

APPLICATION GUIDE

Cane Sugar Refining with Ion Exchange Resins

Sucrose is extracted from the sugar cane stalk in a cane sugar Mill, purified and crystallized into a tan colored raw sugar. The sugar we consume must be further refined so as to not impart color, flavor or odor to the foods and beverages it sweetens. In a cane sugar Refinery the raw sugar is remelted and the sucrose is further decolorized with ion exchange resins, carbon or bone char and crystallized into white sugar for industry, consumers and confectioners.



Purolite[®]

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Cane Sugar Refining with Ion Exchange Resins

Sucrose is extracted from the sugar cane stalk in a cane sugar **Mill**, purified and crystallized into a tan colored raw sugar. The sugar we consume must be further refined so as to not impart color, flavor or odor to the foods and beverages it sweetens. In a cane sugar **Refinery** the raw sugar is remelted and the sucrose is further decolorized with ion exchange resins, carbon or bone char and crystallized into white sugar for industry, consumers and confectioners. Although the ion exchange resins are used in the refinery, it is useful to understand the mill operations also.

Cane Sugar Mills

Sugar cane plants are grown in tropical climates until maturity when the stalks achieve a 3-5 cm diameter thickness and stand 2-3 meters tall. In some locations, the fields are burned prior to harvest to remove the leaves from the stalks, eliminate green matter from the fields and drive rodents out to make manual cutting easier. The stalks are then cut and trucked to the mill. In other locations the fields are not burned and the leaves remain on the cane sugar stalk during harvesting. Cutting can be done manually or with a mechanical harvester. The leaves and tops are chopped and left in the field.

At the mill, the stalks are removed from the trucks with cranes and dropped into the mill feed shoots. Whole trucks can also be lifted to dump the load of cane stalks into the feed hopper. As the cane shoots feed the stalks toward the mill, a mechanical leveler rakes the stack of cane stalks to a more consistent height. The cutting knives then shred the stalks into small fiber strips.

The strips are fed to a series of 4-6 cane crushing mills which squeeze the sugary juice out of the cane stalks and further reduce the size of the fibers. Water at 70° C is added countercurrent to the fiber movement during the milling operation to assist the extraction of the sugar from the cane stalk fibers. The resulting mill juice has a sugar concentration of approximately 17° Brix. The remaining fiber, called bagasse, is sent to the boiler where it is burned to produce steam and electricity for the mill. The bagasse can produce most, all or even excess energy for the entire mill's needs.

The 17° Brix mill juice is heated to 105° C and mixed with lime, flocculants and CO₂ and sent to a clarifier. In the clarifier the lime destroys non-crystallizable invert sugars and amino acids. The lime and CO₂ combine to form a calcium carbonate precipitate which attracts color and other impurities which adsorb onto the solids. The color-laden precipitated solids sink and are discharged from the bottom of the clarifier while the clarified juice overflows from the top. Alternatively, the clarifier may use air to float the floc to the surface where it is skimmed off and the clarified juice flows out the bottom.

The clarified juice passes through pressure or vacuum filters to remove any residual colored precipitate. The filtered juice, now at 14° Brix due to some dilution during the lime defecation process, passes through a multiple effect evaporator to raise the concentration to 60° to 70° Brix.

The concentrated syrup is fed to the vacuum pans where further evaporation and supersaturation of the sucrose solution occurs. Crystallization of the sucrose occurs in the first vacuum pan and the resulting mixture of sugar crystals and syrup, called massecuite, is dropped into a centrifuge.

The centrifugal spins the mixture at high speed to separate the lighter colored sucrose crystals from the darker colored syrup (machine syrup). The sucrose crystals are retained by the centrifugal screens. After the dark syrup is spun off, the raw sugar is dropped out of the bottom of the centrifugal.

The tan raw sugar crystals from the first (A pan) crystallization are either sent to an attached cane refinery for further purification to white sugar or they are dried and shipped to non-associated refineries. The machine syrup, still containing a large amount of syrup, but at lower purity and higher color, is sent to the B vacuum pan for further crystallization of sucrose. The B pan sugar recovered is mixed with the concentrated syrup fed to the A pan. The B pan machine syrup is fed to the C pan. C pan sugar is added to B pan feed. C pan machine syrup is fed to a crystallizer. Crystallization of sucrose becomes more difficult as the impurity level in the syrup rises. In the crystallizer, the sucrose is further reduced until the remaining syrup contains only about 50% sucrose. This syrup, at 80° Brix, is called blackstrap molasses and is sold as an animal feed additive.

Cane Sugar Refinery

Sugar Receiving

Some refineries are attached to cane mills while others are stand alone facilities. In a stand alone sugar refinery, raw sugar will arrive in bulk by barge, rail or trucks for unloading into the raw sugar warehouse. The raw sugar will undergo metal and debris removal and large lumps will be crushed prior to transfer to the mingler to begin remelting and refining.

Affination

The raw sugar is mingled with hot affination syrup which melts just the outermost layer of the raw sugar crystal. This outer layer contains the largest concentration of color. The resulting syrup from melting of the outer layer, is separated from the sugar crystals in a centrifuge. The bulk of the colorants are removed during the affination step (about 50% of raw sugar color) and then during the clarification step (about 40% of melt liquor color).

Melter

The affinated sugar is dissolved with hot condensate to a liquid concentration of approximately 72° Brix at 75°C prior to defecation.

Defecation/Clarification

Approximately 40% of the remaining colorants are removed in the clarification step. There are two alternative types of defecation processes in use in cane refineries, carbonatation and phosphatation:

Carbonatation, also called carbonation, involves adding lime (CaO) to the melt liquor and then passing this juice through a carbonation vessel where carbon dioxide (CO₂) is bubbled up through the juice. The reaction of the carbon dioxide with the lime produces a calcium carbonate precipitate. Color bodies are entrapped in the precipitate and are removed during filtration of the solids. Another action occurring in the limed melt liquor is destruction of invert sugars at the high pH produced by the lime. Polymers are added to the juice to assist in the formation of a precipitate floc which is more easily settled and filtered.

Phosphatation involves addition of lime (CaO) and phosphoric acid (H₃PO₄ or P₂O₅) to the melt liquor which results in formation of a calcium phosphate precipitate. Color bodies adsorb onto the calcium phosphate precipitate and are removed during the subsequent clarification and filtration. Polymers are added to aid in the formation of a precipitate floc which is more easily filtered.

Filtration

The clarified juice from carbonatation or phosphatation contains suspended solids which would plug the interstitial spaces and blind the pores of decolorization resin, bone char or carbon. Precoat vacuum filters, precoat pressure filters, deep bed multimedia filters or some combination of these are used to produce a filtered syrup which will flow through the decolorization columns without causing a pressure buildup.

Decolorization

Several techniques can be used for removing color from the sugar juice and they are subject to continuous developments. The main ones being:

- **Activated carbon:** Numerous types of activated carbon are available in the marketplace according to the precursor carbonaceous material (coal, wood, coconut, etc.) and their size. The most common types used for sugar juice decolorization being powdered activated carbon (usually termed as PAC) and granular activated carbon (GAC).
- **Polymeric media:** This term mostly refers to synthetic ion exchange resins or adsorbent resins (functionalized or not). There are 2 main polymeric structures commercially available which differ by their hydrophobicity; the styrenic matrix which tends to be more hydrophobic and the acrylic structure which is hydrophilic. In addition to their chemical structure, polymeric adsorbents exhibit some important porosity.
- **Bone char:** Pyrolyzed ground animal bones have a high surface area which adsorbs color and remove some ash.

Evaporation

The raw sugar was melted to 72° Brix to lower the viscosity for filtration and decolorization, but requires a much higher Brix to achieve a supersaturated sugar concentration for crystallization in the vacuum pans which are effectively single effect evaporators. Multiple effect evaporators are used to improve steam economy while raising the Brix from 68° Brix (after dilution) to approximately 80° Brix.

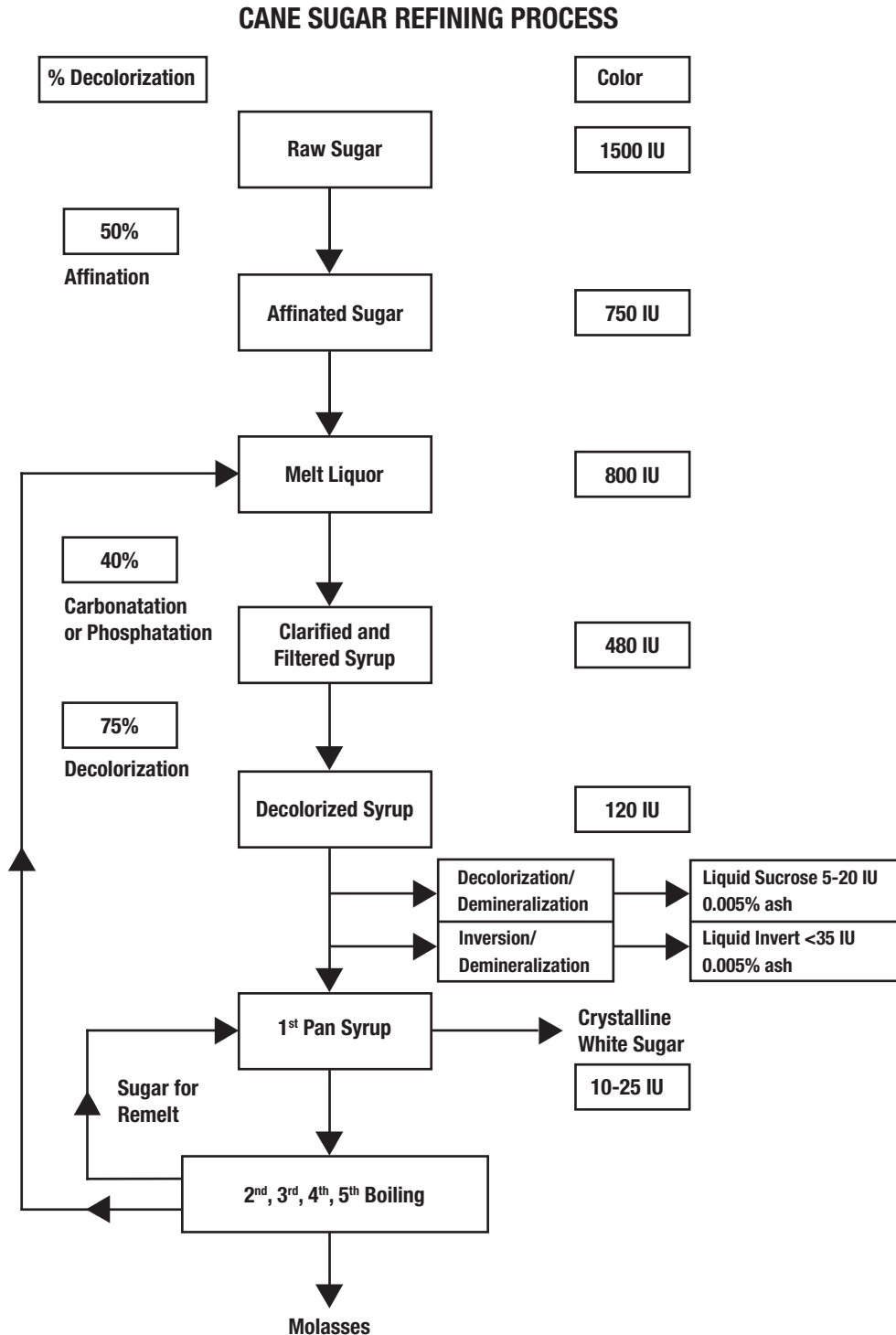
Crystallization

Evaporative crystallization of the 98° Pol (sucrose purity) decolorized syrup occurs in a heated vacuum pan. As the water evaporates from the syrup, the solution becomes supersaturated. The mix is seeded with fine sucrose crystals which initiate uniform crystal growth. As the crystals grow, most of the color bodies are excluded from the crystal. The first strike sugar crystals will have a color approximately 1/10th that of the pan liquor. The massecuite is then dropped into a centrifugal where the crystals are separated from the remaining liquor and washed with a small amount of hot water to remove any adhering color bodies. The liquor, now at a reduced purity of 92-94° Pol is sent to another vacuum pan for further crystallization of white sugar. The sugar produced from the second pan is higher in color than from the first, but still meeting white sugar specifications.

