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Automation of *Kimchi* Fermentation Based on Pattern Analysis

J. K. Chun, K. M. Kim and D. H. Woo
Department of Food Science and Technology, Seoul National University

Abstract

A bubble counting sensor was used to construct fermentation pattern of *kimchi*. The cumulative gas production data were differentiated to obtain the gas production rate as the characteristic fermentation pattern with one or two peaks depending on the variety of *kimchi*. Among factors affecting the pattern, temperature was dominant over the other process variables on the peak time. The peak time was the criterion of judging fermentation process. Automation of *kimchi* fermentation was achieved on the basis of the first peak time concept by controlling the temperature and curing time. The *kimchi*-controller designed with one chip micro-controller and software was developed to search the peak time and control the speed and degree of the fermentation. The result was applied to the production of the commercial automatic *kimchi* fermenter.

Key words: *Kimchi*, automation, fermentation pattern, gas production, bubble counter, controller

INTRODUCTION

Urbanization in Korea forced housewives to change their traditional eating habits and *kimchi* is one of these cases. Since *kimchi* have been fermented in a jar buried under ground of their garden, it is necessary for housewives in the apartment and similar housings to find out the new and secure ways of fermenting and storaging of *kimchi* (Chun, 1981; Kwon and Min, 1984). In this consequence, the demand for a larger refrigerator have been steadily increased to store cured *kimchi*. The microbial flora and the progressing of the curing are not predictable because *kimchi* fermentation is conducted in natural environment. The control of the fermentation, therefore, is not easy unless an on-line monitoring method is provided in a *kimchi* jar. Accordingly, a monitoring system was developed to measure gas production rate during *kimchi* fermentation (Lee and Chun, 1990; Lee and Chun, 1994). The system has been proved to be effective for on-line monitoring of gas forming fermentation such as *kimchi*, *tackjoo* and methane fermentations (Kim and Chun, 1993; Choi and Chun, 1996).

In order to develop an automatic *kimchi* fermenter, a modern kimch-jar, the standardized control point and variables have to be established, and also a control logic has to be provided to imitate the natural fermentation of *kimchi*. This work was focussed to carry out the pattern analysis of the fermentation of *kimchi* and develop the control logic of the automatic *kimchi* fermenter.

Corresponding author : Jae-Kun Chun, Department of Food Science and Technology, College of Agriculture and Life Sciences, Seoul National University, Suwon 441-744, Korea (Tel.: 0331-290-2586, E-mail: chunjae@snu.ac.kr)

MATERIALS AND METHODS

Kimchi preparation

Kimchi was prepared with Chinese cabbage (Brassica Campestris L. spp. Peciensis), table salt, red pepper powder, fresh garlic, fresh leek and fresh ginger. The amount of seasoning mix used was 1~2% of the cabbage weight. Radish *kimchi* was made with cubing of radish (Raphanus Sativus) adding salt and red pepper powder. Cucumber (Cucumis Sativus) was sliced and used in the cucumber *kimchi*. Salt concentrations of the various types of *kimchi* ranged from 1 to 8% (w/w).

Construction of fermentation pattern

The fermentation pattern was constructed on the basis of gas production rate using bubble counting sensor reported elsewhere (Lee and Chun, 1994; Choi and Chun, 1996). Raw *kimchi* was bottled in a glass bottle (1 L) and capped with a rubber plug. A venting tubing (Teflon, 2 mm diameter) was connected between the top of the jar and a bubble counting sensor (detectable bubble size, 20 mm^3) to measure the gas production during fermentation period (Choi and Chun, 1996).

Kimchi fermenter

An experimental *kimchi* fermenter was constructed by installing an electrical heater and a microcontroller (MC68705R3) in a refrigerator (model SR-120, 120 L, SamSung Electronic Co., Korea) for the regulation of temperature ranging from 0 to 30°C.

RESULTS AND DISCUSSION

Pattern analysis of *kimchi* fermentation

The pattern analyzing system was composed of a laboratory built *kimchi* fermenter, bubble counting sensors and a controller. The system measured the gas production under the controlled environment and communicated with host computer to carry out the pattern analysis. The pattern of *kimchi* fermentation was obtained by differentiation of the cumulative gas production during the fermentation period as shown in Fig. 1.

