VARIOUS COMMERCIAL PROCESSES

(A) CHOICE OF PROCESS

In sugar manufacture, there are no specific processes, which are different from each other. Instead sugar manufacture has a generalized process consisting of various unit operations such as milling, evaporation, drying, crystallization etc. Hence a selection can be made inly with respect to particular choice of equipment and unit operation. Thus a variety of combinations can be made by differing the number of mills, number of effects in evaporator, the kind of dryer etc.

(B) PROCESS DESCRIPTION

At the sugar factory, the cane is piled as reserve supply in the cane yard so that the factory, which runs, 24 hr/day will always have cane to grind. The delivery of the cane to the factory depends upon the time of day, weather, and some other factors. Very closely controlled operations never have more than a few hours worth of cane in the cane yard, but more generally, the cane yard is fairly full toward evening and nearly empty the next morning.

The cane is moved from the cane yard or directly from the transport to one of the cane table. Feed chains on the tables move the cane across the tables to the main cane carrier, which runs at constant speed carrying the cane into the factory. The operator manipulates the speed of the various tables to keep the main carrier evenly filled.

In order to remove as much dirt and trash as possible, the cane is washed on the main carrier with as much water as is available. This includes decirculated wash water and all of the condenser water. Of the order of 1 –2 % of the sugar in the cane is washed out and lost in the washing, but it is considered advantageous to wash. In areas where there are rocks in the cane, it is floated through the so- called mud bath to help separate the rocks. The sugar recovered is normally 10-wt % of the cane, with some variation from region to region. Sugar cane has the distinction of producing the heaviest yield of all crops, both in weight of biomass and in weight of useful product per unit area of land.

Extraction of juice:

The juice is extracted from the cane either by milling, in which the cane is pressed between the heavy rolls, or by diffusion, in which the sugar is leached out with water. In either case, the cane is prepared by breaking into pieces measuring a few centimeters. In the usual system, the magnets first remove the tramp iron, and the cane then passes through two sets of rotating knives. The first set, called cane knives turns at about 700 rpm, cuts the cane into pieces of 1 – 2 dm length, splits it up a bit, and also act as a leveler to distribute the cane more evenly on the carrier. The second set, called shredder knives turn faster and combine a cutting and a hammer action by having a closer clearance with the housing. These quite thoroughly cutter and shred the cane into a fluffy mat of pieces a few centimeters in the largest dimensions. In preparing cane for diffusion, it is desirable to break every plant cell. Therefore the cane for diffusion is put through an even finer shredder called a buster or fiberizer. No juice is extracted in the shredders. In milling, the cane then goes to the crusher rolls, which are similar to the mills, but have only two rolls, which have large teeth and are widely spaced. These complete the breaking up of the cane to pieces of the order of 1 – 3 cm. The large amount of juice is removed here.

Milling:

The prepared cane passes through a series of mills called a tandem or milling train. These mills are composed of massive horizontal cylinders or rolls in groups of three, one on the top and two on the bottom in the triangle formation. The rolls are 50 – 100 cm diameter and 1 –3 m long and have grooves that are 2 –5 cm wide and deep around them. There may be anywhere from 3 – 7 of these 3 roll mills in tandem, hence the name. These mills, together with their associated drive and gearing, are among the most massive machinery used by industry. The bottom two rolls are fixed, and the top is free to move up and down. The top roll is hydraulically loaded with a force equivalent about 500 t. The rolls turn at 2 – 5 rpm, and the velocity of the cane through them is 10-25cm/s. After passing through the mill, the fibrous residue, from the cane, called bagassae, is carried to the next mill by bagassae carriers and is directed from the first squeeze in a mill to the second by turn plate. In order to, achieve a good extraction, a system of imbibition is used, bagassae going to the final mill is sprayed with water to extract whatever sucrose remains; the resultant juice from the last mill is then sprayed on the bagasse mat going to the next to last mill, and so on. The combination of all these juices is collected from the first mill and is mixed with the juice from the crusher. The result is called the mixed juice and is the material that goes forward to make the sugar.

The mills are powered with individual steam turbines. The exhaust steam from the turbines is used to evaporate water from the cane juice. The capacity of the sugarcane mills is 30 – 300 t of cane per hour.