After the purity of the massecuite approaches about 50° Pol, crystallization of additional sugar becomes very energy intensive. The resulting syrup is called molasses. It is possible to use chromatographic separation to enrich the purity of the cane molasses to 90+° Pol where additional sugar can be recovered, but the pretreatment to remove waxes and proteins which foul the chromatographic separation resin limits the economics of this process.

Amorfo Sugar

An alternative product to crystalline or liquid sugar is the microcrystalline Amorfo Sugar which is produced primarily in Brazil and to a much lesser degree in Mexico. Amorfo is produced by rapid crystallization (45 seconds) under intense agitation in an open pan. This process results in nearly 100% yield and has the advantage of low capital cost, low steam and power consumption, no molasses and high production ratio per equipment. Since there is no separation from the mother liquor, it is necessary to start with low color sugar (50 IU) with minimum impurities and reducing sugars less than 0.2%. Ion exchange decolorization and demineralization is used to achieve the level of purity required.



Decolorization with Ion Exchange Resins

Ion exchange resins used in the sugar industry as decolorizers are of the strong-base anionic type, with quaternary amine functional groups. They are operated in the chloride form.

The resin matrix is usually composed of one of two types of polymeric material: polystyrenic with divinylbenzene crosslinks, resulting in a hydrophobic matrix, or a polyacrylic with divinylbenzene crosslinks which results in a more hydrophilic matrix.

Some refineries, for the major decolorization, use only one resin type, acrylic or styrenic. Others employ an acrylic resin followed by a styrenic resin for polishing. The acrylic resin removes large molecular weight colored compounds which tend to foul the styrenic resin, providing good protection to the polishing resin.

Acrylic resins have a slightly lower selectivity for sugar colorants but, unlike polystyrenic resins, they can be completely regenerated with sodium chloride solutions. This can be explained by the more hydrophilic character of the acrylic resin matrix. Even dark regenerant effluents from styrenic resins can be used to regenerate acrylic resins. The use of acrylic resin is justified when the color load is high and a low level of decolorization may be expected. Also, the use of a two pass system gives a more constant level of decolorization than when only one resin bed is used.

Styrenic resins are more prone to fouling by organic compounds than acrylic resins and need occasional acid regeneration. Also, their decolorization capacity is higher than that of acrylic resins, but the color is not so efficiently removed during regeneration and capacity can drop rapidly if overloaded.

Styrenic resins have a higher decolorization power because of their ability to fix colorants both through ionic bonds to the ionic active groups and through hydrophobic interactions with the resin matrix. Hydrophobic interactions increase with salt concentration, explaining the difficulty of using salt solutions to remove colorants fixed to the resin matrix.

Polystyrenic resins with an aromatic matrix should have a higher affinity for unsaturated colorants than acrylic resins.

Styrenic resin types are favored when the inlet color is on the low end (i.e. up to 800 ICUMSA) and acrylic types when it is higher. Numerous plants today operate with a combination of both types, which is advisable when the inlet feed color fluctuates during the season.

Colorants

The sugar colorants are a very complex mixture of organic compounds from various sources. They can be categorized into two main types, natural colorants resulting from the cane plant and those developed during the juice processing. The main characteristics of the colorant to be removed are that they are mainly hydrophobic (non-polar) and they cover a large range of molecular weights (Table 1). They exhibit anionic behavior.

Table 1: Colorant Classification

Natural Colorants			Colorants Developed During Juice Processing		
Flavonoids	Melanins	Chlorophylls Xanthophylls Carotene	Melanoidins	Caramels	HADPs
			Maillard Reaction Products	Glucose and Fructose Degradation in Acidic Media	Hexose Alkaline Degradation Products
<1kDa	>150kDa	<1kDa	<50kDa	<25kDa	1 to 5kDa

Table 2 below compares the color removal efficiency of adsorbents for various color compounds.

Table 2: Colorants Removal Efficiency

% of Component Removed by Adsorbent

Components	Carbon	Styrenic SBA	Acrylic SBA
Total Color	78	83	65
Color > 20 kDa	62	83	55
Phenolic Colorant	70	50	50
Polysaccharides	20	30	15
Starch	16	15	20
Dextran	30	40	10

kDa is kiloDalton or a thousand Daltons. A Dalton is the atomic mass unit.

Color Removal Mechanism

Two main mechanisms are involved in sugar colorant fixation to strong base anion exchange resins: ionic bonding between anionic colorants and the resin's fixed charges, and hydrophobic interaction between non-polar parts of the colorant and the styrene divinylbenzene resin matrix.

Since most sugar colorants have an anionic nature, being charged negatively, strong base anionic resins are efficient decolorizers. However, both mechanisms can affect the same colorant molecule in amplified ionic binding. Carboxylic acids and phenols of low molecular weight are fixed by chemical reaction and by molecular interaction to the resins. Large, high molecular weight organic acids can be bound chemically and by interaction at several different resin sites, reinforcing the binding, and making their removal from the resin difficult.

Also, colorants fixed to resin can switch from one mechanism to the other during regeneration. This may explain the high efficiency of styrenic resins as sugar decolorizers when new, the difficulty of removing colorants from them during regeneration, and the rapid decrease of their efficiency in use.

It has been claimed that about 10% of the resin ion exchange capacity is actively involved in decolorization, most probably on the surface of the resin beads. It has also been suggested that most of the decolorization of strong base polystyrenic resins (except at high pH) occurs in the resin structure and not at the functional groups. This is due to the relatively high electronic density in the aromatic structure, which is attractive for non-polar and electrophilic species. At high pH values, ion exchange mechanisms will predominate.

Adsorption of sugar colorants to ion exchange resins are governed by:

- Colorant molecular weight
- Charge density
- Type of charge (highly anionic, weakly anionic, amphoteric or weakly cationic)
- Degree of hydrophobicity
- pH
- Ionic strength of the medium.

Several mechanisms have to be considered:

Steric effect: The colorants vary in molecular weight; thereby the porosity of the decolorizing media is a key parameter. The molecular weight of sugar colorants varies from 30 kDa to 1000 kDa for cane sugar. In order to achieve good decolorization kinetics the ratio of micropores, meso pores and macropores is an important parameter. This illustrates why the decolorization of sugar juices is carried on at relatively low flow rate.

Hydrophobic effect: Activated carbon has a virtually non-polar surface whereas polymeric adsorbents have a polarity (acrylic matrix decolorizers are more hydrophilic than the styrenic ones). The colorants are basically hydrophobic (not highly soluble in water) and will tend to be adsorbed on the hydrophobic part of the adsorption media. This is most probably the main mechanism in color removal. Pure polymeric adsorbents have demonstrated their effectiveness in removing colored species (high hydrophobicity, high surface area). Being not functionalized (or slightly) they can operate in a salty

environment. Their osmotic stability results in a very long life time and they can withstand very aggressive conditions (temperature, pH, concentration, and oxidant media). They are very effective in polishing steps and can be considered as an alternative to powdered activated carbon.

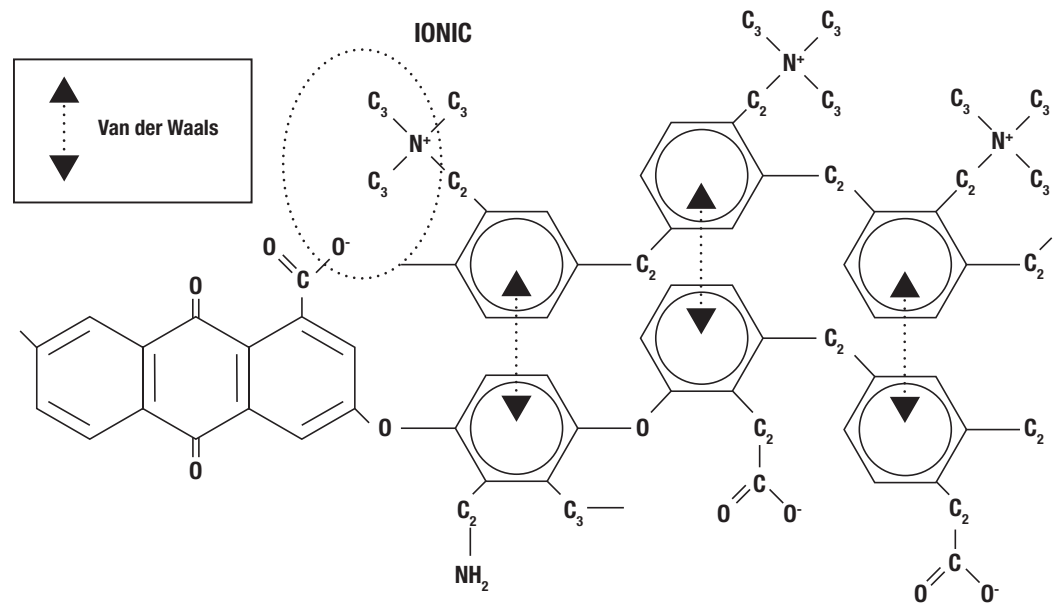
Van der Waals forces effect: These are attractive forces between chemical groups in contact. They result from a temporary dipole formation. Van der Waals force bonding is the main adsorption mechanism taking place on the surface of activated carbon

Ion exchange: The colorants exhibit mostly an anionic behavior at alkaline pH and thereby they can be exchanged against the mobile chloride ions. This results in an ionic bond (electrostatic attraction) between the resins positively charged ionic group and the negatively charged part of the colorant. However this mechanism is not the predominant one in color removal.

Hydrogen bonds: It is an electrostatic attraction that occurs between molecules in which hydrogen is in a covalent bond with a highly electronegative element (oxygen or nitrogen).

The main mechanism for granular activated carbon adsorption is the Van der Waals (or London) force binding. Ion exchange resin decolorization process is a combination of several phenomena (Fig 1) such as ion exchange, hydrogen bonds and London forces.

Figure 1. Ion Exchange Resin Adsorption Mechanism



Note: Subscripts after C refer to number of H atoms not shown.

Table 3 provides a comparison of the 3 different anionic decolorization resins primarily being used today, macroporous acrylic, macroporous styrenic and gelular styrenic.