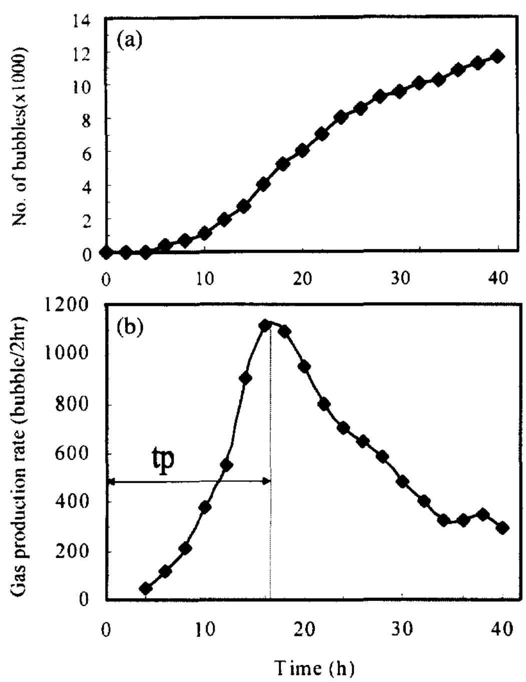

Fig. 1. Construction of the pattern curve of *kimchi* fermentation from the cumulative gas production data. (a) Cumulative curve, (b) Pattern of gas production rate.

Patterns of *kimchi* fermentation

The characteristic fermentation patterns were obtained for various types of *kimchi* prepared with Chinese cabbage, radish or cucumber as shown in Fig. 2. These patterns revealed that the number of peaks and the peak time were remarkably affected by the raw materials used. The first peaks appeared at 14, 18 and 20 hours after onset of the fermentation for radish, cucumber and Chinese cabbage *kimchi*, respectively.

The important finding is the consistency of the first peak existence in their pattern curves in spite of the different variety of *kimchi* as shown in Fig. 3. The first peak, therefore, was regarded as an informative criterion of judging the fermentation stage and could be used for the control of the fermentation process.

Factors affecting the *kimchi* pattern

1. Effects of quantity of raw materials and seasonings

The quantity of raw materials used in *kimchi*

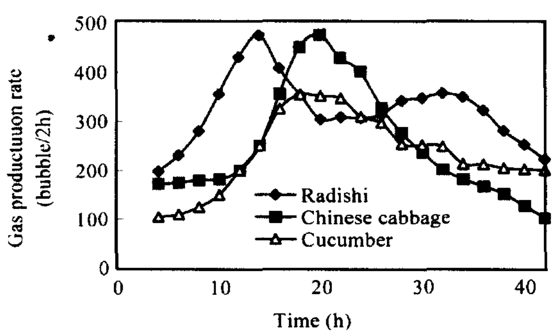

Fig. 2. The fermentation patterns of various types of *kimchi*.

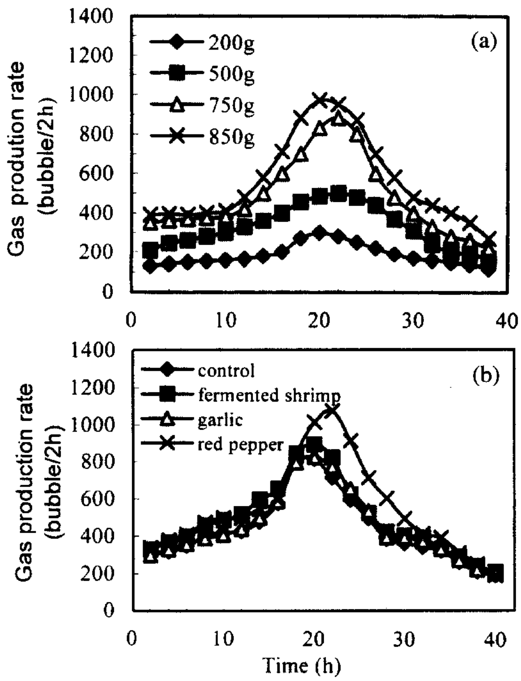

Fig. 3. Effects of the quantities of raw materials and seasonings on the *kimchi* pattern. (a) Pattern at different quantities of raw materials, (b) Pattern at various seasonings.

rarely affected the first peak time (t_p) even it was shifted within less than one hour in Chines cabbage *kimch.* But it affected to the peak height, i.e., gas production rate. The gas production rate was linearly proportional to the quantity of material (Fig. 3a). The effect of seasonings on the peak time was negligible in the view point of peak time shift except the red pepper as shown in Fig. 3b.

