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TWICE™ — an ice-cold process for highest food concentration

With the following white paper, Sulzer presents TWICE™, a cutting-edge liquid food concentration process. It offers a viable alternative to evaporation and produces the finest quality with high concentration levels.

When it comes to food, we all have different tastes and needs. But we all want our food to taste fresh, look good, have the best nutritional content, and be healthy.

To meet all these requirements, food companies invest considerable efforts in research and development and marketing. And they all rely on process technologies to produce and develop new products that will enable them to satisfy their existing consumers and gain new ones. As a proactive and committed technology and process solutions supplier, Sulzer applies its expertise to support food companies in meeting their ambitious and exciting challenges.

At Sulzer, we design innovative food processing technologies and equipment. We understand the market and provide appropriate solutions to meet its needs. In our ultramodern test center, our skilled engineers have developed a new process to produce highly concentrated liquid foods that present unequaled nutritional and organoleptic properties. Organoleptic properties are the aspects of food, water or other substances that are experienced using the senses — including taste, sight, smell and touch.

With the following white paper, Sulzer presents TWICE™, a cutting-edge liquid food concentration process. It offers a viable alternative to evaporation and produces the finest quality with high concentration levels. This new concept will provide food companies new product development opportunities to ensure and strengthen their position on the demanding and rapidly changing liquid food market. It is now possible to overcome challenges that were insurmountable before with the help of this ingenious process.

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Abstract

The global liquid food industry is expected to reach an estimated USD 1.9 trillion by 2021 [1]. Growing urbanization and disposable income are the major drivers for the growth of this market. According to the United Nations, 68% of the world population will live in urban areas by 2050, compared with 55% today [2]. Urban lifestyle and higher disposable income have led to a growing interest in sports and a healthier way of eating and drinking [3]. Indeed, consumers are paying more attention to nutrition and its impact on their health and environment. This results in strong market demand for premium quality, fortifying products and healthy liquid foods [4, 5, 8]. All product categories (ready-to-drink tea and coffee, juices, nutraceuticals, beer, wine, etc.), as well as all the ingredients used to produce these drinks, are affected by this general market trend.

Liquid food production results in the composition of several ingredients and water. For production purposes, natural ingredients (e.g., plant extracts, fruit juices) are often concentrated and used to produce final products (e.g., functional and flavored drinks, nutraceuticals, cosmetics). The concentration of liquid foods (e.g., tea, coffee, juices, beer, wine) is also a common process to reduce the volume of water for storage, transport and shelf life purposes. The liquid food industry widely uses such concentrates. However, they have certain

limits and suffer from negative opinion. Indeed, thermal concentration processes degrade the natural qualities of ingredients, and consumers usually assimilate concentrates as non-natural or non-fresh products. Therefore, liquid food producers have a double challenge to address. On the one hand, they wish to reach higher concentration levels, and on the other hand, they want to preserve the nutritional and organoleptic properties of the ingredients to meet consumers' expectations.

This paper will present TWICE™, a new process developed by Sulzer to produce high liquid food concentrates with top-grade organoleptic and nutritional properties. TWICE™ combines two crystallization technologies, namely, suspension freeze concentration and static layer crystallization. Freeze concentration is a proven technology to concentrate liquid foods gently. Layer crystallization is mainly used for non-aqueous liquids. The combination of these two technologies is a significant step forward for the liquid food industry. It offers food companies an innovative solution to develop new products and appeal to the premium market.

1. Introduction

Liquid foods concentration has been used for decades. The technique is extensively used in the liquid food industry because its scope of application is broad, and its economic benefits are substantial. The main goal is to reduce the volume of water in a product so that the relative amount of the product increases. This provides multiple advantages. The process reduces the volume and weight of the product, it facilitates storage, handling and transportation and lowers the related costs. The product's shelf life is also substantially longer. Concentrates can be easily reconstituted by adding water. Orange juice is a notable example of liquid food concentration. The global success of this juice results mainly from this process. Brazil is, by far, the world's leading producer and exporter of orange juice [6]. Once the fruit is harvested, it is squeezed, then concentrated through evaporation, and later frozen. The frozen concentrate is stable and can, therefore, be shipped around the world and stored before it is sold. Thanks to these concentration and freezing processes, consumers enjoy Brazilian orange juice all year long with constant quality at a reasonable price.