Table 3: Properties of Acrylic and Styrenic Strong Base Anion Decolorization Resins

	A860S Acrylic Macroporous	A502PS Styrenic Macroporous	A420S Styrenic Gel
Primary Decolorization Mechanism	Ion Exchange	Adsorption	Adsorption
Typical Decolorization	50-60%	65-75%	65-75%
Regeneration Efficiency	Excellent	Good	Good
Regenerant	10% NaCl	10% NaCl/0.5% NaOH	10% NaCl/0.5% NaOH
Matrix	Aliphatic	Aromatic	Aromatic
Max Feed Color IU	2500	800	200
Color Loading BV x IU (68 Bx)	35,000	25,000	20,000

Advantages of Ion Exchange Resin Decolorization

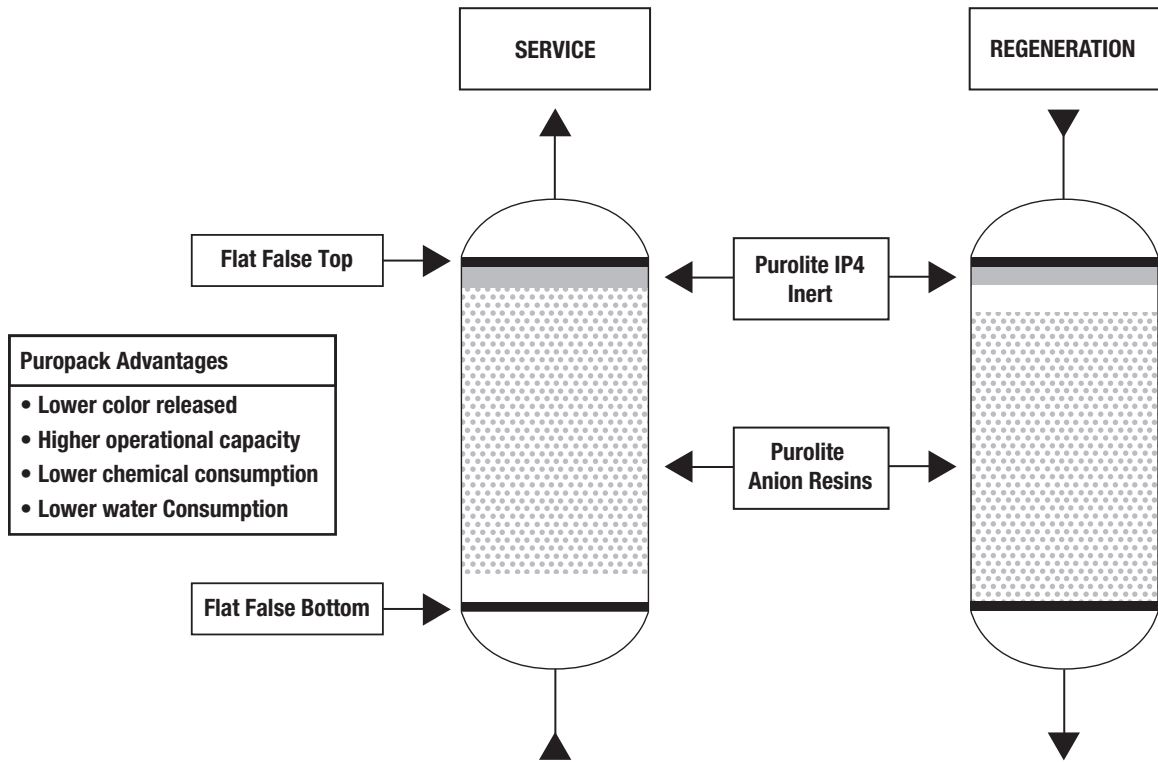
Cost: One advantage of ion exchange resins as sugar decolorizers is economy. The costs are considered to be about half those of traditional granular carbon or bone char methods. These costs comprise resin and char uses, energy, labor, maintenance, sugar losses and costs due to greater ash. Water use decreases from 30% to 50% per sugar output. Energy savings arising from use of resins come mostly from lower hot water requirements, and lower volumes of sweetwater produced, with consequent reductions in energy needed for heating and concentration, respectively. As brine is cheap, regeneration cost is low, so resin decolorization is a low cost alternative to traditional methods such as activated carbon or bone char.

Equipment Size: Flow rate is also much greater through resin than alternative materials. Thus, less bulky apparatus is needed for given liquor flows. Also, shorter retention times reduce sucrose degradation during decolorization. As regeneration can be performed inside resin columns, no special handling systems or other equipment for regeneration are required.

Automation: The resin process is easily automated, and the liquor and adsorbent are always contained inside a closed vessel, so the process is more hygienic than other decolorization processes.

Puopack Packed Bed Upflow System

A typical configuration for ion exchange decolorization system is an upflow packed bed system such as Purolite's Puopack System. Since the specific gravity of 68 Brix syrup is 1.3325 (@standard conditions) and the specific gravity of strong base anion resin is 1.09, the flow of syrup during decolorization service is often run upflow to ensure the bed is undisturbed during a service flow interruption. A schematic of the operation and the advantages of Puopack are shown below.

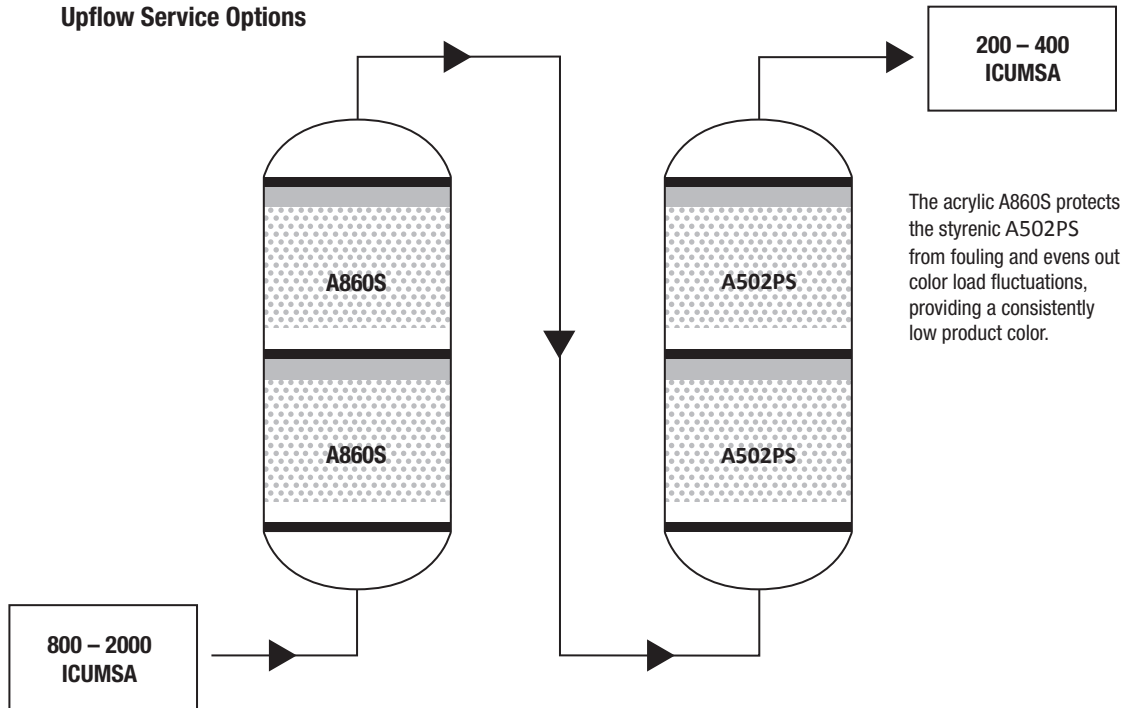


Service

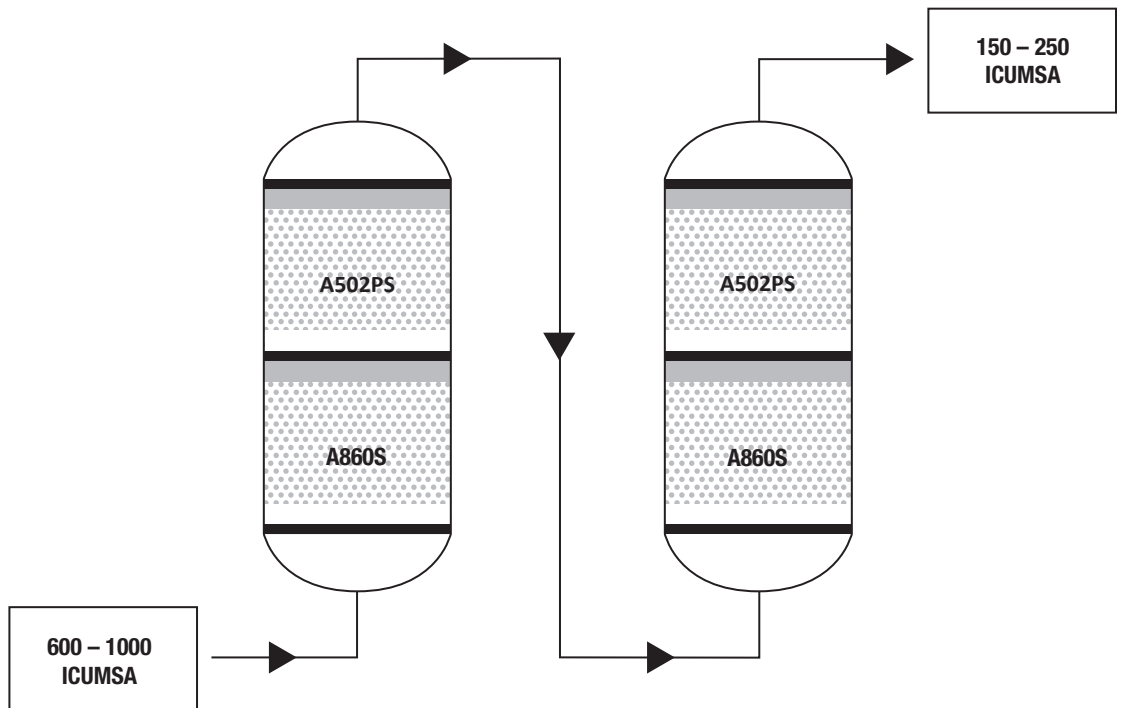
The typical service flow rate is 2.0-4.0 bed volumes/hour. (i.e. Syrup flowing through a bed containing 10 m³ of resin operating at 2 bed volumes/hour (BV/hr) would be flowing at 20 m³/hr)

