Current Design of Ice Cream Freezers

Frozen Desert Center Conference
October 22-23, 2018
Continuous Ice Cream Freezers

Students learn to make ice cream at the University of Wisconsin during the early 1920s. Note the Mojonner overrun tester (left) and vertical freezer (second from right).
Continuous Freezers

- Almost a Century of Innovation
- Still many mysteries
- Also widely used outside of ice cream production for the preparation of:
  - Whipped cream cheese
  - Chilled Desserts
  - Whipped Topping
  - Cosmetics
  - Plasticized Shortening
  - Freeze-dried Coffee
Invention

► Attributed to Henry Vogt in 1928
► His first Patent was awarded when as US Army Captain he developed an automatic delayed firing mechanism for high explosive shells.
Continuous Freezers

1945 - and some still in operation

1975

1996

2003

2013 ->

Launched in 2013
Tetra Pak® CF x000 A2.0

Current Operating Range:
80l/h (21gal) to 4,500l/h (1200gal)
Modern Freezer

- Cleaning & Sanitation
- Refrigeration System
- Air System
- Power Plant
- Human/Machine Interface
- “Core Process”
- Ice Cream/Mix Handling
Core Process
Making ice cream

- Initiating extremely many ice crystals
- Incorporating air and creating a fine, stable foam
- Achieving a uniform and stable ice cream texture
Modern Freezer – Mix Flow
How it is done
Function of the continuous freezer

- Ice cream
- Knifes / Scraperblades
- Dasher
- Refrigerant
- Ice cream mix & air

Diagram showing the flow of ice cream and the components of the freezer.
Freezing of water into ice crystals
Freezing of water into ice crystals

TPH reference recipe - 10% dairy fat

Ice cream temperature vs. Percent frozen water

- Percent frozen water:
  - 0%
  - 20%
  - 25%
  - 35%
  - 40%
  - 46%
  - 50%
  - 55%
  - 60%
  - 65%
  - 75%
  - 80%
  - 82%

- Temperature:
  - -25°C
  - -20°C
  - -15°C
  - -10°C
  - -5°C
  - 0°C
  - 5°C
  - 10°C
  - 15°C
  - 20°C

Moulding fluid - viscous
Filling - Extrusion viscous
Low temperature Extrusion viscous
## Dasher Design

<table>
<thead>
<tr>
<th>Type</th>
<th>Application</th>
<th>Picture</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Standard Dasher</strong></td>
<td>▪ Round holes &lt;br&gt; ▪ Standard ice cream recipes. &lt;br&gt; ▪ Long retention time &lt;br&gt; ▪ Good aeration &lt;br&gt; ▪ Lower shear</td>
<td><img src="image1.png" alt="Standard Dasher Image" /></td>
</tr>
<tr>
<td><strong>Multi Dasher</strong></td>
<td>&quot;Today Standard in most freezers&quot; &lt;br&gt; ▪ Oblong holes &lt;br&gt; ▪ All ice cream recipes. Particularly including low/non fat, organic and low solid content recipes. &lt;br&gt; ▪ Less building up &lt;br&gt; ▪ Long intervals between thawing</td>
<td><img src="image2.png" alt="Multi Dasher Image" /></td>
</tr>
<tr>
<td><strong>Solid Dasher</strong></td>
<td>▪ Recipes demanding short retention time &lt;br&gt; ▪ low mechanical treatment &lt;br&gt; ▪ High shear &lt;br&gt; ▪ Retain shape after extrusion due to high amount of partially coalesced fat</td>
<td><img src="image3.png" alt="Solid Dasher Image" /></td>
</tr>
</tbody>
</table>
# Beater Design

<table>
<thead>
<tr>
<th>Type</th>
<th>Application</th>
<th>Picture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wing Beater</td>
<td>- Standard ice cream recipes</td>
<td><img src="image1.png" alt="Wing Beater" /></td>
</tr>
<tr>
<td></td>
<td>- High agitation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Static</td>
<td></td>
</tr>
<tr>
<td>Dynamic Beater</td>
<td>- Recipes needing gentle/low agitation</td>
<td><img src="image2.png" alt="Dynamic Beater" /></td>
</tr>
<tr>
<td></td>
<td>- Rotating bars eccentrically placed inside dasher</td>
<td></td>
</tr>
<tr>
<td>Solid Cage Beater</td>
<td>- In connection with water ice production where reduced agitation is needed. Rotating tube with holes eccentrically placed inside dasher</td>
<td><img src="image3.png" alt="Solid Cage Beater" /></td>
</tr>
</tbody>
</table>
# Dasher Speed