Diffusion:

Diffusion is used universally with sugar beets but is little used with sugarcane. The process in cane is mostly lixiviation (washing) with only a little true diffusion from unbroken plant cells. Since the lixiviation is much faster, great effort is expanded in preparing the cane by breaking it so thoroughly that nearly all of the plant cells are ruptured. In many instances, diffusers were added to an already existing mill, and, therefore, the diffuser unit was placed after the crusher rolls. In the diffusers, the shredded cane travels countercurrent to hot (75^{o}C) water. In the ring diffuser, the cane moves around in an annular ring. In tower diffusers, the cane moves vertically, and in rotating drum diffusers, it travels in a spiral. Whatever the apparatus, the juice obtained is much like juice from mills.

Milling achieves 95% extraction of the sucrose in the cane, diffusion 97% extraction. Diffusion juice contains somewhat less suspended solids (dirt and fibre), and is of higher purity (sucrose as percent of solids). The diffusion plant costs much less and takes much less energy to run. The bagasse from diffusion contains much more water.

Bagasse:

The bagasse from the last mill is about 50-wt% water and will burn directly. Diffusion bagasse is dripping wet and must be dried in a mill or some sort of bagasse press. Most bagasse is burned in the boilers that run the factories.

Clarification:

The juice from either milling or diffusion is about 12 – 18% solids, 10 – 15 pol (polarization) (percent sucrose), and 70 – 85% purity. These figures depend upon geographical location, age of cane, variety, climate, cultivation, condition of juice extraction system, and other factors. As dissolved material, it contains in addition to sucrose some invert sugar, salts, silicates, amino acids, proteins, enzymes, and organic acids; the pH is 5.5 – 6.5. It carries suspension cane fibre, field soil, silica, bacteria, yeasts, molds, spores, insect parts, chlorophyll, starch, gums, waxes, and fats. It looks brown and muddy with a trace of green from the chlorophyll.

In the juice from the mill, the sucrose is inverting (hydrolyzing to glucose and fructose) under the influence of native invertase enzyme or an acid pH. The first step of processing is to stop the inversion by raising the pH to 7.5 and heating to nearly $100^{o}C$ to inactivate the enzyme and stop microbiological action. At the same time, a large fraction of the suspended material is removed by settling. The cheapest source of hydroxide is lime, and this has the added advantage that calcium makes many insoluble salts. Clarification by heat and lime, a process called defecation, was practiced in Egypt many centuries ago and remains in many ways the most effective means of purifying the juice. Phosphate is added to juices deficient in phosphate to increase the amount of calcium phosphate precipitate, which makes a floc that helps clarification. When the mud settles poorly, polyelectrolyte flocculants such as polyacrylamides are sometimes used. The heat and high Ph serve to coagulate proteins, which are largely removed in clarification.

The equipment used for clarification is of the Dorr clarifier type. It consists of a vertical cylindrical vessel composed of a number of trays with conical bottoms stacked one over the other. The limed raw juice enters the center of each tray and flows toward the circumference. A sweep arm in each tray turns quite slowly and sweeps the settled mud toward a central mud outlet. The clear juice from the top circumference overflows into a header.

Diffusion juice contains less suspended solids than mill juice. In many diffusion operations, some or all of the clarification is carried out in the diffuser by adding lime.

The mud from clarification is filtered on Oliver rotary vacuum filters to recovery the juice. The mud mostly consists of field soil and very fined divided fibre. It also contains nearly all the protein (0.5 wt% of the juice solids) and cane wax. The mud is returned to the fields.

Although the clarification removes most of the mud, the resulting juice is not necessarily clear. The equipment is often run at beyond its capacity and control slips a little so that the clarity of the clarified juice is not optimum. Suspended solids that slip past the clarifiers will be in the sugar. Clarified juice is dark brown. The colour is darker than raw juice because the initial heating causes significant darkening.

Evaporation:

Cane juice has sucrose concentration of normally 15%. The solubility of sucrose in water is about 72%. The concentration of sucrose must reach the solubility point before crystals can start growing. This involves the removal by evaporation of 93% of the water in the cane juice. Since water has the largest of all latent heats of vapourization, this involves a very large amount of energy. In the energy crunch of the late 1970s, the DOE found that the sugar industry was one of the largest users of energy. The sugar industry already knew this very well and had been using multiple-effect evaporators for saving energy for more than a century.

