

## **Ice Cream Production**

Ice cream production involves traditional chemical engineering, product design, and multi-scale analysis. The components of this design are briefly summarized below, followed by an executive summary of the student-generated results for this design.

### **Ice Cream Science**

There are three categories of ingredients in the ice cream mix: dairy, sweeteners, and additives. Milk, cream, and non-fat milk solids make up the dairy portion of ice cream. Sucrose or Splenda® is used to sweeten the mix, and stabilizers and emulsifiers are added to give the ice cream the desired body and mouth feel. Also present in finished ice cream is air. Standard ice cream contains an equal volume of mix and air, or an over-run of 100%. Premium ice cream, however, has an over-run of only 80% to give it a richer, more-creamy mouth feel.

Milk is a colloidal suspension of water, fat, and milk solids. Fat particles in suspension range in size from 0.8 to 20  $\mu\text{m}$ . Also present in milk is the sugar lactose at a concentration of about 4.9%. In lactose free ice creams, the milk is treated with the enzyme lactase, which breaks lactose down into the simpler sugars glucose and galactose.

Regular table sugar, or sucrose, is used as a sweetener in all the ice cream mixes except the low carb ice cream. Splenda®, or sucralose, is used to sweeten the low carb ice cream because it is indigestible but still sweetens the mix.

Stabilizers and emulsifiers are essential in the production of ice cream products. Both components help to give ice cream the smooth body and texture and help to improve the overall mouth feel of the ice cream. Stabilizers work by reducing the amount of free water in the ice cream mixture. This effect retards ice crystal growth during storage and also provides resistance to melting. This is accomplished through two mechanisms, depending on the type of gum. Charged gums, including carageenan, help to reduce the amount of free water by introducing

partial charges into the mixture. These charges interact with the partial charges of water and help to restrict the movement of the water molecules within the mixture. Branched gums, including guar gum, provide the same ability to reduce free water within the system, but accomplish this by introducing many branched side chains into the mixture. Both types of gums limit the amount of hydrogen bonding that can occur, thereby giving the ice cream the desired properties [1].

Likewise, emulsifiers help to reduce fat globule coalescence by decreasing the interfacial tension between the fat and the matrix within the ice cream mixture [2]. Common types of stabilizers used for ice cream production include guar gum, carageenan and gelatin. Mono and diglycerides are the most commonly used emulsifying agents. Addition of stabilizers and emulsifiers is essential for ice cream base mixes lower in fat content; this is a result of the milk and milk proteins containing natural stabilizing and emulsifying materials. Therefore, premium ice cream will need minimal amounts, if any, of additional stabilizers or emulsifiers.

As water begins to freeze in the mix, the concentration of dissolved solids in the liquid phase increases due to freezing point depression.

Good mixing is essential to the mouth feel and taste of finished ice cream. Large fat globules increase the viscosity of the mix beyond what is desirable.

Typical ice cream viscosities range from 50-300 cP. The viscosities of low carb ice cream were found to be approximately an order-of-magnitude greater than that of regular or premium ice cream. It was thought that these higher viscosities were the result of increased fat content as well as increased additive content.

