Sugar syrup from dairies for the food industry

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1 Introduction

The use of nanofiltration (NF) makes it possible to recover different sugar solutions from hydrolysed ultrafiltration (UF) permeate or whey.
The Swiss Federal Research Station for Animal Production and Dairy Products (ALP) and the Swiss College of Agriculture (SHL) investigated interesting possible ways of obtaining sugar syrup from milk serum on a laboratory scale /1/. The studies present a new process made up of four stages: pre-concentration and partial demineralisation of milk serum; pasteurisation; continuous, enzymatic hydrolysis of lactose, and separation and concentration of sugar syrup and mineral salt solutions. Continuous lactose hydrolysis combined with ultrafiltration allows multiple use of the expensive enzymes, which greatly improves the efficiency and profitability of this process.

2 Theory

2.1 Recovery of sugar syrup

The aim of the work is to combine nanofiltration technology with lactose hydrolysis, in order to obtain a sugar syrup from UF-permeate on a laboratory scale. Sugar syrup is understood to be a solution made from a mixture of the monosaccharides glucose and galactose together with residual lactose.
UF-permeate has a dry matter (DM) of around 55 g/kg, the principle part of which (approx. 85%), consists of lactose (Table 1). Apart from lactose, the UF-permeate is rich in mineral salts /2/, monovalent anions (Cl^-), bi- or polyvalent anions (phosphates), monovalent cations (K^+, Na^+) and bivalent cations (Ca^{2+}, Mg^{2+}). Calcium, phosphorus and citric acid can be present as a true or complex solute (Ca-phosphate, Ca-citrate).

2.2 A four-stage process

Based on the findings obtained from the trials, production of sugar syrup from UF-permeate seems possible from the technological point of view.
Four process stages make up the main structure of a possible procedure (Fig. 1): a first nanofiltration (stage 1), pasteurisation of the NF-retentate (stage 2), continuous lactose hydrolysis (stage 3) and a second nanofiltration stage (stage 4).

NF pre-treatment is used for partial demineralisation and concentration of the UF-permeate /2/. Firstly, this increases the purity of the sugar syrup and secondly the volume of hydrolysis is greatly reduced. After reverse osmosis the permeate is present in concentrated form as product 1 (lactose-/ mineral salt concentrate). Pasteurisation of the NF-retentate in stage 2 is used to improve the microbiological stability of the process on the one hand and on the other produces better demineralisation values and increasing flux values in the second NF. The polyvalent salts (Ca, P, citrates) partially precipitate from the solution after thermal treatment. This makes easier the subsequent separation of salts from the singular sugars. Continuous lactose hydrolysis (stage 3) increases the economic success of the procedure. By including an ultrafiltration stage, the expensive enzymes can be used several times. The conditions during hyrolysis favour microbiological growth. An additional microfiltration membrane between ultrafiltration and hydrolysis tank would greatly limit the cell count in the system. Separation of the monosaccharides glucose and galactose from the polyvalent salts (citrate, Ca, P) and from the lactose requires a second nanofiltration after hydrolysis as a fourth stage. Diafiltration of the retentate washes out further sugar molecules (glucose and galactose), which leads to improvement of the sugar yield in the permeate /3/. Enzymatic hydrolysis of the residual lactose before reverse osmosis (RO) would further improve the purity of the sugar, but would make the procedure more expensive.