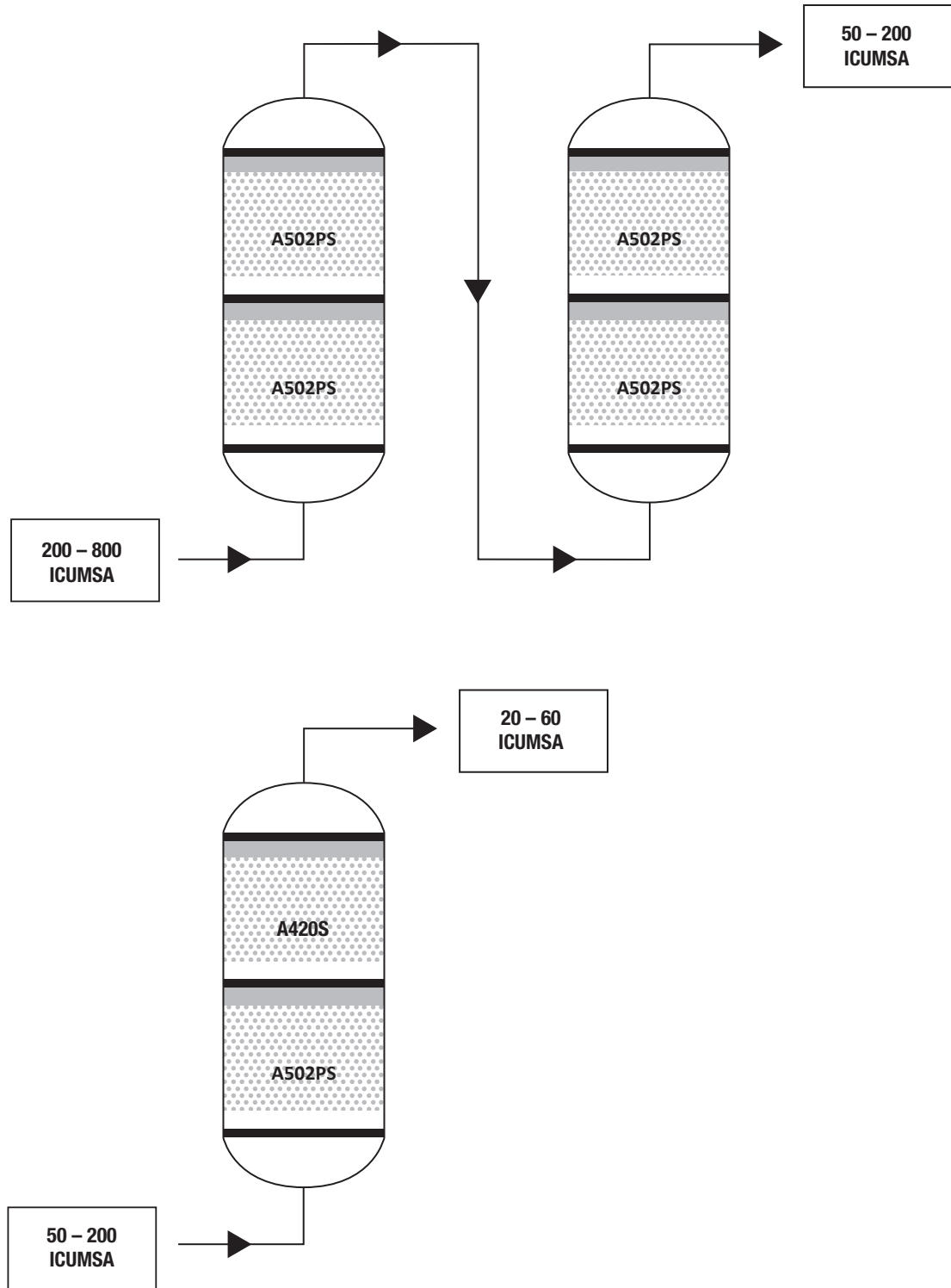
The following diagrams illustrate the configuration and performance achieved by decolorization resins.

Upflow Service Options

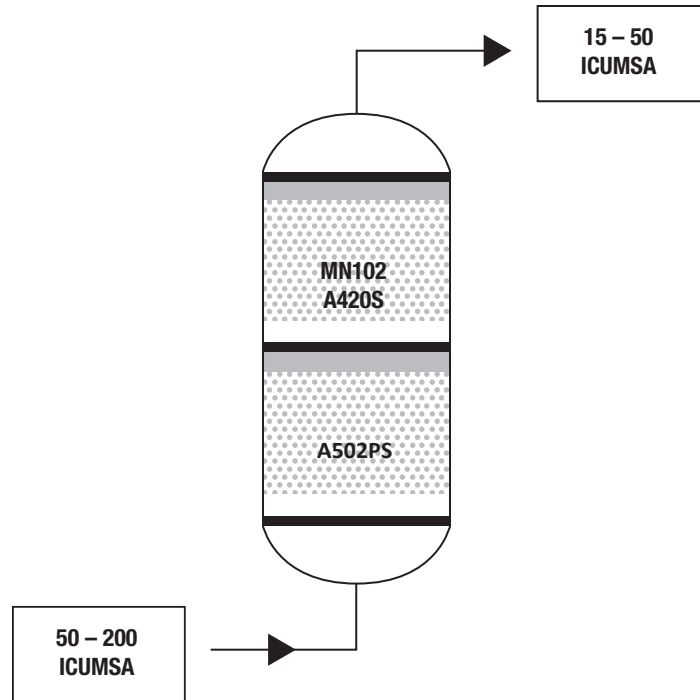


The acrylic A860S protects the styrenic A502PS from fouling and evens out color load fluctuations, providing a consistently low product color.





Decolorization With Additional Taste and Odor Removal



Taste and Odor Removal

Cation resin is often used in conjunction with the decolorization anion resin because it is regenerated with the same NaCl regenerant that passes through the anion. It is used ahead of the anion resins when softening of the juice is desired to reduce the hardness scale formation on evaporators and crystallizers which lowers the heat transfer rate. It is also used after the styrenic anion resins to remove amine odor which can occur from the use of the NaOH for anion regeneration. The cation resin will readily exchange Na^+ for amine. Since it is regenerated with the same NaCl regenerant that passes through the anion, no additional brine is required for cation regeneration.

Macronet adsorbent MN150 or MN102 can be used as a final color, taste and odor polishing adsorbent to achieve the highest decolorizer product quality. By virtue of its lighter density, the Macronet will layer on the top of an upflow anion decolorization resin so a small volume of it can replace some of the decolorizer resin and no separate vessel is required. The alkaline brine regeneration of the decolorizer resin is first preceded by NaOH only to regenerate the Macronet.

Regeneration

Color bodies are desorbed from the strong base anion resins using a 10% NaCl solution (for acrylic strong base anion resin) or a mixture containing 10% NaCl and 0.5% NaOH (for styrenic strong base anion resin). The NaCl solution dehydrates the resin forcing exchanged and adsorbed color bodies out. The regeneration is concentration dependent and not stoichiometric. It requires a salt concentration inside the resin bead to be 4+% NaCl which usually requires 10% NaCl in solution to achieve this. The NaOH provides additional desorption energy.

The regeneration flow direction is downflow at a rate of 2.0 bed volumes/hour.

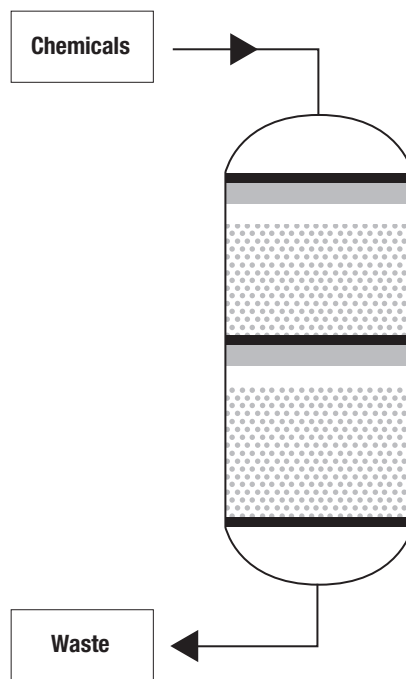


Table 4: Regeneration Sequence

Operation	Solution	Flow	Time	Volume	Temp	Dose
Sweeten Off	Condensate	2-4 BV/hr	30-60 min	1.5-2 BV	60-80° C	
Chemical In	10% NaCl 0.5% NaOH	1-2	60-90	2-3	60-80	200 gm NaCl/L+ 10 gm NaOH/L
Slow Rinse	Condensate	1-2	45-60	1.5-2	60-80	
Fast Rinse	Condensate	10-20	15-30	3-5	60-80	
Sweeten On	Sugar Syrup 68° Bx	2-4	30-60	1-2	70-80	
Service	Sugar Syrup 68° Bx	2-4			70-80	

An external backwash is recommended to remove fines and suspended solids when pressure drop achieves 2 Kgf/cm² or 30 psi in the bed or during special cleaning.

Special Cleaning for Sugar Decolorization Resins

It is strongly recommended to use the procedure below for decolorization resins every 30 cycles or when an important drop in throughput is noticed.

It is very important that resin be regenerated prior to beginning this treatment.

Step 1: Prepare 2 BV solution with 6% HCl or 10% H₃PO₄

Step 2: Pass half the volume of acid solution at a flow rate of 1 BV/h for one hour downflow

Step 3: Introduce second half and keep for 2 hours in contact with resin. Injection of air every 20 minutes assists in declumping

Step 4: Pass condensate or demineralized water at 3 BV/h downflow for 1 hour

Step 5: Rinse resin bed with condensate or demineralized water at 8 BV/h downflow until pH = 7.0

After completing this procedure, perform a normal regeneration but with twice the standard amount of NaOH in order to neutralize residual acid and the acid adsorbed onto the small amount of weak base sites of the resin.

The acid cleaning should restore decolorization performance for an extended period if the resin is in good shape. As the resin nears the end of its life, the acid cleaning will provide a more temporary improvement in decolorization.

Regeneration without NaCl

It has been observed that NaCl, alone or alkalized with NaOH is not the best regenerant for this kind of resin.

It has been suggested that during regeneration at high salt concentration amphiphilic compounds will be fixed to the resin by hydrophobic interaction. During salt washing, as salt concentration decreases, these compounds will be removed from the resin matrix but will be fixed to the ionic groups (switch effect). Washing the resin at low pH, however, can avoid this. Another possibility is to regenerate the column at a low chloride concentration in the presence of calcium in an alkaline medium; a process developed by Dr. Luis Bento. Sucrose is added in order to maintain calcium in solution. During this regeneration, hydrophobic interaction is reduced and colorants are removed from the ionic bond; possibly through formation of a colorant/calcium/sucrose complex.

As mentioned above, NaCl does not efficiently remove sugar colorants from ion exchange resins because at high concentrations it does not remove compounds fixed by hydrophobic interactions to the resin matrix. An organic solvent, such as ethanol, mixed with salt can be used to improve removal of hydrophobic colorants. With this mixture, salt will remove anionic colorants and ethanol will decrease the hydrophobic interaction effect. This has been tried using a mixture of NaCl, at 100 g/l, and Ethanol, at 20% (v/v), with a great improvement in removal of colorants from the resin. Although efficient, this process is not economical if applied to each regeneration.

Another possibility, as mentioned above, is to use salt at low concentration with a mixture of calcium hydroxide in sucrose solution. This mixture greatly enhances the removal of colorants fixed to ion exchange resins. The formation of a complex sucrose-calcium-colorant, may shift the equilibrium towards regeneration. Thus, chloride ions, even at low concentration, can efficiently dislocate colorants fixed ionically to resins. At low salt concentrations, non-polar colorants are also easily removed. A regeneration process using 3BV of a mixture of CaCl (0.4N) and CaO (10g/l) in sucrose solution (150g/l) has been tried, for instance.

With this regeneration process, a higher level of decolorization is obtained. An average decolorization of more than 90% is obtained; better than results with standard regenerations using alkalized salt solutions. Colorants adsorbed on the resin matrix may form a layer with a degree of anionic character. During regeneration, not all colorants are removed and doubly positively-charged calcium ions may be bonded to this layer, producing extra positive fixed ions in the resin. This may explain the increase of resin capacity often found when using this regeneration system.

