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OUTLOOK FOR EMERGING TECHNOLOGIES IN SUGAR PROCESSING

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ABSTRACT

Emerging technologies related to sugar factory operations are reviewed in the context of the potential impact of new factory technology. Increased productivity is the key goal and is a more complex issue than factory output alone. It is related to the efficient use of resources, including energy, equipment design and reliability and performance optimization. New technology is divided in this discussion into two types. Primary technology, which includes new equipment and operations, and secondary technology, which includes all knowledge and data based systems such as design, automation, performance evaluation and optimization. The potential of these technologies and their application to each stage of sugar production processes are outlined.

INTRODUCTION

The purpose of this paper is not to discuss new technology per se but to describe emerging technologies for the sugar industry that have the potential to improve productivity. The sugar industry has tended to operate in isolation from large-scale commodity producers and to think of itself as separate from the chemical processing industry (CPI). However, many of the unit operations are the same. As a commodity food product, there is only modest opportunity for product innovation but significant opportunities for process innovation, especially that related to improved productivity.

Some relevant comments from the CPI – J.A. Miller (Dupont) quoted in *Chemical and Engineering News*, Feb. 8, 1999 (pp17-22).

“Our goal is a revolution in asset productivity.”

“We need growth with enhanced knowledge intensity and diminished capital intensity.”

“Ultimate sustainability, viability and the continuous development of share-holder value will require an infusion of new technology.”

PRODUCTIVITY

Any new technology must lead to an improvement in productivity. Some emerging technologies are quite fascinating from the perspective of a research technologist but a hard-boiled analysis from a business standpoint is essential. One of the problems is to confirm whether improvement in product quality is necessarily an improvement in productivity. Perhaps we should define productivity increase as the same, or better, results at lower cost. In the sugar industry productivity may be defined in terms of overall recovery or in terms of maintenance of throughput under adverse conditions, always taking into account the cost factors.

The concept of productivity may be oversimplified if it is considered only in terms of labor productivity. In many cases, a process innovation requires substituting or additional equipment, energy or materials for the labor that is saved. Thus a proper measure of productivity change should take into consideration the changes in the quantities required of all inputs, not just labor. This concept has been called multi-factor productivity change. In the sugar industry the factors to be considered include –

- Efficient personnel utilisation.
- Low capital utilization.
- High time efficiency - high and steady throughput.
- High sugar recovery.
- Product consistency.
- Low maintenance and repair costs.
- Low operating costs.
- Low energy consumption.
- Operability or suitability.

The scope of new technology includes any combination of the following –

- Equipment;
- Processing technology and materials;
- Computer systems and automation, including design systems;
- Performance evaluation technology, including on-line analytical systems.

TECHNOLOGY OVERVIEW

For the purpose of this paper it is useful to think in terms of primary and secondary technologies. Primary technologies are the unit operations in sugar production that may or may not be optimized. Secondary technologies are used to support and optimize the primary technology. Productivity increase in the sugar industry may be more dependent on secondary technologies.

The most cost-effective approach to improving productivity is to optimize the system, especially the control aspects, rather than investing in new equipment. There is, of course, a limit to the possibility of resurrecting old equipment. The design and simulation aspects of the new secondary technology are a guide in these choices. Short-term productivity increases will be achieved using technology for optimization of current operations, with emphasis on maintenance, quality control and good manufacturing practice and training. These should be fairly easy decisions with relatively low capital investments required and the most difficult aspect is the change in mindset required.

New primary technology would be part of a strategic plan for technological improvement. These involve hard decisions with high capital costs.

Constraints on New Technology

Innovation must be based on solid engineering judgement and the research and development work must be thorough and based on in-depth knowledge of the industry and its requirements. Any new technology must be sufficiently robust to cope with these variations in cane quality, especially those due to adverse weather conditions and mechanical harvesting. Improved productivity also requires that environmental impacts are minimal. For example, purification processes that emphasize physical rather than chemical treatments would be preferred.

