



Sugar Production from Sugar Cane

The basic process

Sugar cane must be crushed to extract the juice. The crushing process must break up the hard nodes of the cane and flatten the stems. The juice is collected, filtered and sometimes treated and then boiled to drive off the excess water. The dried cane residue (bagasse) is often used as fuel for this process. The remaining liquid is allowed to set into a solid mass known as jaggery, gur, chancaca or panela (Gur is used in the rest of this document).

Terminology

The following terminology is used in this technical brief:

Bagasse	The fibrous residue of sugar cane which remains after the crushing operation.
Boiling	The evaporation of moisture from the juice at temperatures of between 90 and 116°C.
Brix	The term 'degrees Brix' (or more usually °Brix) is the sugar 'technologists' measure of the concentration of dissolved solids in solution.
Clarification	Removal of impurities from the juice.
Extraction	The removal of juice from the cane by crushing.
Factory	This term is used throughout to indicate a sugar processing plant regardless of its type, processing capacity or physical size.
Invert sugar	High temperatures and acid conditions can cause chemical decomposition of the sucrose resulting in simpler sugars such as glucose and fructose forming. These sugars are known as invert sugars and are not desirable in the final product.
Massecuite	The concentrated cane juice obtained after boiling, also known as rab or final syrup.
Molasses	A syrup by-product from the manufacture of sugar, containing sucrose, invert sugars, moisture, ash and other insoluble matter.
Open Pan (OP)	Describes sugar produced by boiling juice in open pans at atmospheric pressure.
OPS	Open Pan Sulphitation (OPS) is a method for production of white granular sugar, developed in India.
Recovery	The proportion of sugar produced by weight of cane processed, usually expressed as a percentage. For example, 10% recovery means that for every 100kg of cane processed 10kg of sugar is produced.
Strike	The removal of massecuite from the boiling operation at the required concentration.
Sucrose	An organic chemical of the carbohydrate family, found in the sap of most green plants. Ordinary white crystal sugar is almost (99.9%) pure sucrose while some of the non-crystalline sugars may contain less; for example syrup and jaggery which contain as little as 50 and 80% sucrose respectively.

technical brief

- TCD** Tonnes of Cane per Day refers to the amount of cane a processing plant crushes each day and not the amount of sugar produced. Most sugar processing plants are sized according to this figure which is based on a 24 hour day. However, many small-scale factories, and some large ones, only operate for part of a day and in some cases for only part of the year. Therefore care must be taken when analysing TCD figures as they only represent a factory's capacity and do not necessarily reflect the actual throughput.
- Vacuum Pan** Vacuum (VP) pan describes a particular type of technology used to boil or evaporate the sugar cane juice. It was developed by the large-scale industry to improve efficiency but some small-scale VP factories are in operation, especially in India.

Yields

The yield of gur from sugar cane depends mostly on the quality of the cane and the efficiency of the extraction of juice. The table below gives some extreme values.

	High quality cane	Poor quality cane
Juice per 100kg of cane	50kg	40kg
% sugar in juice	22	17
Gur per 100kg of cane	10kg	7kg

High quality cane has a good juice content with high sugar levels (20%+). Poor quality cane or cane that has been harvested early may have similar juice content but the sugar levels will be reduced.

The efficiency with which juice can be extracted from the cane is limited by the technology used. The simple three roller crushers used by most artisanal producers will never extract more than 50kg of juice from each 100kg of cane.

Yields are also improved by careful control of the boiling process. Boiling should be completed as rapidly as possible and the conditions kept as clean as possible.

Mass balance

$$\text{Weight of gur} = \text{Weight of cane} \times \frac{\text{weight of juice}}{\text{weight of cane}} \times \frac{\text{sugar in juice}}{\text{sugar in gur}}$$

For the technically minded, the weights of the gur, juice and cane can be related as follows:

$$10\text{kg gur} = 100\text{kg cane} \times \frac{50\text{kg juice}}{100\text{kg cane}} \times \frac{19\% \text{ sugar in juice}}{95\% \text{ sugar in gur}}$$

Scale of production

Scale	Cane processed/day	Type of enterprise
Small	up to 50 tonnes	Cottage and small village industry using traditional OP technology.
Medium	50 to 500 tonnes	Small to medium enterprise using modified traditional, OPS or small-scale VP technology.
Large	500 tonnes upwards	Large industry using modern VP technology.

