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Automation of Koji Manufacturing Process Based on Microcontroller and Its Comparison with Manual Method

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Abstract

A Multi-purpose Agricultural Controller (MpAC) was used to build an automation system for the Koji manufacturing process. An operation program was also developed to manipulate the control box for the heating, ventilating and humidifying devices. The system was applied to the monitoring of the Koji-bed and Koji-room temperatures, as well as the humidity through bi-directional communication with a monitoring computer in a field scale conventional Koji manufacturing facility. Five trays of cooked barley (3.2 kg/tray) served as the sample cultures for *Aspergillus oryzae*. The time course change in the temperature of the bed and the temperature and humidity of the Koji room were compared with the manual processes operated by a bimetal thermo-regulator. In the automation system a restacking operation of the Koji boxes was conducted on the basis of the monitored Koji-bed temperatures, and thus, abrupt increases in the bed temperature and in the humidity due to microbial respiration could be regulated.

Key words: Koji, process control, automation, microcontroller, on-line monitoring, *Aspergillus oryzae*

Introduction

Koji is a solid culture of *Aspergillus oryzae,* cultured on steamed barley or rice grain, and commercially manufactured by both batch and continuous presses depending on the production scale. Koji is widely used as the seed culture for the fermentation of soybean paste and sauce.

Even though, programmable logic controllers (PLC) have been used in large scale food processors (Kao, 1987; Cook, 1995), the installation cost becomes a heavy financial burden for the small scale processor. Early research on the automation of the Koji process has been carried out by Kwon and Chun (1988) using a 6502 microprocessor on a laboratory scale system. Cho (1993) designed a controller with a one chip microcontroller to display the temperature and humidity. For small scale food processors, including green house culture, the Simplified Food Process Controller (SFPC) was developed by Chun and Jun (2000). A multi-purpose agricultural controller (MpAC), by Kwon (Kwon et al. 2004), was designed for versatile applications through upgrading of the SFPC(Chun and Jun, 2000) by implementing a multi-functional operation system. From the series of automation studies of Chun and his coworkers, a one-chip microcontroller may be suitable for Koji processors with respect to the installation cost and operation technology.

The purpose of this study was to construct a Koji automation system with MpAC, apply it to a field scale Koji manufacturing facility and validate its performance in relation to the Koji product.

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Materials and Methods

Materials

Barley (*Hordeum sativum*) purchased from local market was used as the substrate for the Koji process. *Aspergillus oryzae* was supplied from Hakyung Fermented Food Co., Korea.

Koji culturing procedure

Barley was socked in water at 25°C for 2 hours, drained and then steamed at 0.6 kg/cm^2 for 40 minutes.

After cooling to 30°C, *Aspergillus oryzae* was inoculated and cultured using the tray method at 28°C and 70% RH for 40 hours in an insulated Koji room. The conventional Koji culturing room (31.25 m^3) was equipped with two 1.5 kW heaters(ERT-15ABN, HungShin Co., Korea), 0.042 kW humidifier(GH-600U, LG electronics, Korea) and 50 trays (3.2kg steamed barley/tray).

Sensors

Five thermistors (1k, Dong-Kwang Electronics, Korea) and humidity sensor (SY-HS-200, Sam-Young Electronics, Korea) were used as the measurement probes for the temperature and humidity, respectively. The fabricated sensors were used after calibration, according to the method of Jun and Chuns (2000).

Software development

The operating program for the Koji culturing system was developed using an EVM board (E-TMS73S, Young Tec. Co., Korea), IBM PC(Terminator P3, Asus Co., Taiwan) and XTALK(V2.0.0.b, Shareware), as well as EPROM and piggy back. C language(Turbo C 3.1, Borland Co., USA) was used to write the monitoring program.

