A Proposed Grinding and Mixing System using Fuzzy Time Control Discrete Event Model for Industrial Applications

M. Saleem Khan, Khaled Benkrid

Abstract—**This paper presents a time control grinding and mixing system as an application of fuzzy time control discrete model. The system is designed by keeping in mind a large number of its industrial applications. The proposed simulation design of control system has four inputs: volume, density, viscosity, and selection of product. There are four controlling elements: rotatory motor, grinding motor, heating and cooling units, and valves selection, each with time control constraint. The system consists of four controlled variables measurement through its sensing mechanism for feed back control. Time control fuzzy rule is formulated, applied and tested using MATLAB simulation for the grinding and mixing system.**

***Index Terms*— Fuzzy time control, grinding and mixing system, industrial application and time control systems.**

I. INTRODUCTION

The fuzzy logic and fuzzy set theory deal with non-probabilistic uncertainties issues. The fuzzy control system is based on the theory of fuzzy sets and fuzzy logic. Previously a large number of fuzzy inference systems and defuzzification techniques were reported. These systems/techniques with less computational overhead are useful to obtain crisp output [3],[4]. The crisp output values are based on linguistic rules applied in inference engine and defuzzification techniques [5]. Indeed existing fuzzy models have addressed the way to reason using membership function and fuzzy rule but did not take into account the time dependency of output(s) in control systems [2].

In this paper time control issues of binary control outputs with a specific required time are applied. The output state and its time are based on the linguistic rules, applied on this new system. The output logic levels instead of crisp values can be used as the control outputs to activate the plant components (or valves) ON or OFF for a specific time determined by the linguistic values of inputs and fuzzy inference system. This research work applies the fuzzy time control concept on grinding and mixing system. This proposed design work can be utilised in a wide range of industrial applications: paints, food processing, dairy products, ice cream plants, bio-medicines, detergents and soaps manufacturing. This control system is applicable in the manufacturing plants of a large number of daily used items, composed of various grinded materials, mixed with liquids and processed for certain time limit under temperature controlled environment. The proposed system can be adapted for grinding the various items and mixing with liquids or gasses need to be processed in temperature control environment with a limit of specific time.

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II. FUZZY TIME CONTROL DISCRETE EVENT SYSTEM

Fuzzy logic time control system along with a discrete event system is called a fuzzy time control discrete event system.

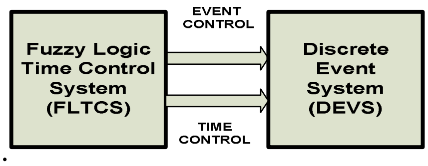

Fig. 1 Two modules of FDECS

Fuzzy logic time control system needs a fuzzifier, inference kernel connected with knowledge base including data base, rule base and output membership functions (for output variables and output time control). In this system as shown in Fig. 2, two defuzzifiers: one for output variable, and another for output time control are used [2].Time control pulsar converts the time crisp value into a pulse of specific time duration. In analog to digital converter (ADC) pulse strobe unit, ADC converts the output crisp value into binary code and pulse strobe part allows the code to pass for the specific pulse duration. This binary code is used to activate the discrete event control system to generate specific event for a certain time. In this way combination of fuzzy logic time control system and discrete event system will form a fuzzy discrete event control system [3], [6].

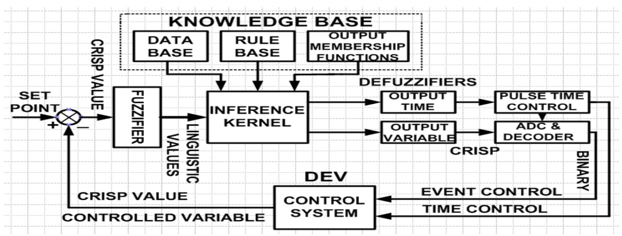

Fig. 2 Fuzzy discrete event controller system (FDECS) block diagram.

This new technique reduces complexity of the existing fuzzy DEV system. We can combine fuzzy logic systems with

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discrete event (DEV) systems as well as with discrete time system (DTS) using a minor hardware burden. The system can also work as a fuzzy discrete time control system with minor changes in system control, time control and event selection techniques. The new approach will also reduce complexity of traditional modeling and its implementation. These advantages of the new system will make the system popular in control system industry [2].