Types of cane sugar

Processed sugar comes in two forms: non-crystalline and crystalline of which there are two basic types; centrifuged and non-centrifuged. The different forms of sugar are produced in many different countries and often have different names, therefore for clarity the different types are described as follows:

Non-crystalline sugars

Syrups

A non-crystalline liquid of high viscosity (thickness) concentrated from whole cane juice. It can vary from golden brown to dark brown and contains; up to 50% sucrose, high levels (up to 20%) of invert sugars, up to 20% moisture and the remainder is made up of other insoluble matter (ash, proteins, bagasse etc).

Crystalline sugars

These can be divided into two types: non-centrifugal sugars and centrifugal sugars. Non-centrifugal sugars are basic lump sugars where the molasses and crystals have not been separated. Centrifugal sugars are free flowing granular sugars where the molasses and crystals have been separated to some degree.

Non-centrifugal sugars

Lump sugars

These sugars are a concentrated product of the cane juice and are produced in many countries for direct consumption. They vary from yellowish brown to dark brown (almost black sometimes) in colour and contain up to 80% sucrose with the remainder made up from moisture, invert sugars and other insoluble matter such as ash, proteins and bagasse fines in varying proportions.

Lump sugars are produced in many countries around the world and are known by a range of names: jaggery in Africa, gur in India and Bangladesh, desi in Pakistan, chancaca in Peru; other names include panela, piloncillo, and rapadura.

Centrifugal sugars

Khandsari

A basic raw granular sugar, developed in India, that has been separated from most of the molasses. Khandsari varies in colour from golden yellow to brown and contains between 94 and 98% sucrose.

It is produced by the small to medium-scale sector and has a considerable market in India. At its most basic, khandsari is manufactured using simple animal-drawn crushers, is subjected to simple clarification, boiled to the consistency of a thick syrup, and allowed to stand until sugar crystals are formed. The small crystals are then separated in manually operated centrifuges and sun dried.

At the other end of the scale the production plant can use diesel or electrically driven crushers, crystalliser to ensure uniform formation of crystals, power-driven centrifuges, and forced-air driers to dry the product. Factories processing between one and two hundred tonnes of cane per day are common, yielding between 6.5 and 13 tonnes of sugar per day respectively.

Since the late 1950s traditional khandsari production has been in decline in favour of a modified process known as open pan sulphitation (OPS) sugar processing. The OPS production method produce an off-white to white crystal sugar which can be of the same quality as that produced by modern large-scale VP sugar factories.

White granular sugars

Free flowing white granular sugars are often referred to as plantation white. These sugars are traditionally produced in large-scale VP factories. It is possible for the medium-scale sector to develop small-scale or mini VP plants for the production of good quality white sugar.

Brown granular sugars

There are two categories of granular brown sugar: those produced directly from the cane juice at the place of origin and those that are produced during the refining of raw sugar. The first type includes demerara, muscovado and turbinado sugars. The second types are coated brown or 'soft' sugars and manufactured demerara.

Those produced directly from the cane juice at the place of origin can be made using medium-scale open pan production methods. The refined brown sugars, however, tend to be produced in modern large-scale VP sugar factories.

Demerara sugar

Named after the area in Guyana where it was first produced, demerara is a centrifuged sugar prepared from the first crystallisation of cane syrup and has large yellow crystals and a slightly sticky texture. Production of this sugar is suited to the medium-scale sector as the juice needs to be carefully clarified to ensure purity and crystalliser are required to ensure uniform grain size.

Muscovado

Also known as Barbados sugar, muscovado is the product of the third crystallisation. It is dark brown in colour with small grains and sticky texture. A by-product of both the OPS and mini-VP scale of production, muscovado tends to be produced as an alternative to white sugar if the standard is not very high.

Technology

The technology used will depend on the type and amount of sugar being produced. Syrup and lump sugars can be produced using relatively basic low-cost equipment consisting of a crusher and a furnace with boiling pan. Granular sugar production also uses crushers and boiling equipment but requires additional equipment such as a clarification plant, crystallisers, driers and packaging equipment.

The crushing and boiling technology used by the OP factories in both the small and medium-scale sector are similar. In most cases the technology used by the medium scale sector is a development of that used by the small-scale sector or sometimes vice-versa.

