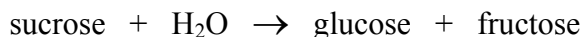


SUGAR REFINING

Sugar was first manufactured from sugar cane in India, and its manufacture has spread from there throughout the world. Chemically, sugar is the substance sucrose, which can be hydrolysed in acidic solution (i.e. below pH 7) to form the monosaccharides glucose and fructose as follows.



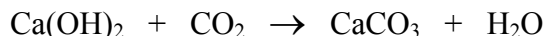
In New Zealand sugar is refined by the New Zealand Sugar Company Ltd. from cane sugar imported from Australia, Cuba and Fiji. A four step process is used, but since March 1996 the first three steps have been carried out overseas.

Step 1 - Affination

The raw sugar is mixed with a saturated syrup and then centrifuged to extract the crystals. Surface impurities (molasses) dissolve in this syrup and are removed.

Step 2 - Carbonatation

The sugar is redissolved and calcium hydroxide and carbon dioxide are added to the solution. These react according to the following equation



Colour, gum and amino acid impurities precipitate out with the calcium carbonate.

Step 3 - Char filtration

Activated charcoal is added to the syrup, removing colour and inorganic ash.

Step 4 - Crystallisation

The solution is boiled under vacuum and the crystal growth monitored to produce particular sizes of crystal.

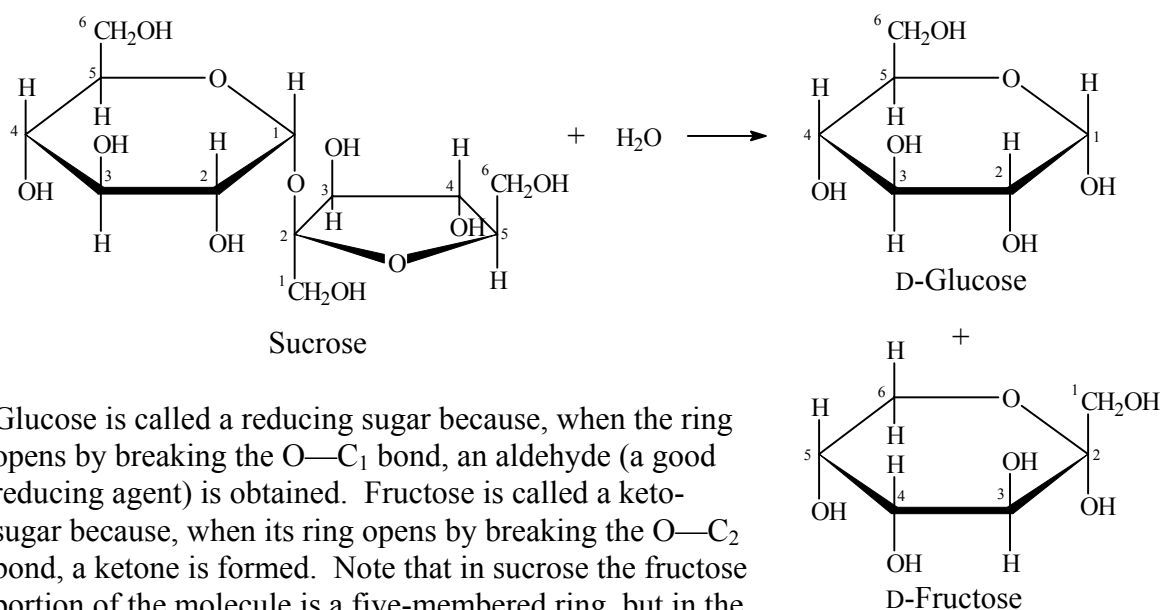
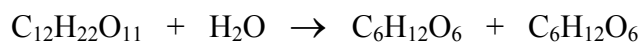
The sugar is made into a variety of different products (raw sugar, golden syrup, treacle, soft brown sugar, coffee crystals, 1A sugar, castor sugar, liquid sugar) with varying amounts of glucose, fructose and inorganic impurities.

