

Corn Sweetener Refining with Ion Exchange Resins

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ION EXCHANGE RESINS



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Introduction

Corn Sweetener Refining Overview

Liquid and solid sweeteners are produced around the world from several starch sources including corn, wheat, tapioca, potatoes and even cellulose hydrolyzate. The most widely used of these is corn, with nearly 1 billion bushels of corn processed to sweeteners in the U.S. alone. High fructose corn syrup (HFCS) is the largest single sweetener syrup produced. HFCS is found in canned fruits, cereals, chemicals, drugs, pharmaceuticals, condiments, confectionery items, gum, cough drops, dairy products, ice cream, frozen desserts, jellies, meat products and, most notably, carbonated beverages.

HFCS, the most highly refined of the liquid corn sweeteners, is produced in a corn wet milling process which includes the following unit operations:

- A. **Steeping:** Corn kernels soak in sulfurous acid to soften them.
- B. **Germ Separation:** Kernels are fractured into starch, gluten, hull and germ components. The oil rich germ is separated and processed for oil extraction.
- C. **Fiber Recovery:** The slurry of starch, gluten and hull is finely ground and the hull is separated.
- D. **Starch/Gluten Separation:** Starch and gluten are separated in centrifuges and each is washed.
- E. **Liquefaction:** The solid starch particles are liquefied by enzymatic breakdown into dextrins — partially degraded starch chains.
- F. **Saccharification:** Dextrins are enzymatically hydrolyzed into soluble mono-, di-, tri- and oligosaccharides.
- G. **Filtration:** Diatomaceous earth or membrane filters remove retrograde starch, oil, proteins or other insoluble material.
- H. **Decolorization:** Carbon or adsorbent resins remove color, flavor and odor compounds from filtered syrup. Adsorbent resins are used after Ion Exchange whereas carbon is most often used ahead of Ion Exchange.
- I. **Demineralization:** Ion exchange resins remove ash, protein, organic acids and color from the corn sweetener to provide color and flavor stability.
- J. **Isomerization:** Dextrose is enzymatically isomerized to fructose (42% fructose or 42 HFCS) for increased sweetness.
- K. **Demineralization:** Ion exchange resins remove color and the salts which were added to facilitate isomerization.
- L. **Evaporation:** Dilute syrup is concentrated by evaporation of water.
- M. **Chromatographic Separation:** Fructose/dextrose mixture (42 HFCS) is separated with a chromatographic separation resin to produce a fructose rich (90% fructose or 90 HFCS) stream and dextrose rich stream.
- N. **Polishing/Decolorization:** Color, hydroxymethylfurfural (HMF) and residual ash are removed with ion exchange resins from the fructose rich product before or after blending to 55 HFCS.
- O. **Evaporation:** 55 HFCS product is concentrated prior to shipment by evaporation of water.

Ion exchange resins are utilized in the demineralization, enrichment and polishing/decolorization unit operations of HFCS refining as described below to produce a pure colorless syrup having the desired sugar profile.

Demineralization

Demineralization of glucose syrup removes ash, protein and color from the solution. It also increases the long-term color stability of the syrup without the need for addition of sulfur dioxide which can cause a human allergic reaction in the final consumer products. Ash, calcium in particular, present in the dextrose (95% dextrose) solution will have a negative effect on the performance of isomerase enzymes and must be removed by demineralization prior to isomerization of a typical 95% dextrose to a 42% fructose (42 HFCS) solution. Salts are added back into the 95% dextrose solution to facilitate isomerase enzyme performance and are removed after isomerization via demineralization to produce a pure sweetener for sale or for subsequent enrichment to a 55% fructose (55 HFCS) solution.

Chromatographic Separation

Different sugars passing through a bed of strong acid cation resin in the calcium or sodium form will separate from one another chromatographically due either to a difference in affinity for the resin or due to different rates of diffusion into and out of the resin beads. This separation technique can be used to create solutions which have sugar profiles that provide the desired sweetness, taste or physical properties for a particular consumer product.

A 55% fructose solution will match the sweetness of sucrose when used in soft drinks. This sweetener is produced by passing a 42% fructose solution through a calcium form strong acid cation resin to effect a separation and create a 75-90% fructose solution which can be blended back with additional 42% fructose to produce a 55% fructose purity. Crystalline fructose is also used to replace white table sugar in some dry mix applications. For production of crystalline fructose, the enrichment process is tuned to produce a 95+% fructose solution which can be crystallized and dry packaged.

Another class of sweeteners produced utilizing chromatographic separation are the sugar alcohols. Hydrogenation of sugars to produce sugar alcohols such as sorbitol, mannitol, maltitol, erythritol, xylitol or polyols requires high purity feedstocks in order to avoid unwanted byproduct sugar alcohols. As a common example, 95% dextrose is enriched to a 99.4+% dextrose purity on a sodium or potassium form strong acid cation resin prior to hydrogenation to sorbitol.

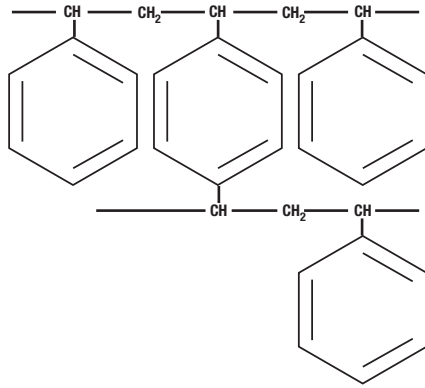
Polishing

Degradation of sugars through bacterial action or excessive residence time on the fractionation resin at elevated temperatures can produce contaminants which decrease the long-term color stability of the finished product. Additionally, incomplete purification prior to chromatographic separation may have left unwanted impurities in the product stream. These impurities can be removed from the product prior to final evaporation using strong base anion resins in the salt form by themselves or in the hydroxide form with a companion bed of strong acid cation resin intermixed with the anion. The units utilizing the companion cation resins are termed mixed beds and remove color, ash, HMF and residual protein to produce a consistent quality of finished product.

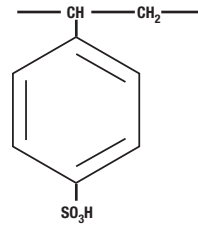
Resin Structure

The vast majority of ion exchange resins utilized in corn sweetener refining are copolymers of styrene and divinylbenzene which have been activated with sulfuric acid or one of a number of amine compounds to produce cation and anion resins respectively:

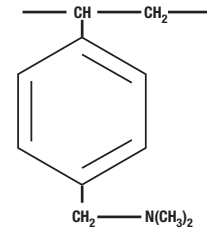
Styrene and Divinylbenzene Copolymer



**Strong Acid
Cation Resin**



**Weak Base
Anion Resin**



The insoluble resin matrix and bonded functional groups are capable of exchanging ions or adsorbing molecules from solution and thereby affecting a change in the ionic or molecular concentrations of the syrup. These properties have made the use of ion exchange resins critical in HFCS refining.

Unit Operation Process Design

Demineralization Process

Glucose syrup from starch hydrolysis contains ash, color bodies and proteinaceous materials which produce an unacceptable color, taste or odor quality in the finished product and reduce isomerization enzyme performance. Whether the syrup will be evaporated and sold as a finished product or continue on in the refining process to isomerization, demineralization is required to remove objectionable soluble components. Color stability of some corn syrups is obtained through the addition of sulfur dioxide, but due to human sensitivity to sulfites, this practice has partly been replaced with ion exchange.

The ash content of glucose syrups is typically 0.25-0.45% by weight of total syrup dry solids and predominantly contains the following ions:

- Sodium Na^+
- Calcium Ca^{++}
- Magnesium Mg^{++}
- Chloride Cl^-
- Sulfate SO_4^{--}

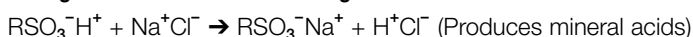
To facilitate isomerization of dextrose to a 42% fructose solution, salts are added back to the syrup after demineralization and will be present in the 42% fructose. These salts must be removed prior to final evaporation or chromatographic separation. The ash content of 42 HFCS is typically 0.15-0.25% by weight of total syrup dry solids and consists primarily of:

- Sodium Na^+
- Magnesium Mg^{++}
- Sulfate SO_4^{--}
- Sulfite SO_3^{--}

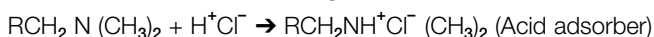
As the dextrose or fructose syrup solution passes through the resin bed, the sugars, ash, color bodies and proteins diffuse into the resin beads and can be exchanged or adsorbed onto the resin. In the strong acid cation bed, sodium, calcium, magnesium and other cations will replace the hydrogen ions on the resin due to their greater affinity for the resin than hydrogen ion. The hydrogen ions displaced from the resin by other cations cause a drop in the solution pH to a level of about 1.5-2.0 in the "primary" cation column and 3.0-3.5 in the "secondary" cation column. Thus, neutral salts are changed to their corresponding mineral acids. Proteinaceous compounds, at low pH, may be sorbed onto the cation resin either by ion exchange or adsorption on the resin matrix.

The syrup then passes through a bed of weak base anion resin where the mineral acids, organic acids and color bodies diffuse into the resin beads and are adsorbed onto the tertiary amine functional groups. The chemical equations depicting the service ion exchanges are shown below:

Strong Acid Cation Service Exchange Reaction



Weak Base Anion Service Exchange Reaction



("R" indicates the resin matrix)

The weak base anion resin has negligible mobile OH^- counter ion which can be exchanged by an anion in solution. Without this ability to split neutral salts, the weak base anion resin must rely on the cation resin to first produce acids in order for it to remove ions by acid adsorption.

The service breakthrough point can be more easily and accurately detected prior to leakage of impurities if it is consistently the result of anion resin exhaustion rather than cation resin exhaustion. Because of this, demineralization systems are typically operated with an excess amount of cation exchange capacity (not necessarily volume) relative to anion acid adsorption capacity. This ensures that the service breakthrough point is consistently the result of anion exhaustion. The designated exhaustion point corresponds to a rapid increase in mineral acid leakage from the anion resin, a pH drop, conductivity rise and/or an increase in color leakage. A typical service effluent profile is indicated in Figure A.

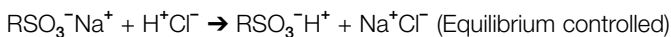
While the affinity of the cation resin for highly dissociated salts is good, the affinity for proteinaceous materials is much weaker and the cation resin will leak higher percentages of proteins during service as shown on the cation leakage curve (Figure B). The weak organic acids show less affinity for the weak base anion resin than do the mineral acids and will also leak through in greater percentages as indicated in the anion leakage curve (Figure C). To prevent proteins and organic acids from affecting the finished product quality, the syrup is typically passed through a secondary cation/anion pair for more complete removal of the impurities leaking from the primary demineralizer pair. This two-pass demineralization system will remove 95-98% of the salts, 65-75% of the protein, 50-75% of the weak acids and 70-90% of the color.

Upon reaching the service exhaustion point of the primary demineralizers, the primary pair is regenerated, the secondary pair is moved into primary demineralization service and a third pair of freshly regenerated demineralizers is placed into secondary demineralization service. This sequence is commonly referred to as "Merry Go Round" service. Alternative configurations include systems utilizing a multiport valve and a number of rotating resin beds and systems utilizing fixed upflow service dual compartment columns. Another equipment arrangement for glucose and fructose demineralization commonly used in the Pacific Rim is a demineralizer two-bed pair coupled with a polishing strong base anion (Type II) mixed bed for even greater removal of the soluble impurities at the expense of some chemical efficiency. The higher product quality can increase isomerase enzyme life and provide a better feed for the fructose enrichment system. In this scheme one cation/anion/mixed bed train is in service while a second is in regeneration.

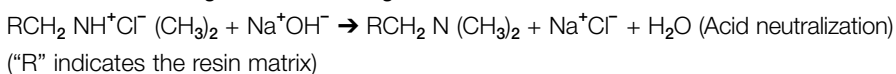
Upon exhaustion, the syrup is displaced from the resin bed and the resin is restored to a working condition with a chemical regeneration treatment. The metal ions are displaced from the cation resin by passage of a strong mineral acid in an amount in excess of the stoichiometric exchange capacity of the resin in order to drive the equilibrium reaction. Hydrochloric acid is widely preferred to regenerate cation resins by displacing the metal ions and stripping off the proteinaceous compounds. The acids adsorbed onto the weak base

anion resin are neutralized utilizing a base such as sodium hydroxide, sodium carbonate or aqueous ammonia. This acid neutralization is accomplished with a smaller excess of regenerant chemical than is required for the cation resin. The chemical equations depicting the regeneration exchanges are shown below:

Strong Acid Cation Regeneration Exchange Reaction



Weak Base Anion Regeneration Exchange Reaction



Regeneration of the resins is accomplished in a simultaneous sequence as follows:

1. **Sweeten Off** : Syrup is displaced from the cation/anion pair by introduction of condensate or demineralized water into the cation column which then pushes the syrup out through the anion. This step continues until the anion effluent syrup concentration has decreased to 0.1- 0.5 % dry solids (Figure D).
2. **Backwash**: Process water is passed in an upflow direction simultaneously in both the cation and anion columns to fluidize the resin to allow particulates and resin fines to pass up through the beds and out of the vessels.
- 3a. **Chemical-In Cation**: A dilute hydrochloric acid solution passes through the bed exchanging hydrogen ions for the metal cations fixed onto the resin. While sulfuric acid could alternately be used, a lower operating capacity is achieved and the threat of calcium sulfate precipitation makes it less desirable.
- 3b. **Chemical-In Anion**: A dilute basic solution passes through the resin bed neutralizing and releasing the adsorbed acids. Sodium hydroxide, sodium carbonate or aqueous ammonia can be used as a weak base anion regenerant.
4. **Cleanup Regeneration**: At intervals of once per 5 to 25 cycles it becomes desirable to strip off proteins adsorbed onto the cation resin utilizing caustic or ammonia. Organic acids adsorbed onto the anion resin are stripped utilizing an alkaline brine or hydrochloric acid solution. Following the cleanup regeneration is another chemical-in step with a double dosage of regenerant chemical.
5. **Slow Rinse**: Water passes through the resins and pushes out the regenerant chemical at a rate which ensures sufficient contact time for completion of regeneration. The use of condensate or demineralized water ensures that no precipitation will occur and no dissolved ions in the slow rinse water will exchange onto the resin and decrease its exchange capacity for the subsequent service cycle.
6. **Fast Rinse**: Condensate or demineralized water is used to rinse out the residual chemical in the beds.
7. **Series Rinse**: Condensate or demineralized water passes through the cation and anion beds in series in a once-through or recirculating manner until the effluent quality reaches the desired conductivity limit of 10-30 microsiemens/cm ($\mu\text{S}/\text{cm}$).
8. **Sweeten On**: Syrup is passed in series through the cation and anion beds displacing the rinse water. Sweeten On is terminated when the anion effluent dry solids concentration reaches in excess of 95% of the feed syrup solids concentration (Figure E).

The demineralization sequence chart below lists the various process modes and typical parameters.

Demineralizer Sequence

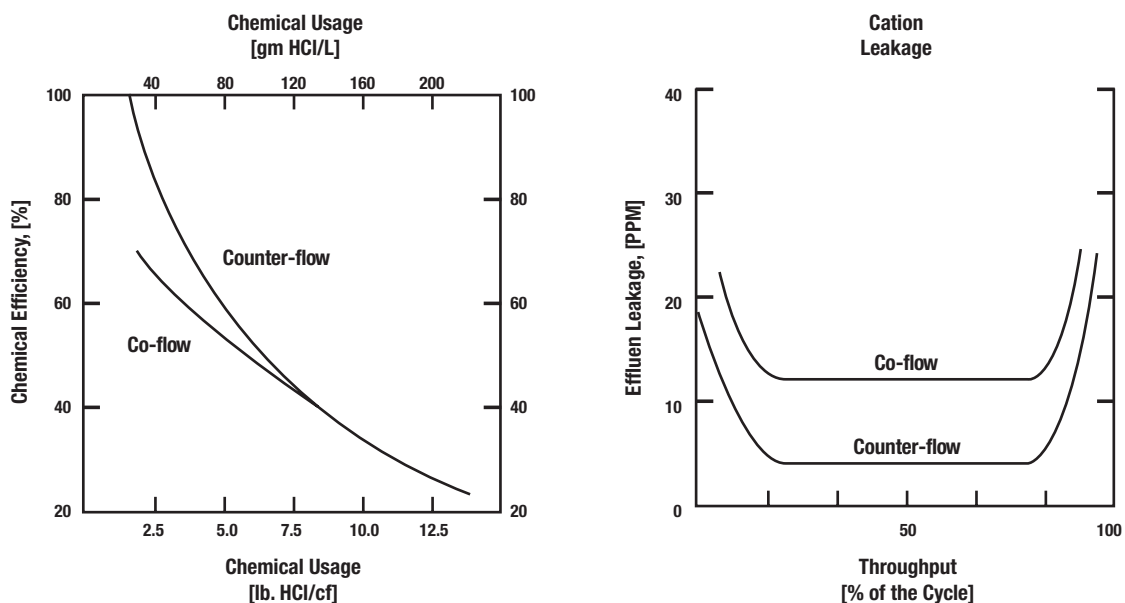
OPERATION	SOLUTION	FLOW RATE [BED VOLS/HR]	VOLUME [BED VOLS]
1. SWEETEN OFF	H ₂ O	2.0-4.0	1.5-3.0
2a. BACKWASH CATION	H ₂ O	1.0 ft/min	1.5-2.0
2b. BACKWASH ANION	H ₂ O	0.33 ft/min	1.0
3a. CHEMICAL IN CATION	7% HCl	1.0-1.5	1.0
3b. CHEMICAL IN ANION	4% NaOH	1.0-2.0	1.5
4a. CLEANUP CATION	4% NaOH	1.0-2.0	1.0
(Alternate)	3% NH ₃	1.0-1.5	1.5
4b. CLEANUP ANION	7% HCl	1.0-1.5	1.0
(Alternate)	1% NaOH/10% NaCl	1.0	1.5
5a. SLOW RINSE CATION	H ₂ O	1.0-1.5	1.5
5b. SLOW RINSE ANION	H ₂ O	1.0-2.0	1.5
6a. FAST RINSE CATION	H ₂ O	10-20	2.0-4.0
6b. FAST RINSE ANION	H ₂ O	10-20	3.0-5.0
7. SERIES RINSE	H ₂ O	5-10	2.0-5.0
8. SWEETEN ON	30-50% DS SYRUP	2.0-4.0	1.0
9. SECONDARY SERVICE	30-50% DS SYRUP	2.0-4.0	30-60
10. PRIMARY SERVICE	30-50% DS SYRUP	2.0-4.0	30-60

Demineralization Equipment

The demineralization equipment train typically consists of three cation/anion pairs or two cation/ anion/mixed bed triplexes. The equipment utilizes food grade rubber lined carbon steel pressure vessels containing two or three sets of distributors made of CPVC or stainless steel and wrapped with polypropylene or stainless steel screen. In anion columns which do not see a hydrochloric acid cleanup solution, stainless steel distributors are often employed for greater strength against the large shrink/swell and pressure drop forces in the bed. Piping manifolds utilize polypropylene-lined carbon steel, rubber lined carbon steel or stainless steel pipe. Control of fluid direction is accomplished utilizing lined and stainless steel plug valves, butterfly valves or diaphragm valves. Service flow can proceed either down through the resin beds, maintaining them packed in the lower half of the vessels, or up through the resins, maintaining them in a packed state in the upper half of the vessels. Compartmentalized vessels with external backwash are also utilized.