### **Facility Design**

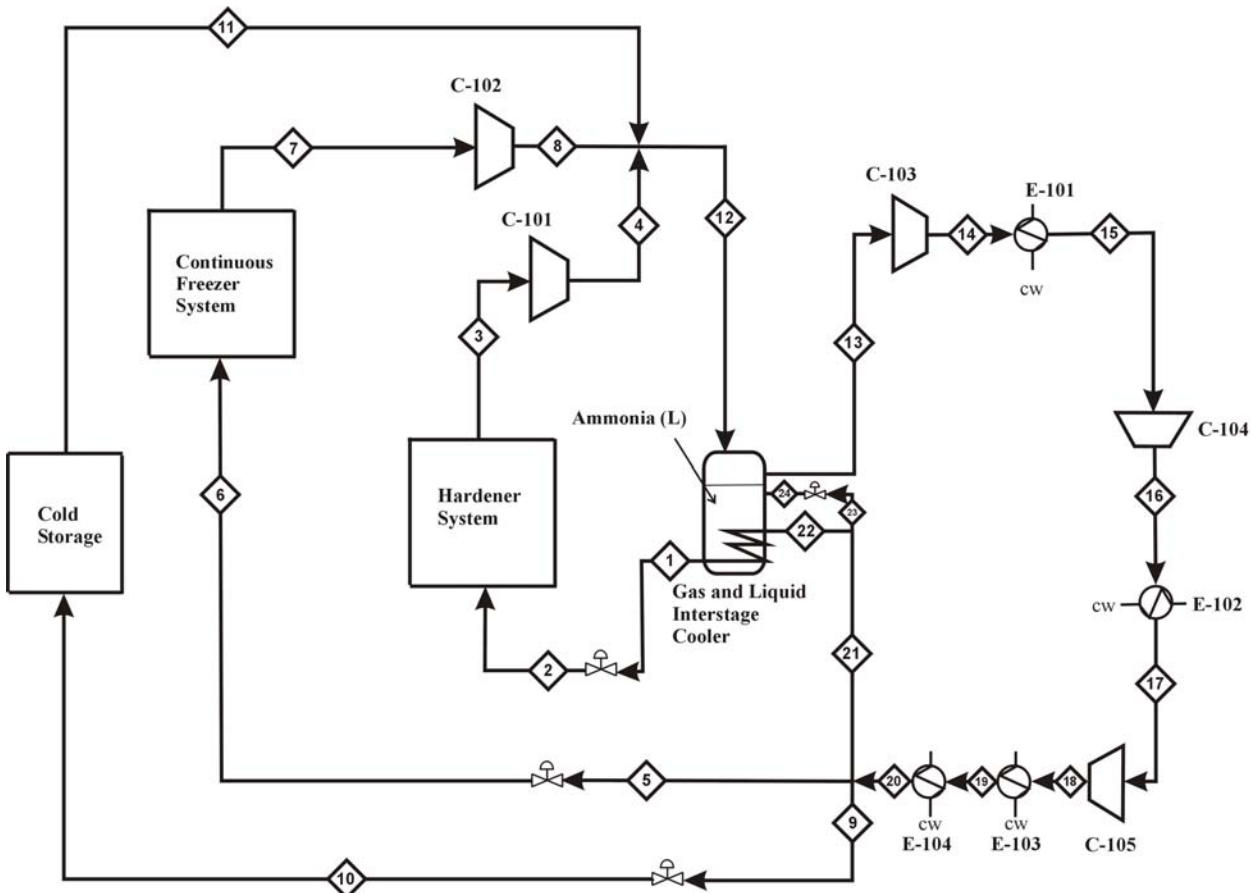
A facility to manufacture, store, and ship ice cream was designed.

## **Manufacturing Process**

The manufacturing process of the ice cream facility is broken down into 7 steps: raw material delivery and storage, base mixing, homogenization and pasteurization, aging, flavor addition and continuous freezing, cartoning, and finally hardening. Three separate process lines are utilized, with two of the three lines containing aging tanks for premium products. The ice cream for novelty items is produced from the line without aging tanks.

