

Tzschaezsch, Oliver<sup>1\*</sup>, Bill Jacob<sup>2</sup> and Tim Pryor<sup>2</sup>, <sup>1</sup>ESCON, Schlosstrasse 48 a, D-1265 Berlin, Germany and <sup>2</sup>Amalgamated Research Inc., 2531 Orchard Drive East, Twin Falls, ID 83301. **Fractal applications for sugar decolorization processes.**

## ABSTRACT

Ion exchange decolorization to date plays no significant role in white sugar production from sugar beet. An increasing demand for high performance decolorization equipment in the refining and liquid sugar industry has pushed ion exchange resin manufacturers to improve selectivity, kinetics, color uptake capacity and cycle lifetime of their products. Fractal processing equipment allows for the best possible utilization of the advantages of the enhanced resins resulting in extremely effective and compact systems. In conjunction with nanofiltration systems the demand for water and salt as well as the waste water production are significantly reduced. Thick juice or molasses desugarisation extract are disposing of very high colors in comparison to typical cane liquors. Trials to decolorize these products in fractal decolorizing systems have proved successful thus representing a backup or alternative for existing unit operations. The flow turndown ratios of fractals allow for the combination of high throughput thin juice softeners and comparably low flow syrup decolorization applications in one dual-use installation helping to further improve economics.

### History:

In the beet sugar industry from beet storage to final sugar crystallization, color control and removal are among the key processing challenges. Relevant processes currently incorporated use conventional technology, such as liming, carbonation, sulfitation and crystallization. The beet sugar industry has used these conventional processes for over a century with success, leaving little room for new decolorization processes. In the cane and refining industry, ion exchange decolorization and carbon are used frequently in addition to conventional processes <sup>(1)</sup>. However the changing environment and economics of the world today has demanded for new developments to be trialed and tested.

For the past several years, decolorization developments have been made in regeneration methods, exhaustion methods and ion exchange resins <sup>(2)</sup>. Although these developments have been beneficial, relatively small attention was paid to the design of ion exchange decolorizer equipment. Fractal fluid distribution systems are one of the new developments currently being used in ion-exchange decolorization and ion-exchange decalcification systems. Although the development of fractal distribution in the late 1980's was originally for the use in large scale chromatography, it was soon realized that the application of this technology was far more reaching. Liquid distribution, mixing applications, reactors, and aeration fractals are just a few of a large assortment of developments currently in use <sup>(3)</sup>.

Fractal distribution systems on an industrial scale have been in use since 1991 in large chromatographic separation systems and ion exchange softening equipment utilizing fractal distribution have been in installed since 1999 <sup>(4,5)</sup>. Fractal distributors have proven to be highly efficient in both these applications. Although ion exchange

decolorization has been infrequently used in the beet sugar industry, there are several applications where this process could improve the factory operation and final sugar quality, specifically using fractal distribution in the ion exchange decolorizer equipment. The possibility of newly developed dual-use ion exchange systems for softening and decolorization applications results in significantly improved economics for such installations and justifies a closer look.

What are Fractal Distribution Systems?

Fractals can be defined in several ways, but for this specific application the definition is as “self-similar objects whose pieces are smaller duplications of the whole object” (6). Each iteration results in a smaller and exact reproduction of the larger object. When fractal geometry is applied to fluid distribution (7), the resulting distributor exit points over the entire surface have equal path lengths and hydraulic equivalence from the central entry point.

What are the Benefits of Fractals in Fixed Bed Systems in brief?

1. Hydraulically equivalent distribution
2. Uniform and increased resin utilization
3. Smaller resin quantities / smaller systems
4. Shallow resin bed design / low pressure drop
5. Reduced cross-sectional velocities / further improved resin utilization
6. Cutoff for regeneration/exhaustion rinse very sharp / reduced utilities & waste
7. Large turn-down ratio of flow rates / multi-use systems possible
8. Expandable and modular systems
9. Less system space demand / reduced floor loads & building requirements

Complete and even distribution across the entire surface of a column allows for the maximum possible utilization of all the resin in the cell. Areas that are prone to channeling of the flow or “dead zones” are eliminated.

