Knowledge-Based Rules for Control of the Sake (*Ginjoshu*) Making Process and Their Application in Fuzzy Control

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ABSTRACT

For temperature control of excellent sake (*Ginjoshu*) making process, the construction of the knowledge-based rules was studied From the interview with process operators (*Toji*), 4 knowledge based rules were listed up. Especially, it was found that Alcohol-Baumé plot and BMD curve were important as a reference for making *Ginjoshu* with good quality. Fermentation period was separated into 4 control regions. Fuzzy production rules and membership functions for temperature control in each region were constructed by using above references. Tuning of membership function was done using the simulator as proposed by us and the brushed-up rule was applied to 25L and 250L-*Ginjoshu* fermentation. Time course of temperature, acidity, Baumé, glucose, pyruvic acid, some alcohols and some esters were judged to be similar to those of traditional fermentation process by *Toji.*

1. INTRODUCTION

Ginjoshu making process is one of Japanese traditional fermentation process. *Toji* are experts for this process and they have many precise know-hows and rules based on their experience. Recently, however, the aging of their population and the decrease of the young successor have caused a crisis for sake brewing companies.

To solve this problem, the development of labor-saving process has been required to engineers from both software [1] and hardware side. Especially for fermentation (*moromi*) process, it is needed to construct the software based on many know-hows and rules, from which the strategy for process control could be decided. In this paper, a fuzzy resonance was applied to construct the strategy for temperature control, which is the most important variable in *Ginjoshu moromi* process.

2. MATERIALS AND METHODS

58 data sets of time course of *Ginjoshu* brewed between from the year 1989 to 1991 in Aichi prefecture in Japan was used for data analysis. The data sets consist of temperature, Baumé, and alcohol concentration which were collected everyday. Baumé is a technical term used in sake making process, which corresponds to a specific gravity of fermentation broth, *moromi*. Software of fuzzy control was programed by N88-Basic language using a personal computer (PC-9801 RA2; NEC Co.Ltd.,Tokyo).

For the experimental fermentation, *Saccharomyces cerevisiae* FIA-2 was used as a microorganism. As a raw material, 10 kg of steamed rice and 15L of water were used for 25L fermentation.

3. RESULTS AND DISCUSSION

3.1 ANALYSIS OF FERMENTATION DATA

Figure 1 shows time courses of temperature, Baumé and alcohol concentration of 58 *moromi* fermentations. Temperature distribution was narrow in the early period and became wider in the later period. This means that the degree of temperature decreasing at later period was changed widely in each of batch processes depending on the initial condition or the fermentation state such as the rate of alcohol fermentation and saccharization. Average temperature of the first day was 6.1°C. The highest temperature was attained after the 10th day and its average was about 9.8°C. The day corresponded to the day that the foam on the broth disappeared (the *bouzu* day), after that temperature had been lowered slowly until about 5 °C.

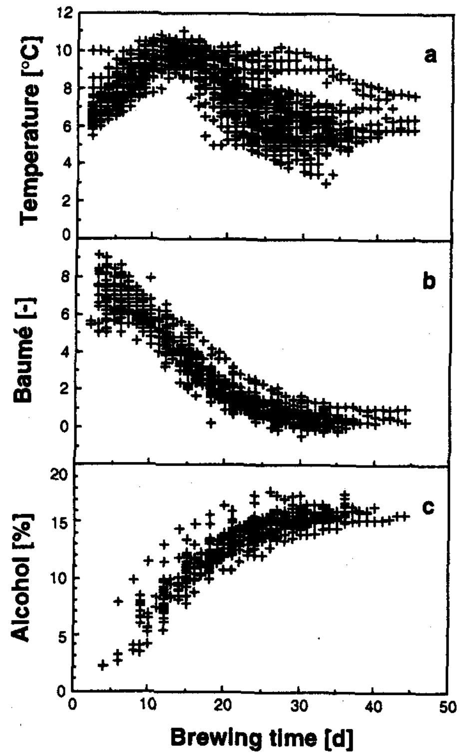


Fig. 1 Profiles of fermentation parameters; temperature (a), Baumé (b) and alcohol concentrarion (c), in 58 *ginjyo moromi* fermentations.