The working of multiple-effect evaporator can be seen in fig. In each succeeding effect, the vapours from the previous effect are condensed to supply heat. This works only because each succeeding effect is operating at a lower pressure and hence boils at lower temperature. The result is that 1 kg of steam is used to evaporate 4 kg of water. The steam used is exhaust steam from the turbines in the mill or turbines driving electrical generators. The steam has therefore already been used once and here in the second use it is made to give fourfold duty.

The usual evaporator equipment is a vertical body juice-in-tube unit. Several variations are in use, but the result is the same. The only auxiliary equipment is the vacuum pump. Today, steam-jet-ejectors are general, although mechanical pumps were formerly used.

Since the cane juice contains significant amounts of inorganic ions, including calcium and sulfate, the heating surfaces are quick to scale and require frequent cleaning. In difficult cases, the heating surfaces must be cleaned every few days. This requires shutting down the whole mill or at least one heat-exchanger unit while the cleaning is done. Inhibited hydrochloric acid or mechanical cleaners are usually employed. Magnesium oxide is sometimes used instead of lime as a source of hydroxide. Magnesium costs more, but it makes less boiler scale on the heaters. It is also easier to remove because it is more soluble; however, for the same reason, more gets into the sugar. Whether it is used or not depends upon the influence, standing, and persuasiveness of the chief engineer who must keep the plant running and the chief chemist who must make good sugar.

The evaporation is carried on to a final brix of 65 – 68. The juice, after evaporation, is called syrup and is very dark brown, almost black, and a little turbid.

Crystallization:

The crystallization of the sucrose from the concentrated syrup is traditionally a batch process. The solubility of sucrose changes rather little with temperature. It is about 68 brix at room temperature and 74 brix at 60^{o}C. For this reason, only a small amount of sugar can be crystallized out of solution by cooling. Evaporating the water must instead crystallize the sugar. Sucrose solutions up to a super saturation of 1.3 are quite stable. Above this super saturation, spontaneous nucleation occurs, and new crystals form. The sugar boiler therefore evaporates water until the supersaturation is 1.25 and then seeds the pan. The seeding consists of introducing just the right number of small sugar crystals (powdered sugar) so that, when all have grown to the desired size, the pan will be full. After seeding, the evaporation and feeding of syrup are balanced so that the supersaturation is as high as possible in order to achieve the fastest possible rate of crystal growth, without exceeding 1.3.

The boiling point of a saturated sugar solution at 101.3 kPa (1 atm) is 112^{o}C. Sugar is heat-sensitive and, at this temperature, thermal degradation is too great. The boiling is therefore done under the highest practical vacuum at a boiling point of 65^{o}C. The sugar boiler therefore must manipulate the vacuum along with the steam and feed. A proof stick on the vacuum pan allows the contents of the pan to be sampled while under vacuum. When the pan is full, the steam and feed are stopped, the vacuum is broken, and the batch, or strike, is dropped into a receiver below.

A strike is 50 metric tons of sugar and it is boiled in 90 min. at the end of this time, the mixture of crystals and syrup, called massecuite, must still be fluid enough to be stirred and discharged from the pan. In practice, about half of the sugar in the pan is in crystal form and half remains in the syrup. In this case, the pan yield is said to be 50%. Some very good sugar boilers are able to achieve as much as 60% yields on first strike.

Vacuum pans:

Vacuum pans have a small heating element in comparison to the very large liquor and vapour space above it. The heating element was formerly steam coils but is now usually a chest of vertical tubes called calandria. The sugar is inside the tubes. There is a large center opening (downcomer) for circulation.

The vacuum pan has a very large discharge opening: typically 1 m dia. At the end of a strike, the massecuite contains more crystals than syrup and is therefore very viscous. This large opening is required to empty the pan in a reasonable time. At the top or dome of the pan, there are viscous entrainment separators. The pan may also be equipped with a mechanical stirrer. This is usually an impeller in or below the central downcomer, driven by a shaft coming down all the way from the top. The strike is started with liquor just above the top of the calandria. The strike level cannot be very near the top because of vapour space must be allowed for separation of entrainment. In operation, the boiling is very vigorous with much splashing of liquid.

