Thermal diffusivity estimation of mashed potatoes and olive oil at high pressure

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Introduction

Knowledge of the thermal properties of food under high pressure is very important for numerical modelling and simulation of the process. It is one from limiting factors of developing of reliable mathematical models convenient for the prediction of food temperature changes during the whole compression cycle (pressure rise-holding the pressure – pressure decrease). From the literature is known measurements and methods for estimation of the thermal properties but at atmospheric pressure. Under the high pressure is measurement of the thermal properties more difficult. There is possibility used indirect method for estimation of thermal diffusivity by connection of experimental data and numerical solution.

The main goal of this work was to show how to determine the thermal diffusivity of mashed potatoes and olive oil materials for constant pressure conditions (400 and 500MPa) on the basis of the experiment and the following numerical analysis of the temperature –time experimental data.

Material and methods

Food samples: Olive pomace oil (Ondoliva, Spain)
Mashed potatoes (Podravka - Lagris a.s., Czech Republic)

Equipment: HP iso-static press CYX 6/0103 (Zdas j.s. co., Czech Republic)
volume of chamber: 2 litres (320mm height a 90mm diameter).
pressure: 0 -500 MPa

Methods:

Thermal diffusivity was predicted by indirect method combining numerical modeling of heat conduction and experimental data fitting. The sample of food was placed into a cooper cup of steeple cylindrical shape (diameter 40 mm, length 165 mm). This shape enables to eliminate the influence of heat transfer from the both ends of cylinder (cylinder was considered as infinite and only radial heat conduction was taken into account). Top lid was fastened to cylindrical part and served as guide for three type K thermocouples. One thermocouple was placed at the cooper wall, second thermocouple was placed 7 mm from the wall and third thermocouple was placed at the cylinder axis. Bottom lid of the cup was created by the piston sealed in the cylindrical part by O-ring.

