Determination of an effective diffusion coefficient in raw sausage mass by a combination of measurement and numerical simulation

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Background

The industrial process of raw sausage ripening should not only be based on practical experiences. For an optimization of the drying process of raw sausages the physical transport properties of these process need to be known. By an exact knowledge of the transport phenomena inside the sausages optimal conditions for an new strategy on raw sausage ripening can be found. Especially the climatic conditions in the ripening chambers in connection with the air flow can be adjusted by this knowledge.
Besides the transport parameters inside the sausage can not be determined by standardized methods used for the determination of the diffusion coefficient. In literature only a few data concerning the determination of the diffusion coefficient in dry sausage can be found (Palumbo *et al*., 1977; Rödel & Hofmann, 1982; Mittal *et al*. 1983; Motarjemi, 1988).

Objectives

In this work results from a new method described from *Kottke et al*. 1996 are presented. The diffusion coefficient inside the sausages is examined by a combination of measurement and numerical simulation. The influence of temperature, pH, fat content and degree of comminution on the inner transport parameter is studied. To describe the transport phenomena the diffusion coefficient D_w as the most important intrinsic transport parameter is defined as follows in a formulation of the first law of Fick:

$$\dot{m}_w = -D_w \frac{dc_w}{dx}$$

with the mass flux of water $\dot{m}_w$, the diffusion path dx and the concentration of water difference dc_w.
In food and especially in sausages, the mass transport is not just pure diffusion, but it is based on other mechanisms of transport as well for example salt transport towards the core of the dry sausage (Rödel & Hofmann, 1982). Therefore, for the description of the overall water transport an effective diffusion coefficient D_{eff} is introduced (Spiess & Wolf, 1989),

$$D_{eff} = \frac{M}{A*t}\frac{\Delta x}{\Delta c}$$

with the mass M, the surface area A, the time t, the diffusion path Δx and the concentration difference Δc.
Drying of course is an instationary process and therefore the above mentioned first law of Fick must be expanded to the second law of Fick, which describes the mass transport during an instationary process:

$$\dot{m}_w = -D_w \frac{\partial^2 c_w}{\partial x^2}$$

This differential equation can not be solved analytically anymore. Even the effective diffusion coefficient

$$D_{eff} = \frac{M}{At}\frac{\Delta x^2}{\Delta^2 c}$$

can not be examined from instationary continuos measurement data of a drying process without numerical methods. Therefore only discontinuous measurement data are available.

Methods

The loss of weight of five membrane separated sausage samples in a sorption container is derived over the period of one week. Within this week also the loss of weight of the single sausage slices between the membranes is examined once every day. These measurements result in a data set which represents a discreticised, time dependent concentration profile of the water content in the sausage samples. On the other side a numerical model of the samples is built within the commercial CFD-program (computational fluid dynamics) FIDAP. In this model the exact geometrical data of the sausage samples are built by a set of finite elements, to which the initial conditions of the measurements are implemented, as well as the time dependent mass flux derived from the measurement data. An instationary analysis of the problem, focusing on the distribution of the water content in the samples, is performed. By a comparison of the results of the simulation and the measurements iteratively the effective Diffusion coefficient in dependence of the water content of the sausage mass can be evaluated.

Results and discussion

In Fig.1 a comparison between the measured and calculated data is presented. It shows the relative mass coefficient, which represents the quotient from water to dry mass at time t correlated to the same quotient at time t = 0 for the five separated sausage layers at different time steps at 20°C with a water content of 55.72% at the beginning. A very good agreement between the measured and calculated values is obtained. The results show the possibility to achieve the required data by a combination of measurement and numerical simulation. These data can now be used to perform calculation on real sausages to get optimal condition for the drying process.

Units

A	surfacearea	m^2	M	mass	kg
D_{eff}	effective diffusion coefficient	m^2 / s	m_w	mass flux	$kg / m^2\, s$
D_w	diffusion coefficient	m^2 / s	t	time	s
c	concentration	kg / m^3	x	length	m
c_w	concentration of water	kg / m^3			

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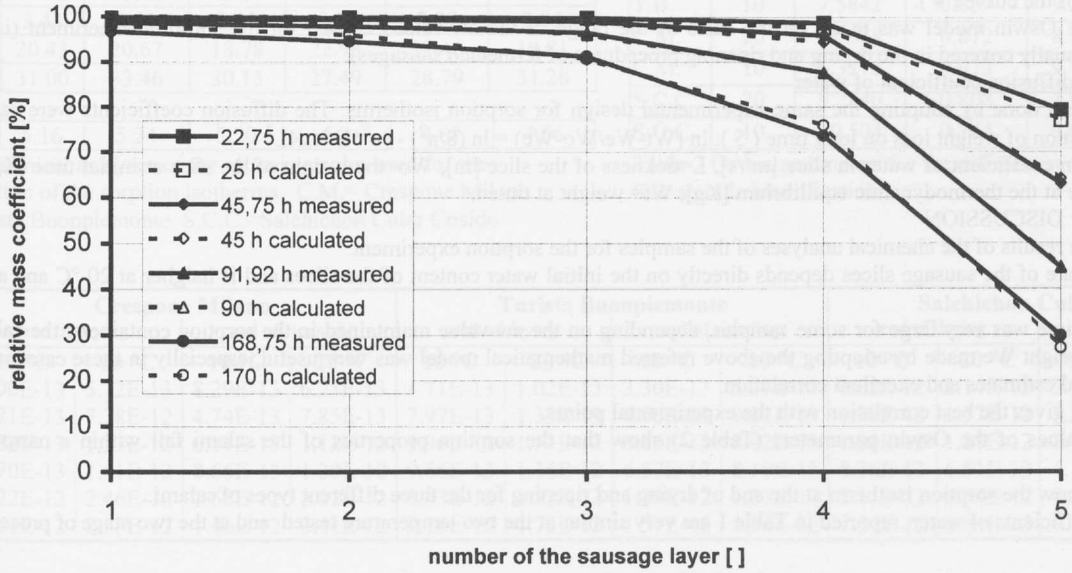

Fig 1: Relative mass coefficient of every sausage layer at different time steps by a temperature of 20°C.