ION EXCHANGE THIN JUICE SOFTENING USING FRACTAL TECHNOLOGY

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Ion Exchange Thin Juice Softening using Fractal Technology

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Introduction

Reduction of hardness in thin juice is a major task following juice purification step in sugar beet processing. In a conventional sugar plant minimization of limesalts is accomplished during the second carbonation step by bringing the juice to optimum alkalinity. Sodium carbonate (soda ash) is frequently added prior to second carbonation step to further reduce hardness. Soda ash addition is especially effective, when beet quality is low and juice hardness needs to be reduced either to control scaling downstream or reduce the hardness loading onto the ion exchange juice softeners. Thin juice ion exchange softening is a mature process utilized by sugar industry for over 25 years. The main advantage of thin juice softening is that it exchanges calcium ions for non-scaling monovalent ions (sodium, potassium, etc.) in near stoichiometric amounts. In some cases a combination of chemical and ion exchange softening is used to lower the level of calcium salts in thin juice before evaporation. Most existing ion exchange softening installations have been justified economically as a necessary prerequisite for molasses desugarization systems. The fact that despite obvious processing benefits of softening it has not become a standard part of any sugar beet factory operation implies that the process economics must be at least marginal.

A little over a decade ago, the feasibility of thin juice softening systems was considered questionable for the following reasons (Schick, 1992):

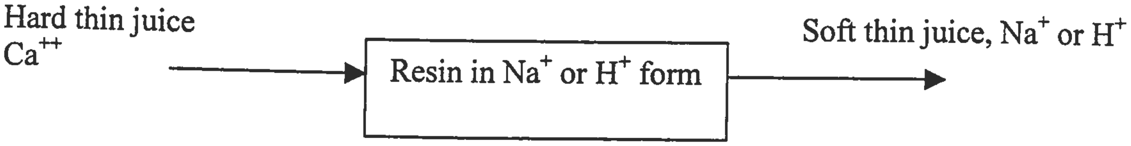
- high investment cost for ion exchange plants
- high operating cost of regenerant chemicals
- low capacity of ion exchanger resins, hence, large installation size
- large amounts of waste water with high organic and inorganic loads

Four years of commercial operation of fractal weak acid cation softeners demonstrate that many of these concerns have either been eliminated or their impact has been significantly reduced. Now, therefore, is a good opportunity to re-evaluate the economics of the process under improved conditions.

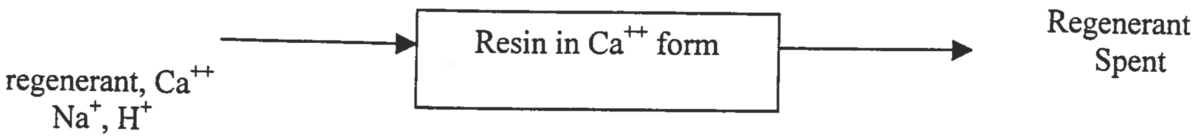
The purpose of this paper is to analyze the impacts of the thin juice softening step on the operation of a beet processing facility and estimate a target cost for the softening process to make it economically attractive. Besides energy savings due to scale reduction, elimination of antiscalants and potential increase in factory throughput, other factors will be discussed that positively affect factory operation and performance. Economic feasibility of various scenarios of process implementation will be presented taking into account different regional and process specifics.

Material Balance of the Softening Process

The following discussion may help provide a better understanding of the material balance of ion exchange softening. The information on the mechanism and chemistry of ion exchange is available elsewhere (Dorfner, 1991). Softening resin is initially loaded in a monovalent form (e.g., hydrogen, sodium or potassium); therefore all active sites are occupied by monovalent cations. During the exhaustion cycle sodium ions are gradually replaced by calcium in the resin bed. Displaced sodium ions are released into the effluent.



In the regeneration cycle sodium or hydrogen loaded solution (e.g., brine, sugar solutions with sufficient concentration of sodium ions, or acid) is brought into contact with resin.



Due to the preferential affinity of different ions to resin and the concentration of regenerant solution calcium ions are displaced from the resin bed, and the monovalent ions occupy their place in the resin matrix. Calcium salts are formed in spent regenerant.