## **Refrigeration Cycle**

An optimized ammonia refrigeration cycle design is displayed in Figure 1. The three temperatures utilized for this process are  $-45.6^{\circ}\text{C}$ ,  $-40.0^{\circ}\text{C}$ , and  $-34.7^{\circ}\text{C}$  for the hardener system, the continuous freezer system, and the cold storage room, respectively. The streams entering the refrigeration equipment via Streams 2, 6, and 10 consist of a vapor-liquid mixture, which boils and undergoes a complete phase change to a saturated vapor leaving the equipment. Stream 3 and Stream 7 are then pressurized to the ammonia operating pressure for the refrigeration equipment utilizing the highest temperature, that in the cold storage room, and the three streams are sent through the Flash Gas and Liquid Interstage Cooler, V-101. The saturated vapor exiting V-101 undergoes a cascaded series of compressors and heat exchangers that results in the pressure of 2.02 MPa exiting C-105. This exiting pressure corresponds to the temperature where the ammonia can be condensed with cooling water in E-103 and E-104. Streams are then split to the respective refrigeration equipment and throttled to achieve the necessary pressures and temperatures. Prior to throttling the stream entering the hardener system, Stream 22 is cooled to  $-28.9^{\circ}\text{C}$  in V-901.



**Figure 1: PFD for the Optimized Ammonia Refrigeration System Unit 1**

A separate ammonia refrigeration system was designed for cooling the milk at the front end of the process. This was suggested by Gunther, in which multi-temperature systems with multi-compressors operate at similar evaporator temperatures [3], as with Unit 1. The PFD for Unit 2 is depicted in Figure 2. The ammonia enters the milk storage tank system as a vapor-liquid mixture at  $-1.22^{\circ}\text{C}$ , and exits as a saturated vapor. A series of compressors pressurizes the ammonia to 2.02 MPa, and Stream 7 is throttled to give the desired temperature.

