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Automatic Operation System for Microwave Assisted Extraction of Food

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Abstract

To control the process variables of the Microwave-Assisted Extraction (MAE) operation, an automatic control system using PLC was incorporated to acquire the temperature of the extraction flow streams and control the power mode in the cavity of the MAE. Elution temperatue of the extract was in good agreement with the duty ratio of magnetron. Outlet temperatures of the extraction flow were successfully controlled with the duty ratio control within the range of 45 to 86°C. Concentration of the extract was automatically monitored by measuring the absorbance at 480 nm. On applying the system to the green tea extraction with 0.50 duty ratio, a 16% yield increase was obtained compared to the hot-water extraction.

Key words: MAE, microwave, extraction, PLC, green tea, power mode

Introduction

Microwave-Assisted Extraction (MAE) system has revealed destructive actions against the biological cell walls which impose high resistance to mass transfer during the extraction process. The evidence of decreasing resistance to mass transfer rate was discussed by Yeum and Chun (1996), who observed remarkable yield increases during the extraction of coffee, green tea, red pepper, and barley tea using a conventional home microwave oven. Compared to the conventional hot water extraction system, up to 30-40% yield increase was recorded.

Since most MAE studies have been carried out using conventional microwave ovens with rectangular cavity, localized and subsequent overheating problems remained unsolved, which brought on the need for a special cavity for the extraction purpose. Jun and Chun (1998) designed a cylindrical cavity, which formed a focusing power mode at the central axis to accomodate the cylindrical extraction column for the extraction of *Cape Jasmine*. They also designed a U-shaped extraction column to match the developed power mode in the cavity. This U-shaped extraction column was made by combining two cylindrical columns, one for solvent heating and the other for food extraction. The column for solvent heating was positioned in the center of the cavity to absorb maximum microwave power, and the packed column was placed in the lower power zone. The MAE system in the extraction of pigments from Cape Jasmine resulted in 50% yield increase compared with the conventional hot water method (Jun *et al.*, 1998). On the other hand, controlling the power mode with a uniform intensity was difficult throughout the extraction period, suggesting that a power mode control method is required for the consistency of the MAE system and for the manipulation of the extraction variables inside the cavity.

The objective of this work was, thus, to design an MAE automation system for controlling the duty ratio of magnetron to provide a uniform power mode and strength in the cavity, and to monitor and control the process variab les of the MAE of food.

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Materials and Methods

Materials

Green tea powder (+40 mesh, Jin-Hyang, Pacific Inc., Korea) and distilled water were used as food and solvent of the MAE system, respectively.

Experimental apparatus

The U-shaped MAE system developed by Jun and Chun (1998) was used with the incorporation of an automatic control system. The modified MAE system was constructed using a peristaltic pump and a spectrophotometer for constant feeding and in-line analysis of the extract, respectively.

The operation and control system, composed of a PLC (GLOFA GM3 series, LGIS, Korea) with modules for communication, thermocouple, DC input, relay output, and AD converter, was used.

Detection of power mode formation in the microwave cavity

Thermal sensing paper (Starfax G3, Hansol, Korea) was used to detect the power mode in the microwave cavity. A strip of paper (100 mm×200 mm) was hanged at the top of the cavity, facing parallel to the waveguide, and exposed to the microwave radiation for 10 seconds. Locations and sizes of the burned dark spots formed on the paper were analyzed to identify the location and intensity of the power mode, respectively. A stub matching was made by moving the stub on the microwave waveguide backward and forward from antenna of magnetron to control the power mode formation for maximum microwave power in the cavity.

Microwave power control

The electromagnetic power strength in the cavity was controlled using the duty ratio control method of the magnetron by setting specific ON/OFF time intervals. The duty ratio is defined in Equation (1). The duty ratio was controlled by setting t_{on} and t_{off} values at the PLC.

$$\text{Duty ratio} = \frac{t_{on}}{t_{on} + t_{off}} \qquad (1)$$

where t_{on}: time of magnetron at ON state, seconds
t_{off}: time of magnetron at OFF state, seconds.

MAE extraction procedure

The cylindrical column packed with 2 g of green tea powder was soaked in 20°C water for 30 minutes prior to installation in the cavity. Upon onset of the magnetron, solvent (distilled water) was fed at a rate of 50 ml/min. The soluble solid content in the extracted solution was measured spectrophotometrically at 480 nm using a flow-through cell. The MAE operation and control software developed for this study was used.

The extraction yield of green tea in MAE system was compared to that of conventional extraction system (hot water extraction) under the identical thermal energy basis.