Figure 2 shows time course of difference in temperature (△T) between the day and the previous day. From Fig.2, it was found that temperature was controlled as follows; only raised from the first day to the *bouzu* day, only lowered from about the *bouzu* day to the 22nd day and both raised and lowered from about the 22nd day to the last day. It was also found that the *bouzu* day was the day that alcohol concentration was over 10.5% and Baumé was under 3.5 and the 22nd day was almost equal to the day that Baumé become under 2.0.

3.2 KNOW-HOWS FROM *TOJI* [2] AND KNOWLEDGE-BASED RULES STRATEGY FOR TEMPERATURE CONTROL [3]

From the interview with *Toji* , the following knowledge-based rules for making *Ginjoshu* with good quality were listed. 1) *Moromi* fermentation should be finished at about 30day. 2) Keeping low temperature at end of *moromi* is important. 3) Temperature should be controlled based on straight line of Alcohol-Baumé plot after 9th day, and 4) based on straight line of BMD (Baumé Multiplied Day)-Day plot in the later period. In order to confirm the third and forth rules, we analyzed 58 data sets. As shown in Figure 3, it was found that the average data of A-B and BMD-D plot could be put on a straight line. Based on these rules and results from Fig. 2, we constructed the knowledge-based rules for temperature control.

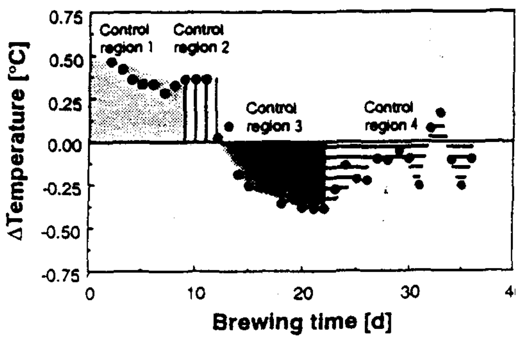


Fig.2 Time course of average values of ΔTemperature

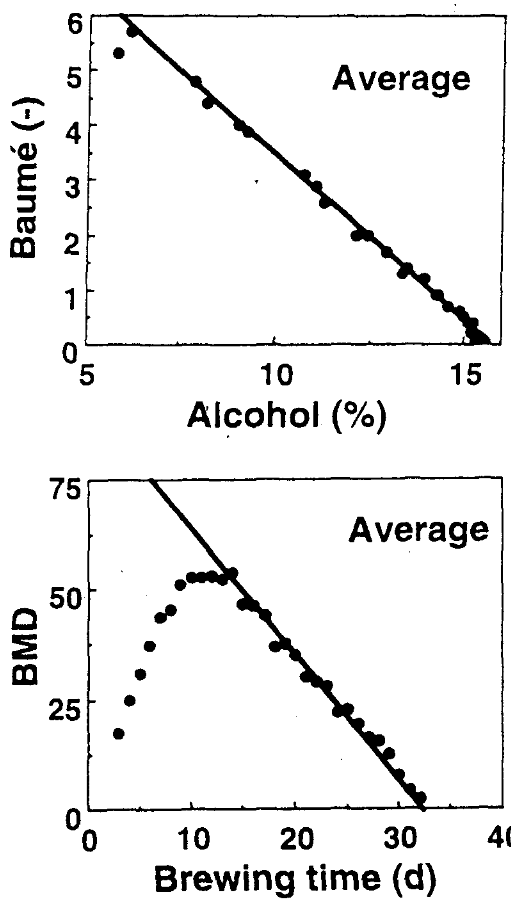


Fig. 3 Alcohol - Baumé plot and BMD - D plot of 58 data sets of actual *moromi* fermentation

Set point of temperature of next day was determined by the following equation.