Cane crushers

A wide range of crushers are suitable for use by the small to medium-scale sugar processors with capacities ranging from 200kg to over 900kg of cane per hour. There are two basic types: the roll mill, which is the most common, and the screw expeller.

It is important to remember that cane must be crushed within 24 hours of being cut. After this time the sugar begins to 'invert' into different sugars that will not set solid.

Roll mills

Roll mills, of various types, are a proven technology which are easy to use and maintain and are extensively used in the large-scale sector as well as in the small. Typically roll mills used in the small-scale sector are either two or three-roll configuration set vertically or horizontally. The rolls, usually made from cast iron or steel, are located in wooden, steel or cast iron frames.



Figure 1: Animal powered crusher. Photo: Neil Cooper/Practical Action.

Some of the smaller crushers, with capacities of between 200 and 500kg cane per hour, have vertically set rolls and are animal powered but can be modified to use small engines or electric motors. A crusher driven by a single ox can be expected to process around 50kg of cane per hour. A 5HP diesel set could increase this to around 300kg per hour.

Others are horizontal and are usually powered by small engines or electric motors. Some small manually powered horizontal crushers are available but they tend to be used by street vendors, especially in South and South East Asia, to provide cane juice for drinking.

For the small-scale producer the main advantage of using automated crushers is that of throughput rather than extraction efficiency. An extraction rate of up to 65% is achievable from both animal driven and small automated roll mills. However, the medium to large-scale producers use much larger roll-mills that are can extract up to 80% of the available juice depending on the fibre content of the cane and if the cane is prepared carefully.

If greater extraction is required then it is usual to use two or more automated three-roll mills in tandem, one behind the other. Cane is fed through the first mill and the resulting bagasse is then fed into the second mill and so on with each stage extracting juice. Although some large-scale factories use five three-roll mill tandems it is more usual for the larger open-pan factories to use two or three crushers in tandem.

The pressure exerted by the mill on the cane is determined by the gap between the top roller and the bottom rollers. If the gap is too wide then poor extraction will result; if the gap is too small then the cane may not pass through it or may cause the rollers to jam. The correct setting of the rollers has to be determined at the site of crushing as it will be dependent upon the cane variety, size and quality.

Improved extraction can be achieved by hydraulically loading the pressure roller and by slicing or shredding the cane along its length before crushing. This type of system can achieve extraction of around 66%.

Another important factor for efficient extraction is the operational speed of the crushers. Operating speeds are typically between 5 and 50 r.p.m. The lower speeds are easily achievable when using animal power but the use of engines or motors requires speed reduction.

Typically diesel and petrol engines have speeds of 700 to 2000 r.p.m while electric motors are usually rated at 750 or 1500 r.p.m. Speed reduction is usually achieved by coupling the engine to the crusher via flat or vee type belts and pulleys. The use of flat belts is a common and well proven technology while at the same time it is also one of the cheapest and easiest methods. Its major draw back is the distance required between the prime mover and the crusher to ensure maximum efficiency from the drive mechanism. Where space is limited then vee belts and pulleys can be used as they allow for relatively close coupling. However, vee belts and pulleys are more complicated and expensive to manufacture than flat belts and pulleys.

Direct coupling between prime mover and crusher is possible but a reduction gear box will be required to obtain the optimum crushing speed. Compared to belt and pulley systems gear boxes are expensive and complex requiring more maintenance.



Figure 2: A Diesel powered cane crusher with three vertical rollers in Bangladesh. Photo: Neil Cooper

Screw expellers

Screw expellers are not commonly used in the small-scale sugar industry although they are more efficient than roll mills. Typically a single expeller will have the same extraction efficiency as a three or four three-roll mill tandem. Their use in the small-scale sector has been limited to experimental machines which have proved to be unreliable thus requiring more maintenance.



Figure 3: A simple open pan used for processing the juice extracted from the sugar.
Photo: Neil Cooper / Practical Action.

Furnaces

Furnaces for open pan boiling use dried bagasse as fuel but can vary in design and size to suit local conditions and preferences. The following section describes a range of basic designs that are used in small to medium-scale factories.

Simple temporary single-pan furnaces

The most basic design, common in many countries, consists of a furnace built into the ground with a small brick or block wall (100 to 150mm high) placed around the top to ensure a level flat surface to support the pan. If bricks or blocks are not available then the wall can be built from mud and stone but care is required to ensure that the top of the wall is level and flat.