This regeneration process uses lower quantities of chemicals than classic regeneration systems. However, it is necessary to use sucrose to maintain the calcium hydroxide in solution. In order to recover sucrose from the effluents, tangential filtration techniques are used. An ultra-filtration (UF) membrane has been used to concentrate colorants in the retentate, while the permeate was used in the regeneration process. The retentate, with minor proportions of the sucrose, calcium and chloride ions, and the major part of the sugar colorants, can be sent to affination and/or recovery sections of the refinery or to the low grade sections of sugar factories. As this effluent is highly alkaline it can be used to make pH corrections in such processing units, instead of the more commonly-used lime.

Regeneration using sodium carbonate has also been tried. In this process, carbonate ions bind to the resin and during decolorization the ions are released to sugar liquor where they precipitate any calcium ions present. Average carbonated liquor decolorization of 89% and decalcification of 70% has been achieved with this technique.

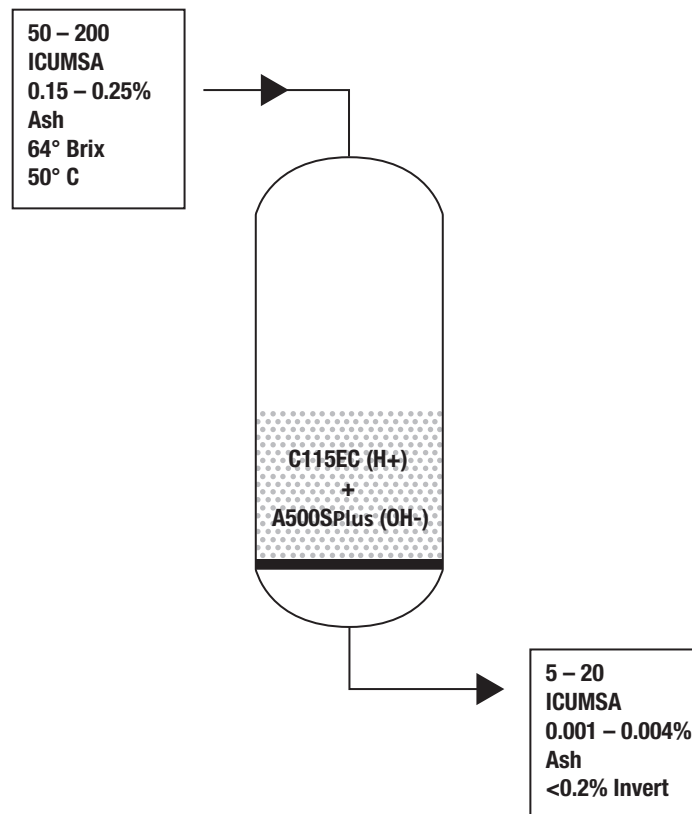
Demineralization of Liquid Sugar

Liquid Sucrose

When highly refined liquid sucrose is desired for customers who prefer to receive liquid instead of dry sugar, there are a few options for producing a non-inverted liquid sucrose product.

1. Weak Acid Cation Mixed Bed

One process for producing liquid sugar involves passing the high Brix, moderate temperature liquid sucrose through a mixed bed containing a high pK weak acid cation resin (H⁺ form) and strong base anion resin (OH⁻ form). This process produces a liquid sucrose with <0.2% invert and color <20 ICUMSA.



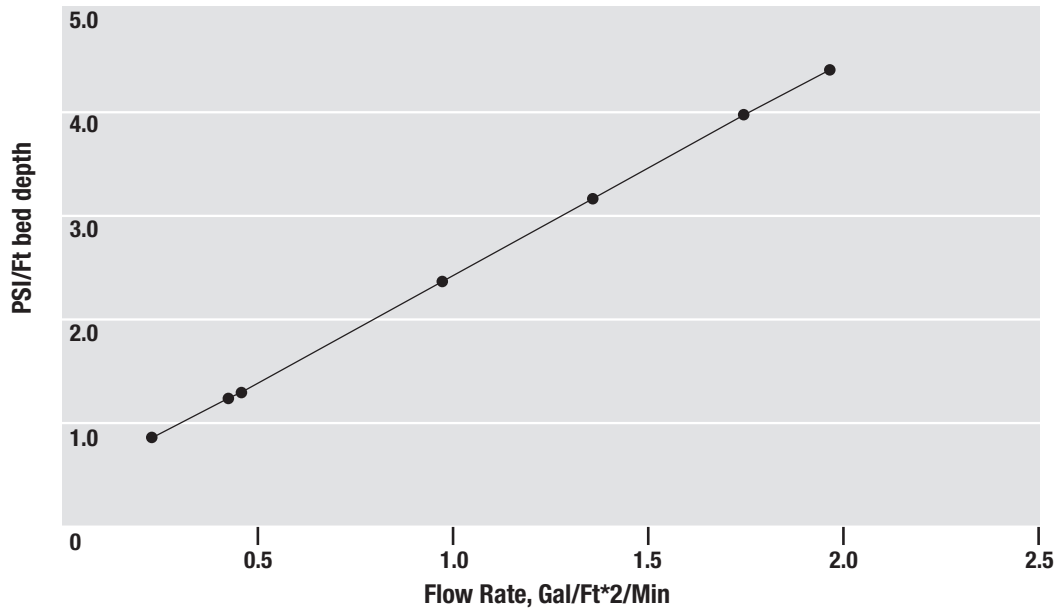
Weak Acid Cation Mixed Bed

Feed Color	50-200 ICUMSA
Feed Ash	0.15-0.25% on DS
Product Color	5-20 ICUMSA
Product Ash	0.001-0.004% on DS
Inversion	<0.2%
Brix	55-65° Brix
Temperature	50°C
Flow	0.5-1.0 Bed Volumes/Hour

Pressure Drop of Mixed Bed 1/3 C-115EC(H+) + 2/3 PFA-500S(OH-)

67° Brix Sucrose, 60° C, 1.85 Foot Bed Depth

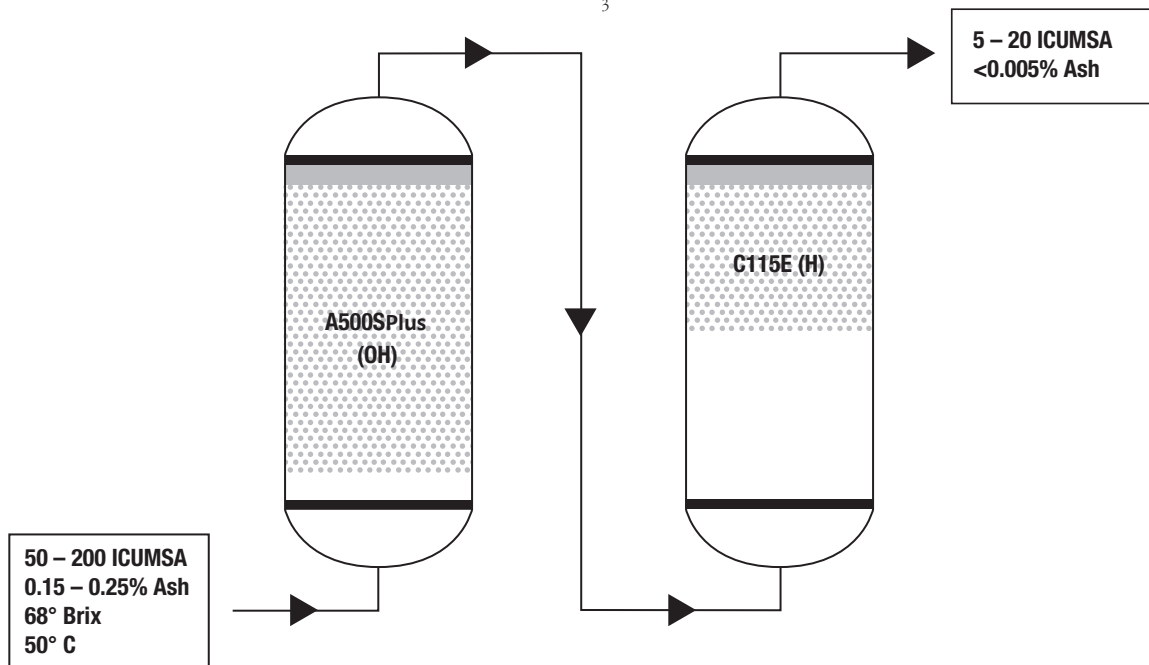
$y = 2.0454x + 0.3617$



2. Strong Base Anion / Weak Acid Cation Two Bed

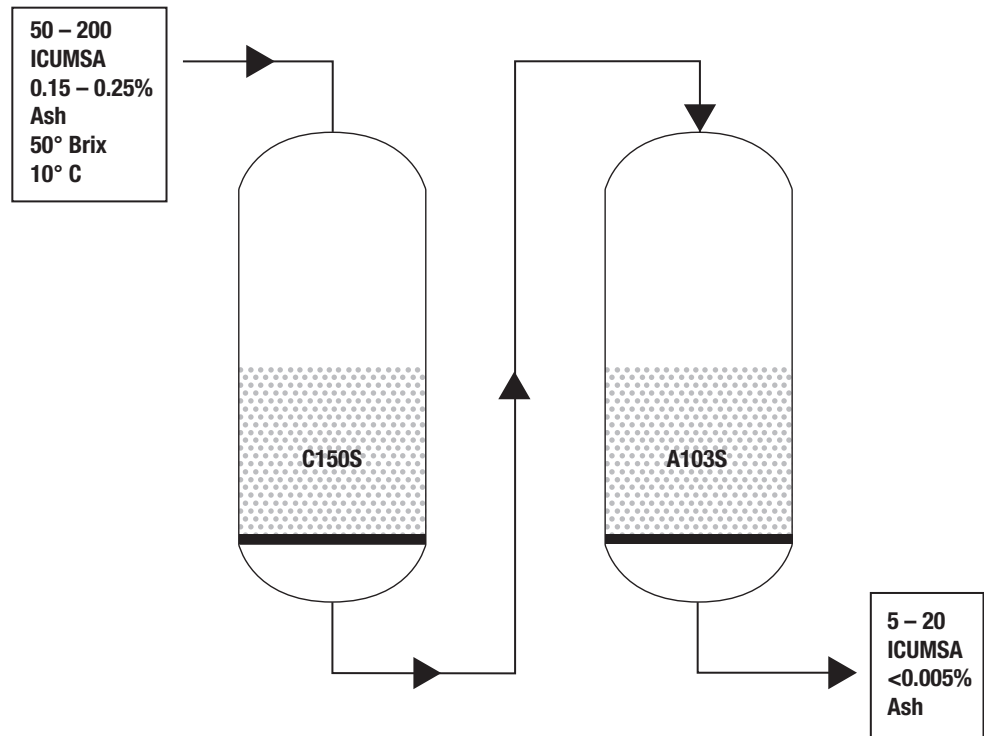
The sucrose solution can be decolorized and demineralized by passing first through a bed of strong base anion (OH- form) to convert all the salts to base and then passing through a separate bed of high pK weak acid cation resin which will exchange the cations and neutralize the base. The weak acid cation effluent pH will be approximately 4.0 and must be either blended with a sidestream of syrup to bring the pH up to avoid inversion or run through a SAC (Na) to exchange H+ for Na+ or run through a WBA to adsorb acidity.

In order to avoid precipitation of $Mg(OH)_2$ or $CaCO_3$ in the resin bed, either a cation resin can be used to soften the syrup or the anion can be run in the HCO_3^- form which will produce more highly soluble bicarbonate salts. Conductivity reduction and color removal will be somewhat less in the HCO_3^- form.



