THE MANUFACTURE OF LACTOSE

Lactose is a simple sugar found in milk and is a major component of whey. If whey is disposed of in rivers as a waste it has serious adverse environmental effects, but after processing it can be made into a variety of useful products.

As lactose is only 30% as sweet as sugar it is used as a sugar supplement, and also in food and confectionery. It is used in infant milk formulas (as bovine milk has a much lower lactose content than human milk), and it is also used as a binder and filler in tablets.

In New Zealand, lactose is purified from the whey produced as a by-product of the cheese and casein industries. It is purified by Lactose New Zealand to form food- and pharmaceutical-grade lactose in a process involving evaporating, crystallising, centrifuging and filtering and *Proliq* (a cattle feed supplement) as shown schematically in **Figure 2**.

Lactose purification is an example of producing useful products from biologically hazardous waste.

INTRODUCTION

Industry throughout the world is faced with a common problem - that of the disposal of waste materials from manufacturing processes. In the case of the dairy industry, one such 'waste' which is produced in enormous quantities is the whey resulting from cheese and casein manufacture. In the 1996/97 season alone it is estimated that around five billion litres of whey were produced in New Zealand. In New Zealand, much of this whey is used in ethanol production, for recombination into baby milk powders and for whey powder production, but there remains an excess. Whey proteins, mineral salts and other residual components of this complex mixture are readily extracted, but there is still a major component present: lactose.

This simple sugar poses a serious potential risk to the environment, as its disposal into rivers and onto fields promotes bacterial growth. Whey degradation by bacteria causes oxygen depletion of water and soil, as whey has a high biological oxygen demand (B.O.D.) - resulting largely from the lactose content. One hundred kilograms of whey has a B.O.D. estimated to be equivalent to the daily activities of 46 people. Obviously, it is highly desirable to extract the lactose and other solids from the whey to reduce its ecological impact. This is the role which Lactose New Zealand plays in the local dairy industry, taking the equivalent of approximately 1.1 billion litres of whey in the 1996/97 season for the production of edible and pharmaceutical grades of lactose.

Lactose

Lactose (**Figure 1**) is a disaccharide carbohydrate which is only produced as part of the milk of mammals and as a storage carbohydrate in the seeds of a few plants. The enzymology of lactose synthesis in the mammary gland is well understood. It is formed by the condensation of the hexose sugars glucose and galactose to give a β-(1$\rightarrow$4) linked product. Carbon 1 of the glucose moiety is said to be anomeric in that it carries a hydroxyl group which is free to lie above or below the plane of the ring. This hydroxyl group is thus responsible both for the

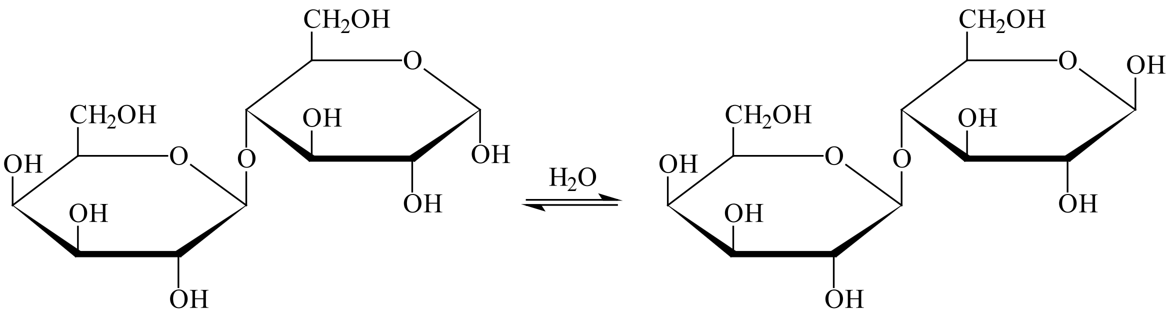


Figure 1 - The structure of α- and β-lactose

existence of α- and β-lactose forms and the reducing ability of lactose. The α- and β-anomers differ markedly in their physical properties (**Table 1**) which lend them to different commercial applications.

