

Highlights of the twentieth century progress in sugar technology and the prospects for the 21st century

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Introduction

Before dealing with the important technical progress in sugar processing during the finishing century, it is of relevance to glance at the preceding centuries to know where this industry comes from. Innovations in sugar cane technology were imposed by economic constraints already in the 18th and 19th century. Labour and energy costs are two of the expenses to reduce if it is desired to increase profitability. As long as slavery was not abolished, there was no need of innovation. A technological advance and important economy of fuel was achieved by the substitution of firewood by bagasse and the introduction of the three-roller mill which leaves the cane stalks intact and combustible after drying. The second achievement was the Jamaican train, which consists in a battery of 5 or 6 cauldrons heated by one fire through internal flues which improves the efficiency in fuel consumption. The battery is designed so that greater heat could be applied to smaller cauldrons than to the larger ones. The juice was clarified in the two first cauldrons and boiled to the point of crystallisation in the remaining cauldrons. Adding of rye, lime or ash was made by slaves who had to agitate, mix, skim or discharge a cauldron in another at temperatures above 100°C in conditions so bad as to be compared by a Jesuit Portuguese priest to a vision of souls in Hell.

Slavery was abolished in 1833 in English colonies and in 1848 in the French colonies. Heavy taxes were imposed on the importation of refined sugars in the metropolises. This was at the origin of the creation of refineries in England first, then in France. After slaves brought from Africa, there was an episode of transportation of cheap workers from China to Carribean Islands and South America.

The other historical remarkable fact was the England's blockade of Europe after the Napoleonic wars which led to the interruption of supply to the continental states. This was the trigger event for sugar beet industry. Very rapidly and also because of the taxation policy, sugar beet industry was developed. In less than a century (1850-1915) beet sugar production increased for 150 000 tons/year to nearly, 8 millions of tons/year. The % of cane at the end of the 19th century was below 40 % of the total sugar production. However, recovery followed in the early years of the 20th century. First world war was fought in the fields of sugar beet and this contributed to the increase of cane share in world sugar production. It reached in 1919 a percentage of 78 % not surpassed since that time (Galloway, 1989).

This competition between cane and beet sugar was one of the movers of the technology of sugar processing. Now, at the end of the twentieth century, owing to the emancipation of emerging economies,

especially Brazil, and to the market laws, cane sugar is again at the rank with a production exceeding 73 % of total.

It is beyond the scope of this presentation to analyse the economic and geopolitical reasons of the evolution of sugar production. We will keep within the limits of sugar science and technology. Alternately, mechanical engineering and chemistry were the two major disciplines governing the progress in sugar processing. We will recall the highlights of twentieth century innovations in sugar processing before presenting some of the perspectives we foresee for the twenty-first century.

1 – Evolution of sugar processing in the twentieth century :

The basics of sugar processing was developed since the end of the 19th century, especially thanks to the numerous chemists of that period (Claasen, Hertzfeld, Grut, Stanek, Saillard, Wohryzeck,...). An indication of the importance of the progress in beet sugar processing in France may be derived from the increase in capacity of the factories. Whereas 300 factories having an average capacity of 200 to 250 tons/day were in operation around 1900-1905, to produce less than 1 million tons of sugar, only 40 factories continue to exist with a tonnage of 8000 to 20 000 t/day and a production of 5 millions t/year. Just after 1914-1918 world war, reconstruction of destroyed factories was made with a substantial increase in capacity with, in certain cases, central factories having satellite extraction units to solve the problems of conveying sugar beets to the factory. After the second world war, the scarcity and cost of labour, led to set continuous processes and to generalise the automatic control.

That was the period of intensification of basic and applied research. C.I.T.S (Commission Internationale Technique de Sucrierie) was launched in 1949. Setting of pilot workshops like that of G.T.S. (Groupement Technique de Sucrieries) in France was established. The conception of equipment was modified for a better efficiency, more and more continuous processes and a centralised computerised control. Even sampling and laboratory analysis are more and more automated.

1.1. Extraction

Progress in plant breeding was made since the last decades of the nineteenth century. It allowed increase in % of sugar in beet from 8.8 to 18.8% in the period 1838 - 1908. The last years of the century are devoted to the controversial gene modification studies. Prediction of the technological value of sugar beet was proposed by Wieninger and Kubadinov (1971) using a formula for juice purity and molasses sugar based on the knowledge of the concentration of melassigenic non-sugars, Na⁺, K⁺ and α -nitrogen, R being the sugar content of beet.

