Possibilities in simulating frying processes with respect to minimizing acrylamide contents

Franke, K.; Reimerdes, E.H.

Deutsches Institut für Lebensmitteltechnik, Prof.-von-Klitzing-Str. 7, D-49610 Quakenbrück
(German Institute for Food Technology)

Heat transfer during frying
Internal processes during frying (temperature and moisture changes)
List of relevant variables for the frying process
Why do we need simulation?
Simulation of frying processes
Summary and Outlook

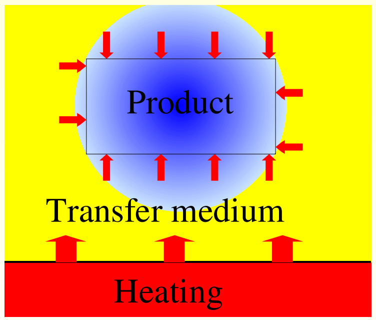
1 Heat transfer during frying

Possibilities for heat transfer to product surface

Heat conduction

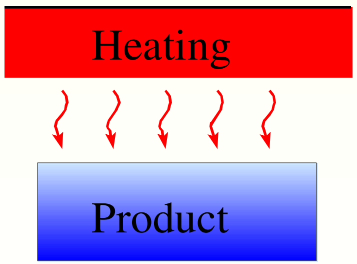
direct contact, only one side
no additional medium required
good heat transfer

Convection



all sides contact
additional medium required
(gas, liquid)
medium and good heat transfer

Radiation



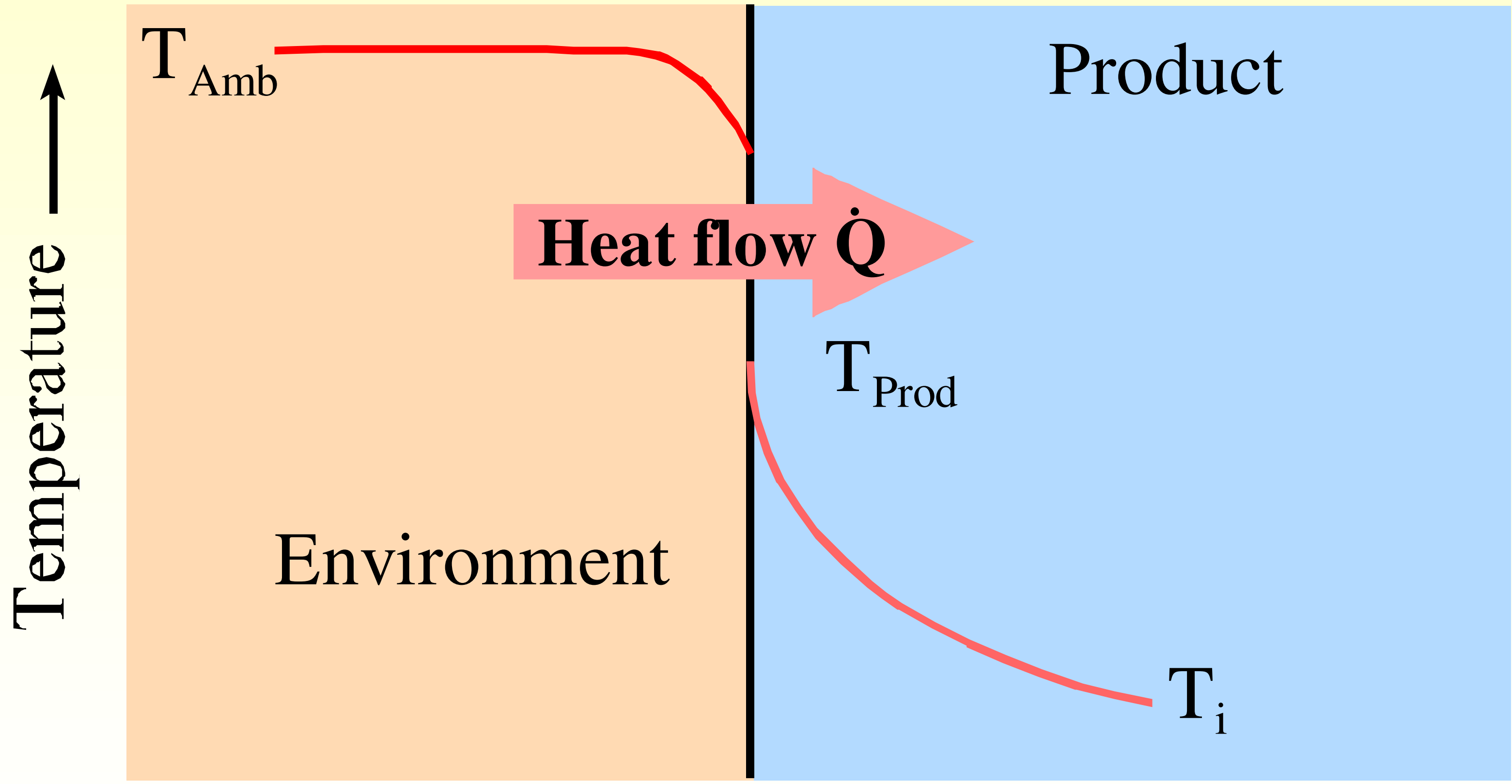
no contact
no additional medium required
low heat transfer

1 Heat transfer during frying

Process	Temperature range	Type and quality of heat transfer		
		Conduction	Convection	Radiation
Baking	180 - 300 °C	-	high	high
Grilling	approx. 200 - 300 °C	(high)	-	high
Roasting	130 - 250 °C	-	high	high
Pan frying	120 - 250 °C	high	low	-
Frying	**140 - 175 (190) °C**	**-**	**high**	**-**

1 Heat transfer during frying

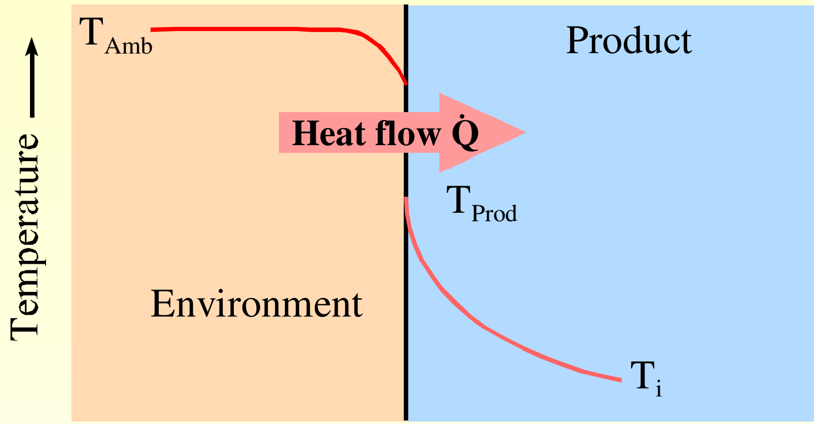
Heat transfer through convection, principle



1 Heat transfer during frying

Calculation:

$$\dot{Q} = \alpha \cdot A \cdot (T_{Amb} - T_{Prod})$$



$\dot{Q}$	Heat flow transferred
α	Heat transfer coefficient
A	Product surface for heat transfer
T_{Amb}	Ambient temperature
T_{Prod}	Temperature at product surface

1 Heat transfer processes

Parameters which influence the heat transfer coefficient α

$$\dot{Q} = \alpha \cdot A \cdot (T_{amb} - T_{prod})$$

	Conditions for a **high** heat transfer	Conditions for a **low** heat transfer
State of heat transfer medium	Fluid or condensing vapour	Dry gas (air)
Flow conditions around the product	Forced convection (e.g. circulating air or stirring)	Free convection
Viscosity of heat transfer medium	Low	High

Area **A** where heat transfer takes place

- Number of single products
- Shape of a single product
- Accessibility for the heat transfer medium