Results and Discussions

Construction of Automation system for Koji manufacture

The automation system for Koji manufacture was constructed with MpAC (Kwon et al, 2004), two electrical heater units (1.5 kW), two sets of humidifiers (2×42 W) and a ventilation fan (50 W). The system was installed into the Koji culturing room (31.25 m^3, 5×2.5×2.5 m; W×D×H), with a control box including a relay, as shown in Figure 1. For one batch process 5 trays (wood, 65×48×8 cm; W×D×H, 3.2 kg of steamed barley/tray) were stacked.

The bi-directional communication between MpAC in the Koji room and the monitoring computer was conducted via an RS-232C with intervals of 10 seconds.

On-line monitoring of process variable for Koji manufacture

The temperatures were measured and monitored using five thermistor probes positioned at the Koji trays (T_1, T_2, T_3) and the Koji room (T_4, T_5). The humidity was monitored with a humidity sensor installed at the center of the Koji room (H), as shown in Figure 2.

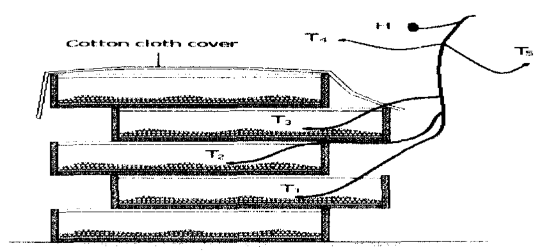

Fig. 2. Locations of the sensors in the trays and Koji room.

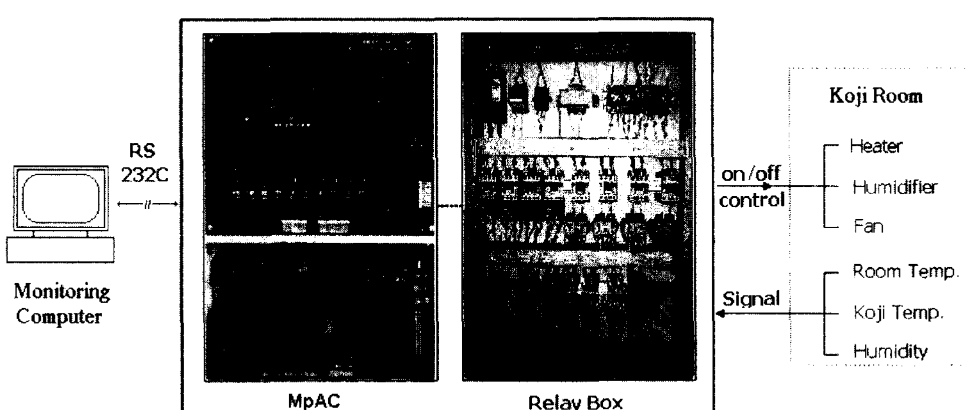

Fig. 1. Structure of automation system for Koji manufacture.

The acquired data from the sensors were transmitted to the monitoring computer in a 12 byte word format, consisting of 2 bytes for the header and tag, 5 bytes for the temperatures (T_1, T_2, T_3, T_4, T_5), 1 byte for the humidity and 3 bytes for time (hour, min, sec). One byte was reserved for future use. Two control words (5 bytes) were used for the actuator control and set-point for feedback control. One control word was assigned for the actuator control, with 2 bytes for the heater and humidifier and 3 bytes for the set-points for the temperature, humidity and mode-selection between the manual and automatic operations.

On-line monitoring of conventional manual Koji manufacturing process using MpAC

In order to develop an automation system for the Koji process, a conventional manual process operated by a skilled operator was monitored using MpAC. Table 1 shows the procedure of the Koji manufacturing process.

The time course changes in the process variables were monitored, as shown in Figure 3. The temperature of the Koji-room fluctuated around 27°C, with a variance of 4 in the first half period, but remained stable at 27°C there after. The temperature of the Koji-bed increased after 10 hours, but also fluctuated, with some abrupt changes due to the restacking operations. The temperature profile showed that most operational effort was used in the regulation of temperature by frequent checking every 1 or 2 hours for half the entire process period. These temperature records show how the expert conducted heating control using an ON/OFF switch to regulate the temperature at around 27°C. Accordingly, automatic control of the room temperature was therefore important for the success of the process as the Koji-room acted as a heat sink for the microbial respiration heat.

