Design of Liquids Mixing Control System using Fuzzy Time Control Discrete Event Model for Industrial Applications

M.Saleem Khan, Khaled Benkrid

Abstract—This paper presents a time control liquids mixing system in the tanks as an application of fuzzy time control discrete model. The system is designed for a wide range of industrial applications. The simulation design of control system has three inputs: volume, viscosity, and selection of product, along with the three external control adjustments for the system calibration or to take over the control of the system autonomously in local or distributed environment. There are four controlling elements: rotatory motor, grinding motor, heating and cooling units, and valves selection, each with time frame limit. The system consists of three controlled variables measurement through its sensing mechanism for feed back control. This design also facilitates the liquids mixing system to grind certain materials in tanks and mix with fluids under required temperature controlled environment to achieve certain viscous level. Design of: fuzzifier, inference engine, rule base, deffuzifiers, and discrete event control system, is discussed. Time control fuzzy rules are formulated, applied and tested using MATLAB simulation for the system.

Keywords—Fuzzy time control, industrial application and time control systems, adjustment of Fuzzy system, liquids mixing system, design of fuzzy time control DEV system.

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 [4],[5]. The crisp output values are based on linguistic rules applied in inference engine and defuzzification techniques [6]. 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 [3].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 liquids mixing system. This proposed design work can be utilized in a wide range of industrial applications: chemical plants, paints, food processing, syrups production, dairy products, ice cream plants, bio-medicines, detergents and soaps manufacturing. This control system is applicable on the manufacturing plants of a large number of daily used items, composed of various grinded materials, mixed with liquids and processed for certain time under temperature controlled environment. This system can easily be adapted for grinding the various items and mixing with liquids or gasses need to be processed in temperature control environment under certain time frame. The design concept of fuzzy time control DEV system is elaborated with fluids mixing system under time frame constraints. The design of component parts: fuzzifier, inference engine, rule base, deffuzifiers, and discrete events control system for liquids mixing, is explained.

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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.

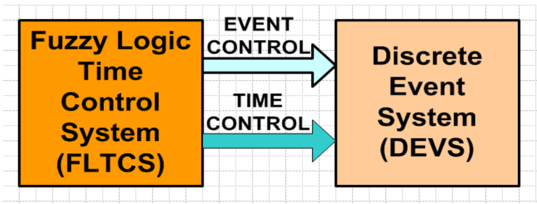


Fig. 1 Two modules of FDECS

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 [3].

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 [4] [7].

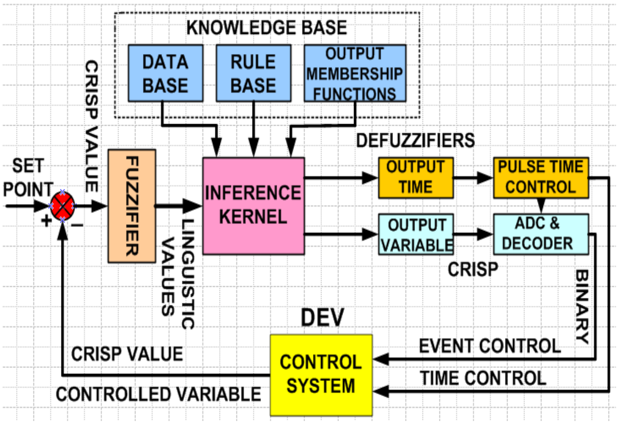


Fig. 2 Fuzzy discrete event controller system (FDECS) block diagram

This new technique reduces complexity of the existing fuzzy DEV system. We can combine fuzzy logic systems with 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 [3].

III. BASIC STRUCTURE OF LIQUIDS MIXING CONTROL SYSTEM

Fig. 3 shows the three set points: volume, viscosity and select items. These set points provide the crisp values of three fuzzy input variables to the fuzzifier.

There are three adjustment points for volume, viscosity and, item select. These minor adjustments are used to calibrate the system under offset conditions or to increase or decrease the crisps values provided to fuzzifier under the tuning conditions of the plant.