The amount and the method of utilization of spent regenerant play an important role in the economics of a softening process. Resin regeneration typically requires a certain excess of regenerant solution compared to stoichiometric quantities. Weak cation resin requires only about 10 % excess regenerant, while strong cation resins may need 50 - 250 % excess. Excessive regenerant in some cases also ends up in the final molasses affecting sugar losses and thus, the economics of the softening process. From this standpoint the Gryllus process (Dorfner, 1991), which uses the intergreen syrup to regenerate strong cation resin, provides minimal interference with the ion balance in the solution. The Imacti process (Mottard, 1983) or its modification, NRS process, results in addition of melassigenic sodium ions depending on the usage of caustic above stoichiometric requirements. Some reports show that caustic in the amount of up to 200 % on equivalent capacity is added to fully regenerate the resin. Besides the operating cost related to caustic, Mottard has reported an additional sugar loss of 0.03-0.04 % on beets due to increase in molasses production.

From theoretical calculations the total weight of sodium released into solution will be 15 % higher than the weight of calcium originally present in the juice. For example, if juice contained 100 ppm of calcium by weight the effluent from the softener will contain 115 ppm of sodium that replaced calcium. These numbers are low, however, compared with total concentration of monovalent ions in thin juice.

In case of weak cation exchange resins in hydrogen form hydrogen ions would at first be displaced by monovalent ions (sodium and potassium) that are present in the solution. Therefore, no additional sodium or potassium would be added to the solution. Hydrogen ions released into the thin juice stream will reduce its pH. However, due to buffering capacity of thin juice, very little (if any) alkaline agent addition is required downstream in the first phase of the exhaustion cycle. Therefore, in the best case, when no pH adjustment is needed only 5 ppm of hydrogen by weight will be added to the softener effluent compared with the initial 100 ppm of calcium. Adjustment of pH downstream may slightly increase this number, but it compares favorably with the amount of sodium added during the strong cation operation. Based on the above discussion it is reasonable to assume that weak cation softeners in hydrogen form have the smallest effect on molasses production compared with other softening technologies.

The issue of potential sucrose inversion across resin is often raised when weak cation resin in hydrogen form is considered. Based on twenty years' experience of operating weak cation softeners in hydrogen form Kearney and Rearick (2003) concluded that sucrose inversion was negligible. Rossiter et al. (1999) have not reported any concerns over sucrose inversion in a commercial installation using 3 ft. high beds of weak cation resin. With the implementation of fractal softeners (Kearney, 2001), where resin bed height is only six inches, and the residence time is thus reduced by a factor of 10 (as compared with conventional weak cation systems) sucrose losses due to inversion should not be considered as a factor for economic calculations.

Effect of the softening process on factory performance

A clear understanding of the impacts of thin juice softening on various unit operations in a beet sugar plant is critical for evaluating economic feasibility. It is also quite useful to review potential interactions with the equipment or process technologies that are considered for future implementation. Table 1 summarizes changes expected in various areas of a plant resulting from the introduction of thin juice softening process. Depending on the energy efficiency, campaign length and operating strategy the impact level of different factors will vary. It is also important that the factors listed in Table 1 may or may not be added simultaneously in economic calculations. Several approaches will be considered below.

Because of the differences in operating conditions in plants, where softening processes had become a part of the industrial production, it was quite difficult to find reliable parameters that could be included in the ROI calculations. Furthermore, the effect of softening on sugar quality is impossible to quantify for feasibility studies. However, these issues may become critical in today's competitive market. The authors of the current paper chose to leave the "soft" numbers to the discretion of the specialists, who would evaluate project feasibility in each specific case. Our goal is to provide the "hard" numbers that can be included in economic calculations with a certain level of confidence. Before proceeding with the case studies some explanations will be provided in Table 1. The numbering of the comments corresponds to the appropriate rows in the table.

Table 1 Summary of benefits for thin juice softening process

No	Station	Expected changes
1	Beet storage	Because of increased throughput sugar losses during storage can be reduced
2	Boiler house/turbine	Fuel and energy savings (depends on overall steam efficiency)
		Increase in electric power generation
3	Standard liquor filtration	Reduction in filter-aid usage (less precipitate)
		Reduction of sugar loss with the filter cake
		Longer filtration cycles, no filter scaling
4	Thick juice storage/filtration	No precipitate formed in storage
5	Evaporators	Improved heat transfer
		20 % reduction in cost, labor and materials for maintenance
		No antiscalants required
		No downtime (or waste of production capacity)
		No chemical usage or labor for boilouts
		Reduced corrosion
		Operating safety for high efficiency plate packs due to reduced scaling
		More efficient energy utilization throughout the plant
6	Vacuum pans	Improved heat transfer, less color formation
		Reduced turbidity in the final sugar
		Reduced color formation due to the possibilities of using lower pressure vapors or low delta T
		Chemical usage for scale control and boilout
		Presence of fine matter in the pan affects quality of sugar boiling
		Reduced wash water in white pans in case if ash content is controlled by conductivity
7	Pulp pressing	In case of weak cation resin softening gypsum in the regenerant can be used as a pressing aid
		Less acid for diffuser supply water pH control due to regenerant use
8	Molasses formation	May or may not be increased depending on soda ash addition prior to softening (see discussion in the text)