Pollution is minimised by ensuring complete fuel combustion, monitoring liquid and gaseous effluents. The solid mud from carbonatation is buried on site.

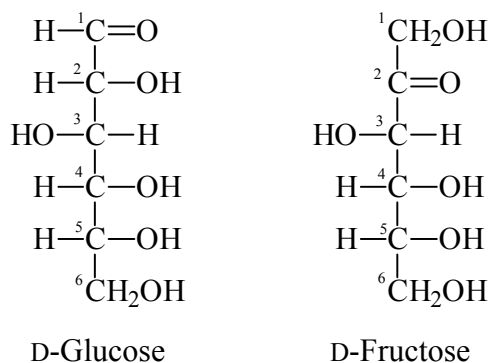
INTRODUCTION

The word "sugar" used in everyday life refers to the chemical sucrose. Sucrose is a member of a group of substances generally known as sugars, which contain up to ten monosaccharide units (monosaccharides are carbohydrates that cannot be further hydrolysed). These, in turn, are part of a wider group of carbohydrates which account for 75% of the dry weight of the plant world. All carbohydrates are compounds built up from the elements carbon, hydrogen and oxygen. All sugars are crystalline, water soluble and sweet tasting. Some common examples are glucose, sucrose (table sugar), fructose (fruit sugar) and lactose (milk sugar).

Sucrose has the chemical formula $\text{C}_{12}\text{H}_{22}\text{O}_{11}$. It may be readily converted by acid or enzymatic hydrolysis into a mixture of the two simpler sugars, glucose and fructose, each with the formula $\text{C}_6\text{H}_{12}\text{O}_6$.



Glucose is called a reducing sugar because, when the ring opens by breaking the O—C₁ bond, an aldehyde (a good reducing agent) is obtained. Fructose is called a keto-sugar because, when its ring opens by breaking the O—C₂ bond, a ketone is formed. Note that in sucrose the fructose portion of the molecule is a five-membered ring, but in the free form more than 70% of the fructose exists as a six-membered ring.



In sugar refining, glucose and fructose are regarded as impurities due to the difficulty in crystallising them from solution. Strict process control, particularly of pH, must be maintained to avoid loss of sucrose in processing through its chemical hydrolysis to the unwanted sugars glucose and fructose.

Manufacture of sugar from cane originated in India and cane cultivation then spread westwards to Egypt. In the 18th century the West Indies became the main source of production. The raw sugar refined in New Zealand today originates from Australia, Fiji, the West Indies and South America.

THE REFINING PROCESS

Sucrose is purified from raw sugar (97.5% sucrose) in a four step process as follows:

affination - dissolving off some surface impurities

carbonatation - removing further impurities that precipitate from solution with calcium carbonate

char filtration - removing further impurities with activated carbon

crystallisation - using a vacuum process (see salt recovery)

The process is shown in schematic form in **Figure 1**. Since March 1996 New Zealand has imported a higher grade of sugar (VLC - very low colour sugar), which means that the first three steps are no longer necessary and the sugar is only recrystallised in New Zealand.

During purification various lower grade products, including molasses, golden syrup and treacle are removed. Accordingly, these products contain proportions of both sucrose and impurity, sufficient to give each product its particular characteristic chemical and physical properties.

Raw materials

Raw sugar is the name applied to sugar crystals from the juice of sugar cane or sugar beet plants. Raw sugar imported to New Zealand is exclusively cane sugar and is processed by the New Zealand Sugar Company Limited at its Auckland Chelsea Refinery. As the name implies it is a raw, or relatively crude quality of sugar. The actual quality of raw sugars varies widely, with Australian sugars being of quite a high quality, and those imported from Cuba, for instance, of lower quality. Australian raw sugar normally contains about 98.7% of sucrose, Fijian and Cuban raws contain approximately 97.5% sucrose. Apart from sucrose, raw sugar contains reducing sugars (glucose and fructose), inorganic ash (mainly calcium and potassium salts) and other organic matter which includes gums, amino acids and colour components, essentially from the cane. These impurities must be removed from the sucrose during refining.