III. BASIC STRUCTURE OF PROPOSED GRINDING AND MIXING SYSTEM

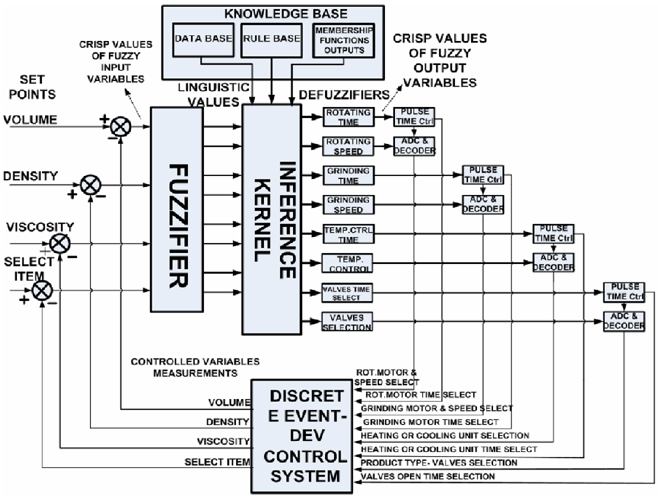

Fig. 3 Fuzzy logic time control DEV grinding and mixing system.

There are four set points: volume, density, viscosity and select items. These set points provide the crisp values of four fuzzy input variables to the fuzzifier. The fuzzifier compares the inputs crisp values with certain levels and generates linguistic values of each input variable for inference kernel connected with knowledge base. The knowledge base consists of: data base; which provides the necessary definitions used to define linguistic control rules and fuzzy data manipulation in a fuzzy logic controller, rule base; which characterizes the control goals and control policy of the domain experts with the help of a set of linguistic control rules and, output membership functions; for output variables strength and output time control. The inference kernel simulates human decision with fuzzy concepts, implication and rules of inference in fuzzy logic [1]. The defuzzifier converts the inferred fuzzy control action into crisp values. This system has eight defuzzifiers: four defuzzifiers; for the output variables, rotating motor speed, grinding motor speed, temperature control unit and valves selection for a particular product, and four defuzzifiers; for the time constraints of output variables.

IV. DESIGN ALGORITHM

This system is designed for four fuzzy input variables. The membership functions for the four variables, volume, density, viscosity and item select are shown in Table I.

TABLE I
MEMBERSHIP FUNCTIONS OF INPUT VARIABLES: VOLUME-DENSITY-VISCOSITY AND ITEM SELECTION

Membership Function- MF	Volume in m^3	Density in Kg/m^3	Viscosity (in % of a value)	Select Item Categories (% of total valves)
Very small-VS	0-20	0-20	0-20	0-20
Just small-JS	0-40	0-40	0-40	0-40
Below medium BM	20-60	20-60	20-60	20-60
Above medium AM	40-80	40-80	40-80	40-80
Just high-JH	60-100	60-100	60-100	60-100
Very high-VH	80-100	80-100	80-100	80-100

We have to open a number of valves according to the given select item scheme shown in Table II, considering maximum 100 valves used at feed lines for materials in flow. The plots of membership functions for each input fuzzy variable are shown in Fig.4, Fig5, Fig.6 and Fig.7.

TABLE II
FEED VALVES SELECTION

Category Very Low	0-20%	Very Few	0 to 20 valves are open
Category Just Low	0-40%	Just Few	0 to 40 valves are open
Category Below Medium	20-60%	Below Medium	20 to 60 valves are open
Category Above Medium	40-80%	Above Medium	40 to 80 valves are open
Category Just High	60-100%	Just Large	60 to 100 valves are open
Category Very High	80-100%	Very Large	80 to 100 valves are open

The crisp value output of valve selection defuzzifier is converted into digital signal using analog to digital converter ADC and decoded for the selection of specific valves opening.

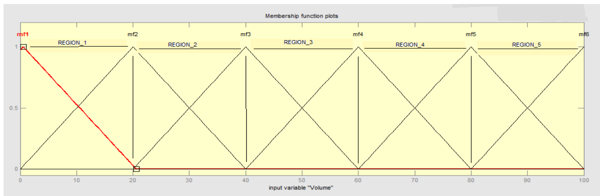

Fig. 4 Plot of Membership Functions for Input Fuzzy Variable- VOLUME

The six membership functions, f_1 [1], f_1 [2], f_1 [3], f_1 [4], f_1 [5] and f_1 [6] are used to show the various ranges of input fuzzy variable “VOLUME” in a plot consisting of five regions as shown in Fig.4.