Juice purity :

$$P = 99.36 - 0,1427 \times (K + Na + \alpha N) \times 100/R$$

Sugar in molasses (as a function of alcalinity coefficient Ka)

$$K_a = (Na + K)/\alpha N$$

For $K_a > 1.8$: $S_m = 0.3492 \cdot (K + Na)$

$$K_a \leq 1.8 ; S_m = 0.6285 \cdot \alpha N$$

The coefficients of these equations are adapted to each crop of sugar beet depending on the composition of non-sugars.

Evaluation of sugar cane quality as concerns the quantity of sugar (pol) to be recovered was made since 1888 in Indonesia. Among the formula still used the Winter formula gives the recoverable commercial sugar (Ws) as a function of pol (Sj) and Brix (B) :

$$W_s = S - 0.4 (B-S)$$

Of course the formula used do not represent absolute values of sugar extracted and differ from a country to another. Although, it is difficult to have representative sample of cane, Hugot (1974) recommends the direct analysis of a small sample after extraction of juice in laboratory 3-roller mill or hydraulic press. The recoverable sugar (R.S.) is calculated using the formula :

$$RS = k.(1-1.45.f) \times (S-0.3.B)$$

Where k is an efficiency coefficient and f : fibre content, S sugar content in primary juice and B : Dry substance of primary juice.

Extraction of sugar evolved from the batch maceration of beet gratings to methodical counter-current diffusion. Gain of time and efficiency were achieved together with the removal of polluting wastewater and the recycling of process water.

Batch vessels diffusion was commonly used in beet sugar factories during the first half of the century. In text books of the beginning of the century, one can realise how important labour cost. For instance, a sugar factory crushing 200 t/day needs for the batch diffuser :

- 1 batch operator
- 1 young assistant
- 2 workers for the cossettes (tamping down after vessel filling (with feet))
- 1 unskilled worker to sweep up
- 1 young assistant for different tasks.

Optimisation of sugar extraction by diffusion was studied since the 1930's. The well known formula of Silin (1937) is only slightly changed during the following decades.

$$N(n-1).\log(n-1 + C/Co)/(n.C/Co) = \gamma = A.L.Z.\theta.$$

Where A = constant ; L = length of cossette % (m) ; Z = duration of diffusion (min.) ; θ = temperature coefficient ; γ = constant called "temporary constant" ; C = sugar loss in pulp ; C_0 = sugar content of beet (%) ; S = draft (L of juice % kg beet) ; $n = 0.93 (S + 0.43C_0)$. Labour cost and the advance of technology were at the origin of the numerous achievements of continuous diffusers. Many problems appeared in the early apparatus. These problems were either mechanical due to the continuity of functioning or chemical such as corrosion, foaming, bacterial growth and fermentation.

Very rapidly the advantages of continuous diffusers were indisputable :

- automatic control of operation
- optimisation of extraction.
- reduction of labour to a simple supervision form the centralised post of control
- increase in capacity of diffusers
- energy saving (by heat exchange raw juice/cossettes and juice/hot water).
- Recycling of press water with fresh water

Different types of a beet extractors are found in the end of this century based on different principles (Van der Poel et al., 1998) :

- controlled transport of both juice and cossettes (RT extractor, De Smet extractor)
- controlled transport of cossettes and uncontrolled transport of juice (silver chain-type, Olier)
- uncontrolled transport of juice and cossettes : towers extractors (BMA, Buckau Wolf), sloping trough extractors (DDS, silver slope-type).

Extraction of sugar from cane is still using the crushing in a series of roller mills. A counter flow washing is applied. The whole milling process is completed after 20 minutes. Improvements were made at the level of the feeding of mills as is the case for the six-roll mill in Australia. Extraction is made more efficient as reabsorption factor increases with roll surface speed. The quality of feed bagasse, the temperature and concentration of imbibition liquid may affect imbibition coefficient which is also sensitive to imbibition level.

Beside the classical cane mill, continuous counter-current diffusers were also used for cane sugar since 1960's. Differences mainly related to the preparation of raw material exist between beet and cane extraction by diffusion. Adequate preparation of cane is needed to meet the requirements of efficient extraction in cane diffuser. Different types of diffusers exist, most of them being inspired from beet diffusion, and generally constructed by the same suppliers as sugar beet diffusers (DDS, BMA, De Smet).