1 Heat transfer processes

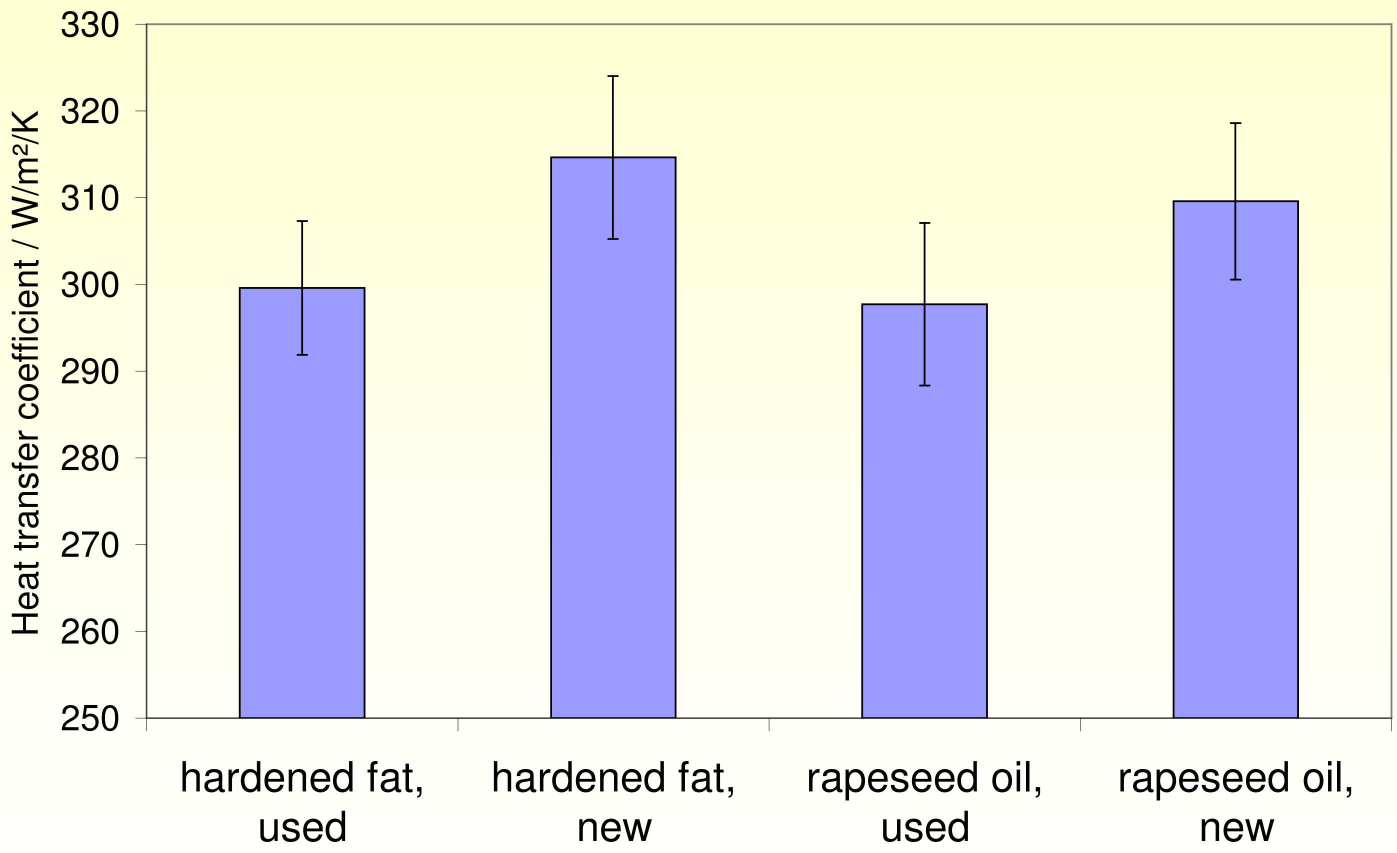
Examples of heat transfer coefficients in deep-frying processes

Authors	Product	Heat transfer coefficient / W/m²/K	Influencing parameters: time	Oil temperature	Oil	other
Miller et al., 1994	Al-sphere	250 - 280			age, type	
Vijayan & Singh, 1997	chips	500				
Sahin et al., 1999	model system	90 - 200		x		
Ni & Datta, 1999	potato slabs	250				
Costa et al., 1999	steel piece, stick or disc	320 - 750	x			geometry, evap.
Hubbard & Farkas, 2000	potato cylinder	200 - 900	x	x		
Vitrac et al., 2002	Al-slab	260 - 400		x	age	
	with evaporation	200 - 500				evap.
Yamsaengsung & Moreira, 2002	chips	285				

Baking processes: 10 .. 50 W/m²/K

1 Heat transfer processes

Measured heat transfer coefficients in deep-frying processes (Al-cylinder)