The vessels are most commonly operated with a “water dome” (water fills the freeboard space between the middle and top distributors) rather than an “air dome” to improve rubber lining life and minimize microbiological activity in the vessels during service.

Improved product quality can be obtained from the cation resin by utilizing regenerant chemical passed in a direction counter to the service flow. Since the syrup leaving the cation column is in equilibrium with the resin located at the outlet collector, the counter-flow passage of regenerant chemical creates an area of highly regenerated resin at the column effluent. At constant chemical dosage, the cation effluent quality is constant and contains less impurities than a co-flow regenerated cation resin bed.



If the backwash step can be utilized only infrequently, then the resin bed will be undisturbed during regeneration and a counter-flow regeneration may produce a high quality syrup with the same throughput capacity at a somewhat lower chemical dosage. Since a weak base anion regeneration is an acid neutralization step and only a small excess of regenerant is required, no advantage is gained from counter-flow regeneration of the weak base resin.

Separation Process

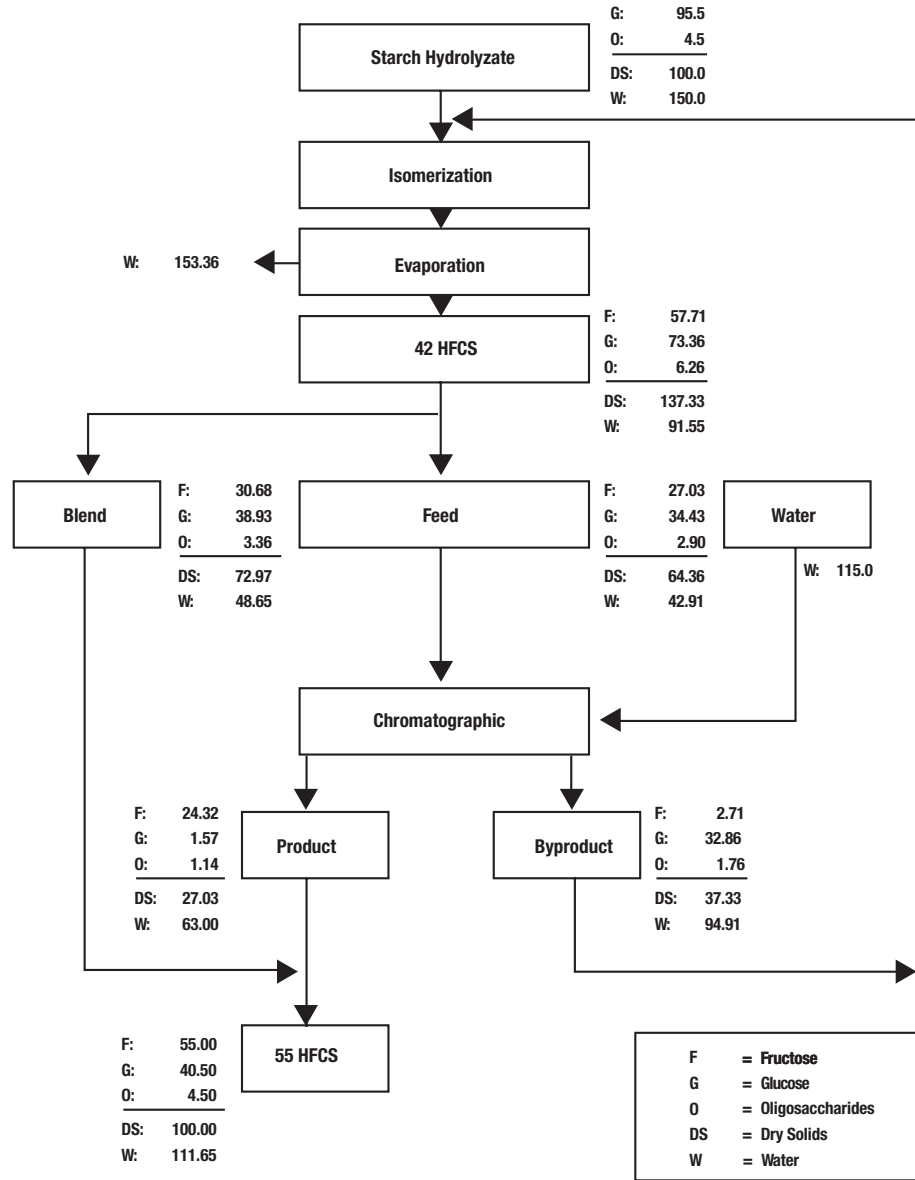
In the production of 55 HFCS from dextrose, an economical limit of 42-46% fructose is achieved using isomerase enzyme. To obtain a higher purity fructose solution, the dextrose and fructose must be separated to produce two fractions, both of which are enriched in either sugar. This is accomplished via chromatographic separation on a fractionation ion exchange resin. The fructose-rich fraction can be blended into a 55% fructose solution while the dextrose-rich fraction is recycled in the HFCS refining process.

Owing to a greater number of sites available for hydrogen bonding, the fructose molecule will form a coordination complex with calcium ions fixed onto a strong acid cation resin. This results in a preferential affinity of the resin for the fructose molecule over the glucose molecule and hence a chromatographic separation of the two sweeteners as they pass through the resin bed. From a feed solution containing a purity of 42% fructose by weight, the fructose in the product fraction can reach in excess of 99% purity. However, when producing 55% fructose, the optimum productivity and efficiency of the system is achieved by enriching to an 85-90% fructose concentration and blending this product with a 42% fructose solution to produce the 55% fructose which matches the sweetness of sucrose in soft drinks. When enriching to produce crystalline fructose, a product purity in excess of 95% fructose is desired prior to the crystallization step.

When enriching fructose to produce 55 HFCS with a simulated moving bed chromatographic separation system (see next section), a product purity of 90% fructose can be achieved at a 90% recovery of the fructose in the feed stream and a desorbent consumption of 1.1-1.25 lbs. water per lb. of 55 HFCS dry solids. The production achieved will be approximately 200 lbs. of 55 HFCS dry solids/cu. ft. resin per day depending on the type of system and resin utilized. At constant production and desorbent consumption the purity and recovery will vary inversely with each other.

Chromatographic separation of dextrose is also commercially practiced to separate the dextrose from the oligosaccharides and produce a dextrose purity in excess of 99% in order to minimize unwanted byproducts in the subsequent hydrogenation to sorbitol or in fermentation. Dextrose separation from oligosaccharides occurs due to a difference in the rate of diffusion into and out of the monovalent form cation fractionation resin.

Fructose Enrichment Material Balance

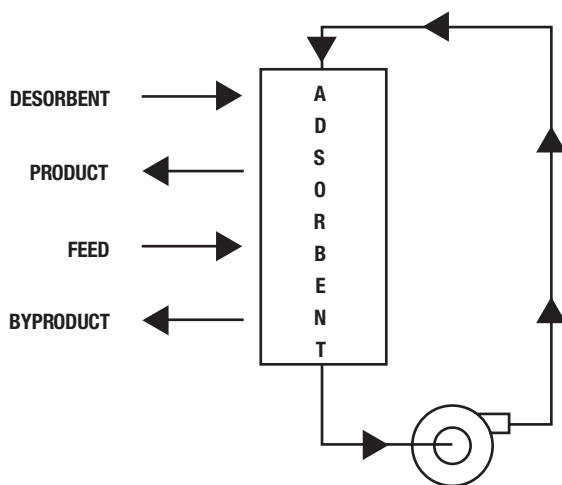


Chromatographic separation is a diffusion controlled process and those variables that affect the length of diffusion path, uniformity of diffusion path and ease of diffusion through the resin bed will affect the performance of the separation. Separation performance is affected by resin characteristics such as bead size, bead uniformity, moisture, capacity and bead strength. For example, increasing moisture will improve diffusion through the resin, decreasing particle size will reduce the length of the diffusion path and increasing bead uniformity will equalize the diffusion path for all species at a given mass transfer stage. The combination of these resin characteristics is interrelated and optimization is dependent both on process performance requirements and the particular separation system design.

Enrichment Equipment

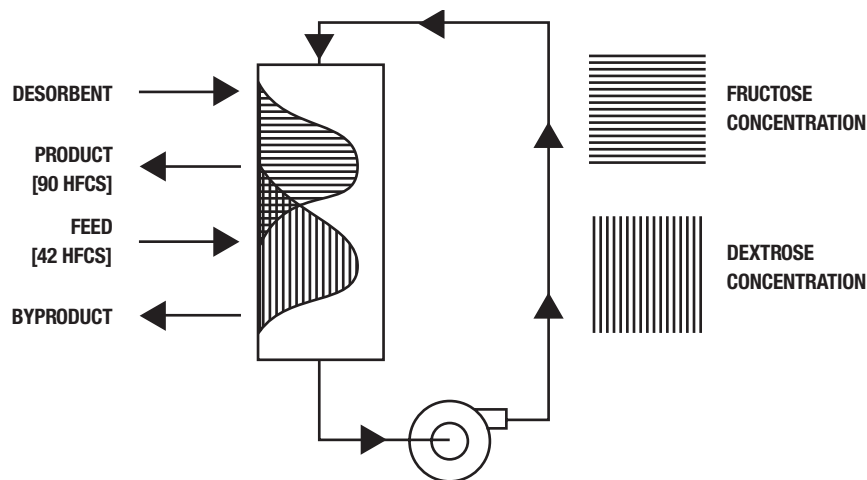
Fructose and dextrose enrichment had initially been accomplished in batch separation systems where introduction of a pulsed volume of feed was both preceded and followed by recycle fractions and then eluted with desorbent water. In the 1970s, the technology was developed for continuous chromatographic separation of fructose utilizing a simulated moving bed (SMB) separation system. The SMB technology employs continuous feed and desorbent introduction and continuous product and byproduct withdrawal into and out of a recirculating fluid flow. The recirculating fluid flow can range up to six times greater than the feed flow rate.

Simulated moving bed chromatographic separation system

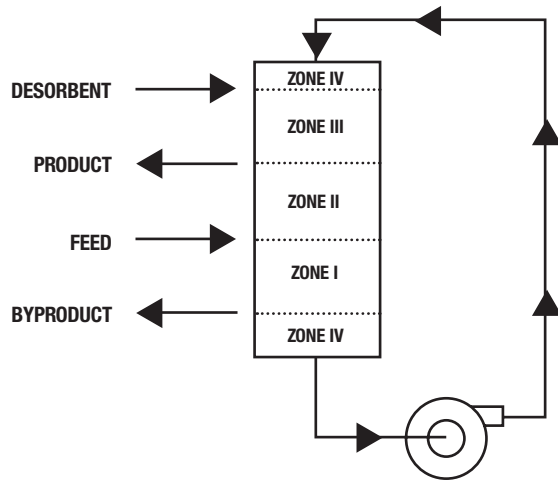


In the SMB system, fructose purity in the resin bed upstream from the feed introduction point increases as the distance away from the feed point increases. From a feed inlet reference point, it seemingly appears that the adsorbent media is moving upstream and carrying with it the fructose molecules which it has adsorbed, thus the terminology “Simulated Moving Bed”.

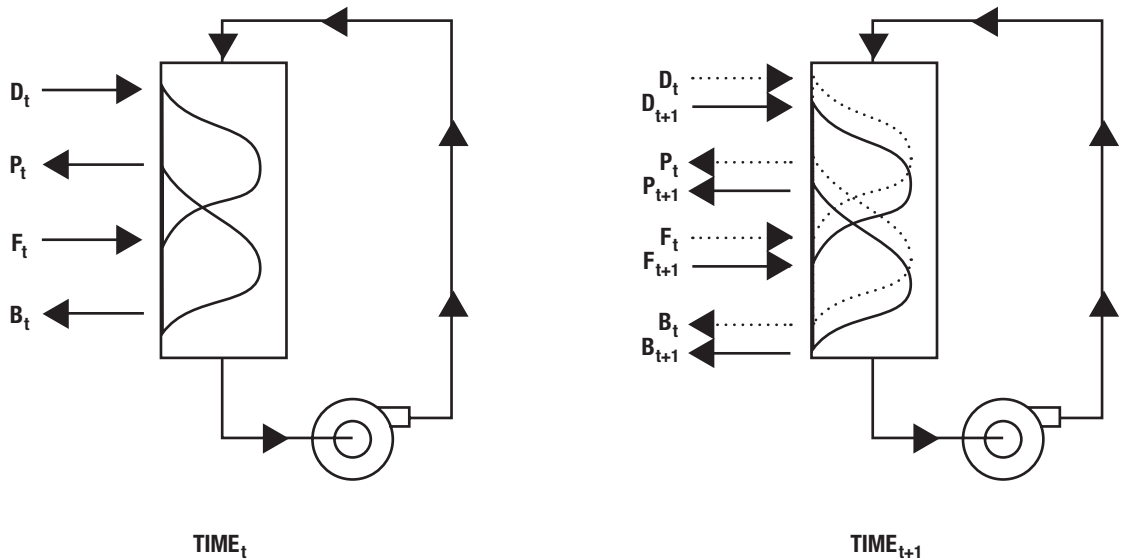
Fructose enrichment simulated moving bed



The SMB separation system is divided into four process zones with each zone having a unique flow rate. A fifth zone is added when withdrawal of a polysaccharide rich stream is desired.



Once a stable concentration profile has been established across the entire length of the separation system it moves slowly down the system with the aid of the recirculation flow. The sugar concentrations are maintained constant by moving the location of the feed, desorbent, product and byproduct inlet and outlet points down the system at the same rate as the concentration profile moves.



Movement of the introduction and withdrawal points is accomplished using either a multiport valve or with multiple manifolds of two-position valves.

Auxiliary systems complement the chromatographic separation system. Degasification of feed and desorbent streams prior to introduction to the resin bed ensures minimal oxidation of the resin will occur. Calcium salt addition to the separator feed is sometimes utilized to maintain a high calcium ion content on the resin, but this increases the ash load to the polishing mixed beds by a small amount.

Polishing Process

The fractionation system product fraction contains 85-90% fructose and can also contain ppm quantities of impurities such as color bodies, weak acids, HMF, residual ash and protein. The level of impurities can vary as a result of the fractionation system operating conditions or performance of upstream refining unit operations. To produce a heat stable product of consistently high quality (See Table L for 55 HFCS specs), the syrup can be polished by passage through a single bed of strong base anion resin or a mixed bed of strong acid cation/strong base anion resin. The syrup can be treated as a 90% fructose solution or, after blending, as a 55% fructose solution.

A salt form strong base anion resin will remove color bodies to produce a heat stable product. These strong base anion polishers can be operated with a single bed in service while the second bed of the pair is in regeneration or on standby. Salt regeneration with occasional caustic cleanup is sufficient to remove color. For complete removal of weak acids, HMF, ash and protein in addition to color, a mixed bed of hydrogen form strong acid cation resin and hydroxide form strong base anion resin (Type II) is utilized. In order to more closely match the capacity of the cation and anion resins, a 50% excess of strong base anion resin volume is required to approximately equalize the number of anion exchange groups with the number of cation exchange groups in the mixed bed column since the capacity per unit volume of the strong base anion resin may be 40-50% lower than the cation resin. Thus, the mixed bed resin volume will typically be 60% anion and 40% cation.

Some degradation of the HFCS can occur in the mixed bed due to contact with the high pH strong base anion resin. Fructose will convert to psicose at elevated pH, so to limit the amount of fructose lost in the mixed beds the velocity of the syrup is kept high enough to minimize contact time with the anion without affecting the kinetics of the mixed bed exchange.

In service, syrup passes down through one bed of homogeneously mixed cation and anion resin while the second column of the pair is in regeneration or on standby. The primary function of a polisher is color removal and service is terminated based on color leakage. The conductivity of the mixed bed effluent at breakthrough will be on the order of 1-2 $\mu\text{S}/\text{cm}$. Upon exhaustion of a polisher, the service unit is sweetened off and regenerated while the standby unit is sweetened on and put into service.

To regenerate an exhausted mixed bed unit, syrup is displaced from the resin bed with water, the intermixed resins are separated from each other due to density difference with a backwash and each is then chemically regenerated. The cation resin is stripped of protein and ash with a dilute hydrochloric acid solution while the strong base anion resin is stripped of color bodies, weak acids, ash and HMF with a dilute caustic solution.

The regeneration is accomplished in a stepwise sequence as follows:

1. **Sweeten Off:** Syrup is displaced from the bed of intermixed cation/anion resin by introduction of demineralized water into the feed distributor which pushes the syrup down through the bed and out to sweetwater collection. This step is terminated when the effluent sweetener concentration has decreased to 0.1-0.5% dry solids.
2. **Blowdown:** The water in the freeboard space between the feed distributor and backwash collector is displaced by pushing the water down through the bed with pressurized air until the liquid level has reached the feed distributor point. Evacuation of the freeboard space results in less back pressure and hence a more rapid rise of the bed of mixed resin during the initial minutes of the backwash step. This provides for a better separation of the more dense cation resin from the lighter anion resin.