2. Effect of salt contents on *kimchi* fermentation pattern

Saltiness of *kimchi* varies from one district to another due to the climate, and generally known as the residents at warm district prefer to salty one. When *kimchi* containing salt ranging from 1 to 7% were subjected to pattern analysis, first peak time was delayed as increase of salt content. The delay period was approximately 2 hours as 1% of salt content increased (Choi and Chun, 1996).

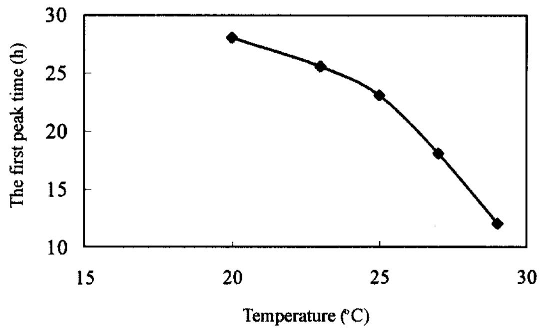

Fig. 4. Effects of temperature on the first peak time.

3. Effect of temperature on *kimchi* fermentation pattern

As is the case of other fermentations, *kimchi* processing is significantly affected by temperature. The peak time was decreased as temperature increased as observed in Fig. 4.

Design criteria of *kimchi* fermenter

Since the first peak time is a common and characteristic phenomenon in the pattern curve, it can be an indicative criterion of judging the fermentation progress. The weights of the various factors affecting the peak time were rated on the basis of the shifting span of the peak time and they are shown in Table 1. Comparing the weights, temperature is the most dominants one. It means that the control of fermentation temperature is enough for the peak time adjustment under any types of fermentation circum-stances.

Table 1. Factors affecting the first peak time during *kimchi* fermentation

Factors on *kimchi* fermentation pattern	Weight (Peak time shifted, Δt_p (hour))
Kinds of raw material (Chinese cabbage, Radish, Cucumber)	6
Quantity of raw material (200~850 g)	1
Salt (2~6%)	6
Seasoning (non, pickled shrimp, combination)	4
Temperature (20~ 30°C)	16

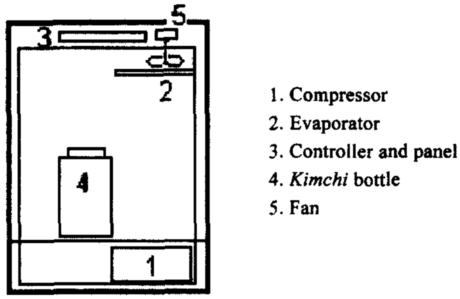

Fig. 5. Structure of *kimchi* fermenter.
1. Compressor, 2. Evaporator, 3. Controller and panel, 4. *Kimchi* bottle, 5. Fan.

Design of *kimchi* fermenter

Since a thermocontrol system was enough to control the fermentation rate for any kind of *kimchi*, a fermenter was designed to regulate the temperature from 0 to 30°C with one-chip microcontroller. It was fabricated with a refrigerator by adding an electrical heater and a fan as shown in Fig. 5.

Operation program of *kimchi* fermenter

The operation program was developed to regulate the temperature of the fermenting room at the set point to carry out fermentation of *kimchi* and then switch to cold storage environment when the peak time was reached. It includes data acquiring and peak time searching algorithms. Fig. 6 shows how the *kimchi*-fermenter was controlled and the peak time was searched.