Today, multiple technologies are used to concentrate liquid foods. Each has its features and drawbacks. The concentration method chosen depends on the composition of the product, the sensitivity of the product to heat, and the economics of the process. Evaporation is the method most widely used to concentrate liquid foods [7]. The latent heat of condensation is transferred to the liquid food to raise its temperature to the boiling point and release some of the water. Then, the vapor is removed from the surface of the boiling liquid. Evaporation has great advantages for large amounts of liquid and for high-viscosity liquids. However, liquid foods tend to lose their organoleptic and nutritional properties when processed by evaporation [7]. Further, because aroma compounds are lost, an additional step is needed in most cases to recover the aroma. Finally, evaporation consumes a relatively high amount of energy. Membrane concentration stands as an alternative to classical evaporation. However, this method is mainly used as a preconcentration step rather than a full concentration process.

At low processing temperature, membrane concentration avoids the thermal degradation of nutrients and, therefore, is suitable for heat-sensitive products. Moreover, this method produces products of superior quality (aroma, taste, color and nutritional value) to those produced by conventional thermal evaporation [8]. The basis for membrane separation is the difference in permeability of a semiporous membrane to differentsized molecules. Smaller molecules pass through these membranes more easily than larger ones. Since water is one of the smallest molecules, concentration is easily accomplished using membranes with appropriate molecular- weight cutoffs. However, high concentration levels are not achievable with membranes [7]. Products are less stable, and shelf life is short. The result of a limited selectivity due to the size of molecules passing the membrane, is that some flavor components might be lost by permeation through the membrane.

In addition to the concentration methods described above, freeze concentration is an efficient way to produce liquid food concentrates or to preconcentrate extracts prior to drying processes. Freeze concentration is an application of suspension crystallization. It presents undeniable advantages over any other concentration method.

When superior quality is the key factor for your product, freeze concentration produces better results than other concentration methods. Freeze concentration preserves the aroma, flavor, color and nutritional qualities in the concentrate [9, 10]. As a result, the concentrate’s properties and qualities are closest to those of the pure product. Furthermore, freeze concentration is an ideal technology to treat heat-sensitive juices because the process takes place at subzero temperatures.

With all available concentration technologies our clients can save storage and distribution costs. With a focus on high-quality and value-added products, freeze concentration has a wide spectrum of applications. Products such as fruit

and vegetable juices, coffees, teas, herbal and algae extracts, as well as beer, wine and many more are concentrated successfully with best-in-class nutritional and sensorial qualities.
To summarize, the major advantages of freeze concentration are:

- Guarantee of aroma, flavor and color in the product — only pure water is removed
- Low operating temperature — concentration of heat-sensitive products
- No filters (no fouling) and no centrifuges

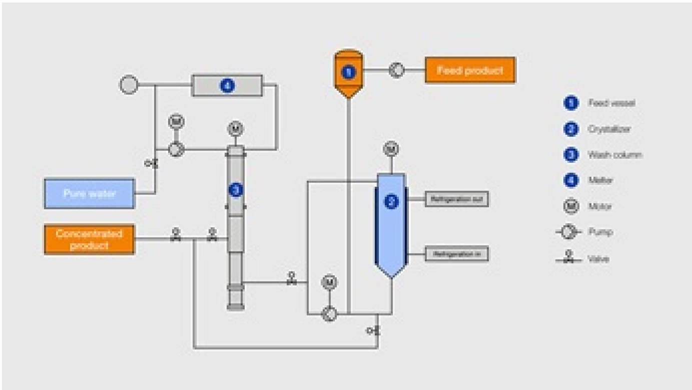

Fig. 1 The process flow diagram (PFD) of Sulzer’s freeze concentration technology.

2. Freeze concentration of liquid foods

Freeze concentration involves freezing water to ice crystals and then separating the ice from the concentrate. Sulzer has proven expertise in designing freeze concentration processes and manufacturing freeze concentration equipment. Fig.1 shows the process flow diagram of Sulzer’s freeze concentration technology. The process relies primarily on a loop with two key equipment units — namely a suspension crystallizer and a wash column. The crystallizer consists of an inner tube surrounded by a shell that holds the refrigerant medium. The refrigerant cools the product in the inner tube as the heat of the product is transferred to the shell. As the refrigerant absorbs the heat from the slurry, there is some degree of undercooling (liquid temperature below equilibrium temperature) of the liquid.

