Development of Fuzzy Control System for Uniform Drying in Continuous Dryer

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ABSTRACT

A control system using fuzzy logic for a large capacity continuous dryer has been developed in order to minimize the damage of rice quality. The system has been verified in the case of 17% of object moisture content. With the initial input moisture contents of 20.46%(wb), 20.96%(wb) and 18.98%(wb), the final moisture contents of 17.99%(wb), 17.6%(wb) and 17.23%(wb) are obtained, respectively. The results show that the system controls the moisture content with the maximum error of 0.99% of the object moisture content.

Keywords : Continuous dryer, Drying model, Fuzzy control

INTRODUCTION

The harvested rice should be dried in a limited time to prevent rapid deterioration of the rice quality. Drying rice requires much labor in a short time and is considered hard work because of the domestic situation which shows reduction of farm labor and the getting old age.

In order to reduce the hard work of drying rice, the supply of dryer are increasing. The statistics shows that the supply numbers of dryer are increased from 10,000 of 1988 to 34,000 of 1994 and quarter millions of dryers are expected to be supplied in 2001.

Dryers which are using heated air to high temperature has advantage of rapid drying uncomparable to sun drying. However it costs the quality deterioration caused to cracked rice and high energy consumption. The supplied dryer are circulation type and its maximum capacity is 6tons with the drying rate of 0.7~0.9%(wb) per hour. Therefore, it takes approximately 12 to 14 hours to dry 6tons of rice with 24%(wb) to 15%(wb).

The RPC has been constructed in order to increase price competition and to improve the rice quality by drying a large amount of rice in situ. Its capacity is about 120tons(24%,wb) per day and has problems of capacity with circulation dryer and increasing the number of dryers has a limitation because of investment expenses. Therefore, in case of drying rice in a large amount like RPC the continuous dryers are needed. Unlike the circulation dryer, the continuous dryer has the large capacity over 10tons(24%,wb) per hour and the drying time is fast with the drying rate of over 2%. The continuous dryer has the advantage of fast drying speed and handling a large amount of rice at a time. However, it also has the disadvantage of causing a large amount of the cracked rice in case of inadequate control of drying process.

The cracked rice which occurs during the drying process affects the rice quality directly. The effect results in low efficiency of the milling process producing broken rice during the process of brown rice and white rice and reduction of rice taste. The cracked rice is closely related with drying factors, such as drying speed, drying air temperature, initial moisture content and final moisture content. Therefore it is important that the drying factors should be adjusted properly to achieve drying speed as fast as possible with minimum of the ratio of cracked rice. For the proper adjustment of drying factors, it is necessary to predict the drying process correctly and to functionalize and signalize parameters which affect the cracked rice. The functionalized and signalized factors are used as input parameters for the dryer control system. Because the fuzzy control is able to express the ambiguous phenomena which can not be expressed by a standardization and quantification, it is expected that the fuzzy control could be used effectively for selecting drying parameters and for the drying control system. The objectives of this paper is to develop a control algorithm for selecting parameters for a uniform drying process using drying model and fuzzy logic, and to verify the system through experimentation.

MATERIALS AND METHODS

The cracked rice which occurs during the rice drying process in the continuous dryer is affected mainly by drying speed, drying air temperature, initial moisture content and final moisture content, and the drying speed is affected by drying air temperature, air rate and conveying velocity. Since the air rate is normally fixed when the dryer is designed, the main factors to the drying speed are the drying air temperature and the material conveying velocity. In a continuous dryer, the material conveying speed is between 20 to 40 minutes and the drying air temperature is between 40 to 55℃. When the conveying speed is over 40 minutes the drying capacity is reduced and when the drying air temperature is over a certain temperature the ratio of cracked rice is increased rapidly.

1. Fuzzy parameters

In order to produce the uniform drying, the initial moisture content and the moisture content difference between the initial moisture content and the desired moisture content are used as input variables and the drying air temperature and the material conveying speed are used as output variables. The language variables are set to 3 levels based on the ratio of cracked rice and the moisture content difference is set between -5%(wb) and 5%(wb) considering general drying convention and the material conveying speed is set between 20 minutes and 40 minutes based on drying capacity. Tables 1, 2, 3 and 4 show that the initial moisture content, the drying air temperature, the moisture difference and the material conveying speed, respectively and Figures 1, 2, 3 and 4 show the membership function accordingly.