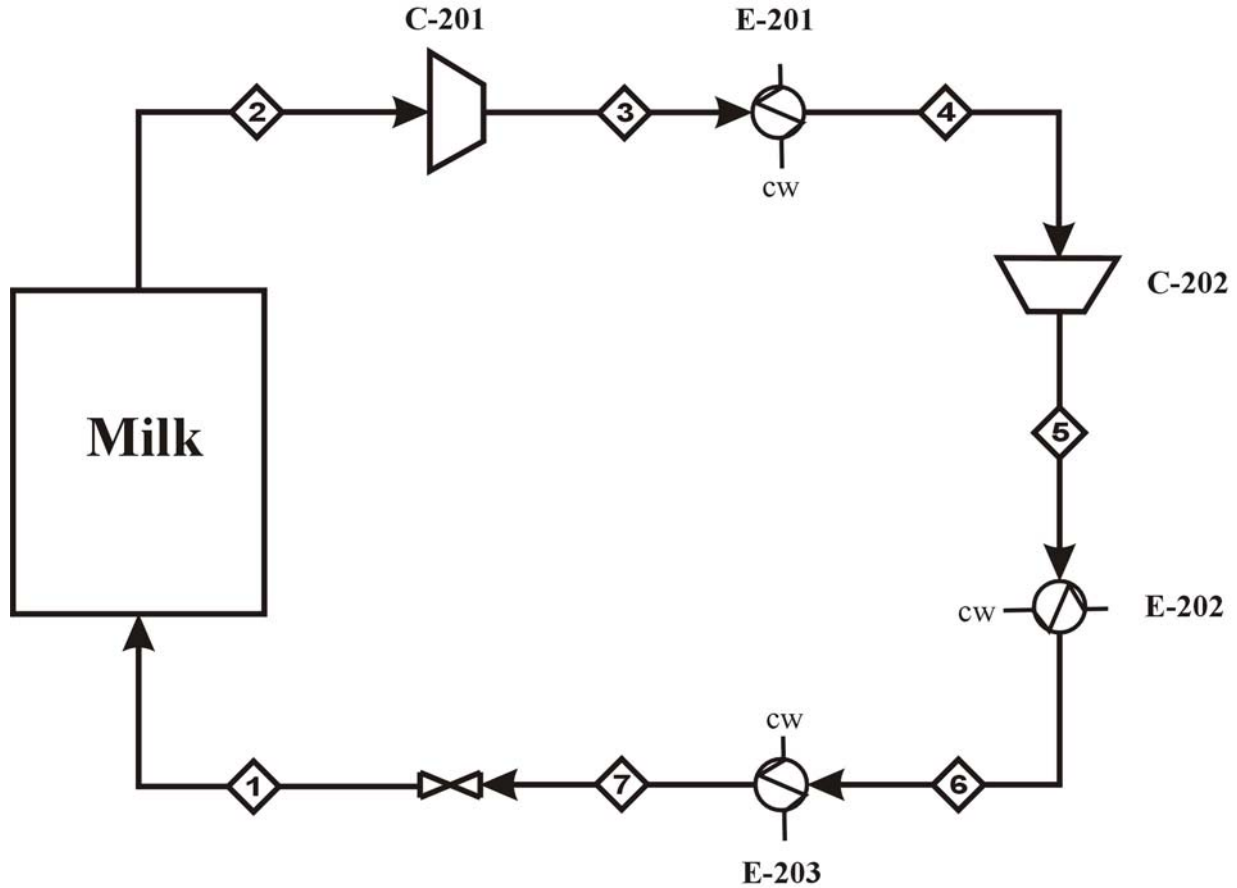


Figure 2: PFD for the Optimized Ammonia Refrigeration System Unit 2

### Warehouse Design

The warehouse for the ice cream storage has a surface area of 17,450 m<sup>2</sup>, an operating temperature of -24°C, and is able to hold three months of production. Because of the need to refrigerate the warehouse, the construction requires special insulation, and the capital investment for this part of the process dominates the overall fixed capital investment. Optimization of the warehouse facility in terms of the inventory and market demands could lead to substantial savings.

## **Wastewater**

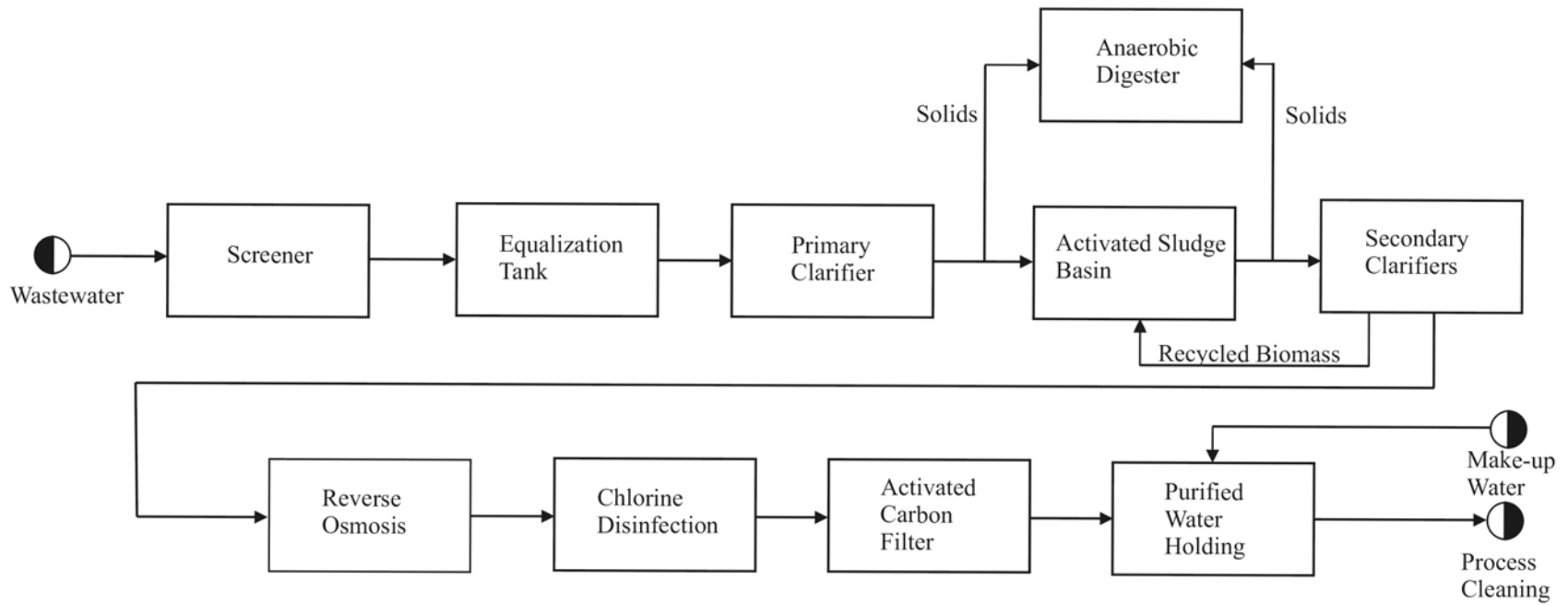
A wastewater system was designed to process approximately 1,630 m<sup>3</sup> per day of wastewater from the ice cream manufacturing facility. The proposed design processes the wastewater and purifies it again for cleaning at a cost of \$1.58/m<sup>3</sup>. Figure 3 gives the block flow diagram for the process.