3. **Backwash/Separation:** Process water is passed upflow through the bed of mixed resins to achieve a 100% fluidized expansion of the resin bed and accomplish a separation of the cation from the anion resin in addition to removing resin fines and particulates from the bed. Owing to specific gravity differences, the anion resin will be fluidized to a greater height in the vessel and settle at a slower velocity than the heavier cation resin. Thus, the cation and anion resin separate into two discrete beds with the resin interface occurring at the same level in the vessel as the interface takeoff distributor.
4. **Chemical-In Anion:** The dilute caustic solution continues to enter the feed distributor located above the separated resin bed and passes down through the anion bed and out the interface collector while a simultaneous flow of deionized water enters the bottom distributor and passes up through the cation resin and out through the interface collector with the spent caustic solution. The 50% excess volume of strong base anion resin requires a regenerant chemical volume in excess of the cation regenerant volume. In order to ensure equal contact times per unit volume of resin, regeneration of the anion resin begins prior to the cation resin.
5. **Chemical-In Cation/Anion:** The dilute caustic solution continues to enter the feed distributor located above the separated resin bed and passes down through the strong base anion resin and out the interface collector while a simultaneous flow of dilute hydrochloric acid enters the bottom distributor and passes up through the cation bed and out the interface collector with the spent caustic solution.
6. **Slow Rinse Cation/Anion:** Demineralized water streams simultaneously enter the feed and bottom distributors and pass down through the anion and up through the cation respectively and mix as they exit the column through the interface collector. The demineralized water displaces the regenerant chemicals from the resins at a rate which ensures that all of the resin receives an adequate regeneration contact time.
7. **Fast Rinse Cation/Anion:** Demineralized water streams simultaneously enter the feed and bottom distributors and pass down through the anion bed and up through the cation bed respectively and out the interface collector to rinse out the residual chemicals from the bed. Due to the excess volume of strong base anion resin, and its higher rinse requirement per cubic foot, it is desirable to rinse the anion resin at a higher rate than the cation resin.
8. **Blowdown:** Pressurized air enters the top head of the vessel and pushes the water in the freeboard space down through the resin until the liquid level reaches the feed distributor point. Lowering the liquid level prevents water and resin from being carried out the vent nozzle during the subsequent resin mixing steps.
9. **Air/Water Mix:** An air/water mixture enters the bottom distributor and flows up through the bed producing a churning action which mixes the resin. The air escapes through a vent while the added water raises the liquid level in the column slowly. The water provides a strong initial hydraulic force to slightly fluidize the resin so the churning air bubbles will easily effect a mixing of the cation and anion resins.
10. **Air Mix:** After the churning action is initiated with the air/water combination, the water flow rate is terminated and the resins continue mixing through the action of the air bubbling up from the bottom distributor and escaping out through the vent.
11. **Air Draindown:** In order to settle the well-mixed resins without incurring a separation due to differences in terminal settling velocity, air continues to be introduced into the bottom or interface distributor with the vent valve closed while water is withdrawn from either the bottom or interface distributor.
12. **Fill:** Demineralized water enters the top distributor to completely fill the mixed bed vessel with water.

13. **Service Rinse:** Demineralized water enters the top distributor and passes down through the freeboard space and through the resin until the effluent conductivity decreases to less than 1 microsiemen/cm. The speed at which the conductivity declines and the value attained serves as a check against the quality of the regeneration.
14. **Sweeten On:** Syrup enters the feed distributor under a demineralized water dome and passes down through the intermixed resin bed and out the bottom collector until the effluent dry solids concentration equals 95% of the feed solids concentration.

The following mixed bed polisher sequence chart lists the various process modes and typical parameters:

HFCS Mixed Bed Polisher Sequence

OPERATION	SOLUTION	FLOW RATE [BED VOLS/HR]	VOLUME [BED VOLS]
1. SWEETEN OFF	H ₂ O	2.0-4.0	1.5-3.0
2. BLOWDOWN	AIR	4.0	1.0
3. BACKWASH	H ₂ O	0.9 ft/min	2.0
4. CHEMICAL-IN	ANION	4% NaOH	1.0
		H ₂ O	1.0
5. CHEMICAL-IN	CATION	7% HCl	1.33
	ANION	4% NaOH	1.33
6. SLOW RINSE	CATION	H ₂ O	2.0
	ANION	H ₂ O	2.0
7. FAST RINSE	CATION	H ₂ O	5.0
	ANION	H ₂ O	5.0
8. BLOWDOWN	AIR	4.0	1.0
9. AIR/WATER MIX	AIR	5-6 scfm/sq ft	10 min
	H ₂ O	0.24 ft/min	
10. AIR MIX	AIR	5.5 scfm/sq ft	10 min
11. AIR DRAIN DOWN	AIR	5.5 scfm/sq ft	1-5 min
12. FILL	H ₂ O	2.0-4.0	1.0
13. SERVICE RINSE	H ₂ O	2.0-4.0	0.5-1.0
14. SWEETEN ON	30-55% DS SYRUP	2.0-4.0	1.0
15. SERVICE	30-55% DS SYRUP	2.0-4.0	35-100

Mixed Bed Polisher Equipment

The mixed bed polishing equipment typically consists of a pair of food grade rubber lined pressure vessels containing four sets of distributors. The distributors are constructed of stainless steel and CPVC piping wrapped with polypropylene screen and clamped to rubber lined steel support bars. The vessels contain a flat false bottom for resin support and sight windows in the sidewall for visual inspection of backwash expansion, separation and mixing of resins during regeneration.

The piping manifolds utilize polypropylene lined carbon steel, rubber lined carbon steel or stainless steel pipe. Control of fluid direction is accomplished with lined and stainless steel plug valves, diaphragm valves or butterfly valves.

Ion Exchange Resins

Resin Specifications

Process performance and operating life of resins for any application are optimized through specification of the resin characteristics which affect them. They cannot, however, be independently optimized. Resin characteristics having a positive effect on operating capacity can have a negative effect on the useful life of the resin. Additionally, a set of characteristics optimized for one particular syrup refining application may not perform effectively for purification of another type of syrup solution. Optimization of resin characteristics for each type of application is achieved through specification of resin manufacturing variables. These variables include total capacity, salt splitting capacity, moisture, macroporosity, microporosity, average particle size, particle size uniformity and others. These characteristics affect the resin performance in the following ways:

1. Total capacity is a general indicator of operating capacity, but the two are not directly proportional. For a new resin in a syrup demineralization application, the operating capacity is typically 50-60% of the total theoretical capacity. The resins are limited by equilibrium and kinetic constraints from achieving their total theoretical capacity in typical syrup refining operations.
2. Salt splitting, or strong base, capacity affects the physical stability of weak base anion resins by limiting the amount of reversible swelling which occurs upon exhaustion and also affects the resin's moisture level.
3. Moisture levels inside the resin beads affect the rate of diffusion of soluble ions and molecules into the resin bead where exchange or adsorption can occur. A higher moisture content in a resin improves the rate of diffusion.
4. Macroporosity also facilitates diffusion into and out of the interior of the resin bead. Large organic molecules have greater difficulty diffusing out of gel resins, thus resulting in a higher degree of fouling of these resins. Additionally, macroporosity imparts flexibility to the resin bead which gives it greater physical durability when subjected to osmotic shock or mechanical stresses. Gel resins, not having macroporosity, are more susceptible to osmotic shock and mechanical attrition.
5. The microporosity of the structure is determined by the degree of crosslinking and affects both ionic and molecular selectivity due to steric hindrance and water adsorption.
6. Particle size affects the kinetics of ion exchange. Smaller resin beads have shorter film diffusion and particle diffusion path lengths for ions and molecules to travel.
7. Uniformity of particle size affects both pressure drop through the bed and sharpness of the adsorption and desorption wavefronts. As the particle size distribution widens, the adsorption and desorption bandwidths also increase.

Corn Sweetener Refining Resins

Demineralization

PUROLITE RESIN	TYPE	FEATURE	TOTAL CAPACITY	MOISTURE	STRONG BASE	SWELL	MAX TEMP	SIZE RANGE
A-103S	WBA, Macro	Standard	1.6 Eq/L	48-55%	10-15%	20%	140°F	300-1200 μ
PFA-103S	WBA, Macro	Uniform Size	1.6 Eq/L	48-55%	10-15%	20%	140°F	400-700 μ
A-133S	WBA, Macro	High Capacity	1.9 Eq/L	43-49%	10-15%	20%	140°F	300-1200 μ
A-148S	WBA, Macro	No Strong Base	1.6 Eq/L	40-45%	<2%	18%	180°F	300-1200 μ
C-150S	SAC, Macro	Standard	1.8 Eq/L	48-53%	n/a	5%	250°F	300-1200 μ
PFC-150S	SAC, Macro	Uniform Size	1.8 Eq/L	48-53%	n/a	5%	250°F	400-700 μ
C-160S	SAC, Macro	Protein Removal	2.4 Eq/L	35-40%	n/a	4%	250°F	300-1200 μ

Color, Taste and Odor Removal

PUROLITE RESIN	TYPE	FEATURE	CAPACITY	MOISTURE	MAX TEMP	SIZE RANGE
MN-500	Adsorbent, Macro	Taste, Odor, Color	0.9 SAC Eq/L	52-57%	230°F	300-1200 μ
MN-150	Adsorbent, Macro	Color Taste, Odor	0.1-0.2 WBA Eq/L	52-57%	230°F	300-1200 μ

Fractionation

PUROLITE RESIN	TYPE	APPLICATION	MOISTURE	AVG. SIZE
PCR-642 Ca	SAC, Gel	Fructose, Polyols	59-61%	320 μ
PCR-642 Na	SAC, Gel	Dextrose, Maltose	59-61%	320 μ
PCR-631 Ca	SAC, Gel	Fructose, Polyols	59-61%	210 μ
PCR-631 Na	SAC, Gel	Dextrose, Maltose	59-61%	210 μ

Mixed Bed Polishing

PUROLITE RESIN	TYPE	TOTAL CAPACITY	MOISTURE	STRONG BASE	MAX TEMP
A-510S MB	SBA(II), Macro	1.25 Eq/L	44-51%	1.15 Eq/L	105°F
C-150S MB	SAC, Macro	1.8 Eq/L	48-53%	n/a	200°F

Higher Performance Weak Base Anion Resin

Purolite A-133S has been developed to provide 20-25% more throughput per cycle than current commercial weak base anion resins using the same regeneration procedure, resulting in savings which EXCEED the cost of the resin itself. (See Figure L)

Purolite A-133S gives superior performance in glucose, dextrose, fructose, polyols, maltodextrin and other hydrolyzate syrups.

Impact on Regeneration Costs

A throughput increase of 20-25% per service cycle equates to 20-25% less frequent regeneration with consequential savings in chemicals, sweetwater evaporation, water and waste costs.

	DOSE	SAVINGS @ 20%	SAVINGS @350 CYCLES
NaOH	4.0 lbs/cf	0.80 lbs/cf	280 lbs/cf
Sweetwater Evaporation*	15 gals/cf	3.0 gals/cf	1050 gals/cf
Water & Wastewater**	70 gals/cf	14.0 gals/cf	4900 gals/cf

*Includes sweeten on and sweeten off dilution

**Includes backwash, chemical dilution, slow rinse and fast rinse water

Additional advantages of Purolite A-133S that may be realized depending on operating plant requirements are:

- Higher production rate with the same cycle time as current commercial resins.
- Increased cycle life from a greater number of cycles before fouling reduces the throughput per cycle to the minimum level.
- Large bead size providing minimal pressure drop and higher flow rates.
- Excellent color removal.
- Superior osmotic shock resistance reducing attrition losses.

Life Expectancy

The useful operating life of resin is limited by the physical and chemical degradation and fouling which occurs as a result of the particular operating conditions it is subjected to. These include service and regeneration temperatures, syrup dry solids concentration, organic load, cleanup regeneration frequency, type of regenerant chemical and selection of the criteria for the point of replacement. The table below lists the typical life cycle range for ion exchange resins in sweetener refining:

Resin Life Expectancy

RESIN	TYPE	TYPICAL LIFE [No. of Cycles]
A-103S, A-123S, A-133S	WBA	350-750
C-150S	SAC-MACRO	1000-2000
A-510S	SBA-TYPE II	200-500
PCR 642 Ca	FRACTIONATION	5-10 years

Degradation

Successful ion exchange refining of corn sweeteners will result in degradation of the resins in a number of ways. The predominant mechanism of degradation will differ depending on the type of resin, type of service and choice of regenerant chemical. The table below lists the predominant mechanisms of degradation for each type of resin product:

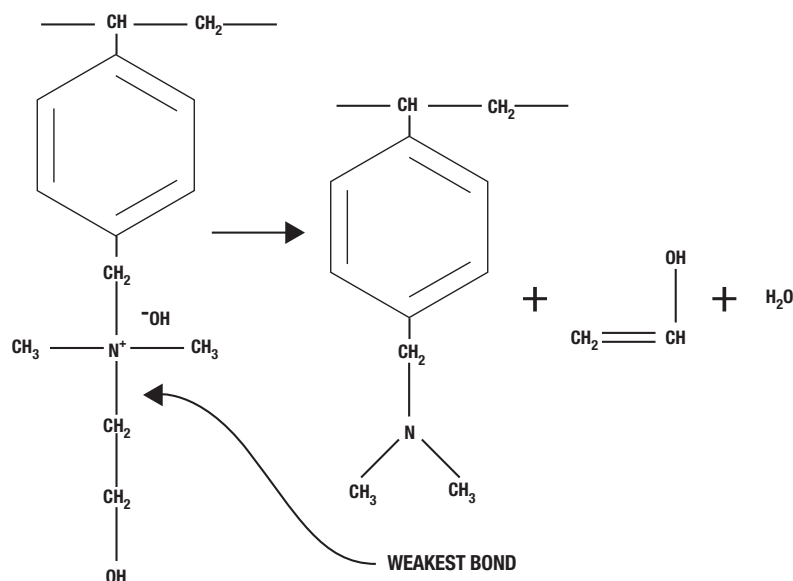
Degradation Mechanisms

RESIN	MECHANISM	CAUSE
Cation	Fouling	Irreversible Protein Adsorption
	Oxidation	Dissolved Oxygen in Feed
WB Anion	Fouling	Irreversible Organic Acid Adsorption Cation Oxidation Products
	Thermal	High Operating Temperature Rapid Temperature Change High Rinse Temperature
	Osmotic Shock	Rapid Change of Electrolyte Concentration Rapid Exchange of Ions
	Mechanical Attrition	Resin Abrasion High Pressure Drop Across Bed
	Physical Loss	Backwash Overfluidization Leaking Distributor Screens
	SB Anion-Type II	Thermal
Fractionation	Fouling	Organic Acid Adsorption
	Oxidation	Dissolved Oxygen in Feed or Desorbent
	Mechanical Attrition Osmotic Shock	Resin Abrasion Rapid Change in Syrup Solids Concentration
	Breakup	Re-wetting dried resin with water only Rapid thawing of frozen resin

In addition to the chemical mechanisms of degradation, the resin is also subject to breakdown through mechanical attrition and operational problems such as resin retaining screen failures and overfluidization during backwash.

When a resin is in static equilibrium, the chemical bonding forces holding the copolymer network together are balanced by the osmotic swelling pressure from hydration of the functional groups which are attached to the polymer network. A rapid change in the ionic or syrup concentration of the solution will cause an osmotic pressure that is greater either inside or outside of the bead which cannot be relieved through solvation. This will result in stresses on the polymer backbone that can fracture and break resin beads. A rapid exchange on the resin of one type of ion with another ion of greatly differently hydrated radius will cause the resin to rapidly shrink or swell. These osmotic shock forces occur during each ion exchange or fractionation cycle during sweetening on, sweetening off and regeneration.

Fouling of resins can occur as a result of irreversible adsorption of organic molecules or precipitation of salts within the resin matrix. When large molecular weight organic compounds become sorbed in the resin bead they can block the pores from further diffusion of ions or bind to an exchange site and prevent utilization of resin capacity. Organic acids with carboxylic groups can become irreversibly sorbed onto the resin due either to a high affinity or to a stereo-chemical effect. The carboxylic group will pick up sodium ions from a caustic regenerant solution which will hydrolyze only very slowly off the resin during the fast rinse. This "caustic cling" can result in an extended rinse requirement that is several times higher than new resin rinse requirements. The increase in rinse requirement becomes a measure of the degree of fouling. Precipitation of magnesium hydroxide can occur within a cation or anion resin bead causing high ion leakage and low capacity. The magnesium hydroxide will precipitate in a cation resin undergoing a cleanup regeneration with caustic if it is not first acid stripped. Magnesium hydroxide precipitation can occur in an anion resin if the rinse water is not at least softened or if the cation resin is overrun during service.



Hofmann degradation of strong-base resins. (Type II Strong Base Anion)

When the temperature of the resin during service or regeneration becomes excessive, the rates of the degradation reactions which result in loss of functional groups increase to a significant level. The recommended maximum operating temperatures to minimize degradation of the sweetener refining resins are listed in the resin specifications table on page 17. Product degradation, rather than resin degradation, will limit the cation resin operating temperature, but the strong base anion resin will start to degrade significantly before the syrup. The Type II strong base anion resin in the polishing mixed beds is the least thermally stable resin. The most thermally susceptible bond on a Type II strong base anion resin is the bond holding the alcohol group to the nitrogen atom.

If the bond undergoes cleavage, called a Hofmann degradation reaction, the particular functional group of the Type II strong base anion which has lost its alcohol group will become a tertiary amine with weak base exchange properties. Thus, the functional group will no longer split neutral salts and will adsorb colored compounds to a lesser degree. The other degradation product is vinyl alcohol which rearranges to acetaldehyde.