<table>
<thead>
<tr>
<th>Dasher Speed</th>
<th>Advantage</th>
<th>Disadvantage</th>
</tr>
</thead>
</table>
| **High**     | - Higher fat churning  
- More stable foam structure  
- Better constancy for high overrun and low viscous filling  
- Smaller ice crystals at lower viscosity / higher ice cream temperatures | - Higher power consumption  
- Reduced freezing capacity |
| e.g. 350 rpm for CF 2/3000  
Big Pulley – Standard configuration | |
| **Low**      | - Recipes needing gentle/ low agitation  
- Ice cream with high butterfat content, that have a higher risk of “churning out” by too much agitation  
- Less agitation energy is added to the ice cream – more kneading happens in the cylinder due to the lower temperature / higher viscosity | - Poorer ice cream structure at warm outlet temperature |
| e.g. 230 rpm for CF 2/3000  
Small Pulley - Optional | |
| **Variable** | - Is recommended, when several different recipes, viscosities and capacities must run on the same freezer during a short time span | |
Variation of a solid dasher: Extruder Auger

- Typically used as a secondary freezer for further temperature reduction and to reduce ice crystal and air bubble size, thereby improving perceived creaminess
- Solid dasher without knives
- Threads do not contact the cylinder wall
- Machines incorporating both twin and single Auger designs are available
Refrigeration System
Refrigeration Concept

► The heat transfer from one medium to another is controlled by a few simple but fundamental rules:

- There must be a temperature difference in order for energy transfer to take place.
- Energy (heat) will always flow from the warmer medium towards the colder medium.
- The energy (heat) rejected from the warm medium is equal to the heat absorbed by the cold medium plus losses to the surroundings.
Refrigeration Concept

- Liquid refrigerant is introduced into an annular space around the freezing cylinder and evaporated under controlled conditions and thereby removing (using) energy from the media – in this case “The ice Cream Mix” to boil of the refrigerant.
Central Refrigeration Systems are typically used in larger plant settings for efficiency. The compressors are used to service the continuous freezers, cold storage and other applications. (Flooded System)

Freezers with self-contained refrigeration systems have become very popular due to the ease of installation and operation. (DX Expansion)
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Refrigeration
Flooded Central System & Direct Expansion

► Stable and Uniform output
► Larger # option available
► Requires 3 party approval
► High’er installation cost
  - Fixed & authorised piping installation
  - Capex: 1000 l/h (264gal/h) = Index 80
  - Capex: 2000 l/h (528gal/h) = Index 100

► Standard with few options available
► Off the shelf / Short delivery
► Flexible installation
► Low’er installation cost
  - No fixed installations
  - Capex: 700 l/h (185gal/h) = Index 40
  - Capex: 1500 l/h (396gal/h) = Index 65
Refrigerant Types

► Early refrigerants included Ammonia, Carbon Dioxide, Methyl Chloride (CH₃Cl) and Sulfur Dioxide (SO₂). Could be lethal.

► Chlorofluorocarbon gas (Freon) for use as a refrigerant was invented 1928.

► Currently phasing out of Freon and investigating alternative “eco-friendly” alternatives

► Carbon Dioxide (CO₂) emerging as one of the potential solutions…
Modern Refrigerants Comparison

<table>
<thead>
<tr>
<th>GWP</th>
<th>A/C &amp; ref</th>
<th>Ref</th>
<th>A/C</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 4,000</td>
<td>R404A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 2,500</td>
<td>R452A</td>
<td>R22</td>
<td>R407A/R407F</td>
</tr>
<tr>
<td>&lt; 1,500</td>
<td>R134a</td>
<td>R449A</td>
<td>R448A</td>
</tr>
<tr>
<td>&lt; 700</td>
<td>R450A</td>
<td>R513A</td>
<td>R515</td>
</tr>
<tr>
<td>&lt; 150</td>
<td>R123zd</td>
<td>R1270</td>
<td>R600a</td>
</tr>
</tbody>
</table>

Source: www.Danfoss.com

R600a = Iso Butane / R290 = Propane
Freezing Cylinder

- Refrigerant surrounding the heat exchange cylinder, ice cream mix inside
- Heat exchange cylinder is typically nickel with chromed interior surface
- Self Contained cylinders are typically brass base chromed surface and Stainless shell
Freezing Cylinder

► Ribbed Barrel introduced during the 1980s
► Significant improvement to heat transfer efficiency
► Newer exterior patterns show up to 21% more efficiency than smooth barrels
► Permits Higher Evaporation Temperatures (raise suction by 5.4°F (3°C) or higher ice cream capacity.)
Freezing Cylinder
Ice Cream / Mix Handling
Mix Handling - Steps

► Deliver the mix to the continuous freezer
► Meter the mix into the cylinder at the proper capacity in ratio with the overrun air
► Preconditioning - if required (Pre-aerator)
► Control the pressure of the mix in the cylinder (stable conditions)
► Handling of CIP cleaning
Mix Metering – where the accuracy starts

► Positive pumps have been used on ice cream freezers to meter the ice cream mix into the freezer, control of the mix flow is critical for output performance.