(Temperature of the n+1 st day) = (Temperature of the n th day) + $\triangle T$

$\triangle T$ was decided by the following rules based on the knowledge of *Toji*. In the first period (control region 1 : from the first day to the 9th day), temperature is simply raised 0.4°C day by day, since fermentation broth has no fluidity and measuring values aren't reliable as process data. Initial temperature is set at 6°C. In the second period (control region 2 : from the 10th day to the *bouzu* day), temperature is only raised in order that A-B plot adjusts to that of average values. $\triangle T$ was decided from fuzzy rules. In the third period (control region 3 : from the *bouzu* day to the day that Baumé is over 2.0), also using fuzzy control, temperature is only lowered so that A-B plot follows a straight line. In the last period (control region 4 : from the day that Baumé is under 2.0 to the last day), using fuzzy control, both increasing and decreasing of temperature is controlled so that BMD value decreased linearly. These knowledge-based rules are summarized in Table 1.

Table 1 Control strategy and reference.

	period	operation of temperature	reference
Control region 1	1-9day	simply increasing (0.4℃/d)	—
Control region 2	10day-Bouzu	increasing by Fuzzy control	straight line on A-B plot
Control region 3	Bouzu-Baumé over 2.0	decreasing by Fuzzy control	straight line on A-B plot
Control region 4	Baumé under 2.0	increasing or decreasing by Fuzzy control	straight line on BMD curve

3.3 ACTUAL STRATEGY FOR TEMPERATURE CONTROL

Control strategy by using A-B plot was described in Fig. 4. If temperature in the tank is increased, the decrease of Baumé is promoted. As a result, lower value of Baumé will be obtained at the next day. In the other words, $\triangle T$, which is an output from fuzzy resonance, should become positive, if the data of a certain day is plotted on the upper side of reference.

Figure 5 shows the control strategy by using BMD-D plot. In the region 4, BMD reference was drawn according to the data in the region 3. If the cross point of the reference with X-axis is out of the range between 29 to 33 day, the reference is redrawn as it is into this range. $\triangle T$ is basically controlled as the same as the strategy in Fig. 4. Out put, $\triangle T$, is positive, if the data of a certain day is plotted on the upper side of reference. Membership function and production rules of the region 2 and 3 and region 4 were described in Figs. 6 and 7, respectively. Production rules were constructed by using the ratio of length and △degree in Fig. 6 and temperature and △BMD in Fig. 7.

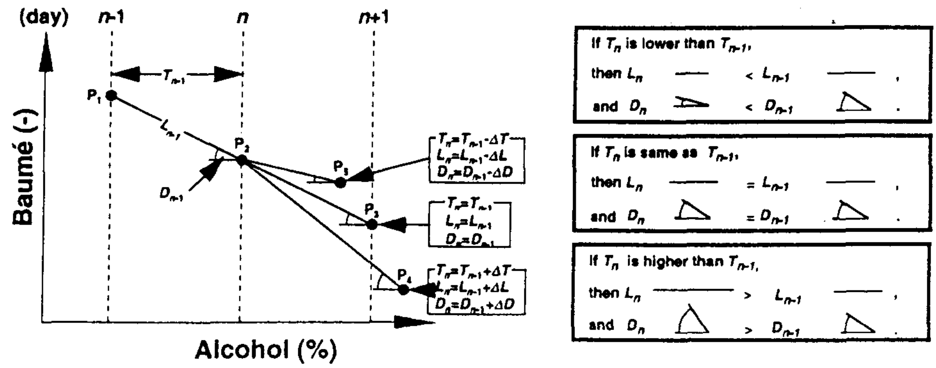


Fig. 4 Control strategy for *Ginjo moromi* fermentation on A - B plot

In the region 2, all of production rules are zero or positive, since temperature in this region should be increased; if the ratio of length is big and △degree is big, then the production rule is positive big. On the other hand, in the region 3, all of production rules are zero or negative, since temperature in this region should be decreased; if the ratio of length is small and △degree is small, then the production rule is negative big. In the region 4, there are negative, zero and positive of the production rule. If the △BMD is big and temperature is small, then the production rule is positive small in order to increase temperature slightly.