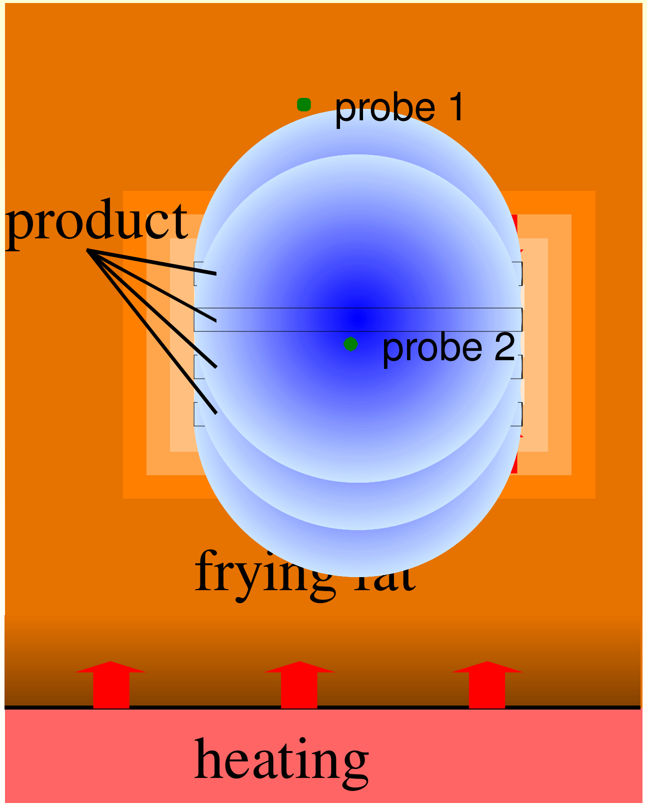


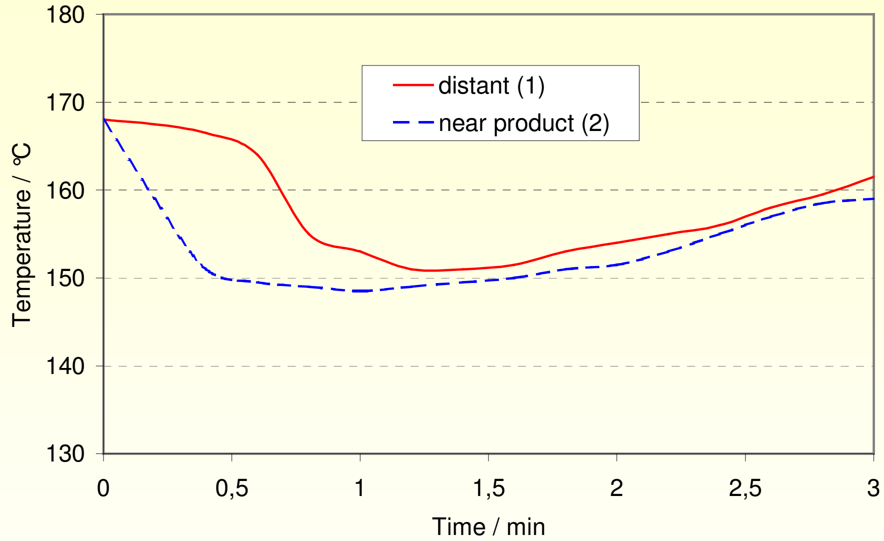
1 Heat transfer processes

Ambient temperature T_{amb}

$$\dot{Q} = \alpha \cdot A \cdot (T_{amb} - T_{prod})$$

Example: batch frying process

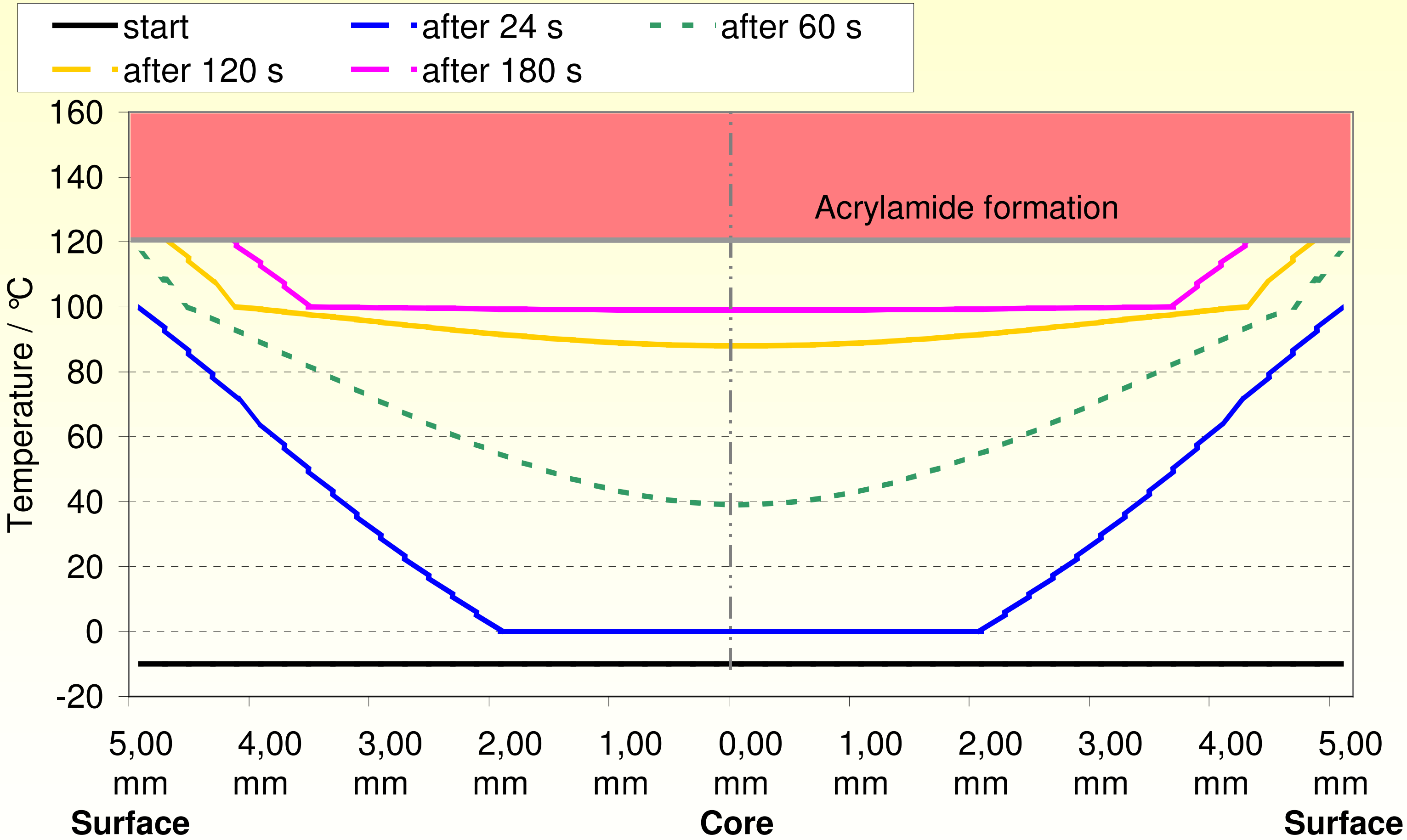




Temperature course in the frying oil at different points of the frying equipment during frying process

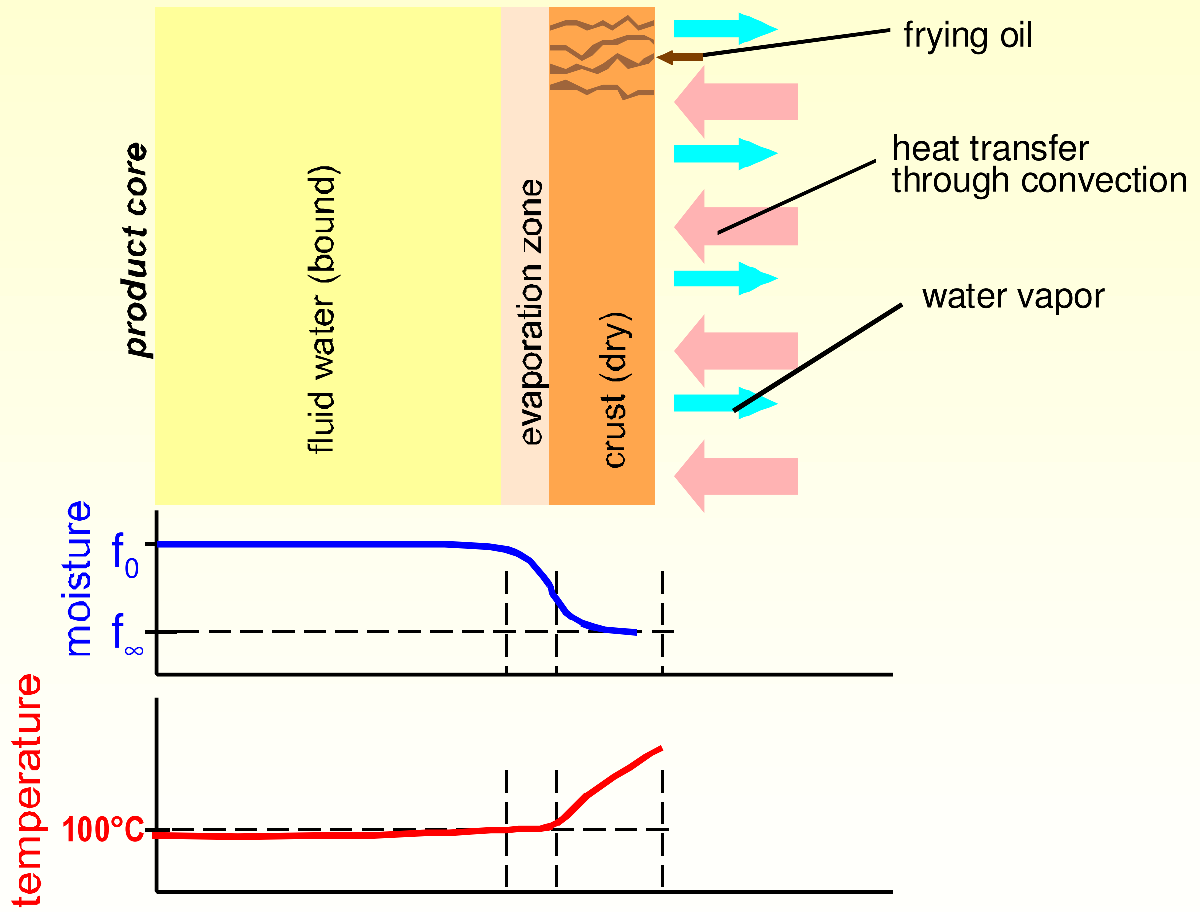
2 Internal processes during frying

Temperature courses during frying (schematic)



