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INTRODUCTION

Aims of the SINTEF-project DANTEQ^a:

- Reduce energy consumption of a freezer-trawler and at the same time preserve / enhance fish quality.
- This needs an overall look on the big consumers on a freezer-trawler.

First step: Look at the freezing system on board.

Aims of this study:

- Find a model to estimate the temperature distribution in a fish block during freezing in vertical platefreezers.
- For a known temperature distribution the energy input to freeze the fish block can be precisely set.

^aDevelopment and assessment of novel technologies improving the fishing operation and on board processing with respect to environmental impact and fish quality

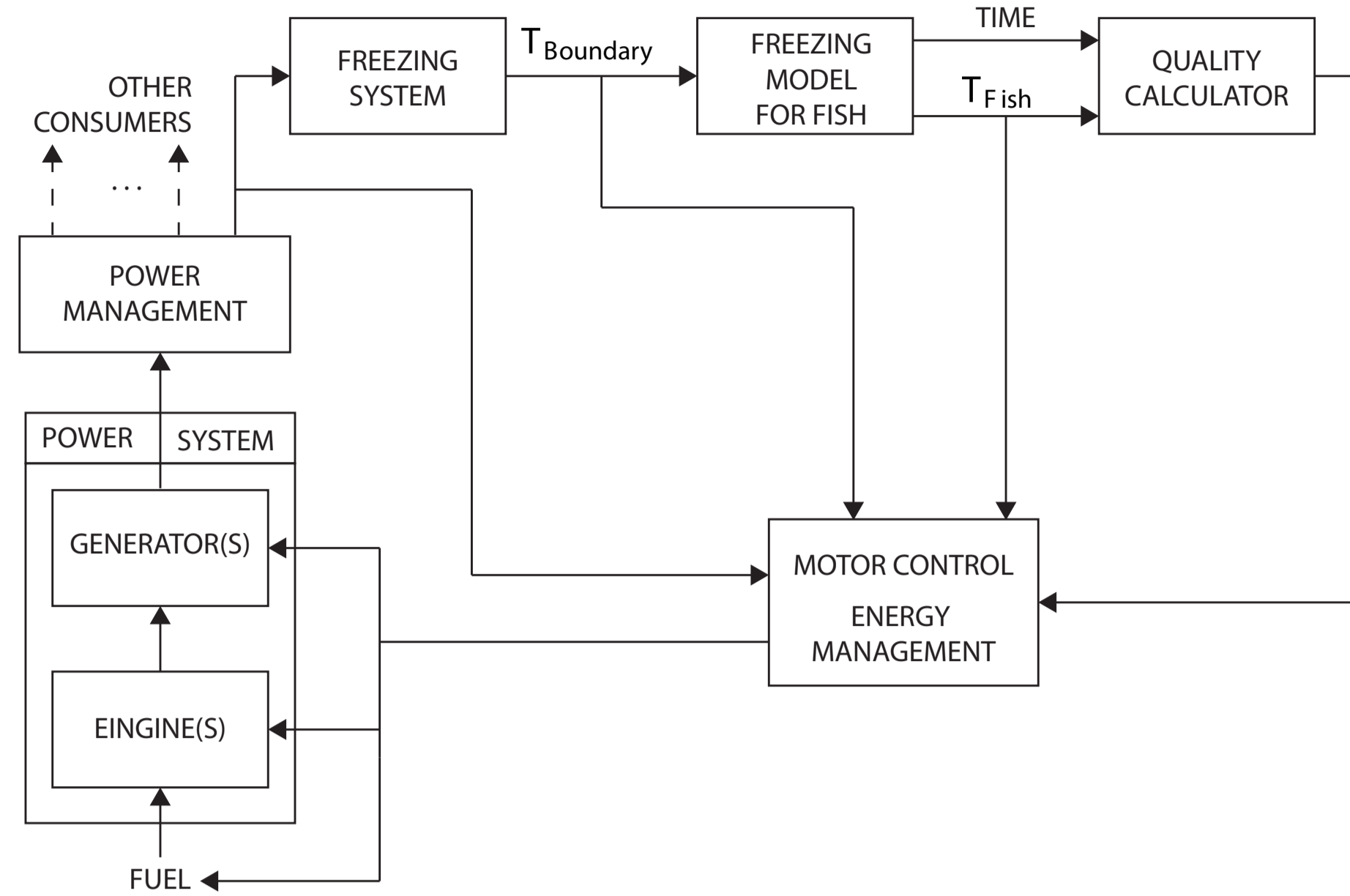


FIGURE 1: Simplified control scheme

The freezing system is an ammonia-circle-process and consists of [2]:

- compressor-unit
- condenser-unit
- separator (ammonia in liquid and vapor state)
- ammonia pump
- platefreezer

The freezing model for fish is a parameter-modified partial differential equation.

The quality calculator returns a number, that depends on the sizes of the ice-crystals, which grow depending on time and temperature of the freezing process.

METHODS



FIGURE 2: Vertical platefreezer

The temperature distribution is described by a partial differential equation [1]:

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

Further, the Dirichlet boundary conditions and the initial condition are set to:

$$\begin{aligned} T(t, 0) &= 235.15 \text{ K}, \\ T(t, L) &= 235.15 \text{ K}, \\ T(0, x) &= 283.15 \text{ K}. \end{aligned}$$

Fish is considered as a thermodynamical alloy of basic components (water/ice, protein, fat, carbohydrates and ash). The overall parameters are calculated by adding up the component's parameters multiplied by the mass fractions:

$$\begin{aligned} c(T) &= \sum_i c_i(T) \cdot x_i, \\ \rho(T) &= \sum_i \rho_i(T) \cdot x_i, \\ \lambda(T) &= \sum_i \lambda_i(T) \cdot x_i. \end{aligned}$$

Calculation of $c_i(T)$, $\rho_i(T)$ and $\lambda_i(T)$ according to [3]:

$$\begin{aligned} c_i(T) &= a_{c0,i} + a_{c1,i} \cdot (T - 273.15) + a_{c2,i} \cdot (T - 273.15)^2, \\ \rho_i(T) &= a_{\rho0,i} + a_{\rho1,i} \cdot (T - 273.15) + a_{\rho2,i} \cdot (T - 273.15)^2, \\ \lambda_i(T) &= a_{\lambda0,i} + a_{\lambda1,i} \cdot (T - 273.15) + a_{\lambda2,i} \cdot (T - 273.15)^2. \end{aligned}$$

Mass fractions are considered constant, except that for water. Based on [4], an approximated function for the iced fraction of water is chosen to

$$x_{ice}(T) = -1.342 \cdot e^{\frac{2}{3}(T-273.15)} + 0.9$$

for $233.15 \text{ K} \leq T \leq 272.15 \text{ K}$.