The humidity of Koji room gradually decreased during the 16 first hours of the process, then steeply increased and showed a growth associated pattern.

The humidity decreased for the first 18 hours indicating that the capacity of humidifier was not sufficient and that supplemental humidifying capacity was needed. Also, an increase in the humidity after 25 hours indicated the need for a ventilation system to reduce the excess humidity caused by the microbial respiration.

Automatic temperature control in Koji room by MpAC

Unlike the temperature control of a vacant room, the control of the Koji-room with loaded culture media requires a skilled expert who is able to manually control the temperature using a heater and thermometer. Despite

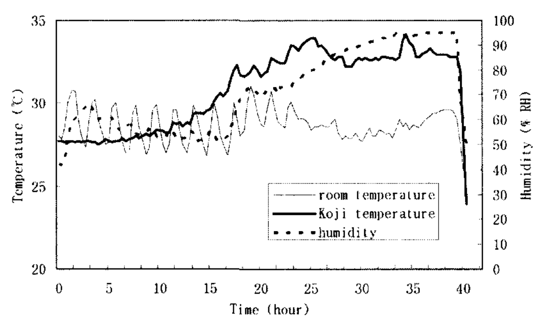

Fig. 3. Time course changes in temperature and humidity during the manual Koji manufacture process.

Table 1. The operation data sheet for the Koji manufacturing procedure

Time(hour)	Operation	Remark
00:00	Steaming barley	Steam cooked, 0.6 kg/cm^2
00:45	Tempering	
01:30	Mixing and cooling	Cooled down to 30°C
03:30	Inoculation	3.4 g of seed culture on barley, dried
04:00	Set up thermistor in Koji boxes	See Figure 2
04:04	Set point adjustment at 28°C and 70% RH	
07:40	Covering wetted cotton cloth over Koji tray	To prevent drying
26:00	1st re-stacking Koji tray	
34:00	2nd re-stacking Koji tray	
39:30	Finish	

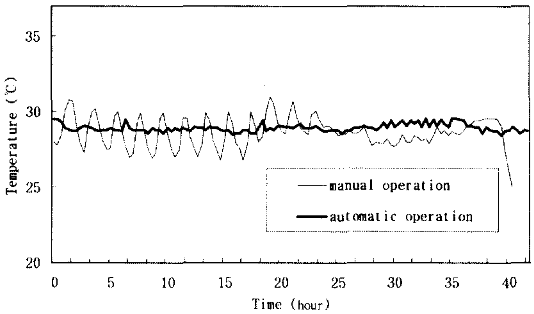

Fig. 4. Comparison of the mean value of room temperature patterns between a manual operation and an automated operation by MpAC.

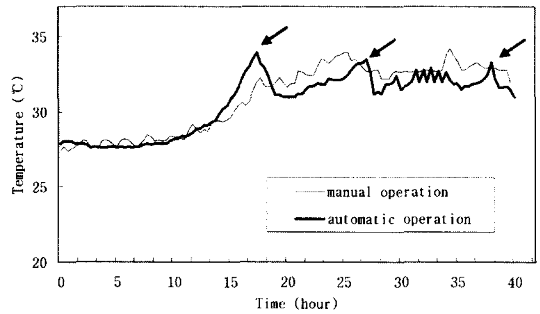

Fig. 5. Comparison of temperature profiles of the Koji bed between the manual operation and the automated operation by MpAC.

an experts skill, a temperature variance of 4°C was recorded in Figure 4.

When the automatic control method was employed, the temperature variance was reduced to 2°C due to feedback of the measured value for comparison with a set point in Figure 4. The measured value was supplied to the actuator system at 10 minute intervals after averaging 60 data points every 10 seconds.

Therefore, MpAC performed its role as a temperature controller in the Koji manufacture process.