The furnace can be either round or rectangular to suit the pans used. A round or circular furnace is the most efficient design but the ease of manufacture and cost of the pans often dictates which type of furnace design is used.

Two holes positioned opposite each other are required, one to feed bagasse into the furnace and the other to exhaust smoke and other products of combustion.

An improvement to this design is to build a chimney at the exhaust end which should improve the performance of the furnace and help ensure that smoke and particulates produced during combustion are removed away from the sugar processing area. Care must be taken when siting the furnace to ensure that small particles of burning fuel, which can be emitted with the exhaust gasses, cannot cause a fire risk to surrounding dwellings or buildings.

Rectangular pans are usually flat bottomed with relatively low sides. This shape does not allow for even heating of a product and care is required when using them as burning of the product can occur. Pans for the round furnace should be hemispherical or cone shaped. These shapes allow for more even heating than rectangular pans but are usually more expensive to manufacture. Cones are often used in parts of Asia for syrup production but less often for jaggery production as the thick viscous massecuite is difficult to remove from the cone.

Simple permanent single-pan furnaces

Although similar in design to temporary furnaces they tend to be larger and are often built, or have a large proportion of their structure, above ground. The walls of the furnace are usually made from brick or building blocks and the boiling pans fit into the structure.

Permanent multi-pan furnaces

Multi-pan furnaces are used for the production of both non-centrifuged and centrifuged sugars. They utilise waste heat from the boiling process to pre-heat and boil a successive concentration of juice at progressively higher temperatures.

The primary pan is located directly above the combustion chamber. Behind and slightly above the primary pan a secondary pan is located. A third pan is located above and behind the secondary pan, and so on depending on the number of pans used. Hot gases from the combustion process pass under the pans heating the juice, the combustion gasses are exhausted to atmosphere through a chimney. Improved heat transfer can be achieved by adding fins to the underside of the pans increasing the surface area in contact with the hot gasses.

There are two basic types of furnace, the original 'Standard Bel' furnace and the 'shell' furnace which was developed in India during the late 1970s. The 'standard bel' is a natural draught furnace where bagasse is burnt on a grate in a combustion chamber located below a series of round boiling pans. There are a number of variations of this type of furnace but in all cases they are designed to operate on dry bagasse (moisture content of 10% or less) which means having to dry the bagasse before use. Even with dry bagasse this type of furnace often requires excess fuel (either bagasse from another factory or wood) to complete the boiling operation.

The 'shell' furnace was developed to burn wet bagasse straight from the extraction process. The furnace is a forced draught design using hot flue gasses (at around 500°C) which pass over heat exchanger tubes heating incoming combustion air to around 120 - 140°C. Bagasse is burnt in a heap on a fixed hearth inside a cylindrical brick built combustion chamber lined with firebricks. The bagasse is fed through a chute just below the throat allowing it to fall through hot combustion gases which pre-dry it before burning. With careful operation this type of furnace will not require additional fuel to complete the boiling operation.

The transfer of juice from one pan to the next is controlled by valves through overflow pipes, or the juice can be ladled manually. The massecuite from the final pan is usually too viscous to flow easily so it is ladled into buckets and transferred to the next stage of production.

Sugar production methods

Lump sugar and syrup production

Although lump sugars and syrups are produced by the medium and large-scale sector they are ideally suited for production on the small-scale. Both lump sugars and syrup can be produced using the same equipment so a single factory can be used to manufacture either product to suit demand. The size of the plant will depend on the local situation. Where there is sufficient cane grown for a substantial part of the year it is common to have a permanent factory centrally located. In areas where cane is grown in small plots harvested over short seasons, it is more common to have semi-permanent or temporary factories set up close to the point of harvest.

There are four stages of production

- Extraction of juice from the cane
- Clarification of the juice
- Boiling of the juice
- Moulding and packaging

Extraction

Small-scale extraction is done using small two or three-roll mills driven either by draught animals or small engines. The larger small-scale and the medium-scale factory will use a single motorised three-roll mill.

Juice treatment

Juice should be filtered through a cloth before boiling in order to remove any solids such as dirt or particles of cane.