If **u** is the value of input variable, **v** is feedback control value and, **a** is the adjustment value than $\underline{u}$ entry of fuzzifier will be,

$\underline{u} = u - v + a$, or $\underline{u} = u - v - a$, depending to increase or decrease the effect.

For quality control caution; adjustment **a2** may be applied at viscosity terminal, for quantity control; adjustment **a1** can be applied at volume terminal, and in case of pipe line blockage or valve not operating properly; adjustment **a3** at select item terminal can manage to select other valves with the minor voltage adjustments for the steam lining of tank intakes.

These adjustments can also be controlled by multi-agents if need to take over the control of the system autonomously in local or distributed environment [8].

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 [2]. 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..

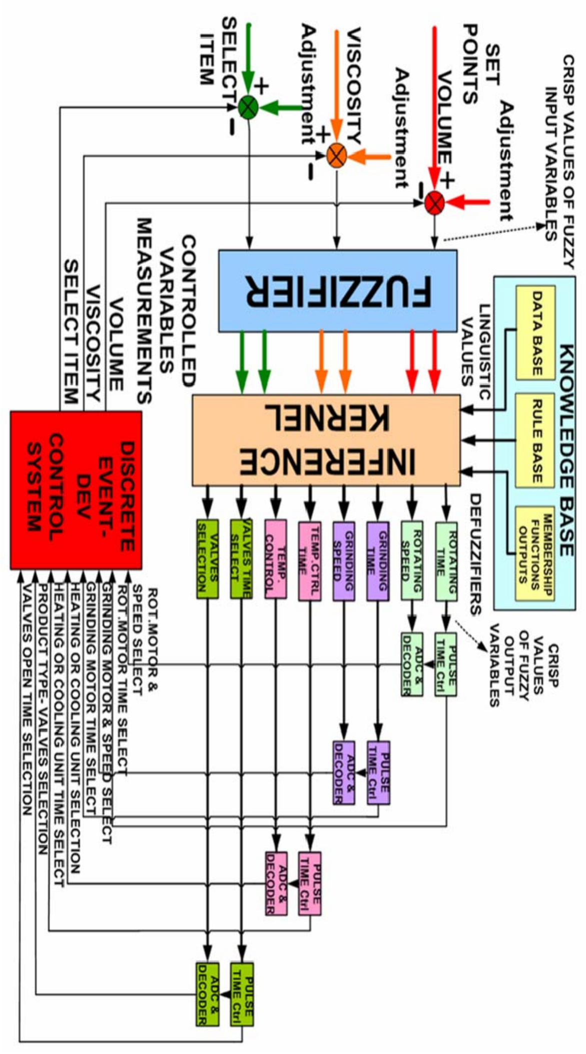


Fig. 3 Fuzzy logic time control DEV liquids mixing system

IV. DESIGN ALGORITHM

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

TABLE I
MEMBERSHIP FUNCTIONS OF INPUT FUZZY VARIABLES-VOLUME, VISCOSITY AND ITEM SELECTION

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

We have to open a number of valves according to the scheme of item select given 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, Fig. 5, and Fig. 6.

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

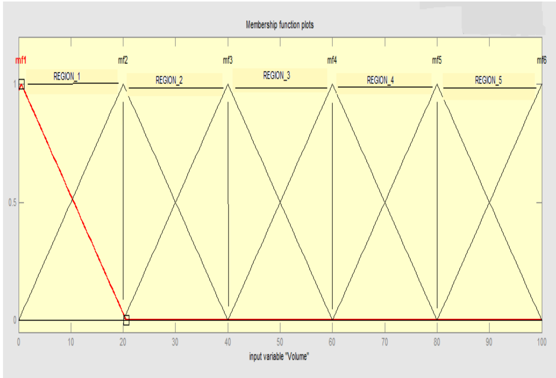


Fig. 4 Membership functions plot for input fuzzy variable- volume

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.