Results and Discussion

Construction of the MAE applicator for food extraction

The MAE system described in Figure 1 was constructed as shown in Figure 2.

Automatic operation and control system for MAE

PLC was installed into the MAE system as illustrated in Figure 3 to provide tools for the automatic control of the MAE process variables, which include temperature, flow rate of solvent, and duty ratio of the magnetron.

Optimization of power mode for the MAE cavity

For the development of optimum power mode in the cavity of MAE system, stub matching on the waveguide was made detecting the burned spots on the thermal paper strip. Stub position at 50 mm from the antenna of the magnetron was performed for determining the optimum condition at which two major modes, both at the top and the bottom, and one minor close to the waveguide of the cavity were formed. The results revealed the modes were sufficient for covering the heating area of the extraction units (coil section of the extraction column in Figure 1) to be accommodated.

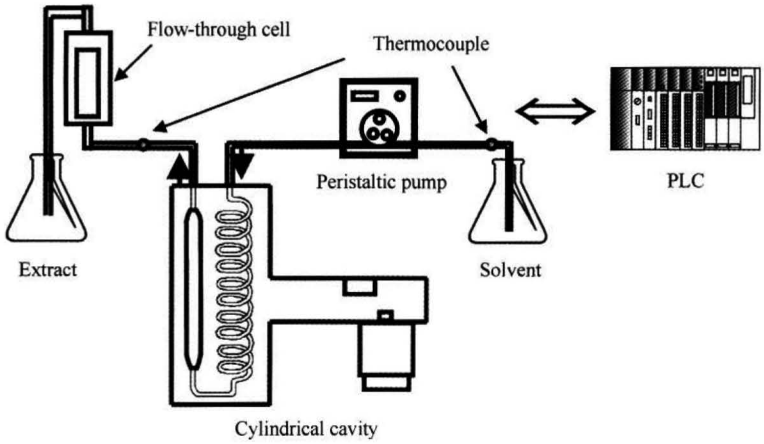

Fig. 1. The modified MAE experimental apparatus.

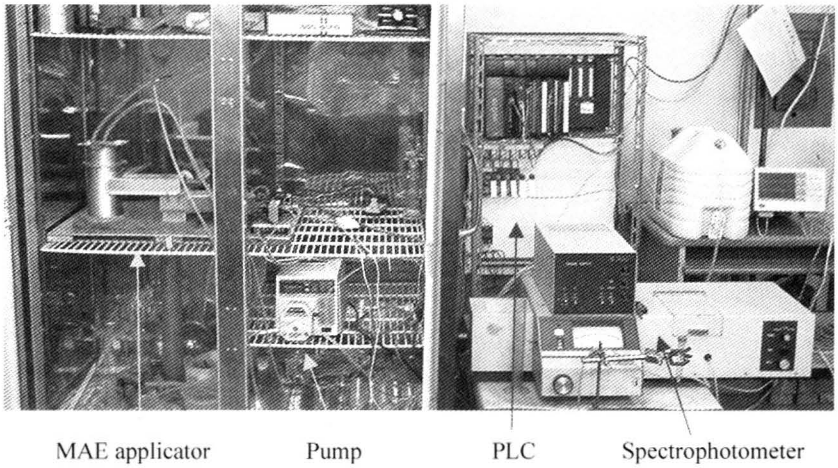

Fig. 2. MAE applicator built with PLC controller.

Temperature control of the green tea extract

To investigate the relationship between the duty ratio applied and the temperature of the extract under the MAE system, temperatures of the inlet and outlet flows of the extracting unit were measured at various duty ratios. The outlet temperature of the extractor was in good agreement with the duty ratio (Figure 5), an indication that the heating rate in the cavity could be successfully controlled by the automatic duty ratio control system.

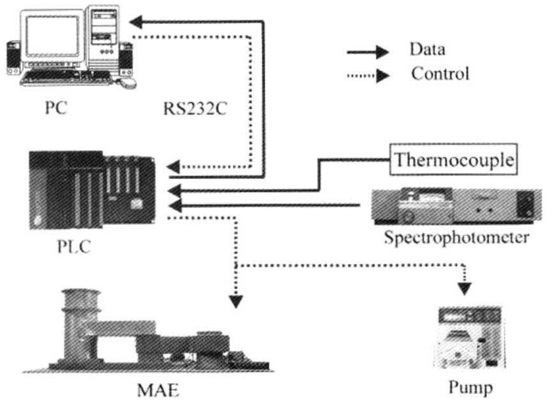

Fig. 3. Automatic operation and control system for MAE.