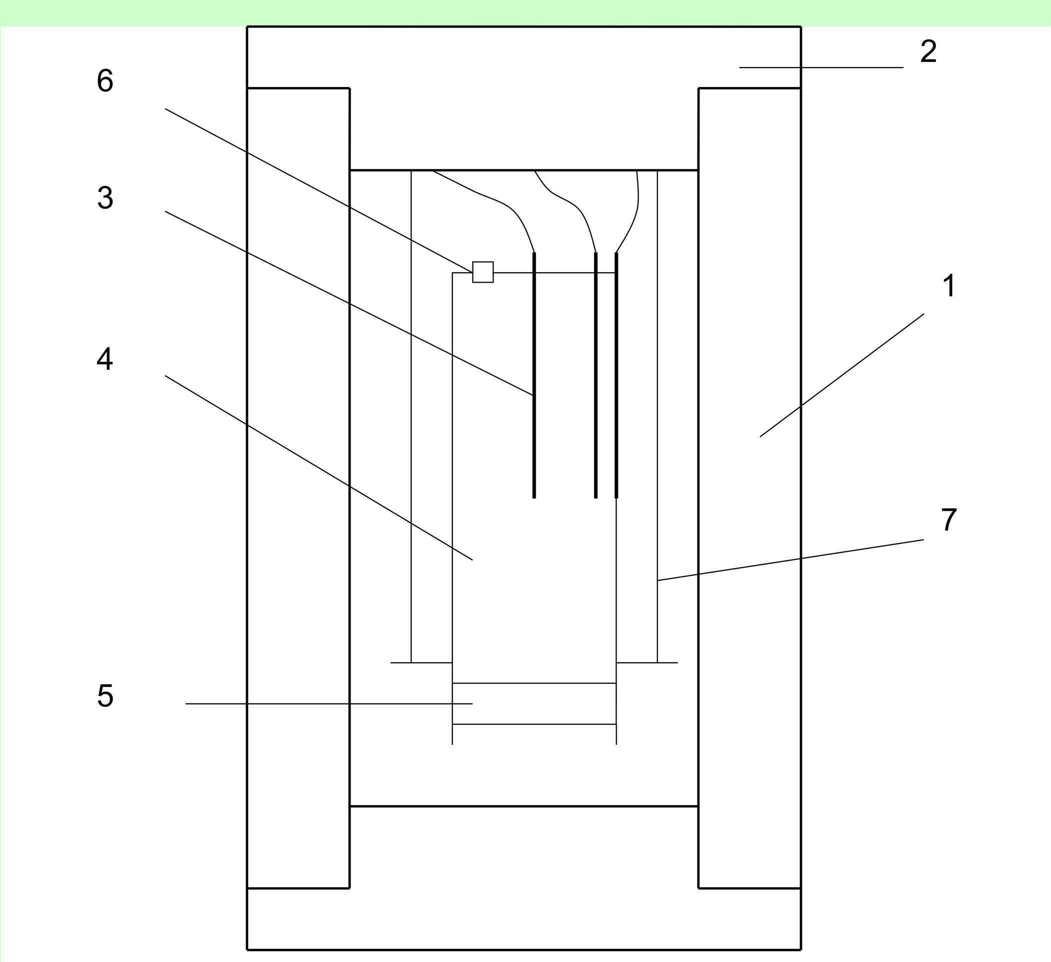

Fig.1 Scheme of the experimental set-up
1 - HP chamber with heating jacket
2 – lid of the chamber
3 – thermocouples
4 – cooper cup with sample
5 - movable piston
6 – air-outlet valve
7 – holder of the cup

The cup was tempered outside the press chamber to the temperature higher than the press chamber temperature and the pressure transmitting water. The sufficiently high initial temperature difference between temperatures of the tested food and the pressure transmitting water was thus received. Thermal diffusivity prediction was based upon the following temperature decay during the pressure holding stage. The experiment was done at three different nominal temperatures (20, 35 a 50°C) of the pressure transmitting water and the chamber.

The tempering was done by using thermostatic bath circulating heated water through the heating jacket of the press chamber. As far as the chamber and water inside had the same temperature the chamber was closed by the lid where the preheated cup was placed. Then pressure in the chamber was increased to the nominal value (400 or 500 MPa). During pressure up time (about 60 seconds) the pressure and temperature recording started with the sampling interval 1 second. The data were collected via digital multimeter (HP 34970A, USA) into the PC for the time longer than 1000 seconds nearly up to the steady state. Cooling of the food sample started after reaching the maximum of pressure when the compression heat generation stops. During the pressure up time the radial temperature profile was created in the food sample. Near cup walls the food sample temperature was lowest due to much lower temperature of pressure transmitting water in the chamber. We have used for mathematical analysis the time-temperature data since the time when the radial temperature profile was fully developed. This radial temperature profile was reconstructed from the temperature data measured at three radial coordinates: centre, wall and 7 mm from wall. These data were fitted by the empirical parabolic equation and this temperature profile was used as an initial condition for numerical analysis. The measured wall temperature as a function of time was also fitted by the empirical equation (polynomials of second or third order) and used as a boundary condition. This form was more convenient for numerical analysis than table with measured experimental data.

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The numerical analysis was done by the software package FEMINA solving the problem of unsteady heat conduction in infinite solid cylinder by using the method of finite elements. The density and the specific heat capacity were input constants and optimization was made only for the thermal conductivity. Its temperature dependence was expressed as the linear function. Its parameters were subject of non-linear optimization algorithm of Marquardt Levenberg type minimizing differences between numerically predicted and measured time temperature dependencies valid for food sample in the axis.

We eliminated the free convection effect by using a small amount of the thickener Aerosil added in the olive oil. Verification of the influence of the Aerosil additive on thermal behavior was done at atmospheric pressure by heating experiment. Small decrease of pressure caused by the press chamber leaks and the corresponding cooling of the chamber content could influence the time – temperature data due to the decompression cooling effect (inverse effect of the compression heating). Therefore, this effect had to be corrected.