Large-scale sugar processors add lime to the juice in order to coagulate impurities which then settle out. (This is rarely done at the artisanal level.) The juice is then neutralised with sulphur dioxide. Small-scale producers add a variety of clarificants to the juice including wood ash. All

of these have the effect of settling out impurities. Many producers also add 'hydros' (sodium hydrogen sulphate) at the final stages of boiling. This releases sulphur dioxide into the juice and lightens the colour of the final product. (Note that a high sulphur content often remains in the final product.)

Filtration and Clarification

The amount of non-sugars such as bagasse and other particulates in the juice will affect its purity, resulting in discoloration and reduced sweetness. Therefore filtration is essential and if done with care can remove up to 60% of non-sugars from the juice.

A filter press, if available, will give the best results but can be expensive for small-scale operations. However, reasonable levels of filtration can be achieved by allowing the juice to stand for a few hours to allow particulates to precipitate out. The tanks should be fitted with a fine mesh lid, through which the juice is poured to filter out large particles of bagasse and other foreign bodies. The mesh will also prevent infestation from insects and help prevent contamination by small animals and birds.

After settling the juice should be drawn from the tank ensuring that particulates settled at the bottom of the tank are not disturbed. The juice can then be poured into the boiling pan through a coarse cotton cloth to filter out fine particles that may remain in suspension.

Clarification, if undertaken, is carried out during the boiling process by adding a small amount of vegetable or chemical matter to the juice. The clarificants do not react with the juice but coagulate during the heating process, trapping particles and contaminants and bringing them to the surface during boiling. This appears on the surface as a scum which can be removed using long handled fine-mesh ladles or by passing a fine cotton cloth through the juice.

In India barks from the following plants are used:

- Hibiscus figulneus
- Hibiscus esculentus
- Bombus malbaricum
- Grewia asiatic
- Kydia calycina

These barks are soaked in water and the resulting solution added to the juice just before boiling commences. Approximately 10 to 15% of non-sugars can be removed using this method. These barks may not be available else where and so some investigation is needed to find out what local alternatives are available or traditionally used.

Boiling

For syrup production the juice is boiled until the required concentration is reached and the strike is made at around 105°C when most of the moisture has been boiled off and just before crystallisation occurs. If the juice is over-boiled then crystals may be present which may cause discoloration. If under-boiled, too much moisture will remain in the syrup which may, with time, cause cloudiness and shorten its shelf life. For lump sugars the juice is boiled for longer and the strike is made at between 116 and 120°C.

In all cases the furnaces use sun dried bagasse as fuel. The bigger factories often have a surplus at the end of operations while smaller units have to operate their furnaces with much greater care to ensure that they do not use all the bagasse before boiling is completed.

Moulding and packaging

For syrup production the juice is poured or ladled from the boiling pan into containers where it is allowed to cool. For lump sugar production, the massecuite is poured into cooling trays where it is stirred to promote even cooling and crystallisation. Upon setting, the lump sugar is cut or moulded into shapes to suit the local market and customer requirements. Alternatively, before the massecuite solidifies it can be poured into pots or moulds to produce various shapes.

In Bangladesh where small temporary factories are common the pan is removed from the furnace allowing cooling and crystallisation to occur within the pan while a new pan with fresh juice is placed on the furnace.

Production methods for granular sugars

Medium-scale production of white and brown granular sugars can be undertaken using either the open pan (OP) or vacuum pan (VP) processes. These processes use more complex technology than used for jaggery and syrup production. Open pan sulphitation (OPS) is probably the most common open pan method. In each case the production process can be divided into six stages:

- Extraction of juice from the cane
- Clarification of the juice
- Boiling of the juice
- Crystallisation
- Centrifuging
- Drying and packaging

Open Pan Sulphitation (OPS) sugar processing

Developed in India during the 1950s for the production of white granular sugar, OPS is based on an upgrade of khandsari production. The technology uses a mix of traditional and scaled-down versions of modern sugar technologies and is ideally suited to processing between 100 and 500 tonnes of sugar cane per day, with recovery rates of between 5 and 8%.

Unlike large-scale sugar factories, OPS plants do not usually have their own estates to supply cane but rely instead on contractual agreements between local growers and the factory. This level of technology can be beneficial to rural communities by creating employment opportunities at the factory and providing income for cane growers in the area.

Since the introduction of the technology, large numbers of OPS sugar plants have been built throughout India, with estimates of several thousand still in use by the late 1980s. Dissemination of the technology outside the South Asia has been limited; however, the potential for OPS is considerable in countries that produce non-crystalline sugars (jaggery, gur, panela, muscovado, etc) as they already have some of the necessary expertise.

