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RECENT DEVELOPMENTS IN LARGE SCALE VACUUM PAN SUGAR TECHNOLOGY WITH PARTICULAR REFERENCE TO DEVELOPING COUNTRIES 1/

by

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INTRODUCTION

The cane sugar industry is one of the oldest food processing industries in the world. The ancient civilisations of Egypt and India knew how to make sugar, and their methods were not significantly different to those in use today in small jaggary factories. The noble strains of sugar cane were found widely distributed through the East, and remained in cultivation for hundreds of years until the modern plant breeding techniques of the last hundred years introduced new and more prolific varieties.

In common with almost every other traditional industry, the sugar industry existed not simply to make a primary product, sugar. It was also required to make a profit for its owners, for the farmers who grew the cane, the entrepreneurs who built factories and for the thousands of people employed in the industry. Without this profit motive it is difficult to envisage the industry developing in the way it did. It has been the need to produce sugar both economically and profitably, aided by the means of improving efficiency provided by the industrial revolution of the late nineteenth century which have dictated the direction in which the sugar industry has grown; namely, towards increased output per unit of input at competitive cost to the consumer.

In the agricultural sphere research has led to new varieties of cane with lower fibre content, higher sucrose levels, disease resistance, tolerance of soil and climate variables. New methods of cultivation, fertilisers, pesticides and herbicides, irrigation methods and harvesting methods have steadily been developed to increase yields while restraining cost increases.

Similar effort was also directed towards improvements in the factory processing. The biggest single breakthrough in manufacturing was probably the harnessing of steam power in the

19th century. This led, over the years to an industrial process which is almost unique in its independence of both energy and water. This factor in itself has led to a certain technological specialisation within the cane sugar industry. Where the beet sugar industry has had to develop energy conserving techniques so as to cut fuel costs, the cane sugar producers have been able to continue with the basic process almost as it stood 50 years ago. The steam generated from bagasse is used to drive the prime movers for the mills and alternators, which in turn provide exhaust steam for process use. The water evaporated from the juice is available for process and for boiler feed water. Such changes as have been made (and there have been many), were aimed at producing incremental increases in yield or recovery. It is only comparatively recently that the value of the potential cane by-products have come to represent a significatnt factor in the planning of sugar factories, with consequent changes in the energy balance.

The object of this paper is to trace the origins of modern cane sugar technology and in doing so to explain the processes involved and, to indicate possible lines of future development. Reference is made to some of the differences between "large scale sugar technology" compared with "small scale sugar technology", and the costs, both capital and operatting are discussed briefly. These aspects have been, or will be covered in more detail in other papers in this seminar.

I THE EVOLUTION OF MODERN SUGAR TECHNOLOGY

It was suggested in the introduction that the harnessing of steam power was the single greatest technological advance in the sugar industry, as indeed it was in many other industries.

A. The Milling Function

Originally, cane was ground between two vertical rollers driven by oxen or water power. With the advent of steam engines of increased power potential the design of mills changed to three roller horizontal units of very much heavier construction.

The number of rollers in a tandem increased progressively to nine, twelve, fifteen or more rollers, as it was found that successive squeezings would increase the extraction without increasing the quantity of water used to "wash out" the sugar. It also proved possible to dramatically increase the rate of throughput for a given mill size provided the mill engines could deliver enough power. Around the year 1900 a 34" x 78" mill was rated for about thirty five tons of cane per hour whereas today the same sized mill would be capable of 250 tons per hour or more. As recently as 1947 steam turbines were introduced as mill drives, and these very rapidly spread throughout the industry until today the Corliss and drop valve steam engines are becoming very rare indeed.

B. The Steam Generation Function

Bagasse boilers have also undergone very substantial changes since the days when sun-dried bagasse was direct fuel under open pans as in present day jaggary units. In the early days, particularly in Hawaii, fire tube boilers were popular, but as the demand for higher pressures increased these were replaced with water tube boilers. Today many factories operate with steam pressures in the range 21 - 25 kg/cm but some modern installations are using pressures of up to 42 kg/ cm^2. As steam pressures rose so the complexity and efficiency of the installation increased. Superheaters, economisers and air pre-heaters become necessary or desirable, the standards of purity of boiler feed water became more and more stringent and instrumentation increased in order to safeguard what had become the most capital intensive station in the whole factory. This is discussed in more detail in Section II C.