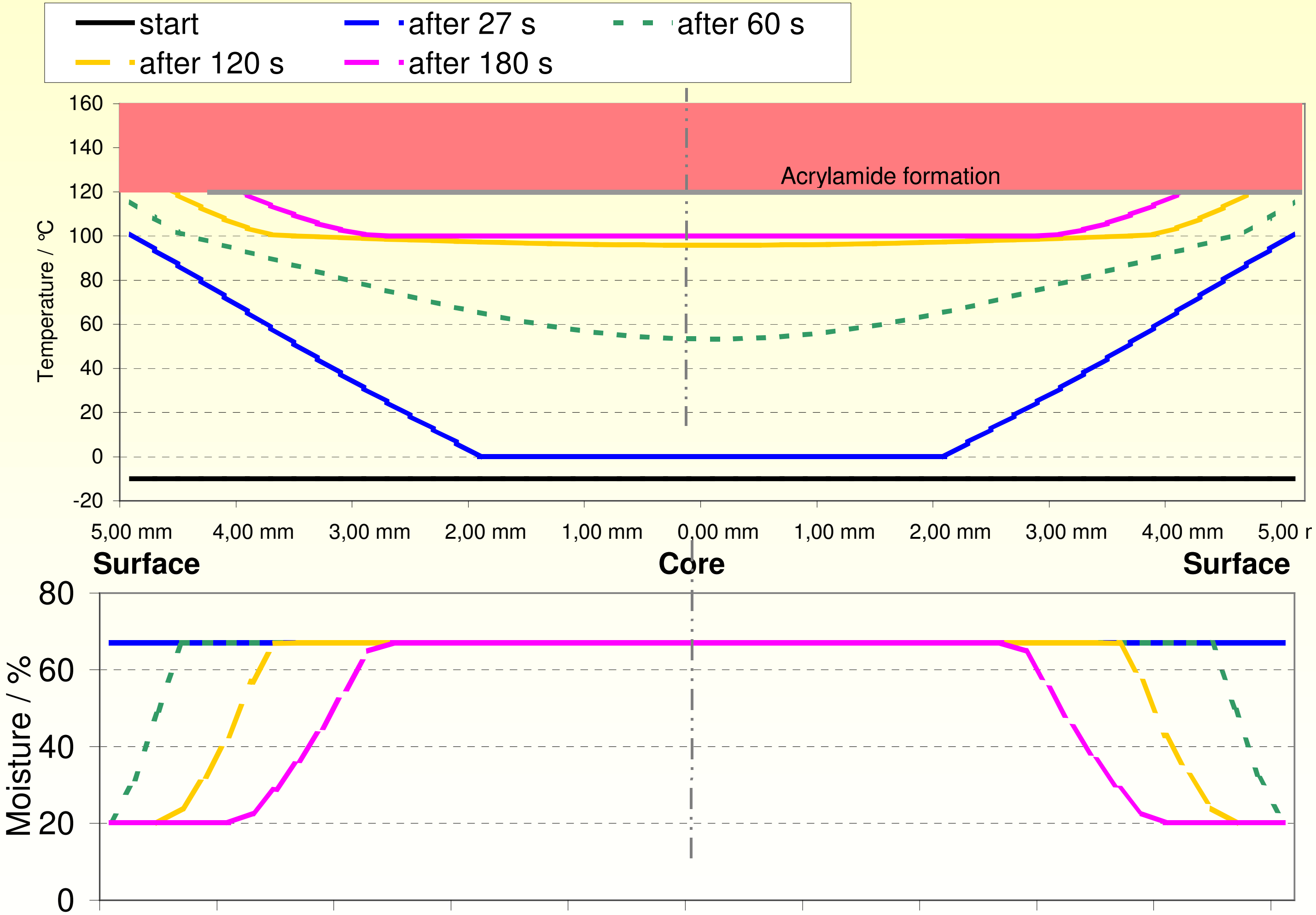
2 Internal processes during frying

Moisture distribution and crust formation



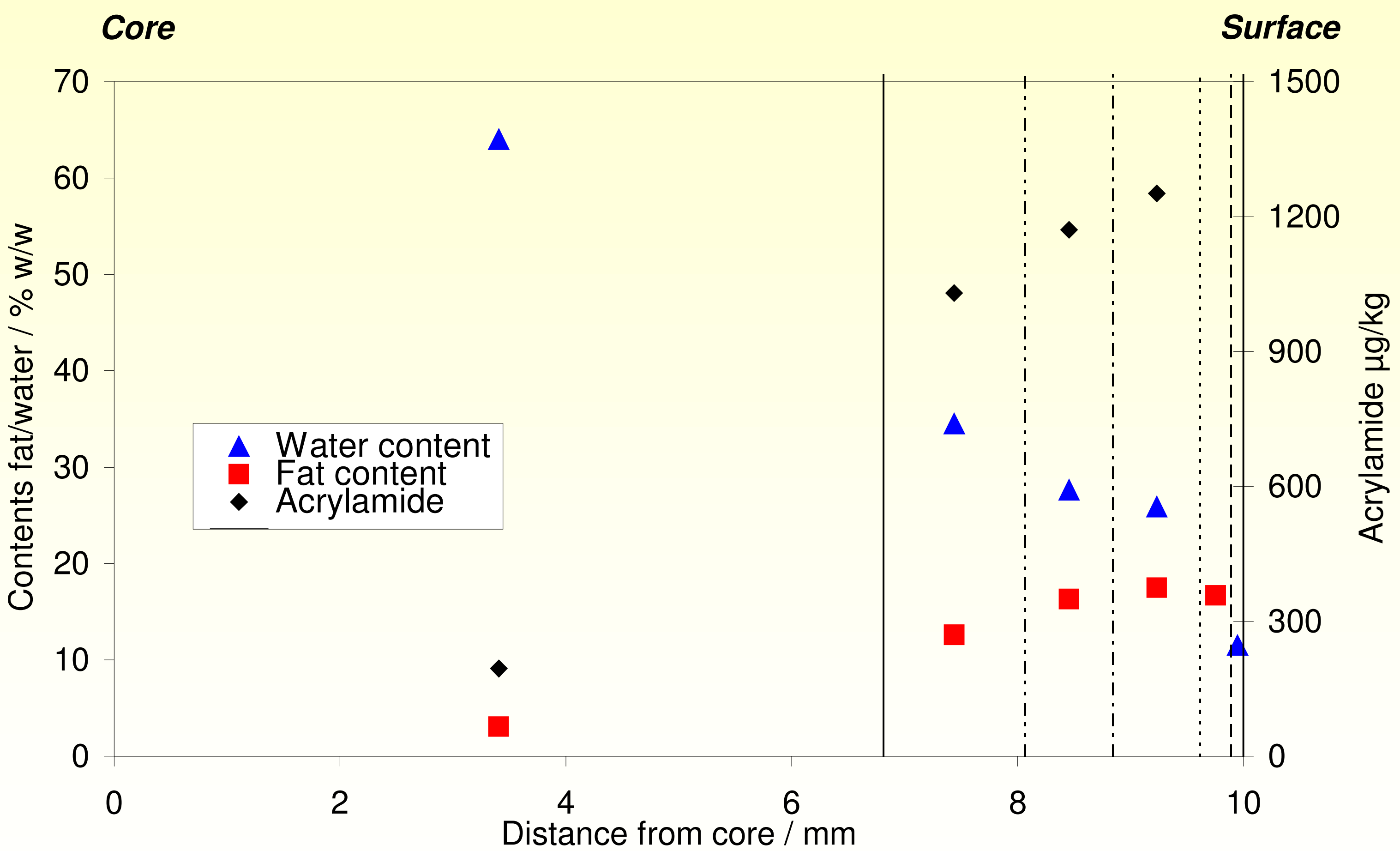
2 Internal processes during frying

Temperature and moisture during frying (schematic)



