Technical Reports
Optimizing Your Chilling Process

Introduction

What the processor works so hard to achieve in the smokehouse can often be adversely affected by improper cooling of the product after cooking. Critical factors such as product quality, consistency, and cost of manufacture are directly related to the proper cooling of product just as they are to the proper processing of product in the smokehouse. The following discussion concerns itself with the importance of "Post-Smokehouse Processing" through cooling technology.

Product Cooling

Proper cooling of processed meat products is a matter of necessity in today's market. Proper cooling is needed to preserve the product in most cases. A majority of meat products depend upon cooling to prevent spoilage. Government regulations to a large extent dictate the safe temperatures to which product must be cooled, and often prescribe the amount of time in which a particular product must reach the chilled temperature. Product taste and quality can be affected by the efficiency of product cooling. After cooking, processed meats which depend upon cooling for preservation will fare better if cooled promptly, rapidly, and uniformly.

Cooling also plays a role in the profitability of processed meats.

Product quality, in terms of taste, shelf life, texture, and appearance, can be influenced by the cooling process. Overall product yield, yield uniformity, and slicing yield can also be affected by the manner in which product is cooled. Inefficiently cooled product may result in higher percentages of rework. And finally, operating costs are affected by the efficiency (or inefficiency), with which products are cooled. Clearly, product cooling should be considered important to the processor's profitability.

Cooling Methods and Theory

The proper cooling of processed meat products is directly influenced by two factors: the physical characteristics of the product, and the method of heat transfer. For these reasons, both cooling methods and cooling theory are important in understanding and evaluating the cooling of meat products. Cooling theory is used to develop cooling methods. At the same time, new cooling methods generate increased knowledge of cooling theory and product characteristics during the cooling process.

Cooling Methods

Four methods of cooling processed meat products are illustrated in this discussion
1. **Conventional Air Chilling** has been the most predominant method of chilling used by meat processors. The air cooler and the air blast chill (both in various configurations) are widely used. (Figures 1 and 1A)

2. **High Performance Air Blast Chilling** is a more recently developed chilling method combining air as a cooling medium with highly efficient air handling systems to achieve significant improvements over conventional air chilling methods. (Figure 2)
3. **Liquid Chilling** (beyond the use of water as a cooling medium) has been used successfully for chilling processed meat products since the late 1960’s. These chillers employ highly effective liquid cooling mediums of either sodium chloride brine or propylene glycol. (Figure 3)

![Figure 3](image)

4. **Evaporative or "Intensive" Chilling** has been in use, primarily in Europe, since the 1970’s. These systems take advantage of the evaporative cooling effect achieved by wetting product surfaces with water while at the same time directing air movement over the product. Overall, evaporative cooling allows improved efficiency over air chilling, but is greatly limited in performance when compared to liquid chilling. (Figure 4)

![Figure 4](image)

These methods each have advantages, disadvantages, and limitations with respect to chilling of particular processed meats. A more detailed comparison of air chilling and liquid chilling methods appears later in this discussion.

**Cooling Theory**

Cooling technology is greatly affected by underlying cooling theory. A general knowledge of the basic principles of heat transfer, thermal properties of processed meat products, and temperature relationships between product and cooling medium is beneficial. An understanding of these principles will provide a better opportunity to evaluate the efficiency and effectiveness of a cooling system and compare alternate methods of cooling.

**Principles of Heat Transfer**

Two basic modes of heat transfer, **conduction** and **convection**, occur during the cooling of meat products.

- **Conduction** refers to the movement of heat through the product from the interior to its surface. The same principle is at work during cooking, but in the opposite direction.
• **Convection** in terms of product cooling, refers to the transfer of heat from the product surface to the cooling medium. The method of product cooling strongly influences the efficiency of convective heat removal.

Thermal Properties

A number of thermal properties of processed meats are of specific interest in establishing a basic understanding of cooling theory. They are listed as follows:

• **Specific heat (Cp)** refers to the energy, in Btu per pound, needed to raise or lower pound of a product 1°F. The specific heat is directly related to the molecular structure of a product, and is important in determining the refrigeration capacity for a cooling system.