1.2. Juice purification

In sugar beet factories, the use of lime and carbon dioxide was applied since 1859 according to a procedure set by the French Chemists Perrier and Possoz. At the beginning of the twentieth century, a massive liming (2-2.5 kg of lime % L of juice) was applied as well as double carbonation. Most of operations (filling, emptying, heating,...) were made manually. The second half of century was that of modern factories inspired from achievements in cane sugar processing made in the U.S.A. The Benning carbonation saturator with external recycling of juice received simultaneously preheated raw juice and lime milk, which limits the alkaline degradation of hexoses and improves the decantation and filterability. Static decanter (Dorr-Oliver) allows a good clarification. Clarified juice is fed into the second saturator where excess of free CaO is removed and the sludge is filtered on continuous vacuum-drum filters. The main adjustments in beet juice purification are :

- progressive preliming of raw juice which allows a protection of the precipitate against desagregation during massive liming
- a complete destruction of hexoses (weak concentration in beet juice) during the contact at high pH in liming tanks prevents the risk of non enzymic browning reactions with the relatively high concentrations of amino-acids
- recycling of thickened sludge in the prelimer.

The important innovations in the field of juice purification which aimed at a better efficiency are :

- regular running of the whole purification chain owing to automatic control
- optimisation of thin juice quality because of a precise determination of pH, temperature and alcalinity optima (at the laboratory-pilot scale)
- centralised computerised control and labour reduction
- reduction in maintenance cost.

Meanwhile, an important increase in equipment capacity was achieved which reduces purification costs. The prevalent purification scheme corresponds to a pre-liming reaching an alcalinity of 2.8 to 3g/L.

However, total lime used is below 15g/L because of recycling of first carbonation sludge in the pre-limer. So that the consumption of lime stone remains around 19 to 25 kg per ton of sugar beet depending on draft (Bonnenfant, 1999). Consumption of lime has been decreasing regularly these last decades because of the improvement of quality of beet and to technological advances.

In cane sugar manufacture, the juice purification used for several centuries is the simple defecation method (Honig, 1953). It consists in adding a small amount of milk lime to reach pH close to 7.0 at a temperature of about 103°C before adding a flocculating agent to improve clarification. The clarifier underflow is mixed with bagacillo (fine bagasse) and desweetened on rotary drum filters. This original procedure was diversely modified changing the sequences of liming, heating and addition of phosphates or flocculants before clarifying.

The procedure of lime-carbon dioxide treatment applied for beet was also used to clarify cane juices. Lime consumption is lower than for beet and the consumption of energy in a double carbonation purification system is higher than in simple defecation (Van der Poel et al., 1998).

Other innovations used in juice purification are based on the use of ion exchange resins. These are applied to decalcification, decolourisation or the exchange of Mg^{2+} ion, less melassigenic against Na^+ and K^+ which are melassigenic. These techniques have backdraws as they produce large quantities of waste water.

1.3. Juice evaporation

Equipment and processing are common in beet and cane sugar factories. At the beginning of 20th century, the basic principles were known :

- multiple – effect evaporation
- supply of vapour to the process
- vapour thermocompression

Important progress was made during this century :

- thorough study of thermal scheme of sugar factories for heat economy achievement
- improvement of evaporators and heat exchangers (falling film, 2-body evaporator..)
- increase in number of effects (2 to 3 in the beginning, now : six to seven effects with higher temperature of inlet steam and last effect under vacuum)
- increase in efficiency by use of vapour compression (mainly in beet factory)
- rationalisation of thermal scheme including condensed water and other heat flows
- because of sensitivity of cane juice to heat, reduction of time in first evaporator, limitation of boiling temperature or pressure, vacuum evaporation with elimination of condenser loss
- compliance to emission regulations in steam boilers (SO_x, NO_x, HCl, HF, CO, fly ash, soot).
- Better knowledge of the reasons of colour formation (sucrose hydrolysis, thermal degradation, retention times, omission of SO₂ addition for technical or regulation reasons).
- Scale removal by chemical cleaning or processing aids (polyelectrolytes).
- Concentration of thick juice for storage or crystallisation feed purposes (time saving during the footing of crystalliser, decrease in vapour consumption).