Higher exhaustion rates results in less resin inventory requirement for the same task. Increases in exhaustion rates are achieved by reducing the cross-sectional velocity and shortening the overall path length of the cell. With short resin path lengths, the overall pressure drop is reduced even in high viscosity materials such as thick juice, centrifugal run-offs or liquors. This reduced pressure drop across the resin allows the use of lower pressure rated cells and pumps to supply the material. In some decalcification systems, there is no supply pump, but a head tank to supply flow to the cells. Understandably, the smaller the resin volume requires more frequent regenerations, but it must be noted the overall utilization of resin is greater thereby reducing the frequency of regeneration. Our preliminary studies indicate that using fractal equipment could potentially cut by half the amount of ion exchange resin used for decolorization by increasing the specific flow rate in BV/h (resin bed volumes per hour) respectively without giving up on decolorization performance.

The shorter resin path length allows the use of smaller, higher surface area ion exchange decolorizer resins that have been developed. Testing has shown the high

surface area and high kinetic activity of smaller resins is advantageous to use in fractal cells. The low cross-sectional velocity and short bed depth utilize the advantages of these resins that create higher pressure drop due to the small nature of the bead size.

Complete and equivalent surface distribution results in sharp regeneration and sweeten on/off curves. Current fluid distributor designs prevent uniform residence time within the distributor. This results in a spreading or bowing of the concentration front, reducing process efficiency. Fractal distribution systems eliminate this problematic distribution. The uniform residence time and hydraulic equivalency to all distribution points creates a perfect plug flow with virtually no mixing or turbulence (8). The sharp interface between the fluid phases reduces dilution caused by the mixing and results in less energy required for evaporation or waste disposal.

Hydraulically equivalent distribution points eliminate the need for pressure drop in the distributor for good operation. In many cases, pressure drop across the distribution system are lower than the pressure drop of the entry piping. All points in the fractal distributor are equal in path length and hydraulic pressure drop and therefore do not require pressure drop as a design parameter assuring good fluid distribution.

#### Better Economy through Multiple-Use Ion Exchange Units:

An interesting option is to use the same equipment for various ion exchange applications (with different resin type). For example, the same equipment can be used as softeners during beet campaign and as decolorizers for thick juice, centrifugal run-offs or molasses desugarisation extract after the beet campaign. Because fractal equipment is very compact, it is technically and economically feasible to replace the resin for various applications.

Modular systems that have been currently developed can be used for dual function purposes, mainly decolorization and softening. Fractal "clusters" can be used to modularize the system, allowing the increase or decrease of cells to suit the need of the user. Turn-down ratios of most fractal fluid distributors are 10 to 1, allowing flows only 10% of the full flow design and still maintaining complete distribution. High flow de-ashing processes use the same cells as low flow decolorization processes, requiring only changing resin and supply pumps. It has been demonstrated in many tests that fractals provide uniform distribution within a wide range of flowrates.

#### Carbon vs. Ion-Exchange decolorization?

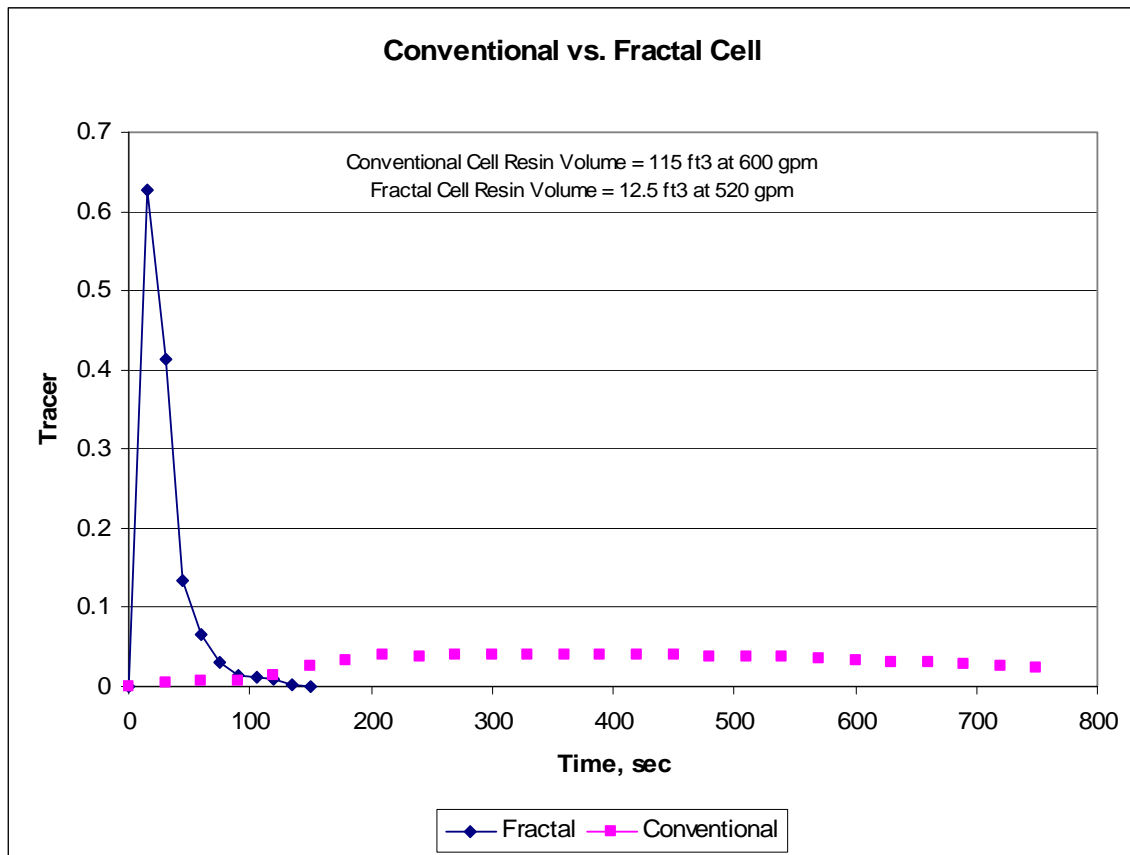
Carbon decolorization is currently still utilized in most cane refinery operations although life cycle costs are reportedly significantly higher. Detractions to this process are low capacity of carbon compared with ion-exchange resins, need for re-burning of used carbon, and handling and disposal costs associated with the waste carbon. Depending on the process, streams may have to be filtered after the carbon columns as well to prevent leakage into final processes. The benefits of carbon use along with decolorization include some odor reduction and additional reduction in organic contaminates.