Results

Tab.1 Thermal diffusivity of olive oil and mashed potatoes

sample	pressure (MPa)	temperature (°C)	$10^9 \cdot a$ ($m^2.s^{-1}$)	$10^9 \cdot a$ ($m^2.s^{-1}$)	R^2 (-)
mashed potatoes	400	25.0 - 84.4	168 - 188	$0.3328 \cdot T + 159.67$	0.74
mashed potatoes	500	26.7 - 89.5	177 - 200	$0.3584 \cdot T + 167.91$	0.72
olive oil	400	27.2 - 95.5	98 - 156	$0.8447 \cdot T + 75.096$	0.76
olive oil	500	28.5 - 99.6	93 - 154	$0.8487 \cdot T + 69.221$	0.78

Fig.2 Typical measured temperature courses of the measured sample, nominal pressure 400 MPa

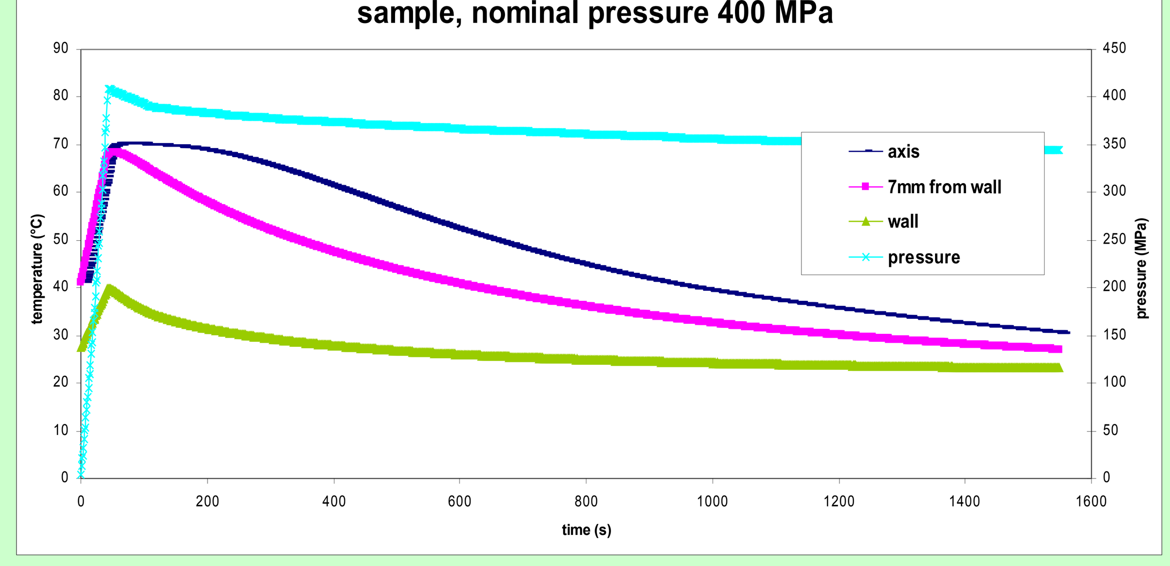


Fig.3 Dependence of thermal diffusivity of mashed potatoes on temperature for 400 MPa