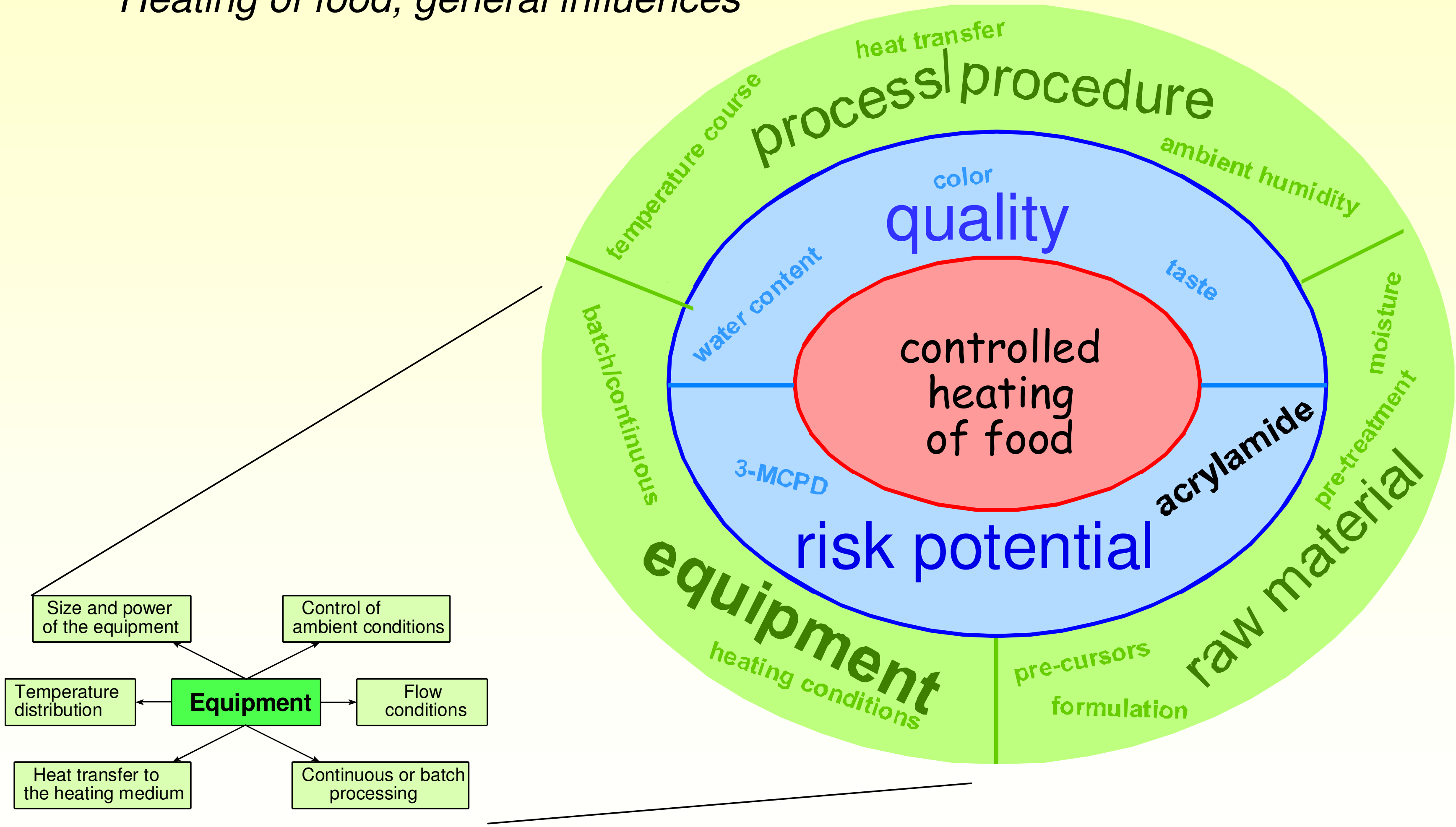
2 Internal processes during frying

Moisture and fat distribution, acrylamide



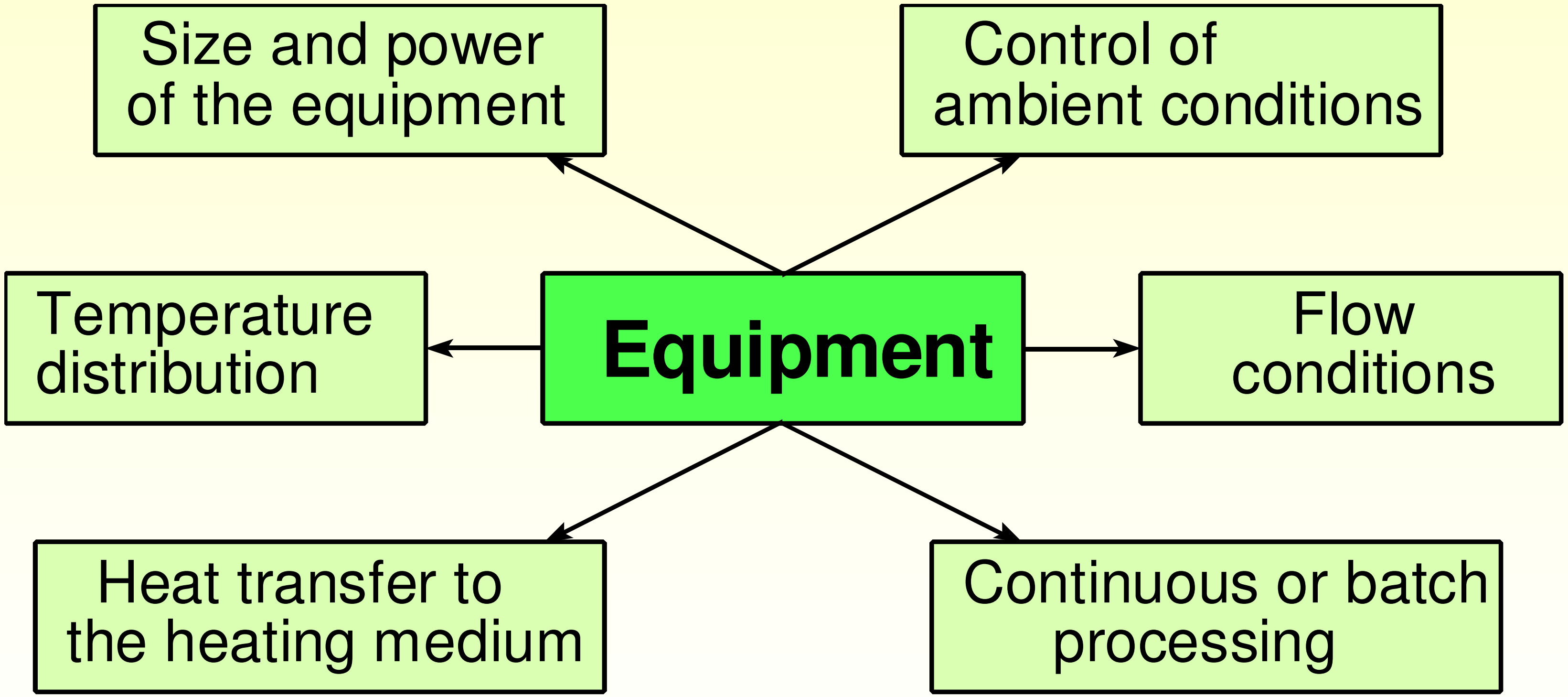
3 List of relevant variables for the frying process

Heating of food, general influences



3 List of relevant variables for the frying process

Influence of equipment



3 List of relevant variables for the frying process

Relevant variables of catering fryers

- Size of fry pot
  - ratio of pot size and product quantity
  - position of frying basket in the pot (e.g. double basket pots)
- Cold zone
  - dimension and position
  - effect of cold zone on thermal flow of frying fat inside the pot
  - temperature layering in the cold zone
- Energy input by the heating equipment
  - type of heating, specific heating area for heat transfer
  - position in the pot (distance from product)
- Temperature control
  - frying temperature as set by the operator
  - position of temperature probe in the fryer
  - type and precision of temperature control system

Additionally: *Influence of **product** and **frying fat***

4 Why do we need simulation?

Variables have direct influence on thermodynamic parameters

- heat transfer coefficient (flowing of fat around the product)
- ambient temperature (temperature of the frying oil near product)
- evaporation of water from the product

Also indirect influence on:

distribution of temperature and moisture in the product

product quality and acrylamide content

Therefore: The influence of each variable has to be determined to enable sustainable statements about the relationships between equipment parameters and acrylamide contents of products.