Power mode stability of the MAE system

To certify the stability of the power mode formed at various duty ratios, the time-temperature profiles were monitored during the operation period of 6 minutes. As the temperature profiles revealed, the stability was improved by increasing the duty ratio,

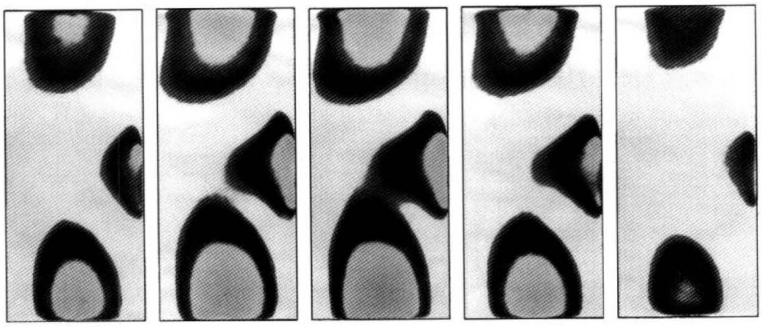

Fig. 4. Microwave power distribution in the cylindrical cavity at various stub positions from the antenna of magnetron.

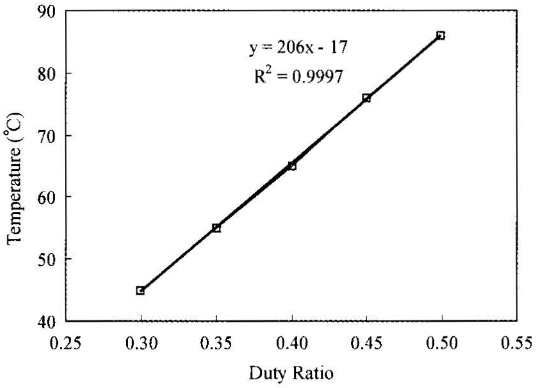

Fig. 5. Effect of duty ratio on the outlet temperature of the green tea extract.

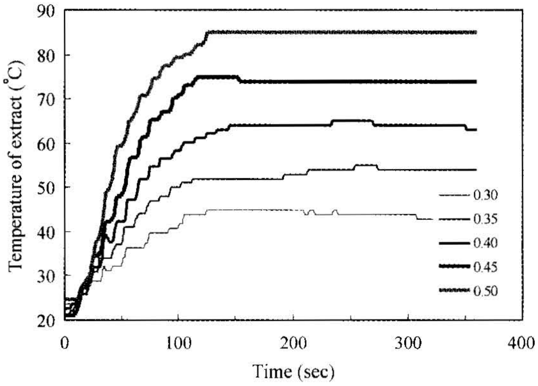

Fig. 6. Effect of duty ratio on the time-temperature profile of green tea extraction.

although slight temperature fluctuations were observed below 0.45 duty ratio. The come up times were approximately 120 seconds at each duty ratio.

Extraction curve of green tea using the automated MAE control system

By applying the control system to the extraction of green tea, the extraction yield could be automatically determined on a real time basis, and the extraction curve could be constructed based on the extraction yield. (Figure 7).

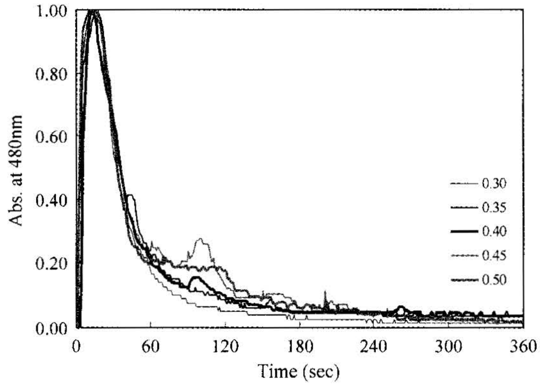

Fig. 7. Effect of duty ratio on the extraction curve of green tea.

The break-through curve of the green tea extraction is shown in Figure 7, with a major peak at 30 seconds and a minor peak at 100 seconds. The yield increase is attributed to the minor peak, which was probably produced by the influence of the destructive microwave power to the cell wall (Jun *et al.*, 1998) of green tea. The maximum yield increase per run was 16% at the duty ratio of 0.50 under the flow rate of 50 ml/min in MAE system compared to the extraction yield in the conventional extraction system(hot water extraction). Therefore, the minor peak is an indication of a non-thermal effect on the increase of mass transfer in MAE system. Based on these results, the automated MAE control system was found to be effective on extraction of food materials.

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