Here and further in the text (unless specified otherwise) a model 10,000 t/day factory with a steam demand of 30 % on beets operating a 150-day campaign will be considered.

1. Several studies have indicated that an increase in factory throughput could be one of the major contributors to the feasibility of a new process. This may benefit the factories planning to increase the slicing capacity or having extremely poor storage

conditions towards the end of campaign. Under assumption of 0.25 lbs sugar loss/ton beets/day, if a sugar plant reduces slicing campaign by 10 %, the total savings would amount to about $700,000 per year. The savings are calculated using conservative "straight line" approach. In reality abnormal weather conditions may cause significant losses towards the end of campaign. With addition of savings in fixed cost due to the reduction in total operating days another $300,000 can be added to the benefits. A factory, which is operating at its limit in terms of vapor temperatures and heating surface for pan boiling and preheating, will have to reduce slice following the decrease in u-values in the evaporator station (i.e., 10 % reduction of heat transfer coefficients translate into 10 % less slice without any vapor users being switched to higher evaporator effects).

2. Because of various constraints, increase in factory capacity may not be the primary choice for certain companies. Plants that are not limited in boiler capacity may elect to gradually increase steam pressure as heating surfaces become scaled. This approach is usually accompanied by some efforts to control scaling. Factories processing high quality beets operated at design capacity with relatively short campaign are more prone to using this approach. Because of increased resistance to heat transfer due to scaling higher temperature difference in evaporators and on the pan floor leads to more color formation. Lower pressure vapors in the pan floor may not be available toward the end of campaign, which disturbs the energy balance and the operation stability. In addition, the capability of generating electric energy in the turbine is reduced because of higher backpressure (if the turbine is already operated at the maximum throughput). The cost associated with this reaches around $ 25,000 per campaign at $ 0.05 per kWh at an assumed average backpressure rise of 4.35 psi.

3. Another benefit observed during operation of softening plants is improved filtration of thick juice and standard liquor. Reduction in filter-aid usage results in direct savings, but more importantly leads to reduction in sugar losses with filter-cake (depending on factory configuration and existing methods of recovering sugar from filter-aid sluice). The cost associated with filter-aid disposal is proportionally reduced. Increased filtration cycles, reduction in filter scaling are reported as additional benefits at this stage.

4. Factories utilizing thick juice storage will benefit from elimination of precipitation of calcium salts and resulting pumping, filtration, labor and maintenance expenses. For factories considering thick juice storage (e.g., Pfeifer & Langen's Appeldorn factory in 1996) the decision is often whether to invest into a precoat filtration for thick juice from storage or into a thin juice softening system. In the Appeldorn case, the additional processing benefits have clearly favored softening (Burkhardt et al., 2000).

5. It has been proven in multiple industrial installations that softening completely eliminates the need to add antiscalants to the evaporators. The avoided cost for our model factory would be in the vicinity of $ 80,000 per year at a limesalts content of 0.1 g CaO/ 100 g DS. Ekern (1991) has estimated the savings of 44 lbs. of exhaust steam per ton of beets, which corresponds to 7.3 % steam savings for a 30 % steam

on beets factory. These numbers can be confirmed by an assumption of u-value decrease in the evaporator station by 10 % at constant factory throughput. In this case certain vapor users on the pan floor and at technologically significant points (1st and 2nd carbonation, defoam juice) will have to be operated with higher vapors.

Amalgamated Sugar observed 20 % reduction in the cost of labor, materials and maintenance of evaporators after the softeners were first installed in 1985. About 7 % savings in fuel cost was also reported. In the case of the above factory example and at an assumed cost of $ 10 per ton of steam the corresponding savings add up to $ 315,000 per year. Downtime due to 28 boilouts during campaign of 1985 was also eliminated. Among additional benefits reduced evaporator corrosion should be mentioned, because hydrochloric acid would not be applied any longer for boilouts.