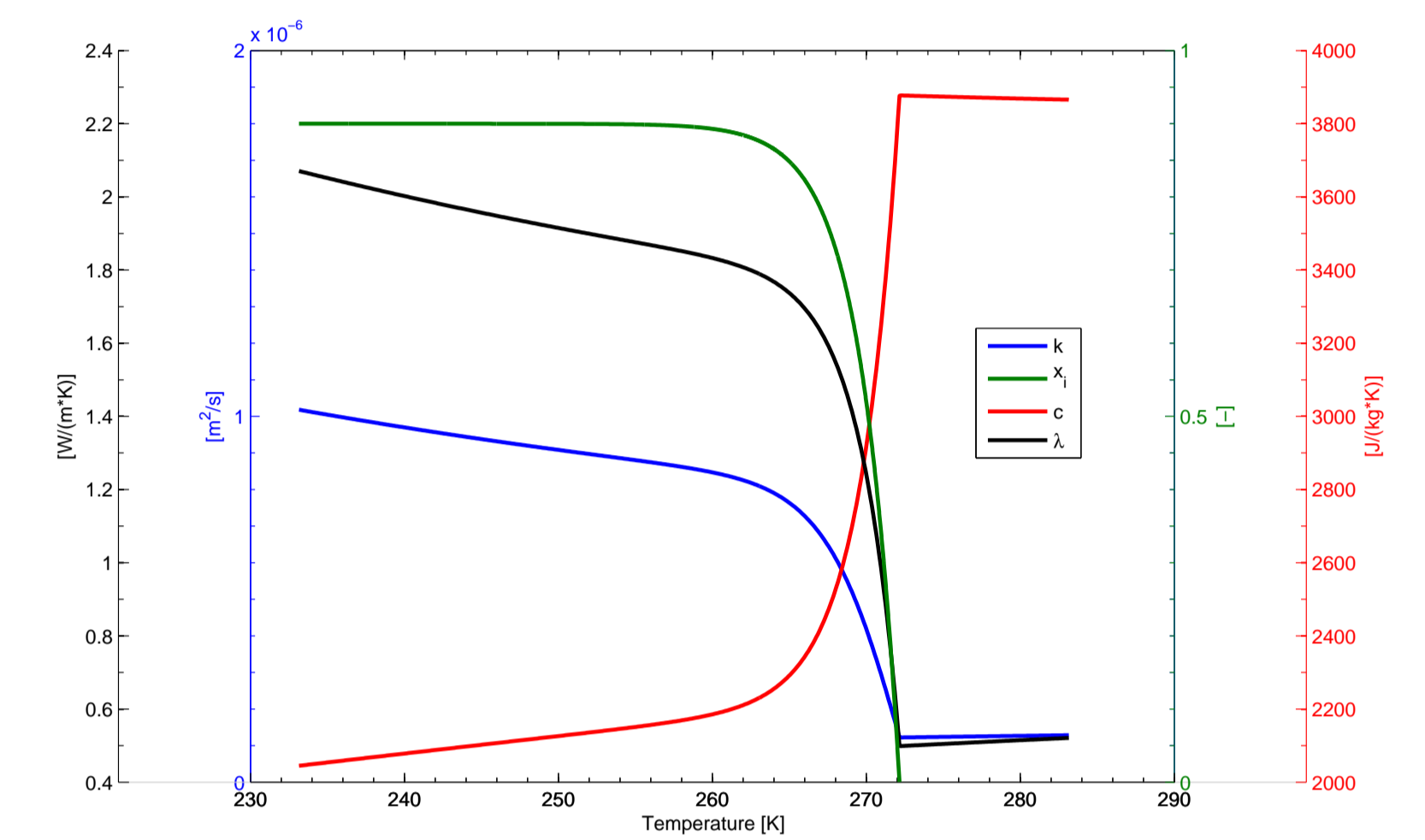


FIGURE 3: Essential parameters

The PDE is solved in MATLAB by

- discretizing in space (center difference approach)
- using a quasi-continuous stiff ODE-solver in time

$$\frac{\partial T}{\partial t} = \frac{k(T_n) \cdot (T_{n+1} - 2T_n + T_{n-1}))}{\Delta x^2}$$

with thermal diffusivity $k(T) = \lambda(T) \cdot (\rho(T) \cdot c(T))^{-1}$. Thus, after reaching the freezing point (here 272.15 K) the properties of water change.