Development of alarm annunciation program on the basis of temperature of Koji bed

Even with skilled manual operation by an expert, it was not easy to predict the time required to conduct a restacking job to prevent the temperature rising above 33°C. Conventionally, an expert would check the Koji-bed temperature every 2 hour, conducting a restacking operation twice, once after 26 hours and again after 34 hours, from the start of culturing. Thus, the restacking operation has been well acknowledged as a key manipulation within Koji manufacture.

To supply accurate information on the restacking time, the operation program was developed to announce the time of restacking on the basis of the measured temperature of the Koji-bed in the trays. The program continuously monitored the bed temperature and generated an annunciation of alarm whenever one of bed temperatures elevation exceeded 33°C for 10 minutes or more. Three alarms were annunciated at 18, 27.5 and 37.5 h, respectively, as marked by the arrows on the thick solid line curve in Figure 5. Therefore, the temperature was able to be control in a similar manner to an expert, as seen in the curve of the manual operation.

Analysis of humidifying capacity during Koji manufacture

To obtain the optimum humidity conditions during Koji manufacture, the time course humidity change was investigated. As seen in Figure 6, decreases in the humidity lasted for half of the total culturing period, and then an exponential rise appeared, probably due to the respiration activity of the microbes. This suggests that the humidifying capacity is low for the culture of Koji, and that an increase in the humidifying capacity is needed.

Automation of Koji manufacture process using MpAC

The control of the temperature and humidity were key

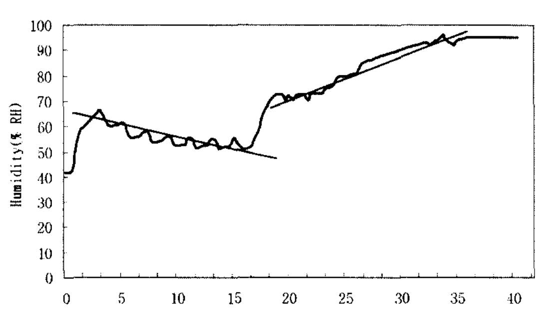

Fig. 6. Trend of humidity change during the Koji manufacturing process.

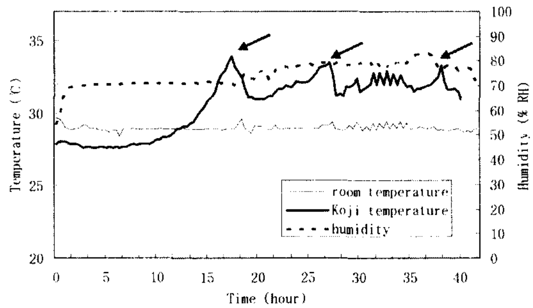

Fig. 7. Temperature profile of the Koji bed under automatic control of the temperature and humidity using MpAC.

manipulation variables under automatic control using MpAC. The Koji process was conducted after installation of another humidifier and ventilation fan for the dehumidifying device for when the humidity increased above the set range.

When the set points for the temperature and humidity were given as 28°C and 70 - 90% RH, respectively, the Koji room temperature was regulated at 28±1°C and humidity was controlled within the given range, as shown in Figure 7. The temperature rise of the tray was steeper than that of the manual mode. This indicates that early humidity regulation helped growth of mold, and annunciations of alarm were conducted three times to inform the operator to restack the Koji trays to retard a temperature rise.

The quality of the Koji product manufactured by the Koji culturing automation system was better than that of an expert, with improved productivity.

Conclusion

A MpAC was developed on the basis of 8 bit microcontroller technology and its performance tested in a Koji processing facility with satisfactory results as a process controller in several aspects, such as simplicity of technology, cost and software development. Considering the number of I/O ports, MpAC was proved to be applicable to similar processes with more process variables than the Koji process. Design and software developments for versatile applications take several years, but conversely the speed of microcontroller upgrading is generally too fast for application engineer to catch up. This technological speed gap between chip producer and users leads a serious problem in the availability of outmoded hardware and its software development. For the practical application of microcontroller technology, a stable supply of the main part is important.

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