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Modeling of time-temperature history and enzymatic inactivation of cloudy apple juice in continuous flow microwave assisted pasteurization

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ABSTRACT

Enzyme inactivation can be the target of a pasteurization process of fruit juices. Fresh cloudy apple juice was subjected to continuous flow microwave assisted pasteurization in a pilot scale unit at three processing temperatures (70 °C, 80 °C and 90 °C), two flow rate levels and two heating systems (conventional and focused microwave). A heat transfer model was developed and combined with mean residence time information to provide the average time-temperature history of the product. Inactivation kinetics (first order with two fractions) was used to calculate the integrated lethality. The thermal model was validated with measurements along the product path and the final residual activity was compared with the model prediction. Good results were obtained for polyphenol oxidase (PPO) and peroxidase (POD) but not for pectin methylesterase (PME), which showed to be the most resistant enzyme. Focused microwave heating resulted in a high heating rate with a temperature profile close to the ideal of instantaneous heating, consequently reducing the lethality contribution from the heating step. The results show the importance of modeling and simulation in process analysis.

1. Introduction

Research on apple juice processing focused on evaluating electric and dielectric emerging technologies that can replace conventional heat exchangers, such as high voltage pulsed electric fields (Ortega-Rivas et al., 1998; Charles-Rodríguez et al., 2007), ohmic heating (Kim et al., 2017), microwave heating (Tajchakavit et al., 1998; Cañumir et al., 2002; Gentry and Roberts, 2005) and radio frequency heating (Geveke and Brunkhorst, 2008). These technologies seek efficient energy use, better product quality and better use of space (Tang, 2015).

In 2000, only two commercial microwave pasteurization or sterilization systems were recognized according to U.S. Food Drugs Administration – FDA standards (IFT, 2000). Continuous flow microwave assisted pasteurization is on the verge of industrial application with some pilot scale systems underway for scaling (Coronel et al., 2005; Cinquanta et al., 2010; Resurreccion et al., 2013; Marszałek et al., 2015; Arjmandi et al., 2016; Stratakos et al., 2016; Tuta and Palazoğlu, 2017).

In continuous flow thermal treatment, the food product stream is heated, held for a specific period of time in a holding tube and then cooled. From food safety aspects, FDA only considers the inactivation of organisms that occurs in the holding tube (Singh and Heldman, 2009). In practice, quality changes also occur in the heating and cooling sections, as well in tubing connections (Aguiar and Gut, 2014). Modeling and simulation of the time-temperature history of the product combined with integrated lethality calculation is useful for evaluating changes in a new process design. The biochemical markers (Tucker, 1999) mostly used to evaluate the microwave processing of apple juice are enzymes (Siguemoto et al., 2018a) and microorganisms (Tajchakavit et al., 1998; Cañumir et al., 2002; Gentry and Roberts, 2005; Siguemoto et al., 2018b).

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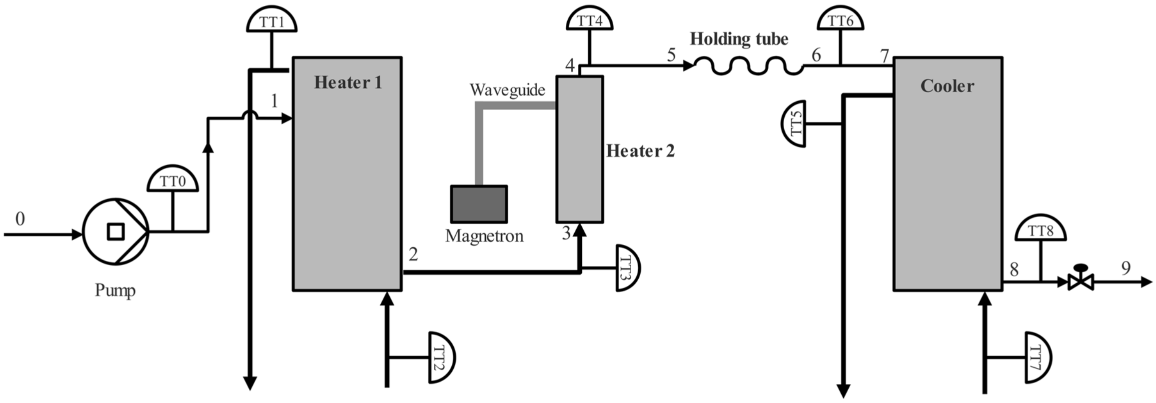

Fig. 1 – Diagram of microwave-assisted pasteurization unit Lab25-UHT/HTST EHVH (MicroThermics, Raleigh, USA).