The vacuum is maintained mostly by condensing the vapours in a barometric condenser. In some cases, a surface condenser is used. This serves as a source of distilled water and recovers heat. More often, however, a jet condenser is used in which the cold condensing water is sprayed into the hot vapour and both condensate and condenser water are mixed. A supplementary vacuum pump is required to remove noncondensable gases.

Centrifuging:

The massecuites from the vacuum pans enter a holding tank called a mixer that has a very solely turning paddle to prevent the crystals from settling. The mixer is a feed for the centrifuges. In a batch-type centrifuge, the mother liquor is separated from the crystals in batches of about 1 t at a time.

Boiling systems:

In raw-sugar manufacture, the first strike of sugar is called the A strike, and the mother liquor obtained from this strike from the centrifuges is called A molasses. The pan yield in sugar boiling is about 50%. Because crystallization is an efficient purification process, the product sugar is much purer than the cane juice and the molasses much less pure. As an approximation, crystallization reduces the impurities by factor of 10 or more in the product sugar. Therefore, almost all of the impurities remain in the molasses. Enough molasses accumulates from boiling two first strikes to boil a second strike. The B sugar from the second strike is only half as pure as that from the first strike, but the B molasses is twice as impure. This can go on to a third strike. At this point, 7/8 of the sugar from the cane juice is in the form of crystals and 1/8 in the C molasses. In practice, three strikes is about all that can be gotten from cane juice. The trick is to maneuver to obtain good sugar, but at the same time have the C or final molasses as impure as possible. The purity of the feed to the final strike is adjusted to obtain the lowest possible purity of final molasses. Some of the C sugar is redissolved and started over, some is used as footing for A and B strikes. The C sugar is of very small crystal size so it is taken into the A or B pans as seed and grown to an acceptable size. This practice is actually a step backward because it hides impure C sugar in the center of better A and B sugars. The product raw sugar is a mixture of A and B sugars.

There are many variations in the boiling scheme, such as two and four billings, blending molasses, and returning molasses to the same strike from which it came. All of these tricks are used, depending on cane purity and capabilities of the equipment available.

Crystallizers:

When the steam is turned off at the end of a sugar boiling, evaporation ceases immediately and the mixture of crystals and supersaturated syrup in the pan starts toward equilibrium, which is the po9int of saturation. In relatively pure sugar solutions, this equilibrium is reached in few minutes well before the syrup crystallization is slower and reaching equilibrium can take a significant amount of time. In the final strike, the time an amount to days, so final strikes are not sent directly to the centrifuges, but instead to crystallize, holding tank is in which the crystals grow as much as possible and the super saturation in the molasses is reduced to 1.0. Since the intention in handling the final molasses is to remove as much sugar as possible, advantage is taken of the small temperature coefficient of solubility and the massecuite is also cooled. The crystallizers are large tanks, some open-top, with a slow-moving stirrer that is sometimes also a cooling coil. At the end of the holding time, the massecuite is warmed slightly as it enters the centrifuge to lower the viscosity and achieve better separation. The limiting factor in exhaustion of masses is the viscosity. A little more water can always be boiled out, but the molasses must remain fluid enough to run out of the pan, into the centrifuge and to flow between the sugar crystals on the centrifuge screens.

Refining:

Sugar refineries are located in large cities. They are near seacoast with harbors and facilities for receiving raw sugar by ship. They thus can receive sugar from anywhere in the world, although each refiner has favorites that suit the refinery, market, or have been the traditional supplier. Refineries are open all year, although the busy season is in the summer.

Refineries are always large. Their capacity is expressed in terms of daily melt. Melt is the sugar term for dissolving, and means the amount of sugar melted or processed each day. The smallest refineries have a daily melt of 450 t, and large ones have as much as ten times that amount. The yield of refined sugar is nominally 93% of the raw-sugar input.

Raw sugar is light to da4rk brown in color and sticky. The size of the sucrose crystals is ca 1 mm. Refiners would like to have raw sugar that is high in sucrose and of uniform quality; however, they must be prepared to refine anything. Raw sugars are about 98 pol, although they are always described in terms of the equivalent "raw value" expressed as 96 pol, a base value from the 1920s when raw sugars were of this pol.