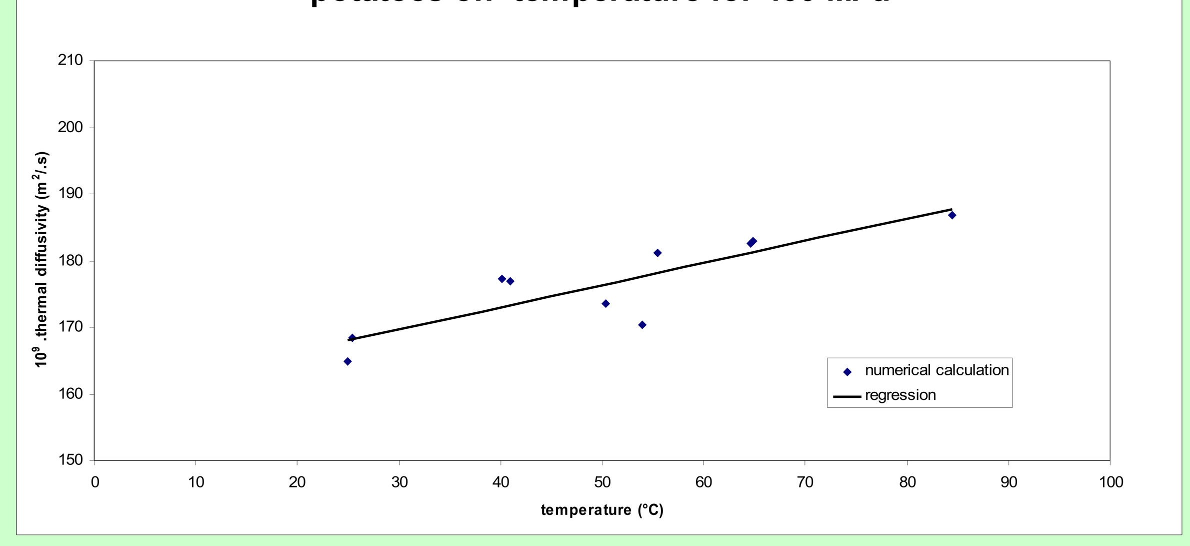
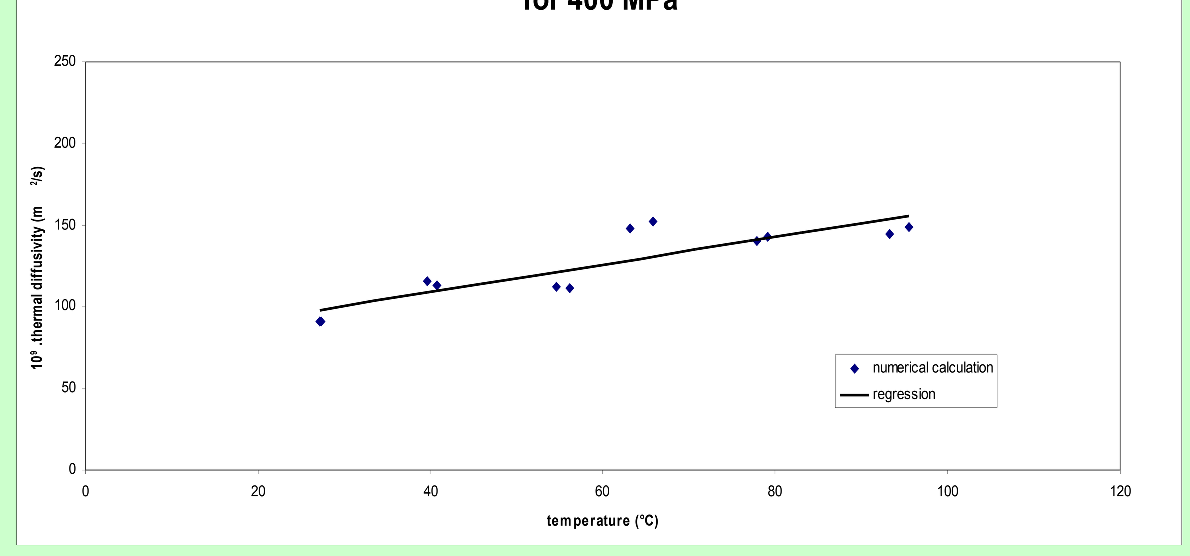


Fig.4 Dependence of thermal diffusivity of olive oil on temperature for 400 MPa



Conclusions

The effect of high pressure on thermal diffusivity of mashed potato and olive oil was estimated for nominal pressure 400 and 500 MPa and temperature range about 25 – 100°C. We used indirect method by combining experiment and finite element calculation method with optimization of input thermal properties.

There was used 4 % dose of thickener Aerosil R202 for suppression of the free convection during measurement of olive oil. This small dose of inert SiO_2 does not influence the thermal diffusivity of the material. The corresponding evidence was provided only at atmospheric pressure conditions but the received thermal diffusivity values did not contain any abuse known from previous work.

Optimization methodology seems very useful tool for predicting thermal diffusivity of foods at extreme conditions of high pressure assisted sterilisation.