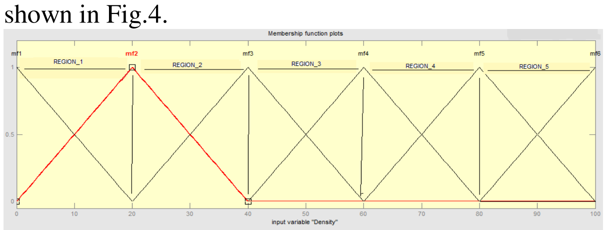

Fig. 5 Plot of Membership Functions for Input Fuzzy Variable- DENSITY

The six membership functions, f_2 [1], f_2 [2], f_2 [3], f_2 [4], f_2 [5] and f_2 [6] are used to show the various ranges of input fuzzy variable “DENSITY” in Fig.5. This plot consists of five regions.

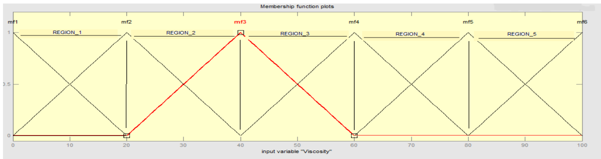

Fig.6 Plot of Membership Functions for Input Fuzzy Variable- VISCOSITY

f_3 [1], f_3 [2], f_3 [3], f_3 [4],) f_3 [5] and f_3 [6] are the membership functions used to show the various ranges of input fuzzy variable "VISCOSITY" in a plot consisting of five regions in Fig.6.

The numbers of membership functions and the range values for each variable may be taken different according to the need. In this system, these are taken same as for simplification.

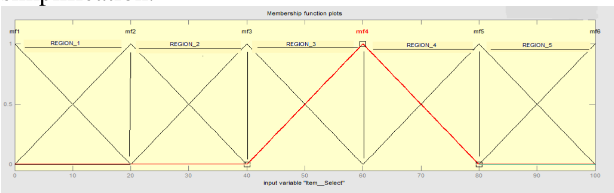

Fig.7 Plot of Membership Functions for Input Fuzzy Variable-ITEM-SELECT.

The six membership functions, f_4 [1], f_4 [2], f_4 [3], f_4 [4], f_4 [5] and f_4 [6] are used to show the various ranges of input fuzzy variable "ITEM- SELECT" in Fig.7. The plot in Fig.7 consists of five regions.

There are eight output variables. The plot of membership function for each variable consists of five functions. The detail of each membership function is shown in Table III

TABLE III
OUTPUT MEMBERSHIP FUNCTIONS

Membership Function	Range	Rotating Speed	Rot. Time	Grinding Speed	Grind. Time	Temp	Temp Time	Valves	Open Time	Singleton Values
MF1	0-5	Stop	None	Stop	None	OFF	None	None	None	S1=0
MF2	0-40	Slow	Small	Slow	Small	Low	L	Few	S	S2=0.3
MF3	40-60	Medium	Medium	Medium	Medium	Medium	M	M	M	S3=0.5
MF4	60-80	Fast	Long	Fast	Long	High	L	Large	L	S4=0.7
MF5	80-100	Very Fast	V.Long	Very Fast	V.Long	V.H	V.L	V.L	V.L	S5=1

For simplification, the range values of each output membership function plot are taken same. Therefore, shape of the plot for each output variable used in this proposed design is same and shown in Fig. 8

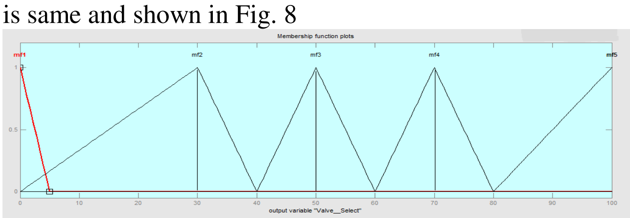

Fig.8 Plot of Output Membership function

A. Fuzzification

The proposed fuzzy time control design model for Grinding and Mixing System consists of four fuzzy input variables.

The value of each variable may lie in any one of the five regions. f1 and f2 are the linguistic values of fuzzy variable "Volume", f3 and f4 for "Density", f5 and f6 for "Viscosity", and f7 and f8 for "item-Select"..

The linguistic values are the mapping values of the fuzzy input variables with the membership functions occupied in the regions. As we are using four variables, therefore eight linguistic values are shown in Fig.9

The mapping of input fuzzy variables with the functions in five regions is listed in Table IV.