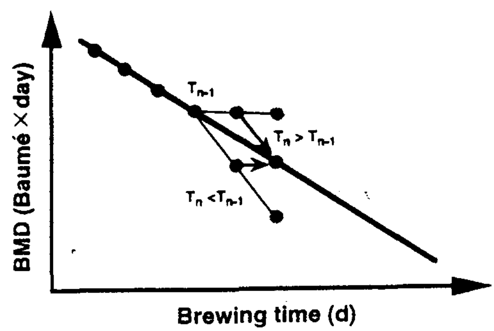
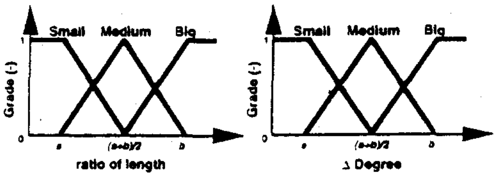


Fig.5 Control strategy for temperature control based on straight line of BMD curve.

Production rules for control region 2

		ratio of length		
		Small	Medium	Big
Δ Degree	Small	ZE	ZE	PS
	Medium	ZE	ZE	PM
	Big	PS	PM	PB

Membership functions for inputs



Production rules for control region 3

		ratio of length		
		Small	Medium	Big
Δ Degree	Small	NB	NM	NS
	Medium	NM	ZE	ZE
	Big	NS	ZE	ZE

PB: positive big PM: positive medium
PS: positive small ZE: zero

NS: negative small NM: negative medium
NB: negative big.

Membership functions for outputs

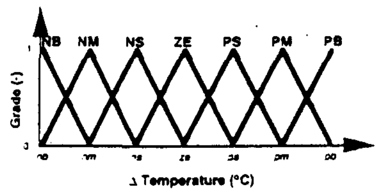


Fig. 6 Production rules and membership functions for control region 2 and 3

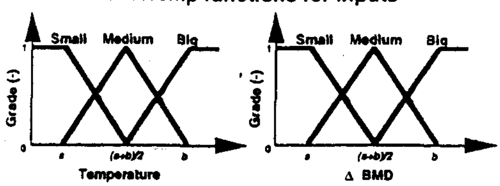
Production rules for control region 4

		Δ BMD		
		Small	Medium	Big
Temperature	Small	NS	ZE	PS
	Medium	NM	NS	ZE
	Big	NB	NM	NS

PB: positive big PM: positive medium
PS: positive small ZE: zero

NS: negative small NM: negative medium
NB: negative big

Membership functions for inputs



Membership functions for outputs

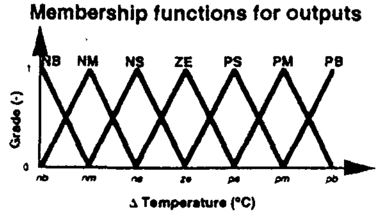


Fig. 7 Production rules and membership functions for control region 4

Some parameters were tuned by the calculation using the simulator. This simulator was constructed by us based on the relationship between the integrated temperature and the alcohol concentrations or Baumé (formulation was not shown). Some parameters of membership function determined by the calculation are listed in Table 2.

Table 2 Parameters of membership functions

		a	b
Control region 2	ratio of length	0.5	1.5
	△degree	-15	15
Control region 3	ratio of length	0.5	1.5
	△degree	-15	15
Control region 4	△BMD	-2.0	2.0
	temperature	5.0	8.0

		nb	nm	ns	ze	ps	pm	pb
△Temperature	Region 2	-	-	-	0.0	0.1	0.2	0.3
	Region 3	-0.3	-0.2	-0.1	0.0	-	-	-
	Region 4	-0.7	-0.5	-0.2	0.0	0.2	-	-

3.4 TUNING OF THE FUZZY RULES

The suitability of fuzzy rules was confirmed from the simulation under various initial conditions, in which various 9 days-Baumé values (maximum Baumé value) were used. Results are described in Table 3. The calculated results were coincided well with the actual experimental data.

Table 3 Comparison of the calculated values with the average values of actual fermentation

		Brewing time (day)					
		10	15	20	25	31	32
Temperature (C)	Calculation	9.3	9.5	7.6	5.9	5.5	5.4
	Measurement	9.3	9.3	7.5	6.1	5.2	5.2
	Difference	0.0	0.2	0.1	- 0.2	0.2	0.2
Baumé (-)	Calculation	5.3	3.2	1.6	0.8	0.2	0.0
	Measurement	5.3	3.1	1.7	0.9	0.2	0.1
	Difference	0.0	0.1	- 0.1	- 0.1	0.0	- 0.1
Alcohol (%)	Calculation	6.5	10.4	12.8	14.3	15.5	15.6
	Measurement	5.8	10.7	12.9	14.3	15.3	15.3
	Difference	0.7	- 0.3	- 0.1	0.0	0.2	0.3