C. The Juice Treatment Function

Treatment of the extracted juice has not changed as dramatically as some of the other unit processes in cane sugar manufacture. In simple terms the juice is still treated with lime, heated to boiling, and allowed to settle in order to remove as much as possible of the insoluble and colloidal impurities. At the turn of the century heating was still done by direct injection of steam, although tubular heaters were coming into use. Liming and settling was still largely a batch process, but by the late 1920's continuous clarifiers were becoming widespread, with very often some form of automated lime addition based on flow rate.

The evaporation of juice to form a syrup has benefitted from what Hugot [(1)] describes as "the greatest and most striking advance in the history of sugar manufacture". In 1830 Rillieux conceived the development of the multiple effect evaporator. The original method had been to thicken the juice in open pans over direct fires. This led to uncontrolled heating, caramelisation of the sugar with consequent colour formation, high viscosities and sugar loss. This was changed in favour of steam heating with the advent of steam engines. The introduction of the multiple effect evaporator, in which successive reductions in pressure across the effects allowed the steam from the first vessel to boil the second vessel and so on, completely revolutionised this key stage in the process. By increasing the difference in temperature between the steam and juice through the use of vacuum in the last vessels, 1 kg of steam entering the first effect calandria could be made to evaporate 4 kg of water from the juice, a vast improvement in the utilisation of heat. Furthermore the lower temperature obtaining in the last vessel, where the juice is thickest, considerably reduces the danger of caramelisation of the sugar at this stage.

D. The Crystallisation Function

The next stage in the process, crystallisation and separation, has also undergone many changes in evolution to the present day factory. Vacuum pans were invented early in the 19th century by Howard, and a great number of designs have been experimented with over the last 150 years, all with the object of improving the efficiency of the formation and production of crystalline sugar. Generally speaking coil pans have been superseded by calandria pans, but the principles involved remain unchanged. Pan boiling remains one of the few batch unit stages left in the process, but developments over the last five years suggest that continuous pan boiling will gain ground rapidly in the next decade.

Centrifugal machines for separating the sugar crystals from the mother liquor were introduced in about 1850, and for the next hundred years the suspended basket batch machine was the standard pattern throughout the world. Various drives were tried, notably belt, and water driven machines, and a Report of the Hawaiian Sugar Planters Association [2] of 1931 showed that of 796 machines reported, 661 were belt driven, 124 were water driven and 11 individual electric driven. Since that time individual electric drives have become universal (made possible by improved steam generation and the use of steam turbine generators), and batch machines have become fully automated, capable of handling up to 20 tons of massecuite (sugar and mother liquor), per hour. Continuous centrifugals are taking over from batch machines very rapidly today, with only the high grade sugar being handled in batch centrifugals in most new installations at present.

The foregoing is a very brief summary of some of the major process areas and the changes which have taken place to maintain the competitive situation of the Cane Sugar Industry worldwide.

A more detailed discussion of these operational areas now follows.

II RECENT DEVELOPMENTS IN LARGE SCALE VACUUM PAN TECHNOLOGY

It is customary when discussing the operations in a sugar factory to break these down into easily definable unit processes.

A. Cane Handling

Many cane sugar industries in the world are finding it increasingly difficult to persuade labour to carry out the traditional tasks of cutting and loading cane. Often this is not related to a full employment situation but stems from changes in the social and educational status of the former cane cutters (manual labour). As they become better educated fewer and fewer young men are willing to undertake what is an extremely onerous form of manual labour for relatively poor returns. Thus the industry is finding itself forced, in some areas, into a position of having to mechanise or go out of production.

The degree to which field mechanisation is taken depends on local conditions; the nature of the terrain, whether there are existing agricultural practices which limit the degree of mechanisation, technical expertise in maintaining heavy equipment and so on. In simplified terms the options for in-field mechanisation can be classified as follows:-

(i) Mechanical aids to cane cutting or loading - In many industries labour has shown considerable and early resistance to hand gathering and loading cane into transport units. It is possible in such cases to make use of self-loading trailers from stacks formed by cutting gangs. Alternatively, mechanical grab-loaders of various types can be used to pick up cane which has been laid in windrows by the cutters. Such systems in addition greatly increase the utilisation (turn round time improved), of the transport fleet, with consequent savings in capital investment.

In other areas resistance has been towards cutting rather than loading and in consequence several types of mechanical cane cutters, such as the McConnell Stage I machine have been developed to supplement or replace hand labour.

(ii) Wholestick Harvesters - Wholestick harvesting systems have been in use for many years, particularly in Louisiana, Puerto Rica, Peru and Hawaii. Some of these systems have serious drawbacks, such as the necessity for large and expensive cane cleaning plants with the Hawaiian System.

