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Quality Model of Foodstuff in a Refrigerated Display Cabinet

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ABSTRACT

Commercial refrigerating systems need to be defrosted regularly to maintain a satisfactory performance. When defrosting the evaporator coil, the air temperature inside the display cabinet will increase, and float outside the normal temperature range for a period of time, the question is what happens to the food inside during this period, when we look at the quality factor?

This paper discusses quality model of foodstuff, different scenarios of defrost scheme are simulated, questions such as how the defrost temperature and duration influence the food temperature, thus the food quality, as well as what is the optimal defrost scheme from food quality point of view are answered.

This will serve as a prerequisite of designing of optimal control scheme for the commercial refrigeration system, aiming at optimizing a weighed cost function of both food quality and overall energy consumption of system.

1. INTRODUCTION

Quality of food has become a way of profiling the high end supermarkets, which prefer to compete on quality rather than price.

Today the refrigeration in the supermarket is controlled based on the food authorities regulations, keeping the food within the allowed temperature limits, but this regulation is only applicable when the refrigeration system is in the normal operational mode.

On normal commercial refrigeration system, frost build-up on the evaporator coil is almost unavoidable, it is a function of time and some environmental factors such as air humidity, air velocity, air and fin temperature etc. It is undesired, and if nothing is done, the accumulated frost layer will lead to a dramatic degradation of the system performance, so defrost has to be performed regularly to maintain a satisfactory system performance. During defrost, the air temperature inside the display cabinet around the food will increase, and float outside the normal temperature internal for a period of time, depending on the different defrost scheme and techniques.

There are a lot research on when and how to defrost, while most of it is from the system efficiency or energy point of view (Hoffenbecker *et al.*, 2005) (Payne *et al.*, 1992). Few reports on how defrost will influence the food quality, and how to optimize the defrost scheme to minimize the quality decay exists.

Our approach is by establishing a quality model, to investigate what kind of food is more sensitive to the temperature change, and by simulating the different scenario of defrost scheme, to find out what kind of defrost scheme is most optimal for food quality.

This paper is organized as follows: the refrigeration of foodstuff in the supermarket is described in section 2, in section 3 we discuss the quality model, finally some discussions and conclusion in section 4.

2. Refrigeration of foodstuff in a supermarket

The display cabinet depicted in Figure 1 consists of a food container and an air tunnel, circulating cold air around the food container. An evaporator in the air tunnel cools the passing air which creates a carpet of cold air on top of the food.

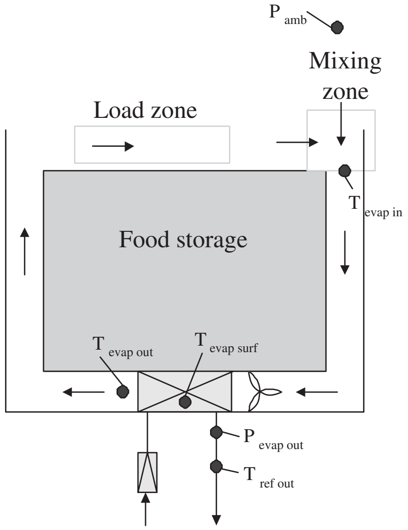

Figure 1: Simplified display cabinet in supermarket

The fact that the air carpet is colder than the food and ambient air, will keep the air carpet in place and denser, enabling the desired effect of heat transfer from the curtain to the container and food. A side effect is that the ambient air will infiltrate into the curtain at the load zone.

The display cabinet's temperature is normally controlled by a hysteresis controller which opens and closes the inlet valve, to control the flow of refrigerant into evaporator, thus keeping the air temperature within the specific bands, see Figure 2 and Figure 3, where the big change in temperature is caused by defrost cycle.

