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Development of a Heat and Mass Transfer Model to Simulate the Conventional Chilling of a Beef Carcass

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Development of a Heat & Mass Transfer Model for Chilling of a Beef Carcass

Graham Fahey, Ross Gilsenan, Niall Ó'Murchú, Joseph Hannon, Garrett Keane

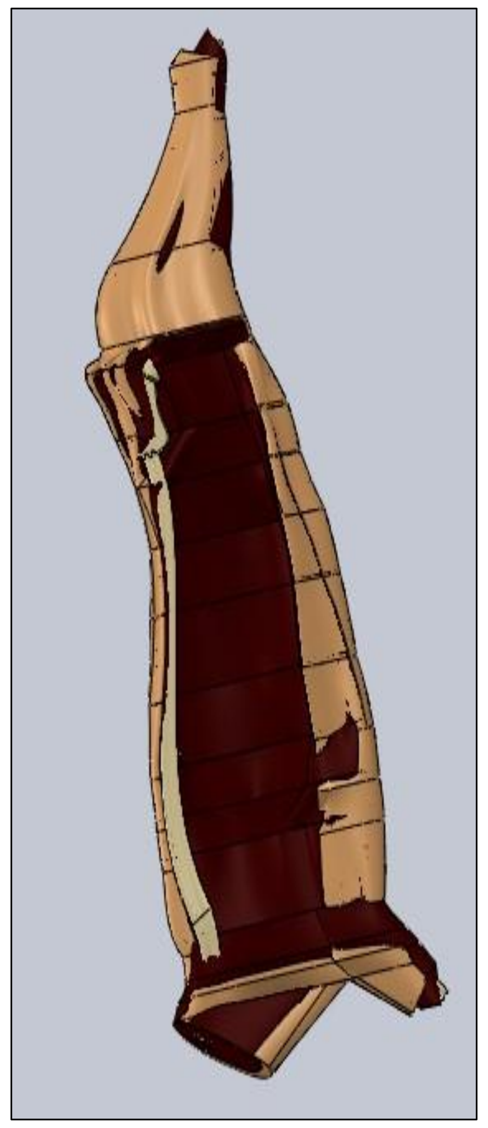
Abstract

This project concerns the development of a coupled heat and mass transfer model to simulate the chilling of a beef carcass post slaughter. The methodology outlined by Mallikarjunan, P., & Mittal, G. (1994) was adopted for this study and results were compared with experimental results obtained from previous research. Cost benefits can be gained from being able to predict heat and mass loss profiles more accurately. Finite differential analysis was researched and implemented on the beef carcass based on established methodologies. The project demonstrated that results from the finite difference method documented can relatively closely replicate the process of beef chilling in relation to both heat and mass transfer.

Background

According to reviewed literature, upon slaughter the temperature of a beef carcass is generally in the region of 38 ºC. But this temperature could be higher due to ATPase reaction in muscle post-mortem.

This project was based upon Mallikarjunan's paper on chilling of a beef carcass and attempted to model the heat transfer process and mass transfer processes involved. When chilling beef carcasses, a crucial aspect is the rate at which the chilling process takes place. Cold shortening of the meat can occur is the rate is too high. Muscle toughening and mass loss can occur. So it is desirable not to allow the muscle temperature to fall below 10 ºC within the first 10 hours post mortem. This is in direct contradiction to the fact that chilling rapidly can extend the shelf life of the beef considerably. Chilling rates also affect the tenderness of the meat and therefore its quality and selling price. Therefore it is important to be able to predict the temperature at various points in the carcass throughout the chilling process in order to identify any areas that may be cooled too fast or too slow. For this reason temperature and mass profiles are required.



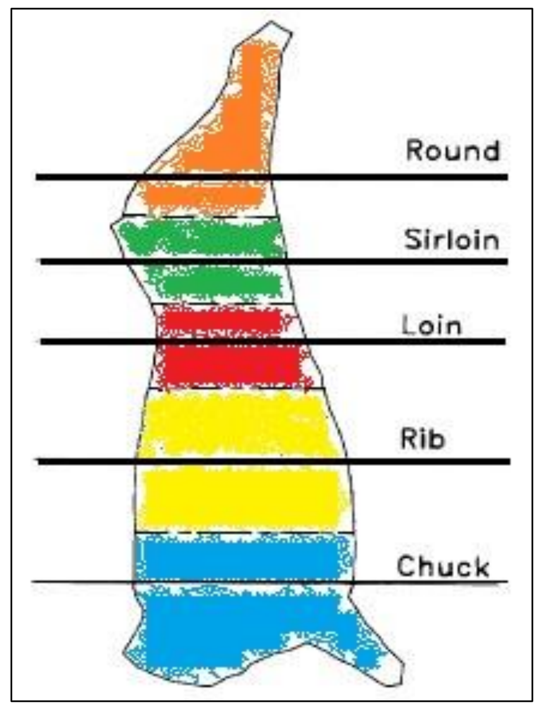
Source: Joseph Hannon

Objectives

- Derive suitable nodal equations based on models for predicting heat and mass transfer during beef carcass chilling.
- Improve upon the heat transfer model from previous years through the addition of heat generation due to ATPase reaction.
- Review and improve upon existing VBA coding.
- Compare results obtained with experimental results.