6. Scale reduction leads to better utilization of steam in the factory resulting in increased capacity of the sugar end. Several factory managers have indicated that 25-40 % increase in sugar end throughput had become possible after the installation of softening process. This factor is extremely important for factories looking for a capacity increase. The strategy of raising heating steam temperature throughout campaign results in increased color formation and, therefore, in increased sugar recycle to control the color of the final product. A certain cost is associated with "back boiling" of sugar. An increased steam demand of e.g. 20 % in the sugar end corresponds to about 5 % increase in exhaust steam demand for a typical factory in the 20 – 30 % steam on beet range), Savings of $ 225,000 are expected for our model factory (at $ 10 per ton of steam).

   An important benefit of the softening process is improvement of sugar quality resulting from lack of precipitate and scale particles in the pans and an improved washing procedure. It is commonly acknowledged that turbidity in white sugar solutions is reduced, thus improving sugar quality. The benefits, however, are difficult to quantify for inclusion into economic calculations.

7. In case of resin regeneration with relatively dilute sulfuric acid (weak cation resin) gypsum is formed in the regenerant stream. The latter can be used as a pulp pressing aid. The quality of such gypsum solution is usually quite high, because gypsum is already dissolved rather than being present in suspension. Presence of excess acid in the solution is beneficial for pH reduction in the (press) fresh water. As a result, softening process utilizing weak cation softening resin does not generate any waste (Henscheid, 1990). According to Kearney (2003) the value of spent regenerant exceeds the cost of chemicals for softener regeneration, which makes operating cost minimal.

8. The issue of changes in molasses formation due to introduction of a softening process deserves special discussion, since factory operation strategy plays an important role in the end result. Removal of calcium in the weak cation exchange softener (assuming pH is not adjusted downstream from the softener and initial limesalts are 0.1 g CaO/100 g DS) may result in about $200,000 per campaign savings because of less

sugar loss in molasses. Because soda ash addition to second carbonation (which is essentially a chemical softening process) is used in factories as an energy control method, molasses production in such factories can possibly be reduced, thus adding to the benefits of the softening process.

Effect of soda ash addition and the softening process on molasses production

Soda ash addition to second carbonation tank has been proved to be an effective method for hardness control. The process is essentially a chemical softening occurring as a result of equilibrium established between relatively soluble bicarbonates and less soluble carbonates of calcium. The process chemistry is complicated by the presence of salts of organic acids and other components having various levels of interaction with each other. The changes in juice quality during the course of campaign make the results of soda addition even less predictable. One obvious consequence of adding soda ash is the increase of non-sugar concentration in the thin juice, which affects molasses formation in two ways. Ffirst, additional molasses is formed due to the presence of non-sugars. Second, soda ash addition changes ionic balance of sugar solution, which affects melassigenic properties of the solution and, therefore, the final molasses purity. Individual melassigenic contributions of various ions have been seriously studied, and references can be found elsewhere (Silin, 1958, McGinnis, 1982). This issue is particularly important for the economics of softening process, because sugar losses to molasses is a major factor that influences process feasibility. Some controversy exists, however, about the validity of using high melassigenic coefficients for certain chemicals, such as caustic or soda ash in economic calculations, because they are not often supported by the actual data on molasses production. This opinion is also supported by Mottard (1983), who cautioned against using high melassigenic numbers to evaluate effects on molasses formation. After our discussions with experienced sugar operators worldwide we decided for practical purposes to evaluate the summary contribution of soda ash using melassigenic coefficient of 1.5, which corresponds to molasses purity of 60 %.

Molasses production is affected by non-sugars present in the beet as well as by the non-sugars added during juice purification. To correctly evaluate the economics of juice softening one needs to differentiate between the levels of non-sugars already used in the existing process and the contribution related to the introduction of the new process.

1. Earlier discussion in this paper indicates that in terms of adding non-sugars to the thin juice stream, the acid form weak cation resin process does not have any practical impact on molasses production because calcium is exchanged to hydrogen ions. Downstream pH adjustment with soda ash or caustic (that may or may not be needed depending on juice quality) generally does not exceed the stoichiometric requirements. The Gryllus process using non-sugars already present in the green syrup from second boiling does not add any melassigenic ions to the juice (assuming the total quantity of the syrup is sufficient to regenerate the resin completely without adding caustic to it). All other existing softening processes using strong cation resin result in increase of sodium ions in the solutions in the amounts exceeding stoichiometric requirements.

