which the mother liquor around the crystals can spontaneously crystallise. The process is controlled such that the number of crystals that are introduced at the start (seed) is the same as the number present at the end. The crystals grow by deposition of sucrose from the liquid phase in the pan (mother liquor). Consequently, the boiling action concentrates both the mother liquor, which is progressively depleted of sucrose by crystal growth, and the new material added at a concentration below that controlled in the pan.

The presence of fine grain in raw sugar, caused by spontaneous crystallisation or by poor control of seed addition, interferes with subsequent processing in the refinery (the affination stage). Fine grain above a certain level results in a lower price for the sugar produced. Fine grain is primarily a miller's problem. However, the presence of particular impurities in the incoming cane supply, such as dextran, so reduces crystal growth that the tendency to fine grain formation is enhanced.

A and B sugars leave the fugals in a moist, warm state and must be cooled and dried prior to despatch. This is completed in the driers.

The pan boiling stage in the factory is the key to factory throughput. As much of the incoming sucrose as possible must be converted to raw sugar. The sucrose in discard molasses is worth a fraction of the sucrose in raw sugar.

Pan stage equipment is expensive and the pan boiling station is designed to deal with the cane supply to be crushed and its sugar and impurity loading. A and B massecuites are required to produce the tonnage of sugar available in the cane at the crushing rate proposed.

Typically, early in the season, when the cane's sugar content is lower, higher crushing rates may be tolerated if the rest of the process is in balance. As the season progresses and cane sugar contents typically rise, capacity limitations may arise at the A and B massecuite pans or 'shipment pans' to the extent of necessitating reduction in crushing rate to below that expected. Conversely, the impurity loading in the cane supply governs activity at the C massecuite pans and crystallisers.

These vessels have their biggest load early in the season and towards the end of the season at normal crushing rates. High and unexpected impurity loadings or particular characteristics in the impurities that slow boiling may make it difficult to maintain efficiency at a programmed crushing rate. The miller has two options: either slow the crushing rate or accept that the exhaustion of the C massecuite of sugar on to crystal will be less than expected due to insufficient time or poor crystallisation characteristics. In the latter case, sugar will be lost to C molasses without comparable return.

Perhaps the most unfortunate combination a mill encounters is the situation where the sugar and impurity loadings are high at the same time, which significantly departs from the expected circumstance and often results in a prolonged reduction in crushing capability.

Raw sugar centrifugals are controlled to produce raw sugar at the quality level desired by the market. The pol of the sugar (similar to sucrose content) is the major index. Australian factories produce Brand JA sugar around 97.8 pol, Brand 1 at around 98.9 pol and VHP around 99.3 pol, with other brands being made to special request of the marketers.

Driers

Sugar drying is accomplished by continuous passage through flighted rotating drums with a counter-current flow of air. The flights pick up and drop the sugar as it moves through the drum. The air may be heated, or air-conditioned and then heated suitably above dew point, or simply at ambient conditions, depending on conditions and requirements for the dried sugar.

The moisture content of the raw sugar is most important. If it is too dry, too much dust is produced in subsequent handling, and there is a risk of explosion. If it is too wet, flow characteristics are affected, and conditions could be favourable for bacteria to cause deterioration of in-storage sugar.

The temperature of the raw sugar product is also critical, and must be controlled to close tolerances to avoid development of colour in storage.

Boiler station

Sugar mills are usually self sufficient in fuel and energy. Bagasse provides fuel for high-pressure steam generation in purpose-designed boilers, but they can use coal, oil or wood to satisfy needs in situations where demand exceeds fuel supply. A mill typically requires 0.52 tonnes of steam for each tonne of cane crushed. Some surplus bagasse is stored in bins and recovered as required. Further quantities of surplus bagasse are stored in outside dumps, often covered with tarpaulins. Mills generate electricity for all internal requirements, and export to the power grid any surplus power.

Shipping

The raw sugar is transferred to terminals in bulk by road or rail. Each load or wagon is weighed at the terminal and a sample added to a running composite. Mill production is evaluated by independent analysis of the composite in 2000 tonne representative samples.

The raw sugar is allocated or blended with other raw sugar to meet the needs of the customers.

The sugar is bulk loaded into large bulk carriers for shipping to refineries in about 30 countries of the world.

CANE ANALYSIS SYSTEM

Dr Kottmann of the Colonial Sugar Refining Company Limited developed the Australian cane analysis system in 1893. It has been the subject of many reviews over the years, but has not been bettered by alternatives.

The cane analysis is inferred from an analysis of the first expressed juice from the cane at or before the first two rollers of the first three-roller mill of a milling set or tandem. It is the aggregate of all the juice expressed at or before the feed opening of the first three-roller mill, including all juice extracted by the pressure feeders.

A portion of this juice is screened and is pumped continuously past the juice analysis laboratory and returned to the mill bed and the process. The juice laboratory has the facility to take appropriate pulses of juice from the passing stream to sample about 20 L from a supplier's parcel of cane. This quantity is sub-sampled to 2 L for analysis. The process is strictly monitored to be free of contamination, e.g. from steam or water, and reliably samples the cane being evaluated.