• **Thermal conductivity (k)** relates to the rate or "speed" at which heat travels through a product to its surface. Thermal conductivity determines how fast heat transfer can occur. Various products have different thermal conductivities. A high moisture content usually indicates a high thermal conductivity. Fat content usually has an inverse on conductivity. Due to fat's insulating ability.

• **Product geometry** is another factor closely related to thermal conductivity with regard to cooling time. Though not specifically a thermal property, product geometry factors such as configuration, thickness, or diameter are critical to the time required for a product to cool.

• **Latent heat** is important only in those instances where a product must be cooled below its freezing point. This may be required for certain sliced products. Latent heat is the amount of energy needed to change the phase of a product (e.g. from above freezing to below freezing). It is specified in Btu's per pound, and varies for different products. The obvious importance of latent heat is in determining the amount of refrigeration needed for a chilling system.

• Selected thermal properties for various meat products are shown on Table 1.
Table 1.
Thermal Properties of Meat Products

<table>
<thead>
<tr>
<th>Product</th>
<th>% Solids</th>
<th>%Water</th>
<th>Cp</th>
<th>K</th>
<th>Latent Heat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bacon</td>
<td>61</td>
<td>29</td>
<td>0.60</td>
<td>0.28</td>
<td>74</td>
</tr>
<tr>
<td>Bologna</td>
<td>35</td>
<td>65</td>
<td>0.86</td>
<td>0.31</td>
<td>86</td>
</tr>
<tr>
<td>Franks</td>
<td>40</td>
<td>60</td>
<td>0.86</td>
<td>0.31</td>
<td>86</td>
</tr>
<tr>
<td>Ham</td>
<td>51</td>
<td>49</td>
<td>0.68</td>
<td>0.28</td>
<td>87</td>
</tr>
<tr>
<td>Turkey</td>
<td>32</td>
<td>68</td>
<td>0.79</td>
<td>0.29</td>
<td>106</td>
</tr>
</tbody>
</table>

Temperature Differential

In establishing effective product cooling parameters, the temperature difference between the product surface and the product core will determine the cooling rate. Just as a high surface-to-core temperature difference results in a faster heating rate, the same relationship exists for product cooling. This is important in achieving rapid chilling rates and in developing a proper cooling system design. Factors limiting the cooling rate, however, will be the thermal conductivity of a product and the feasible or practical refrigeration temperatures that can be used.

A basic knowledge of cooling theory will allow a better understanding of product cooling and how the product is affected by different cooling methods. Experimental testing is still important, and should be relied upon to establish the basis for cooling system design.

Air Versus Liquid Chilling

Air and liquid chilling are the two primary methods of cooling processed meat products in use today. Each method is often promoted as superior to the other by both manufacturers and processors alike. In reality, methods, air and liquid, have advantages and disadvantages.

Depending upon specific circumstances, one method may indeed be better suited than the other. It is important to consider the type of products being chilled, the particular cooling criteria demanded by a product, and limitations which might be imposed by the facility or by environmental or other regulations. This discussion presents a comparison of air and liquid cooling methods.
**Heat Transfer Coefficient:** When evaluating cooling methods, efficiency is of significant importance. The measure of a cooling system’s efficiency is expressed in terms of a heat transfer coefficient. It is often called a "U" factor.

The heat transfer coefficient expresses the heat removal efficiency as Btu per hour-foot °F. It is actually a measurement of a system's capability to remove heat via convection.

As noted previously, convection is the mode by which heat is transferred from the product surface to the cooling medium.

The heat transfer coefficient of a cooling system is affected by two primary factors, the type of convective heat transfer and the cooling medium. Convection is classified as either "free" or "forced" convection. The cooling medium, for purposes of this discussion, refers to either air or liquid.

Free convection is a mode of heat transfer in which the product heat is transferred to a non-moving cooling medium.

Forced convection, on the other hand, is a mode of heat transfer in which the cooling medium is agitated or fan-driven.

Of primary interest is the fact that forced convection creates a higher heat transfer coefficient than free convection because of the movement of the medium. Further, a liquid cooling medium has a significantly higher coefficient than air. Table 2 illustrates these comparisons.