2. It is important in this context that an ion exchange softening process always replaces calcium in the solution by hydrogen or sodium (depending on the resin form used) in stoichiometric quantities. The main reason that additional melassigenic ions end up in molasses is due to excessive use of regenerant (which is necessary to completely regenerate resin). In the case of hydrogen form resin, where spent regenerant is used as a pressing aid, the small excess of sulfuric acid is not wasted but replaces the acid used in existing operation for pH adjustment of diffuser supply water. In the case of strong cation resin in sodium form (with the exception of the Gryllus process) excess sodium always ends up in molasses.

3. It is of particular interest to consider the chemical softening process (or soda ash addition to the second carbonation step) in terms of its impact on molasses production. The process is sometimes used as a step preceding ion exchange softening to reduce the resin calcium loading (and hence the size and the cost of process vessels and resin). Let us consider two sample curves (Figure 1), where soda ash was added to the second carbonation juice with various levels of limesalts (data courtesy of Larry Velasquez). In both cases initially the limesalts decrease linearly and later become almost independent of the rate of soda ash addition. The case of ion exchange softening in this graph would be represented by a straight line (see dashed line in Figure 1). If we assume that initial straight portion of the curves corresponds to the stoichiometric part of chemical softening, then for a "factory 2" case ion exchange softening would make sense after limesalts reach about 0.15 gCaO/100 g DS. The relative position of "stoichiometric" straight line and the experimental curve needs to be verified in each case, but typically soda ash is used to reduce the limesalts down to the 0.1-0.15 g CaO/100 g DS range. The inflexion point in the curve would generally determine the level of limesalts, below which the softening process is more feasible in terms of additional molasses production. A reduction in molasses production may be expected in a factory that uses excessive soda ash for controlling hardness.

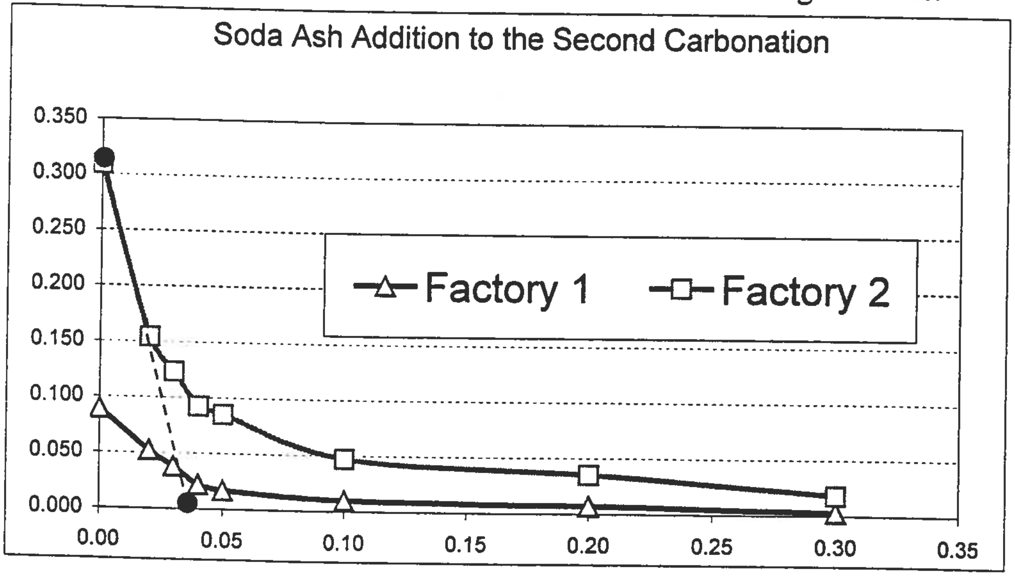


Figure 1 Soda Ash Addition to the Second Carbonation

Economic evaluation: case studies

Factory operating strategy, beet quality, storage conditions, length of campaign, specifics of factory design and configuration are among many factors that have a direct influence on the feasibility of softening process. Political and economic conditions in various processing areas also significantly influence operating strategies. For our study we have selected three different cases that would be considered typical for several growing regions. The weak cation softening process was used for these case studies.

Table 2 contains assumed cost figures for economic calculations. Obviously, the numbers would vary depending on a particular factory location and type of fuel used.