Once the liquid reaches the freezing point, ice crystals (nuclei) start to form. The percentage of ice crystals increases slowly. The inner tube employs a rotating shaft that is fitted with scraper blades. The blades continuously scrape the inner wall of the tube. This keeps the tube surface free of crystals during the operation — which is important for efficient heat transfer. The slurry of ice crystals is continuously recirculated over the crystallizer by the circulation pump. The entire unit is kept full by an atmospheric feed tank above the main unit. Therefore, the main unit is always kept at a slight overpressure blanketed with nitrogen.

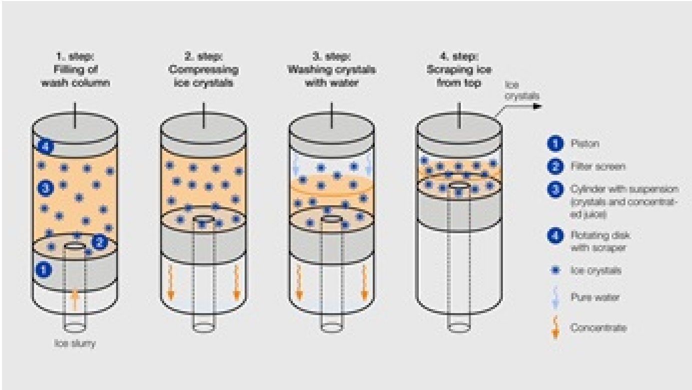

Fig. 2 Illustration of the separation steps taking place in the wash column.

The wash column is a mechanical separation device that removes ice crystals from the concentrated juice. The main body of the wash column is a cylinder. In this cylinder, a piston moves up and down, creating a compact crystal bed. The efficiency of the wash column depends on the size of the crystals and viscosity of the juice. Larger crystals and lower viscosity make the separation more efficient and allow higher throughput.

The separation between the concentrated juice and the solid requires four steps that are represented in Fig. 2.

Filling

The filling step starts with the piston at the highest position. As the piston moves downward, the space that is created above the piston is filled with an ice slurry consisting of a mixture of crystals and concentrated juice from the circulation loop. At the same time, the space below the piston decreases and pushes the concentrated juice either back to the circulation loop or out of the process as the final product. The filling stroke ends with the piston at the lowest position.

Compressing

The space between the piston and the crystal bed is filled with ice crystals and concentrated juice. The piston then moves upward, and concentrated juice flows through the filter screen above the piston to the space below the piston. The ice crystals cannot pass through the filter screen and, thus, they remain in the wash column where they are compressed into a bed of crystals within the cylinder. The piston has not reached the highest position yet.

Washing

A small overpressure from the melting loop forces pure water (ice molten in the melter in Fig. 1) downward through the filter screen thereby washing the crystal bed. The wash front gets displaced and moves downward.

Scraping

The fourth step starts by activating the rotating disk equipped with scraping knives . The piston continues to push against the crystal bed and moves it upward as the scraper knives shave pieces from the ice crystal bed. The scraping step is finished when the piston has reached its highest position and the rotating disk has been switched off.

Freeze concentration with separation of washed ice crystals has been used for more than 30 years. Commercial units are in operation around the world. The technology is every much appreciated, and results achieved with it exceed customers' expectations. Despite these strengths, freeze concentration with crystal suspension shows its limits at concentration levels higher than 45 Brix (°Bx)* [10]. To overcome this challenge, Sulzer developed TWICE™, a new two-step crystallization process.

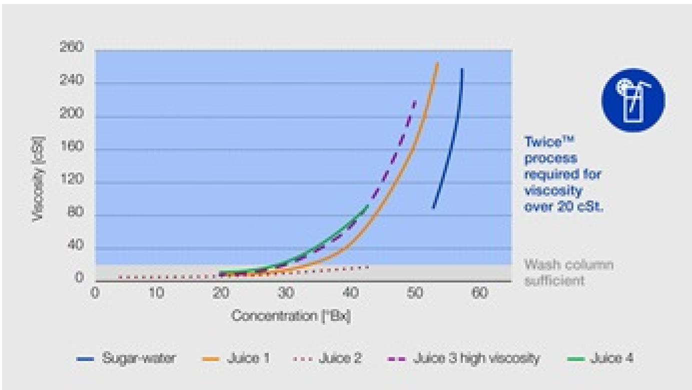

Fig. 3 Behavior of the viscosity (cSt) of several juices and a sugar-water solution at different concentrations (°Bx).