- Advanced automation with computerised systems : better accuracy of measurement, supervision of plant from centralised control rooms, reduction of manpower, increase in safety.

1.4. Crystallisation

At the start of 20th century, solubility tables, boiling point elevation as a function of concentration and other physical chemical properties of sucrose solutions were known. However, the extraction of pure crystals from technical sugar solutions was a specialisation of the hand-picked personnel. The art of the pan man is to appreciate supersaturation and to grow crystals without formation of fines.

During the 20th century, the major improvements were :

- a better knowledge of sucrose solubility in water and of the properties of saturated solutions
- a systematic study of crystal growth rate as a function of supersaturation, purity and temperature
- a better knowledge of the effect of impurities on crystal growth and morphology
- studies were made of the molecular structure of saturated solutions and on the kinetics of nucleation
- in beet sugar factories, solubility in impure solutions is determined with a satisfactory accuracy using the variation of saturation (or solubility) coefficient as a function of non-sugar/water ratio (independent of temperature)
- in cane sugar factories, the high amount of invert sugar and mineral ions makes it difficult to predict the solubility coefficient.

This is achieved at the laboratory using saturoscope device. Such a determination of saturation point allows an approximate calibration of control devices.

- continuous evaporating crystallisation was invented with advantages like constant flow, lower temperature between heating steam and magma, easier process control and the lower cost of investment and operation and disadvantages like a large C.V. of crystals, incrustations and the need of production of seeds outside the crystalliser.

Despite the advent of continuous vertical vacuum pans with improvements such as lower energy consumption, higher crystal yield, better process control (Kraus and Kordel, 1997), the batch vacuum pans still have the preference of the factories because of an optimised commercial quality of sugar (grain size distribution and C.V., especially). Among the recent advances in crystallisation, we can give as an example, the mastering of the delicate process of seeding. This is based the theoretical principle of introducing the same number of particles as desired to find at the end of boiling after growth of crystals. Different seeding methods were developed recently. Seed magma was introduced into CSM beet factory in Breda (Van der Poel, 1982) and further improved and computerised (Van der Poel et al., 1985). Another procedure was developed at the Braunschweig institute with BMA (Eichhorn, 1991).

The operation consists in seeding a saturated syrup at high temperature with a slurry (10 µm of average size). Cooling crystallisation contributes to the growth of these particles. The magma obtained is used as a footing in a crystalliser where it should meet the requirements of uniformity of size and absence of conglomerates. Seed magma is needed for continuous vacuum pans.

Another interesting progress is that of the low product exhaustion. Owing to a better appreciation of parameters to optimise, especially as concerns the satisfactory work of low product centrifugals, it was possible to define precise set points for saturation and viscosity of mother liquor and compacity along the chain of low-product crystallisers. This was achieved using a pre-centrifugation step to reduce crystal percentage at the optimal value. Equipment at this stage was also tremendously improved owing to the replacement of classical multiple crystalliser chain with large capacity vertical vacuum crystallisers.

1.5. Automatic control

The nineteenth century ended with the vanishing of old-style mills and the advent of central factories in most cane-growing regions. Only large factories could afford sophisticated machines and the control instrument associated as well as the employment of qualified engineering staff.

One of the workshops the most critical to run automatically was that of crystallisation. Different properties were used as variables in control loops for the automatic control of pan boiling. It is the case for electrical conductivity, as a reference for the supersaturation, which was adopted since 1932 in Java (Honig, 1959). Other variables like boiling-point elevation, refractometric Brix of mother liquor, viscosity, crystal content, level and temperature of massecuite, steam consumption or flow of syrup intake (Knovl et Moller, 1975/76) were applied.

Pneumatic and electro-pneumatic controllers were used. Generally, the tricky phase of filling, concentration, seeding, graining and thinning under low vacuum were controlled manually. The role of the pan man was preponderant.

Final boiling and tightening of massecuite was programmed. A considerable extension of automatic control to the whole crystallisation process was achieved in the 1960's. Increase in automation of the different steps of sugar industry together with the difficulty of finding highly qualified workers led to the construction of central control rooms with few staff members able to control all process sections. In general, there were two control rooms, one for the head of factory and one for the back.