Table 1 - Physical differences between the α- and β- lactose anomers.

	Units	α-lactose	β-lactose
Molecular weight	Da	360.3*	342.3
Melting point	^{o}C	202	252
Density	$g\ mL^{-1}$	1.545	1.59
Specific optical rotation	α^{20}_{589}	+91.1	+33.5
Heat of solution	$J\ g^{-1}$	-50.24	-9.62
Solubility in water at 20°C	g/100mL	7.4	50.00

* for the monohydrate form, in which α-lactose is found when crystalline

A molecule of water is associated with the crystalline α- form of lactose and so it is referred to as the monohydrate. At temperatures over 120°C and under vacuum, however, this water is lost and the highly hygroscopic α-lactose anhydride is formed.When lactose is dissolved in water, mutarotation occurs, ie. α- and β- anomers interconvert to produce a solution of 62.7% β-lactose at 20°C. As α-lactose is the far less soluble species, concentration of the solution results in α-lactose precipitating and further mutarotation takes place to maintain the same equilibrium position.

The formation of good crystals and crystal growth are critical to the extraction and purification of lactose. α-lactose crystallises from super-saturated solutions at temperatures below 93.5°C to produce a variety of crystal shapes. The usual ones obtained resemble prism and tomahawk shapes, and are hard and only sparingly soluble. Above 93.5°C, β-lactose crystallises out, usually as an uneven-sided diamond. Riboflavin, lactose phosphates, β-lactose and lactic acid are among compounds found in whey that are known to affect α-lactose crystallisation. These crystallisation inhibitors tend to bind to specific crystal faces, although the degree of growth inhibition can vary with the concentration and types of inorganic salts present in the liquor.

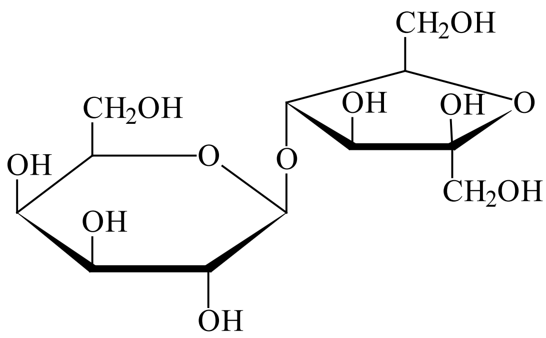
Uses of lactose

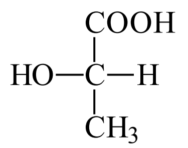
The first major application of lactose was as a Penicillium growth medium for the production of penicillin, but newer strains of the fungus in the 1950's allowed the use of cheaper substrates. However, some fermentation products are still being produced using lactose substrates taking advantage of the hydrolysis delay for lactose.

Today, lactose is widely used in the food and confectionery industries since it has a low sweetness (30% that of sucrose), binds flavours and aromas and increases the storage life of products. Lactose is used in preparing baked goods as it will undergo the Maillard reaction with proteins (see article on bread) and thus produce a browning effect. As human milk contains 7% lactose (compared with 4.4 - 5.2% in bovine milk), lactose is added to cow's milk in the preparation of infant formula.

The purest form of α-lactose has always been used by the pharmaceutical industry as an excipient: a compound which is chemically inert, aids the manufacturing system, protects or enhances the biological availability of the drug or enhances any aspect of the safety of the drug. As such, it is the second most widely used compound and employed as a filler/binder in tablets, capsules and other oral product forms.

α-lactose is also used for the production of various other compounds. These include lactitol (in diabetic products, low calorie sweeteners and slimming products), lactic acid (widely used in the food industry), and lactulose (a lactose isomer, used by the food industry). Japanese infant formula manufacturers are evaluating lactulose as a supplement. There is also interest from the chemicals industry in using lactose as a feedstock in the manufacture of lactosylurea, ammonium lactate and lactitol palmitate. β-lactose also has applications in the pharmaceutical industry as an excipient and in the manufacture of foodstuffs.