3. TWICE™

The solution to achieve highest concentration levels

Freeze concentration faces separation difficulties with higher concentrated products due to the increasing viscosity at the freezing point. Consequently, separating the ice crystals from the remaining liquid concentrate turns to be a challenge. The viscosity at freezing point is an important parameter. Sulzer's engineers observed that when the viscosity exceeds 20 centistokes (cSt), the separation of ice crystals in the wash column becomes critical. Therefore, viscosity is the limiting factor of freeze concentration technology. Figures 3 and

4 illustrate multiple juices and coffee extracts. When the concentration level exceeds 40 °Bx, the concentrate surpasses the viscosity of 20 cSt.

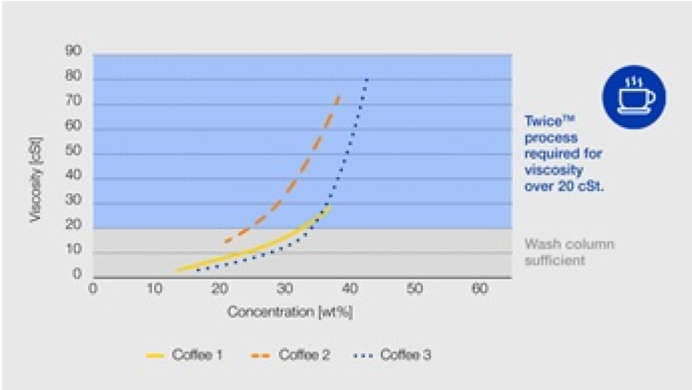

Fig. 4 Behavior of the viscosity (cSt) of several coffee extracts at different levels of concentration (wt%).

The situation is similar with various coffee concentrates. We noticed that when the concentration level overtakes 30 wt% (weight percent %), the viscosity surpasses the 20 cSt.

Fig. 5 Suspension freeze concentration unit.

The new TWICE^{TM} concept

Sulzer developed a new cold crystallization process — which combines suspension freeze concentration (Fig. 5) and static layer crystallization (Fig. 6) — called TWICE™.

Freeze concentration with ice crystal suspension is performed as a preconcentration step. The goal is to reach a concentration level of 40-45 °Bx for sugar content solutions and ca. 30 wt% for coffee solutions. Up to this level, the separation of ice crystals in the wash column is still feasible. To increase the product concentration without degrading the properties of the feed, the feed is further concentrated using static layer crystallization. The desired final concentration drives the number of concentration stages.

Static layer crystallization is used for highly viscous products. In the past, the technology has been tested to purify water applications. Suspension freeze concentration is used to concentrate aqueous foods and produce pure water within one crystallization stage [9]. The combination of suspension freeze concentration and layer crystallization has been presented successfully for the desalination of reverse osmosis retentate [11, 12]. The strong features of both technologies synergize powerfully.

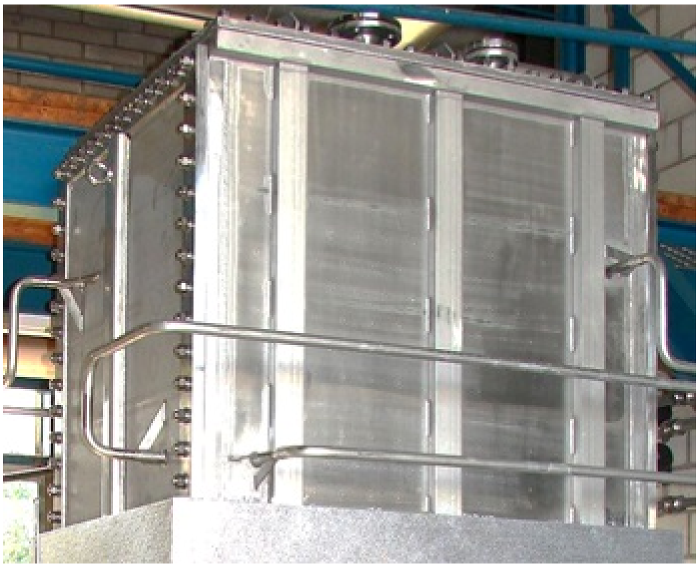

Fig. 6 Static layer crystallization unit.