TABLE IV
LINGUISTIC VALUES OF FUZZIFIERS OUTPUTS IN ALL REGIONS

Input Variables	Linguistic Fuzzifier Outputs	Region-1	Region-2	Region-3	Region-4	Region-5
Volume	f_1	f_1 [1]	f_1 [2]	f_1 [3]	f_1 [4]	f_1 [5]
	f_2	f_1 [2]	f_1 [3]	f_1 [4]	f_1 [5]	f_1 [6]
Density	f_3	f_2 [1]	f_2 [2]	f_2 [3]	f_2 [4]	f_2 [5]
	f_4	f_2 [2]	f_2 [3]	f_2 [4]	f_2 [5]	f_2 [6]
Viscosity	f_5	f_3 [1]	f_3 [2]	f_3 [3]	f_3 [4]	f_3 [5]
	f_6	f_3 [2]	f_3 [3]	f_3 [4]	f_3 [5]	f_3 [6]
Item Selection	f_7	f_4 [1]	f_4 [2]	f_4 [3]	f_4 [4]	f_4 [5]
	f_8	f_4 [2]	f_4 [3]	f_4 [4]	f_4 [5]	f_4 [6]

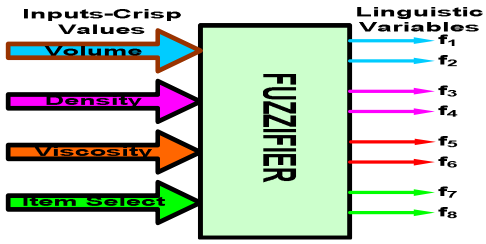

Fig.9 Fuzzifier Showing, 4- Inputs- Crisp Values and 8-Outputs- Linguistic Variables.

As the density and viscosity are directly proportional to each others, therefore these two variables will lie in one region but volume and item-select may lie in any of the regions. In this case 36 rules are required for the complete simulation of the control system keeping density and viscosity in one region but if we need any one of the other region for density and viscosity, the number of rules for complete simulation will be exceeded to 216 rules and the rule base will maintain the record of these rules. Again in this case 16 rules will be fired for the values of one set of input variables.

For the discussion of design algorithm, we used specific values of input fuzzy variables, "Volume", "Density", "Viscosity" and "Item-Select" in region 1. VOLUME=10, DENSITY= 15, VISCOSITY=12 and ITEM-SELECT=15.

The corresponding mapping values of f_1 [1], f_1 [2], f_2 [1], f_2 [2], f_3 [1], f_3 [2], f_4 [1] and f_4 [2] with membership functions were used to establish the 16 rules.

B. Inference Engine

The inference engine consists of sixteen AND operators, these are not the logical ANDs but select minimum value input for the output. This inference engine accepts eight inputs from fuzzifier and applies the min-max composition to obtain the output R values.

The min-max inference method uses min-AND operation between the four inputs.

R1= f_1 ^ f_3 ^ f_5 ^ f_7 = f_1 [1] ^ f_2 [1] ^ f_3 [1] ^ f_4 [1]
= 0.5^0.75^0.6^0.75=0.5

R2= f_1 ^ f_4^ f_6 ^ f_8 = f_1 [1] ^ f_2 [2] ^ f_3 [2] ^ f_4 [2]
= 0.5^0.25^0.4^0.25=0.25

R3= f_1 ^ f_3^ f_5^ f_8= f_1 [1] ^ f_2 [1] ^ f_3 [1] ^ f_4 [2]
= 0.5^0.75^0.6^0.25=0.25

R4= f_1 ^ f_3^ f_6^ f_7 = f_1 [1] ^ f_2 [1] ^ f_3 [2] ^ f_4 [1]
= 0.5^0.75^0.4^0.75= 0.4

R5= f_1 ^ f_4^ f_5^ f_7 = f_1 [1] ^ f_2 [2] ^ f_3 [1] ^ f_4 [1]
= 0.5^0.25^0.6^0.75= 0.25

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$R6 = f_1 \wedge f_3 \wedge f_6 \wedge f_8 = f_1[1] \wedge f_2[1] \wedge f_3[2] \wedge f_4[2]$
$= 0.5 \wedge 0.75 \wedge 0.4 \wedge 0.25 = 0.25$

$R7 = f_1 \wedge f_4 \wedge f_5 \wedge f_8 = f_1[1] \wedge f_2[2] \wedge f_3[1] \wedge f_4[2]$
$= 0.5 \wedge 0.25 \wedge 0.6 \wedge 0.25 = 0.25$

$R8 = f_1 \wedge f_4 \wedge f_6 \wedge f_7 = f_1[1] \wedge f_2[2] \wedge f_3[2] \wedge f_4[1]$
$= 0.5 \wedge 0.6 \wedge 0.4 \wedge 0.75 = 0.4$

$R9 = f_2 \wedge f_3 \wedge f_5 \wedge f_7 = f_1[2] \wedge f_2[1] \wedge f_3[1] \wedge f_4[1]$
$= 0.5 \wedge 0.75 \wedge 0.6 \wedge 0.75 = 0.5$