Terminology changes slightly in the refinery. In raw sugar, syrup is a concentrated solution going to the pans. After the boiling, the solution separated from the crystals is molasses. In the refinery, it is liquors that are fed to the pans, and syrups that are separated from the crystals. Local jargon adds to the confusion with such terms as greens and jets, meaning syrups, and barrel syrup, meaning final molasses.

Affination:

The first step in refining is to remove the molasses film from the outside of the raw-sugar crystals. This is done by a washing process known as Affination. Syrup that is not quite saturated with sucrose is mingled with the incoming raw sugar in a large trough containing a mixer paddle and scroll. This mixture is then centrifuged and washed in the centrifuge rather more than less. A uniform crystal size is important in raw sugars because a mixture of different sizes or broken crystals does not wash well in the affination centrifuge. The syrup formed is called affination syrup not wash well in the affination centrifuge. The syrup formed is called affination syrup and is used for mingling. The sugar is called washed sugar and is ten shades lighter in color than the raw sugar. It is estimated that 90% of refining is done in this first step. About 10% of the sugar becomes apart of the affination syrup, which thus keeps increasing in volume and is sent to the recovery house.

The recovery house is route through a set of equipment in the same building. IT uses the same processes that are used in the main refinery, but in manner more like a raw-sugar operation. As the name suggests, sugar is recovered in the recovery house, but the main object is to transfer impurities into molasses that contains the least possible amount of the sucrose. The recovered sugar is called remelt and is sent back to process.

Melting:

The washed sugar is melted in hot water, and usually the pH is adjusted with lime. Water that contains a little sugar from anywhere in the refinery is called sweetwater, and if it does not contain much impurity, is used in the melter. The washed sugar liquor coming from the melter is adjusted to the operating concentration, usually about 65 brix. The trend is to operate refineries at higher brix up to 68, because if water is not added, it does not have to be boiled away later. The washed sugar liquor is dark brown and quite turbid, and appears much darker than the sugar from which it came. The melter liquor is strained through a plain screen to catch debris in the raw sugar.

Clarification:

The object of clarification is the complete removal of all particulate matter. The particles in the sugar come from all sources, eg, field soil and fiber which escaped clarification in the raw-sugar factory; all microbiological life, including yeasts, molds, bacteria, and their spores; colloids and very high molecular weight polysaccharides; and foreign contaminants such as insect and rodent dropping. The very diversity of the nature of the particulate matter and wide range of particle sizes makes clarification a difficult and critical step in the refining of sugar. One of three processes is used: filtration, carbonization, or phosphatation.

Phosphatation:

In the phosphate clarification scheme, lime and phosphoric acid are added simultaneously with good mixing. The phosphoric acid is added in proportion to the milt at about 0.01-0.02%. The lime is added to bring the pH to 7.8. The calcium phosphate precipitate forms a floc of no particular crystal structure. It is even better at scavenging impurities by entrapment than the carbonate precipitate. It also has the useful property of attaching or entrapping air bubbles. Thus, at the same time that the floc is being formed, some air is injected, mixed, or pumped into the system. Raising the temperature a few degrees also helps tiny air bubbles materialize throughout the liquor. The precipitate then floats to the surface as a scum of 80% organic matte and is scraped off without any filtration. The mixing is very thorough just as the reagents are added, gentle in a floc-development section, and then minimal in the flotation zone.

The phosphate clarifiers are also called frothing clarifiers and have many sizes and shapes with scrapers going forward, backward, and around. Some are heated and some are deep. Sugar is recovered from the scum by clarifying again. The phosphate system uses only about $^1/_{10}$ as much reagents as the carbonate system, and so produces only $^1/_{10}$ the scum volume.

No matter what the method of clarification, the clarified liquor is brilliantly clear without any sign of turbidity. It is, however, dark, rather like a cup of weak coffee.

Decolorization:

The key process in sugar refining is decolorization. Color is the principal control in every sugar refinery. It is the main property that distinguishes refined sugar from raw sugar. The word color is used loosely. It usually means visual appearance, but in technical sugar work it means colorant, the material causing the color. It can be classified in three groups: plant pigments; melanoidins resulting from the reaction of amino acids with reducing sugars; and caramels resulting from the destruction of sucrose. Many, but not all, compounds in each of these classes have been identified. In sugar work, color refers collectively to the optical sum of all the colorants.