This successful combination paved the way for the development of aqueous food applications. The additional increase in concentration is necessary for the stability of the food. If a product is kept below a certain water activity, then mold growth is inhibited. This results in a longer shelf life. The water activity of a liquid food is defined by its water content. The lower the water content the lower the water activity is. A stable liquid food needs a concentration above 55 °Bx.

For layer crystallization a prerequisite is the existence of a uniform crystalline layer that grows slowly on a cooled heat-transfer surface. Vertical plates are used; they are cooled or heated by the internal circulation of a heat-transfer medium. The driving force for the crystallization results from the net effect of the temperature gradient across the solid and liquid phases. Slow cooling of the heat-transfer medium below the freezing point of water causes a structure of ice crystals to grow on the outer surface of the plates. After the desired fraction has been crystallized, the concentrated liquid is drained from the crystallizer. The crystalline layer adheres to the plates. The ice crystal layer is then entirely melted and drained. A complete sequence consisting of loading the feed into the crystallizer, crystallization, draining the residue, melting and unloading the water is referred to as a stage.

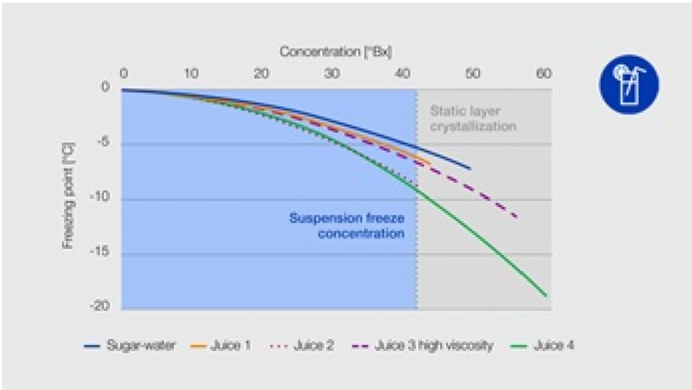

Fig. 7 Freezing point / concentration of various juices

Tests and results

So far, high concentrated liquid food concentrates (> 60 °Bx) have only been produced using evaporation technology. However, evaporation has associated drawbacks such as loss of aroma, flavor and color. The combination of suspension freeze concentration and layer crystallization, named TWICE™, can increase the concentration of various juices up to 61 °Bx (Fig. 7). That is equivalent to results achieved by evaporation but without the associated drawbacks.

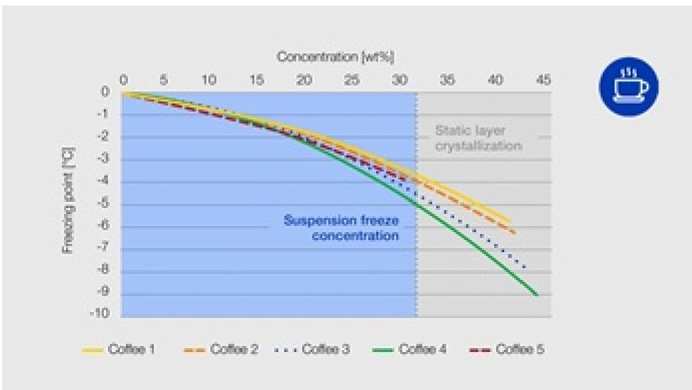

Fig. 8 Freezing point / concentration of various coffee extracts.

The combination of suspension freeze concentration and layer crystallization increased the concentration of various coffee extracts to 42 wt% (Fig. 8).

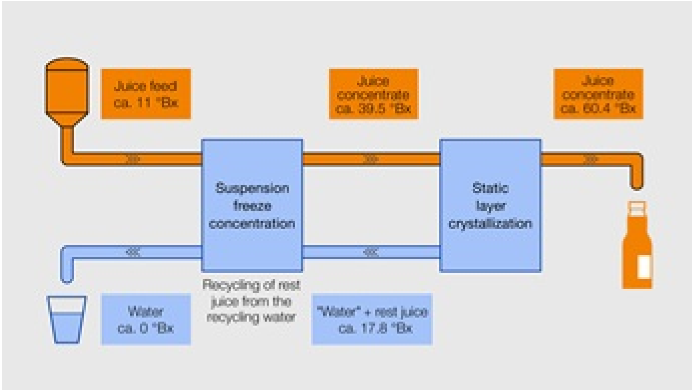

Fig. 9 Concentration balance of suspension freeze and static layer crystallization technology.