Table 2: Cost figures used for economic calculation

Item	Assumed Cost, $/US ton
Sugar	$ 500
Molasses	$ 100
Steam	$ 10
Electricity	$ 0.05 /kWh
Labor (fixed factory cost per US ton of beets)	$ 2.50
Antiscalants (per US ton of beets @ 0.1 g CaO/100 g DS)	$ 0.055

Case 1. A 15,000 tpd plant with high energy efficiency (20 % steam on beets), good beet quality, low limesalts (around 0.12 g CaO/100 g DS), short campaign (100 days), operated at or close to design capacity

Case 1 would be characteristic for a Western European sugar beet plant. All benefits listed in Table 1 would be applicable, perhaps to a lesser extent compared to less energy-efficient plants. A factory of this type does not boil out evaporators during the processing season. A combination of soda ash (chemical softening) and antiscalants addition keeps scaling under control. Maintaining the slice rate at a constant level is typically accomplished by raising steam pressure. For our calculations we assume that evaporator U-values are reduced by 10 % by the end of campaign. A linear approximation results in 5 % average decline.

The benefits from Table 1 related to increased factory throughput would apply in this case if raising turbine backpressure is not possible any longer. A potential reduction in soda ash usage may result in decreased molasses production. No antiscalants will be required, and spent regenerant gypsum solution will be used for pressing and pH adjustment of press water simultaneously. It is also important that softened juice does not form any precipitate or scaling during evaporation. This reduces the risk of installing plate-stack evaporators that are known to be sensitive to scaling and harder to clean. Table 3 contains a summary of savings achieved as a result of the softening process implementation. More items from Table 1 should be estimated for each specific case.

Table 3: Results for Case 1

Item	Assumptions	Savings, $$/year
Sugar Pile Losses	3 % higher throughput	141,000
Labor	3 % shortened campaign	112,000
Steam	3 % decreased steam demand: 10 % less sugar end steam due to reduction back boiling (color formation), improved evaporator economy	90,000
Antiscalant	Elimination of antiscalants	82,000
Electricity	Production increase due to 10 % increase of evaporator U-values	14,000
Miscellaneous "soft" numbers	Positive impact on thick juice and standard liquor filtration, sugar quality, constant operation, no more evaporator boilout after campaign,	???
Summary "hard" numbers		**440,000**

Case 2. A 10,000 tpd factory with medium energy efficiency (30 % steam on beets), good beet quality, average limesalts (around 0.15 g CaO/100 g DS), long campaign (150 days), operated above the design capacity.

Energy savings in case 2, which is more typical for a US or Canadian beet sugar factory will be more significant. Molasses production due to soda ash addition will probably stay at the same level. Since most US factories operate above their design capacity, the increase in steam pressure may not be sufficient to maintain the required slice rate. In this case decrease in pile losses due to slice increase may be an important factor contributing to the feasibility of the softening process. Improvement in energy efficiency would also important in today's competitive environment. A factory operation strategy similar to Case1 would apply. However, higher juice hardness and longer operating campaign may still require some boilouts or result in decreased factory throughput. Decreasing vapor temperatures would eventually limit the factory throughput and evaporator economy at the same time. The estimated impact on factory economics is shown in Table 4.

Table 4: Results for Case 2

Item	Assumptions	Savings, $$/year
Sugar Pile Losses	3 % higher throughput	211,000
Labor	3 % shorter campaign	113,000
Steam	3 % decreased steam demand with 10 % less sugar end steam due to reduction back boiling (color formation), improved evaporator economy	135,000
Antiscalant	No more antiscalants used	120,000
Electricity	Production increase due to 10 % increase of evaporator U-values	16,000
Miscellaneous "soft" numbers	See table 3	???
Summary "hard" numbers		**595,000**

The above-mentioned 7 % in steam savings are adding up to annual savings of $ 420,000 for this factory.

<u>Case 3</u>. A 5,000-tpd factory with low energy efficiency (40 % steam on beets), low beet quality, high limesalts (over 0.2 g CaO/100 g DS), poor storage conditions, short campaigns (100 days), operated at design capacity.