RESULTS

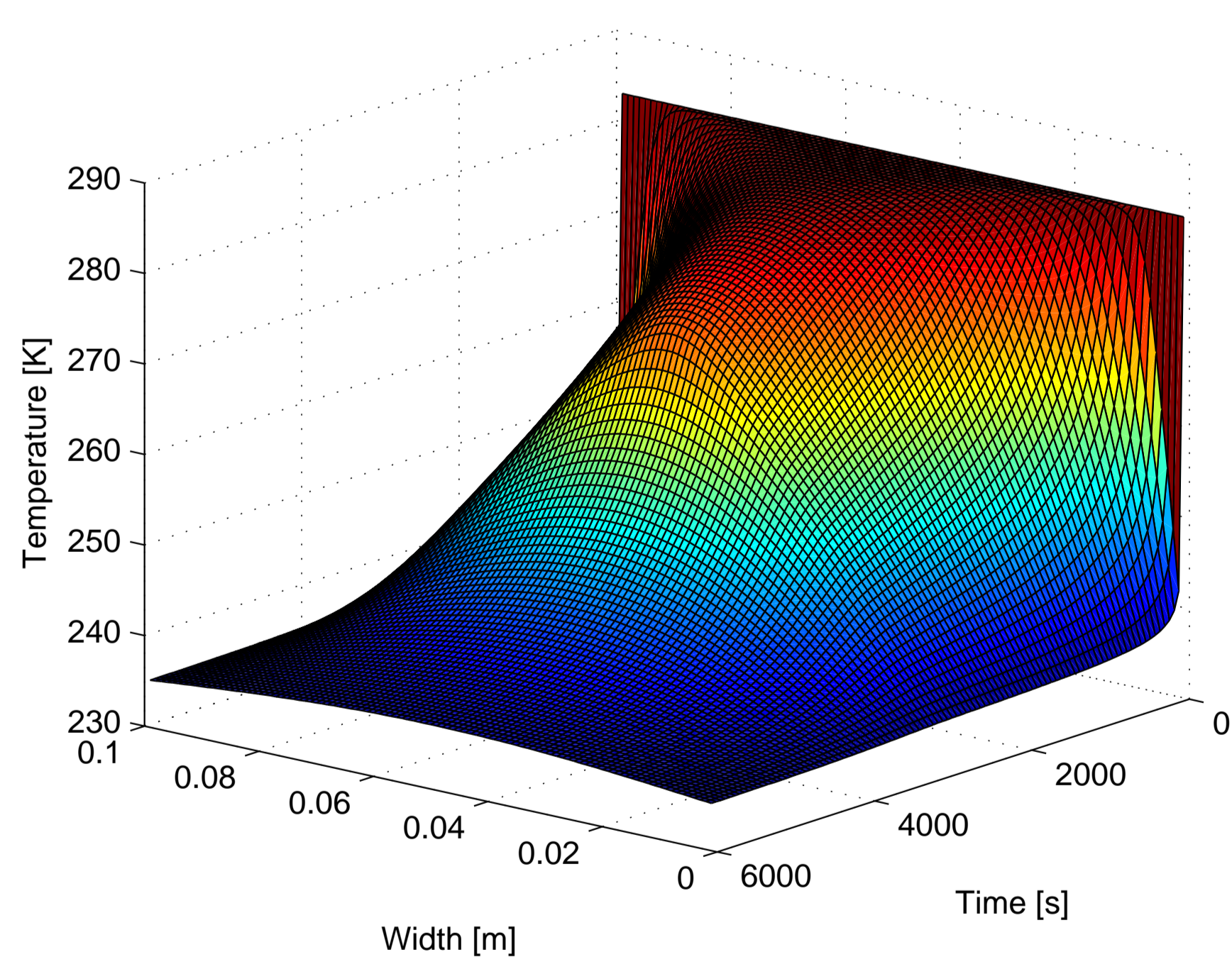


FIGURE 4: Temperature distribution (time and space)

- The temperature drops faster after reaching the freezing point due to changing parameters at this point.
- The simulated freezing happens faster than in a real plate freezer due to the simplifications that have been chosen.