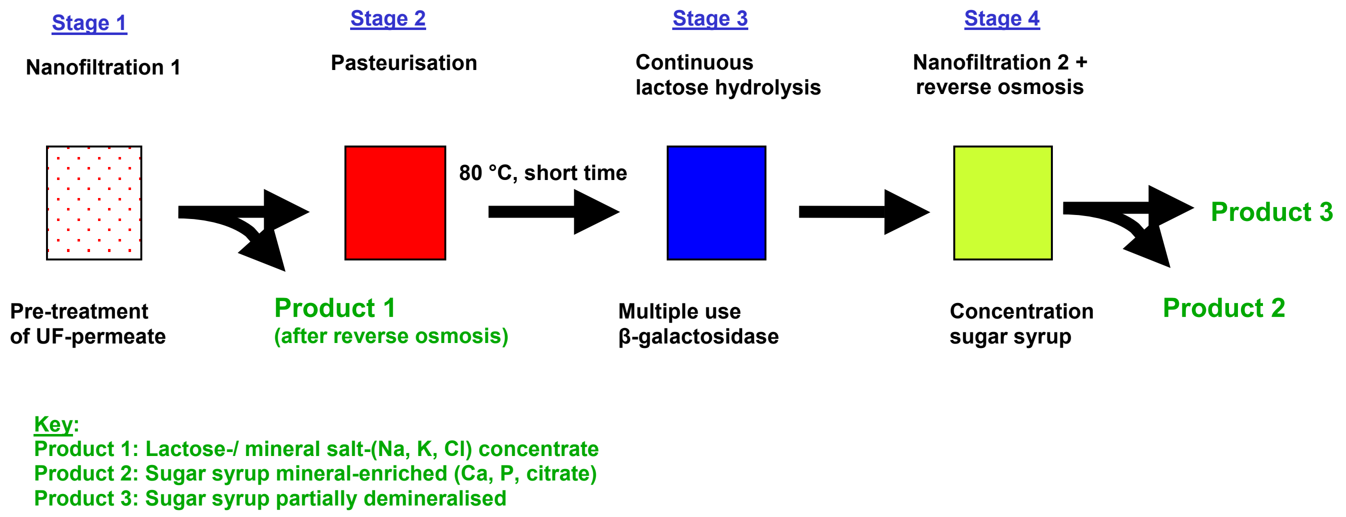

Fig.1: Schematic diagram of sugar recovery from UF-permeate in 4 process

2.3 Enzymatic lactose hydrolysis is expensive

Lactose, the main carbohydrate of milk, is a disaccharide, consisting of the monosaccharides D-glucose and D-galactose, which are linked to each other β-glycosidically via a 1 - 4 bond. The breakdown of lactose into glucose and galactose by the addition of a water molecule can basically be carried out chemically or biochemically (enzymatically). The enzyme β-D-galactosidase is necessary for breakdown /4/. An advantage of enzymatic hydrolysis over che-

mical hydrolysis lies in the high specificity of the enzyme. Practically no by-products arise. The reaction conditions are also very mild: temperatures generally lie between 35 and 60°C and the pH-value between 3.0 and 7.3.
So far enzymes have mainly been used in batch procedure in practice. However, the usual trade enzyme products are very expensive, which has clearly limited their use for the transformation of by-products from milk processing.

3 Results

3.1 The results of continuous lactose hydrolysis are promising

After lactose hydrolysis in batch mode for two hours, the β-D-galactosidase was held back in the retentate in the trials in a semi-continuous ultrafiltration process, in order to achieve multiple use of the enzyme through constant feeding of UF-permeate. With a constant flow rate of 0.5 l/h the lactose molecules remain in the system for two hours. After a reaction time of two hours in the batch system, the degree of hydrolysis of the lactose was 91.3%.
Then ultrafiltration was started and the hydrolysis system set to continuous operation. The continuous phase of the process ran for 8 hours and 10 minutes, which corresponds to a fourfold additional use of the same enzymes.
During the course of further filtration, the amount of monosaccharide in the permeate first decreases and the lactose concentration increases (Fig. 2). This is due to the „levelling out effects“ of the system after feeding of fresh original solution is begun and to the initial permeate flow, which was higher than the desired value of 0.5 l/h, which in turn required the lactose to remain in the reaction tank for a shorter period. If the solution is maintained microbiologically stable during the period of continuous hydrolysis and the flux rates of the UF-process are kept high, it seems possible to achieve a seven- to eightfold reutilization of the enzymes.