Sources of New Technology

The sugar industry has been inclined to think of its technology as distinct and special and to develop it in isolation. Productivity increases will be achieved by utilizing the developments that are taking place in other major processing industries, especially the chemical processing industries. Optimum productivity increase, especially return on capital, requires attention to detail at each stage.

We should question whether there has been a lack of generalized industrial training and exposure of sugar technologists. Broad training and exposure are essential if new technology is to generate increased productivity.

SECONDARY TECHNOLOGIES

Secondary technology may also be defined as Process Manufacturing Information Technology. Its goal is to use the information available in the optimum manner in all aspects of process, from design through training of operators to business decisions.

The sugar industry is a data rich but information poor industry. For example, much work has been done on crystallization kinetics but it is rare that this information is used in design and even less in operations. In the end individuals must make decisions but the better the information and insight available, the better will be the productivity gains. For the goal to be achieved it is essential to take information and knowledge away from being the personal property of key individuals and transfer this to corporate or institutional memory that can be accessed by all who need to know. Although sugar production from cane or beet and sugar refining are a series of discrete operations, their interactions, especially related to energy requirements must be understood if the operation is to use its resources efficiently.

Equipment and Design

The technology used to design equipment to be efficient and reliable is critically important for industry productivity. The traditional approach to equipment design involves empirical safety factors which may be essential when control of operations is manual and the process is poorly understood. Modern design technologies allow us to create a 'virtual factory' in the computer before the factory is built. This can include all controls, piping and instrument diagrams, flow

schemes and even 'virtual realities' that can be 'walked' through. Two new design technologies should be considered for new and complex equipment - computational fluid dynamics (CFD) and finite element methods (FEM). CFD is a software system used to solve complex equations related to fluid flow and heat and mass transfer. FEM techniques are particularly useful in designs requiring non-standard shapes and complex loading situations. This technique can be used to extend the life of equipment by giving confidence that repairs and modifications are safe and reliable.

High capital costs make it difficult for factories to justify the purchase of additional equipment to match increases in grinding rate. The most cost-effective expansion may be to maximize the throughput and to accept some decline in performance.

Simulation and Modelling

Detailed process engineering is critical to identify the best plant design and also key to determining how best to run the plant. Optimization of the process flow sheet and basic engineering definitions before detailed plant design can save up to 30% of capital costs and minimize operating costs.

A question that must be asked at this stage by the sugar industry is whether we know enough about the process to be able to use these tools to their potential. All aspects of an integrated design, including models, data, documents and decision-making rationales can be saved and reused, ensuring consistency and eliminating the effort to reconstruct designs from diverse and incomplete sources.

Operations, Controls, Maintenance and Quality

The day-to-day application of secondary technology can lead to improved factory performance and should be the starting point for its introduction to operating personnel. Equipment maintenance and reliability are essential to achieve improved productivity and new technological applications in these areas are data intensive. The benefits are increased equipment utilization and delay of capital investment for replacement.

DEVELOPMENTS IN PRIMARY TECHNOLOGY

In this section recent and potential developments of new technology are described. The new technologies are of two basic types (i) the same operations but with larger, differently configured and automated equipment and (ii) a different or additional process to achieve the same goal more efficiently. The following discussion deals with developments in cane processing which are illustrative of trends throughout the industry.

Juice Extraction Systems

Milling rates are continuously increasing and upgrading a mill is very expensive and it is therefore essential to maximize the productivity of existing equipment. The goal of milling models is to predict the effect of changes in milling parameters and to assist in financial decisions. Modeling of extraction using the Australian MILSIM model has been improved to make its application more relevant to factory engineers. This model is used to assess mill performance and further development is ongoing for prediction of performance under different conditions. An

Australian study presents a useful review of the decision making in choosing the expansion requirements for a mill. Although diffusion was considered to have a number of advantages, the installation of a diffuser would require relocation of some equipment. Long term maintenance would be more with a mill plus a diffuser than with two mills since many of the spares and training would be reduced with only a single technology.

A significant new technology that could simplify mill operations is the use of electrically driven hydrostatic drives. The primary advantage claimed is that many parts of a traditional steam turbine plus reducing gear may be eliminated, leading to easier maintenance.