3. Low Temperature Strong Acid Cation/Weak Base Anion Two Bed

The liquid sucrose can be treated through a macroporous cation resin (H⁺ form) followed by weak base anion resin (free base form) for removal of salts and color to below liquid sugar standards. This process requires a treatment temperature less than 10° C to avoid sucrose inversion. To be able to operate at this low temperature without high viscosity causing pressure drop and kinetic problems, the syrup concentration must be below about 50° Brix. The liquid sucrose must then be evaporated back up to 80° Brix prior to storage and shipment to avoid bacteria growth.



4. Powdered Resin – Decolorization

Ion exchange resin can be ground into fine 50-100 micron size pieces which are added as a body feed to the syrup and filtered out with a pressure filter. The finely ground resin has rapid kinetics and a greater surface area than the same amount of bead resin. The powdered resin can be mixed with an inert fiber to assist in achieving high filtration rate with low pressure drop. The powdered resin is used on a once through basis and discarded. The advantage of powdered resin is the simple equipment requirement and lack of regeneration chemicals.

Powdered resin can be cost effective at low color levels, reducing 50-100 IU sugar to 20-35 IU.

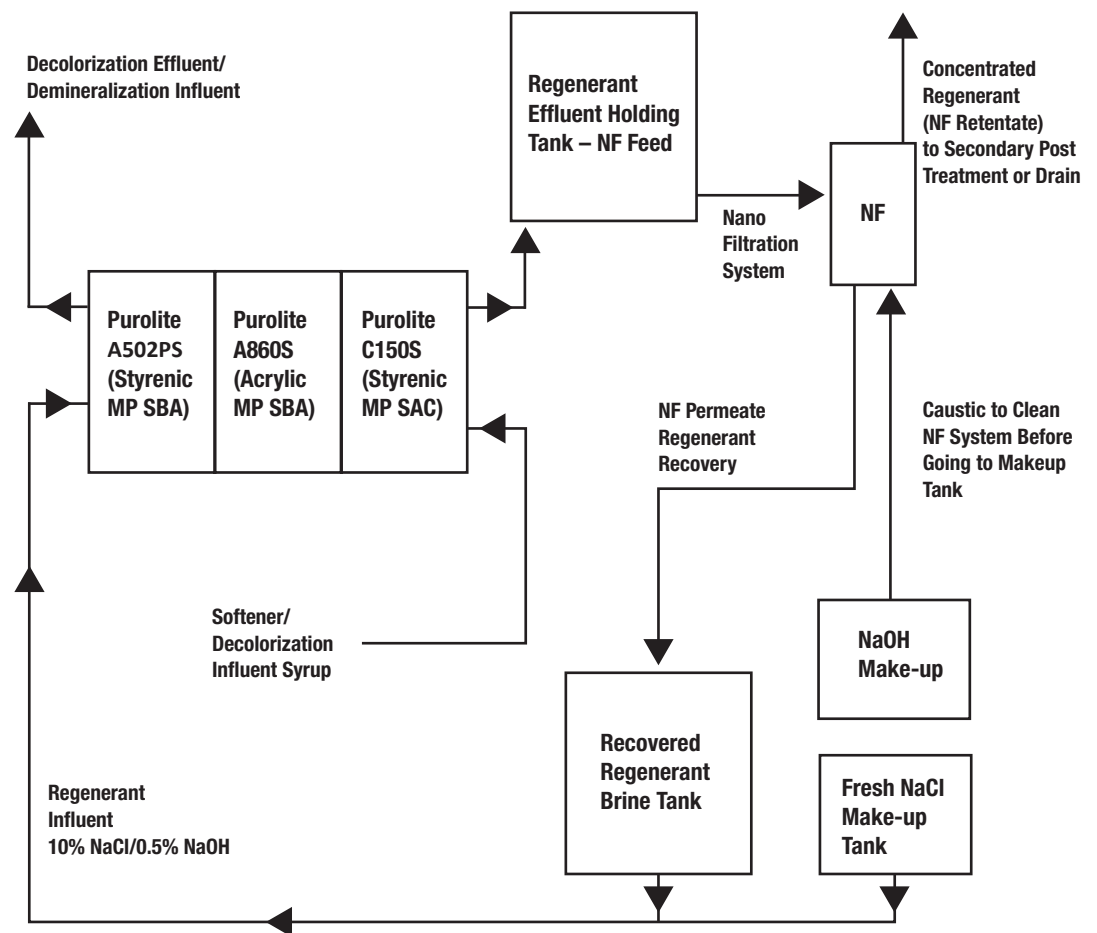
5. Powdered Resin – Demineralization

The same strong base anion and weak acid cation resins used in bead form in a column are available in powdered resin form which can be used to produce high purity sugar when melting white sugar. A 35 IU white sugar can be melted and purified to <20 IU and the ash level reduced. A powdered strong acid cation and strong base anion mix including fiber is also used to polish low color syrup. The low dosage of the powdered mix prevents significant inversion from occurring.

Nanofiltration Recovery of Regenerants

One of the main drawbacks of an ion exchange resin decolorization process is the production of wastes during the regeneration procedure. The production of highly colored salty effluents has found an answer with the use of nanofiltration (NF). The brine recycling plant permits a decrease in the waste rejection up to 75-90%. The retentate contains a concentrated fraction of BOD which can more easily be disposed of and the permeate containing NaCl and small color bodies can be reused for regenerating the decolorizing resin. This combination of resin and membrane processes is especially attractive for plant locations where the waste disposal is a critical issue.

Regenerant Recovery System



Lab Testing Protocol

PROTOCOL FOR LABORATORY TESTING OF ANION RESINS FOR SUCROSE DECOLORIZATION

1. Discussion of the Treatment Process

The following test protocol is based on Purolite's experience with sucrose decolorization with strong base anion resins. It is suitable for demonstrating the feasibility of the process and for testing the effectiveness of the regeneration procedures. The information generated will be a guide to the design of a full scale continuous plant. As this process is well established industrially it is not anticipated that intermediate scale testing will be required.

The customer should have the following information before running the tests:

- As full an analysis as possible of the syrup to be treated and its consistency over the anticipated campaign runs particularly with respect to color and any other property to be modified e.g. odor.
- The specification of the color and other components in the treated syrup.
- Analytical methods for the color and other properties to be modified.

2. Delivered Resin

The following tests should be carried out using the Purolite Anion resins supplied by Purolite for the purpose of these tests.

3. Apparatus

The test program will require one column as defined below. As the tests are to be carried out at elevated temperature the column should be water jacketed to maintain the required operating temperature.

The resin should be loaded into the water jacketed glass column fitted with a means of retaining the resin at the base of the column. This may be either:

- A sintered glass disc
- A nylon cloth fitted into a Quickfit or other flanged fitting.

The sintered disc method is preferred.

The bottom of the columns should be fitted with a tap for on/off and flow adjustment and for connecting a line for flow entry and exit. The exit line from the column can be raised to the height just above that of the resin bed to prevent the liquid level in the column from falling below the resin bed top. It can also be fitted with a siphon breaker for down-flow operation.

The top of each column should be fitted with an attachment for flow introduction and exit and should have sufficient space between the resin bed top and the column exit for at least 75% bed expansion with an additional 25% freeboard.

The column should have a minimum diameter of 1 inch (2.5 cm). Recommended minimum resin volumes for columns of different diameters are as follows:

- 200 ml for a column of 2.5 cm diameter, resulting bed height approximately 40 cm.
- 1200 ml for a column of 5 cm diameter, resulting bed height approximately 60 cm.

A column of approximately 2.5 cm diameter is preferred for resin comparison purposes as the volumes of resin and solutions are more manageable at this scale.

4. Column Filling

The column is most easily filled by pouring the measured volume of resin in via a funnel as a slurry in deionized water. As the column fills with water it can be drained to just above resin bed height via the bottom tap. Air bubbles in the resin bed are avoided by this method.

5. Resin Backwashing

After loading into the columns the resins should be backwashed using an upflow of deionized water to classify and remove any extraneous material. The flow should be introduced slowly to prevent the resin rising as a plug in the column. Backwashing is carried out at ambient temperature and should expand the bed by approximately 75% and continue for 10 minutes. After stopping the backwash flow the resin should be allowed to settle, drained to just above the top of the resin bed and the bed height measured and recorded.

6. Syrup Preparation

For treatment in the Anion columns the feed syrup should be that produced by the process at the same temperature.

A sufficient quantity of the feed syrup for each run should therefore be available. This may be as a batch carefully stored at the required temperature.

Before beginning the tests the syrup should be analyzed for the major components of interest and the treated syrup specification to meet end use requirements should have been identified. Methods of analysis should also have been identified to measure the required components and arrangements made for the analysis.

It is preferable to use a single source of the same syrup and to operate without interrupting the flow during the length of the syrup feed run.

7. Service Operation

The feed syrup should be preheated and the resin bed temperature controlled by passing water at the same temperature through the water jacket of the column. The resin beds can be preheated by passing water at the specified temperature through the bed and the bed temperature should be maintained at the same temperature throughout the period of the feed flow.

As noted in item 4. above, the column should be drained to just above the resin bed top. The feed syrup should be carefully introduced in downflow at a rate of 2 bed volumes (BV) per hour i.e. for 2 BV /hour and for 200 ml of resin the feed flow will be 400 ml/hour. If the resin at the top of the resin bed begins to float it can be retained in position by a plug of polyurethane sponge or glass wool which should be removed at the end of the feed flow cycle. The feed flow rate should be carefully controlled and recorded throughout the syrup flow cycle. A reservoir of feed at the top of the bed should be maintained at all times so that the resin bed never operates dry.

Samples of treated syrup should be taken periodically from the exit of the Anion column and analyzed for color, and any other components required, to obtain a record of the resin performance in the form of a color breakthrough profile. A sampling regime i.e. the frequency of sampling required, may be less frequent at the start of the feed flow period than towards the anticipated end of the cycle.

It is anticipated that 100 to 150 BV of syrup can be treated each cycle depending on the influent color level (200 to 300 ICUMSA)

Flow should be stopped as soon as possible when the color or other component end point is reached.

At the end of the cycle the syrup should be drained to just above the top of the resin bed and the bed height measured and recorded.

Summarizing the data which should be measured and recorded:

- Feed syrup analysis for major components of interest.
- Temperature of the resin, recording temperature throughout the feed flow cycle.
- Flow rate through the column recorded at regular recorded intervals of time after flow started (at time zero), recording the time of each measurement.
- Treated syrup analysis for major components of interest at the exit of the column at regular recorded intervals of time after time zero. These intervals will be widely spaced until breakthrough is anticipated and will then decrease in order to obtain a breakthrough concentration profile for color etc.
- Resin bed height before syrup flow starts and after syrup flow has been stopped.
- Resin color and any gradation of color down the bed noted.

8. Syrup Displacement (Sweetening Off)

Syrup displacement from the bed is carried out on the full production scale either by air or using softened water preferably at the same temperature as the feed syrup and the displaced syrup is retained. On the scale of the laboratory tests displacement by 3 BV of softened water in downflow at a flow rate of approximately 2 to 4 BV/hour is recommended.

9. Resin Backwashing

Resin backwashing is carried out by an upflow of demineralized water preferably at the same temperature as the feed syrup. The flow should be slowly introduced to prevent the resin from rising in the column as a plug. When the resin is fully fluidized the flow should be adjusted to expand the bed by 75% and be continued for 15 minutes. After stopping the backwash flow the bed should be allowed to settle, drained to just above the bed top and the bed height measured and recorded.