2. Fuzzy Rules

According to the results of the drying experiment, in case of moisture content of 20%(wb), the effect of cracked rice caused by drying speed is uniform within 5% error. This shows that making drying speed fast with high air temperature is efficient in case the initial moisture content is high. Therefore, the fuzzy rule is defined using the initial moisture content as a first factor. In case of same ratio of cracked rice, the fuzzy rules are defined considering increasement of drying speed within the range the capacity is not affected by the speed instead of high temperature drying because the experiment results show that the ratio of cracked rice is reduced when the conveying time is increased instead of increasing drying air temperature.

The fuzzy rule for the output variables with respect to the input variables are represented as IF<input> ~, THEN<output>. Table 5 shows the detailed contents.

3. Algorithm for uniform drying control

The uniform drying control algorithm is using fuzzy rules and drying model. First of all, final moisture content is calculated from the drying model based on the input drying air and conveying speed. The calculated moisture content is compared to the object moisture content producing moisture difference. With the input variables of the moisture difference and the input moisture content, drying air temperature and the conveying speed are calculated through fuzzy inference process. The drying model uses the calculated conveying speed and drying air temperature producing final moisture content. The difference between the calculated final moisture content and the object moisture content are obtained. If the difference is below prescribed error, the execution of the program is stopped. Otherwise, the process is repeated. The finally obtained drying air temperature and the conveying speed are transported to the dryer in order to control the process.

Figure 5. shows the flowchart of the uniform drying control algorithm.

4. Experimentation

The input moisture content of material is set to 3 levels and 17%(wb) is used for the final drying moisture content. The moisture content obtained from the drying model using the drying air temperature and drying speed is compared to the final moisture content which is obtained by experimentation.

Oven method is impossible because input moisture content is known in advance. Therefore, the moisture content is measured using single grain moisture meter. The measurement process are repeated several times to reduce the sampling error and the mean value is used as a moisture content.

The experimental conditions are shown in Table 6.

RESULTS AND DISCUSSION

The final moisture contents along with the experimental condition are shown in Table 7. Table 8 shows the comparison between the input moisture contents, the final moisture contents and the object moisture contents in case of experiment number F-1. Figure 8 shows the final moisture contents with drying time. For the experimental number of F-1 and F-2, the results are shown in Table 9 and 10 and in Figure 9 and 10, respectively.

Table 6 shows that the deviation of input moisture content is over 2%. The reason for this is that the material was under drying process in the cold storage room in the period of 10 days. From the same reason, the deviation of final moisture content is slightly high. This kind of effect could be neglected and the final results does not affected by this effect significantly.

The differences between the final moisture content and the object moisture content for the each case are 0.99%(wb), 0.6%(wb) and 0.23%(wb) and could be considered in a good agreement considering sampling error and input moisture content distribution.

From the above results, the developed algorithm for the uniform drying could be applied to a real drying process. Moreover, the algorithm could be adopted to control units of large continuous dryers.

CONCLUSION

A control system has been developed in order to prevent the damage of rice quality. The system has been designed for a large continuous dryer. The system has been verified through experiments which show good agreement between the predicted values and the experimental values. For the future research, the energy consumption for drying process and the milling efficiency could be adopted to fuzzy rules and the development of the control system could be more efficient.

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Table 1. Linguistic variables of "Initial moisture content"

MTNB	MTZE	MTPB
MoisTure Negative Big	MoisTure ZEro	MoisTure Positive Big

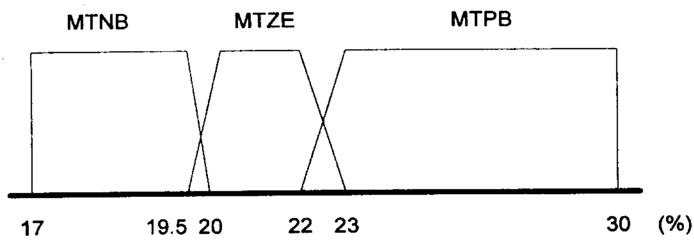

Figure 1. Membership function of "Initial moisture content"