Purification Systems

The extent of purification required is determined largely by the sugar quality required. Conventional clarification and underflow treatment with rotary vacuum filters can produce raw sugar very suitable for refining. New technologies should not be considered until there is confidence that they can maintain capacity under all operating conditions.

The most significant work on new technology for clarification involves design optimization using CFD. The intent was to eliminate shortcomings in the standard SRI single tray, short retention clarifier. The result is a clarifier with peripheral feed and center take-off. The mean residence time can be reduced to less than half that for the standard clarifier. The benefits claimed are the reduced cost of new installations and the modification of existing clarifiers at about 10% of the cost of a new clarifier and a capacity increase of 50%.

Rotary vacuum filters are preferred in raw sugar factories for several reasons. Automation is not one of them. Maximization of productivity requires the technology for control of cake thickness, bagacillo content, rotational speed and quantity of wash water.

New technology for more efficient processing of clarifier mud remains a challenge and the optimization of rotary vacuum filters remains, for the present, the best option. Flexible diaphragm chamber press filters are standard in beet operations and have been introduced into carbonatation refineries. In trials in sugar mills they have been shown to produce much less and drier cake than rotary vacuum filters with low sugar content in the cake.

A desirable option would be to eliminate the filters entirely. The mat of shredded cane in a diffuser is a fairly efficient filter and the proposal has been made to recycle the clarifier underflow to the diffuser and thereby eliminate the filters. The results of trials in South Africa showed that this recycle had no adverse effects on extraction or bed percolation and additional sucrose loss in the diffuser was not observed.

The most intensely discussed new primary technology for sugar cane operations is membrane filtration. Research work on membranes in the sugar industry area has been intense and optimism high. One of the initial expectations of this technology was that it would replace standard clarification techniques but this has not been achieved. There is no doubt that this technology can lead to improved sugar quality. Increased recovery is a reasonable expectation but yet to be demonstrated on a commercial scale. Other benefits claimed are reduced evaporator scaling, juice sterilization, increased utilization of downstream equipment and as pretreatment for other new unit operations such as juice softening and chromatographic recovery of sucrose.

The major issues related to the introduction of membrane filtration are –

- High cost.
- Complexity and maintenance issues.
- Sophisticated automation.
- The handling of the retentate or reject stream.
- System ruggedness. A membrane system cannot be considered a success until full capacity is achieved under all operating conditions.
- Membrane lifetime and the development of efficient cleaning systems.

The development of this technology is in its early stages. Part of the learning process is making mistakes and not every attempt to apply membrane technology will be successful. Neither of the factory scale membrane filtration systems, one using ceramic membranes and the other with polymeric capillaries, has met expectations and both are currently not operating. Reliability and reasonable operating costs remain the goals. The current problems will be solved but whether the final result is an increase in productivity is quite another question.

Ion-exchange and adsorbent technologies have potential application in the cane sugar factory for demineralization, softening and color removal but may be more applicable in refined sugar production. However, with the increased emphasis on the production of direct consumption sugars at the cane mill or on the production of very high quality raw sugars requiring minimal refining, some of these techniques may be applicable.

The fundamental technology for softening or deashing is well known and the benefits of softening may be divided into two categories –

- The prevention of the precipitation of insoluble calcium salts.
- The suitability of the softened process material for subsequent processing by ion-exclusion processes for recovery of sucrose.

New technology for the efficient and environmentally benign regeneration of both ion exchange resins and adsorbents is essential. ISEP^R technology is designed to be more efficient in the use of both the stationary phase and regeneration chemicals. A large number of small columns are rotated on a carousel through a fixed system of ports to allow the sequential contact of the solid phase with process liquor, wash water and regeneration chemicals. Good results have been published on the operation of a variety of pilot plant test systems.

An alternative approach for both decolorization and demineralization has evolved out of work with the chromatographic recovery of sucrose from beet molasses. Major advantages of this approach are mechanical simplicity and complete automation and that no regeneration chemicals are required. This new technology has the capability of producing high purity liquor with low color and very low ash from clean and softened cane syrup. This process is currently in the development stage.