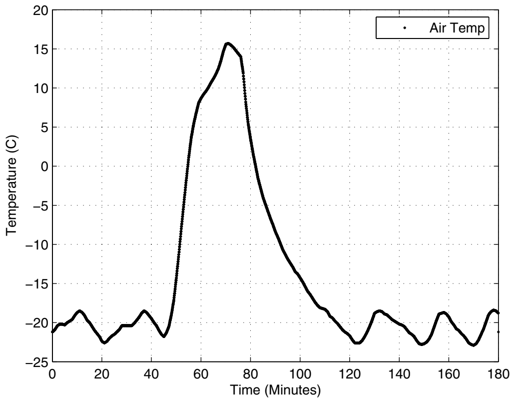

Figure 2: Frozen fish air temperature profile

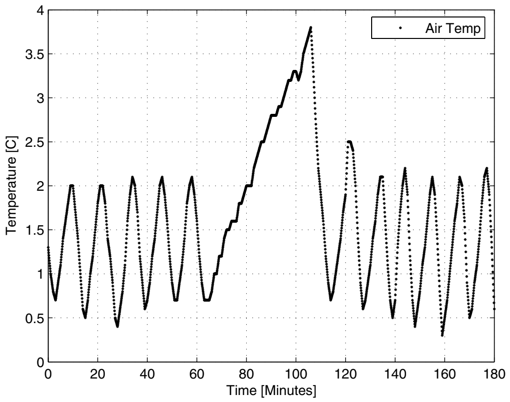

Figure 3: Fresh fish air temperature profile

2.1 Frost formation and defrost cycle

Frost forms on display cabinet evaporator as water vapor in the air condenses and freezes when it contacts the coil surface which is normally below 0 ºC. This is a well known and undesirable phenomenon. It deteriorates the system performance by decreasing the effective air flow area and increasing the thermal resistance between the air and the evaporator coils. Currently there are no clear and reliable measures that can prevent frost formation (Shin *et al.*, 2003). When frost accumulates to a certain level, defrost must be done to maintain a satisfactory system performance.

Defrost methods vary depending on the refrigeration application and storage temperature, and initiation and termination of defrost can be controlled by many different parameters, such as timer or temperature, sometimes up to 3 cycles per day. During the defrost cycle, the air temperature will increase and remain outside of the normal temperature range for a period of time.

2.2 Legal requirements

In Danish supermarkets, there are legal requirements regarding the storage temperature for different foodstuff in the display cabinets (DSK *et al*., 2004), here temperature is air temperature:

- Frozen food, the maximum temperature is -18 ºC.
- Fresh fish, the maximum temperature is +2 ºC.
- Milk, the maximum temperature is +5 ºC.

In general, the requirement is a temperature below +5ºC (web, 2005). There are also some temperature requirements during the food processing and transportation.

3. Quality model

3.1 Background

During food processing and storage a lot of "chemical" reactions occur. In general chemistry "reaction kinetics" are often treated in terms of reaction rates under specified conditions (normally isothermal). In food processing the actual reaction rate is interesting, but only as a means of obtaining the most interesting information: the integral effect, i.e. the accumulated effect after some processing steps or storage periods with varying conditions.

Examples of "chemical" reactions:

- Loss of vitamins
- Growth of microorganisms
- Enzymatic, non-enzymatic browning
- Changes in color
- Toughness due oxidation

The purpose of reaction kinetics in a food process is thus to be able to predict/calculate/estimate the consequences of a given treatment of a food item. The results may be as an absolute number such as a concentration, a fraction remaining or an index of the changes.

3.2 Shelf life calculations and quality loss

The shelf life of a product is a very important parameter. If the shelf life is too short, it will be impossible to market the product, and if it is declared too long, the consumer may wonder why.

The definition of shelf life depends on the limiting factors for the product. It may be microbial spoilage or decolorization as often in chilled storage, or it could be loss of vitamins or color as in frozen storage. These factors may all be observed by objective methods. Not so with the sensory values of the products.
Here we are forced to make observations regarding if the product has changed with respect to the fresh product. The investigation is carried out by triangular sensory tests, to establish if the assessors can detect a difference between a product that has not altered (stored at very low temperature) with significance.