$R10 = f_2 \wedge f_4 \wedge f_6 \wedge f_8 = f_1[2] \wedge f_2[2] \wedge f_3[2] \wedge f_4[2]$
$= 0.5 \wedge 0.25 \wedge 0.4 \wedge 0.25 = 0.25$

$R11 = f_2 \wedge f_3 \wedge f_5 \wedge f_8 = f_1[2] \wedge f_2[1] \wedge f_3[1] \wedge f_4[2]$
$= 0.5 \wedge 0.75 \wedge 0.6 \wedge 0.25 = 0.25$

$R12 = f_2 \wedge f_3 \wedge f_6 \wedge f_7 = f_1[2] \wedge f_2[1] \wedge f_3[2] \wedge f_4[1]$
$= 0.5 \wedge 0.75 \wedge 0.4 \wedge 0.75 = 0.4$

$R13 = f_2 \wedge f_4 \wedge f_5 \wedge f_7 = f_1[2] \wedge f_2[2] \wedge f_3[1] \wedge f_4[1]$
$= 0.5 \wedge 0.25 \wedge 0.6 \wedge 0.75 = 0.25$

$R14 = f_2 \wedge f_3 \wedge f_6 \wedge f_8 = f_1[2] \wedge f_2[1] \wedge f_3[2] \wedge f_4[2]$
$= 0.5 \wedge 0.75 \wedge 0.4 \wedge 0.25 = 0.25$

$R15 = f_2 \wedge f_4 \wedge f_5 \wedge f_8 = f_1[2] \wedge f_2[2] \wedge f_3[1] \wedge f_4[2]$
$= 0.5 \wedge 0.25 \wedge 0.6 \wedge 0.25 = 0.25$

$R16 = f_2 \wedge f_4 \wedge f_6 \wedge f_7 = f_1[2] \wedge f_2[2] \wedge f_3[2] \wedge f_4[1]$
$= 0.5 \wedge 0.6 \wedge 0.4 \wedge 0.75 = 0.4$

The sign ^ between the membership function values is used for Min-ANDing process. In this process we get the minimum of the function values being ANDed. This interpretation is used in Mamdani-min process. The diagram of interference process in Fig.9 shows this type of process.

C. Rule Selector

The rule selector for this system receives four crisp values of volume, Density, viscosity and item-select. It provides singleton values of output functions under algorithm rules applied on design model. For four variables, sixteen rules are required to find the corresponding values S1, S2, S3, S4, S5, S6, S7, S8, S9, S9, S10, S11, S12, S13, S14, S15 and S16 according to division of regions. These rules are listed in Table V