The juice is analysed for brix (i.e. weight percent dissolved solids) after settling for at least 20 minutes to allow dirt to settle out, air to rise, and bagasse particles to float to the top of the vessel. Analysis is by brix spindle, density meter or, in particular circumstances, by refractometer.

The juice is analysed for polarisation by the passage of plane polarised light through clarified and filtered juice. The fibre content of the cane, which is non-juice material, comprises cane fibrous matter and dirt. It is measured by sampling prepared cane, washing it free of dissolved solids, and drying.

A common practice is to obtain a representative sample of prepared cane across the cane supply by variety group, analyse the fibre content, and apply that value to each parcel of cane supplied in that fibre group using a 3-day rolling average. The industry would like a method for determination of fibre in individual parcels of cane. Near infra-red spectroscopic analysis is now being used for this purpose in a number of mills.

The juice and fibre analyses vary considerably between cane parcels and across the season. Typical levels for pol of juice, brix of juice, and fibre of cane are 16.0, 18.0, and 14.0, respectively. Sugar content of the cane is predicted using a linkage arrived at by Dr Kottmann from sampling and analysis in Colonial Sugar Refining Company mills. The estimation, or 3 and 5 formulae, have withstood, favourably, numerous inspections and comparisons with painstaking whole-cane analyses.

The 3 and 5 formulae are:

Brix in cane = Brix in juice × (100–(fibre+3))/100

Pol in cane = Pol in juice × (100–(fibre+5))/100

The sugar that may be produced from a parcel of cane is estimated by CCS (or commercial cane sugar). CCS is a measure of pure sucrose that is obtainable from the cane and is another contribution of Dr Kottmann. It is also referred to as POCS (pure obtainable cane sugar).

CCS is based on the effect impurities in cane have on the mill process where:

Impurities in cane = Brix in cane – Pol in cane

The formula assumes that 25% of the impurities in cane are removed in clarification. All the remaining impurities are in final molasses of 40 purity in which 40 parts of sugar accompany each 60 parts of impurities, so reducing the potential to produce raw sugar.

The possible sugar output or CCS is computed as the percent pol in cane less that not recoverable as it is caught up in the molasses.

Given that $\frac{3}{4}$ of the impurities in cane remain after clarification,

$$\text{CCS} = \text{Pol in cane} - \frac{3}{4}(\text{impurities in cane} \times 40/60)$$
$$= \text{Pol in cane} - \frac{1}{2}\ \text{impurities in cane}$$

The ultimate cane payment formula links the tonnes of cane delivered to the mill, its CCS, and the price obtained for the sugar in $/tonne of sugar IPS (International Pol Scale).

The formula is based on the assumption that at 12 CCS and where a mill operates at 90% coefficient of work, the proceeds of the sale of the sugar will be distributed 2/3 to the grower and 1/3 to the miller, where it is assumed that this is how costs of production are distributed. Millers may improve their share by operating at better than 90% coefficient, and the grower receives all the benefit of producing cane at higher than 12 CCS.

The cane payment formula or payment to grower per tonne of cane supplied is

(Sugar price × (CCS-4) × 0.009) + locally negotiated increment.

This is calculated for each parcel of cane delivered. A relative CCS system, finalised after all the cane has been crushed, is used to relate the CCS obtained for that parcel in that week of crushing to the mean of the cane supplied in that week and scale the comparison to the mean CCS for the season.

The constant 4 is the element which brings about the 2/3 : 1/3 split in sugar monies. The equivalent of 4 units of CCS is retained by the miller which is 1/3 of 12. The factor 0.009 accounts for the assumed 90% efficiency of operation in the base situation.

Mills judge their efficiency in a number of ways:

(1) The percent of pol in cane recovered in the product raw sugar—typically 90%;

(2) The ratio of sugar produced to incoming CCS;

- **(a)** **coefficient of work** in which tonnes sugar produced is referred to 94 NT (net titre, a quality standard based on sugar impurities and pol) where
  tonnes 94 NT = actual tonnes at actual NT × actual NT/94 and
  coefficient of work = tonnes 94NT produced × 100 / tonnes CCS introduced or
- **(b)** **pool sugar index**, the current industry measure, where the tonnes sugar produced is referred to as pool sugar units which is actual sugar produced converted to tonnes at 98.95 pol, in turn converted to the international pol scale price premium for 98.95 pol with the commercial scaling factor.
  Pool sugar units (tonnes IPS) = tonnes at 98.95 pol × 1.037.
  Pool sugar index = tonnes IPS produced / tonnes CCS introduced

The cane price formula is related to milling operation at a 0.9 pool sugar index.

The pool sugar index dispenses with the × 100 factor. Its presence in the coefficient of work formula has for years caused misunderstanding by implying that there was an implied relationship between tonnes 94 NT and tonnes CCS and that the coefficient of work is a percentage. This is not the case. Nor is there an implied relationship between pool sugar units and CCS. The ratio is an index by which mills can compare production and cane supply.