10. Resin Regeneration and Rinsing

The resin regeneration should be carried out in four steps:

a) 2.0 BV of 10 % NaCl at 1 – 2 BV/hour at a dosage of 200 g/L with 0.5 % NaOH (10 g/L resin) (60 to 90 minutes)

b) Rinse using 2 BV of condensate at 1 to 2 BV/hour flow rate. (45 – 60 minutes)

c) Rinse using 5 BV of condensate at 10 – 20 BV/hour. (15 – 30 minutes)

The regenerant flow rate should be carefully controlled to achieve even flow through the bed. A reservoir of regenerant should be maintained above the resin bed top.

To obtain useful design data samples of regenerant may be taken periodically and analyzed for the components of interest. The time when the concentration of the color bodies in the solution has reduced to insignificant levels should be noted.

The bed height should be measured and noted at the end of each of the above steps.

11. Number of Cycles

The above procedure should be repeated using the same anion bed for a sufficient number of cycles to achieve equilibrium and to observe the extent of any fouling of the resins. If fouling is observed or if cycle times are observed to decrease from cycle to cycle then Purolite will advise what action should be taken. This will normally involve modifying the regeneration procedure using dilute HCl solution (cross regeneration).

12. Application of Test Data

The results from the above tests will demonstrate the anion decolorization process and will provide a guide for the design of the next scale of operation for syrup decolorization.

Technical Information

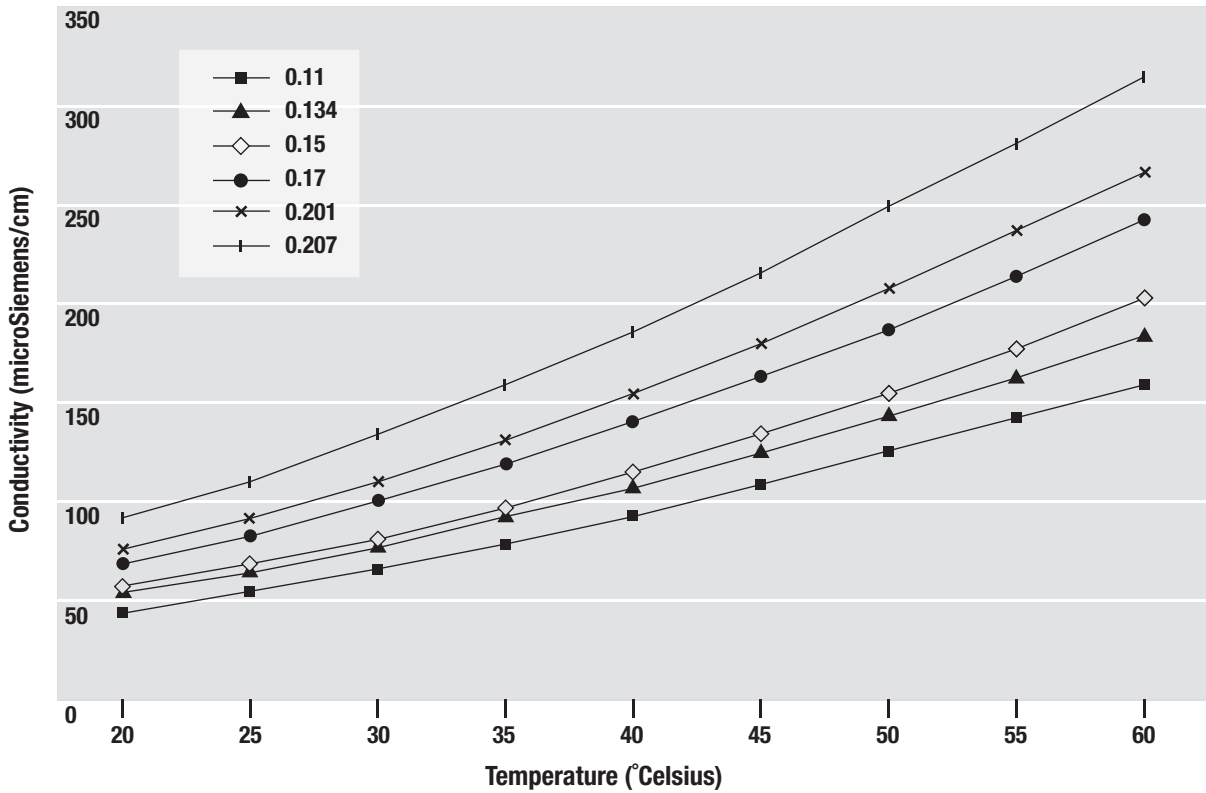
PHYSICAL CONSTANTS OF SUCROSE

% DS	AT 20°C 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

PHYSICAL CONSTANTS OF SUCROSE (continued)

% DS	AT 20°C REFRACTIVE INDEX	SPECIFIC GRAVITY IN AIR	TOTAL POUNDS PER GALLON	TOTAL SOLIDS PER GALLON
45.0	1.4084	1.2036	10.016	4.507
46.0	1.4104	1.2089	10.060	4.627
47.0	1.4124	1.2141	10.104	4.749
48.0	1.4144	1.2194	10.148	4.871
49.0	1.4364	1.2248	10.192	4.994
50.0	1.4184	1.2302	10.237	5.118
51.0	1.4205	1.2356	10.282	5.244
52.0	1.4225	1.2410	10.327	5.370
53.0	1.4246	1.2465	10.373	5.497
54.0	1.4267	1.2520	10.418	5.626
55.0	1.4287	1.2575	10.464	5.755
56.0	1.4309	1.2631	10.511	5.886
57.0	1.4330	1.2687	10.557	6.018
58.0	1.4351	1.2743	10.604	6.150
59.0	1.4373	1.2800	10.651	6.284
60.0	1.4394	1.2857	10.699	6.419
61.0	1.4416	1.2914	10.747	6.555
62.0	1.4439	1.2972	10.795	6.693
63.0	1.4460	1.3030	10.843	6.831
64.0	1.4483	1.3088	10.891	6.970
65.0	1.4505	1.3147	10.940	7.111
66.0	1.4528	1.3206	10.989	7.253
67.0	1.4550	1.3265	11.039	7.396
68.0	1.4573	1.3325	11.088	7.540
69.0	1.4596	1.3385	11.138	7.685
70.0	1.4620	1.3445	11.188	7.832
71.0	1.4643	1.3506	11.239	7.980
72.0	1.4667	1.3567	11.290	8.129
73.0	1.4690	1.3628	11.341	8.279
74.0	1.4714	1.3690	11.392	8.430
75.0	1.4738	1.3752	11.444	8.583
76.0	1.4762	1.3814	11.496	8.737
77.0	1.4787	1.3877	11.548	8.892
78.0	1.4811	1.3940	11.600	9.048
79.0	1.4836	1.4004	11.653	9.206
80.0	1.4861	1.4067	11.706	9.365
81.0	1.4886	1.4131	11.760	9.525
82.0	1.4911	1.4196	11.813	9.687
83.0	1.4937	1.4261	11.867	9.850
84.0	1.4962	1.4326	11.921	10.014
85.0	1.4988	1.4391	11.976	10.183

Ash [% on DS] vs Conductivity at Temperature



VISCOSITY [CENTIPOISE] OF SUCROSE SOLUTIONS

% SUCROSE BY WEIGHT IN VACUUM	°Celsius								
	0	5	10	15	20	25	30	35	40
20	3.782	3.137	2.642	2.254	1.945	1.695	1.493	1.325	1.184
1	3.977	3.293	2.768	2.357	2.031	1.769	1.555	1.379	1.231
2	4.187	3.460	2.904	2.469	2.124	1.846	1.622	1.436	1.281
3	4.415	3.642	3.050	2.589	2.224	1.931	1.692	1.497	1.333
4	4.661	3.838	3.208	2.719	2.331	2.021	1.769	1.563	1.390
5	4.931	4.051	3.380	2.859	2.447	2.118	1.852	1.634	1.451
6	5.223	4.282	3.565	3.010	2.573	2.223	1.941	1.709	1.516
7	5.542	4.533	3.767	3.175	2.708	2.336	2.037	1.791	1.587
8	5.889	4.807	3.986	3.352	2.855	2.459	2.140	1.880	1.663
9	6.271	5.107	4.225	3.546	3.015	2.592	2.251	1.974	1.744
30	6.692	5.435	4.487	3.757	3.187	2.735	2.373	2.078	1.833
1	7.148	5.794	4.772	3.988	3.376	2.892	2.504	2.188	1.927
2	7.653	6.187	5.084	4.239	3.581	3.062	2.645	2.306	2.029
3	8.214	6.623	5.428	4.515	3.806	3.246	2.799	2.437	2.141
4	8.841	7.106	5.808	4.818	4.052	3.448	2.967	2.578	2.260
5	9.543	7.645	6.230	5.154	4.323	3.670	3.150	2.732	2.390

VISCOSITY [CENTIPOISE] OF SUCROSE SOLUTIONS (continued)

	% SUCROSE BY WEIGHT IN VACUUM									
	0	5	10	15	20	25	30	35	40	
	°Celsius									
6	10.31	8.234	6.693	5.524	4.621	3.914	3.353	2.901	2.532	
7	11.19	8.904	7.212	5.933	4.950	4.182	3.573	3.083	2.687	
8	12.17	9.651	7.791	6.389	5.315	4.476	3.815	3.285	3.856	
9	13.27	10.49	8.436	6.895	5.718	4.803	4.082	3.506	3.039	
40	14.55	11.44	9.166	7.463	6.167	5.164	4.375	3.747	3.241	
1	16.00	12.53	9.992	8.102	6.671	5.565	4.701	4.014	3.461	
2	17.67	13.76	10.93	8.821	7.234	6.014	5.063	4.310	3.706	
3	19.58	15.17	11.98	9.630	7.867	6.515	5.467	4.639	3.977	
4	21.76	16.77	13.18	10.55	8.579	7.077	5.917	5.004	4.277	
5	24.29	18.60	14.55	11.59	9.383	7.710	6.421	5.412	4.611	
6	27.22	20.72	16.11	12.77	10.30	8.423	6.988	5.869	4.983	
7	30.60	23.15	17.91	14.12	11.33	9.231	7.628	6.381	5.400	
8	34.56	25.99	19.98	15.67	12.51	10.15	8.350	6.960	5.868	
9	39.22	29.30	22.39	17.47	13.87	11.20	9.171	7.613	6.395	
50	44.74	33.18	25.21	19.53	15.43	12.40	10.11	8.358	6.991	
1	51.29	37.76	28.48	21.94	17.24	13.78	11.18	9.203	4.669	
2	59.11	43.18	32.34	24.76	19.34	15.37	12.41	10.17	8.439	
3	68.51	49.64	36.91	28.08	21.79	17.23	13.84	11.20	9.321	
4	79.92	57.42	42.38	32.00	24.68	19.39	15.49	12.57	10.34	
5	93.86	66.82	48.90	36.65	28.07	21.93	17.42	14.06	11.50	
6	111.0	78.27	56.79	42.23	32.12	24.92	19.68	15.80	12.86	
7	132.3	92.35	66.39	48.96	36.95	28.48	22.35	17.83	14.44	
8	159.0	109.5	78.15	57.12	42.78	32.73	25.51	20.22	16.29	
9	192.5	131.5	92.70	67.12	49.84	37.83	29.28	23.06	18.46	
60	235.7	159.1	110.9	79.49	58.49	44.03	33.82	26.46	21.04	
1	291.6	194.2	133.8	94.91	69.16	51.60	39.32	30.53	24.11	
2	364.6	239.5	163.0	114.3	82.42	60.92	46.02	35.45	27.80	
3	461.6	298.6	200.4	138.9	99.08	72.49	54.27	41.46	32.26	
4	591.5	376.5	249.0	170.4	120.1	87.00	64.48	48.84	37.69	
5	767.7	480.7	313.1	211.3	147.2	105.4	77.29	57.97	44.36	
6	1013	621.9	398.5	264.9	182.0	128.8	93.45	69.40	52.61	
7	1355	816.1	513.7	336.3	227.8	159.1	114.1	83.82	62.94	
8	1846	10.88	672.1	432.6	288.5	198.7	140.7	102.3	75.97	
9	2561	1476	892.5	564.0	370.1	251.1	175.6	126.0	92.58	
70	3628	20.38	1206	746.9	481.6	321.6	221.6	157.0	114.0	
1	5253	2871	1658	1006	636.3	417.8	283.4	198.0	142.0	
2	7792	4136	2329	1379	854.9	551.0	367.6	253.0	178.9	
3	11876	6103	3340	1929	1170	738.9	484.3	327.9	228.5	
4	18639	9245	4903	2759	1631	1009	648.5	431.6	296.0	
5	30207	14428	7402	4039	2328	1405	884.8	577.4	389.5	