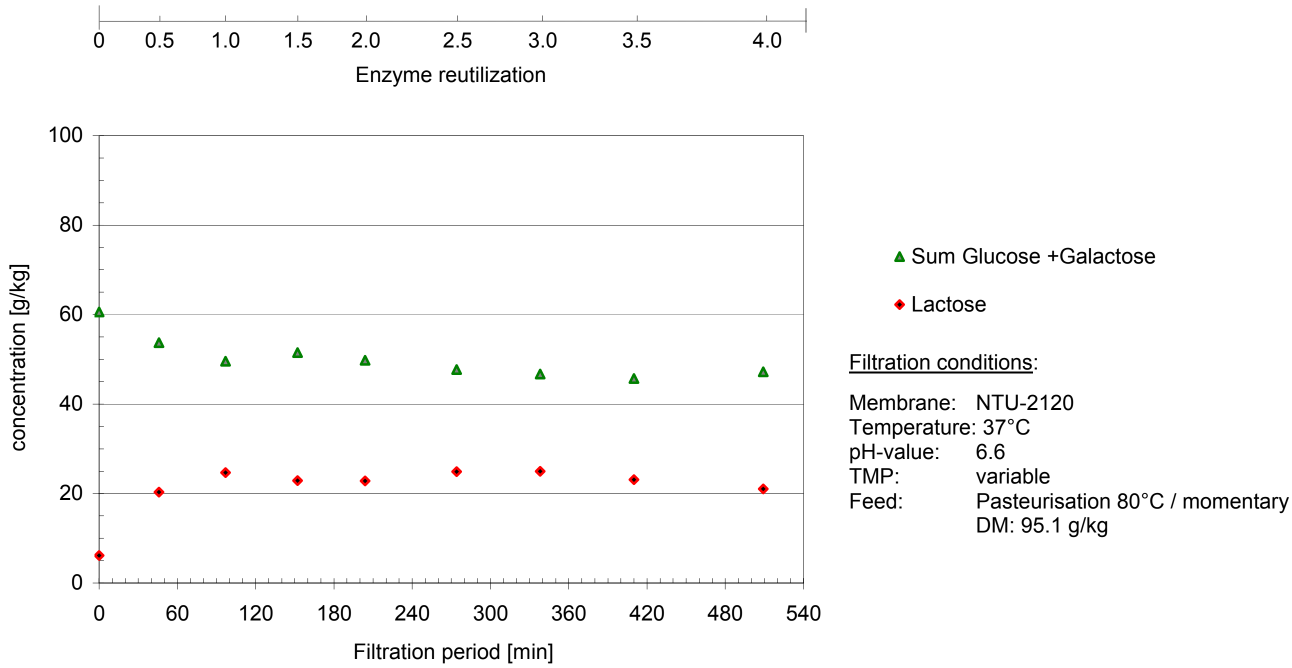

Fig. 2: Progression of sugar contents during continuous lactose hydrolysis

3.2 Use of nanofiltration to recover sugar syrup

In the recovery of sugar syrup from UF-permeate, there are three main criteria for the product with regard to the process. Firstly, the sugar yield in the product should be as high as possible and the demineralisation of the sugar solution as pronounced as possible. Furthermore, a high permeate flux is desired in the nanofiltration. In earlier studies carried out at ALP on the partial demineralisation of UF-permeate using NF-techniques, over 50% of minerals were eliminated with high permeate flux values.

The additional NF experiments confirm the influence of the concentration factor (c_V) on the retention of the different ingredients. The concentration factor is not equally high for each of the substances analysed. Retention of the monosaccharides remained relatively constant at a low level in spite of an increase in the concentration factor from 2.0 to 4.0. In the case of galactose, there was even a slight decrease in retention as the concentration factor increased. The concentration factor seems to have relatively little effect on the retention of potassium, sodium, chloride and non-protein nitrogen. However, the picture is different for lactose, ash, phosphorus, calcium and citrate. The highest retention values occurred for lactose, ash and citrate at a concentration factor of 3.0 and for phosphorus and calcium at c_V = 3.5.

By increasing the concentration factor, a rise in the sugar yield was achieved in the hydrolised NF-permeate as well as a reduction of polyvalent salts, which is due mainly to the reduction of the amount of retentate. At a concentration factor of 3.5, glucose and galactose yields of almost 60% (w/w) were achieved without diafiltration.

3.3 Possible uses of the manufactured products

The three sugar concentrates obtained from the proposed production process (Fig. 1), partially demineralised sugar syrup, mineral-enriched sugar syrup, and lactose-/mineral-concentrate, differ in their composition. Table 1 shows the percentages of individual ingredients in the dry matter, resulting from the experiments /1/.

Table 1: Percentages of the individual ingredients in the dry matter of the three sugar concentrates, using the proposed production process (degree of hydrolysis 80%) and with a given composition of the UF-permeate

	Dry matter percentages [% w/w]			
	UF-Permeate	Sugar syrup (partially demineralised)	Sugar syrup (mineral-enriched)	Lactose- / mineral-concentrate
Lactose	83.5	6.6 – 8.0	32 - 38	60 - 73
Singular sugars	0	75 - 88	54 - 66	0
Minerals (MS):	8.9	4.6 - 5.6	12.0 – 14.6	21 - 26
- Polyvalent MS (P, Ca, citrate)	4.2	1.3 - 1.5	2.5 – 3.1	2.2 – 2.7
- Monovalent MS (K, Na, Cl)	5.5	2.7 – 3.4	9.0 – 11.1	18.7 – 22.8
NPN (non protein nitrogen)	0.6	ca. 0.3	0.3 – 0.4	2.4 - 2.9

It is possible to influence the chemical composition of the individual sugar concentrates in a specific way depending on the use of the concentrate. Three examples show the optimization potential depending on the application of the products:

1. Not using diafiltration in nanofiltration 1 (stage 1) reduces the loss of sugar (lactose) in the process. However, the partially demineralised sugar syrup (product 3) contains more monovalent salts.
2. Further addition of enzyme (batch-hydrolysis) after process stages 3 (continuous hydrolysis) or 4 (nanofiltration 2) reduces the lactose percentage in the concentrates to a minimum. However, the process becomes more expensive with the higher enzyme use.
3. Additional diafiltration combined with nanofiltration 2 increases the sugar percentage (glucose, galactose) in the (partially demineralised) sugar syrup and consequently reduces the sugar percentage in the (mineral-enriched) sugar syrup.

There are many possible uses for the different sugar concentrates. Ice cream seems to be an ideal area for the use of partially demineralised sugar syrup /5/. The mixture of glucose, galactose and lactose can produce a desired low-

ering of the freezing point in the ice cream as well as setting the level of sweetness. Other possible applications of the partially demineralised sugar syrup are in beverages, sauces and other sweetened foods. Here the sugar syrup is primarily used for sweetening, that is as a substitute for sucrose or for glucose syrup obtained from starch.
The use of mineral-enriched sugar syrup is recommended more for salted or spiced products because of the higher mineral content. The syrup is rich in polyvalent minerals (Ca, P, citrate) and is a component for setting the melting properties in the area of processed cheese. The lactose- / mineral-concentrate could be used as an additive in animal fodder, as a fermentation substrate or in the manufacture of cured meat products.
At the end of the day, the decision about possible marketing of the sugar syrup made from UF-permeate in the food industry will be taken on the basis of the selling price. The benchmark is set by the prices of sucrose and glucose syrup.

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