Control panel of *kimchi* fermenter

The control panel of *kimchi* fermenter was de-

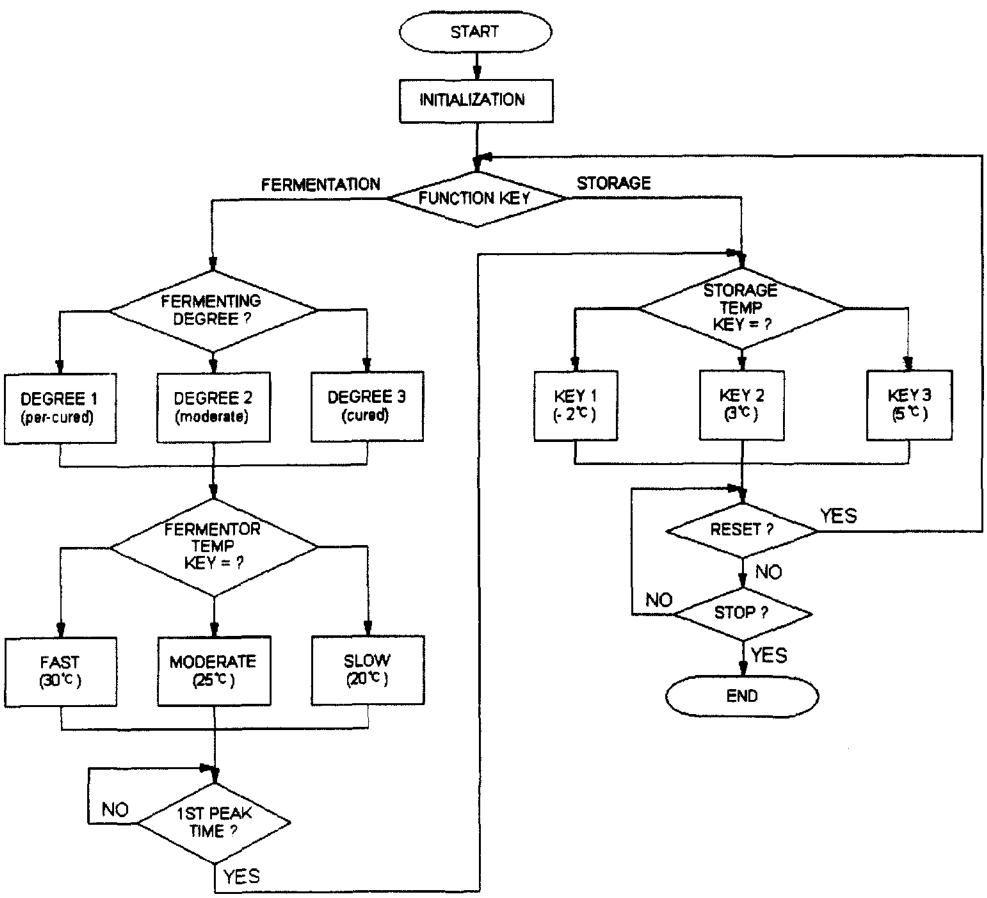

Fig. 6. The program flow chart of *kimchi* fermenter.

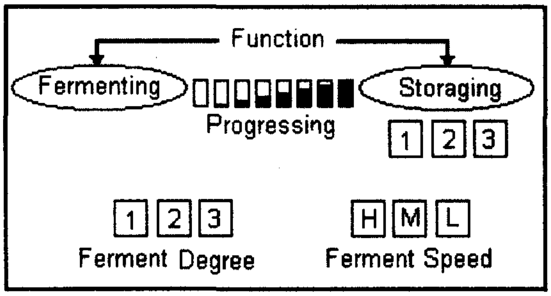

Fig. 7. The control panel of *kimchi* fermenter. (Numerical numbers in keys indicate their degrees and the characters H, M, L stand for high, moderate and low, respectively.)

signed and fabricated on the basis of control algorithm as illustrated in Fig. 7.

Temperature control profile of *kimchi* fermenter

The temperature profile of *kimchi* fermenter and *kim-chi* in bottle were well controlled as illustrated in Fig. 8.

CONCLUSION

From the pattern analysis of *kimchi* fermentation, a new concept of fermentation control logic was established. The concept is to search the first peak on the fermentation curve and use it as the control criteria to set the optimum environmental conition of the process.

After the control of the fermentation environmental variables at the set point during curing process, the temperature was programmed to switch to the cold storage course. An 8-bit microcontroller was enough to carry out the automatic fermentation process for various types of *kimchi*. This monitoring technology is expected to be applied to other fermentation processes where gas is produced.

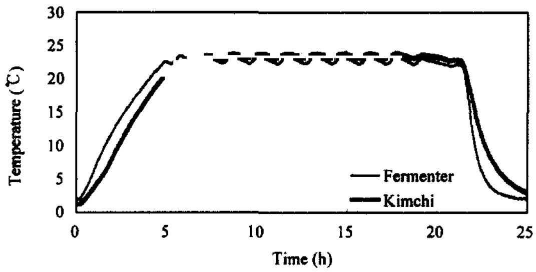

Fig. 8. The temperature control profile of *kimchi* fermenter and *kimchi* in bottle.

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