Wholestick harvesters have another disadvantage, shared by chopper harvesters in being limited to relatively flat terrain. Their advantage is that they can employ the same transport and handling system designed for hand-cut cane.

(iii) Chopper Harvesters - Systems using chopper harvesters have reached a high degree of development in Australia, Texas, Florida, Cuba and many other countries. Very high rates of harvesting have been achieved with choppers, but it must be emphasised that for this system the whole cane growing regime, from field layout, drainage, row spacing, variety selecti[illegible], cultural methods, access road networks and tr[illegible]sportation system have to be laid out, designe[illegible] to meet the requirements of the harv[illegible]ximum utilisation is to be achieved. The [illegible]omplexity of the machinery also calls f[illegible]le mechanical skills and well-developed [illegible]rvices such as spare parts supplies and wor[illegible] facilities. In turn, of course, they create skills in a rural agricultural environment which have side benefits to the economy.

(iv) Cane Yard Handling - As in-field cane handling systems become more sophisticated, so cane yard procedures have developed to handle the volume of traffic demanded by a large sugar factory. A typical modern cane sugar factory will handle 5,000 - 10,000 tonnes of cane per day. The simple logistics of handling this quantity of cane demands that unit loads should increase from the old, traditional bundle of four to six tonnes to loads of ten to twenty tonnes. The high initial cost of a railway transport system has led to a decline in this form of transport. The increase in mechanised in-field loading has accelerated the movement away from rail systems, except in specialised cases such as Queensland, in favour of tractor drawn trailers using high flotation tyres. With the increased cost of oil, however, a swing back to railways may occur. Sometimes these are followed by localised transloading stations, to increase unit loads delivered to the factories, but often the in-field vehicles deliver directly to the factories. Hilo type cane unloaders have become very common, tipping cane directly on to cross-carriers, feed tables, or into a gantry storage area from where it can be fed to the mill by overhead cranes.

The advent of chopper harvesters, and the rapid rate of deterioration of billetted cane, has brought into focus the need to process cane as soon as possible after harvesting. Many studies have confirmed that cane, especially after burning, declines rapidly in "recoverable sucrose", and the modern trend is to improve the transportation system and reduce the cane yard stocks to a minimum.

B. Cane Preparation and Milling

(i) Preparation - In 1936 Tromp [3] wrote "the proper extraction of juice is only possible when the tissue is ruptured to the greatest possible extent and the juice holding cells are opened up". For the next 20 years the advances in cane preparation were relatively insignificant, and in 1956 the conclusion of an ISSCT symposium on cane shredders [4] was that there existed a wide variation in opinion on the usefulness of the shredders.

Nevertheless, work was going on in both Australia and other countries which indicated quite clearly the advantages of fine preparation. Murray and Shann [5] (1959), concluded that the use of more finely prepared cane increased the extraction when operating in the practical compression ratio range and that the energy consumed by the first mill decreased with finer preparation. Buchanan et al [6] analysed the results for 18 mills in Natal and found that the 11 which had shredders showed a 10% lower lost absolute juice percentage fibre and 23% higher specific feed rate than those without shredders. Even more significantly, it was found that the residual absolute juice in the first mill bagasse was 30% lower when the mill was preceded by a shredder.

This trend towards intensive preparation has continued apace, and it is not uncommon these days to find as much as 65 - 70 kW per ton fibre per hour being applied to preparation alone. To put this into perspective, a 7,000 tonne per day factory may install a total of 3,000 kW in turbines on the knives and shredder drives compared to 1,500 kW 25 years ago. Once again technology is developing to improve the efficiency of the process and to maintain the competitive nature of the industry.

(ii) Milling - The designs of milling plant have not changed substantially in recent years. The increased fineness of preparation has however led to changes in feeding techniques with elevated "Donnelly" feed chutes and heavy force-feed rollers being employed more and more. Four roller mills, with the force-feed roller driven through a suitable gearing arrangement from the top roller, are now commonplace. Even five roller mills, in which two rollers are used to compress the bagasse and force it into the feed opening are quite widely used, especially in Australia. Very intensive preparation is coupled with high rates of milling, to improve both the extraction and throughput of the plant.

The use of mill turbines as prime movers on mills has now become very widespread. Their advantages over steam engines were seen to be [7] their smoother running, oil-free exhaust steam, the ease of remote control and the ability to operate at higher steam pressures. The additional advantage of very much lower dead-weights compared to steam engines of the same horse power has become especially important as mill capacities increased. The power requirements of a milling tandem vary according to the number of rollers, the gearing, the peripheral speed and many other factors. As a general guide Hugot quotes figures of between 20 - 25 hp per ton fibre per hour per mill, with figures as low as 12.5 hp/t.f.h./mill being reported for a very long tandem. By comparison a small scale plant with two mills 13" x 18" grinding five tons per hour would require a 60 hp motor (8), a rate of 40 hp/t.f.h./mill, generated by diesel fuel rather than bagasse. This is another example of the improved efficiency that comes with size of operation. The use of steam turbines is discussed in more detail in Section II D.