The wastewater from the process first passes through the screener to remove all solids larger than 2 mm, and then passes on to the equalization tank. Here, the water is slowly released to the primary clarifier, where organic material is removed to lower the biological oxygen demand (BOD) to 525 mg/L before the water goes to the activated sludge basin. In the activated sludge basin, the water is aerated, and, through biological activity, the BOD is reduced by 95% to 25 mg/L. In the secondary clarifiers, the biomass is removed and a fraction is recycled back to the activated sludge. The remaining fraction is sent to the anaerobic digester along with the matter from the primary clarifier, where it is desiccated and turned into compost.

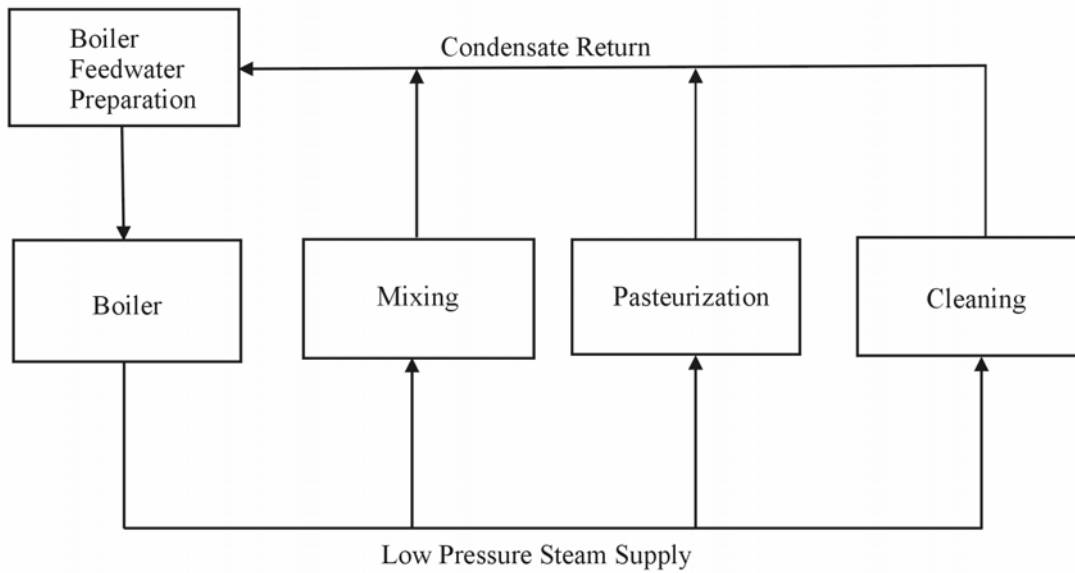
After the water leaves the secondary clarifiers, it passes through a reverse osmosis step to prepare the water for reuse. The water is then disinfected using chlorine and passed through a bed of activated carbon to remove any colors, odors, or flavors. A large holding tank is used to store the purified water for the next cleaning shift.