Methodology

In order to establish changing values for heat and mass transfer a finite difference method with forward time step was used. This method is especially useful for solving differential equations and it solves the problem iteratively, which is applicable for this problem because the value at each time step is given and then can be compared to those around it to see trends in the data. The finite difference equations were formulated for Cartesian co-ordinates and coded in Microsoft Excel VBA. The scheme used ambient temperature of 0.44ºC, average relative humidity of 85% and air speed of 0.5 m/s over a period of 47 hours.



Beef Cut Sections

The model was based on the following assumptions:

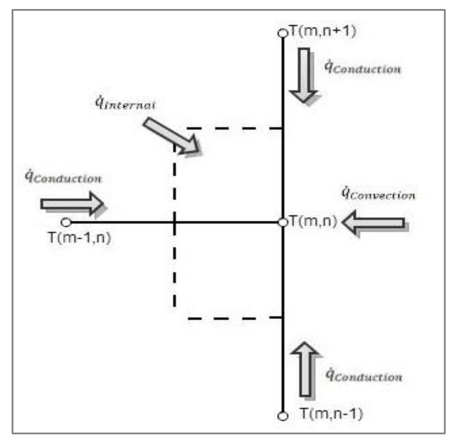
- The carcass shape is consistent with the shape shown based on given literature and is divided into five two dimensional sections.
- Heat and mass transfer in the vertical direction is negligible. For this reason a two-dimensional was used.
- Density was deemed uniform for the transfer model.

$$M_{carcass} = 0.22M_{round} + 0.1M_{sirloin} + 0.31M_{rib/loin} + 0.37M_{chuck}$$

Finite Difference Formulation from First Principles

The first set of equations produced were for the heat transfer across the carcass.

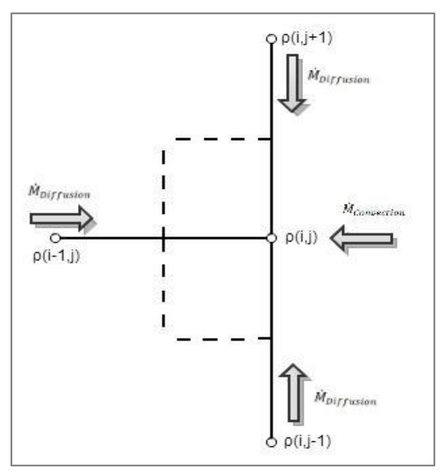
These were derived based on the orientation of nodes in the beef section. The equation below for heat transfer across the carcass sections now includes a q ("dot") term which has been added in to account for ATPase reaction.



Heat Transfer: Planer Right

$$T_{m,n}^{P+1} = T_{m,n}^{P}(1 - 4Fo - 2FoBi) + Fo\left(T_{m,n+1}^{P} + T_{m,n-1}^{P} + 2\,T_{m-1,n}^{P} + 2BiT_{\infty} + \frac{\dot{q}(\Delta x^2)}{k}\right)$$

A key aspect of the project was the derivation of the mass transfer equations. They needed to be in a similar form to the heat transfer so that they could be coupled together with values for heat driving mass transfer rates via the saturation pressure (P_s) value. Equations from Mallikarjunan were combined with the equations from Cengal (2007). The formula below shows one such equation produced for a planer surface.