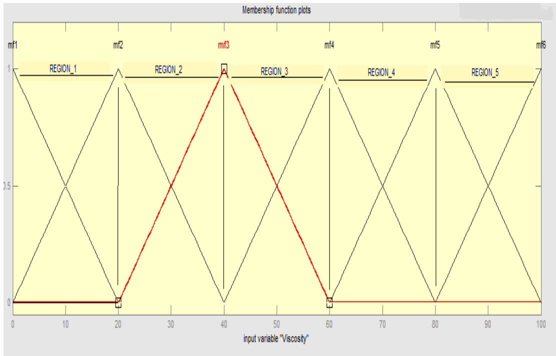


Fig. 5 Membership functions plot for input fuzzy variable- viscosity

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 "VISCOSITY" in Fig.5. This plot consists of five regions.

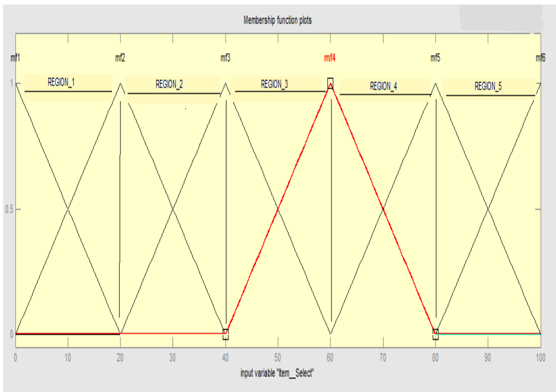


Fig. 6 Membership functions plot for input fuzzy variable- item selection

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 "ITEM-SELECT" 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.
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	0
MF2	0-40	Slow	Small	Slow	Small	Low	L	Few	S	0.3
MF3	40-60	Medium	Medium	Medium	Medium	Medium	M	M	M	0.5
MF4	60-80	Fast	Long	Fast	Long	High	L	Large	L	0.7
MF5	80-100	Very Fast	V. Long	Very Fast	V. Long	V.H	V.L	V.L	V.L	1

For simplification, the range values of each output membership function plot are taken same. Therefore, the shape of the plot for each output variable, used in design is the same and shown in Fig. 7.

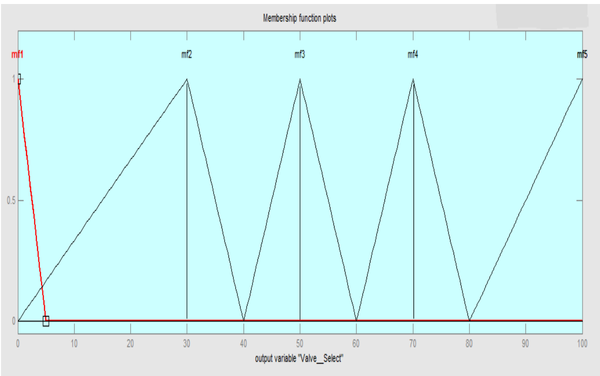


Fig. 7 Plot of output membership function

A. Fuzzification

The fuzzy time control design model for liquids mixing system consists of three 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 "Viscosity", f5 and f6 for "Item-select".

The linguistic values are the mapping values of the fuzzy input variables with the membership functions occupied in the regions. As three variables are used, therefore six linguistic values are shown in Fig. 8.

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

For the simplified design of a fuzzifier, symmetry of membership functions for each variable is required.