(iii) <u>Diffusion</u> - An alternative system to extraction by milling is diffusion, and this process has gained rapidly in popularity in the last five to ten years. Started in Egypt many years ago, as a batch process, there are now a number of continuous cane or bagasse diffusers on the market operating on a variety of principles. These generally have lower capital and maintenance costs than mills of similar capacity.

It has been well established, (10, 11, 12), that diffusers work by a combination of two processes:

a) a washing or displacement of sugar rich juice from ruptured cells by water or more dilute juice.

b) a true diffusion of sucrose from within unopened cells. This is a much slower process and accounts for a relatively small fraction of the total sucrose extracted.

Clearly the extent to which the cane is disintegrated prior to the diffuser is critical, and this has influenced both the diffuser design and the specification of knives and shredders.

A common design is the bed-type percolation diffuser in which the bagasse or cane is conveyed through a rectangular vessel on a slow moving conveyor while the juice is percolated through it in counter-current stages. The main advantage of this type is their simple construction but they have been known to have difficulties with percolation of the juice through the bagasse bed, particularly when processing very finely prepared or dirty cane.

The second basic type of design is the submerged bed, in which the cane is totally immersed in a stream of juice flowing counter to the direction of movement of the cane. This system should, in theory, increase the "wetting" of the cane, improving the efficiency of the extraction process. However, to some extent the same problems exist in both systems in that the cane tends to mat together to form a relatively impermeable mass, and does not 'float' freely in the submerging juice.

There are other designs of diffusers which attempt to combine the best of both systems. These include a bed-type diffuser which constantly breaks up the bed of bagasse by tumbling it on to a new conveyor for each stage, and a diffuser which successively rinses and squeezes the bagasse in a screw-press.

C. Boiler Plant

As explained above steam boiler plant now accounts for almost the largest single item of factory capital expenditure. Shell Boilers with riveted joints and equipped with fire tubes were unsuitable for higher steam pressures and outputs. The possibilities for furnace constructions are less flexible than for water tube boilers. Skills to build riveted boilers are no longer available and the riveted drums of the early water tube boilers were often damaged by corrosion when feed water contamination was chronic. The present practice is to specify water tube boilers with welded steam and mud drums, and the output of steam per unit heating surface has trebled from the early days of water tube boilers. Assemblies of water tubes and drums are very flexible in permitting the heating surfaces to be arranged in the best way to suit the furnace design. Boilers which perform badly do so usually because the bagasse furnace is unsuitable and less often as a result of unsatisfactory boiler pressure parts.

A factory should have at least two steam boilers so that in the event of a failure of one boiler a limited operation can continue with the other boiler. Many small boilers, as seen in older factories provide flexibility but would be prohibitively expensive today. A small factory of say 1,500 TCD requiring two boilers each of 24 tonnes per hour steam output compared with, say a 4,000 TCD factory with two boilers each of 65 tonnes per hour is at a disadvantage. The 24 tonne boiler will cost more than 50% of the 65 tonne boiler.

With boilers costing over £1 million each, protection devices to prevent damaging malfunctions of feed water purities, levels and combustion control, become essential. Similar devices have been developed for marine and power generation boilers and they are well proven. Despite the instrumentation the boiler operator still has a responsible job.

Boiler thermal efficiencies do not vary irrespective of size for boilers of similar specification. Additional steam from the same quantity of bagasse fuel (i.e. higher thermal efficiencies), can be obtained by building on air heaters (which recover heat from the flue gases and help bagasse to burn), and economisers (which also recover heat from the flue gases, and add it back by raising feed water temperatures). In many situations excess bagasse is a problem and boilers are often operated deliberately as inefficiently as possible to incinerate bagasse surplus. Where other demands arise, for example, for export electric power or for operating sugar refineries or distilleries and extra steam is needed, the boiler plant can be specified accordingly.

Unless the economics justify further consideration it is not in the interest of the sugar industry to replace its free fuel with a costly substitute such as oil unless the bagasse is to be applied to the manufacture of board or paper of a higher value. A large sugar factory might well have available a working surplus of bagasse which could meet the needs of a smaller scale board or paper plant, however.