THE PURIFICATION PROCESS

Bovine milk whey contains about 5% lactose and is the main feedstock for commercial α-lactose production. Milk is essentially fat suspended in whey, which is a complex mixture of proteins, carbohydrates, minerals and vitamins (**Tables 2 and 3**). A schematic flow path of the manufacturing process is shown in **Figure 2**. Due to transportation economics, whey usually arrives at Lactose New Zealand's (LNZ) plant at Kapuni preconcentrated to between 12 and 50% solids. Further evaporation is required to raise the concentration to around 65% solids so that on cooling, the lactose can be induced to crystallise out, usually accelerated by the addition of fine lactose 'seeding' crystals. This process, which may take many days to reach completion, is carried out in stirred crystallising tanks which are slowly cooled using water from the local river. After this time, the crystals are extracted from the 'mother liquor' by centrifugation to yield raw lactose, which is a creamy yellow colour due to the presence of riboflavin. These crystals are washed, recovered by centrifugation and dried in a fluidised bed dryer to give an edible grade. The liquid phase ('mother liquor'), which contains significant quantities of protein, minerals, vitamins and about 18% lactose, is sold under the name of 'Proliq' as a cattle feed supplement, a practice which could well be described as recycling. The 'mother liquor' is known to contain many compounds with commercial potential and some with interesting biological activities. They are not currently extracted although this position may change in years to come.

To obtain a pharmaceutical grade of lactose, refining is necessary. This involves redissolving the lactose crystals and treating the solution with virgin activated carbon, which absorbs a number of solutes including riboflavin and a variety of proteins. Also absorbed are a group of polypeptides known as proteose peptones which are derived from β-casein. These peptones are produced by the action of plasmin, a protease enzyme which migrates from the bloodstream into the milk in the cow's udder. Further protein may be absorbed onto the activated carbon by temporarily adjusting the liquor pH. The carbon is removed by flocculation and filtration and then discarded. After crystallisation, subsequent separation of the crystals by centrifugation and drying, a high purity white pharmaceutical grade lactose is obtained. The crystals are milled or sifted to yield products with specific particle size distributions.

Table 2 - The major components of bovine milk

Component	**Concentration / % w/w**
Water	87.1
Fat	3.95
Protein	3.30
Minerals	0.67
Organic acids	0.18
Lactose	4.8
Vitamins	<0.001

ENVIRONMENTAL IMPLICATIONS

The largest potential environmental risk is posed by the factory effluent stream, which is a very dilute stream composed of CIP (cleaning-in-place) chemicals, minerals, storm waters and a small quantity of lactose. This effluent is corrected for pH and chemical balance and sprayed onto fields in a controlled manner to ensure that there is no run-off into waterways or damage to the grass or soil structure.