Extraction

The cane is usually shredded before crushing using two or three 3-roll mill tandem arrangements either electrically or diesel engine powered. The crushers can be hydraulic loaded to improve extraction rates which can be as high as 70% of the available juice.

Clarification

Chemical clarification, based on modern cold lime sulphitation, is carried out to remove impurities which inhibit the formation of the crystals and can discolour the final product. The addition of lime also has the advantage of reducing the natural acidity of the cane juice, limiting the formation of invert sugars.

Batches of juice are treated simultaneously with milk of lime (CaO) and sulphur dioxide (SO₂) (by air forced through a sulphur furnace) after which the juice is transferred to an open boiling pan and quickly heated to 90°C or above. The lime and heat treatment form a heavy precipitant that flocculates, carrying with it most of the suspended impurities in the juice. The juice is then filtered and allowed to settle. The clear juice is decanted and transferred to the boiling furnaces.

Boiling

The boiling operation uses cascade type furnaces of various configurations. The massecuite is removed from the final boiling pan at about 84°Brix, at a temperature of around 112°C.

Crystallisation

The massecuite is placed in U-shaped vessels where it is slowly rotated and allowed to cool for up to 48 hours. This technique is often referred to as crystallisation in motion. Rotation promotes even cooling of the massecuite which helps to achieve uniform crystal growth.

Seeding can also be carried out: that is granulated massecuite from a crystalliser in which grains have already been developed are placed into the crystalliser before it is filled with fresh massecuite. This helps to promote uniform crystal growth. The massecuite, now consisting of crystals suspended in molasses, is transferred to the centrifuge.

Centrifuging

The centrifuge, a scaled-down version of those used in large-scale factories, consists of a perforated inner drum located inside a larger drum. The perforated drum is rotated rapidly, forcing the molasses to separate from the crystals. Water is sprayed into the spinning drum to assist in the removal of the molasses.

The crystals of sugar are then removed from the centrifuge and transferred for drying. The molasses are collected and can be reboiled, crystallised and re-centrifuged to produce a second, lower quality, crystal sugar known as number two or B-sugar.

Drying and packaging

The crystals can be dried in a number of ways: by placing them in the sun, or by using simple solar driers, or rotary or hopper driers which require fuel to provide drying heat. The dried product can then be packed into suitable containers or bags for distribution.

Mini vacuum pan (VP) sugar processing

This is a scaled down version of large-scale sugar processing technology common throughout the world. It is a high-cost, low-labour process suited to processing upward of 500 tonnes of sugar cane per day with recovery rates of between 10 and 12%.

Extraction

The cane is first shredded then crushed using hydraulically loaded 3, 4 or 5-mill tandems. The major difference between this and OPS roll mills is that water is sprayed onto the bagasse before the final mill and diluted juice is recirculated to the previous mills. This system, known as imbibition, helps to wash out more of the sucrose with the juice. Typically, extraction rates of 75% of the available juice are common.

Clarification

Clarification is carried out by lime sulphitation similar to that used in OPS, but here it is a continuous rather than a batch process.

Evaporation

The major difference between the VP and OPS technology is the method of evaporating or boiling the juice. Instead of in open pans the juice is boiled under vacuum, to about 70° Brix, inside closed vessels or 'effects'. Low pressure steam is used to boil the juice which circulates through tubes within a closed vessel. The vapour driven off passes into a second similar vessel, where it is used to heat more juice. In order to maintain suitable temperature differentials for heat transfer to occur, a partial vacuum is applied to each vessel, effectively lowering the boiling temperature of the juice.

It is common for four vessels to be used in series, each subjected to a progressively higher vacuum. This system is capital-intensive but is highly energy efficient and more importantly boils the juice at progressively lower temperatures from 103 to 50°C, reducing the effects of inversion, minimising discoloration and enhancing the formation of sugar crystals.

Final boiling to over 95° Brix takes place under vacuum in a single vessel, known as the vacuum pan, which is designed to handle the viscous massecuite. During this stage crystallisation begins in a controlled manner, enabling the maximum yield of crystals to be developed before the massecuite is transferred to the crystallisers.

Bagasse is used to fuel highly efficient high-pressure steam boilers. The high-pressure steam is used to generate electricity to meet the VP plant's needs and the low pressure exhaust steam is then used to boil the juice in the vacuum pans.