Since the advent of computers and microprocessors, digital direct control was introduced with increased efficiency. The programmable logical controller (PLC) gave a better flexibility as the process control engineer is led to program a solution to the problems posed in the factory. Digital control systems where computers are connected by a bus prove to be the most reliable and robust tools of automatic control. The work in control rooms is, now becoming one of the most important aspects in factory management (van der Poel et al., 1998).

2 – Perspectives for the 21st century

The starting point of technological advances is always associated to a better knowledge at the molecular level of processes. This is also the case for sugar technology. Current progress and the perspectives of evolution of sugar processing originate from the rapid evolution of separation techniques first set for analytical purposes,

then expanded at the level of pilots and factories. Likewise, structural and molecular studies of sugar, non-sugar and their interactions contribute to unveil some of the complex reactions occurring during the process.

2.1. New trends in analytical techniques

- Chromatographic methods :

Specific separation of sugars, anions and cations using highly selective ion exchange columns made the use of liquid chromatography more popular these last 15 years in sugar factories and research centres. This is due to the increase of sensitivity of pulsed electrochemical detection without derivatisation. It was possible using HPAEC-PAD to detect low levels (nanogram) of sugars, to identify polysaccharides after analysis of hydrolysates and to analyse minor constituents (organic and inorganic) of white sugar with a good accuracy.

- Infrared spectroscopy

Near infrared (NIR) spectroscopic methods have been developed as rapid, non-destructive, on-line tools for the monitoring of sugar processing. The method remains a secondary method depending on the calibration technique. This method has taken advantage from the recent advance in statistical methods (PLS, PCR), the development of fibre optics and the use of Fourier transform, which makes it of higher relevance than the black-box instrument when NIR came out.

Mid-infrared (MIR) also proves to be a powerful technique both for laboratory analysis and process control. The compact, robust, sealed new instruments may have a bright future in sugar factories owing to the wealth of information of the FTIR spectrum and the numerous accessories (ATR,...)

- On-line colour measurement :

A new system for one-line colour measurement was developed recently. It allows rapid measurements [less than 5 seconds], with no sample preparation. The fast feed-back permits optimisation of washing time at the centrifugals and prevention of bad sugar entering in the dryer. Uniformity and improvement of quality are reached with the use of Colour Q-800 Neltec device. This method was tried successfully for white sugars to meet customers specification. It seems also applicable to raw sugars entering in refinery for continuous analysis and monitoring of affirmation.

2.2. Membrane technology

The membrane filtration (micro-ultra- and nanofiltration) processes were investigated in the field of sugar technology at different stages of fabrication, but mostly at the pilot-level. The feasibility of earlier generations of polymeric membranes was questionable as concerns the resistance of membrane to temperature, pH and damage by solid suspensions. Recent development of mineral membranes allowed increase in potential use of industrial ultrafiltration for cane juice purification (Cartier et al., 1996). The nanofiltration process has also been found efficient in the separation of salts and colorants from decolourizing resins elution flow. Coupling nanofiltration with decolourization resins was successfully used at an industrial level in cane sugar refineries (Theoleyre et al., 1999).

Cross-flow microfiltration was investigated as concerns the effect of monitoring conditions on performances when used for cane raw sugar remelts. Optimal conditions were defined and the role of optimal flux density

emphasised (Trichard et al., 1998). A better knowledge of the nature, structure and properties of retentate will improve the exploitation of membranes and lead the numerous pilot studies to industrial applications.

- Chromatographic separation

The chromatographic separation of molasses is used for desugarization of beet molasses since the 1970's. High levels of Calcium and magnesium salts in cane molasses make it difficult to apply chromatographic separation. The possible use of chromatography for low green and thick juices was recently discussed (Paananen, 2000). The improvement of technology and the economic aspects of replacing classical technology of boiling, remelting and boiling again by a process including chromatographic separation does not seem irrelevant.

Simulated Moving Bed (SMB) chromatography was applied to the desugarization of both beet and cane molasses. The SMB-process was developed as a continuous system where counter-current flows of resin on the one hand and molasses on the other were changed at regular intervals to meet balanced rates at the inlet and outlet. Improved Simulated Moving Bed (ISMB) brings further advantage like the reduction of resins volumes, the optimisation of water elution quantities and a minimisation of the dilution of purified product, which gives energy saving in evaporation.

2.3. Combining innovating technologies and the perspectives for the 21st century

No single technology can solve both economic and process constraints. The future of sugar technology relies on a near-real time adaptation of the sugar processing to solve technical problems, comply to regulations (safety, environment, quality assurance) and in the meantime increase profitability. The future sugar factory would not use a common layout for all types of crops, climates and sociological conditions of workers.