D. Steam Prime Movers for Mills and Generators

Steam drives for sugar mills initially were developed using the reciprocating steam engine. Horizontal slow speed mill engines were widely adopted and effective. Manufacture of these large engines and their cost together with costs of installation have become prohibitive and they have largely disappeared together with the skills necessary to maintain them. The engines were limited to about 1,200 hp and they discharged unwelcome lubricating oil into the exhaust steam. A 1,200 hp engine weighed about fifty tons compared with a 1,200 hp turbine and gear-box of say twenty three tons.

Horizontal mill engines were unsuitable for driving high speed electric generators and these were generally driven by enclosed high speed steam engines as the application of electric motor drives was widely adopted for auxiliaries throughout factories. In the end, high speed steam engines were limited in size and output and they became uncompetitive with steam turbines. Such engines are rarely built today.

The steam turbine which is compact and widely applied in the geared form has been developed for ships and the petroleum industry. It is now universally applied to drive cane knives, shredders, mills and electric generators by the cane sugar industry. It works exceedingly well on superheated steam at higher pressures and unit sizes are almost unlimited for very high power outputs. Exhaust steam from turbines is free from oil. As a disadvantage small steam turbines tend to be uneconomical and machines below 200 kW have unacceptably high steam consumptions. Despite the relatively high order of precision demanded in its manufacture and assembly, the steam turbine is a simple machine and it calls for very little maintenance compared with a reciprocating engine.

E. Juice Treatment

(i) Clarification of the juice - It is in this section of the factory that perhaps the fewest changes have occurred in recent years. Cane juice leaving the mills is an opaque, greenish-brown liquid more reminiscent of muddy water than golden syrup. However, the simple action of heating the juice to boiling point will bring about a large degree of coagulation of proteins and other colloidal particles, which can then be allowed to settle out.

It was found very early on in the history of sugar manufacturing that this process was more effective after the addition of lime to the juice. To this day a more cost effective method of clarification has not been discovered, but there have been countless variations on the sequence and method of heating and liming juice.

Cane juice, particularly if it is low in purity or stale, is very sensitive to both pH and high temperature. Low pH or acidity, will cause the sucrose to invert, reducing the recovery both directly and indirectly through the production of more molasses. High pH will have a less direct effect on sucrose, but will bring about the destruction of reducing sugars to form highly coloured non-sugars. These affect both the quality of the sugar and the recovery, as these impurities tend to be highly viscous and increase the losses in molasses. High temperatures will accelerate both these effects, and even at neutral pH, will cause an increase in colour, and some sucrose loss.

Modern sugar technology has therefore aimed at reducing as far as possible these undesirable conditions. Automatic control of pH, with the lime being added as a very dilute milk-of-lime or as soluble lime saccharate is now widely used. Skilled instrument technicians are frequently in short supply in developing countries, but various simple proportioning systems based on juice flow have also been developed.

Juice heating is carried out in high velocity tubular heat exchangers to minimise the time of contact between the juice and the heating surface. Clarifier design has concentrated on reducing residence time, and here the work of Hale and Whayman [13] is especially important. By concentrating on the radial distribution and collection of juice in trayless clarifiers they have shown that it is possible to reduce the retention from a traditional 90 - 180 minutes down to 10 - 20 minutes, albeit with the use of polyacrylimide flocculants.

All these changes have come about as part of the impetus towards more efficient operation of the industry in a highly competitive environment. In the Beet industry this process has proceeded further, in some respects, than in the Cane industry.

(ii) Filtration of Muds - The recovery of sugar from the clarifier mud is done in rotary vacuum filters almost exclusively, in modern sugar factories. These have the advantages over the former plate and frame presses of being able to recover more sugar from the cake and of being a continuous process. Also the facts that they use brass or stainless steel screens as opposed to filter cloths, and they are largely automatic, requiring only one operator per two or three filters, mean that the operating costs are considerably lower than for the outdated presses.

(iii) Improvements in colour of market sugar - Where sugar is being produced for direct consumption, and a "white" product is required, the use of sulphur as a bleaching agent has been common for many years. Juice sulphitation, using about 0.8 kg sulphur per ton cane will undoubtedly yield a very acceptable sugar. However it also gives rise to a number of other problems such as corrosion of plant, increased losses through inversion and in molasses and reduced throughput because of scaling of heating surfaces. On top of this sulphur has risen fourfold in price over the last five years and the cost of this process is becoming increasingly unattractive.