Capacity increase is a major trend in Eastern European nations (Case 3), where single factory slice rates typically do not exceed 3,000-5,000 tpd. Obviously the beet quality and storage practices need to be improved, but among processing options more efficient use of existing equipment provides a low cost solution. Lengthening the processing season is not a viable option due to poor weather conditions; therefore, thick juice storage appears to be a reasonable processing solution that will allow better utilization of capital assets. In all cases thin juice softening would provide benefits required to accomplish the process improvement goals. However, if soda ash is not currently used for hardness reduction, additional sugar loss to molasses is to be expected. The latter can be easily offset by benefits resulting from energy savings, increase in factory throughput, and reduction in pile losses and other factors listed in table 1.

The negative impact on the energy balance for vapors being switched to higher effects is of course more significant when the initial evaporator economy is low. A model calculation assumes 10 % decrease in the evaporator U-values and switching heaters for 1st and 2nd carbonation to a higher vapor in order to maintain the required temperature and boiling 50 % of the massecuites with a higher vapor due to capacity issues. The increase in overall steam demand was estimated at 15 %. Like in the previous cases it is expected that a factory would slow down gradually in response to scaling of heat exchange surfaces.

We have used a conservative estimate that after installation of the softening process a factory would observe a 7 % decrease in steam demand and the campaign length will decrease by 7 %.

Table 5: Results for Case 3

Item	Assumptions	Savings , $$/year
Sugar Pile Losses	7 % higher throughput with constant pressure profile in the evaporator station	109,000
Labor	7 % shorter campaign	88,000
Steam	7 % decreased steam demand due to improved evaporator economy	140,000
Antiscalant	No more antiscalants used	120,000
Electricity	Production increase due to 10 % increase of evaporator U-values	7,000
Miscellaneous "soft" numbers	See table 3	???
Summary "hard" numbers		**$ 464,000**

Advantages of fractal weak cation resin softeners

Industrial implementation of fractal softeners several years ago provided new opportunities for softening process in beet sugar factories. Near ideal fluid distribution allows utilization of very small resin beds resulting in low capital and operating expenses. Several papers have been published on this issue (Kearney 2001, Kearney 2003). Although any type of resin can be used in fractal equipment, weak cation exchange resin in hydrogen form appears to be the best choice for thin juice softening.

Depending on the scope of supply and related engineering and construction services the installed cost of a fractal thin juice softening system has been estimated. The cost of additional heaters/coolers, tanks, pumps and peripheral equipment are included in the estimates. Initial hardness of juice was assumed at 0.1 - 0.15 g CaO/100 g DS. Projected cost for various plant capacities is plotted in Figure 2.

It is quite interesting to compare our estimates with the investment cost for a weak cation system (resin in sodium form) installed at Appeldorn factory in Germany (Burkhardt, et al. 2000). A present value of $2.2M was calculated based on $1.7M investment made 8 years ago under assumption of 3 % per year inflation rate. The Appeldorn system is able to process 400 m³/h of thin juice. Our estimates indicate that an equivalent capacity weak cation exchange fractal system using resin in hydrogen form can be installed today for less than $0.9M.