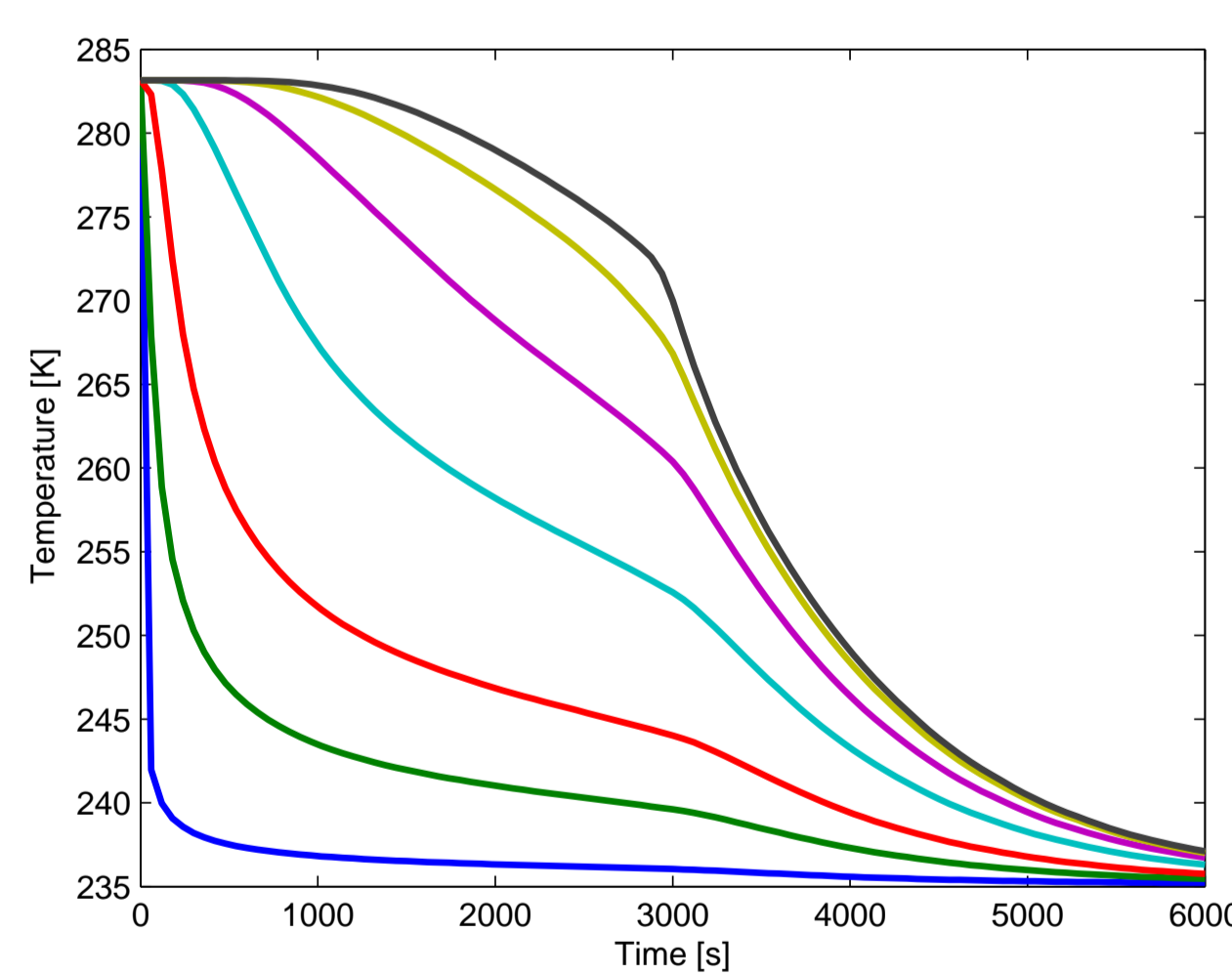


FIGURE 5: Temperature vs. time at different places

- The core temperature in the middle of the fish block has to reach at least 255.15 K (-18°C) as fast as possible.
- Fast freezing will cause small ice crystals and therefore lead to a good quality measure.