There should be three types of approaches. The beet sugar factory in North Europe and North America where environment constraints, together with highly qualified manpower and the possibility of higher investments can allow a high-tech sugar processing (Type 1).

The cane sugar factory in the important regions of cane (Australia, South Africa, North and South America) while using the same technologies as beet should think of optimising the inversion of sucrose and move towards the production of multicomponent sugar syrups, why not a HFCS (where C would mean cane); This is not senseless as we see, how reluctant is the consumer to accept corn syrups from transgenic crop (Type 2).

Finally, for developing countries, small workshops should be better adapted to the local economy and sociology of workers. Small scale factories using modern concepts and standards should be economically viable (Type 3).

2.3.1. Combining membrane separation ion exchange and cooling crystallisation in beet sugar factories (Type 1).

The recent extensive researches on the possibility of crystallising raw juice directly by use of cooling crystallisation (Vaccari and Mantovani, 1987) showed the advantages of this method over classical evaporation crystallisation. Combining cooling crystallisation with microfiltration (Mantovani and Vaccari, 1998) was found efficient to obtain white sugar directly from the first strike together with good exhaustion of molasses. These experiments at the level of the laboratory and the pilot plant were also tried for cane sugar raw

juice for which the classical calco-carbonic purification was replaced by microfiltration and simulated moving bed chromatography (Mantovani and Vaccari, 1999). Raw sugar refining can also use cooling crystallisation after decolourizing the affinated syrup and filtration instead of the classical phosphatation or carbonation. Moreover, working at low temperature favours the concentration of fructo-oligosaccharides (kestoses) in cooling crystallisation molasses. The use of ISMB can help recovering of betaine on the one hand, fructo-oligosaccharides and sucrose on the other. The added value of tebaine in feed an cosmetic applications and the use of kestoses as prebiotic nutrients can help improving the profitability of the new process.

Flow diagrams of the cooling crystallisation of raw beet juice were proposed by Mantovani and Vaccari (1999). The main advantages in this new processing are :

- elimination of calco-carbonic purification
- reduction of the consumption of fuel, limestone and water
- environmental protection by minimising waste.

The adding of innovative technologies such as the evaporative process for recovery of dissolved solids in very dilute process streams (Ramm-Schmidt, 1996) to the microfiltration-cooling crystallisation scheme may help in eliminating all types of waste and recycling water. Application of the new evaporation technology was applied successfully to the chromatographic desugarization process by SMB chromatography. It was at he origin of energy saving, increase in capacity of plant, increase in purity of fractions and economical feasibility of recovery of new dilute fractions (Ramm-Schmidt, 1996).

2.3.2. Separation processes and enzymatic technologies applied to cane raw juice (Type 2) :

Like beet juice, raw cane juice can be purified without having recourse to calco-carbonic method. Different separation processes were proposed as an alternative to liming. It is the case for the “A.B.C.” process which consists in continuous screening, ultraclarification and adsorption of colorants (Monclin and Willett, 1996). The Amalgamated sugar company proposed a chromatographic separation process for raw beet or cane juice which replaces liming and carbonation efficiently (Kearny, 1996). Such a process allows direct production of white sugar in the mill. It can use either the classical evaporation crystallisation or the innovative cooling crystallisation method. Membranes are also efficient in cane sugar factory. Ultrafiltratoin reached the removal of 90 % of turbidity and 20 % of colorants using Techsep mineral membranes for the treatment of cane raw juices (Cartier et al., 1996).

Membrane technology as well as SMB chromatographic separation are also well known in glucose syrups manufactures. The purified raw juice from cane can be inverted using immobilised invertase and separated into fructose and glucose. Enzymes such as dextranases and amylases may be introduced during the extraction step to help recovering the polymerised glucose. Direct production of sugar syrups with varied concentrations in D-glucose, D-fructose and sucrose to meet the demand of food industries can turn out as a response to the reluctance of the customers to use transgenic corn syrups. Diversification of the production of different crystalline sugars grown in cooling crystallisers (α -D-glucose monohydrate and sucrose) and different formula of glucose-fructose-sucrose syrups may prove to be a flexible solution to a continuously changing market.