Troubleshooting

While most operational problems with ion exchange systems are the result of mechanical failure or improper conditions of the ion exchange equipment and support systems, there are also a number of process problems which can arise that can be more difficult to diagnose and correct. Listed below is a table of some common ion exchange process related problems:

Diagnosing Ion Exchange Problems

CONDITIONS	CAUSES
1. Low Throughput	Increase in the feed ash, color or dry solids concentration. Poor fluid distribution or collection. Incomplete regeneration. Low resin volumes. Fouled resins. Inaccurate volume totalization. Microbiological growth in resin bed.
2. High Pressure Drop	Resin fines not being backwashed out. Plugged distributors or strainers. Foreign particulates such as carbon, diatomaceous earth or microbiological growth plugging bed or laterals. High syrup viscosity due to a drop in temperature or increase in dry solids concentration.
3. Excessive Rinse	Organic fouling. High rinse or service temperature has caused thermal degradation. Poor fluid distribution or collection.
4. Resin Breakup	Poor rinse water quality. Excessive service pressure drop across resin bed. Osmotic shock from rapid volume change or electrolyte concentration change.
5. High Conductivity or pH in Service	Incomplete regeneration. Bleed through from leaking service or chemical valve. Poor fluid distribution or collection. Resin fouled or degraded. Excessive service flow rate. Cross mixing of cation and anion resins.

Macronet Adsorbent Resins

Starch hydrolyzate plants around the world are utilizing high surface area synthetic adsorbents to replace granular and powdered activated carbon for removal of color, taste, odor, HMF and other impurities from sweetener solutions. The Macronet line of chemically regenerated styrenic adsorbents offers economic, aesthetic and ease of process advantages for replacing carbon in the production of bottler's quality syrup.

Organic impurities are attracted and held to adsorbents by surface energies such as Van der Waals forces. Since adsorption is a surface phenomenon, the Macronet adsorbents are manufactured with large surface area in the range of 800-1100 square meters/gram. But molecules are three dimensional and not flat, so it is important for the surface area to conform to the molecular size of the impurities being adsorbed in order for the collective surface energy to be large enough to retain them. Thus, the surface area must be employed in micropores which are small enough to form an "adsorption cavity". Most of the surface area of Macronet adsorbents are contained in adsorption cavities of less than 20 Angstroms diameter. Macronet also contains a significant population of large transport pores which facilitate rapid diffusion from the bulk fluid into the microporous region where adsorption occurs.

The hydrophobic styrene/divinylbenzene matrix of the Macronet will readily adsorb nonpolar hydrophobic impurities. Since many of the impurities are polar or even ionizable molecules, the presence of hydrophilic ion exchange functional groups on the matrix improves the range of impurities which can be removed by attracting more hydrophilic compounds. The hydrophilic functional groups also improve the ease of regeneration of the adsorbent.

Macronet Operating Options

A. Color Adsorber for Non-demineralized Syrups	Macronet MN-150 replaces conventional carbon powdered treatment of glucose syrups. Expensive and dirty powdered carbon and carbon filters are replaced with a simple chemically regenerated unit operation which produces no solid discharge to handle.
B. Taste and Odor Polishing	The primary and secondary ion exchange pairs remove the vast majority of impurities, leaving the Macronet MN-500 available to remove the difficult taste and odor impurities and polish the color even further.
C. Color, Taste and Odor Polishing	A layered bed of MN-150 over MN-500 offers improved color and heat color removal in addition to taste and odor polishing.
D. Color, Taste and Odor Polishing with Enhanced pH and Conductivity Stability	The layered bed of MN-150 over MN-500 is air mixed prior to service to offer mixed bed quality pH and conductivity.
E. Color, Taste and Odor Polishing with Enhanced pH Stability	A layered bed of MN-150 over a weak acid cation resin is air mixed prior to service to offer better pH stability.

Service and Regeneration Sequence Purolite MN-150

STEP	SOLUTION	TEMP °C	FLOW BV/hr	VOLUME BV	TIME MIN	COMMENTS
Service	Syrup	40-60	2-5	30-200		
Sweeten off	DI H ₂ O	40-60	4	2	30	Downflow
¹ Backwash	DI H ₂ O	30-60	<u>2.5 gpm</u> sq ft	1.5-2.0	30	Upflow 50% Expansion
² NaOH In	1N NaOH	40-60	1	1.5	90	Downflow
Slow Rinse	DI H ₂ O	40-60	2	2	60	Downflow
^{3,4} HCl In	0.1N HCl	40-60	2	3	90	Upflow
Slow Rinse	DI H ₂ O	40-60	2	2	60	Upflow
⁵ Fast Rinse	DI H ₂ O	40-60	4	4	60	Downflow

1. For MN-500, the backwash flow rate should be increased to 6.0 gpm/sq ft.
2. For HMF removal, the temperature should be increased to 110°C and the first 1 BV is allowed to soak for 2 hours.
3. For MN-500 regeneration, the HCl concentration should be increased to 0.3 N.
4. For a 1/3 MN-150 and 2/3 MN-500 layered bed, the HCl concentration should be increased to 0.2 N.
5. For mixed bed operation, an air mix follows the Fast Rinse.

PUROLITE: About Us

Purolite's primary focus is resins for Ion Exchange; Catalysis & Specialty Applications.

Purolite Corporation is a privately owned company, established in 1981. Since that time, Purolite has grown to become a leading supplier of specialty resins for the ion exchange, catalyst and specialty applications markets world-wide.

Purolite has global manufacturing with factories in Philadelphia, USA, Victoria, Romania, and Hangzhou, China coupled with an established network of sales offices, distributors and agents located close to our customers. Purolite continues to develop its manufacturing capacity, product quality and innovation through investment in new equipment and improved research facilities.

Purolite has the largest commitment to R&D of any specialty resin producer globally, and we strive to develop products that will give our customers a competitive edge. Our ability to quickly custom configure a solution that fits each customer's requirements is what sets Purolite apart from the competition.

Our research and development is aimed at perfecting existing products, discovering new products for existing applications and finding new applications for our core technologies. Collaboration with our customers on specific needs is key to our success.

Purolite is committed to developing products that have the minimum possible environmental impact.

With our market-leading manufacturing capacity, broad product range and record of innovative research, Purolite has a unique commitment to the specialty resins marketplace.

Purolite manufactures products which are widely used in; pharmaceutical production; electronics (where our low TOC resins meet the demand for Ultra Pure water for manufacturing semiconductors); chemical and refining industries; trans-esterification and catalysis; the food industry: metals extraction and chelation; electroplating; nuclear power generation; sugar and sweetener refining.

Special Applications

For some time, the sugar, sweetener and food industries have been using ion exchange resins for different types of decalcification, decolorization, demineralization, taste and odor removal, chromatography and ion exclusion. Products such as PUROLITE C-100S, C-155S, C-150S, A-500PS, A-510S, A-103S, A-860S, MN-150, MN-500, and PUROLITE Chromatographic Resins (PCR's) have been widely used for these applications. Dairy processes, fruit juices and wine products also benefit from this unique treatment by ion exchange. PUROLITE's manufacturing plant in Philadelphia is a world leader in the field of chromatography. Their product line of PCRs are utilized worldwide to purify and separate dextrose, fructose, beet molasses, polyols and other sweeteners. PCR products are tailor-made to exacting specifications, meeting the demands of these industries.

The quality of PUROLITE ion exchange resin conforms with the stringent purity requirements of the pharmaceutical industry, which frequently uses resins and absorbents in its processes (extraction, separation, purification and concentration), and also in galenic pharmacy (drug carriers). The resins used (in bead, granular or powder form) have either strong or weak functional groups or have absorbent properties.

Enzyme fixation currently involves specific ion exchange resins. PUROLITE resins now play a major role in all these specialty fields. PUROLITE works along with pharmaceutical companies in both research and production to optimize products for their specific applications.

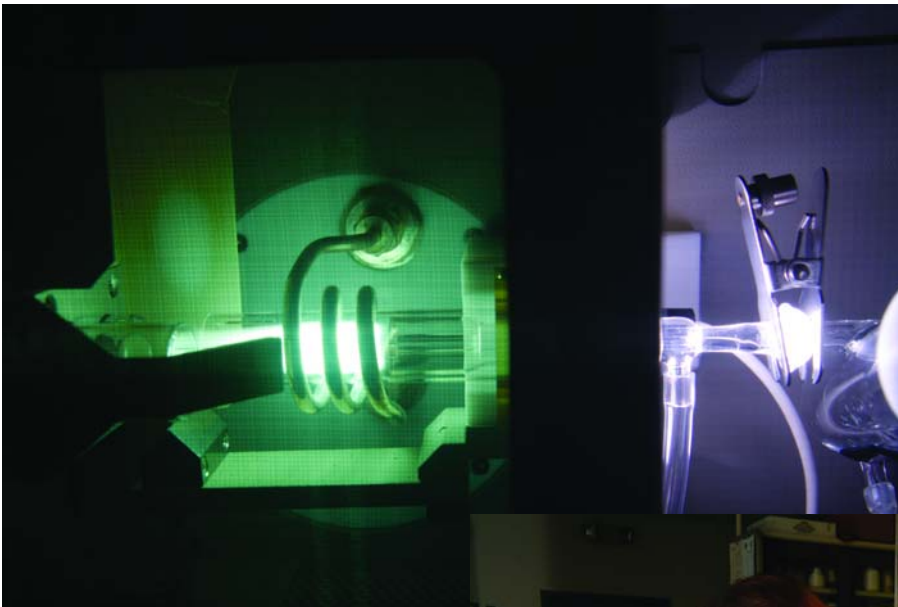
The chemical industry also uses ion exchange resins in many applications such as aldehyde and alcohol purification, separation and extraction of various chemicals.

Focusing its resources on ion exchange alone, PUROLITE is uniquely equipped to solve its customers' most complicated problems. This commitment, along with a dedication to excellence, has brought PUROLITE to a position of world leadership in ion exchange.

Sophisticated analytical equipment and techniques are employed during manufacture to ensure optimum performance of the resin. In addition, this equipment is used to troubleshoot issues and analyze resin performance to develop optimum customer solutions.



ICP and AA Spectrophotometers

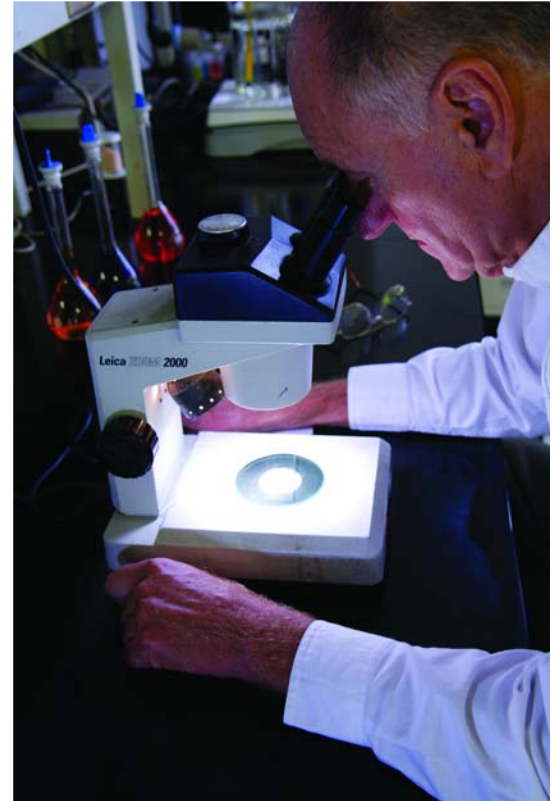


ICP Spectrophotometer

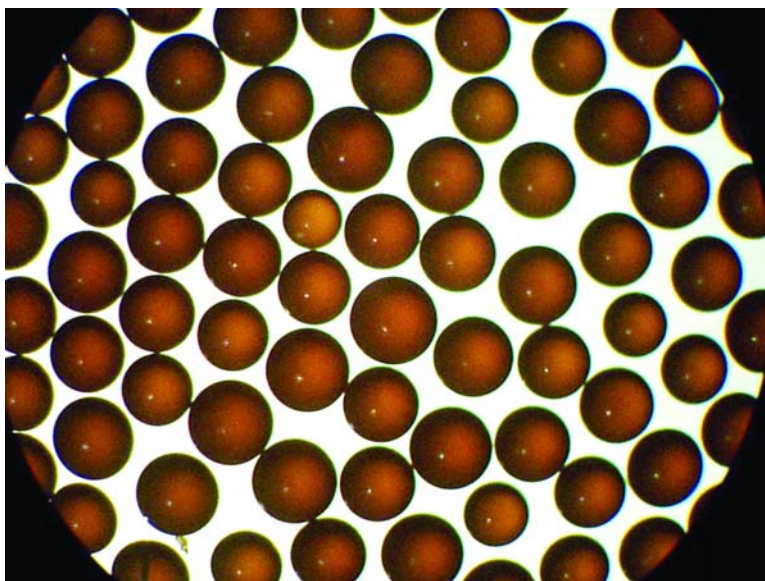


Bench Scale Studies

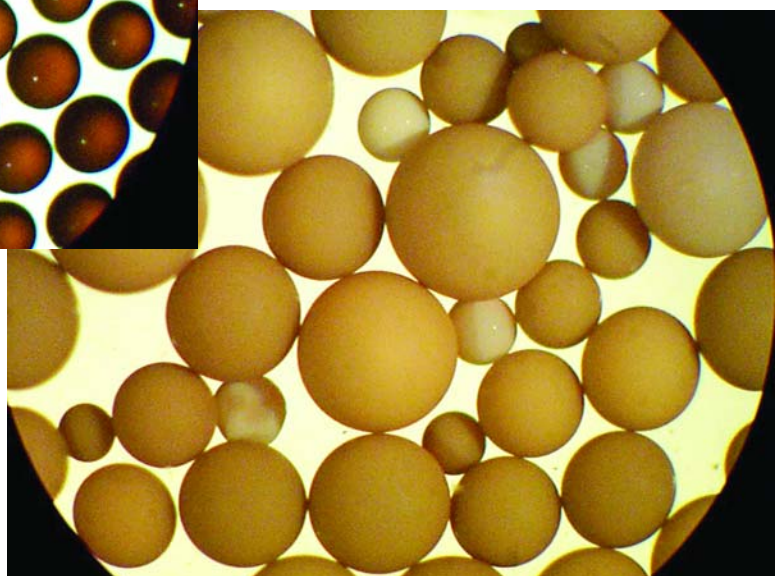
A key tool in investigating the health of a resin is the microscope. Customers resins are routinely sent to Purolite Laboratories for evaluation of performance and expected use life.



Microscope Resin Evaluation



Gel Ion Exchange Resin



Macroporous Ion Exchange Resin



Bulk Tanker Truck Resin Delivery



Packaging Options

PuroLite offers a range of packaging options from bulk tanker delivery through super sacks, fiber drums and small boxes and bags to suit individual customer requirements.



Packaging Plant

Figure A: Typical Service Cycle

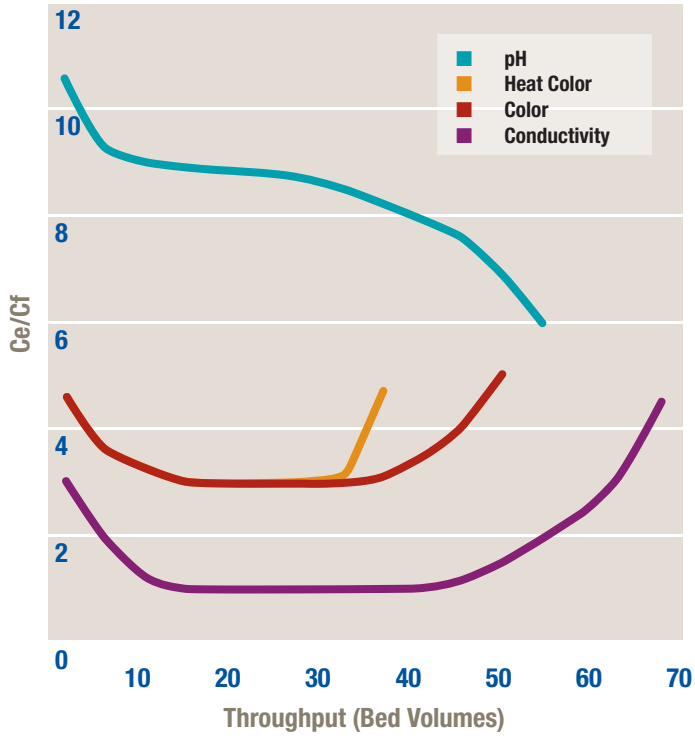


Figure B: Cation Leakage

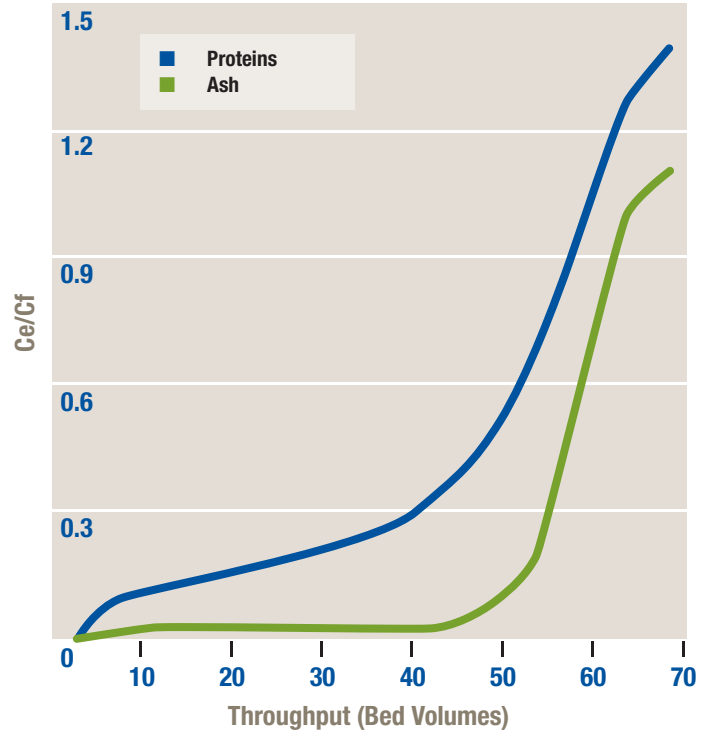
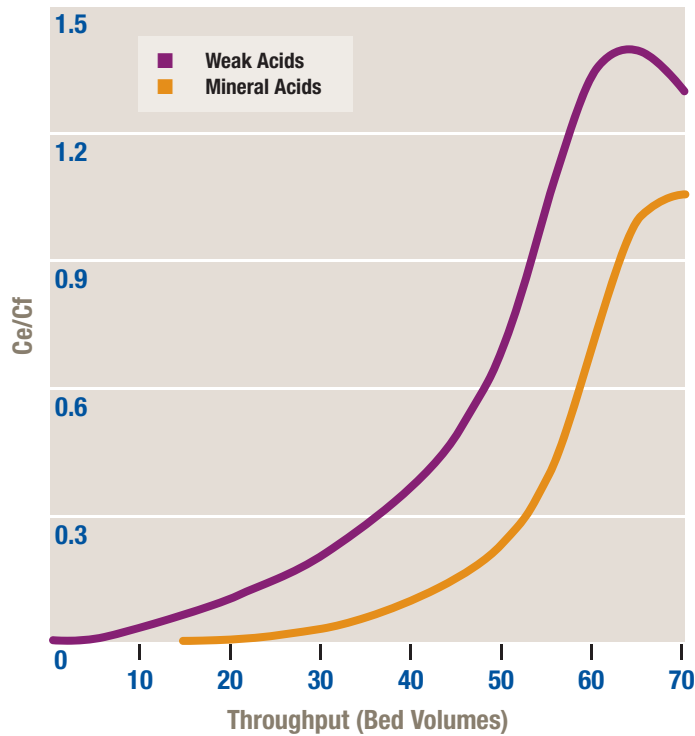