Figure 9 shows the simplified concept with major concentration steps. The new concept produces premium-quality products. TWICE™ is used to easily increase the concentration above 60 °Bx for sugar content solutions or above 40 wt% for coffee extracts. It indicates that with layer crystallization, the concentration is increased another 34%. This preserves the aroma, flavor, color and nutritional properties of the product and lowers the water activity to a level where mold growth is inhibited. In addition, there is no loss of product: The ice produced through layer crystallization at a concentration of ca. 18 °Bx is melted and recycled into the suspension freeze concentration feed.

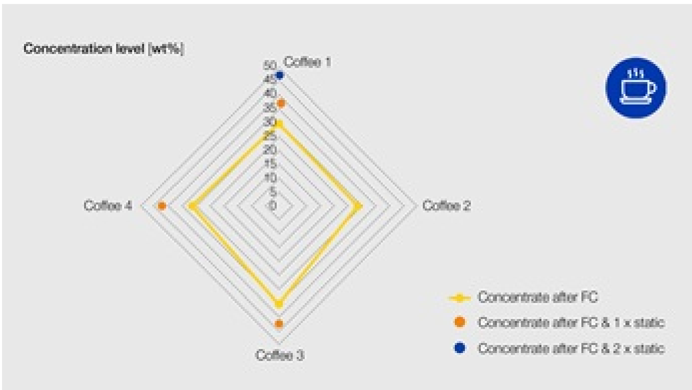

Fig. 11 Concentration of coffee extracts with suspension freeze concentration (FC) and with combination of suspension freeze concentration and static layer crystallization.

Below is shown the concentration of various fruit and vegetable juices, a sugar-water mixture (Fig. 10) and various coffee extracts (Fig. 11) after various concentration procedures: a) suspension freeze concentration (FC), b) suspension freeze concentration and one static layer crystallization stage, and c) suspension freeze concentration and two static layer crystallization stages. After two static layer crystallization stages, the juice concentration is above 60 °Bx, a concentration that is usually only achievable with evaporation. After two static layer crystallization stages the coffee concentration is above 40 wt%.

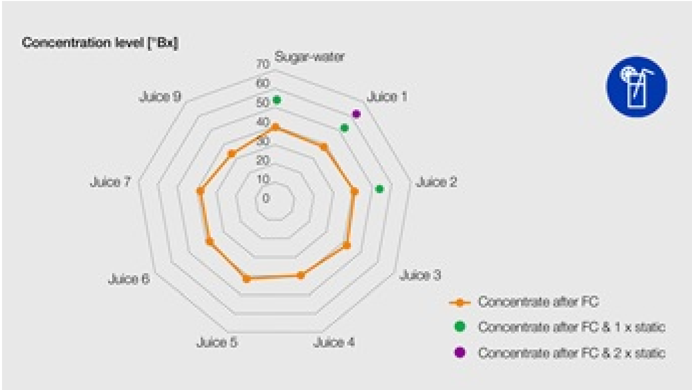

Fig. 10 Concentration of various juices with suspension freeze concentration (FC) and with combination of suspension freeze concentration and static layer crystallization.

Conclusion and outlook

TWICE™ is a new liquid food concentration process. This process is based on the combination of two crystallization technologies offered by Sulzer, namely, suspension freeze concentration and static layer crystallization. The synergy of these two processes enables food engineers to produce liquid food concentrates with unparalleled organoleptic and nutritional qualities. The revolutionary procedure has proven the ability to reach concentration levels up to 60 °Bx for juice applications and up to 40 wt% for coffee extract applications.

Freeze concentration has established itself as the preferred technology for concentrating liquid foods when aroma, flavor, color and nutritional properties are the key parameters. Users have shared feedback that quality achieved with freeze concentration is excellent, and, therefore, they would like to increase the °Bx level of their concentrates. Sulzer took this feedback seriously and decided to design a smart process that will surpass the current performance of freeze concentration. Sulzer's test center has provided a suitable platform to allow engineers to research, test and develop an appropriate process to meet the market's expectations.

The successful tests produced remarkable results, and Sulzer can offer a practical alternative to evaporation for high grade concentrates. This new solution is an asset for the development of new liquid food products to address the strong demand for premium, highly nutritional and delicious products

6. References

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