Frozen storage (-30 ~ -18ºC)

For frozen foods, based on the kind of assessors we define:

- High Quality Life (HQL), when the assessors are trained.

- Practical Storage Life (PSL), when the assessors are untrained (normal consumers).

The relation between HQL and PSL is described by an acceptability factor, which may range from 2 to 10, depending on the product, and may even not be constant for the different temperatures. The experiments are carried out storing the produce at different temperatures, and assessing the quality at certain times. As soon as the assessors detect a difference with significance, the quality is deemed to be zero. The product starts with the quality of 100% and end with 0%. We have to stress, that a product of 0% quality, by this definition, is a very good product. The 0% quality is determined by the fact that a set of assessors looking for differences just found it with significance. The normal consumer would not detect the changes.

The time for loss of quality (100%) at temperature T is termed D_T, the function between D_T and temperature is expressed as Equation (1), where z-value is the product temperature sensitivity indicator.

$$D_T = D_{ref} \exp\left(-\frac{T - T_{ref}}{z}\right) \tag{1}$$

Calculation of shelf life is based on how much "quality" is consumed during different steps of storage (Andersen and Risum, 1994). This can be described by a storage profile expressing how long time t, the product has been kept at certain temperature T.

$$Q_{loss}(T,t) = \frac{100\%}{D_T}.t \tag{2}$$

Accumulated quality decay is based on linear additivity and temperature-time profile, such that

$$Q_{loss,total} = \sum_i Q_{loss}(T_i, t_i) \tag{3}$$

For frozen products one would normally use -18 ºC as T_{ref}, z-value depends on the product.

Chill storage (0ºC~)

For chilled food, in contrast to frozen food, the quality of chilled food from start is defined as 100% and 0% when the product is unsuitable for sale. The calculations are based on the same principles as for frozen food. But for chilled food one would normally use 0 ºC as T_{ref}, z-value depends on the product.

Parameters used in the simulation are shown in Table 1.

Table 1: Parameters used in the simulation

Product	T_{ref}	D_{ref}	**Z-value**
Frozen lean fish	-18	125	20
Frozen fat fish	-18	42	30
Fresh lean fish	0	5	10

Quality decay per minute in % for frozen fat and lean fish, as well as fresh lean fish is shown in Figure 4 and 5, where we can see that the quality decay is not in linear relation with temperature, high temperature has relatively higher deterioration effect.

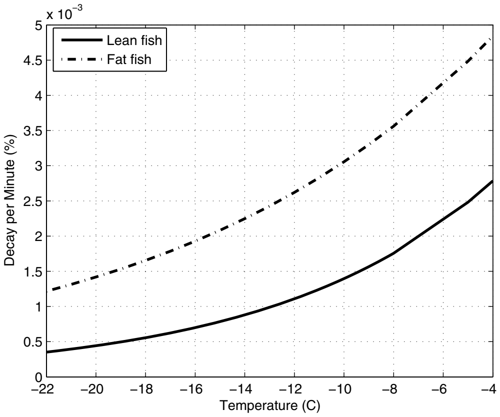

Figure 4: Minute decay for frozen fish

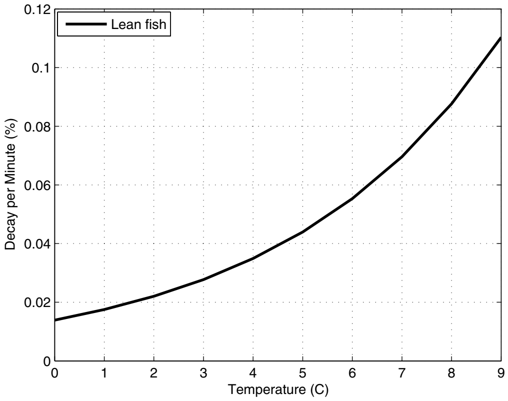

Figure 5: Minute decay for fresh fish

By applying the dynamic heat transfer model, we can get the dynamic food temperature profile, therefore we can calculate the timely decay and accumulated daily or monthly decay.