Figure C: Anion Leakage



C_e = Concentration in effluent
 C_f = Concentration in feed

Figure D: Sweeten-off

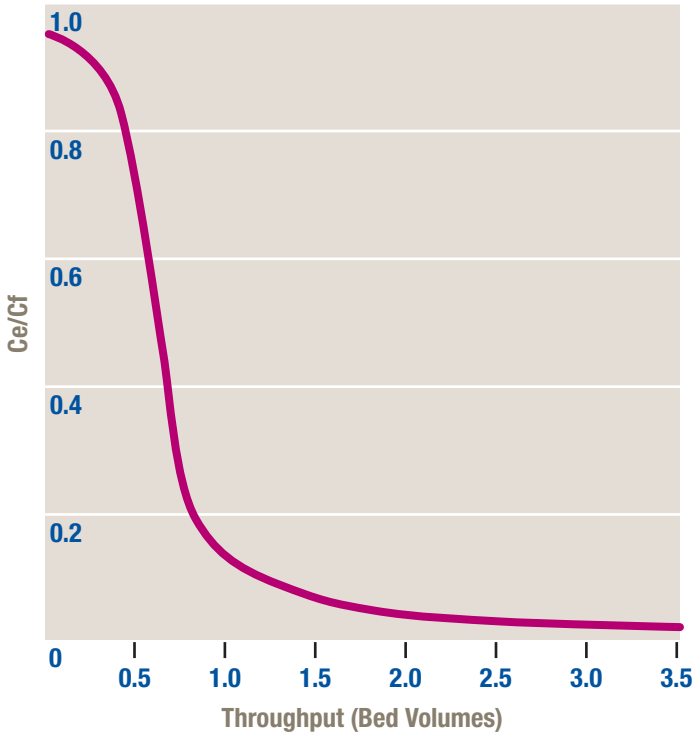


Figure E: Sweeten-on

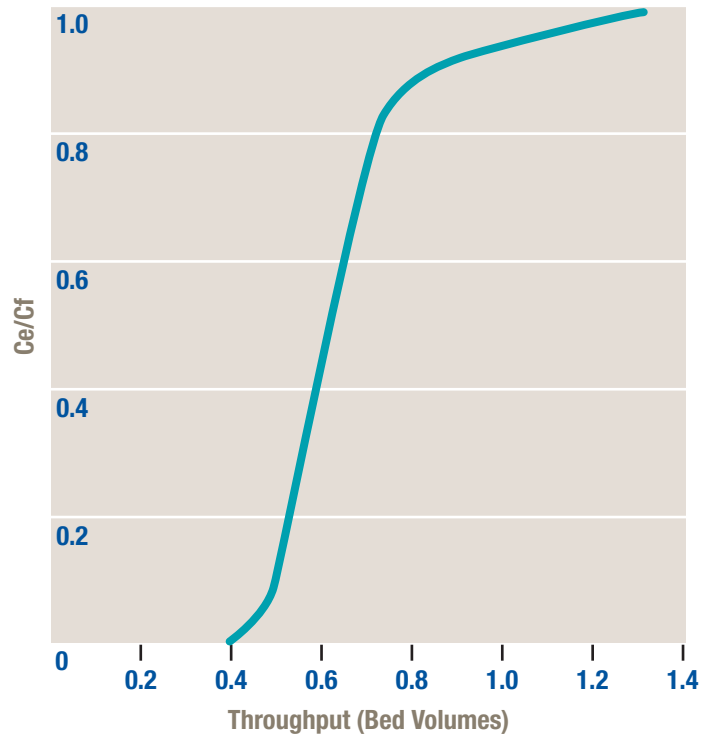


Figure F: Cation Operating Capacity

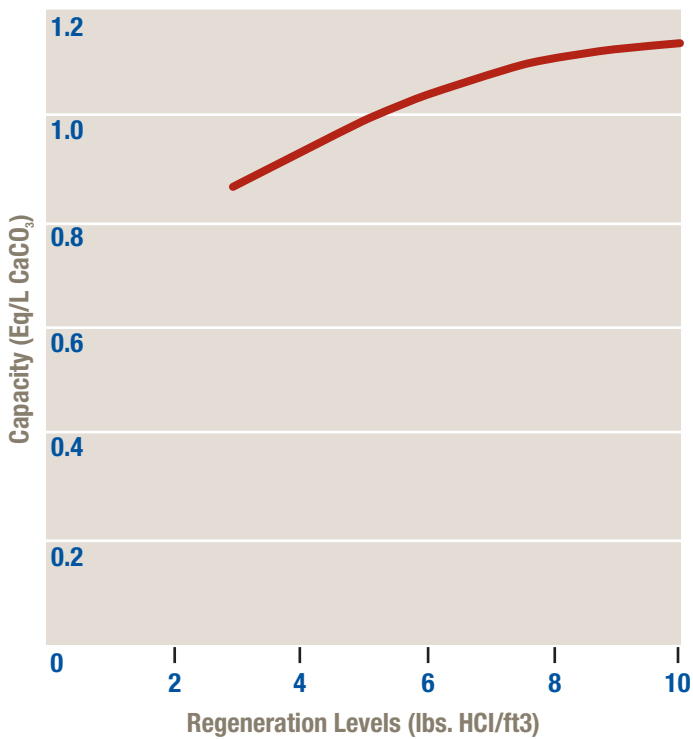


Figure G: Conductance vs. NaCl Concentration in Syrup and Water

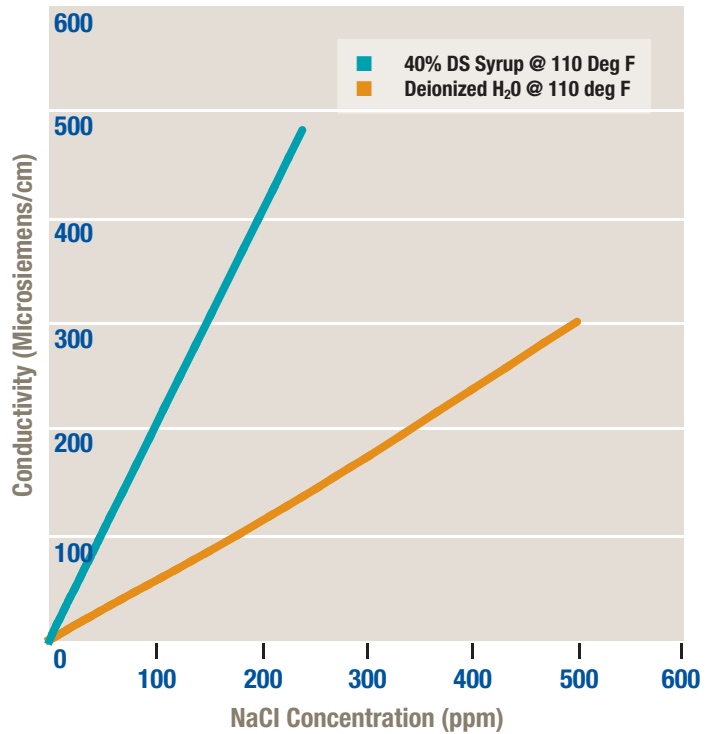


Figure H: C-150S Backwash Expansion

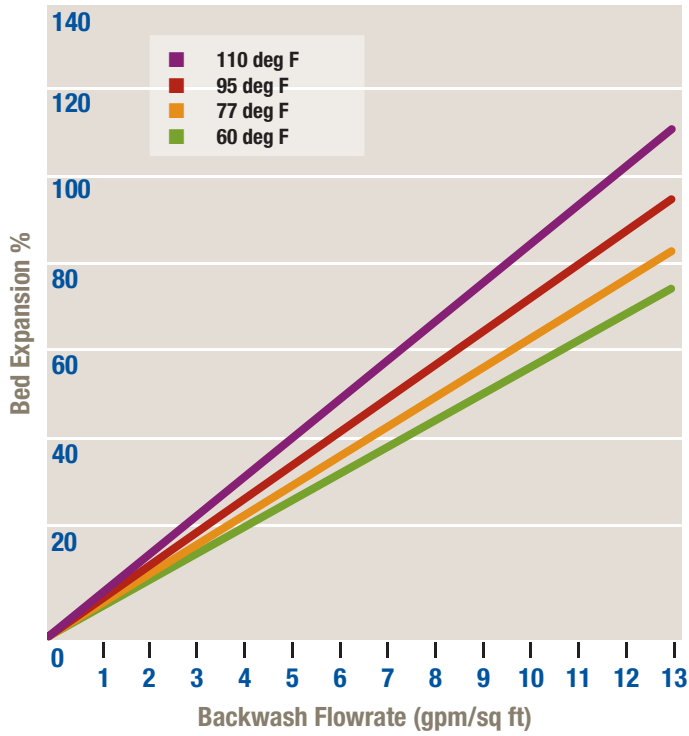


Figure I: A-103S Backwash Expansion

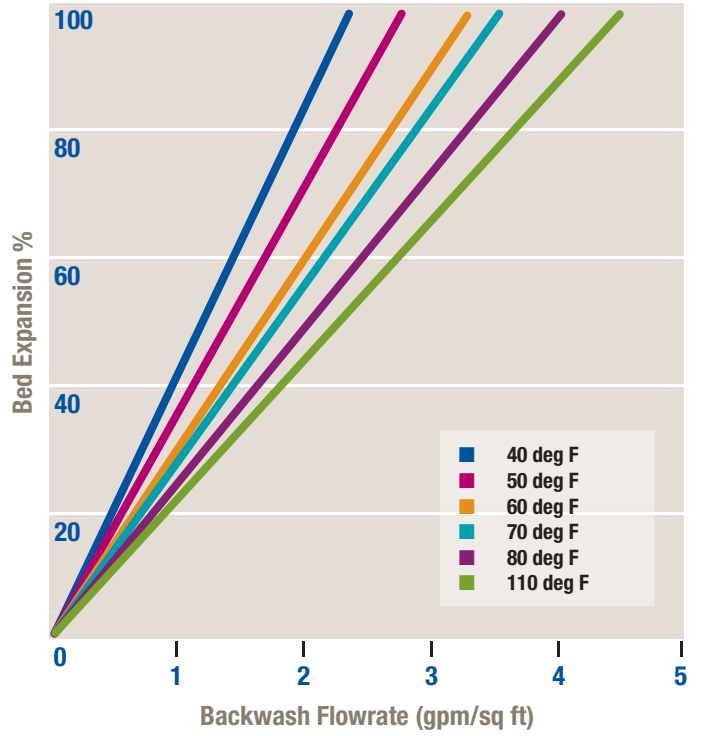


Figure J: C-150S Pressure Drop in Syrup

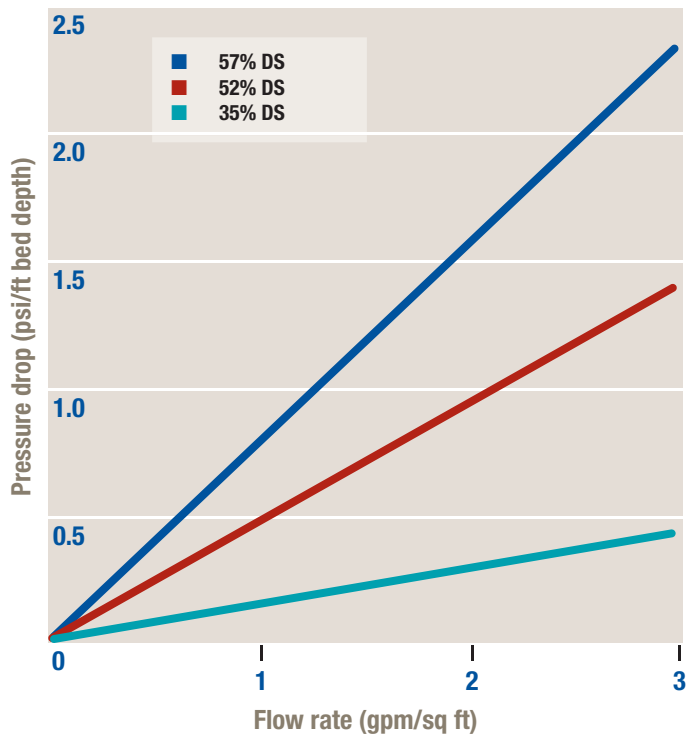


Figure K: A-103S Pressure Drop in Syrup

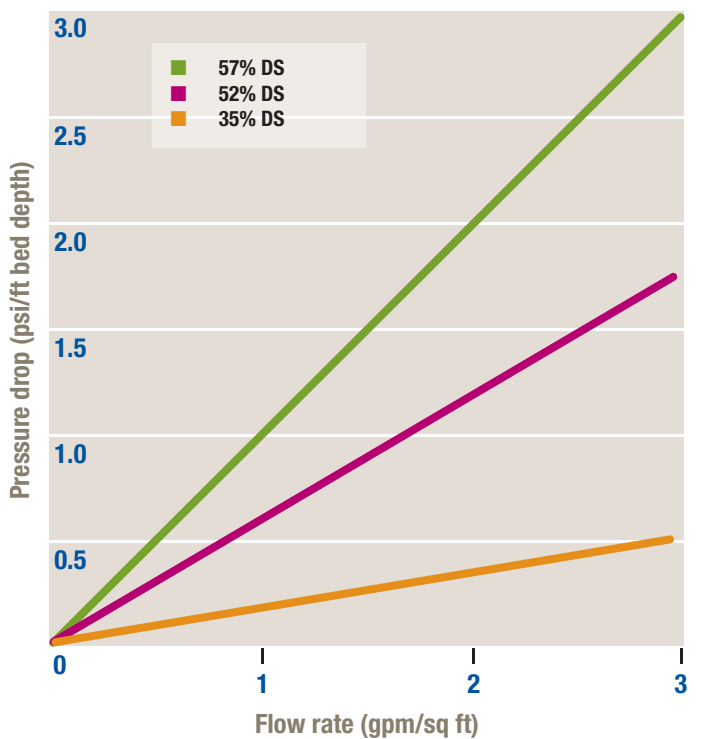


Figure L: High Capacity Weak Based Anion Resin Comparison

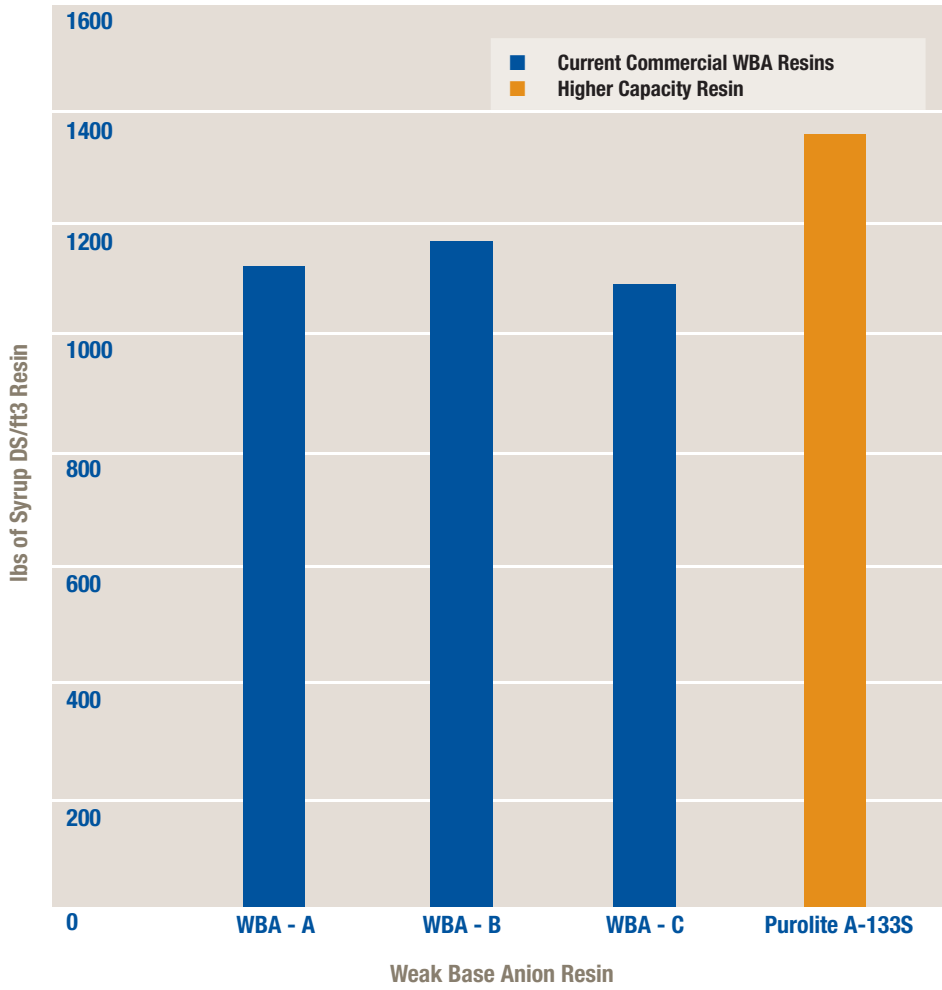


TABLE A: CONDUCTANCE VS. TOTAL DISSOLVED SOLIDS

Conductivity of various compounds at 25°C [Microsiemens/cm and Siemens/cm]

% BY WEIGHT	ppm	NaCl	NaOH	H ₂ SO ₄	SEA SALT	HNO ₃	HC ₁	HF	ACETIC ACID	CO ₂	NH ₃	H ₃ PO ₄	SO ₂
0.0001	1.0	2.2	6.2	8.8	2.2	6.8	11.7		4.2	1.2	6.6		
0.0003	3.0	6.5	18.4	26.1	6.5	20	35.0		7.4	1.9	14		
0.001	10.0	21.4	61.1	85.6	21.3	67	116		15.5	3.9	27		
0.003	30.0	64	182	251	64	199	340	290	30.6	6.8	49		
0.01	100	210	603	805	208	657	1140	630	63	12	84	342	
0.03	300	617	1780	2180	612	1950	3360	1490	114	20	150	890	
0.1	1,000	1990	5820	6350	1930	6380	0.0111	2420	209	39	275	2250	3600
0.3	3,000	5690	0.0169	0.0158	5550	0.0189	0.0322	5100	368	55	465	4820	7900
1.0	10,000	0.0176	0.0532	0.0485	0.0170	0.0600	0.103	0.0117	640		810	0.0105	0.0172
3.0	30,000	0.0486	0.144	0.141	0.0462	0.172	0.283	0.0347	1120		<u>1110</u>	0.0230	0.0327
10.0	100,000	0.140	<u>0.358</u>	0.427		0.498	<u>0.709</u>	0.118	<u>1730</u>		1120	0.0607	0.0610
30.0	300,000		0.292	0.822		0.861	0.732	0.390	1620		210	0.182	

Underlined figure indicates conductivity passes through a maximum between the two listed concentrations.