► Today, most modern freezers supplement the mix pump with a flow meter to verify mix flow and to make speed corrections to the pump (e.g. due to pump wear (“slip”). These flow meters are typically magnetic flow or mass flow type.
Pre-aeration Device

- Essentially a high-shear mixer
- Early development was for improving air incorporation in molded mixes with low viscosity
- Some companies used the device to reduce weight fluctuations of product exiting the freezing cylinder.
- Still further applications involve textural and air bubble size improvement
- The device is installed after the air injection point and before the mix enters the cylinder.
Cylinder/barrel Pressure

- Additional pressure in the freezing cylinder is needed in order to compress the air inside the barrel and increase the retention time of the ice cream.
- … also to secure good agitation for better incorporation of the air and more efficient heat transfer (due to smaller air bubble size).

Reduce air volume inside the barrel resulting in optimal mechanical shear when blades moves in ice cream mix than air, increasing retention time of the ice cream and increases the interaction between ice cream and barrel.
Some applications call for multiple discharge pumps to improve splitting of flow to multiple extrusion lanes.

The freezer at right has five discharge pumps.

It has also become common to supply freezers with inlet and discharge pressure sensors to protect the freezer against low feed or high discharge conditions.
Air System
Air System

► Air is typically the largest ingredient, by volume, in ice cream and also the least expensive, so the regulation of overrun air is critical to the performance of the machine.
► Henry Vogt’s first freezer employed a piston pump system to supply the overrun air.
► Subsequently freezer manufacturers devised different systems to draw the air in under vacuum to eliminate the need for compressed air.
Overrun Air Flow Measurement

- Modern freezers typically use compressed air-supply.
- Air flow is regulated by an Air Mass Flow Meter electronically controlled by the freezer PLC system.
- Measurement is very precise and can track changes to the base mix flow if the freezer speed is adjusted.
- Air Mass Flow meters do not account for changes in Barometric Pressure.
  - Daily effect: up to 6-7% swing in Barometric pressure can occur.
  - Altitude effect: 17% difference in volume from sea level to 5000 feet.
Air measurement
Air Quality Conditioning

- Earliest systems used replaceable cotton filter pads
- Modern freezers typically have multiple filtering stages:
  - Pre-filter Element consisting of a Primary Filter * and Active Carbon Filter **
  - Membrane Drier ***
  - Bacterial Filter ****
- Compressed air is also use air for cycling valves and pump covers during CIP

ISO 8573-1 (1,3,1)
* Removes up to 99.99% of oil, water and dirt particles 0.1 μm or greater
** Removes oil droplets, vaporized oil (0.01 mg/m3)
*** Dries air to -20C dew point
**** Removes up to 99.9999% of solids 0.1 μm or greater
Power Plant
Power Plant

- Along with refrigeration compressor, the dasher and pump motors are the largest source of energy consumption on the freezer, thereby their importance to manufacturers.
- Even before the development of continuous freezers it was realized that the dasher motor load could be used as an indication of the ice cream stiffness, this principle is still used today to control viscosity. In slush freezing applications like molded bar production, temperature control is used.
- Earliest dasher drives used a belt and pulley, fixed speed drive.
- Today variable dasher speed drive is used, in case of special recipes.
Cleaning and Sanitation
Cleaning and Sanitation

► Early continuous freezers were designed cleaning by daily disassembly. Plant piping was taken down and washed in COP tanks.

► The advent of CIP and the increase in size and capacity of continuous freezers brought improvements like the CIP-able pump and programmed CIP cycles to periodically turn on and off the pumps and dasher to improve cleaning.
**Cleaning and Sanitation**

- Today industrial continuous freezers are typically integrated into factory-wide automated cleaning systems that track the CIP process.
- Industrial freezers can be supplied to monitor the CIP flow rate and feed pressure and share information on conditions in the freezer during cleaning.
- Sanitation can be accomplished using chemical disinfection of hot water at temperatures up to 195°F (90°C).