Comprehensive experimental designs are necessary (numereous trials)

4 Why do we need simulation?

Modeling/Simulation can help to save time and money
- possibilities and advantages are well-known in chemical engineering
- approaches also exist for food manufacturing processes including deep fat frying (e.g. Vitrac, Moreira)

Main **advantages** of these techniques are:

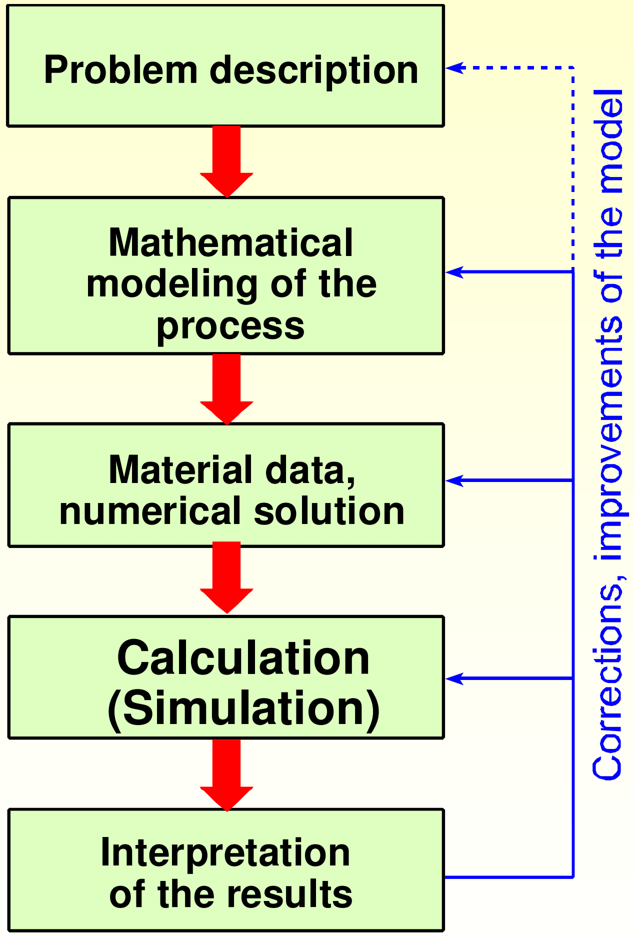
- cost-effective **process optimization** by determination of optimized settings using a computer and not the whole equipment
  - saving of trial costs for parameter identification
  - cost saving through improved process control
  - improved quality management

- cost-effective **design of processes** and equipment
  - saving of development time and capacity due to less trials and faster evaluation of variants

- improved process knowledge

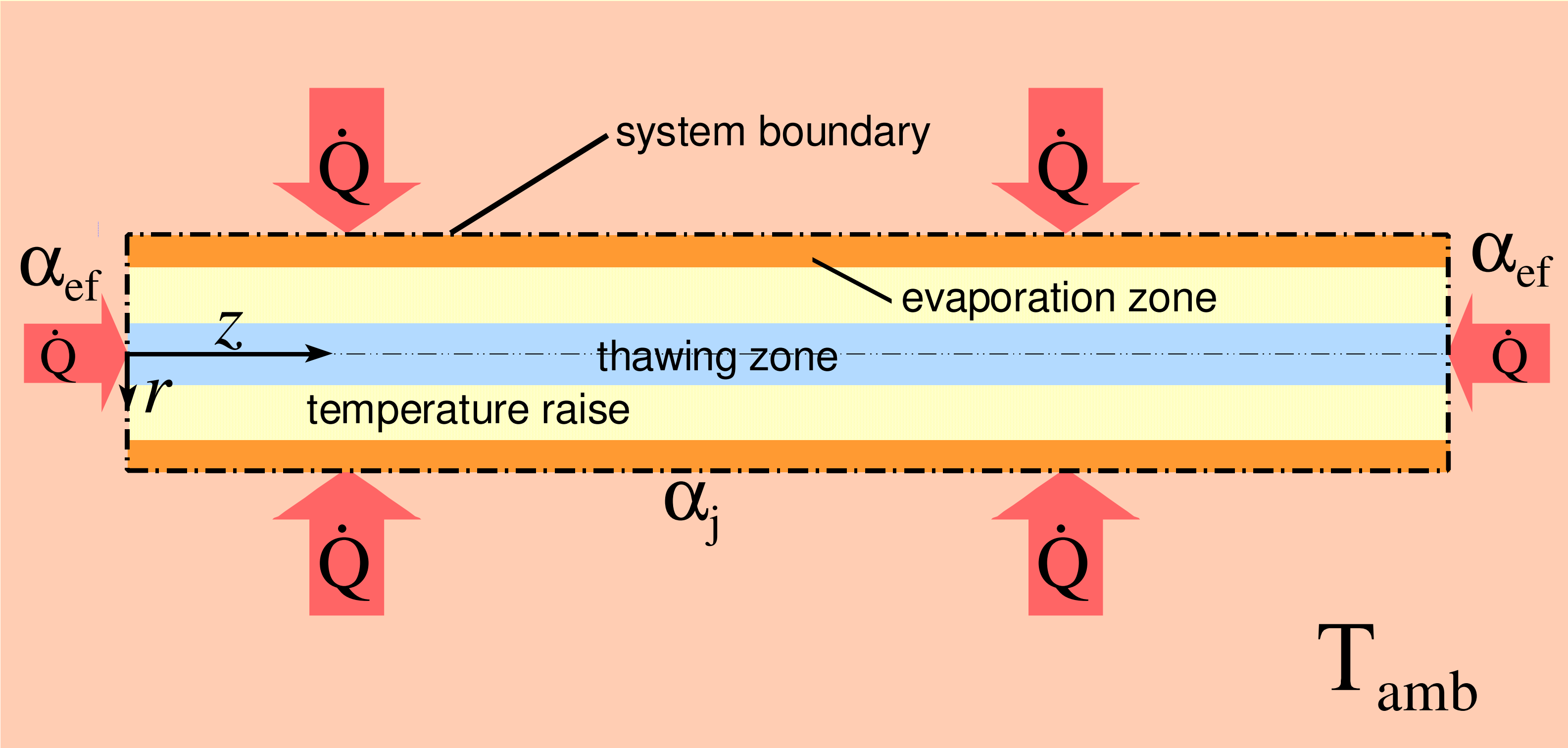
4 Why do we need simulation?