3.5 25L-*GINJOSHU* EXPERIMENTAL FERMENTATION

Brushed-up rule was applied to 25L-*Ginjoshu* fermentation. Figures 8, 9 and 10 show the time course of temperature, A-B plot and BMD curve of this fermentation, respectively. Figure 8 shows that temperature was increased and decreased according to each control rule. As shown in Fig.9, A-B plot was almost straight in control region 2 and 3. BMD curve was also straight in the control region 4 (Fig.10). This means that temperature as an operational parameter was set fairly well and both alcohol and Baumé could be enough controlled.

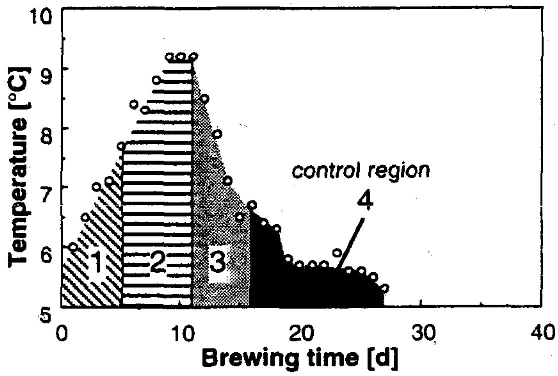


Fig.8 Time course of temperature in 25L-experimental fermentation

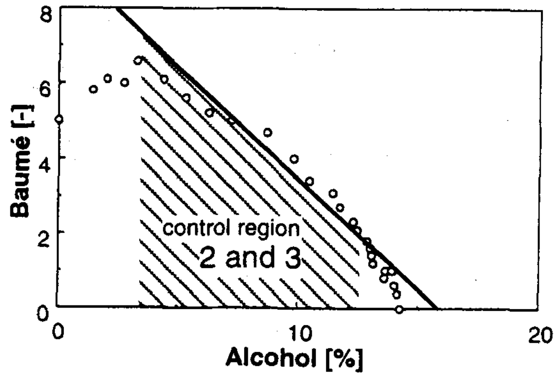


Fig.9 A-B plot in 25L-experimental fermentation

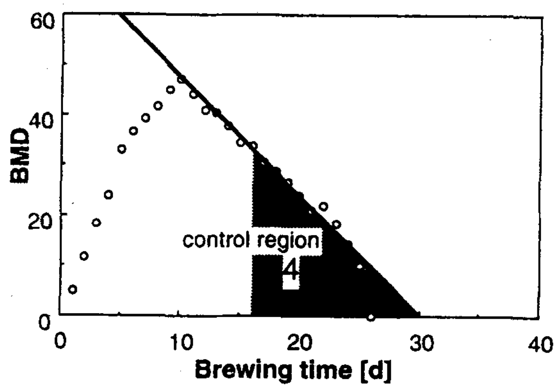


Fig.10 BMD curve in 25L-expermental fermentation

3.6 250L-*GINJOSHU* FERMENTATION

Using the fuzzy rule, actual scale fermentation of 250L containing 100 kg-rice was performed. The result was compared with control fermentation operated in manual by expert. Figure 11 shows the time course of temperature, Baumé and alcohol concentration. In the region 4, temperature in fuzzy control was observed to be slightly higher than that in manual operation. This may be due to the slight difference of fermentation condition such as mixing. However, it was found that in all regions the profiles of Baumé and alcohol concentration were almost similar to those of control culture. This means that using these rules constructed by us, *moromi* temperature was almost controlled similar to the control of *Toji* .

Figure 12 shows the A-B and BMD-D plot in these fermentations. Data points from two fermentations were found to be put on the straight line. From Fig. 12, it was confirmed that the temperature could be operated based on the fuzzy rule and it results in the same time course as that in manual operation by expert, *Toji*.