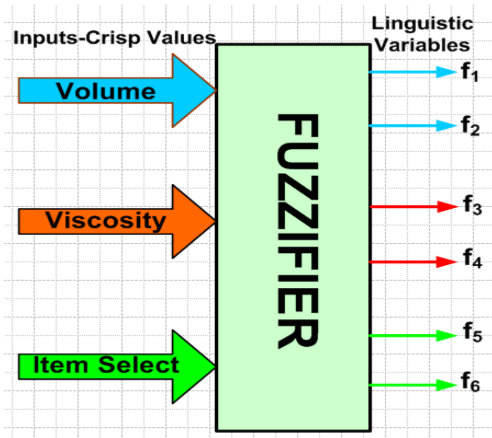


Fig. 8 Fuzzifier with three inputs crisp values and six outputs linguistic fuzzy set values

TABLE IV
LINGUISTIC VALUES OF FUZZIFIER 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]
Viscosity	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]
Item Selection	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]

Each region of membership plot consists of two consecutive functions as shown in Table IV. The relations of linguistic fuzzifier outputs are given in Table V. Each region is divided into two halves for the designing discussion.

TABLE V
RELATION OF FUZZIFIER LONGUISTIC OUTPUTS

Input Variables	Linguistic Fuzzifier Outputs	1st Half Region	2nd Half Region	Region Mid point	Starting Region
Volume	f_1 f_2	$f_1 > f_2$	$f_1 < f_2$	$f_1 = f_2$	$f_1 = 1$ $f_2 = 0$
Viscosity	f_3 f_4	$f_3 > f_4$	$f_3 < f_4$	$f_3 = f_4$	$f_3 = 1$ $f_4 = 0$
Item Selection	f_5 f_6	$f_5 > f_6$	$f_5 < f_6$	$f_5 = f_6$	$f_5 = 1$ $f_6 = 0$

For the discussion of design algorithm, using the specific values of input fuzzy variables, "Volume", "Viscosity" and "Item-Select", VOLUME= 48, VISCOSITY=15 and ITEM-SELECT= 27. This value of volume control input lies in the 1st half of region 3, viscosity control input lies in the 2nd half of region 1, and item selection control input lies in the 1st half of region 2.

Fuzzification process for three input variables need three separate fuzzifiers. Each fuzzifier consists of: input voltage to crisp value converter, operational region for a crisp value detector, fuzzy set membership value mapping and selection arrangements. The design of such a fuzzifier is shown in Fig.9.

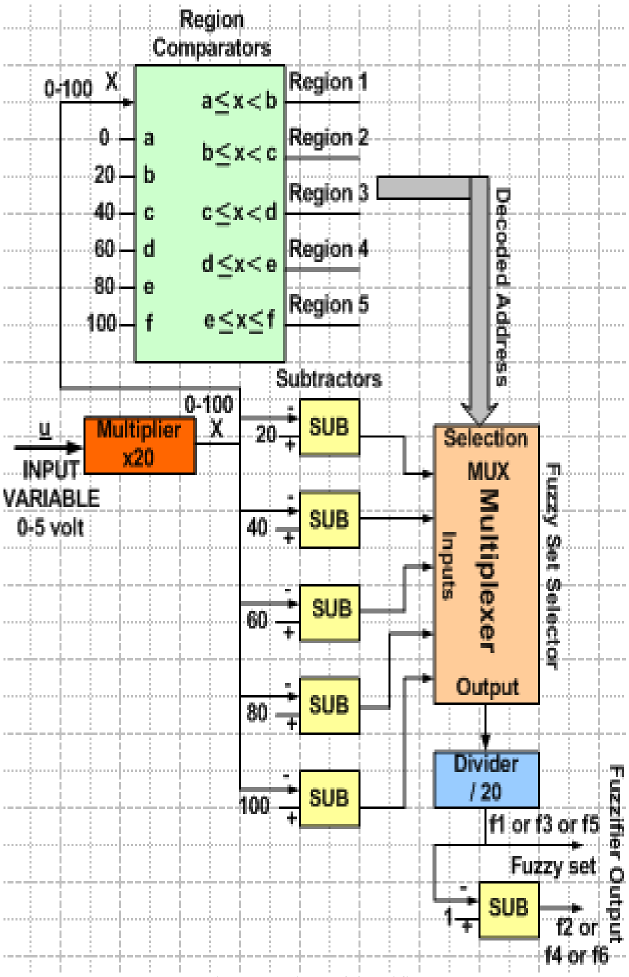


Fig. 9 Design of fuzzifier

Table VI gives the working results of three fuzzifiers using the given values of input variables. These results are achieved using the fuzzifier design shown in Fig. 9.