Modeling/simulation procedure



5 Simulation of frying processes, single French fries

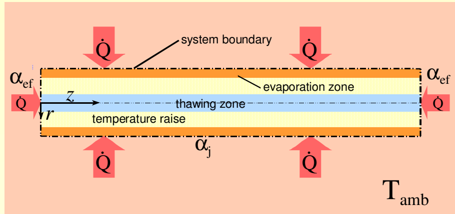
Modeling of frying of single French fries in a batch fryer



5 Simulation of frying processes, single French fries

Energy balance for single French fries

$$\rho \cdot c_p \cdot \frac{\partial T}{\partial t} = div(\lambda(T) \cdot grad\, T) + \dot{q}_{mel}(T) + \dot{q}_{eva}(T)$$



$\rho \cdot c_p \cdot \frac{\partial T}{\partial t}$	time dependency of the internal temperature
$div(\lambda(T) \cdot grad\, T)$	spatial dependency of the internal temperature
$\dot{q}_{mel}(T)$	energy consumption for melting of ice
$\dot{q}_{eva}(T)$	energy consumption for evaporation of water

Boundary conditions:

- ambient temperature
- heat and mass transfer

5 Simulation of frying processes, single French fries

Results, assumptions and data required

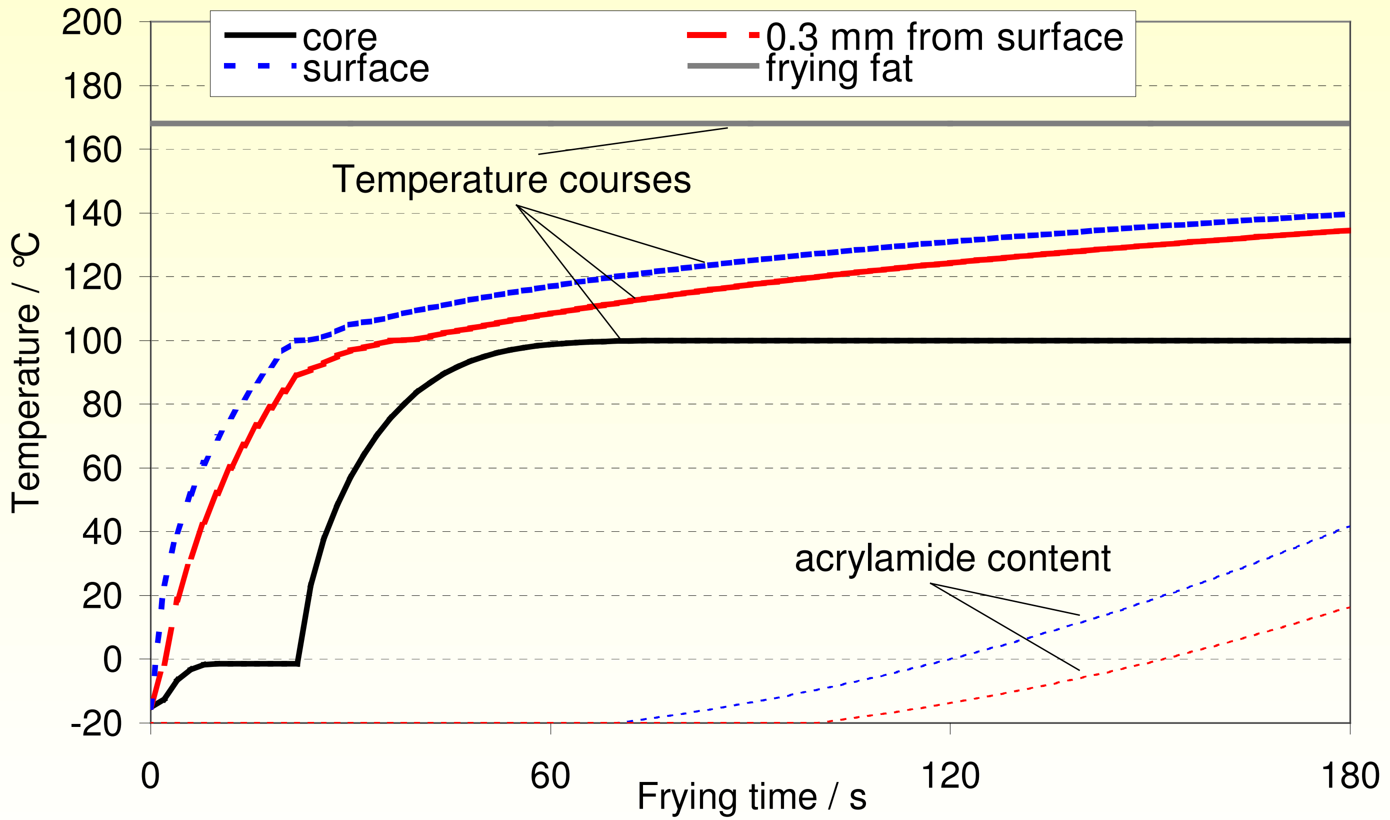
Results of the model

- local internal temperatures during frying process
- local moisture distribution (through evaporation) and evaporation rate

→ **local acrylamide formation**

5 Simulation of frying processes, single French fries

Simulation and acrylamide formation (schematic)



5 Simulation of frying processes, single French fries

Results, assumptions and data required

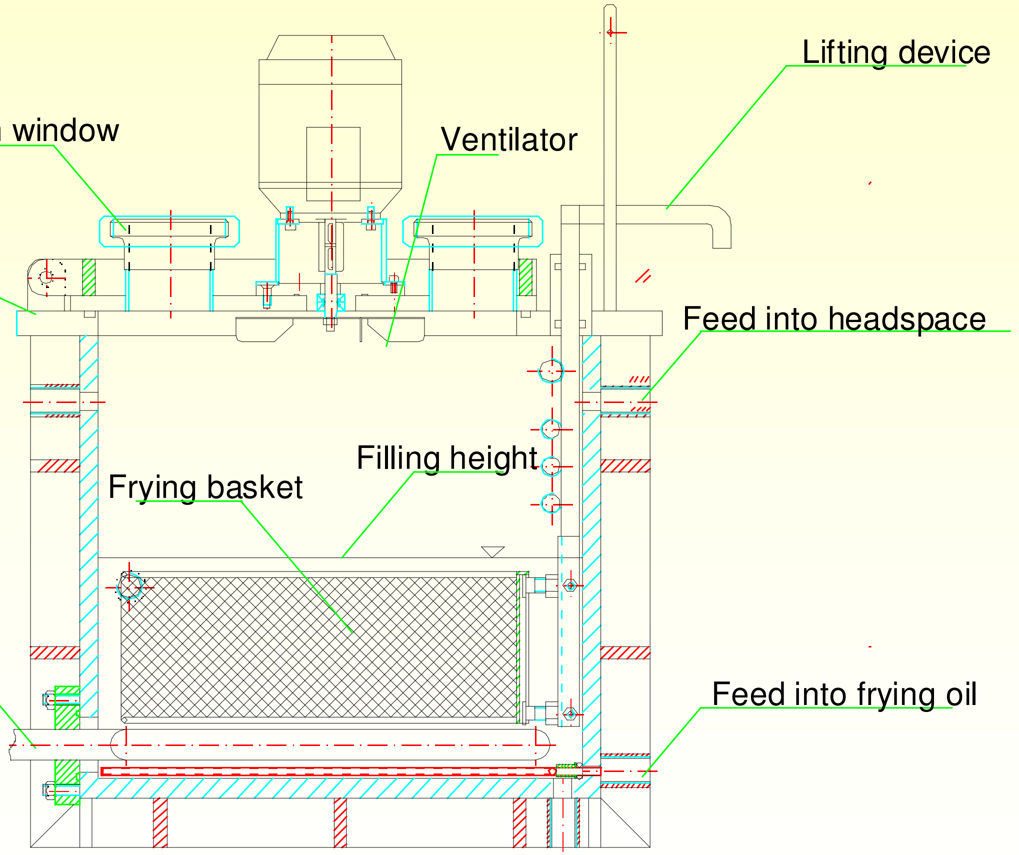
Results of the model
- local internal temperatures during frying process
- local moisture distribution (through evaporation) and evaporation rate
- **local acrylamide formation**
- influence of different internal and external parameters (variables)

Assumptions for the numerical modeling
- uniform heat transfer and ambient temperature
- no shrinkage of the French fries
- uniform start temperature

Data required for modeling of single French fries
- composition of the product (e.g. water content)
- thermodynamic material data (e.g. specific heat coefficient)
- heat transfer coefficients
- ambient temperatures (e.g. measured temperature in the frying oil)