Table 1 – Processing conditions for cloudy apple juice pasteurization with conventional and microwave heating.

Id.	Heating system	Flow rate (L/min)	Processing temperature (°C)	Set-point TT3 (°C)	Set-point TT4 (°C)
C1	Conventional	0.5	70.0	73.5	–
C2	Conventional	0.9	70.0	72.3	–
C3	Conventional	0.5	80.0	84.3	–
C4	Conventional	0.9	80.0	82.6	–
C5	Conventional	0.5	90.0	94.8	–
C6	Conventional	0.9	90.0	93.0	–
M1	Microwave	0.4	70.0	30.0	71.5
M2	Microwave	0.8	70.0	30.0	71.2
M3	Microwave	0.4	80.0	30.0	82.4
M4	Microwave	0.8	80.0	30.0	81.5
M5	Microwave	0.4	90.0	30.0	92.6
M6	Microwave	0.8	90.0	30.0	91.6

The objectives of this work were to: (1) model and validate the time-temperature history of cloudy apple juice processed in a continuous flow microwave assisted unit, (2) validate the model prediction of enzymatic inactivation based on previously determined kinetic parameters and (3) compare enzymatic inactivation using conventional and microwave heating.

2. Material and methods

2.1. *Preparation of cloudy apple juice*

Apples (*Malus domestica* Borkh, cv Fuji Suprema) were harvested in December 2015 from an orchard located in the state of Santa Catarina (Southern Brazil). Selected apples (162 kg) were milled using a fruit crusher 015.095.3 (Brouwland, Beverlo, Belgium), pressed with a fruit press 015.262.9 and bag filter 015.05703 (Brouwland, Beverlo, Belgium). Ascorbic acid reagent grade (Synth, Diadema, Brazil) was mixed with the unpasteurized cloudy apple juice (0.2 g/L) to retard browning and then the juice was subjected to different processing conditions on the same day of preparation.

2.2. *Pasteurization unit*

The pilot-scale pasteurizer Lab25-UHT/HTST EHVH (MicroThermics, Raleigh, USA) consists of three heat exchanging sections and one holding section as shown in Fig. 1. Heater 1 and Cooler are counter-current helical coil heat exchangers connected to an 18 kW hot water and a 3.5 kW cold water closed circuits, respectively. Heater 2 is a microwave heater that consists of a single mode cavity connected to a 6 kW magnetron at 2450 MHz. Through tuning, microwaves are focused on a central ceramic tube (6.7 mm inner diameter and 460 mm length). Tuning was regularly checked to keep the reflected power under 20 W. The holding section was a thermally insulated holding tube with nominal residence time of 18 s at bulk velocity and nominal flow rate of 0.5 L/min (7.7 mm inner diameter). Different holding times can be obtained by changing the flow rate. There are nine temperature transmitters (TT) and data was recorded every 10 s. Temperature at TT3 was automatically controlled by manipulating the power level of the hot water circuit while temperature TT4 was controlled by the manipulation of the magnetron power level. Details of this equipment can be found elsewhere (Siguemoto et al., 2018c).

2.3. *Experimental runs*

The pasteurization of cloudy apple juice was evaluated for three processing temperatures (70, 80 and 90 °C), two flow rate levels and two heating modes (conventional and microwave), thus a total of $3 \times 2 \times 2 = 12$ conditions were tested. The time-temperature combinations were based on commercial pasteurization of apple juice (Tajchakavit et al., 1998; Sinha, 2012) and on heat resistance of cloudy apple juice enzymes (Siguemoto et al., 2018a). Table 1 presents the conditions with corresponding flow rates and set-points for TT3 and TT4. These temperature set-points were chosen by trial and error so that the desired processing temperature could be obtained at TT6, compensating heat losses along the product path. The temperature at TT6 was not automatically controlled in this unit because different holding tubes can be used and each would require different PID controller parameters.

For the microwave assisted pasteurization runs, Heater 1 was used as a pre-heater to obtain a temperature of 30 °C at the inlet of Heater 2. Tested flow rates were 0.4 and 0.8 L/min (nominal times of 30 and 15 s, respectively). For the conventional