Table 4 shows some analytical data of *Ginjoshu* from 250L-fermentation. All analytical data were found to be almost similar to those in manual operation. Since in general those data are strongly related to the quality of *Ginjoshu*, the *Ginjoshu* made by the fuzzy control was concluded to have a good

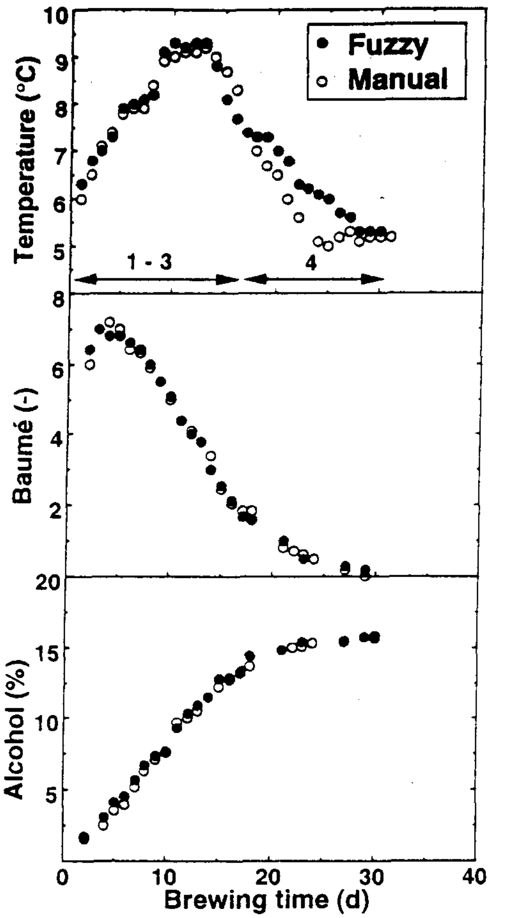


Fig. 11 Time course of 250L-fermentation by fuzzy control and manual control.

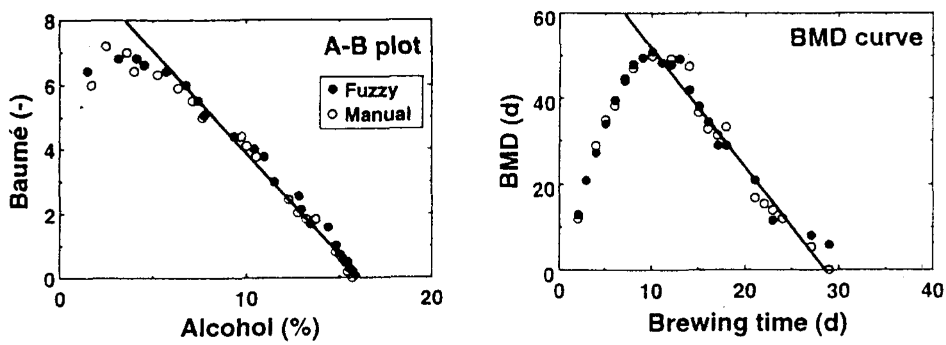


Fig. 12 A - B and BMD - D plot of 250L - *moromi* fermentation

quality comparable with that by manual control. It was confirmed by sensory evaluation that our sake had good taste and flavor and it was comparable with one made by *Toji*.

Table 4 Comparison of analytical data of products, *Ginjoshu*.

	Sake meter	Alcoho l (%)	Acidity (ml)	Amino acidity (%)	Total sugar (%)	iAmO .H (ppm)	iAmOAc (ppm	E/A x 100	Et. Cap (ppm)
Fuzzy	-0.2	15.7	1.6	1.3	50.3	112.8	2.23	1.97	2.3
Manual	0.1	15.8	1.6	1.3	47.1	127.2	2.51	1.97	2.3

4. CONCLUSIONS

From interview with *Toji* and data analysis of 58 *moromi* fermentation, it was found that *moromi* process was separated to 4 control regions, A-B plot and BMD curve were important as indices for temperature control based on the knowledge-based rules. The fuzzy rules were constructed in order to decide temperature set point everyday. 25L and 250L *moromis* could be almost controlled under the fuzzy rule, and the *Ginjoshu* with good taste and flavor was brewed. Therefore, it was concluded that our strategies for temperature control of *moromi* fermentation process could become a useful software tool replacing *Toji*.

5. REFERENCES

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