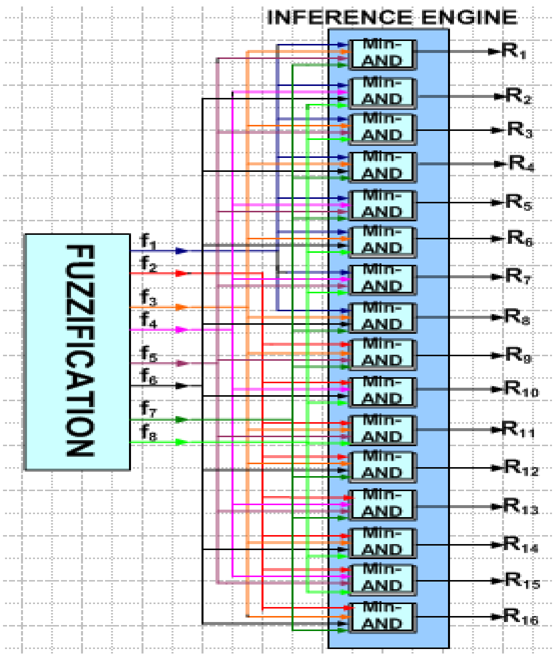

Fig.10 Block Diagram of Inference Process

TABLE V
ILLUSTRATION OF APPLIED RULES ON GRINDING AND MIXING CONTROL DESIGN MODEL

Rule NO.	Volume in	Density	Viscosity	Item Select	Rotating Speed	Rotating Time	Grinding Speed	Grinding Time	Temp	Temp Time	Valves	Open Time	Singleton Values
1	VS	VS	VS	VS	Small	V.Long	Small	V.Long	V.H	Small	Few	Small	S1
2	VS	JS	JS	JS	Small	Long	Small	Long	H	Small	Few	Small	S2
3	VS	VS	VS	JS	Small	V.Long	Small	V.Long	V.H	Small	Few	Small	S3
4	VS	VS	JS	VS	Small	Long	Small	Long	H	Small	Few	Small	S4
5	VS	JS	VS	VS	Small	V.Long	Small	V.Long	V.H	Small	Few	Small	S5
6	VS	VS	JS	JS	Small	Long	Small	Long	H	Small	Few	Small	S6
7	VS	JS	VS	JS	Small	V.Long	Small	V.Long	V.H	Small	Few	Small	S7
8	VS	VS	JS	VS	Small	Long	Small	Long	H	Small	Few	Small	S8
9	JS	VS	VS	VS	Small	V.Long	Small	V.Long	V.H	Small	Few	Small	S9
10	JS	JS	JS	JS	Small	Long	Small	Long	H	Small	Few	Small	S10
11	JS	VS	VS	JS	Small	V.Long	Small	V.Long	V.H	Small	Few	Small	S11
12	JS	VS	JS	VS	Small	Long	Small	Long	H	Small	Few	Small	S12
13	JS	JS	VS	VS	Small	V.Long	Small	V.Long	V.H	Small	Few	Small	S13
14	JS	VS	JS	JS	Small	Long	Small	Long	H	Small	Few	Small	S14
15	JS	JS	VS	JS	Small	V.Long	Small	V.Long	V.H	Small	Few	Small	S15
16	JS	VS	JS	VS	Small	Long	Small	Long	H	Small	Few	Small	S16

D. Defuzzifier

This system consists of eight outputs, four for output variables required to control the actuators of the system and four outputs are required for time constraint to the power provided to the actuators. In this system we use the grinding and rotating motors, the speed of these actuators can be controlled under time constraint of design model. Heating/ Cooling unit and feed valves selection within time limit makes the system more efficient and more versatile to save the time, energy and engagement in the delay response of feed back circuit.

The defuzzification process provides the crisp values outputs after estimating its inputs. In this system 32 inputs are given to the defuzzifier. Sixteen values of R1, R2,…….., R16 from the outputs of inference engine and sixteen values S1, S2, ………, S16 from the rule selector.

Each defuzzifier estimates the crisp value output according to the center of average (C.O.A) method using the mathematical expression , $\sum Si * Ri \,/\, \sum Ri$,where i = 1 to 16.

V. ESTIMATION OF CRISP VALUES FOR OUTPUT VARIABLES

The singleton values for all sixteen rules listed in Table V are given in Table VI

TABLE VI
SINGLETON VALUES FOR ALL OUTPUTS VARIABLE

Rule No	Singleton Values	Rotating Speed	Rot. Time	Grinding Speed	Grind. Time	Temp	Temp Time	Valves Select	Open Time
1	S1	0.3	1	0.3	1	1	0.3	0.3	0.3
2	S2	0.3	0.7	0.3	0.7	0.7	0.3	0.3	0.3
3	S3	0.3	1	0.3	1	1	0.3	0.3	0.3
4	S4	0.3	0.7	0.3	0.7	0.7	0.3	0.3	0.3
5	S5	0.3	1	0.3	1	1	0.3	0.3	0.3
6	S6	0.3	0.7	0.3	0.7	0.7	0.3	0.3	0.3
7	S7	0.3	1	0.3	1	1	0.3	0.3	0.3
8	S8	0.3	0.7	0.3	0.7	0.7	0.3	0.3	0.3
9	S9	0.3	1	0.3	1	1	0.3	0.3	0.3
10	S10	0.3	0.7	0.3	0.7	0.7	0.3	0.3	0.3
11	S11	0.3	1	0.3	1	1	0.3	0.3	0.3
12	S12	0.3	0.7	0.3	0.7	0.7	0.3	0.3	0.3
13	S13	0.3	1	0.3	1	1	0.3	0.3	0.3
14	S14	0.3	0.7	0.3	0.7	0.7	0.3	0.3	0.3
15	S15	0.3	1	0.3	1	1	0.3	0.3	0.3
16	S16	0.3	0.7	0.3	0.7	0.7	0.3	0.3	0.3

$\sum Ri = R1+R2+R3+\ldots\ldots\ldots\ldots+R16 = 5.1$

Using mathematical expression $\sum Si * Ri \,/\, \sum Ri$ the crisp values for output variables was determined and the result was according to the MATLAB simulation shown in Fig.11. These results are compared in Table VII and found correct according to the design model.