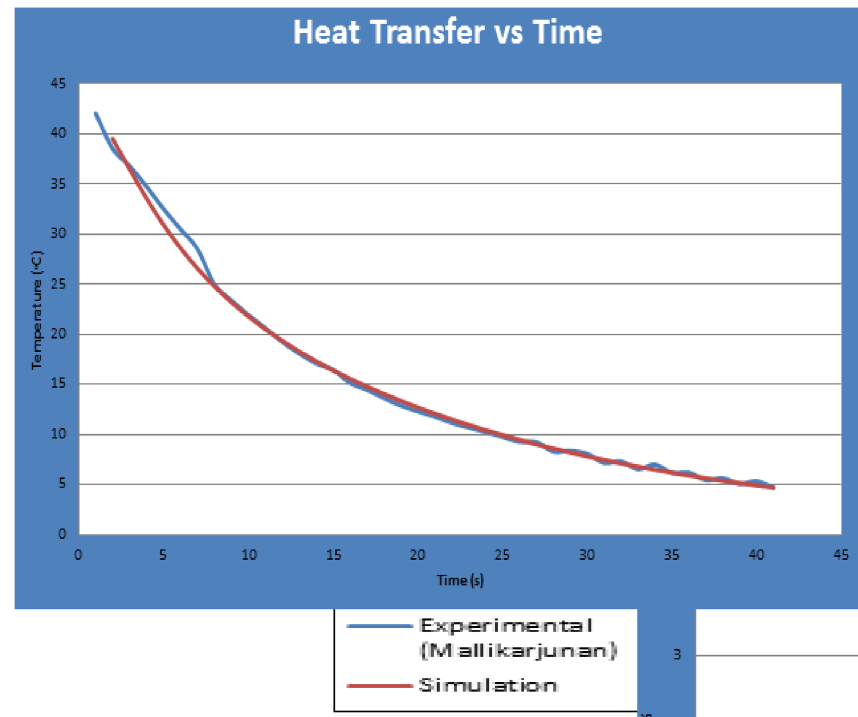


Mass Transfer: Planer Right

$$M_{m,n}^{P+1} = M_{m,n}^{P}(1 - 4Fo_M) + Fo_M\left(M_{m,n+1}^{P} + M_{m,n-1}^{P} + 2\,M_{m-1,n}^{P}\right) + h_M \Delta x \Delta t (P_s - P_\infty)$$

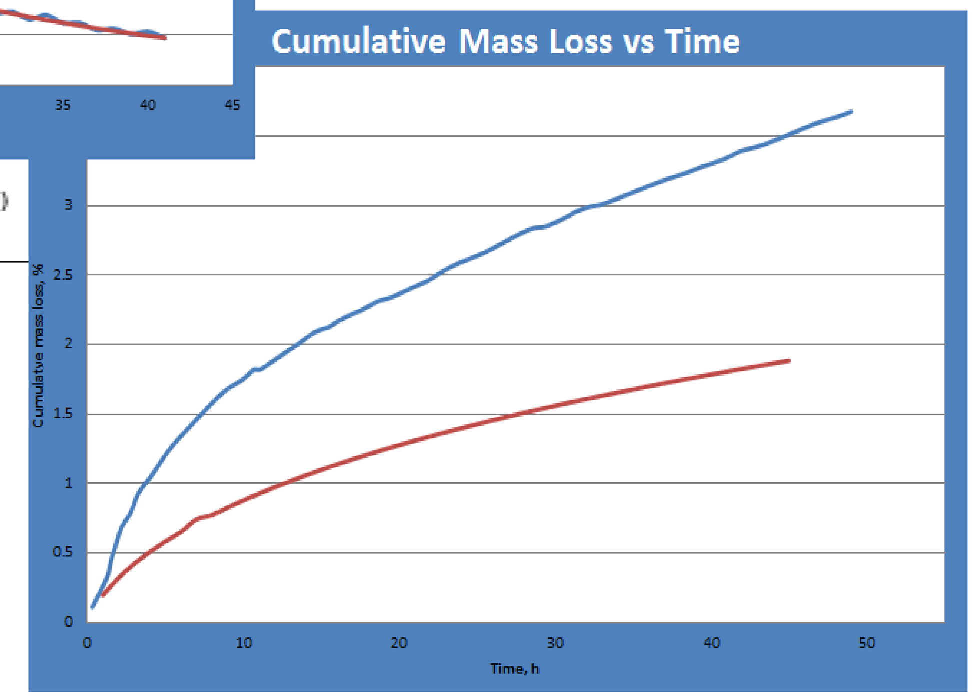
[h_m = surface mass transfer coefficient]

Results



These graphs show a close correlation with the Mallikarjunan's experimental results and the simulated results for heat and mass transfer through the carcass as it is cooled..

They also portray the drop in temperature of the carcass and the percentage mass loss against time.



Conclusions & Recommendations

- From the results, it is evident that the heat transfer model follows experimental data very closely, proving that the model is adequate. The mass transfer however, was not as close to the literature model. It followed a similar shape graph, however the error increased with increase in time.
- The literature from Mallikarjunan included that a term that should be added to the temperature model to account for the change in heat transfer due to the loss of mass at boundaries. In doing so it would fully couple the heat and mass transfer equations. Due to time constraints this was not possible to complete but as a recommendation, this term should be added and could possible reduce the error observed in this project
- Also, h_m, the surface mass transfer coefficient was a constant in this model but this would in reality change with changing temperature. If an equation could be derived to account for this, it may enhance the accuracy of the model and would be a good area for research.

Acknowledgments

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