TABLE VI
FUZZIFIERS RESULTS

Input Variables	Input Voltage u	Values X=20u	Region Selection	Fuzzy Set Calculations
Volume	2.4 volt	48	$40 \le X < 60$ Region 3	$f_1 = (60\text{-}48)/20 = 0.6$ $f_2 = 1 - f_1 = 1\text{-}0.6 = 0.4$
Viscosity	0.75 volt	15	$0 \le X < 20$ Region 1	$f_3 = (20\text{-}15)/20 = 0.25$ $f_4 = 1 - f_3 = 1\text{-}0.25 = 0.75$
Item Selection	1.35 volt	27	$20 \le X < 40$ Region 2	$f_5 = (40\text{-}27)/20 = 0.65$ $f_6 = 1 - f_5 = 1\text{-}0.65 = 0.35$

B. Inference Engine

If any one of the input variables lies in one region and the other two lie in any one of the five regions than 72 rules are required for the complete simulation of the control system but if we need any one of the five regions for all the three variables, the number of rules for complete simulation will be exceeded to 216 rules.

Number of active rules = $\mathbf{m^n}$ where m = maximum number of overlapped fuzzy sets and n = number of inputs [1].
For this design, m = 6 and n = 3, so the total number of active rules are 216.

The total number of rules is equal to the product of number of functions accompanied by the input variables in their working range.

In this case only 8 rules are required for the particular values of three variables because each value of three variables in a region corresponds to the mapping of two functions. The corresponding mapping values of f_1 [3], f_1 [4], f_2 [1], f_2 [2], f_3 [2] and,

f_3 [3] were used to establish the 8 rules. Here f_1 [3] means the corresponding mapping value of third membership function for, the first variable volume in its region and similar definitions for the others.

The inference engine consists of eight AND operators, these are not the logical ANDs but select minimum value input for the output. This inference engine accepts six 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 three inputs.

$R1= f_2 \wedge f_4 \wedge f_6 = f_1[4] \wedge f_2[2] \wedge f_3[3] = 0.4\wedge 0.75\wedge 0.35=0.35$
$R2= f_1 \wedge f_4 \wedge f_6 = f_1[3] \wedge f_2[2] \wedge f_3[3] = 0.6\wedge 0.75\wedge 0.35=0.35$
$R3= f_2 \wedge f_3 \wedge f_6 = f_1[4] \wedge f_2[1] \wedge f_3[3] = 0.4\wedge 0.25\wedge 0.35=0.25$
$R4= f_1 \wedge f_3 \wedge f_6 = f_1[3] \wedge f_2[1] \wedge f_3[3] = 0.6\wedge 0.25\wedge 0.35= 0.25$
$R5= f_2 \wedge f_4 \wedge f_5 = f_1[4] \wedge f_2[2] \wedge f_3[2] = 0.4\wedge 0.75\wedge 0.65= 0.4$
$R6= f_1 \wedge f_4 \wedge f_5 = f_1[3] \wedge f_2[2] \wedge f_3[2] = 0.6\wedge 0.75\wedge 0.65=0.6$
$R7= f_2 \wedge f_3 \wedge f_5 = f_1[4] \wedge f_2[1] \wedge f_3[2] = 0.4\wedge 0.25\wedge 0.65=0.25$
$R8= f_1 \wedge f_3 \wedge f_5 = f_1[3] \wedge f_2[1] \wedge f_3[2] = 0.6\wedge 0.25\wedge 0.65=0.25$

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 [2].