Crystallisation

The massecuite is cooled and the crystallisation process completed using large vessels that stir the massecuite continually for up to 48 hours.

Centrifuging

Takes place on a batch basis using large centrifuges similar in design and operation to those used in the OPS process.

Drying and packaging

Drying is carried out at low temperatures using rotary or fluidised bed driers.

Setting up a sugar factory

Types of sugar factory

Service extraction

All that is required is a site for the crusher and a space to build the furnace. Farmers, growers and merchants provide the raw material for processing and packaging. They take the risk of poor preparation and problems associated with inadequate storage and packaging. The processors charge a rate per unit of cane crushed or juice processed payable either in cash or percentage of the output or both.

The farmers can then rent the furnace or build their own close to the crusher site and produce syrup or jaggery, keeping control of the quality of the product. They could return to the farm and process the juice there or could pay others to process the juice for them.

This type of system is relatively low-cost and is suited to small scale production of up to 50 TCD in areas where cane is grown during short seasons on small plots spread out over a wide area.

Independent sugar factory

The factory buys in sugar cane and is then responsible for all aspects of preparation, processing and marketing the product. This type of business needs a reliable and constant supply of cane of acceptable quality. Although the factory could grow its own cane it is more usual for it to buy in cane from various sources including:

- direct from individual farmers/growers
- agricultural co-operatives or groups
- private traders or companies

Because the cane quality deteriorates quickly after harvest, it is important that the suppliers are contracted to supply cane at given times. This enables the factory to work continually while minimising the time harvested cane is allowed to stand.

This type of factory is suitable for medium scale production of between 50 and 500 TCD where cane is available all year round or for a substantial part of the year.

Sugar estates

The sugar estate takes control of all aspects of sugar production from growing cane to processing and marketing. It is usual for the estate to provide the bulk of their requirements and occasionally to contract local growers to produce certain amounts of cane for them. The estates can be fully owned by the factory or leased from the farmers in the area. In both cases the factory farms the land in accordance with its needs, providing all equipment, fertiliser, pesticides and transport.

Operating and managing an operation of this magnitude requires resources such as tractors, ploughs and harvesting equipment as well as a skilled workforce, all of which add to the cost of the process.

Operation and management

Costs

Sugar production, even at the small scale, is a complex business which requires skilled people to manage and supervise all aspects of the production, from the collection of cane to the delivery of sugar to the market place. If these skills are not available locally then they will have to be brought in to set up the business and to train staff, which will add cost to the project.

The costs involved with any sugar factory need to be taken into account. Small service extraction factories are the cheapest option but will require a crusher, boiling pan and furnace and some means of driving the crusher.

Although OPS is a low-cost option compared to large-scale production plants, it still requires substantial investment. In addition, there would be costs involved with operation, maintenance, transport and marketing.

Energy

Sugar production uses a great deal of energy to boil the juice as well as that required to operate crushers and other equipment. In most cases sugar factories rely on bagasse as the main fuel for the boiling process and care is required, especially with open pan systems, to ensure that sufficient bagasse is available.

For most small to medium-scale single or multi-pan factories producing lump sugars or syrups there is usually sufficient bagasse. In larger multi-pan factories producing granular sugars, such as OPS, it is often difficult to obtain enough bagasse. In these situations additional fuel is required which may be bagasse obtained from another factory or wood. Using forced-draught shell furnaces, as developed for OPS factories, it is possible to obtain a fuel balance for the boiling operation (first sugar only) using bagasse.

To operate the crushers, crystallisers, centrifuges and other powered equipment, an additional energy source is required. This may be electricity or diesel, both of which add to the total cost. If electricity from the grid is not available then it will be necessary to generate power at the factory. This means the installation of diesel powered generators requiring a reliable supply of diesel fuel and engine spares.

Most VP factories are self-sufficient, producing their own electricity and heating for both the process and the factory as a whole. With careful management and using modern, highly efficient bagasse-fired boilers it is possible to produce more electricity than is required by the factory. It

may be possible to sell this excess electricity to the grid or other users, generating another source of income for the factory.

Transportation

Transport may be required to bring cane from the fields to the factory and also to take the product to market. If motor vehicles are used then capital, maintenance and operating costs must be added to the cost of the product. If animal powered transport is used then hire charges and feed costs are also applicable. There may also be costs associated with the loss of the draft animal to other duties.