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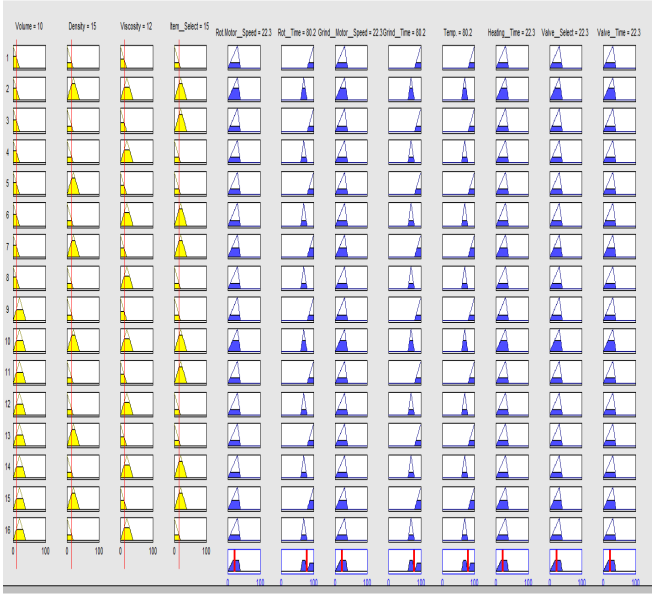


Fig. 11 MATLAB- Rule Viewer and Simulation Result for Grinding and Mixing Fuzzy Time Control System

In Fig.11 values of input variables are taken as same for which system was discussed, VOLUME=10, DENSITY= 15, VISCOSITY=12 and ITEM-SELECT=15.

TABLE VII
COMPARISON OF RESULTS

Results	Rotating Speed	Rotating Time	Grinding Speed	Grinding Time	Temp	Temp. Time	Valves Selection	Valves Open Time
MATLAB Simulation	22.3	80.2	22.3	80.2	80.2	22.3	22.3	22.3
Calculated Values	23.4	81.3	23.4	81.3	81.3	23.4	23.4	23.4

VI. SIMULATION RESULT DISCUSSION

According to design scheme of grinding and mixing fuzzy time control system volume effects; the rotation time, grinding time, heating/cooling time and valves opening time. Viscosity and density are directly proportional to each others and effect; the rotating speed, grinding speed, heating/cooling temperature, and item selection effects; the number of valves to be opened. All of these, dependencies of the output variables on the input variables, are shown in Fig.12.

Fig. 12(a) shows that the valves open time is directly proportional to the volume and it does not depend upon the density.

Fig. 12(b) shows that the number of valves opening does not depend on the volume and density

Fig. 12© indicates that the heating/cooling time depends on volume and it does not depend upon density.

Fig. 12(d) shows that heating/cooling temperature depends on density and it does not depend on volume.

Fig. 12(e) gives the proof of grinding time dependency upon volume and shows that it does not depend on density.

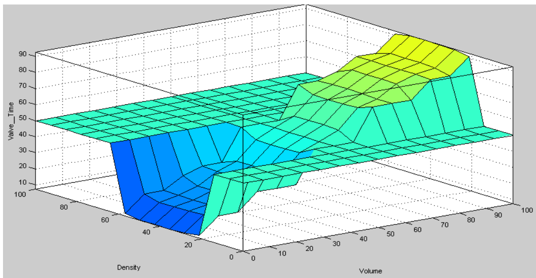
Fig. 12(f) indicates that the grinding motor speed depends on density and it does not depend on volume.

Fig. 12(g) shows that the rotating time depends on volume and it does not depend on density.

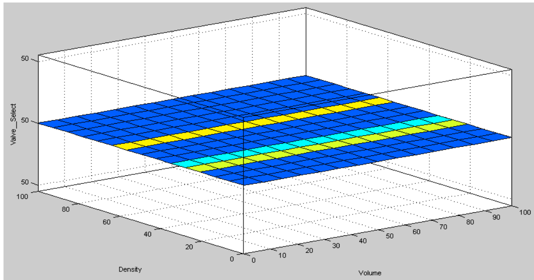
Fig. 12(h) shows that the rotation speed depends on density and it does not depend on volume.

Fig. 12(i) indicates that rotation time depends on volume and does not depend on viscosity.

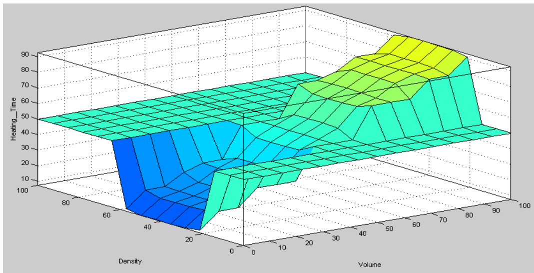
Fig. 12(j) shows that the density and viscosity are directly proportional to each others and effect the rotation speed.