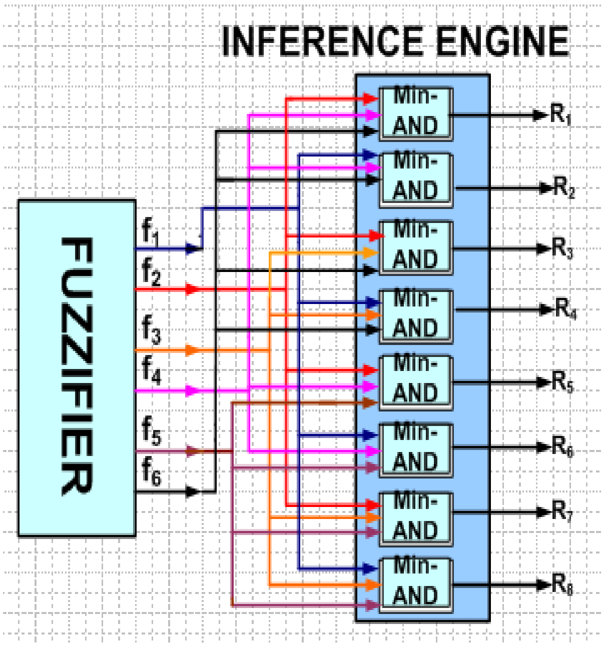


Fig. 10 Block Diagram of Inference Process

C. Rule Selector.

The rule selector for this system receives three crisp values from the volume, viscosity and item-select information signals. It provides singleton values of output functions under algorithm rules applied on design model. For three variables, eight rules are required to find the corresponding singleton values S1, S2, S3, S4, S5, S6, S7, and S8 for each variable according to the division of regions. These rules are listed in Table V.

TABLE V
ILLUSTRATION OF RULES APPLIED ON LIQUIDS MIXING CONTROL SYSTEM DESIGN MODEL

Rule NO.	Volume in	Viscosity	Item Select	Rotating Speed	Rotating Time	Grinding Speed	Grinding Time	Temp	Temp Time	Valves	Open Time	Singleton Values
1	AM	JS	BM	Fast	Long	Fast	Long	H	Long	M	Long	S1
2	BM	JS	BM	Fast	M	Fast	M	H	M	M	M	S2
3	AM	VS	BM	V. Fast	Long	V. Fast	Long	V.H	Long	M	Long	S3
4	BM	VS	BM	V. Fast	M	V. Fast	M	V.H	M	M	M	S4
5	AM	JS	JS	Fast	Long	Fast	Long	H	Long	Few	Long	S5
6	BM	JS	JS	Fast	M	Fast	M	H	M	Few	M	S6
7	AM	VS	JS	V. Fast	Long	V. Fast	Long	V.H	Long	Few	Long	S7
8	BM	VS	JS	V. Fast	M	V. Fast	M	V.H	M	Few	M	S8

The rule base takes in three crisp input values, dividing the universe of discourse into regions with each region containing two fuzzy variables, fires the rules, and gives the output singleton values corresponding to each output variable[-]. Here we have three input variables, so we need three region detectors and decoders.

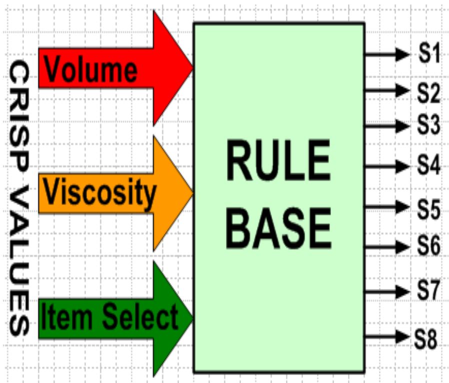


Fig. 11 Rule base block diagram

The rule base consists of: three region detectors and decoders, comparators and lookup tables LUTs to give the rule base information to the defuzzifiers. Fig.12 shows the arrangement of one region detector and decoder.