If there is sufficient steam available from bagasse, the least expensive method in terms of operating costs alone, of improving sugar quality is to dissolve the first product sugar and boil a "remelt" strike. Recrystallisation is the most efficient purification system, and without any further chemical treatment this remelt sugar will compete with the best sulphitation sugar. The drawback to this system is the greater capital expenditure required for pans, centrifugals and other plant. However, it may be a solution as an intermediate stage in a factory which intends to introduce a refinery at some later date.

A new process which has only been developed within the last year or two, involves the clarification of the raw syrup by flotation of the scum precipitated by phosphoric acid. Although it is still early days there are hopes that this technique will fulfil, partially at least, the same purification function as the remelt process (as opposed to the chemical bleaching of the sulphitation process), without the high capital cost.

(iv) Evaporation - Since the introduction of the multiple effect evaporator in 1930 the principle of this process has remained largely unchanged. However the design of evaporator vessels, the ratio between heating surfaces of the different effects, the extent of vapour bleeding for other heating purposes, entrainment arrestors, level and Brix controllers are all features which have undergone refinement over the intervening years. In some countries semi-Kestners and even full Kestners are being used, but with their requirement for a very steady feed rate these have not yet been widely accepted, particularly in developing countries, where technical skills are in short supply.

F. Crystallisation and Separation

Crystallisation of the sugar in vacuum pans, and the separation of crystals from molasses in centrifugals were, until recently, the last remaining batch processes in a modern sugar factory. This is not to say that there has been no development of these stages, as indeed both have been widely automated.

(i) Pan Boiling - The evolution of automated pan boiling systems has taken place largely in the large refineries in developed countries. This has been because of the greater technological skills available in these countries and because of the more uniform composition of refinery liquors and products. Nevertheless, systems suitable for raw factories, based on conductivity, viscosity and boiling point elevation have all been developed commercially and are now widespread.

Development work in France, Germany, Holland and Australia has led to a number of continuous vacuum pans being installed in raw sugar factories. Typically these operate on a plug flow system, with a suitably saturated quantity of syrup and slurry being introduced at the start, and progressing in stages through the pan under the control of conductivity or mobility probes. Inevitably some mixing takes place, and one of the problems in producing a high grade raw sugar has been the wide spread of grain sizes in the final sugar.

(ii) Crystallisers - Continuous crystallisers have been in use for some years now, either as uncooled and even unstirred vessels for high grade massecuites or as cascade or single units with cooling elements for low grade massecuites. Hydraulic drives and vertical crystallisers with static cooling elements are an interesting recent development.

(iii) Centrifugal Machines - Batch centrifugals are still the most common type found in sugar factories, but their size has been gradually increasing. Today the 30" and 36" diameter baskets have virtually disappeared, and 48" x 30", 48" x 36" and 54" x 42" are the commonest sizes. Since the centrifugal force is determined by the speed and the basket diameter the advantages of the increase in size is obvious. At the same speed of rotation a 54" basket has 80% higher centrifugal force than a 30" basket.

Batch machines are driven by electric motors almost exclusively today, and these may be of the a.c. pole-changing induction motor type or a Ward-Leonard d.c. drive system. Both types are capable of full automation, and so a battery of, say five centrifugals with a sequence timing device can operate virtually as a continuous process. Nevertheless because of the frequent acceleration and deceleration required of the motors, there can be heavy demands on factory power and on maintenance costs.

Continuous centrifugals have now been developed, and these are replacing batch machines very rapidly for low grade massecuites. The advantages are the simplicity of the drive, with its lower initial cost, and the ability to cure a more viscous massecuite than batch machines. The movement of the crystals across the face of the basket in a continuous centrifugal leads to crystal fracture which renders them unsuitable for use of high grade product sugars. However there are already prototype machines on the market which claim to overcome this drawback and it is anticipated that once these are proven the batch centrifugal will become a thing of the past.

In addition to improving the efficiency of the use of energy as illustrated in the description of steam generation and steam utilisation equipment, there can be noted in the juice treatment and crystallisation sections of this paper a direction of technological innovation towards improving the quality, both in colour and purity, of the sugar, and towards improved recovery of as much as possible of the sucrose from the juice obtained at the extraction stage.

III SOME DIFFERENCES BETWEEN LARGE SCALE AND SMALL SCALE SUGAR TECHNOLOGY

A. The Concentration of Resources

The establishment of any form of sugar industry to produce, say, 100,000 tonnes per annum calls for a very major capital investment whether it be in the form of one large scale factory or 50 small scale factories. It is therefore important to consider very carefully the availability of resources apart from capital before embarking on such a project.