The chromatographic recovery of sucrose from molasses has yet to become established for cane. This subject has been much studied with various options for pretreatment but no commercial plant is yet in operation. In contrast to the use of membrane filtration the application of chromatographic separation in a cane operation requires a radical rethinking of the process. If implemented the only crystallization would be for commercial sugar and recovery would be by chromatographic means. The productivity benefits could be immense.

Evaporation

New technology for evaporation is intended to improve the capacity of existing equipment and to improve energy efficiency. Essential to these goals is an adequate understanding of the thermodynamics of evaporation and its application to control systems, an example of the importance of secondary technology.

A model has been developed as a simulation tool for evaporator designers and operators and tested against experimental data to improve the model. This model can be used to simulate performance under varying conditions, including changes in tube size and material and scale formation. There have been several differing reports on recently installed falling film evaporators with data indicating that they are easy to operate, control and clean to problems in achieving the expected results with these evaporators. The conclusion could be that subtle differences in evaporator design could have major impact on performance.

Crystallization

Crystallization is the *sine qua non* of the sugar industry and has been practiced for centuries without being well understood. The goal is higher quality sugar by means of better control of crystallization conditions. Modeling is a valuable tool in the optimization of the crystallization operation and there are many reports on this subject. A model has been developed which can predict the color of sugars from various crystallization schemes and good agreement was achieved between the predictions and actual factory performance and it also predicted the impact of variations in operating conditions. Material, energy and color balances were used to predict that replacement of A- and B-crystallizers by a back-boiling system would not increase sugar color and should improve exhaustion.

Models for use in crystallization studies should be dynamic and include factors such as crystallization kinetics, inversion kinetic, color development rate, and the impacts of purity changes in feed materials, pan circulation rate, etc. The capacity of an old pan has been doubled by using the top and bottom of an old pan and inserting an extended mid-section with an expended body. The consequences include reduced fine grain and improved cycle times.

Efficient vacuum pans using vapors from other pans are another means to reduce steam utilization and lower color sugar due to the reduced temperature of crystallization of the high-grade products. Expansion of existing capacity for a continuous pan requires additional cells and in one case the expansion of capacity was achieved by the addition of three modules in series at the end of the original pan. Knowledge of the improvement in productivity of batch vacuum pans by improved circulation; improved feed quality and instrumental control were used in the design of these modules.

Production of commercial sugars by cooling rather than evaporative crystallization has a long history but has been out of fashion since the development of the vacuum pan. Recent re-evaluations of high temperature cooling crystallization show that it could offer major benefits for new construction. CFD has been applied to the study of low-grade crystallizers. The simulations indicate that flow and temperature distributions are non-uniform with significant short-circuiting of non-cooled massecuite.

The conclusion is that, for crystallization, increased productivity will be gained by application of modeling and simulation systems and improved process control. We can expect to see new designs of pans and crystallizers but these will be based on process manufacturing information technology.

Centrifugation and Sugar Handling

Batch centrifugals have become much larger and energy efficient but the major development has been in continuous centrifugals for high-grade sugar. This technology has been applied commercially at several locations and there remain some design and operating problems to be resolved. There can be major problems of reliability at high throughput, lump formation and crystal breakage. Until these are resolved, the benefits of increased productivity will not be realized.

The combination of improved purification; crystallization and centrifugation technology will result in much higher quality sugar that cannot be handled in bulk in the same manner as conventional raw sugar. This will present a serious challenge to the sugar technologist, especially those with experience only in raw sugar production.

SUMMARY

The potential for productivity improvement in the cane sugar industry by application of new technology is very significant. The short-term benefits will be gained primarily by application of knowledge based technologies for design and process optimization rather than by introduction of new processes and these benefits are applicable throughout the industry. Membrane filtration and chromatographic separation have major potential depending very much on local circumstances. Productivity enhancement with these technologies will be critically impacted by their efficient integration into the whole factory process.