Although current carbon columns are constructed using conventional thought, it has been proposed to use a fractal fluid distribution cell for the carbon decolorization columns. Taking advantage of the benefits of short bed depth and low pressure drop may

be promising for powdered or granular (GAC) types of carbon, even considering the short cycle life of the carbon. Fractal cells may be transferred from process to process within the range of their design specifications.

Ion exchange decolorization benefits include very high capacities compared directly with carbon, reduced media handling, and smaller systems (especially using fractal cells). Waste regenerant disposal still seems to be the greatest detraction to ion exchange systems although double regenerant use and nanofiltration brine recovery systems can be considered as today's standard. Double regenerant use reduces regenerant waste by 50 % and membrane filtration by further 80 %, thus resulting in a total of 90 % used regenerant recovery. Fractal systems with their sharp liquid phase interfaces reduce dilution significantly, and this in turn results in less regenerant waste handling and disposal.

Figure 1



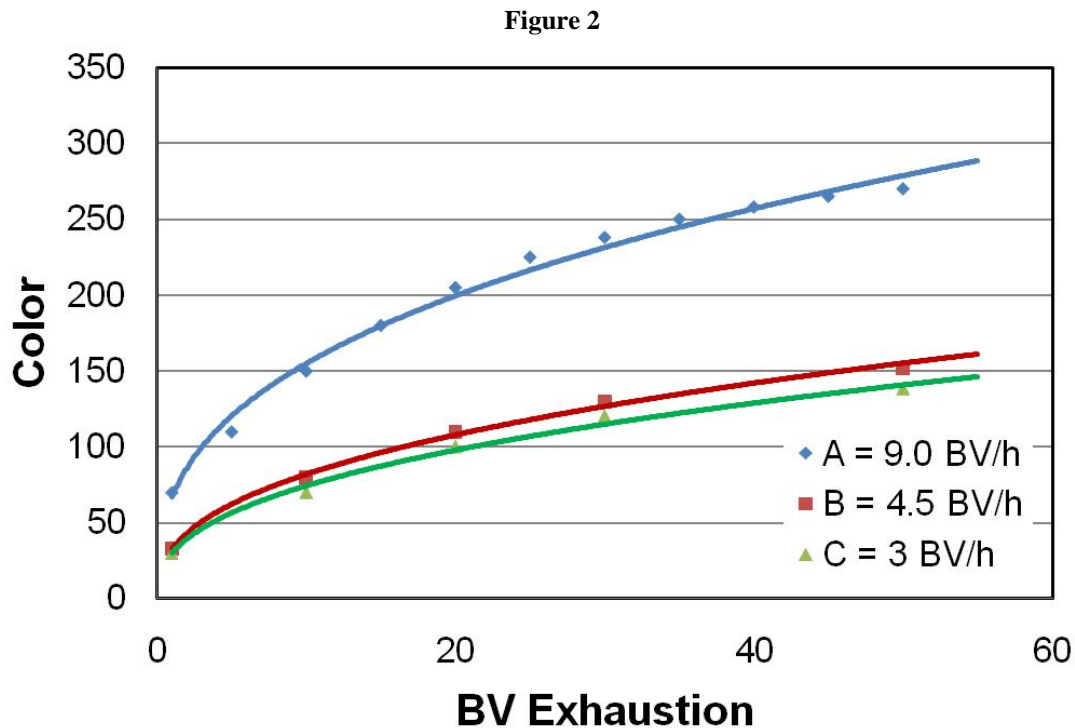
In Figure 1, a direct comparison of two ion exchange softening cells was made. One cell is a conventional ion exchange cell utilizing wedge wire radial distributors, and the other is a cell specially designed for fractal distributors. The exhaustion flow rates were within 15% between the two cells when a tracer material was added to the inlet