TABLE B: CONVERSIONS

Linear Equivalents

INCHES	FEET	YARDS	RODS	MILES	CENTIMETERS	METERS	KILOMETERS
1.00	0.08333	0.02778	0.005051	0.00001578	2.54	0.0254	0.0000254
12	1.00	0.33336	0.060612	0.00018936	30.48	0.3048	0.0003048
36	3.00	1.00	0.181836	0.00056808	91.44	0.9144	0.0009144
198	16.49934	5.50	1.00	0.00312444	502.92	5.0292	0.0050292
63360	5279.79	1760.14	320.03	1.00	160934.4	1609.344	1.609344
0.3637	0.03030712	0.01010359	0.001837	0.000006	0.923798	0.00924	9.2379
39.37	3.2807021	1.0936986	0.198858	0.000621	100	1.00	0.001
39370	3280.7021	1093.6986	198.858	0.6212586	100,000	1000	1.00

Area Equivalents

SQUARE INCHES	SQUARE FEET	SQUARE YARDS	SQUARE CENTIMETERS	SQUARE METERS
1.00	0.00694	0.00077	6.452	0.00065
144	1.00	0.111	929.088	0.09291
1296	8.900	1.00	8361.80	0.8362
0.155	0.00108	0.00012	1.00	0.0001
1550	10.76	1.196	10000	1.00

Area Equivalents

ACRES	SQUARE MILES	HECTARES	SQUARE KILOMETERS
1.00	0.00156	0.4047	0.00405
640	1.00	259.01	2.59
0.0247	3.8622	0.01	0.0001
2.471	0.00386	1.00	0.01
247.1	0.38621	100	1.00

TABLE B: CONVERSIONS (continued)

Volume Equivalents

U.S. QUARTS	U.S. GALLONS	BRITISH IMPERIAL QUARTS	BRITISH IMPERIAL GALLONS	CUBIC INCHES	CUBIC FEET	LITERS	CUBIC METERS
1.00	0.25	0.8327	0.2082	57.75	0.03342	0.9464	0.00095
4.00	1.00	3.3308	0.8328	231.00	0.13368	3.7856	0.00379
1.201	0.300	1.00	0.2501	69.36	0.04013	1.1366	0.00114
4.804	1.201	4.00	1.00	277.43	0.16055	4.54651	0.00455
0.017	0.0043	0.01442	0.0036	1.00	0.00058	0.01639	0.00002
29.92	7.48	24.91	6.229	1727.88	1.00	28.316	0.02832
1.057	0.264	0.880	0.2201	61.04	0.03532	1.00	0.001
1057	264.25	880.16	220.067	61041.75	35.32	1000.00	1.00

Weight Equivalents

GRAINS	AVOIRDUPOIS OUNCES	AVOIRDUPOIS POUNDS	GRAMS	KILOGRAMS
1.00	0.00229	0.00014	0.0648	0.00006
437.5	1.00	0.06252	28.35	0.02835
7000	16.00	1.00	453.6	0.4536
15.43	0.0353	0.0022	1.00	0.0001
15430.00	35.273	2.205	1000.00	1.00

Weight Equivalents

AVOIRDUPOIS POUNDS	SHORT TONS	LONG TONS	KILOGRAMS	METRIC TONS
1.00	0.0005	0.00045	0.4536	0.00045
2000.00	1.00	0.8928	907.2	0.9072
2240.00	1.12	1.00	1016.06	1.0161
2.205	0.0011	0.00098	1.00	0.001
2205.00	1.1025	0.9843	1000	1.00

Capacity and Regeneration Level Equivalents*

MEQ./ML.	POUND EQUIV./CU. FT.	KILOGRAMS (as CaCO ₃)/CU. FT.	GRAMS CaO/ LITER	GRAMS CaCO ₃ /LITER
1.00	0.0624	21.8	28.00	50.00
16.00	1.00	349.00	449.00	801.00
0.0459	0.000286	1.00	1.28	2.29
0.0357	0.00223	0.779	1.00	1.79
0.02	0.00125	436.00	0.56	1.00

*Capacity on a dry weight basis may be calculated as follows:

$$\text{meq/gm of dry resin} = \frac{100 \times 62.4 \text{ lbs/cu ft of dry resin}}{1 \text{ gm/ml}} \times \frac{\text{meq/ml of wet volume capacity}}{\text{Wet density in lbs/cu ft} \times \% \text{ Solids} \times 1 \text{ gm/ml}}$$

TABLE B: CONVERSIONS (continued)

Pressure Equivalents

LBS. PER SQ. IN.	FEET OF WATER*	METERS OF WATER*	INCHES OF MERCURY**	ATMOSPHERES	KILOGRAMS PER SQ. CM.
1.000	2.31	0.704	2.04	0.0681	0.0703
0.433	1.00	0.305	0.822	0.0295	0.0305
1.421	3.28	1.00	2.89	0.0967	0.10
0.491	1.134	0.346	1.00	0.0334	0.0345
14.70	33.93	10.34	29.92	1.00	1.033
14.22	32.80	10.00	28.96	0.968	1.00

* *Equivalent units are based on density of fresh water at 32°F to 62°F.*

** *Equivalent units are based on density of mercury at 32°F to 62°F.*

Flow Rate Equivalents

US GAL/MIN	CF/HR	CM/HR	CF/SEC	L/SEC
1.00	8.021	0.2271	0.0023	0.0631
0.0125	1.00	0.0283	0.0167	0.4721
4.403	35.30	1.00	2118.00	16.67
438.60	60.00	1.70	1.00	28.33
15.85	127.16	3.60	2.12	1.00

TABLE C: PHYSICAL CONSTANTS OF 55% HIGH FRUCTOSE CORN SYRUP

%DS	AT 20% REFRACTIVE INDEX	SPECIFIC GRAVITY IN AIR	TOTAL POUNDS PER GALLON	TOTAL SOLIDS PER GALLON
3.0	1.3373	1.0118	8.419	0.253
4.0	1.3387	1.0157	8.452	0.338
5.0	1.3402	1.0197	8.485	0.424
6.0	1.3417	1.0237	8.519	0.511
7.0	1.3432	1.0277	8.552	0.599
8.0	1.3447	1.0318	8.585	0.687
9.0	1.3462	1.0359	8.620	0.776
10.0	1.3477	1.0400	8.654	0.865
11.0	1.3492	1.0442	8.689	0.956
12.0	1.3508	1.0483	8.724	1.047
13.0	1.3523	1.0525	8.759	1.139
14.0	1.3539	1.0568	8.794	1.231
15.0	1.3555	1.0611	8.830	1.324
16.0	1.3570	1.0654	8.866	1.418
17.0	1.3586	1.0697	8.902	1.513
18.0	1.3603	1.0741	8.938	1.609
19.0	1.3619	1.0785	8.975	1.705
20.0	1.3635	1.0829	9.011	1.802
21.0	1.3652	1.0873	9.048	1.900
22.0	1.3668	1.0918	9.086	1.999
23.0	1.3685	1.0963	9.123	2.098
24.0	1.3702	1.1009	9.161	2.199
25.0	1.3719	1.1055	9.199	2.300
26.0	1.3736	1.1101	9.238	2.402
27.0	1.3753	1.1147	9.276	2.503
28.0	1.3770	1.1196	9.315	2.608
29.0	1.3788	1.1241	9.354	2.713
30.0	1.3805	1.1288	9.394	2.815
31.0	1.3823	1.1336	9.433	2.924
32.0	1.3841	1.1384	9.473	3.031
33.0	1.3859	1.1432	9.513	3.139
34.0	1.3877	1.1481	9.554	3.248
35.0	1.3895	1.1530	9.593	3.358
36.0	1.3913	1.1579	9.636	3.469
37.0	1.3932	1.1628	9.677	3.580
38.0	1.3951	1.1679	9.718	3.693
39.0	1.3969	1.1729	9.760	3.806
40.0	1.3988	1.1779	9.802	3.921
41.0	1.4007	1.1830	9.844	4.036
42.0	1.4026	1.1881	9.887	4.152
43.0	1.4045	1.1932	9.930	4.270
44.0	1.4065	1.1984	9.973	4.388

TABLE C: PHYSICAL CONSTANTS OF 55% HIGH FRUCTOSE CORN SYRUP (continued)

%DS	AT 20% REFRACTIVE INDEX	SPECIFIC GRAVITY IN AIR	TOTAL POUNDS PER GALLON	TOTAL SOLIDS PER GALLON
45	1.4084	1.2036	10.016	4.507
46	1.4104	1.2089	10.060	4.627
47	1.4124	1.2141	10.104	4.749
48	1.4144	1.2194	10.148	4.871
49	1.4164	1.2248	10.192	4.994
50	1.4184	1.2302	10.237	5.118
51	1.4205	1.2356	10.282	5.244
52	1.4225	1.2410	10.327	5.370
53	1.4246	1.2465	10.373	5.497
54	1.4267	1.2520	10.418	5.626
55	1.4287	1.2575	10.464	5.755
56	1.4309	1.2631	10.511	5.886
57	1.4330	1.2687	10.557	6.018
58	1.4351	1.2743	10.604	6.150
59	1.4373	1.2800	10.651	6.284
60	1.4394	1.2857	10.699	6.419
61	1.4416	1.2914	10.747	6.555
62	1.4439	1.2972	10.795	6.693
63	1.4460	1.3030	10.843	6.831
64	1.4483	1.3088	10.891	6.970
65	1.4505	1.3147	10.940	7.111
66	1.4528	1.3206	10.989	7.253
67	1.4550	1.3265	11.039	7.396
68	1.4573	1.3325	11.088	7.540
69	1.4596	1.3385	11.138	7.685
70	1.4620	1.3445	11.188	7.832
71	1.4643	1.3506	11.239	7.980
72	1.4667	1.3567	11.290	8.129
73	1.4690	1.3628	11.341	8.279
74	1.4714	1.3690	11.392	8.430
75	1.4738	1.3752	11.444	8.583
76	1.4762	1.3814	11.496	8.737
77	1.4787	1.3877	11.548	8.892
78	1.4811	1.3940	11.600	9.048
79	1.4836	1.4004	11.653	9.206
80	1.4861	1.4067	11.706	9.365
81	1.4886	1.4131	11.760	9.525
82	1.4911	1.4196	11.813	9.687
83	1.4937	1.4261	11.867	9.850
84	1.4962	1.4326	11.921	10.014
85	1.4988	1.4391	11.976	10.183

TABLE D: CONCENTRATION OF REGENERANTS

Hydrochloric Acid

% HCl	GRAMS HCl/L	NORMALITY (Eq/L)	SPECIFIC GRAVITY	° BAUMÉ	POUNDS PER US GALLON
1	10.03	0.275	1.0032	0.5	0.084
2	20.16	0.553	1.0082	1.2	0.168
4	40.72	1.12	1.0181	2.6	0.340
6	61.67	1.69	1.0279	3.9	0.515
7	72.30	1.98	1.0345	4.6	0.603
8	83.01	2.28	1.0376	5.3	0.693
10	104.70	2.87	1.0474	6.6	0.874
12	126.90	3.48	1.0574	7.9	1.059
16	172.40	4.73	1.0776	10.4	1.439
20	219.60	6.02	1.0980	12.9	1.833
30	344.80	9.46	1.1492	18.8	2.877
34	397.60	10.90	1.1693	21.0	3.318
40	479.20	13.10	1.1980	24.0	3.999

Sulfuric Acid

% H ₂ SO ₄	GRAMS H ₂ SO ₄ /L	NORMALITY (Eq/L)	SPECIFIC GRAVITY	° BAUMÉ	POUNDS PER US GALLON
1	10.05	0.205	1.0051	0.7	0.084
2	20.24	0.413	1.0118	1.7	0.169
3	30.55	0.625	1.0184	2.6	0.255
4	41.00	0.836	1.0250	3.5	0.342
5	51.59	1.05	1.0317	4.5	0.431
6	62.31	1.27	1.0385	5.4	0.520
8	84.18	1.72	1.0522	7.2	0.703
10	106.6	2.17	1.0661	9.0	0.890
12	129.6	2.64	1.0802	10.8	1.082
15	165.3	3.37	1.1020	13.4	1.379
20	227.9	4.65	1.1394	17.7	1.902
50	697.6	14.2	1.3951	41.1	5.821
96	1762.0	35.9	1.8356	66.0	14.710
100	1831.0	37.3	1.8305	65.8	15.280

TABLE D: CONCENTRATION OF REGENERANTS (continued)

Sodium Chloride

% NaCl	GRAMS NaCl	NORMALITY (Eq/L)	SPECIFIC GRAVITY	° BAUMÉ	POUNDS PER US GALLON
1	10.05	0.172	1.0053	0.8	0.084
2	20.25	0.346	1.0125	1.8	0.169
4	41.07	0.703	1.0268	3.8	0.343
6	62.48	1.069	1.0413	5.8	0.521
8	84.47	1.445	1.0559	7.7	0.705
10	107.1	1.832	1.0707	9.6	0.894
12	130.3	2.229	1.0857	11.5	1.087
16	178.6	3.056	1.1162	15.1	1.490
20	229.6	3.928	1.1478	18.7	1.916
26	311.3	5.326	1.1972	23.9	2.598

Sodium Hydroxide

% NaOH	GRAMS NaOH/L	NORMALITY (Eq/L)	SPECIFIC GRAVITY	° BAUMÉ	POUNDS PER US GALLON
1	10.10	0.262	1.0095	1.4	0.084
2	20.41	0.511	1.0207	2.9	0.170
3	30.95	0.774	1.0318	4.5	0.258
4	41.71	1.04	1.0428	6.0	0.348
5	52.69	1.32	1.0538	7.4	0.440
6	63.89	1.60	1.0648	8.8	0.533
8	86.95	2.17	1.0869	11.6	0.726
10	110.9	2.77	1.1089	14.2	0.925
12	135.7	3.39	1.1309	16.8	1.333
16	188.0	4.70	1.1751	21.6	1.569
20	243.8	6.10	1.2191	26.1	2.035
40	571.9	14.29	1.4300	43.6	4.773
50	762.7	19.10	1.5253	49.9	6.365

TABLE D: CONCENTRATION OF REGENERANTS (continued)

Ammonium Hydroxide

PER CENT NH ₃	GRAMS PER LITER	NORMALITY (Eq/L)	SPECIFIC GRAVITY	° BAUMÉ	POUNDS PER US GALLON
1	9.939	0.584	0.9939	10.9	0.0829
2	19.79	1.162	0.9895	11.5	0.1652
3	29.60	1.741	0.9852	11.6	0.2470
4	39.24	2.304	0.9811	11.7	0.3275
6	58.38	3.428	0.9730	13.9	0.4872
8	77.21	4.536	0.9651	15.1	0.6443
10	95.75	5.622	0.9575	16.2	0.7991
12	114.0	6.694	0.9501	17.3	0.9515
14	132.0	7.751	0.9430	18.5	1.102
16	149.8	8.796	0.9362	19.5	1.250
18	167.3	9.824	0.9295	20.6	1.396
20	184.6	10.84	0.9229	21.7	1.540
22	201.6	11.84	0.9164	22.8	1.682
24	218.4	12.82	0.9101	23.8	1.823
26	235.0	13.80	0.9040	24.9	1.961
28	251.4	14.76	0.8980	25.9	2.098
30	267.6	15.71	0.8920	27.0	2.233

Sodium Carbonate

PER CENT Na ₂ CO ₃	GRAMS PER LITER	NORMALITY (Eq/L)	SPECIFIC GRAVITY	° BAUMÉ	POUNDS PER US GALLON
1	10.09	0.1904	1.0086	1.2	0.0842
2	20.38	0.3845	1.0190	2.7	0.1701
4	47.59	0.8979	1.0398	5.6	0.3471
6	63.64	1.201	1.0606	8.3	0.5311
8	86.53	1.633	1.0816	10.9	0.7221
10	111.3	2.081	1.1029	13.5	0.9204
12	134.9	2.545	1.1244	16.0	1.126
14	160.5	3.028	1.1463	18.5	1.339