Table 2. Linguistic variables of "Drying air temperature"

TNVB	TNB	TNS	TZ	TPS	TPB	TPVB
Temperature Negative Very Big	Temperature Negative Big	Temperature Negative Small	Temperature Zero	Temperature Positive Small	Temperature Positive Big	Temperature Positive Very Big

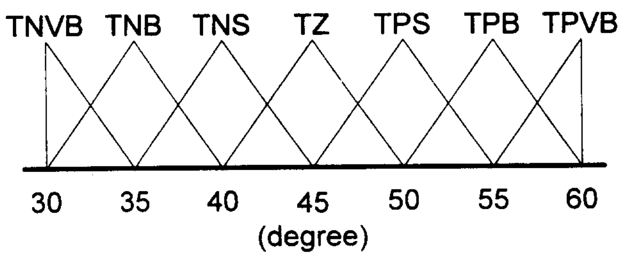

Figure 2. Membership function of "Drying air temperature"

Table 3. Linguistic variables of "Moisture content difference"

DNVB	DNB	DNM	DNS	DNVS	DZE	DPVS	DPS	DPM	DPB	DPVB
Difference Negative Very Big	Difference Negative Big	Difference Negative Medium	Difference Negative Small	Difference Negative Very Small	Difference ZEro	Difference Positive Very Small	Difference Positive Small	Difference Positive Medium	Difference Positive Big	Difference Positive Very Big

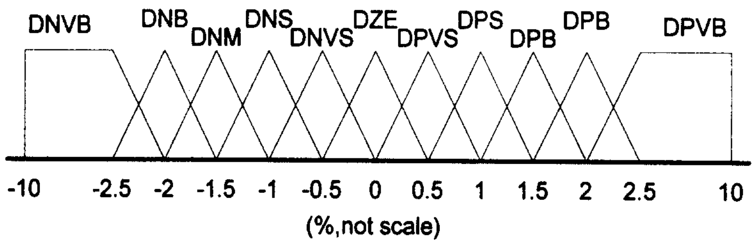

Figure 3. Membership function of "Moistrue content difference"

Table 4. Linguistic variables of "Grain Moving Speed"

NB	NM	NS	ZE	PS	PM	PB
Negative Big	Negative Medium	Negative Small	ZEro	Positive Small	Positive Medium	Positive Big

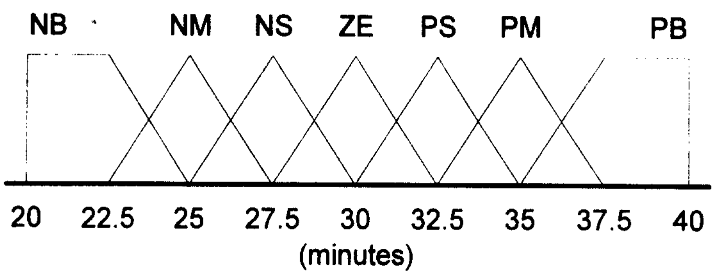

Figure 4. Membership function of "Grain Moving Speed"

Table 5. Part of Fuzzy Rules. (When initial moisture content is MTPB)