Raw sugar sold for home consumption on the New Zealand market is packed specially in Fiji for repackaging in New Zealand.

Step 1 - Affination

The first step is called affination, a French word meaning refining. The process consists of mixing the sugar with a saturated syrup to soften the adhering film of molasses, then spinning and washing off as much of this adhering impure syrup as possible in centrifugal machines. The centrifugal machine utilises the considerable gravitational force at the periphery of a basket spinning at high speed. This means minimum contact time between wash water and sugar, thus reducing the amount of sugar dissolved in this process. The impure syrup is recycled but an excess is produced. This material contains recoverable sugar and is processed separately in the boilout section of the refinery. Recovered boilout sugars are returned for remelting with the washed sugar. The impurities are concentrated into *molasses* which can be regarded as a final by-product. The "washed" or "affined" sugar is then dissolved, utilising "sweet" water from parts of the refinery process. At this stage the melted liquor is temperature and density controlled. The liquor is screened to exclude fibrous material.

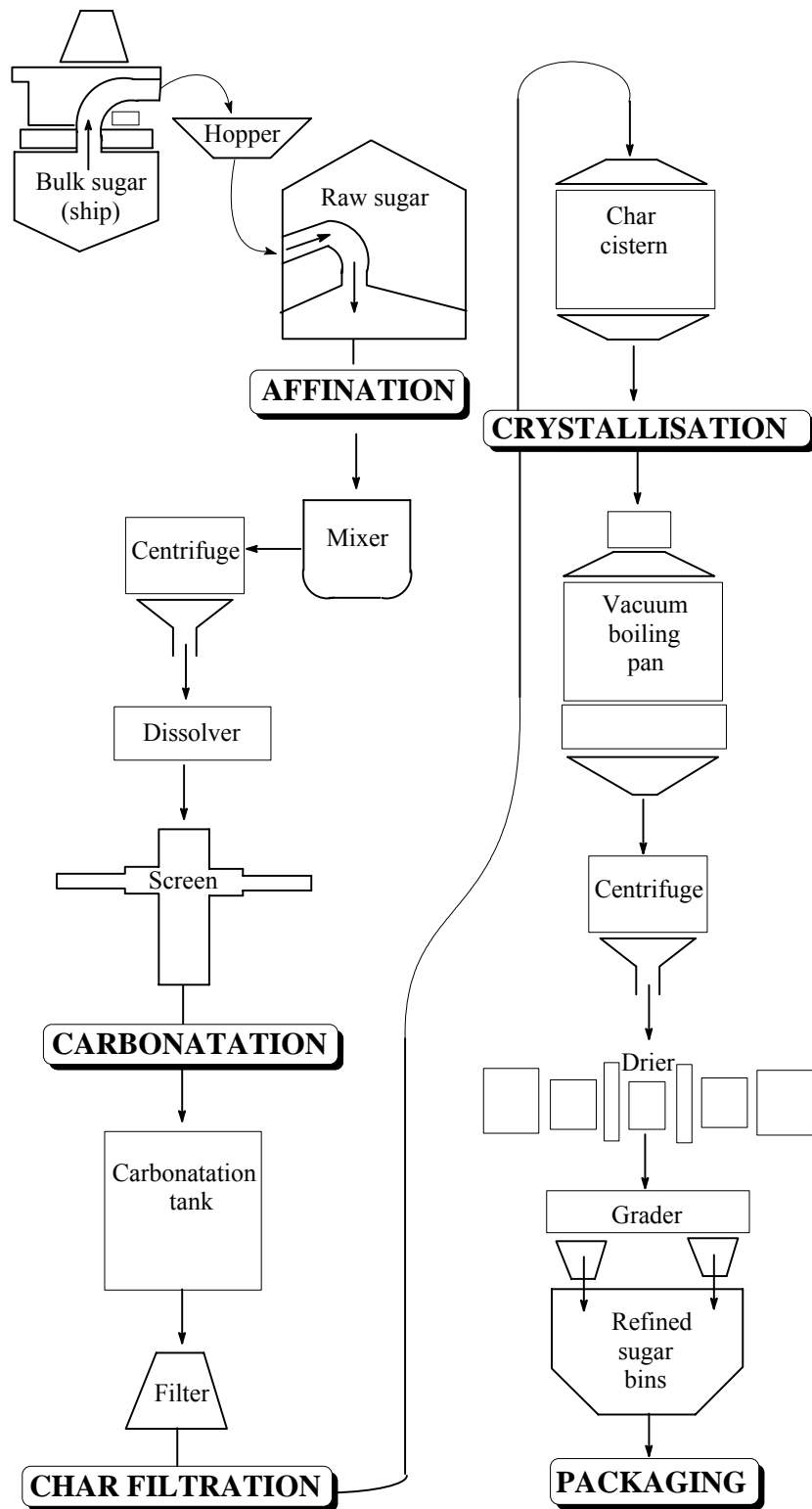
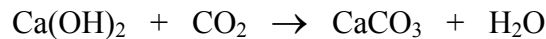