TABLE E: CALCIUM CARBONATE EQUIVALENTS**Cations**

CATION	SYMBOL	ATOMIC WEIGHT	EQUIVALENT WEIGHT	TO CONVERT PPM AS ION TO PPM AS CaCO ₃ MULTIPLY BY
Hydrogen	H ⁺	1.00	1.00	50.0
Ammonium	NH ₄ ⁺	18.00	18.00	2.78
Sodium	Na ⁺	23.00	23.00	2.18
Potassium	K ⁺	39.10	39.10	1.28
Magnesium	Mg ²⁺	24.30	12.15	4.10
Calcium	Ca ²⁺	40.10	20.04	2.49
Ferrous	Fe ²⁺	55.85	27.90	1.79
Cupric	Cu ²⁺	63.54	31.77	1.57
Zinc	Zn ²⁺	65.40	32.70	1.53
Aluminum	Al ³⁺	27.00	9.00	5.55
Chromic	Cr ³⁺	52.00	17.30	2.89
Ferric	Fe ³⁺	55.85	18.60	2.69

Anions

ANION	SYMBOL	ATOMIC WEIGHT	EQUIVALENT WEIGHT	TO CONVERT PPM AS ION TO PPM AS CaCO ₃ MULTIPLY BY
Hydroxide	OH ⁻	17.0	17.0	2.94
Chloride	Cl ⁻	35.5	35.5	1.41
Bicarbonate	HCO ₃ ⁻	61.0	61.0	0.82
Nitrate	NO ₃ ⁻	62.0	62.0	0.81
Bisilicate	HSiO ₃ ⁻	77.1	77.1	0.65
Bisulfate	HSO ₄ ⁻	97.1	97.1	0.52
Carbonate	CO ₃ ²⁻	60.0	30.0	1.67
Silicate	SiO ₃ ²⁻	76.1	38.0	1.31
Sulfate	SO ₄ ²⁻	96.1	48.0	1.04
Carbon Dioxide	CO ₂	44.0	22.0	1.14
Silica	SiO ₂	60.1	60.1	0.83

TABLE F: ACID AND CAUSTIC CONCENTRATION VS. pH

ACID NORMALITY vs pH	
N (Eq/L)	pH
1	0.00
10 ⁻¹	1.00
10 ⁻²	2.00
10 ⁻³	3.00
10 ⁻⁴	4.00
10 ⁻⁵	5.00
10 ⁻⁶	5.996
10 ⁻⁷	6.791
10 ⁻⁸	6.978

CAUSTIC NORMALITY VS pH	
N (Eq/L)	pH
10 ⁻¹	13.00
10 ⁻²	12.00
10 ⁻³	11.00
10 ⁻⁴	10.00
10 ⁻⁵	8.9965
10 ⁻⁶	8.4741

TABLE G: TANK CAPACITIES

DIA. FT.	AREA SQ. FT.	GALLONS PER FOOT OF DEPTH
1.0	0.785	5.87
1.5	1.767	13.22
2.0	3.142	23.50
2.5	4.909	36.72
3.0	7.069	52.88
3.5	9.621	71.97
4.0	12.57	94.00
4.5	15.90	119.0
5.0	19.63	146.9
5.5	23.76	177.7
6.0	28.27	211.5
6.5	33.18	248.2
7.0	38.48	287.9
7.5	44.18	330.5
8.0	50.27	376.0
8.5	56.75	424.5
9.0	63.62	475.9
9.5	70.88	530.2

DIA. FT.	AREA SQ. FT.	GALLONS PER FOOT OF DEPTH
10.0	78.54	587.5
10.5	86.59	647.7
11.0	95.03	710.9
11.5	103.9	777.0
12.0	113.1	846.0
12.5	122.7	918.0
13.0	132.7	992.9
13.5	143.1	1071
14.0	153.9	1152
14.5	165.1	1235
15.0	176.7	1322
15.5	188.7	1412
16.0	201.1	1504
18.0	254.5	1904
20.0	314.2	2350

TABLE H: MESH AND SLOT SIZES

SCREEN SLOT SIZE (INCHES)	U.S. STD. SIEVE MESH DESIGNATION	MICRONS	MILLIMETERS
0.006	100	149	0.149
0.007	80	177	0.177
0.008	70	210	0.210
0.010	60	250	0.250
0.012	50	297	0.297
0.014	45	354	0.354
0.016	40	420	0.420
0.020	35	5000	0.500
0.023	30	5950	0.595
0.028	25	7070	0.707
0.033	20	8410	0.841
0.039	18	1000	1.000
0.047	16	1190	1.190
0.055	14	1410	1.410
0.066	12	1680	1.680
0.079	10	2000	2.000
0.094	8	2380	2.380
0.111	7	2830	2.830
0.132	6	3360	3.360
0.157	5	4000	4.000

TABLE I: RELATIVE ION SELECTIVITIES

Approximate Selectivity Scale for Anions on Strong Base Resins

ANION	SELECTIVITY	ANION	SELECTIVITY
I ⁻	8.0	OH ⁻ (Type II)	0.65
NO ₃ ⁻	4.0	HCO ₃ ⁻	0.40
Br ⁻	3.0	CH ₃ COO ⁻	0.20
HSO ₄ ⁻	1.6	F ⁻	0.10
NO ₂ ⁻	1.3	OH ⁻ (Type I)	0.06
CN ⁻	1.3	SO ₄ ²⁻	0.15
Cl ⁻	1.0	CO ₃ ²⁻	0.03
BrO ₃ ⁻	1.0	HPO ₄ ²⁻	0.01

Selectivity Scale for Cations on Strong Acid Resins

CATION	SELECTIVITY	CATION	SELECTIVITY
Li ⁺	1.0	Zn ²⁺	3.5
H ⁺	1.3	Co ²⁺	3.7
Na ⁺	2.0	Cu ²⁺	3.8
NH ₄ ⁺	2.6	Cd ²⁺	3.9
K ⁺	2.9	Be ²⁺	4.0
Rb ⁺	3.2	Mn ²⁺	4.1
Cs ⁺	3.3	Ni ²⁺	3.9
Ag ⁺	8.5	Ca ²⁺	5.2
UO ₂ ²⁺	2.5	Sr ²⁺	6.5
Mg ²⁺	3.3	Pb ²⁺	9.9
		Ba ²⁺	11.5

TABLE J: REGENERANT CHEMICALS SPECIFICATIONS

Hydrochloric (Muriatic) Acid

GRADE – MURIATIC ACID, TECHNICAL (HCl)	
COLOR – WHITE TO YELLOW	
CONCENTRATION – MINIMUM (18° Bé) 28% HCl	
Sulfuric acid, as SO ₃	= 0.4% maximum
Iron (Fe)	= 0.01% maximum
Freezing point	= -40° F
Organic contaminants	= 0.01% maximum
Weight per gallon	= 9.5 lb

(NOTE: Acid should be free of turbidity.)

Soda Ash – Sodium Carbonate

GRADE – SODA ASH, TECHNICAL, DENSE (Na₂CO₃)	
COLOR – WHITE	TYPICAL ANALYSIS AVERAGE
Na ₂ O	58.26%
Na ₂ CO ₃	99.6%
NaHCO ₃	Nil
NH ₃	Nil
H ₂ O	0.15%
NaCl	0.21%
Na ₂ SO ₄	0.02%
Fe ₂ O ₃	0.0022%
Water Insolubles	0.013%

Sulfuric Acid

GRADE – SULFURIC ACID, TECHNICAL (H₂SO₄)	
COLOR – WATER WHITE TO LIGHT BROWN	
CONCENTRATION – MINIMUM (66° Bé) 93.2% H₂SO₄	

(NOTE-An equivalent amount of 60° Be acid may be used.)

Iron (Fe)	= 50 ppm maximum
Nitrogen compounds	= 20 ppm maximum
Arsenic	= 0.2 ppm maximum
Freezing point	= -24° F
Organic contaminants	= 0.01%
Weight per gallon	= 15.3 lb (60°F)

Acid should be free of turbidity and sediment.

Acid containing inhibitors should not be used.

Aqua Ammonia

GRADE – AMMONIUM HYDROXIDE (NH₄OH), 26° Bé	
Gravity at 60°F	= 26.0° Bé (minimum)
Total ammonia as NH ₃	= 29.4%
Freezing point	= -40°F
Color	= water white
Pounds per gallon (at 60°F)	= 7.5

Sodium Hydroxide Liquid Caustic Soda, Mercury Cell Grade

TYPICAL ANALYSIS	AVERAGE
NaOH	50.6%
Na ₂ CO ₃	0.02%
NaCl	0.002%
NaClO ₃	Less than 1 ppm
Na ₂ SO ₄	10 ppm
SiO ₂	10 ppm
Al ₂ O ₃	3 ppm
CaO	3 ppm
MgO	0.6 ppm
Fe	2 ppm
Ni	0.6 ppm
Cu	0.2 ppm
Mn	Less than 0.2 ppm
Hg	1.0 ppm

Sodium Hydroxide Liquid Caustic Soda, Rayon Grade

TYPICAL ANALYSIS	AVERAGE
Na ₂ O	76.61%
NaOH	98.25%
Na ₂ CO ₃	0.76%
NaCl	1200 ppm
NaClO ₃	Less than 2 ppm
Fe ₂ O ₃	0.001%
SiO ₂	0.0039%
Al ₂ O ₃	0.001%
CaO	0.0027%
MgO	0.0038%
Cu	0.00002%
Mn	0.00005%
Pb	0.00005%
Ni	0.00009%
Na ₂ SO ₄	0.20%
As	0.01 ppm

Sodium Hydroxide Liquid Caustic Soda, Diaphragm Cell Grade

TYPICAL ANALYSIS	AVERAGE
NaOH	100% nominal
NaCl	1200 ppm
NaCO ₃	0.3%
NaClO ₃	30 ppm
Fe	10 ppm
Na ₂ SO ₄	2000 ppm

TABLE K: SPECIFICATIONS FOR HFCS-55

Percent Solids	76.5 - 77.5 g/100 g with a target value of 77.0 g/ 100 g.
Fructose	55.0-58.0 g /100 g of total solids.
Dextrose + Fructose	Not less than 95.0 g /100 g of total solids.
Other Saccharides (D.P. 2+)	Not more than 5.0 g /100 g of total solids.
Ash	Not more than 0.05 g /100 g, sulfated.
Taste	Free from foreign taste.
Titrateable Acidity	Not more than 4.0 mL of 0.05N NaOH to raise 100 g to pH 6.0.
Temperature	Not more than 30° C at time of receipt.
Copper	Not more than 1.5 mg/kg.
Iron	Not more than 3 mg/kg.
Lead	Not more than 1 mg/kg.
Total Heavy Metals	Not more than 5 mg/kg (as lead).
Chlorides	Not more than 50 mg/kg (as NaCl).
pH	4.0 target (undiluted); range: 4.0 ± 0.5.
Sulfur Dioxide	Not more than 6 mg/kg.
Sulfonated Polystyrene	Not more than 1.0 mg/kg, or must pass test for sulfonates.
Odor After Acidification	Free from objectionable odor when one liter of 54° Brix syrup is acidified to pH 1.5 with phosphoric acid (H ₃ PO ₄). Solution is warmed to 30° C and checked for odor every 5 minutes for 30 minutes duration.
Sediment	Not more than 2 mg/kg visual insolubles when 300 g of solids are filtered through a 28-mm (1-1/8 inch) Whatman No. 54 filter disc and compared to a standard NSDA disc; or not more than 7 mg/kg water insolubles determined by a gravimetric method.
Floc	Shall not produce a floc when one 1 liter of 54° Brix solution, acidified to pH 1.5 with phosphoric acid, is allowed to stand 10 days at room temperature. The solution should be viewed with the aid of a strong beam of light.
Color	Not more than 35 Reference Basis Units (RBU), at time of receipt, as determined in accordance with the NSDA standard for "Bottlers" sugar. A supplier's product must not increase in color to more than 50 RBU after storage for 30 days at 30° C.
Turbidity	A 54° Brix syrup acidified to pH 1.5 with phosphoric acid shall be free of turbidity when viewed in a 1 liter container under a strong beam of light.
Microbiological	Not more than 5 viable yeast per 10 mL. Not more than 5 viable mold (mycelium) per 10 mL Not more than 25 viable mesophilic bacteria per 10mL By "Direct Method" the count shall not exceed a total number of viable and non-viable organisms as noted below: Not more than 10 yeast per 1.0 mL. Not more than 10 mold (mycelium) per 1.0 mL Not more than 100 mesophilic bacteria per 1.0 mL

PROCEDURE A: ICUMSA METHOD FOR COLOR MEASUREMENT

Spectrophotometer. For routine measurements it is not necessary to use a spectrophotometer; a photometer with a filter with a narrow band width ($\pm 10\text{nm}$) is suitable. The design of the instrument should be such as to eliminate as far as possible the inclusion of forward-scattered light in the measurement of the transmitted light. This is achieved by restricting the size of the receiving aperture so that it only accommodates the restricted beam.

Cells. For measurements of white sugar, a cell length of 10 cm is recommended. A second or reference cell may be used, provided that a test with distilled water has shown that the two cells are within 0-2% of being identical (with the instrument reading 100% transmittance on one cell, the other should give a reading between 99.8 and 100.2%).

Also, membrane filters, 50 mm diameter, pore size $0.45\ \mu\text{m}$ (mercury intrusion method), and membrane filter holders are required.

Reagent. Kieselguhr, analytical grade.

Procedure. Sample Preparation. The sugar to be tested is dissolved in unheated distilled water. The following concentrations are used:

White sugars	50g/100g
Darker-colored sugars	As high as practicable, consistent with reasonable filtration rates and cell depths.
Liquor, syrups, and juices	Diluted to 50% solids or original density, unless dilution is required to obtain reasonable filtration rates or cell depths.

The solution is filtered under vacuum; white sugar solution and light-colored liquors are filtered through a membrane filter, pore size $0.45\ \mu\text{m}$.

Slower-filtering solutions are filtered with Kieselguhr (1% on solids) through filter paper. The first portion of the filtrate is discarded if cloudy. The pH of darker-colored solutions is adjusted to 7.0 ± 0.2 with dilute hydrochloric acid is removed under vacuum or in an ultrasonic bath, care being taken to minimize evaporation. The density of solution is checked after deaerating.

Distilled water filtered through a membrane filter is used as a reference standard.

Color Measurement. The measuring cell is rinsed three times with the sugar solution and then filled. The absorbency of the solution is determined at 420nm using filtered distilled water as the reference standard for zero color. The cell length is chosen so that the instrument reading will be between 0.2 and 0.8 absorbancy, except for solutions of white sugar, where the cell length should be as long as possible.

Result. The molar absorption coefficient A_s of the solution is calculated as follows:

$$a_s = \frac{-\text{Log } T_s}{bc} = \frac{A_s}{bc}$$

T_s = transmittance

A_s = absorbance

b = cell length (cm)

c = concentration of total solids (mols/liter) determined refractometrically and calculated from density.

a_s = molar absorption coefficient (liter/mol cm)

PROCEDURE B: CLEANING OF ORGANICALLY FOULED ANION RESINS

Caustic salt treatments to elute organic and other foulants from strongly basic anion exchangers.

These treatments consist of a partial caustic regeneration and displacement, followed by warm (150°F) brine (15% NaCl) treatment. This is repeated as many as six times, or until the maximum color eluted during the brine step drops to one fifth of the highest color eluted (which occurs during the first treatment). The procedure is as follows:

1. The anion bed is backwashed as per usual.
2. Regenerate with warm 2% to 5% NaOH as usual, but the amount of caustic is limited to about one third of the normal dosage (1.0 to 2.0 lbs/ft³), flowrate at about 0.2 gpm/ft³.
3. Slow rinse or displace for 10 minutes at the same 0.2 gpm/ft³.
4. Inject warm 10% to 15% NaCl solution (at 150 °F) at 6.5 to 8.0 lbs/ft³, also at 0.2 gpm/ft³ flowrate.
5. Slow rinse or displace for 10 minutes at 0.2 gpm/ft³. Observe for the most concentrated salt (by hydrometer) in the effluent, at which time the color eluted will be the highest.
6. Without backwashing, repeat the above steps 2 through 5 several times, until the color eluted during the salting period drops to one fifth of that observed during the first treatment.

Note: Although a mixture of 10% NaCl and 1% NaOH solution is effective for removing color, the above cyclic method is preferred. The alternate application of NaOH and NaCl causes alternate expansion and contraction of the resin, which loosens the coagulated or foreign matter from the beads by a mechanical or sponge action, as well as by the chemical elution.

This procedure is best done on a regular or periodic schedule before the anion resin is appreciably fouled. If organic matter in the influent is high, this procedure may have to be done every 15 to 30 days. When heavy metals (such as Cu or Fe) are also present in the anion resin, concentrated 30% HCl may have to be applied (1.5 gallons of 30% HCl) as well. Hopefully the underdrain is not made from stainless steel, because HCl attacks it; in this case, the resin will have to be moved to a treatment vessel with a PVC/polypropylene screened underdrain.

PROCEDURE C: FDA CONDITIONING OF ION EXCHANGE RESIN BEFORE FOOD USE

Ion exchange resins tend to be insoluble and infusible polymers. Even immediately after processing, however, there are still more soluble impurities which should be removed prior to most applications. The removal can take place by many methods which include a simple water rinse using several bed volumes of water, a chemical regeneration followed by a water rinse and the most rigorous cleanup which would include an acid/alkali cycling period. These treatments will be described in further detail.

As part of the preparation, Purolite cation resins are steam cleaned to remove all residuals to meet the United States F.D.A. Standards CFR-21 Para.173.25 of the Food Additives Regulations. This procedure is not recommended for anion resins in the free base or hydroxide form. Anion steamed or boiled in the above forms can cause extreme loss of capacity over a very short period of time.