A sugar industry requires, besides capital and a suitable area of land, specialist human resources, engineers, chemists, skilled craftsmen, managers, etc. It also needs training facilities in order to continue operations once the initial commissioing crew have left. It requires workshops, roads, communications and the other resources necessary for an industrial process. All of these are likely to be scarce in a developing country, and there will be a need to establish some order of priority in allocating these to various development projects within a country.

It would seem to be logical, therefore, in terms of utilisation is scarce resources per unit of sugar produced, where there are alternative uses for the resources elsewhere in the economy, to concentrate the effort in large units capable of making maximum use of available resources at least cost. The technological "focus" of resources which can be brought to bear in a large sugar factory will undoubtedly show a better financial return on investment than spreading those same resources thinly over a large number of far flung small scale establishments, particularly as a skilled unit of labour can be far more productive if he can command a larger mechanical or other input.

B. The Capital Costs

The capital cost structure of large and small scale factories have been discussed in detail by other speakers in this seminar. In terms of capital requirement for the factory alone, small scale open pan industries may require less capital per tonne of sugar than a large vacuum pan factory. Small scale vacuum pan industries will not be much less capital intensive than large scale establishments. When one takes into account the fact that the small scale open pan factory requires some 40% more land to produce the cane required because of their lower yield in terms of sugar % cane, the advantage of this technology is not quite so marked.

C. The Operating Costs

In terms of operating costs there is no question but that the large scale enterprise is the most effective. There have been many studies into the relevant costs for each type of technology, and invariably the conclusion has been that provided the crop lasts for more than about one hundred and fifty days small scale open pan technology is not competitive at the cane and sugar prices obtaining in the large scale industry. The reason for this must lie in the fact that in the sugar industry operating costs are largely fixed costs or are related to the amount of cane processed. A technology which requires 40% more cane to produce a given amount of sugar is obviously under a severe disadvantage.

There are of course, certain instances where a small scale unit would be the logical choice. For instance, in small, isolated pockets of suitable land that cannot support a larger factory and where the country has no alternative economic use for such land.

Alternatively, small factories could supplement an existing large scale industry in areas where the cost of transporting sugar into a section of the country from a distant large factory would be unjustified. In areas also, where the traditional art of small scale sugar production already exists (e.g. India), it could be argued that movement away from such an industry should not occur until such a move could be justified by a shortage of labour elsewhere in the economy.

D. The Export Market

The development of an exportable surplus of sugar is generally dependent on a soundly based, economically viable home market. The vagaries of the World Sugar Price are such that an exporter who is not protected by long-term trade agreements is faced with a very uncertain return on his investment. Since the ending of the Commonwealth Sugar Agreement and the U. S. Quota system it has become increasingly important for a sugar exporting country to have a sound home industry on which major investment planning can be based. A substantial investment in small scale technology in place of large scale factories would inevitably limit the potential of that country to become a regular exporter of sugar.

E. By-Products

Yet another sphere in which the large scale production unit shows a marked advantage over "mini" factories is in the field of by-products. The raw materials of the by-product industries which can be supported by a sugar factory are bagasse, molasses, filter cake and effluent.

Bagasse can be used to generate electricity, as is done in Mauritius and many other countries or it can be used to manufacture paper or particle board. Other uses include a "filler" for molasses cattle-feeds and a large number of chemical processes such as furfural, based on cellulosic fermentation. All of these processes, with the possible exception of cattle feeding, are capital intensive, and would require a substantial surplus of bagasse from the sugar factory in order to be viable. Thus, in the unlikely event that the small factory could produce the thermal efficiency to generate a surplus of bagasse, this surplus could not realistically support an economically sized by-product industry as the transportation of large quantities of bagasse, which is very bulky, to a central plant would not be economic.

Molasses is used either as a stock-feed or as a fermentation base for alcohol production. It is quite possible that the small scale factory would be unable to transport molasses to a suitable export dept because the small quantities would make handling costs prohibitive. The molasses could alternatively be used as a cattle-feed for local farmers, in which case its value would be related to the pricing structure in a peasant-type, beef producing context, i.e. relatively low. The production of alcohol in small scale distilleries is a possibility, but would almost inevitably be either an illicit operation or of low social benefit. It has been demonstrated in Brazil that a central, alcohol-based chemical processing company can operate on the basis of molasses supplies from many factories. However the types of chemical produced, such as ethylene, butanol, acetone, acetic acid, phthalic anhydrides and ketones are dependent on a highly developed industrial market for sales, and this is unlikely to exist in a developing country.

On the other hand, a distillery based at a large sugar factory, making use of services such as steam and electricity from the factory could produce sufficient quantities of industrial alcohol to make it viable as a petroleum substitute.