### Chemical Disinfection

<table>
<thead>
<tr>
<th>Freezer type</th>
<th>Cream pipe diameter</th>
<th>Minimum flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>CF 500</td>
<td>1”</td>
<td>2.7 m³/hour</td>
</tr>
<tr>
<td>CF 1000</td>
<td>1.5”</td>
<td>5.4 m³/hour</td>
</tr>
<tr>
<td>CF 2000</td>
<td>2”</td>
<td>9.7 m³/hour</td>
</tr>
<tr>
<td>CF 3000</td>
<td>2.5”</td>
<td>16.4 m³/hour</td>
</tr>
<tr>
<td>CF 4000</td>
<td>2.5”</td>
<td>16.4 m³/hour</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Application</th>
<th>conc. (%)</th>
<th>temp. (°C)</th>
<th>time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neutral disinfectant</td>
<td>0.5</td>
<td>Cold</td>
<td>10</td>
</tr>
<tr>
<td>Acid foam cleaner</td>
<td>2.0 - 3.0</td>
<td>80 - 90</td>
<td>10</td>
</tr>
</tbody>
</table>

**Continuous freezers**

<table>
<thead>
<tr>
<th>Area/Equipment</th>
<th>Product</th>
<th>Product characteristic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mip 5CA</td>
<td>Alkaline cleaner with surfactants</td>
<td>1.0 - 2.0</td>
</tr>
<tr>
<td>FS-foam 999</td>
<td>Neutral disinfectant</td>
<td>0.5</td>
</tr>
<tr>
<td>FS-foam 961</td>
<td>Acid foam cleaner for external cleaning of covers and stainless steel surfaces</td>
<td>2.0 - 3.0</td>
</tr>
</tbody>
</table>
Human/Machine Interface
The human machine interface

- Early machines manually controlled and had only three critical adjustment settings:
  - Regulation of overrun
  - Regulation of speed
  - Regulation of viscosity (refrigeration control)

- These 3 settings are still displayed on the main screen of every modern freezer
Machine Information Displays

► Dasher Speed (if provided with a VFD)
► Barrel Pressure
► Evaporation Temperature
► Machine Alarms
► Maintenance prompts
► Automatic start-up and defrost routines
► CIP conditions
► Due to the proliferation of variables, Recipe Control is now a standard part of most PLC-controlled freezer programs
The Human Machine Interface
The Human Machine Interface
The Human Machine Interface
Performance
Driving Innovation

Operational cost

The total cost of freezing

Investment cost

Operational cost

Investment cost
Greatly reduced product loss

- Improved start-up cycle
- Improved overrun addition during start-up
- Sequenced start-up cycle
- ≤ 2 minutes from outlet pump start until stable production parameters are achieved
  - Viscosity
  - Cylinder pressure
  - Overrun

- Maximum amount of ice cream loss
  = ½ cylinder content (21l (5.5gal) for a CF 2000 (530 gal/hr)
Faster start-up

► Controlled volumes and pressure in the cylinder
► In- and outlets closed during start-up
► Controlled metering of mix and air

Annual savings from 5 minutes’ faster start-up to rework of mix

STG/April 2015
Lower standard deviation

- Extremely high product uniformity
- Reduced giveaway
- Average standard deviation of product weight: < 0.7%

Savings with reduced standard deviation

- KF 4000
- KF 3000
- KF 2000
- KF 1000
- CF 4000
- CF 3000
- CF 2000
- CF 1000

STG/April 2015
Reduced energy consumption

- Synchronous motors with higher efficiency
- 10% increased heat transfer with same cylinder dimensions
- Evaporation pressure valve with reduced pressure loss
- Dasher speed optimized to actual need when running at partial capacity (optional)
Maximum user-friendliness

“The easiest freezer in the world to operate” *

► User-friendly operator panel
► Built-in safeguards
► Extensive, clear production data
► Automatic recipe handling
► Automatic start-up / hold and stop cycles
Future Work
Future work

► To discover the mystery of what happens in the barrel.
► First, for specialized applications, to take advantage of this learning and develop improved dasher arrangements….. which may result in a proliferation of specialized designs for example to improve creaminess in low calorie products, produced enhanced types of water ices and exotic non-dairy products. Frequent exchange of dashers will require ergonomic freezer access solutions.
Future work

► Secondly, for general applications, to find the most balanced design, an optimum in-between for industrial customers with a variety of applications but the need to maintain high machine utilization.
Thank You