5 Simulation of frying processes, water distribution

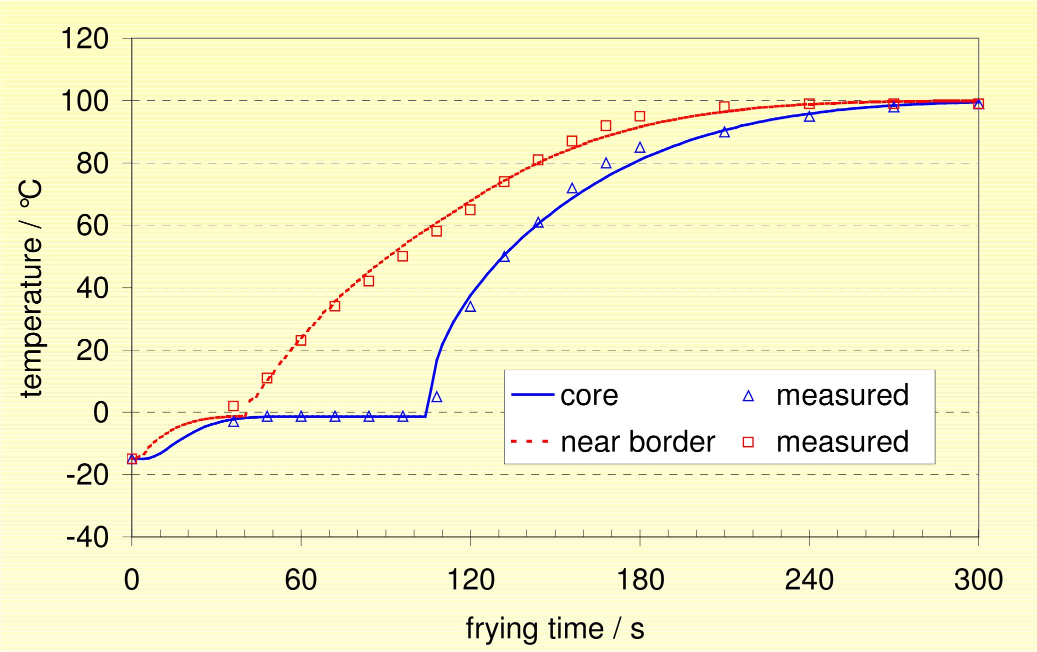
Possibilities for well defined frying processes (special frying apparatus)

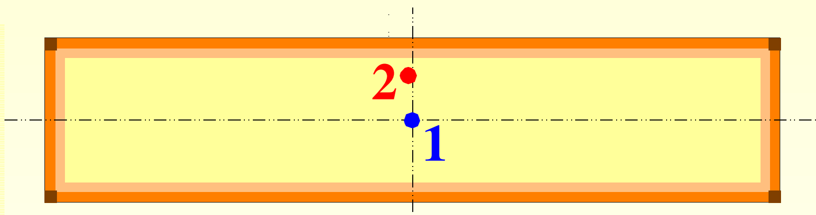


5 Simulation of frying processes, single French fries

validation of model simulation

- special French fries with 2 internal temperature probes
- cylinders (15 x 40 mm)
- frying one single French fry at 180°C for 5 min (constant fat temperature)



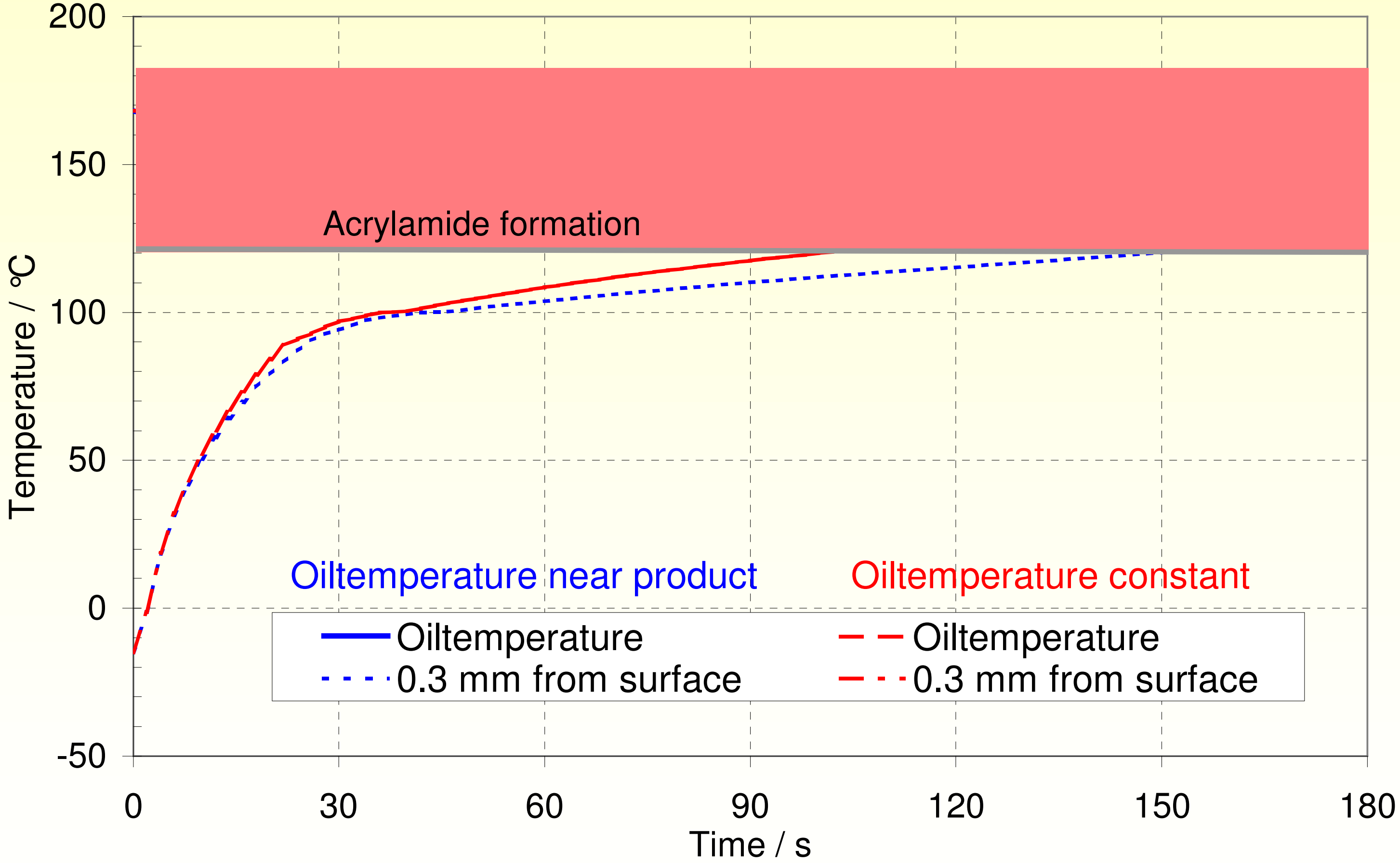


temperature course at the probe locations

5 Simulation of frying processes, single French fries

Influence of ambient temperature (simulation)

(pre-fried, frozen French fries, diameter 6 mm, 3 min at 168°C)



6 Summary

It is necessary to take into consideration both product and equipment for understanding acrylamide formation in high heated food products.

The only observation of single parameters (e.g. temperature) is not sufficient to describe heating processes and their effects on processed food in an adequate way.

Measured acrylamide contents are only comparable and can be used for evaluation purposes if the relevant equipment parameters are similar and known.

6 Summary

Adequate description of raw material influence on acrylamide formation requires the knowledge of the relevant equipment parameters, otherwise clear statements are not possible.

Effects of single variables on product properties can be determined and tested by simulation calculations based on suitable process models.

A lasting minimization of acrylamide contents is only possible if these relationships are known for each equipment and each product.

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