## **Steam Generation**

In the proposed facility, low-pressure steam will be used for pasteurization, jacketed heating of the mixing equipment, and to heat water for equipment cleaning. Figure 4 is a block flow diagram of the steam generation and users.



**Figure 3: Block Flow Diagram of the Wastewater Treatment System**



**Figure 4: Steam Generation and Recovery System**

## References

1. Functions of Gums in Food Systems, Powerpoint, 20 Jan 2005, [class.fst.ohio-state.edu/fst621/Lectures/PPT%20presentations/gums1.ppt](http://class.fst.ohio-state.edu/fst621/Lectures/PPT%20presentations/gums1.ppt)
2. Arbuckle, W.S., *Ice Cream*, 3<sup>rd</sup> ed., Westport, Connecticut, AVI Publishing Company, Inc., 1977, pp.96-103.
3. Gunther, Raymond C., *Refrigeration, Air Conditioning, and Cold Storage*, 2<sup>nd</sup> ed., Philadelphia, Chilton Company, 1957.



## Executive Summary

In designing an ice cream production facility for Capstone Chemical Corporation, more than just the details of ice cream making were considered. Due to the rural location of the plant, a wastewater treatment facility was included and, due to the sheer size of this facility, the warehouse was a major focal point of the design. The systems that provide refrigeration and steam to the ice cream process were also essential, and therefore, a detailed design of these was conducted. All in all, with a ten-year payback period, the net present value (NPV) of this process is \$97.8 million.

The wastewater facility has been designed as a close to zero-discharge unit. Wastewater from the facility is captured and treated to a purity such that it can once again be used in this process. Although it would likely be less expensive to send this waste off-site to the local municipality, by direction of Capstone Chemical Corporation, it was assumed that this was not an option due to the large volume of water (1,630 m<sup>3</sup>) that the plant will generate on a daily basis. This system will cost \$1.5 million in capital investment and have an annual operating costs will top \$280,000 in materials and electricity.

The ammonia refrigeration system supports multiple parts of the process. The primary unit is responsible for supplying the continuous freezers, hardener, and warehouse with sub-zero ammonia in order to achieve the necessary process conditions. The second unit is charged with supplying cooling water to the heat exchangers of the primary unit and to the milk storage tanks so that the milk does not spoil. Two separate units are used because the maximum temperature difference between the two systems reaches 100°F. Under these conditions, the system efficiency drops significantly when the two units are combined. For both units, the cost of equipment is small in comparison to the yearly operating cost for electricity. The total cost for the refrigeration system is \$5.7 million.

Steam is used in the ice cream process for pasteurization, mixing, and for the daily cleaning operations of the process, the last of which will be the major draw on the steam system. To accommodate various steam requirements, the system has been designed to deliver a peak load of 8,900 kg/h of low-pressure steam. With a capital investment of roughly \$300,000, this is a relatively inexpensive part of the process.

The warehouse for this process is very large. It covers an area of 17,450 m<sup>2</sup> and has the capacity to hold 10 million, half-gallon containers of ice cream and an additional 1.6 million boxes of novelty products. It has been designed to maintain a constant temperature of -20°F and to allow 22 trucks to be loaded each day. Costing roughly \$43 million, it is by far the most expensive piece of this facility.

This process will produce 51.9 million, half-gallon containers, 2.3 million six-packs of sandwiches, and 4.3 million six-packs of bars on a yearly basis, bringing the yearly revenue to \$122 million. Labor costs add up to nearly \$7 million each year, raw materials cost \$20 million, and utilities cost \$1 million. This all results in the cost to produce one half gallon container of ice cream, one box of bars, and one box of sandwiches being \$0.56, \$0.60, and \$0.60, respectively.