Maintenance

Equipment cannot be operated effectively without proper maintenance and repair. Engines, electric motors, crushers and permanently sited furnaces will all need routine maintenance if they are to operate efficiently.

Crusher rollers will wear with time and require re-machining which necessitates access to a workshop with a lathe. Usually, rolls can only be re-machined once after which they will be too small for effective crushing. Therefore spare rolls or facilities for refacing old rolls will be required. Other spares such as bearings and gears may also be required.

Therefore due consideration must be given to the provision of maintenance. Several options are available to the factory:

- provide its own spares
- buy spares from local suppliers
- import from outside the region or country.

Sugar cane

Suitable sugar cane must be available if a factory is to be efficiently operated. Because of local conditions and circumstances it may not be possible to grow the best type of cane and so a compromise will have to be made. It will be necessary to investigate what variety is grown locally and assess its suitability for the type of processing undertaken (i.e. jaggery, khandsari, OPS, mini VP etc). If the cane is not suitable, then further investigation will be required to identify a suitable variety taking account of local growing conditions (i.e soil types, climate, watering, fertilisers etc).

Investigatory work can be undertaken with local agricultural research centres or, if possible, established sugar factories which will already have undertaken research into varieties suitable for processing. After selecting a suitable variety it will be necessary to test it to ensure that it will succeed under local conditions. However, introducing a new variety of cane into an area may have a number of problems including:

- Farming practises may have to change to enable the new cane type to be grown successfully and on a sufficient scale.
- Farmer may not wish to invest in a new variety of cane until a market is assured.
- Chemical fertiliser may be required

Most medium-scale factories will require a set minimum amount of cane each day. Because of the rapid rate of deterioration of the harvested cane, it must be used within twenty four hours. In addition, the growing season may be shorter than the operational period of a factory and so farmers may have to grow cane over a longer period to meet demand. Therefore it may be necessary for farmers to change their farming practices to allow for a longer season and staggered harvests.

In return the farmer will receive a guaranteed income per unit weight of cane from the factory and can often claim part of the payment in advance. However, the factory retains quality control and usually has the right to reduce payment if the condition of the cane falls below that required.

References and further reading

Brown Sugar, Practical Action Technical Brief

Honey Processing, Practical Action Technical Brief

Candy Production, ITDG Food Chain No 22

Cane Sugar: The Small-scale Processing Option R. Kaplinsky, IT Publications, 1989

Sugar Cane: The Tropical Agriculturalist R. Fauconnier, CTA/MacMillan, 1993

Crushing equipment manufacturers

Note: This is a selective list of suppliers and does not imply endorsement by Practical Action

CIMAG - Com E Ind de Maquinas Agricola

Rua St Terezinha 1381

13970 ITAPIRA SP

Brazil

- A manual mill with a throughput of around 100 litres per hour. (More suitable for juice drinks than gur production.)

Penagos Hermanos & CIA Ltda

Apartado Aereo 689

Bucaramanga

Colombia

- A vertical roll, animal powered crusher, capacity of 4-6 tonnes of cane per day. A horizontal roll 4.5kW (6hp) crusher with a throughput of 400kg of cane per hour.
- Other models up to 1.7 tonnes per hour.

Tanzania Engineering and Manufacture Design Organisation

P O Box 6111

Arusha

Tanzania

- Electrically powered 2.2kW (3hp) crusher with a capacity of 20 litres of juice per hour.

Dias & Dias

690 Negombo Road

Mabole

Wattala

Sri Lanka

- 2hp and 6hp crushers with capacity up to around 400kg per hour.

Agro Machinery Ltd

PO Box 3281

Bush Rod Island

Monrovia

Liberia

P M Madurai Mudaliar, P M and Sang

Madurai Mudalliar Road

PO Box 7156

Bangalore

India

Nafees Industries

Samundari Road

Faisalbad

Pakistan

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This document was last updated in February 2009 and is based on the book *Small and Medium Scale Sugar Processing Technology* by Andrew Russell published by ITDG (now Practical Action) in October 1998. The book was based on the author's experience of working in the small to medium-scale sugar sector in Bangladesh and Kenya. Methods and technologies may therefore differ from those in other countries.

Practical Action welcomes any information from readers about their own experiences of small to medium-scale sugar production that will enhance, complement or expand on this document.