Bone char and granular carbon behave similarly in decolorization of sugar. For the contact with sugar liquor, both are contained in helds called cisterns ca 3 m-dia and 7 m tall and holding 30-40 t carbon. The liquor flows downward with a contact time of 2-4 h. The first liquors are water white with a very gradual yellowing. The cistern stays on stream until the color of the liquor becomes too great to be handled by the remainder of the refining process. The decolorization is always greater than 90%. The bone-char cycle is about 4 d; for granular carbon, it is 4 wk. The first liquors from bone-char treatment are lighter than the first liquors from carbon. However, from the adsorbent point of view, the two systems are different.

Heating degreased cattle bones to about 7000C in the absence of air makes bone char. IT is about 6-10% carbonaceous residue and 90% calcium phosphate from the bone with an open pore structure supplied by the bone. The surface area available to nitrogen is 100 m^2/g. The particle size is about 1 mm. besides being a carbon absorbent; it has ion-exchange properties that permit removal of considerable ash from the sugar. These same ion-exchange properties result in a buffering effect that keeps the pH of the sugar liquor from falling.

After the decolorization cycle, the sugar is washed out of the bed and then the bed is washed with the cool water to remove as much as possible of the adsorbed inorganic salts. The sweet water is of low purity and cannot be recycled. The organic coloring matter is adsorbed so tightly that no amount of washing will remove it. The water is therefore drained from the char and the char moved from the cistern to a kiln where the organic matter is burned off at 500^0C, with a little oxygen in the kiln atmosphere to burn away freshly deposited carbon and keep the pores open.

On bone char, it has been observed ionic constituents in the liquor affect ionic color removal process. High calcium liquors decolorize well, but high sulfate liquors decolorize as much as ten times more poorly for an ion-concentration change of only 0.01 N.

Crystallization:

The color of the washed, clarified, and decolorized liquor going into the crystallization process ranges from water white to slightly yellow. Many refiners polish-filter the sugar liquor at this stage to make sure that it is sparkling clear with no turbidity. Others rely on good operation upstream and do not polish-filter. In many cases, the brix has become too low, either on purpose or by error; these liquors first go to the evaporators to bring the brix to >= 68.The vacuum pans are the same as were described under Raw Sugar Manufacture, and their operation is the same. They are operated even more carefully to produce crystals of the desired size. Great care is taken to avoid conglomerates and fines. Boiling rate and throughput are important. A new strike of some 50 metric tons must be dropped every 90 min to keep up with the production schedule.

The boiling schemes used in the refinery are more extensive and more extensive and variable than those used in the raw house. This is because the starting material is of much higher purity. Ordinarily, three, four, or five strikes of refined sugar are obtained.

The syrup from the fourth strike may handle in different ways. It may be used in the recovery house, but is more likely used in making specialty syrups or brown sugars. It may also be sent back to decolorization or clarification, and recycled.

The refined sugar centrifuges are always batch type because they leave the crystals intact. The centrifuging is easy and the cycles are short.

The drying of the sugar from the centrifuges is done by rotary dryer using hot air. This dryer is universally misnamed the granulator because by drying in motion, it keeps the sugar crystals from sticking together, or keeps them granular. The hot sugar from the granulator is cooled in an exactly similar rotary drum using cold air.

Conditioning:

The sugar from the coolers would appear to be finished, but after a few days storage it becomes wet with water trapped inside the grain because of the very high rate crystallization and drying. After a few days, this moisture migrates outside the crystal and the sugar is wet again. A process known as conditioning removes the moisture, in which the sugar is stored for four days with a current of air passing through it to carry away the moisture. In one system, a single silo is used with sugar being continuously added to the top and removed from the bottom, and a current of dry air blowing upward. In another system, the sugar is stored in a number of small bins. It is continuously transferred from bin to bin with dry air blowing around the conveyors that move the sugar.

Packing, storing and shipping:

Sugar is sometimes stored in bulk and then packaged as needed. Others package the sugar and then warehouse the packages. The present trend is away from consumer-sized packages and toward bulk shipments.