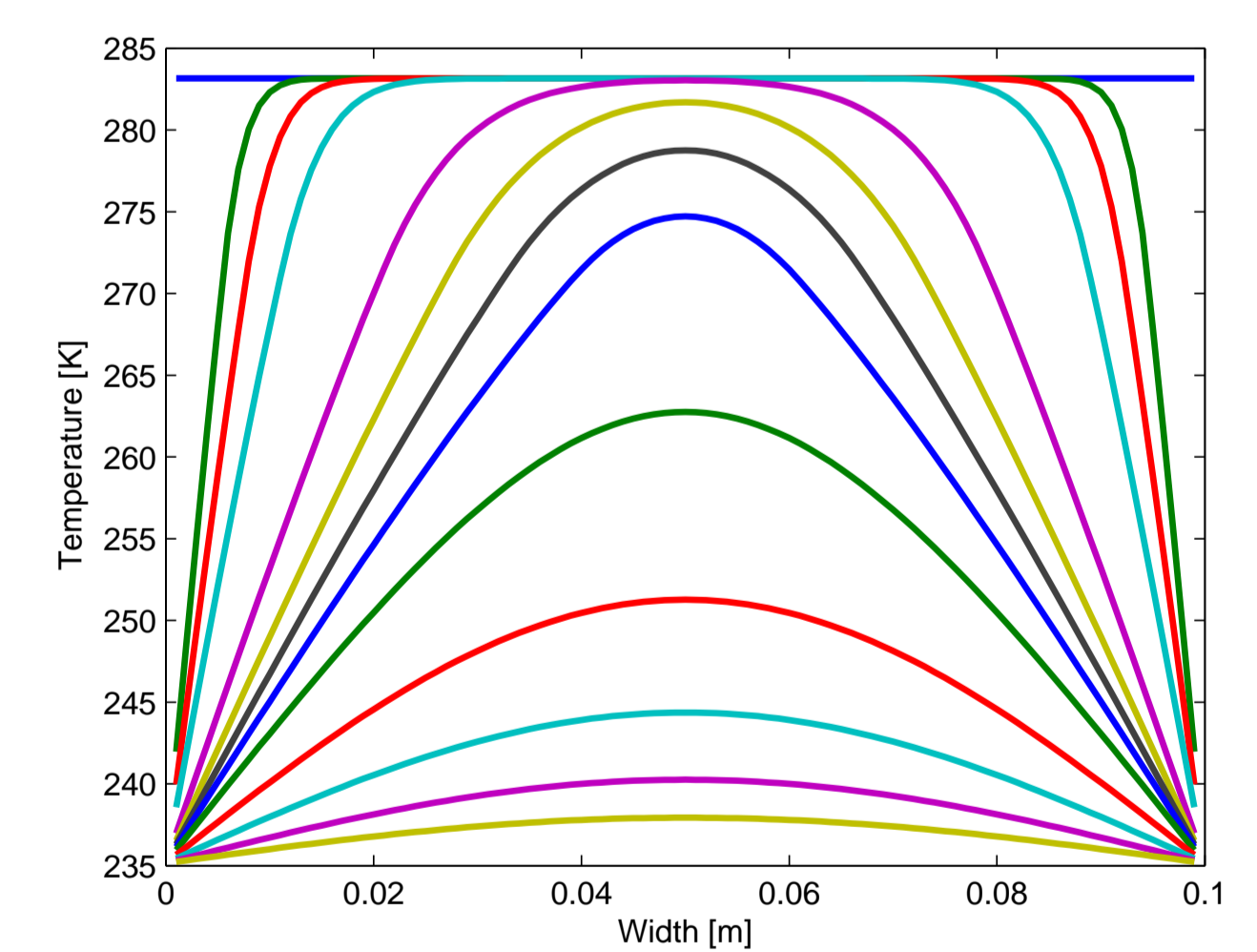


FIGURE 6: Temperature distribution at several times

DISCUSSION

The above presented results were achieved by several simplifications:

- The boundary conditions are set to constant values.
- The initial condition is equally distributed.
- Latent heat of fusion is not explicitly modeled.
- Consideration of only one spatial dimension.
- The platefreezer is perfectly isolated.
- The areas of uninsulated surfaces are small compared to the area of the freezing plates.
- The values of the simulation parameters are approximations of the real values.
- The fish in between the freezing plates is considered as a homogenous mass without any entrapped air.

Future work:

- Describe the boundary conditions, which are the output of the freezing system, as functions of time.
- Consideration of many platefreezers in parallel, what will cause higher load for the freezing system and thus lead to a faster warming of the ammonia.
- Take the latent heat of fusion into account.
- Add a model for nucleation and growth of ice crystals in order to calculate the quality measure.
- Validation of the simulation results by measurements.

REFERENCES

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[4] W. Johnston, F. Nicholson, A. Roger, and G. Stroud. Freezing and refrigerated storage in fisheries. Technical Report 340, FAO Fisheries, 1994.