Figure 1 - Flow chart of the sugar refining process

Carbonatation

In carbonatation, milk of lime (calcium hydroxide) is added to the heated liquor, and boiler flue gas, containing CO₂, is bubbled through the mixture. The chemical reaction



occurs under controlled conditions and as the calcium carbonate precipitate is formed it includes and occludes organic impurities such as the gums, amino acids and colour components mentioned earlier, removing them from the sugar syrup. The carbonatation process is carried out in two stages to obtain an optimum quality precipitate for filtration, i.e. a suitable size and distribution of precipitate particles. Measurement of the electrical resistance of the solution indicates the residual lime content. Eighty to ninety percent of precipitation is sought in the first stage. The second stage is controlled by the measurement of the pH of the solution which is important throughout the process and ensures complete precipitation of the lime.

pH control

The pH of factory liquors is of considerable importance. Below pH 7 sucrose is hydrolysed to the reducing sugars glucose and fructose, while above pH 9, alkali destruction of sugars occurs and coloured components are formed.

Filtration

The calcium carbonate precipitate, including the impurities, is now removed in a pressure filtration stage using polypropylene filter cloth as supporting media and utilising the calcium carbonate as a filter aid. The filter mud is later subjected to water washing to remove sucrose residue and this mud is a waste material. Sweet sugar recovered by washing the mud is used for melting in an earlier stage.

Step 3 - Char Filtration

The relatively pure honey coloured liquor from the filtration stage, "raw liquor", is then subjected to final decolourisation by contact with bone charcoal. The bone char consists of active carbon on a calcium phosphate skeleton. It has a high surface area and the the unique ability to absorb colour and inorganic ash impurities from the sugar. The bone char used at the Chelsea refinery is imported from Portugal or Scotland. Following the decolourisation cycle the bone char is revived first by water washing, to remove inorganic impurities, and then heating in the absence of air to 650°C to volatilise organic impurities. The decolourised 'fine liquor' is now ready for the final refining and recovery step, which is achieved by crystallisation in vacuum pans.

Step 4 - Crystallisation

Crystallisation is not only a means to convert the sucrose to a more usable form, but also an important refining step, since pure sucrose tends to crystallise out of the solution, leaving most of the impurities in the associated syrup. The process is carried out under a reduced pressure of 75 - 90 kPa to allow a reduced boiling temperature (60 - 70 °C), so avoiding the further formation of colour compounds. Vacuum is achieved by the use of an air pump and vapour contact condenser. These condensers utilise salt water for cooling drawn from the nearby Waitemata Harbour. Fine liquor is concentrated until it is super-saturated then stage is shock-seeded by the addition of a small quantity of sucrose to give spontaneous nucleation of fine sucrose crystals. The crystals thus formed are grown under automatically controlled conditions until the desired final grain size is achieved. The pan contents, known as *massecuite*, are then discharged to receivers prior to separation on automatic centrifugal

machines. The sugar thus recovered is then dried and graded prior to packing, the syrup being recycled for three further recovery boilings. The final syrup is used as the starting material for other sugar products, such as soft brown sugar, coffee crystals, golden syrup and treacle.