VISCOSITY [CENTIPOISE] OF SUCROSE SOLUTIONS (continued)

% SUCROSE BY WEIGHT IN VACUUM	°Celsius							
	45	50	55	60	65	70	75	80
20	1.07	0.97	0.88	0.81	0.74	0.68	0.63	0.59
1	1.11	1.00	0.91	0.84	0.77	0.71	0.65	0.61
2	1.15	1.04	0.95	0.87	0.79	0.73	0.68	0.63
3	1.20	1.09	0.98	0.90	0.82	0.76	0.70	0.65
4	1.25	1.13	1.02	0.93	0.85	0.79	0.73	0.67
5	1.30	1.17	1.06	0.97	0.89	0.82	0.75	0.70
6	1.36	1.22	1.11	1.01	0.92	0.85	0.78	0.72
7	1.42	1.28	1.16	1.05	0.96	0.88	0.81	0.75
8	1.49	1.34	1.21	1.10	1.00	0.92	0.85	0.78
9	1.56	1.40	1.26	1.14	1.04	0.96	0.88	0.81
30	1.64	1.47	1.32	1.20	1.09	1.00	0.92	0.85
1	1.71	1.54	1.38	1.25	1.14	1.04	0.96	0.88
2	1.80	1.61	1.45	1.31	1.19	1.09	1.00	0.92
3	1.89	1.69	1.52	1.37	1.25	1.14	1.04	0.96
4	2.00	1.78	1.60	1.44	1.31	1.19	1.09	1.00
5	2.11	1.87	1.67	1.51	1.37	1.25	1.14	1.05
6	2.23	1.98	1.76	1.59	1.44	1.31	1.19	1.10
7	2.36	2.09	1.86	1.67	1.51	1.37	1.25	1.15
8	2.51	2.21	1.97	1.76	1.59	1.44	1.31	1.20
9	2.67	2.35	2.08	1.86	1.67	1.52	1.38	1.26
40	2.84	2.49	2.21	1.97	1.76	1.60	1.45	1.32
1	3.02	2.65	2.34	2.08	1.86	1.88	1.53	1.39
2	3.23	2.82	2.49	2.21	1.97	1.77	1.61	1.46
3	3.45	3.01	2.65	2.35	2.09	1.88	1.69	1.54
4	3.71	3.22	2.83	2.50	2.22	1.99	1.79	1.63
5	3.98	3.46	3.02	2.66	2.36	2.11	1.90	1.71
6	4.29	3.71	3.24	2.85	2.52	2.25	2.01	1.82
7	4.64	4.00	3.48	3.05	2.70	2.40	2.14	1.93
8	5.01	4.32	3.75	3.28	2.89	2.56	2.29	2.05
9	5.45	4.68	4.05	3.53	3.10	2.74	2.44	2.19
50	5.94	5.07	4.38	3.81	3.34	2.94	2.61	2.34
1	6.49	5.52	4.75	4.12	3.60	3.17	2.81	2.50
2	7.11	6.03	5.16	4.47	3.89	3.42	3.02	2.69
3	7.83	6.61	5.64	4.87	4.23	3.70	3.26	2.89
4	8.63	7.27	6.18	5.30	4.60	4.001	3.52	3.12
5	9.57	8.02	6.79	5.81	5.01	4.36	3.82	3.37

VISCOSITY [CENTIPOISE] OF SUCROSE SOLUTIONS (continued)

% SUCROSE BY WEIGHT IN VACUUM	°Celsius							
	45	50	55	60	65	70	75	80
6	10.7	8.88	7.50	6.38	5.49	4.76	4.16	3.66
7	11.9	9.88	8.30	7.04	6.03	5.20	4.54	3.98
8	13.4	11.1	9.22	7.80	6.65	5.72	4.97	4.34
9	15.1	12.4	10.3	8.65	7.36	6.30	5.45	4.75
60	17.0	14.0	11.6	9.66	8.17	6.98	6.00	5.20
1	19.4	15.8	13.0	10.9	9.11	7.75	6.64	5.74
2	22.2	17.9	14.8	12.2	10.2	8.63	7.38	6.35
3	25.6	20.5	16.7	13.8	11.5	9.68	8.23	7.05
4	29.7	23.7	19.1	15.7	13.0	10.9	9.21	7.87
5	34.7	27.05	22.0	17.9	14.8	12.4	10.4	8.81
6	40.8	32.1	25.5	20.6	16.9	14.1	11.8	9.93
7	48.4	37.7	29.8	23.9	19.4	16.1	13.4	11.3
8	57.8	44.7	35.1	27.9	22.6	18.4	15.3	12.8
9	69.8	53.3	41.6	32.9	26.3	21.4	17.6	14.7
70	84.9	64.4	49.7	39.0	31.0	25.0	20.4	16.8
1	105	78.4	59.9	46.6	36.7	29.4	23.8	19.5
2	131	96.5	73.0	56.1	43.9	34.9	28.0	22.8
3	165	121	89.7	68.4	52.9	41.7	33.3	26.9
4	209	152	112	84.1	64.6	50.3	39.9	32.0
5	271	193	141	105	79.6	61.4	48.2	38.3

Regenerant Concentrations

Sodium Chloride

% NaCl	GRAMS NaCl/l	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

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

Linear 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

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

Conversions (continued)

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:

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

Pressure Equivalents

LBS. PER SQ. IN.	FEET OF WATER*	METERS OF WATER*	INCHES OF MERCURY**	ATMOSPHERES	KILOGRAMS PER SQ. CM.
1.000	2.31	2.31	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

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	3360	3.360
0.132	6	3360	3.360
0.157	5	4000	4.000

Resin Technical Data

CANE SUGAR REFINING RESINS

RESIN	PUROLITE® A860S	PUROLITE® A502PS	PUROLITE® A420S	HYPERSOL- MACRONET® MN102	HYPERSOL- MACRONET® MN150	PUROLITE® IP4
Type	Acrylic Macroporous Type I Strong Base Anion	Styrenic Macroporous Type I Strong Base Anion	Styrenic Gel Type I Strong Base Anion	Styrenic Macroporous Adsorbent	Styrenic Macroporous Adsorbent	Polypropylene Inert Cylinders
TEC	0.8 eq/L (Cl-)	0.85 eq/L (Cl-)	0.8 eq/L (Cl-)	0.15-0.3 eq/L	0.15-0.3 eq/L	NA
Moisture	66-72% (Cl-)	66-72% (Cl-)	60-65% (Cl-)	50-60% (FB)	50-60% (FB)	NA
Mean Particle Size	0.52-0.70 mm	0.65-0.9 mm	0.65-0.9 mm	0.45-0.63 mm	0.45-0.63 mm	1.1-1.5 mm 0.8-1.6 mm
Application	Decolorization 800+ IU	Decolorization 200-800 IU	Decolorization 0-200 IU	Decolorization, Taste and Odor Removal 0-200 IU	Decolorization, Taste and Odor Removal 0-200 IU	Upflow Distributor Protection

RESIN	PUROLITE® C115EC	PUROLITE® A500SPlus	PUROLITE® A850S	PUROLITE® A440S	PUROLITE® PRA420	PUROLITE® CT124SH
Type	Methacrylic Macroporous Weak Acid Cation	Styrenic Macroporous Type I Strong Base Anion	Acrylic Gel Type I Strong Base Anion	Styrenic Gel Type I Strong Base Anion	Powdered Styrenic Gel Type I Strong Base Anion	Styrenic Gel Strong Acid Cation
TEC	3.5 eq/L (H+)	1.15 eq/L (Cl-)	1.25 eq/L (Cl-)	1.4 eq/L (Cl-)	0.8 eq/L (Cl-)	1.2 eq/L (H+)
Moisture	46-53% (H+)	57-63% (Cl-)	57-62% (Cl-)	50-54% (Cl-)	60-65% (Cl-)	65-70% (H+)
Mean Particle Size	0.55-0.8 mm	0.65-0.9 mm	0.65-0.9 mm	0.65-0.9 mm	0.05-0.10 mm	0.65-0.9 mm
Application	Demineralization	Demineralization and Decolorization	Demineralization and Decolorization	Demineralization and Decolorization	Decolorization 0-100 IU	Sucrose Inversion

TEC = Total Exchange Capacity

IU = ICUMSA color units

NA = Not Applicable

PF Grade = Purofine (Uniform Particle Size) Grade Available at 0.52-0.62 mm Average Size

PP Grade = Puropack (Uniform Particle Size) Grade Available at 0.6-0.7 mm Average Size

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 de-aerating.

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)

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.

TANK CAPACITIES

DIA. FT.	AREA SQ. FT.	GALLONS PER FOOT OF DEPTH	DIA. FT.	AREA SQ. FT.	GALLONS PER FOOT OF DEPTH
1.0	0.785	5.87	10.0	78.54	587.5
1.5	1.767	13.22	10.5	86.59	647.7
2.0	3.142	23.50	11.0	95.03	710.9
2.5	4.909	36.72	11.5	103.9	777.0
3.0	7.069	52.88	12.0	113.1	846.0
3.5	9.621	71.97	12.5	122.7	918.0
4.0	12.57	94.00	13.0	132.7	992.9
4.5	15.90	119.0	13.5	143.1	1071
5.0	19.63	146.9	14.0	153.9	1152
5.5	23.76	177.7	14.5	165.1	1235
6.0	28.27	211.5	15.0	176.7	1322
6.5	33.18	248.2	15.5	188.7	1412
7.0	38.48	287.9	16.0	201.1	1504
7.5	44.18	330.5	18.0	254.5	1904
8.0	50.27	376.0	20.0	314.2	2350
8.5	56.75	424.5			
9.0	63.62	475.9			
9.5	70.88	530.2			

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.

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 deashing, embraces the removal of all charged constituents or ionizable salts (both inorganic and organic) from solution. See deashing.

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.

Glossary (continued)

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.

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.

Glossary (continued)

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 [$-N(CH_3)_3+$] 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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