4. Discussion and conclusion

In this section, we will simulate the quality decay under the different scenarios of defrost scheme, to see what make difference from the quality point of view, and which kind of food is more sensitive to the temperature change during defrost.

4.1 different scenarios of defrost scheme

Today the most simple way to defrost is scheduled defrost, which uses a timer to initiate and terminate the defrost, depending on the storage temperature, store environmental condition and defrost techniques, the defrost frequency and duration is different, for frozen storage can be 1-2 times per day, for chilled food, around 2-3 times per day.

Scenario 1, one scheme defrosts more frequent and short duration each time, another scheme defrost less frequent with longer duration each time, see Figure 6.

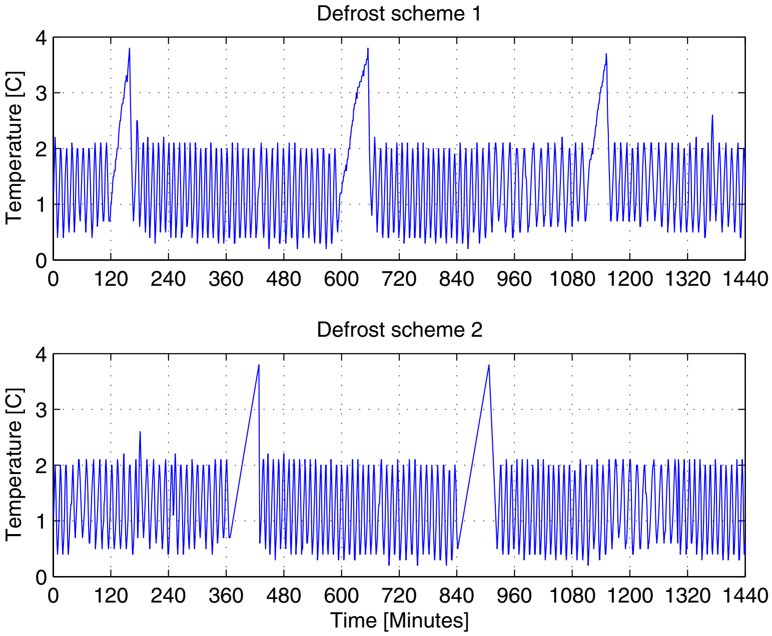

Figure 6: Air temperature profile for defrost scheme 1 and 2

Quality loss for these two defrost schemes is shown in Figure 7 and 8, which corresponding to a daily decay of 27.4% and 27.1% respectively, with difference around 1.1%.