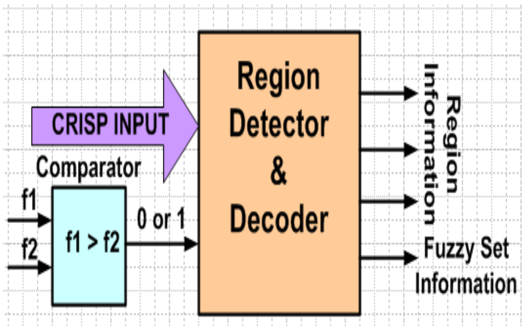


Fig. 12 Region detector and decoder

The region detector and decoder provide the information about region occupied by the variable and the fuzzy set.

The comparators and LUTs block show in Fig.13 takes in the information from three region detectors and decoders and provides the rule based information to the defuzzifiers.

The defuzzifiers work with these information mathematically to give the crisp output for each output variable according to the expression $\sum Si * Ri / \sum Ri$.

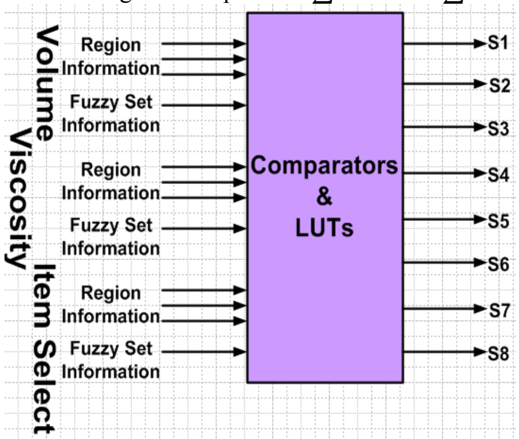


Fig. 13 Block of comparators and LUTs

D. Deffuzifier

This system consists of eight defuzzifiers, four are 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 make 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 16 inputs are given to each of eight defuzzifiers. Eight values of R1, R2,……..,R8 from the outputs of inference engine and eight values S1, S2, ………,S8 from the rule selector as shown in fig.14. 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 8.

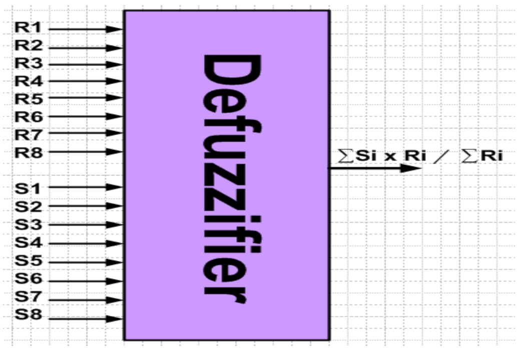


Fig. 14 Defuzzifier block

Fig.15 shows the design arrangement of a defuzzifier. One defuzzifier consists of : one adder for $\sum$ Ri, eight multipliers for Si * Ri, one adder for $\sum$ Si * Ri, and one divider for $\sum Si * Ri \,/\, \sum Ri$. Finally a defuzzifier gives the estimated crisp value output.

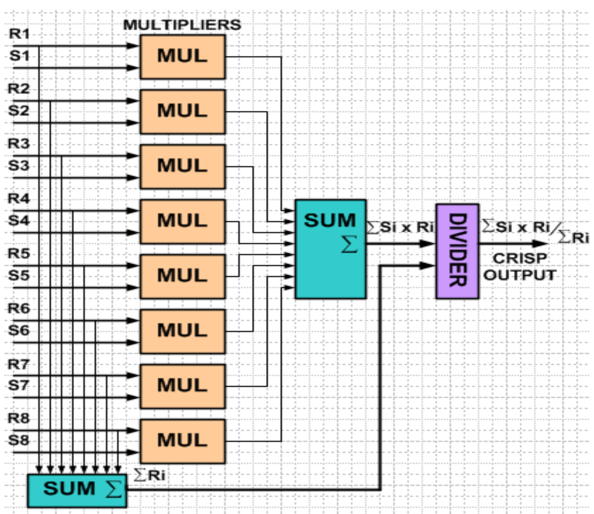


Fig. 15 Defuzzifier design

V. RESULTS DISCUSSION

According to the results of inference engine

$\sum$ Ri = R1+R2+R3+…………+ R8 = 2.75

Using mathematical expression $\sum$ **Si *Ri** / $\sum$ **Ri** the crisp values for output variables were determined and the results were according to the MATLAB simulation as shown in Fig.16. These results are compared in Table VII and found correct according to the design model.