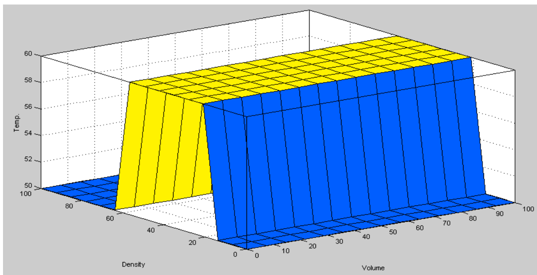
(a) Plot between volume-density-valve open time



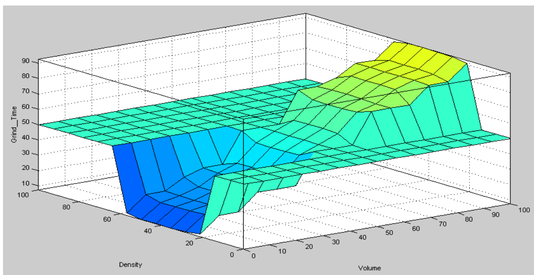
(b) Plot between volume-density-valve selection



© Plot between volume-density- heating/cooling time



(d) Plot between volume-density- temperature



(e) Plot between volume-density-grinding time

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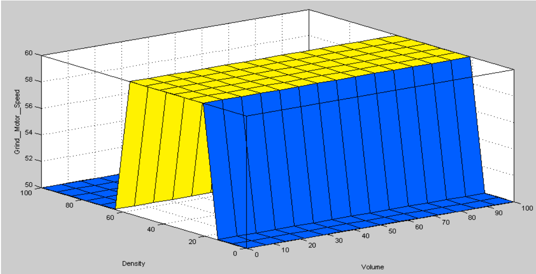
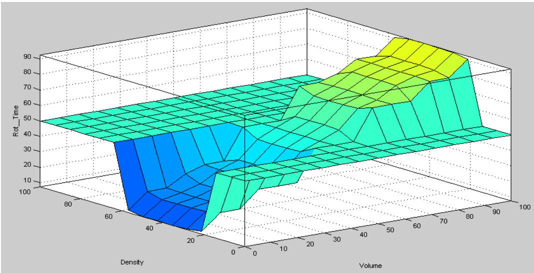
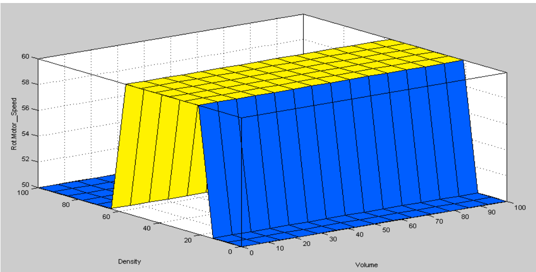


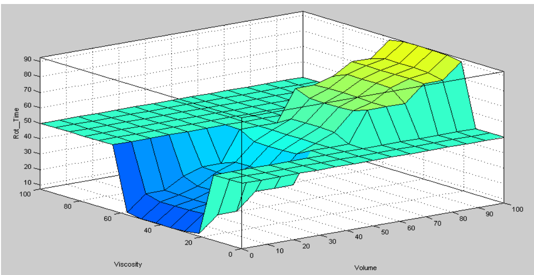
(f) Plot between volume-density- grinding motor speed



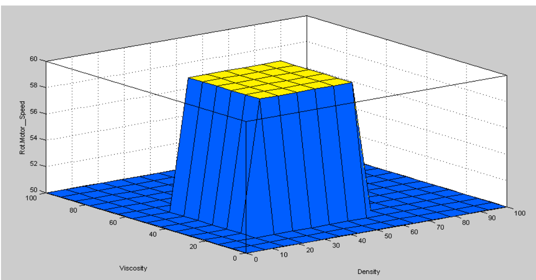
(g) Plot between volume-density-rotating time



(h) Plot between volume-density-rotating motor speed



(i) Plot between volume-viscosity-rotating time



(j) Plot between density-viscosity-rotating time

Fig. 12(a to j) MATLAB simulation plots

VII. Conclusion and Future Work

The result of design model is the same as the simulation result. This system can be extended for any time control system to overcome time control issues and achieve better performance without the burden of extra load for time control.

In this design model rotating motor speed, grinding motor speed, heating / cooling and feed valves open time depend on the amount of volume selected. Rotation time, grinding time and heating time depend on the values of density and viscosity. The number of valves selection depends on item-select input variable. The algorithmic design approach makes the system efficient and completely under time control. This design and simulation work will open a new discussion in the field of simulation and control system design. The fuzzy time control model needs to be developed using FPGA with its large number of industrial applications. The work on it is being carried out and in future it will help to design state of the art fuzzy logic time control discrete event systems in local and distributed environment.

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