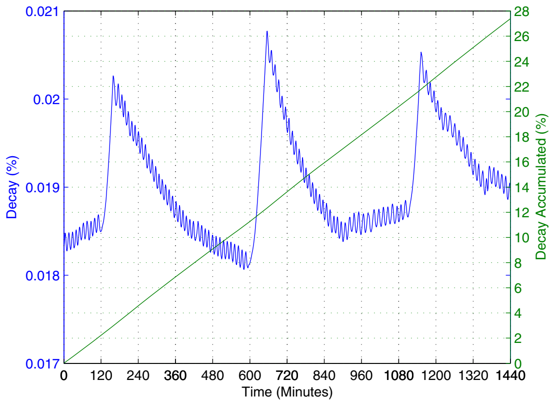

Figure 7: Fresh fish decay for defrost scheme 1

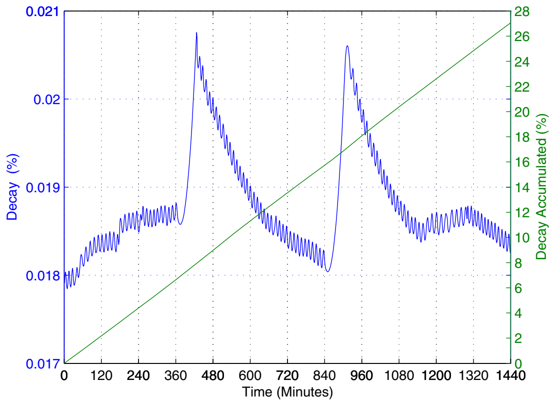

Figure 8: fresh fish decay for defrost scheme 2

Scenario 2, since the peak value of defrost temperature is one of main factors that influence the quality change, the ideal situation will be a low peak value. We lower the temperature before defrost as in Figure 9, to see what we can gain. Decay for 'normal' defrost scheme and manipulated defrost scheme is shown in Figure 10 and 11, which corresponds to a daily quality loss of 27.4% and 26.0% respectively, with difference around 5.1%.