Rule #1	If [Initial moisture content = MTPB] and [Moisture content difference = DPVB] Then [Grain moving speed = PB] and [Drying air temperature = TPB]
Rule #2	If [Initial moisture content = MTPB] and [Moisture content difference = DPB] Then [Grain moving speed = PB] and [Drying air temperature = TPB]
Rule #3	If [Initial moisture content = MTPB] and [Moisture content difference = DPM] Then [Grain moving speed = PM] and [Drying air temperature = TPB]
Rule #4	If [Initial moisture content = MTPB] and [Moisture content difference = DPS] Then [Grain moving speed = PS] and [Drying air temperature = TPB]
Rule #5	If [Initial moisture content = MTPB] and [Moisture content difference = DPVS] Then [Grain moving speed = PS] and [Drying air temperature = TPB]
Rule #6	If [Initial moisture content = MTPB] and [Moisture content difference = DZE] Then [Grain moving speed = ZE] and [Drying air temperature = TZ]
Rule #7	If [Initial moisture content = MTPB] and [Moisture content difference = DNVS] Then [Grain moving speed = NS] and [Drying air temperature = TNS]
Rule #8	If [Initial moisture content = MTPB] and [Moisture content difference = DNS] Then [Grain moving speed = NS] and [Drying air temperature = TNS]
Rule #9	If [Initial moisture content = MTPB] and [Moisture content difference = DNM] Then [Grain moving speed = NM] and [Drying air temperature = TNS]
Rule #10	If [Initial moisture content = MTPB] and [Moisture content difference = DNB] Then [Grain moving speed = NB] and [Drying air temperature = TNB]
Rule #11	If [Initial moisture content = MTPB] and [Moisture content difference = DNVB] Then [Grain moving speed = NB] and [Drying air temperature = TNVB]

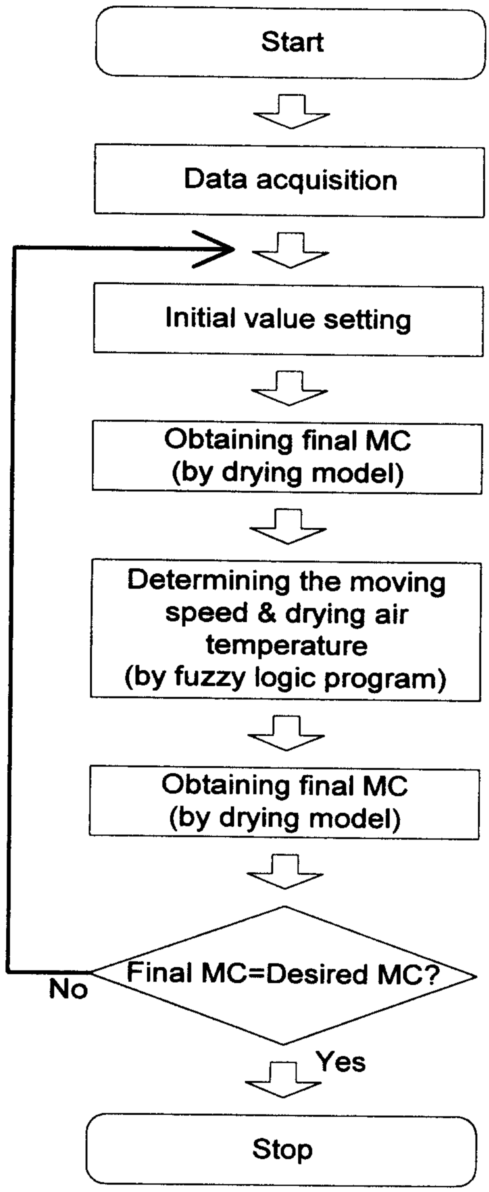

Figure 5. Drying control algorithms

Table 6. Experimental conditions of rice drying

Exp. no.	Input MC. (%,wb)	Deviation of input MC (%)	Input grain temp. (℃)	Amb. air temp. (℃)	Amb. air RH (%)
F-1	20.46	2.2	14.7	20	50
F-2	20.96	2.4	20	20.6	49
F-3	18.98	1.9	20	20.4	50

Table 7. Experimental result of rice drying

Exp. no.	Input MC. (%,wb)	Objective drying MC (%,wb)	Output MC. (%,wb)	Drying air temp. (℃)	Moving speed (hr/pass)
F-1	20.46	17.0	17.99	50	0.554
F-2	20.96	17.0	17.6	50	0.642
F-3	18.98	17.0	17.23	40	0.437