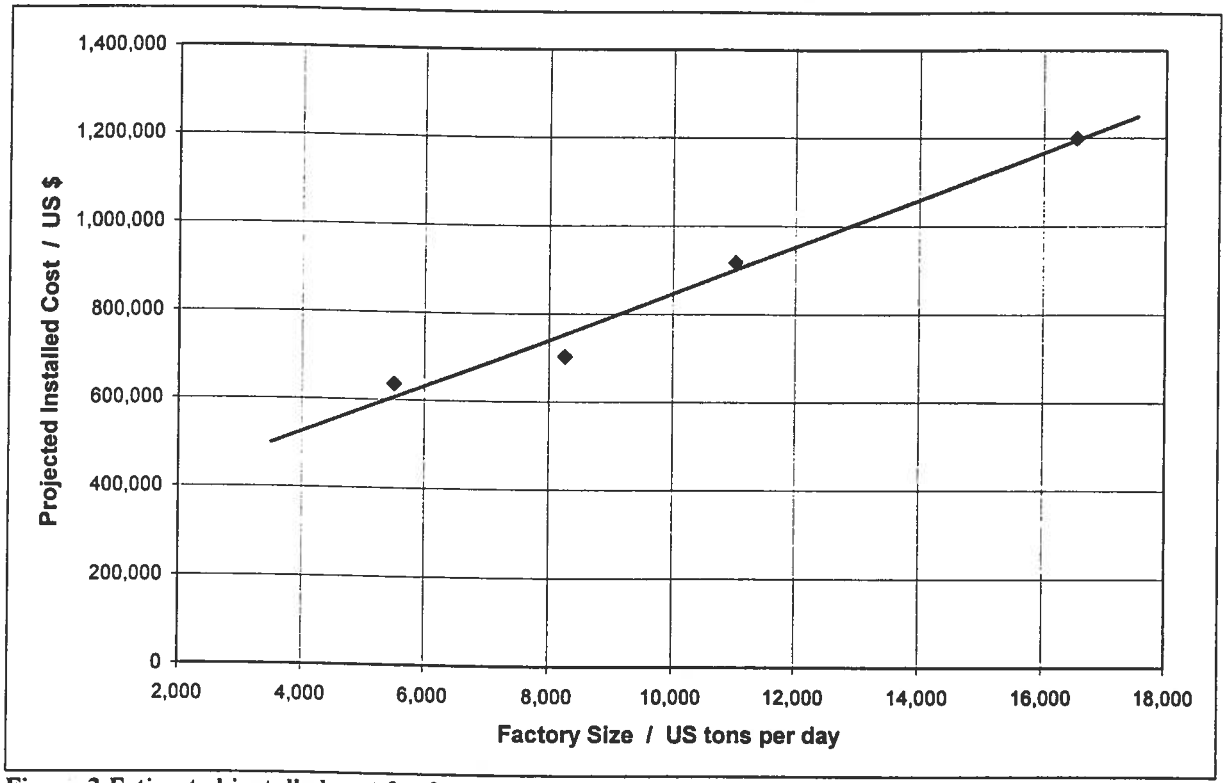


Figure 2 Estimated installed cost for fractal weak acid cation exchanger systems

This comparison drastically changes the economic outlook for thin juice softening process. Even with rather conservative assumptions used in our economic case studies, the combination of efficient weak cation softening and fractal equipment significantly improved softening economics. For an average US factory a simple payback of 1.5 years is estimated. The project is even more attractive for less energy efficient factories, where a payback of just over 1 year is possible. Even for the most energy-efficient factories a simple payback does not exceed 3 years. Considering additional benefits not taken into consideration in our case studies can further improve the numbers.

Conclusions

- Potential benefits of thin juice softening process are summarized. It appears that the softening process provides many benefits for a beet sugar plant and has a potential of becoming a standard unit operation.

- Several case studies for factories with different geographic locations, efficiencies and processing strategies have demonstrated that fractal softeners using weak cation resin in hydrogen form can provide an economic solution.

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References

Beet Sugar Technology, ed by R. A. McGinnis, (1982), Published by BSDF

Burkhardt, M., Schick, R., Freudenberg, T. (2000) "Continuous Thin Juice Decalcification with Weak Acid Cation Exchangers in Pfeifer & Langen's Appeldorn Factory" - Zuckerind. 125 (2000) Nr. 9, pp. 673 - 682

Ekern, E. (1991) "Thin juice softening using the Gryllus process"- Proc. of the 26th General Meeting of the ASSBT. pp. 352-358

Henscheid T., Velasquez, L., Meacham, D. (1990) "Five Year's Experience with Weak Cation Softening on Thin Juice". Sugar Journal. 53(7): 4-7.

Ion Exchangers (1991), ed. K. Dorfner, DeGruyter, 1991

Kearney, M., Velasquez, L., Petersen, K., Mumm, M., Jacob, W. (2001) "The Fractal Softener" - Proc. of the 31st General Meeting of the ASSBT. pp. 110-114.

Kearney, M., Rearick, D.E. (2003) "Weak cation exchange Softening: Long-term experience and recent developments" - Proc. of the 32nd General Meeting of the ASSBT. , San Antonio, TX, Feb.27-March 2, 2003 , pp. 257-264

Mottard, P. (1983) "The Imacti process for juice decalcification"- ISJ,1983,vol.85,No.1016, pp.233-237

Rossiter, G., Senevratne, R., Scarborough, R. (1999) "ISEP Ion exchange technology in Thin Juice Softening" - Proc. of the 30th General Meeting of the ASSBT. , Orlando, FL , Feb.10-13, 1999

Schick, R. (1992) "Effluent Free Decalcification by Weak Acid Cation Exchangers" – Zuckerind. 117 (1992) Nr. 3, pp. 176 - 181

Silin, P.M. (1958) "Technology of beet sugar production and refining" - Moscow Pischepromizdat, (English translation of 1964)