flow. Although the overall size of these cells is significantly different (approximately 10 % of the resin volume is in the fractal cell), the ion exchange removal at equivalent flows is the same. As shown, the distribution curve is extremely sharp for the fractal cell, with very little mixing and tailing evident. Even considering the more frequent regenerations required, a significant reduction in exhaustion sweet-on and sweet-off dilute volume, and regenerant sweet-on and sweet-off volume is generated.

#### Case Study for Ion-Exchange Decolorization:

In 2008, the first industrial fractal cell ion exchange decolorizer system was installed for the purpose of decolorizing filtered cane raw sugar liquor in a beet sugar factory. Other than fractal cells, the system used mostly conventional technologies, including resin and regeneration methods with regenerant recycle and nanofiltration. Implementation of this technology results in concentrated waste water (retentate) quantities of around 0.3 BV per regeneration. Very dilute mixed waste waters (< 0.3 % DS) from rinsing and sweetening on/off steps are in the range of 1 BV/regeneration.

In order to be able to size the system properly test were performed with the target to determine the impact of fractal distribution upon the conventional exhaustion flow rate of 3 BV/h. Results can be taken from Figure 2.



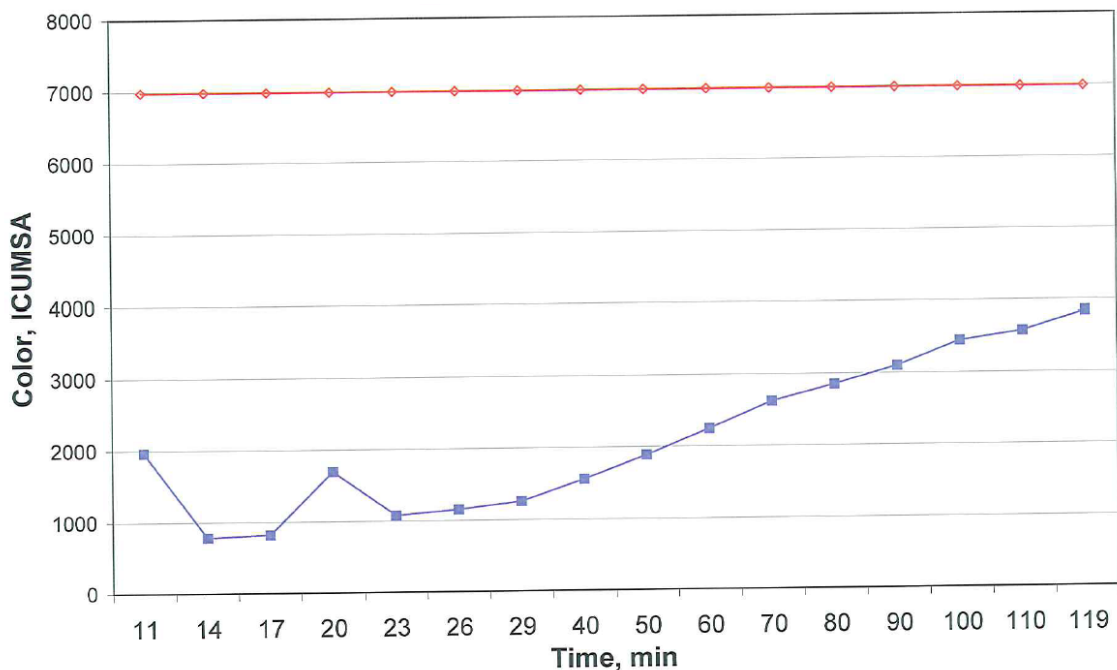
Design parameters included color reduction from 900 ICUMSA to less than 200 ICUMSA at a liquor flow rate of 250 gpm at 65 % DS. Although these were the goals, feed colors routinely exceeded 2000 ICUMSA and flow rates were 50 % above design capacity.