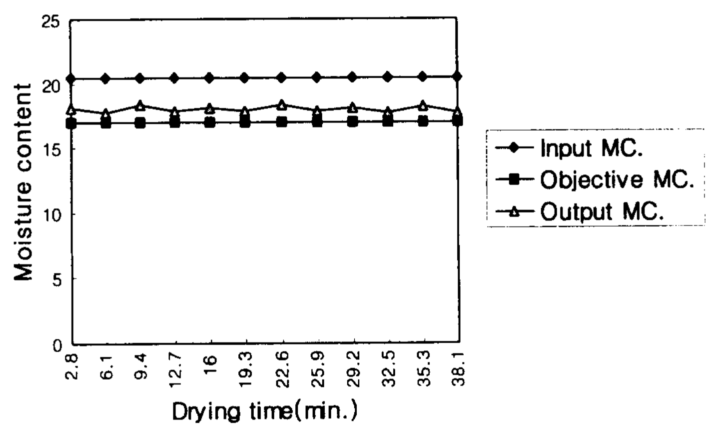

Fig 8. Moisture content comparison for experiment F-1.

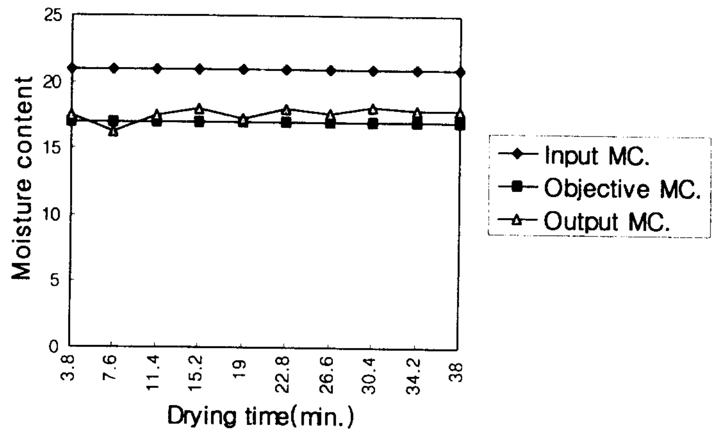

Fig 9. Moisture content comparison for experiment F-2.

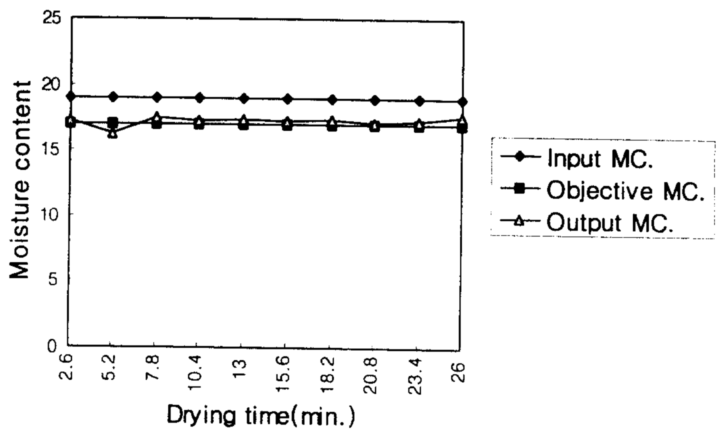

Fig 10. Moisture content comparison for experiment F-3.

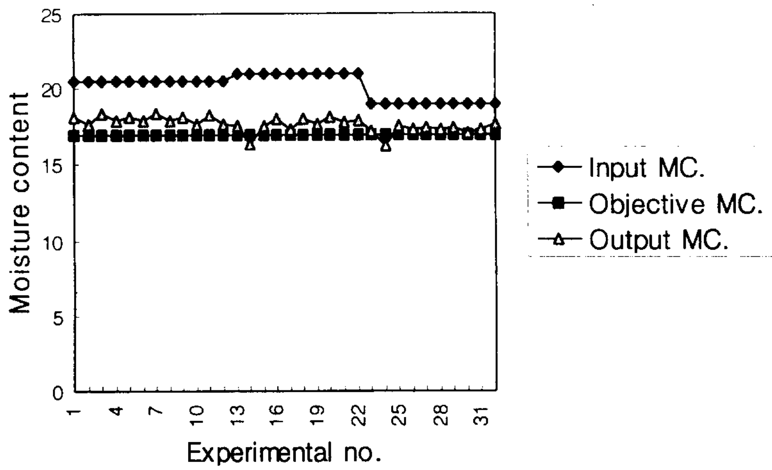

Fig 11. Moisture content comparison for experiment F-1, F-2, F-3.