Freezing of Fish by Vertical Platefreezers

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Abstract: Energy-efficiency is one of the big issues of the 21st century. Due to the limited resources of primary energy carriers and their environmental load, a higher effectiveness for their use has to be achieved. Even small improvement in models, observers and/or control-strategies can have a large impact on consumption of energy carriers. The system we are looking at is a fishing vessel (trawler). The overall aim is therefore, to reduce energy consumption and at the same time preserve or even enhance fish quality.

The vessel is driven by a (diesel-) main engine, which produces electricity. All of the vessel's consumers, such as electric propulsion motors, freezing units, processing units, cooling pumps, ship operation equipment and other facilities are powered by electric energy from the main engine. Besides the propulsion motors, the freezing units are the biggest energy consumers on board. The caught fish shall, after having been processed *, be frozen as fast as possible. The process, that is used to freeze the fish, is a vapor-compression refrigeration circle process run with ammonia (NH_3). The ammonia flows through the freezer's plates, cools them down very strongly (-38 C) and due to direct contact, the fish gets frozen.

The model that is taken for simulating the temperature distribution throughout the fish block with thickness L is the one dimensional heat-equation, a linear partial differential equation (PDE):

$$\rho(T) \cdot c(T) \cdot \frac{\partial T(t,x)}{\partial t} = \lambda(T) \cdot \frac{\partial^2 T(t,x)}{\partial x^2} \tag{1}$$

It has to be noticed, that the parameters $\rho(T)$, $c(T)$ and $\lambda(T)$ change with temperature. Simplified, the fish can be considered as a thermodynamical alloy of many basic components, such as water/ice, protein, fat, carbohydrates and ash. The above mentioned parameters can therefore be calculated by the following equations:

$$c(T) = \sum_i c_i(T) \cdot x_i \ , \ \rho(T) = \sum_i \rho_i(T) \cdot x_i \text{ and } \lambda(T) = \sum_i \lambda_i(T) \cdot x_i \tag{2}$$

It is remarkable, that not 100% of the water in the fish gets frozen in the temperature range, we are looking at. At -30 C only about 90% of the water is frozen. The reason for this is, that, when freezing, solutes remain in the liquid phase, lowering its freezing point. Just at about -70 C all the water can be considered as frozen.

A phenomenon, that has to be considered due to the large fraction of water (60%–80%), is the latent heat of fusion. This means, that there will occur heat transfer at the freezing point without lowering the temperature. This can be explained by energy storage present in the formation of water molecules. This energy has to be removed in order to enable water molecules to nucleate and ice crystals to form and grow.
Ice crystal growth has a big influence on quality, respectively freshness of the product. Dependent on the speed of freezing, ice crystal sizes differ. Slow freezing results in large ice crystals and fast freezing in small ice crystals, respectively. Large ice crystals emerge when extracellular freezing happens prior to intracellular freezing, which disrupts the thermodynamical equilibrium. As a consequence, fluid is drawn from the inside of a cell to the outside, causing destruction of cell walls and thus reducing the quality. Therefore it is crucial to model the fish's thermodynamical properties as accurate as possible in order to predict temperature distribution, ice crystal growth and sizes and, as a result, quality.

* blooded, headed and gutted