This first fractal installation for decolorization proved very successful, even under the extreme conditions. Design parameters were met for decolorizer performance although the system was operated at 6 instead of 4 BV/h. Initial testing of the resin service life after the first campaign indicated the resin is in remarkable condition considering the very high organic load. Apart from particulate solids in the resin which resulted from problems other than the decolorization process, the structural integrity and performance of the resin were within specifications.

#### Decolorization of High Color Media from Sugar Beet:

The high color loading experienced in certain cane raw sugar applications and the significant improvements in resin performance and irreversible fouling and breakage behavior suggested the testing of high color extract from molasses desugarisation and thick juice from storage. Results for a typical decolorization cycle of extract from molasses desugarisation operated at 3 BV/h are shown in Figure 3.

**Figure 3**  
MDS extract decolorization trial results

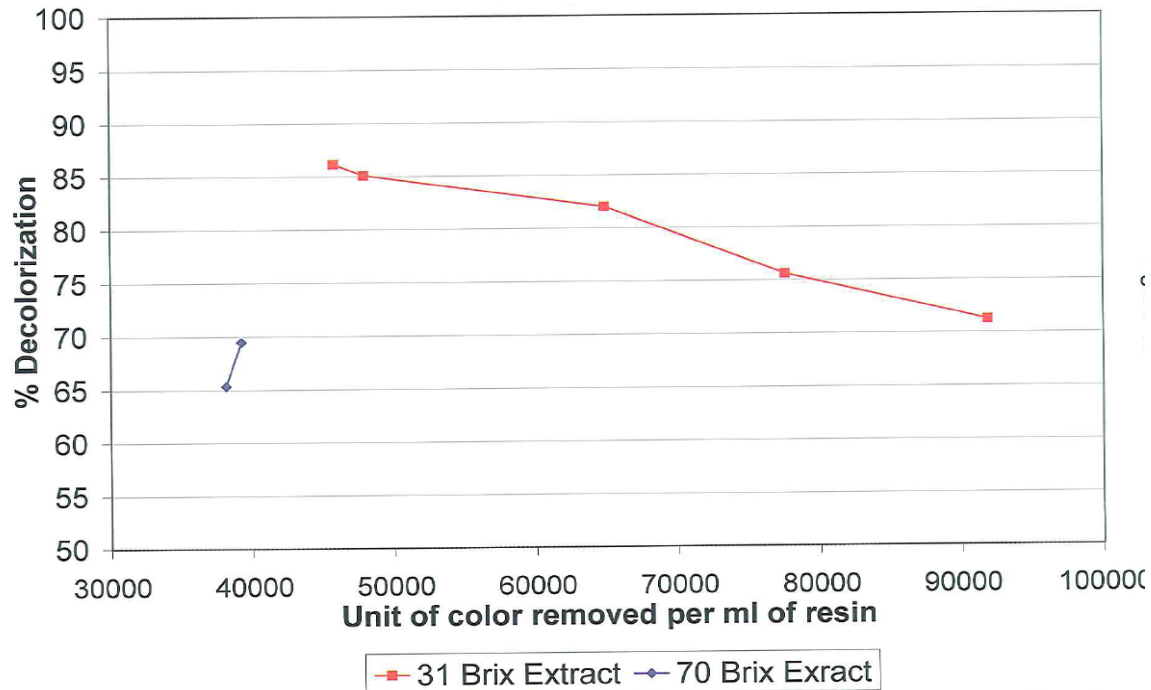


Tests with dilute 31 brix extract direct from the separator show the higher decolorization rate in % for the dilute stream (see Figure 4). It can also be seen that the color loading on the resin gets significantly higher with lower DS material. Pressure drop was negligible for the dilute samples.

Decolorizer resin service life in the past has been determined by quantity of exhaustion cycles. Fractal systems have shorter exhaustion cycles and therefore cycle more often. It has been shown, even with the increase exhaustion cycles, long service life of the resin is still attainable. The nature of the short resin bed depth in fractal cells and the resulting low pressure drop also reduce the hydraulic forces put upon the resin.

Results at ARi indicate that even after 300 exhaustion cycles, the structural integrity of the styrenic resin is still maintained in most cases. One company recently developed a process to restore decolorizer resins to near original specifications (8). Decolorization performance after this restoration process is near that of new resin.

**Figure 4**  
MDS extract decolorization tests: influence of brix



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