3 – Small scale factories (type 3) :

The present trend of capacity increase of sugar factories is reaching its maximum. Such a trend can suit for an expanding economy where labour cost is minimised together with an increase in high-tech equipment. For developing countries, sugar remains an important energy source in man's diet. The situation of employment is such that mechanisation is not advised for all sectors of activity in sugar production. Process development should use batches with adapted automated control. The unit operations chosen for the sugar factory flow sheet in a developing country should not be a simple transfer of what the equipment suppliers use to recommend for European or North American industries. Crucial problems such as the lack of potable water, the need of job-sharing and eventually full employment have priority as compared to increase in yield and profitability. Utilisation of efficient extraction technology like the inverted 3-roll mill in which drainage takes place in the same direction as the bagasse flow (Sullivan, 1995) can be associated with flocculation and cross-filtration to remove impurities from raw cane sugar juices. These units of extraction and purification should have the right size to avoid costly transport of cane. Purified raw juice can be crystallised either using batch evaporation or cooling crystallisation pans for home market. The developing countries can also comply to organic sugar regulations and specialise in this type of production for exportation. A minimum of international solidarity is needed if it is desired to reduce the huge gap between economies of North and South countries.

Conclusion

Sugar industry is an old industry which is now reaching maturity. It has evolved with profitability as the predominant objective. It is now becoming competed by both artificial sweeteners and glucose syrups. Because of the high level of the technologies invented or improved to optimise energy saving, environment protection and quality assurance, it is again possible to sugar industry to relaunch a rational market-share between the different producers of beet or cane. Technologies can be adapted to the specific countries. Awareness of the human dimension of such an activity as sugar production which associates agriculture, engineering, processing, automation, and education for an adapted qualification should be beared in the mind of decision-makers. The twenty-first century should combine modern technologies in North countries for increased profitability and help the developing countries in keeping a modernised industry protected from the tough law of the market.

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References

- Bonnenfant, P. (1999) Proceedings 6th AVH Symposium, Reims.
- Cartier, S., Theoleyre, M.A., Lancrenon, X. and Decloux, M. (1996) Proceedings of the Workshop on separation Processing Sugar Industry, SPRI, New Orleans.
- Galloway, J.H. (1989) The Sugar Cane Industry, Cambridge University Press
- Honig, P. (1953) Principles of Sugar Technology, Elsevier, Amsterdam.
- Hugot E. (1986) Handbook of Cane Sugar Engineering , Elsevier, Amsterdam.
- Kearney, M.M. (1996) Proceedings of the Workshop on separation Processing Sugar Industry, SPRI, New Orleans.

- Knovl, E.A. and Moller, G.R. (1975/76) Sugar Technol. Rev., 3, 275-309.
- Krause, E.W. and Kordel, P. (1997) New Processes in the Sugar Industry, F.O. Licht Yearbook
- Mantovani, G. and Vaccari G. (1998) Patent N° GE 98 A000039
- Mantovani, G. and Vaccari, G. (1999) Proceedings 6th AVH Symposium, Reims.
- Monclin , J.P. and Willett, S.C. (1996) Proceedings of the Workshop on Separation Processes in the Sugar industry, New Orleans.
- Paananen, H. (2000) Proceedings 7th AVH Symposium, Reims.
- Poel van der, P.W. (1982) E.P. O 104277, CSM Suiker, B.V.
- Poel van der, P.W. et al. (1985) Sucr. Belge, 103, 15-21.
- Poel van der, P.W., Schiweck, H. and Schwartz, T. (1998) Sugar Technology, Beet and Cane Manufacture, Verlag Dr Albert Bartens, Berlin.
- Ramm-Schmidt, L.H. (1996) Proceedings of the Workshop on Separation Processes in the Sugar industry, New Orleans.
- Silin, P.M. (1937) 5^{ème} Congrès International de Technologie des industries Agricoles, Scheveningen
- Sullivan, M.D. (1995) Int. Sugar J., 97, 303 – 306.
- Theoleyre, M.A. and Cartier, S. (1999) Proceedings of the 6th AVH Symposium, Reims.
- Trichard, J.M., Tatoud, L. and Decloux, M. (1998), Ind. Alim. Agric., 115, 21-29.
- Vaccari G. and Mantovani, G. (1987) Patent N°1208310
- Wieninger, L. and Kubadinov, N. (1971) Zucker, 24(19) 599-604.