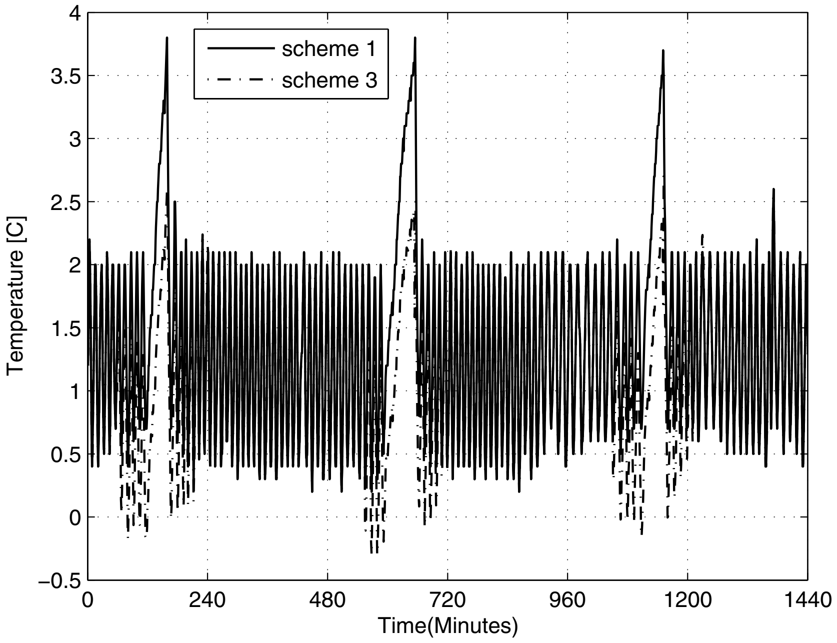

Figure 9: Air temperature profile for defrost scheme 1 and 3

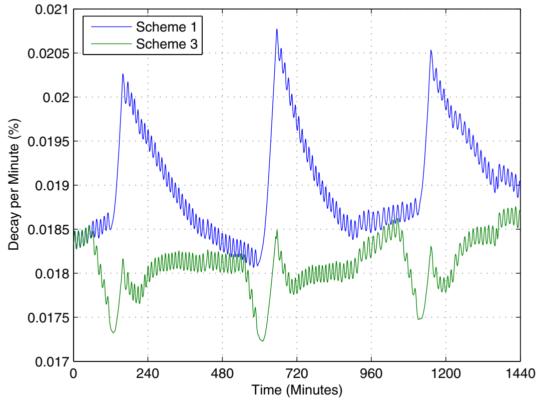

Figure 10: Fresh fish real time decay for defrost scheme 1 and 3

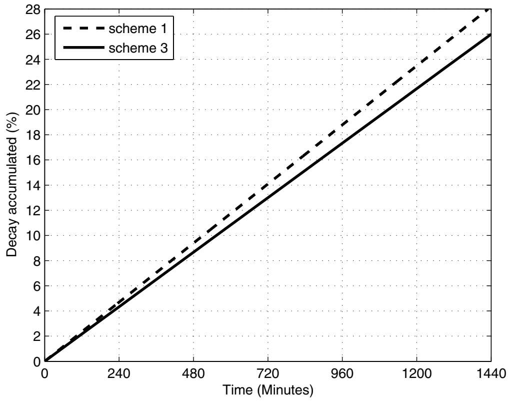

Figure 11: fresh fish accumulated decay for defrost scheme 1 and 3

4.2 Type of fish

Fat fish normally have shorter shelf life. The International Institute of Refrigeration (IIR) recommends the storage temperature for fat fish such as herring to be -24ºC, while for the lean fish such as cod, to be -18ºC. Fat fish has normally higher decay rate comparing with lean fish, recall Figure 4, is that mean that fat fish is more sensitive to the temperature change? Figure 12 shows the fat and lean frozen fish decay under the same air temperature profile, accumulated daily decay is 2.2% and 0.7% respectively.

If we zoom the defrost period, to see what is the difference if we defrost comparing if there is no defrost, meaning keep the fish at more or less constant temperature instead. Figure 13 shows the decay under these two different situations.

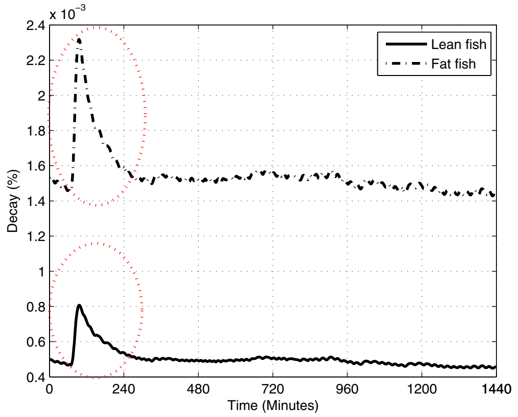

Figure 12: Frozen fish decay –fat vs. lean fish

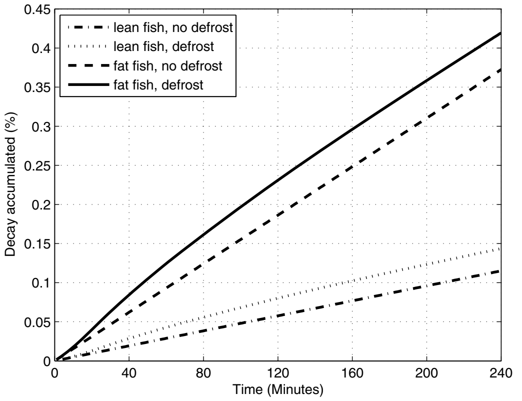

Figure 13: frozen fish decay- defrost vs. no defrost

For the fat fish, if there is no defrost during this 4 hours, decay is 0.37%, with defrost is 0.42%, defrost increase decay about 13.5%; for lean fish, if there is no defrost during this 4 hours, decay is 0.12%, with defrost is 0.14%, defrost increase decay about 14.3%.

4.3 Conclusion

By simulating the different defrosting scenarios, we can see that under the same condition, less frequent defrost with longer time duration, and low peak value of defrost temperature lead to less quality decay, and good for food storage. Fat fish has higher decay rate, but it is not more sensitive to the temperature change, as we assumed.

While when we defrost, for example, the evaporator for frozen food by electric heater, we need firstly supply energy to heat up the evaporator coil to melt the ice, and after defrost, need energy to lower the coil surface temperature again, in order to back to normal operation. If we lower the temperature before defrost, system normally consume more energy. Therefore we need to know what is cost when we use the different defrost scheme, this can be simulated by defrost and energy model.

Finally we can combine these two aspects-energy and quality into a weighted overall objective function, and design the optimal control scheme to optimize the overall system performance.

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