<table>
<thead>
<tr>
<th>CHILLING MEDIUM</th>
<th>HEAT TRANSFER COEFFICIENT (W/m K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AIR:</td>
<td></td>
</tr>
<tr>
<td>• Free Convection</td>
<td>5 - 15v</td>
</tr>
<tr>
<td>• Forced Convection</td>
<td>10 - 200</td>
</tr>
<tr>
<td>WATER:</td>
<td></td>
</tr>
<tr>
<td>• Free Convection</td>
<td>20 - 100</td>
</tr>
<tr>
<td>• Forced Convection</td>
<td>50 - 10,000</td>
</tr>
</tbody>
</table>

BTU/ft²
Air Chilling

**Conventional Air Chilling.** Product cooling utilizing air is by far the most common cooling method used in the meat processing industry. It has a long history of use and remains the most common method of cooling meat products despite the inefficiencies inherent in large holding coolers and many blast coolers. As a cooling method, conventional air chilling is typically applied by means of forced convection.

Some strengths and weaknesses of conventional air chilling are listed as follows:

a. **Strengths**
   - Lower initial cost
   - Relative ease of maintenance
   - Simplicity of design
   - Suitability for chilling all processed meats

b. **Weaknesses**
   - Low heat transfer coefficient
   - Longer cooling times (vs. liquid)
   - Lack of temperature uniformity
   - Higher shrink (vs. liquid)

**High Performance Air Blast Chilling.** A significant improvement in chilling efficiency using air can be achieved using the more recently developed technology of "high performance air blast chilling." This technology effectively utilizes "moving front" air handling methods similar to those successfully used in modern food processing ovens. Results show dramatic improvements are achievable when compared to conventional holding and blast cooler performance.

Some strengths and weaknesses of high performance air blast chilling are listed as follows:

a. **Strengths**
   - High efficiency
   - Reduced shrink
   - Faster chill time (vs. coolers)
   - Energy savings (vs. cooler)
   - Product compatibility

b. **Weaknesses**
   - Highest initial cost
   - Longer chill time (vs. brine)
   - More floor space (vs. brine)
   - Higher maintenance/cleaning (vs. cooler)

**Liquid Chilling**

The use of liquid as a method of cooling processed meats takes various forms in the meat processing industry. Water is the most common form of liquid chilling, whether
used as an initial shower in the smokehouse after cooking, or in tanks for immersion chilling. Water has obvious limitations imposed by its freezing point, and is unacceptable as a recirculated cooling medium.

The most prevalent forms of liquid chilling found in the industry are sodium chloride (salt) brine and propylene glycol solutions. Each of these liquid cooling mediums are widely used and accepted, and achieve the most rapid cooling of the methods compared.

Some strengths and weaknesses of liquid chilling are listed as follows:

- **Strengths**
  - High coefficient of heat transfer
  - 50% - 75% faster than air
  - No shrink
  - Less floor space
  - Energy efficient
  - Reduced in-process inventory

- **Weaknesses**
  - Higher initial equipment cost
  - Requires more maintenance and cleaning
  - Cost of cooling solution
  - Cost of solution disposal (brine)
  - Possible product incompatibility

**Brine vs. Glycol:** When comparing brine and glycol as liquid cooling mediums, it is important to consider a number of factors. Each medium has advantages and disadvantages, as do each of the cooling mediums discussed. Further, considerations regarding the type of product being chilled will undoubtedly point to the liquid cooling medium best suited for your application.

- **Sodium Chloride Brine**
  - Relatively low cost
  - Applicable for most products
  - Can be used to 0°F.
  - Solution life is USDA regulated
  - Corrosive nature
  - Disposal may be a concern

- **Propylene Glycol**
  - Indefinite period of use
  - Can be used to -20°F.
  - Non-corrosive
  - High cost of solution
  - Use for impervious casing products
  - Loss prevention/moisture removal are critical

**Conclusions**
Cooling technology is an important aspect of "Post-Smokehouse Processing". Product quality, yields, consistency, and uniformity can be just as strongly affected by what occurs during cooling as by what happens in the smokehouse. For this reason, the cooling of processed meats requires careful attention:

1. Understand product characteristics and how they are affected by cooling.
2. Evaluate cooling system performance, and monitor it as closely as you monitor smokehouse performance.
3. Consider improvements and/or alternate methods of product cooling -- especially when faced with increasing production demands or upgrading your facility.