Anion resins with amine functional groups have a slight odor, especially after storage in highly heated or closed containers. This odor can be washed out and usually only persists through a few cycles.

The standard ionic forms for Purolite resin are sodium form for the strong acid cations, hydrogen form for the weak acid cations, chloride form for the strong base anions and the free base form for the weak base anions. Other ionic forms are supplied by Purolite upon request.

Resins are prepared for conditioning similar to the ion exchange regeneration procedure:

- A. Resins should be transferred to the column and soaked in water for approximately one hour allowing the resin to come to equilibrium.
- B. Backwash the resin to reclassify the bed so that the finer particles are on the top and the coarse particles on the bottom.
- C. Cease backwashing and allow the bed to settle and then drain the water to 1 inch above the bed.
- D. General Conditioning Steps
 - To a bed of resin in the normal backwashed, settled and drained condition,
 1. add three bed volumes of 4% NaOH at a rate sufficient to allow 45 minutes contact time;
 2. rinse with five bed volumes of potable water at the same flow rate;
 3. add three bed volumes of 10% H₂SO₄ or 5% HCl at a flow rate sufficient to allow 45 minutes contact time;
 4. rinse with five bed volumes of potable water;
 5. convert the resin to the ionic form desired for use, using the normal regeneration techniques.

The above conditioning treatment is for all acidic and basic ion exchange resins with the following modifications.

Cation exchange resins to be used in the H⁺ cycle are conditioned as outlined. If they are to be used in the Na⁺ cycle, the above order of application of acid and base are reversed. In the event that equipment involved will not tolerate acid, the following substitutions can be made in the conditioning steps as tabulated: In step 3, substitute 25 bed volumes of 0.5% CaCl₂ for the 10% H₂SO₄ or 5% HCl, or exhaust with tap water. In Step 1, substitute 10% NaCl for the 4% NaOH.

Anion exchangers to be used in the chloride or hydroxide cycle can be conditioned as outlined above. Again, it is recommended that chloride conversion using 10% NaCl be used in place of the 10% sulfuric acid in Step 3.

PROCEDURE D: METHOD FOR BACKWASHED AND SETTLED RESIN DENSITY

Scope

This test method covers the determination of the backwashed and settled density of ion exchange resin and is intended for testing both new and used materials.

Summary of Test Method

The test method consists of the determination of the backwashed and settled volume of a known number of grams of chemically pretreated resin.

Significance and Use

This test method for the determination of backwashed and settled density of a hydraulically classified and settled bed was developed to correlate with the density of ion exchange materials in operating units. Results obtained by this test in a one-inch column may be expected to agree with those obtained in larger diameter units within the overall precision limits of the test, but the bias of these results, as compared with measurements in larger diameters, is toward lower values.

Procedure

- Weigh a 200 g sample of resin, pretreated in accordance with Section 10, to the nearest 0.1 g. Transfer it quantitatively to a column that has been calibrated every 5 mL above the 200 mL volume.
- Backwash with water for 10 min using a slow rate that will maintain a 50% expansion of the bed.
- Allow the bed to settle and drain at a rate of approximately 100 mL/min until the water level is 20 to 30 mm above the top of the bed. *Do not jar.* Record the volume, in milliliters, of ion exchange resin. Repeat the 10 min backwash until two successive readings of volume agree within 5 mL.

Calculation

Calculate the backwashed and settled density, in grams per milliliter as follows:

$$\text{Density, g/mL} = A/B$$

A = grams of sample used.
B = milliliters of sample.

Calculate the backwashed and settled density in pounds per cubic foot, as follows:

$$\text{Density, lb/ft}^3 = C \times 62.4$$

C = density, g/mL.

Report

Report the density of the tested material as the average of that calculated from two volumes that agree within 5mL

Precision

The precision of this test method may be expressed as follows:

$$S_T = 0.0035x$$

$$S_O = 0.005x$$

S_T = overall precision.
S_O = single-operator precision, and
x = density determined in grams per milliliter.

PROCEDURE E: PARTICLE SIZE DISTRIBUTION (UNIFORMITY COEFFICIENT)

Particle-size distribution of ion exchange resins is determined by sieving a representative sample using a series of standard sieves. The results are usually expressed as percent of the entire sample which is retained by or allowed to pass through specified openings in the sieves. The most useful data are obtained from resins in their fully swollen states. Wet-screen analyses are generally preferred to and are more consistent than dry-screen analyses. Since the swelling of ion exchange resins can be considerable, any report of particle-size distribution from screen analysis should be accompanied by a statement indicating whether the data were obtained wet or dry.

Particle size and size distribution are sometimes expressed in terms of “effective size” and “uniformity coefficient,” both of which may be obtained from screen analyses. Effective size is defined as that opening in millimeters which retains 90% (or passes 10%) of the total resin sample. Uniformity coefficient is the numerical value obtained by dividing the sieve opening, in millimeters, which retains 40% of the sample by that which retains 90%.

PROCEDURE F: DETERMINATION OF ACIDITY

ACIDITY

Procedure

Mineral Acidity: pH 4.3 and below - Steps 1-5.

Total Acidity: initial pH to pH 8.3 - Steps 1-7.

1. 58.3 ml or aliquot sample.
2. Place in 125 ml white evaporating dish.
3. Add 2-3 drops methyl orange.
4. Stirring gently, titrate with 0.02N NaOH (sodium hydroxide) from red to orange-yellow (pH 4.3).
5. *Calculation:*
 Mineral Acid (M.A.) gpg as $\text{CaCO}_3 = \frac{\text{ml titre} \times 58.3}{\text{ml of sample}}$
6. To above sample add 2-3 drops of phenolphthalein and continue titration with 0.02N NaOH until sample becomes pink.
7. *Calculation:*
 Total Acid (T) gpg as $\text{CaCO}_3 = \frac{\text{ml titre} \times 58.3}{\text{ml of sample}}$

The above test is usually applied to cation effluent water.

Glossary

ACIDITY: An expression of the concentration of hydrogen ions present in a solution.

ADSORBENT: A synthetic resin possessing the ability to attract and to hold charged particles.

ADSORPTION: The attachment of charged particles to the chemically active groups on the surface and in the pores of an ion exchanger.

ALKALINITY: An expression of the total basic anions (hydroxyl groups) present in a solution. It also represents, particularly in water analysis, the bicarbonate, carbonate, and occasionally, the borate, silicate, and phosphate salts which will react with water to produce the hydroxyl groups.

ANION: A negatively charged ion.

ANION INTERCHANGE: The displacement of one negatively charged particle by another on an anion exchange material.

ASH: The residual mineral content of resin after incineration at 800° C.

ATTRITION: The rubbing of one particle against another in a resin bed; frictional wear that will affect the size of resin particles.

BACKWASH: The upward flow of water through a resin bed (i.e., in at the bottom of the exchange unit, out at the top) to clean and reclassify the bed after exhaustion.

BASE: The hydroxyl form of a cation or a compound that can neutralize an acid.

BASE-EXCHANGE: The property of the trading of cations shown by certain insoluble naturally occurring materials (zeolites) and developed to a high degree of specificity and efficiency in synthetic resin adsorbents.

BATCH OPERATION: The utilization of ion exchange resins to treat a solution in a container where in the removal of ions is accomplished by agitation of the solution and subsequent decanting of the treated liquid.

BED: The ion exchange resin contained in a column.

BED DEPTH: The height of the resinous material in the column after the exchanger has been properly conditioned for effective operation.

BED EXPANSION: The effect produced during backwashing: The resin particles become separated and rise in the column. The expansion of the bed due to the increase in the space between resin particles may be controlled by regulating backwash flow.

BICARBONATE ALKALINITY: The presence in a solution of hydroxyl (OH⁻) ions resulting from the hydrolysis of carbonates or bicarbonates. When these salts react with water a strong base and a weak acid are produced, and the solution is alkaline.

BREAKTHROUGH: The first appearance in the solution flowing from an ion exchange unit of unadsorbed ions similar to those which are depleting the activity of the resin bed. Breakthrough is an indication that regeneration of the resin is necessary.

BRINE: A salt solution, generally sodium chloride in a saturated solution.

BS&D: A procedure for resin volume measurement where in an ion exchange resin bed is first backwashed, then allowed to settle and then drained of water. The resultant bed height is measured for volume calculations.

CAPACITY, OPERATING: the portion of the total capacity utilized in practical ion exchange operation.

Glossary (continued)

CAPACITY, SALT-SPLITTING: The portion of total capacity to split neutral salt.

CAPACITY, TOTAL: The ultimate exchange capacity of the resin.

CARBONACEOUS EXCHANGERS: Ion exchange materials of limited capacity prepared by the sulfonation of coal, lignite, peat, etc.

CARBOXYLIC: A term describing a specific acidic group (COOH) that contributes cation exchange ability to some resins.

CATION: A positively charged ion.

CHANNELING: Cleavage and furrowing of the bed due to faulty operational procedures, in which the solution being treated follows the path of least resistance, runs through these furrows, and fails to contact active groups in other parts of the bed.

CHEMICAL STABILITY: Resistance to chemical change which ion exchange resins must possess despite contact with aggressive solutions.

COLLOIDAL: Composed of extremely small size particles which are not removed by normal filtration.

COLOR THROW: Discoloration of the liquid passing through an ion exchange material; the flushing from the resin interstices of traces of colored organic reaction intermediates.

COLUMN OPERATION: Conventional utilization of ion exchange resins in columns through which pass, either upflow or downflow, the solution to be treated.

CONDENSATE POLISHERS: Ion exchange resins being used to remove or exchange ions as well as to filter condensate for reuse in the steam cycle.

CROSSLINKAGE: The degree of binding of a monomer or set of monomers to form an insoluble tri-dimensional resin matrix.

CYCLE: A complete course of ion exchange operation. For instance, a complete cycle of cation exchange would involve: exhaustion of regenerated bed, backwash, regeneration and rinse to remove excess regenerant.

DEASHING: The removal from solution of inorganic salts by means of adsorption by ion exchange resins of both the cations and the anions that comprise the salts. See deionization.

DEIONIZATION: Deionization, a more general term than de-ashing, embraces the removal of all charged constituents or ionizable salts (both inorganic and organic) from solution. See de-ashing.

DENSITY: The weight of a given volume of exchange material, backwashed and in place in the column.

DIFFUSION: Usually referred to ion exchange resins as the diffusion of ions through the ion exchange resin beads.

DISSOCIATE: The process of ionization of an electrolyte or a salt upon being dissolved in water, forming ions of cation and anion.

DOWNFLOW: Conventional direction of solutions to be processed in ion exchange column operation, i.e., in at the top, out at the bottom of the column .

DRY SOLIDS: The matter, usually expressed in weight percent, remaining after liquid removal.

EFFICIENCY: The effectiveness of the operational performance of an ion exchanger. Efficiency in the adsorption of ions is expressed as the quantity of regenerant required to effect the removal of a specified unit weight of adsorbed material, e.g., pounds of acid per kilograin of salt removed.

EFFLUENT: The solution which emerges from an ion exchange column.

ELECTROLYTE: A chemical compound which dissociates or ionizes in water to produce a solution which will conduct an electric current; an acid, base or salt.

ELUTION: The stripping of adsorbed ions from an ion exchange material by the use of solutions containing other ions in relatively high concentrations.

EQUILIBRIUM REACTIONS: The interaction of ionizable compounds in which the products obtained tend to revert to the substances from which they were formed until a balance is reached in which both reactants and products are present in definite ratios.

EQUIVALENT WEIGHT: The molecular weight of any element or radical expressed as grams, pounds, etc., divided by the valence.

EXCHANGE SITES: The reactive groups on an ion exchange resin.

EXCHANGE VELOCITY: The rate with which one ion is displaced from an exchanger in favor of another.

EXHAUSTION: The state in which the resin is no longer capable of useful ion exchange; the depletion of the exchanger's supply of available ions. The exhaustion point is determined arbitrarily in terms of: (a) a value in parts per million of ions in the effluent solution; (b) the reduction in quality of the effluent water determined by a conductivity bridge which measures the electrical resistance of the water.

FMA: The free mineral acidity, or sum of the mineral acids.

FINES: Extremely small particles of ion exchange materials.

FLOW RATE: The volume of solution passing through a given quantity of resin within a given time. Usually expressed in terms of gallons per minute per cubic foot of resin, as milliliters per minute per milliliter of resin, or as gallons per square foot of resin per minute.

FREEBOARD: The space provided above the resin bed in an ion exchange column to allow for expansion of the bed during backwashing.

GRAIN: A unit of weight; 0.0648 grams.

GRAINS PER GALLON: An expression of concentration of material in solution, generally in terms of calcium carbonate. One grain (as calcium carbonate) per gallon is equivalent to 17.1 parts per million.

GRAM-MILLIEQUIVALENTS: The equivalent weight in grams, divided by 1000.

GEL: Ion exchange resins that are made up of firm gel structure in a solid bead form allowing for the diffusion of ions through the gel.

HARDNESS: The scale-forming and lather-inhibiting qualities which water, high in calcium and magnesium ions, possesses. Temporary hardness, caused by the presence of magnesium or calcium bicarbonate, is so called because it may be removed by boiling the water to convert the bicarbonates to the insoluble carbonates. Calcium sulfate, magnesium sulfate, and the chlorides of these two metals cause permanent hardness.

HARDNESS AS CALCIUM CARBONATE: The expression ascribed to the value obtained when the hardness forming salts are calculated in terms of equivalent quantities of calcium carbonate; a convenient method of reducing all salts to a common basis for comparison.

Glossary (continued)

HEADLOSS: The reduction in liquid pressure associated with the passage of a solution through a bed of exchange material; a measure of the resistance of a resin bed to the flow of the liquid passing through it.

HYDRAULIC CLASSIFICATION: The rearrangement of resin particles in an ion exchange unit. As the backwash water flows up through the resin bed, the particles are placed in a mobile condition wherein the larger particles settle and the smaller particles rise to the top of the bed.

HYDROGEN CYCLE: A complete course of cation exchange operation in which the adsorbent is employed in the hydrogen or free acid form.

HYDROXYL: The term used to describe the anionic radical (OH⁻) which is responsible for the alkalinity of a solution.

HYDROXYMETHYL FURFURAL, HMF: 5
(Hydroxymethyl) -2-furaldehyde, a precursor of the coloring matter from the decomposition of glucose and also thereby assisting in the color development in sugars. HMF is produced during contact with strong acid cation resins in H⁺ form at elevated temperatures.

INFLUENT: The solution which enters an ion exchange unit.

ION: Any particle of less than colloidal size possessing either a positive or a negative electric charge.

IONIZATION: The dissociation of molecules into charged particles.

IONIZATION CONSTANT: An expression in absolute units of the extent of dissociation into ions of a chemical compound in solution

ION EXCHANGE: See fundamental description beginning page 8.

KILOGRAIN: A unit of weight; one thousand grains.

LEAKAGE: The phenomenon in which some of the influent ions are not adsorbed or exchanged and appear in the effluent when a solution is passed through an under-regenerated exchange resin bed.

MACROPOROUS: Resins that have a rigid polymer porous network in which there exists a true pore structure even after drying. The pores are larger than atomic distances and are not part of the gel structure.

MONOMER: A single reactive molecule capable of combining with another different monomer to form a polymer. Where two different monomers combine the resulting polymer is called a copolymer.

NEGATIVE CHARGE: The electrical potential which an atom acquires when it gains one or more electrons; a characteristic of an anion.

pH: An expression of the acidity of a solution; the negative logarithm of the hydrogen ion concentration (pH 1 very acidic; pH 14, very basic; pH 7, neutral) .

PHYSICAL STABILITY: The quality which an ion exchange resin must possess to resist changes that might be caused by attrition, high temperatures, and other physical conditions.

POROSITY: An expression of the degree of permeability in ion exchange resins to liquids and large organic molecules. Gel resins, even when referred to as highly porous, have a negligible porosity in comparison to the macropores inherent in the macroporous resins.

POSITIVE CHARGE: The electrical potential acquired by an atom which has lost one or more electrons; a characteristic of a cation.

QUATERNARY AMMONIUM: A specific basic group [-N(CH₃)₃]⁺ on which depends the exchange activity of certain anion exchange resins.

RAW WATER: Untreated water from wells or from surface sources.

REGENERANT: The solution used to restore the activity of an ion exchanger. Acids are employed to restore a cation exchanger to its hydrogen form; brine solutions may be used to convert the cation exchanger to the sodium form. The anion exchanger may be rejuvenated by treatment with an alkaline solution.

REGENERATION: Restoration of the activity of an ion exchanger by replacing the ions adsorbed from the treated solution by ions that were adsorbed initially on the resin.

RINSE: The operation which follows regeneration; a flushing out of excess regenerant solution.

SALT SPLITTING: The conversion of salts to their corresponding acids or bases by passage through ion exchange resins containing strongly acidic or strongly basic functional groups.

SELECTIVITY: The difference in attraction of one ion over another by an ion exchange resin.

SILICEOUS GEL ZEOLITE: A synthetic, inorganic exchanger produced by the aqueous reaction of alkali with aluminum salts.

SPHERICITY: Relating to the spherical nature and whole bead content of a resin.

STRONG ELECTROLYTE RESIN: The equivalent of strongly acidic or strongly basic resins and capable of splitting neutral salts.

SULFONIC: A specific acidic group (SO_3^-) on which depends the exchange activity of certain cation exchange resins

SWELLING: The expansion of an ion exchange bed which occurs when the reactive groups on the resin are converted into certain forms.

THROUGHPUT VOLUME: The amount of solution passed through an exchange bed before exhaustion of the

UPFLOW: The operation of an ion exchange unit in which solutions are passed in at the bottom and out at the top of the container.

VALANCE: A measurement of the number of atoms or ions of hydrogen it takes to combine with or be replaced by an element or radical. In short, the number of positive or negative charges of an ion.

VOID VOLUME: The space between particles of ion exchange resins in a settled bed, also called interstitial volume.

WEAK ELECTROLYTE: The equivalent of weakly acidic or weakly basic resins not capable of splitting neutral salts.

ZEOLITE: A mineral composed of hydrated silicates of aluminum and sodium or calcium. The term has been used, sometimes improperly, to describe softening done by synthetic ion exchange resins.

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