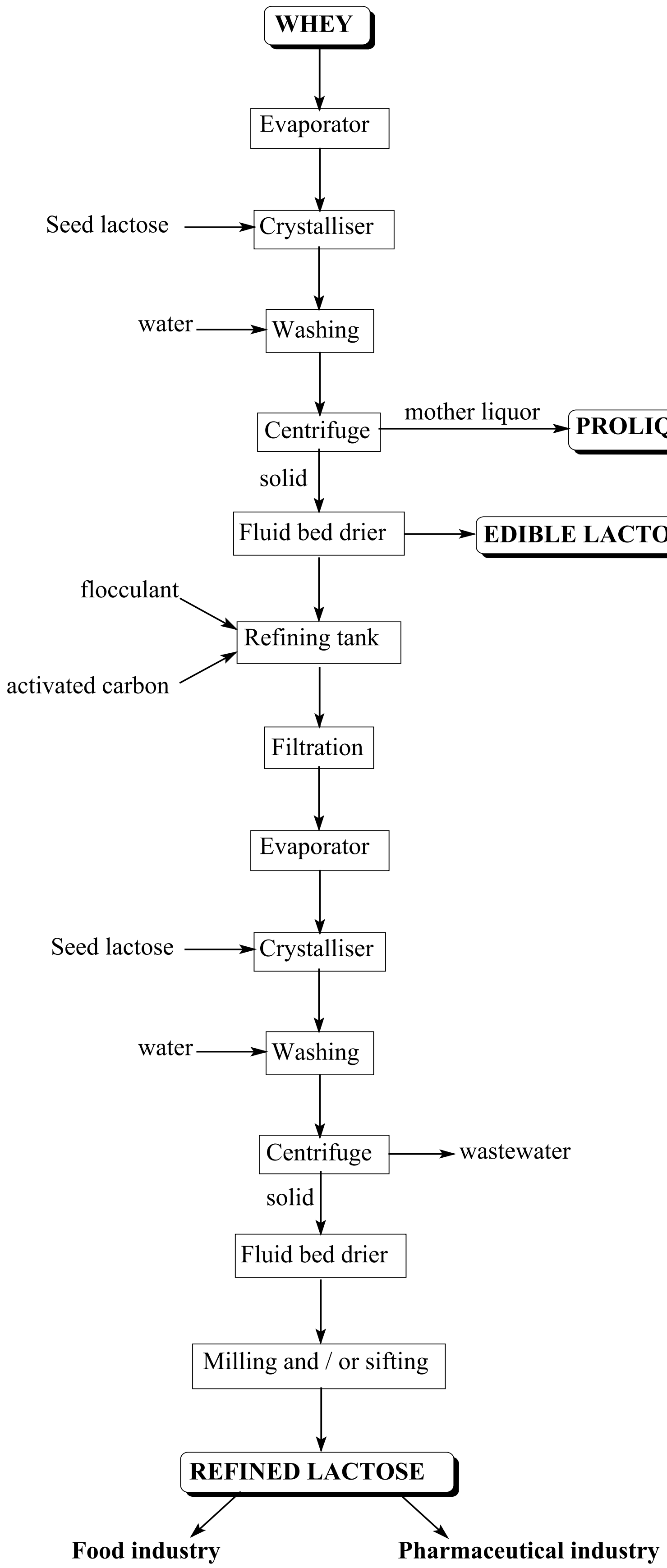


Figure 2 - The lactose purification process

Table 3 - Vitamins and minerals found in bovine milk

Vitamins	Concentration / g L^{-1}	Minerals	Concentration / mg L^{-1}
B_1 (thiamine)	450	Na	500
B_2 (riboflavin)	1750	K	1500
B_6 (pyridoxine)	500	Cl	950
E (tocopherol)	1000	Ca	1200
K	50	Mg	120
		P	950
		Fe	0.5
		Zn	3.5
		Cu	0.2
		Mn	0.03
		I	0.26

Lactose New Zealand also draws water from the Kapuni river for cooling of the crystalliser tanks. The environmental impact of this is negligible since the water is returned *via.* a cooling tower and spraying units suspended over the river. Despite the considerable volumes of water that are drawn, the downstream river temperature is never more than 3^{o}C higher than at the inlet.

ROLE OF THE LABORATORY

The Quality Assurance laboratory plays an essential part throughout the process. All whey arriving on site is tested to ensure that it meets minimum standards for various parameters including microbiological contamination, pH and minerals. It also tests process samples from the factory, ensures that feed waters and air flows are clean and that the plant cleaning procedures are effective. Before release to customers, all products are tested and graded by the laboratory which subjects them to a battery of tests. This is to ensure that the microbial, chemical purity and physical characteristics of the lactose are within specifications so as to meet the requirements of, for example, the United States Pharmacopoeia (USP) or LNZ refined edible grade purities.

ABOUT THE COMPANY

Lactose New Zealand started life in 1913 as The New Zealand Sugar of Milk and Casein Company Ltd, and was based at Edendale in Southland. Although the company expanded to a newly built plant at Kapuni, Taranaki in 1946, the original site is still occupied by a lactose plant operated Southland Dairy Cooperative on behalf of Whey Products New Zealand.

LNZ was originally owned by the U.K. company Unigate, but since 1983 has been a wholly owned subsidiary of the N.Z. Dairy Board. From its humble beginnings, production has risen to 35 000 tonnes in 1996, with Lactose New Zealand employing more than 130 staff. The company is currently undertaking a major expansion programme of building and facilities to enable LNZ to increase production, make new product grades and further improve the quality of its Wyndale brand lactose.

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