General information

The Chelsea Refinery, Auckland, has a production capacity of 4 500 tonnes per week and normally operates on a five day, 24 hour, basis. The main power source is from steam produced in an natural gas fired boiler station. The process represents an efficient heat usage as high pressure steam is used in expansion engines to produce electrical power for pumping cooling water. The exhaust steam from these engines is then utilised for heating and evaporation. Process control instruments are basically electro-pneumatic.

REFINED PRODUCTS

Granulated sugar containing 99.93% sucrose and sold as castor sugar (fine crystals) and 1A sugar is the major refined product. Soft brown sugar is a specialty product with a characteristic flavour, produced by crystals used from a selected syrup with a high reducing sugar and ash content. Coffee crystals are made from the same syrup as brown sugar, but are crystallised over a much longer period of time giving much larger crystals.

Liquid sugars

Several grades are produced in liquid form with quality to meet customer requirements. This sugar is produced at 67° Brix (% solids) at which density it is unlikely to crystallise. Liquid sugar is utilised in industry.

Inverted syrups

Golden syrup and treacle are produced from selected syrups by inverting¹ a portion of the syrup using invertase (an enzyme) or acid hydrolysis to split sucrose into glucose and fructose. Golden syrup contains about 27% sucrose and 47% reducing sugar with 3% ash and 18% water. The high reducing sugar component inhibits crystallisation and allows a table syrup to remain in liquid form. Treacle is produced in the same manner from a similar syrup except that char decolourisation is not used.

The various products manufactured or packaged by the New Zealand Sugar Company are summarised in **Table 1**.

¹Sucrose and glucose are dextrorotatory sugars ($[\alpha]_D = +66^\circ$ and $+52^\circ$ respectively), which means that they rotate plane polarised light in a clockwise direction by the number of degrees given above. Fructose, on the other hand, is laevorotatory ($[\alpha]_D = -92^\circ$), i.e. it rotates plane polarised light anticlockwise. Thus on complete hydrolysis, the rotation of plane polarised light passing through the sugar solution changes from positive to negative. Hydrolysed sucrose is thus often referred to as 'invert sugar' as its rotation has been inverted.

Table 1 - Composition of refined products

	Sucrose %	Reducing sugars %	Inorganic ash %	Water %
1A sugar	99.93	—	0.07	—
Castor sugar	99.93	—	0.07	—
Coffee sugar				
Brown sugar				
Treacle	27	47	3	18
Golden syrup	27	47	3	18
Raw sugar	97.5	—	2.5	—
Liquid sugar	67	—	—	33

ROLE OF THE LABORATORY

Most processes are continuous and semi-automatically controlled with direction from a process control laboratory. Important criteria for control are density, pH and impurity content (reducing sugars and inorganic ash), temperature and production rate.

ENVIRONMENTAL IMPLICATIONS

Pollution control is given a high priority in the refining process. Atmospheric emission from the boiler station is strictly controlled using air/fuel ration mixing equipment to ensure complete combustion with continuous monitoring of smoke emission density. It is anticipated that natural gas fuel will eventually replace the fuel oil presently used, thus eliminating sulfur oxide emission. Carbonation mud is used as dry land fill on the refinery grounds. The material has little recycling potential. Liquid effluent is closely monitored by laboratory staff.

Written by Mrs. H. Armishaw (Seddon High School). Revised by Heather Wansbrough from information provided by Peter Simpson (New Zealand Sugar Company Ltd.).