Filter cake really has only one use whether from a large or small factory. It can be put back on the land as a fertiliser as it contains appreciable levels of phosphorus and organic nitrogen. The user must have suitable means of applying the product at up to 20 tonnes per acre, and this again limits its usefulness in some instances.

Effluent is not normally considered as a by-product but recent advances in anaerobic fermentation techniques suggest that it will soon be feasible to use sugar factory effluent to produce useful quantities of methane gas for domestic or industrial use.

IV ENVIRONMENTAL CONSIDERATIONS

The concern for the environment which has swept the developed countries in recent years is of no less importance in developing countries. Indeed in respect of pollution of rivers it is often of even greater concern in undeveloped countries as there will be people living along rivers downstream of a potential polluter who will be dependent upon untreated river water.

There is no doubt that the total amount of sugar lost in effluent will be greater in a large number of small factories than in a single large unit of equal total capacity. However the pollution from the large unit will be going to a single outfall and hence is potentially more damaging to the immediate environment. Fortunately sugar factory effluent is relatively easily treated, and it is sufficient, in the tropics, to allow it to decompose in shallow ponds for a number of weeks or months before returning the purified effluent to the river. Aerobic digestion by micro-organisms will reduce the BOD to acceptable levels for this discharge. Various means can be used to speed up this process, such as mechanical aerators, anaerobic fermentation, and feeding nutrients such as nitrogen and phosphates. Here again one might expect the large scale factories to be better equipped, technically, to treat their effluent than the small scale producer with limited resources of skills, surplus energy, etc.

V CONCLUSIONS

The sugar industry is a very old and traditional industry which has nevertheless developed over the years with a considerable degree of success. This constant improvement in terms of yield through technological improvement has meant that in real terms sugar prices have barely changed in many parts of the world at a time when prices were rising across a broad range of goods and commodities. To a large extent this has been possible through economics of scale; rising costs forced small scale vacuum pan factories to amalgamate or close; unit plant sizes have increased and this has enabled costs to be contained.

The high cost of capital has made it very expensive today to establish a large scale sugar factory from the grass-roots. There are cases where small open pan technology, particularly of the improved Khandsari type, can fill a gap. However in the long-term the lack of economic viability of these plants, when in competition with large plants, will render them unattractive as an investment prospect.

BIBLIOGRAPHY

1. HUGOT, E. "Handbook of Cane Sugar Engineering", Second Ed., Elsevier, Amsterdam, 1972, 498.

2. TROMP, L. A. "Machinery and Equipment of the Cane Sugar Factory", Second Ed., Norman Rodger, London, 1946, 531.

3. TROMP, L. A. Idem ibid, 118.

4. ARNOLD, K. S. "Symposium on Sugar Engineering", Proc. 9th Congress Int. Soc. Sug. Cane Technol., 1956, 535.

5. MURRAY, C. R. AND SHANN, D. S. "Effects of Degree of Preparation on the Queensland Experimental Mills", Proc. 10th Congress Int. Soc. Sug. Cane Technol., 1959, 122.

6. BUCHANAN, E. J., DOUWES-DEKKER, K, AND VAN HENGEL, A. "Cane Milling Research and Development in South Africa 1961 - 1964", Proc. 12th Congress Int. Soc. Sug. Cane Technol., 1965, 1599.

7. ARNOLD, K. S. Idem ibid, 125.

8. REPORT ON 4TH TECH. SEMINAR ON THE OPEN PAN SUGAR MANUFACTURE. P. R. A. I. Publication No. 350, 1966, 24.

9. FITZGERALD, J. R. AND LAMUSSE, J. P. "Diffusion in South Africa", Proc. 15th Congress Int. Soc. Sug. Cane Technol., 1974, 1486.

10. REIN, P. W. "The Mechanism of Extraction in the Cane Sugar Diffusion Process, Proc. 14th Congress Int. Soc. Sug. Cane Technol., 1971, 1254.

11. FOSTER, D. H. AND SHANN, D. S. "Experiments with Cane Diffusion in Queensland", Proc. 14th Congress Int. Soc. Sug. Cane Technol., 1971, 1267.

12. PAYNE, J. H. "Cane Diffusion - The Displacement Process in Principle and Practice", Proc. 13th Congress Int. Soc. Sug. Cane Technol., 1968, 103.

13. HALE, D. J. AND WHAYMAN, E. "The Development of a Trayless High Capacity Clarifier", Proc. 14th Congress Int. Soc. Sug. Cane Technol., 1971, 1459.

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