MATLAB simulation was adapted according to the arrangement of membership functions for eight rules as given in Table VI.

TABLE VI
ARRANGEMENT OF MEMBERSHIP FUNCTIONS FOR SIMULATION

Rule NO.	Volume	Viscosity	Item Select	Rot. Speed	Rot. Time	Grind. Speed	Grind. Time	Temp.	Temp. Time	Valves	open Time
1	MF4	MF2	MF3	MF4	MF4	MF4	MF4	MF4	MF4	MF3	MF4
2	MF3	MF2	MF3	MF4	MF3	MF4	MF3	MF4	MF3	MF3	MF3
3	MF4	MF1	MF3	MF5	MF4	MF5	MF4	MF5	MF4	MF3	MF4
4	MF3	MF1	MF3	MF5	MF3	MF5	MF3	MF5	MF3	MF3	MF3
5	MF4	MF2	MF2	MF4	MF4	MF4	MF4	MF4	MF4	MF2	MF4
6	MF3	MF2	MF2	MF4	MF3	MF4	MF3	MF4	MF3	MF2	MF3
7	MF4	MF1	MF2	MF5	MF4	MF5	MF4	MF5	MF4	MF2	MF4
8	MF3	MF1	MF2	MF5	MF3	MF5	MF3	MF5	MF3	MF2	MF3

In Fig.16 values of, input variables used, were the same as, VOLUME=48, VISCOSITY=15 and ITEM-SELECT=27, for which the system was designed.

Various values of input and output variables match the dependency scheme of the system design. The simulated values were checked using MATLAB-Rule viewer shown in fig. 16.

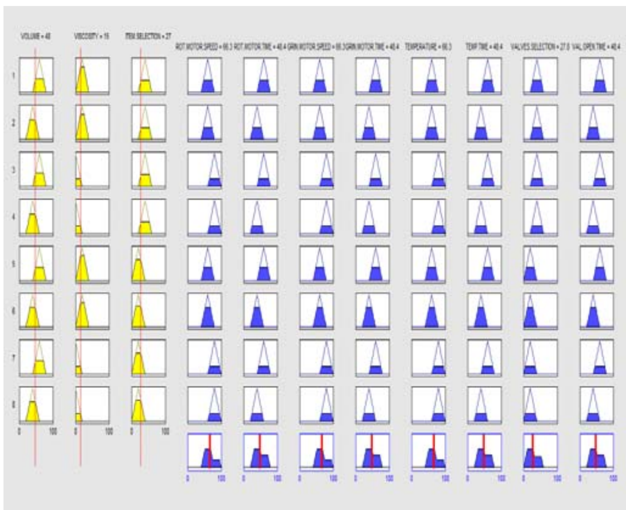


Fig. 16 MATLAB- Rule viewer and simulation result for liquids mixing fuzzy time control system

The calculated values of output variables, according to the given values of input variables for this system design, were the same as the simulation results shown in Table VII. This shows the credibility of the liquids mixing control system using fuzzy time control system.

TABLE VII
COMPARISON OF SIMULATED AND CALCULATED RESULT

Results	Rotating Speed	Rotating Time	Grinding Speed	Grinding Time	Temp	Temp. Time	Valves Selection	Valves Open Time
MATLAB Simulation	66.3	48.4	66.3	48.4	66.3	48.4	27.8	48.4
Calculated Values	65.8	47.8	65.8	47.8	65.8	47.8	27.3	47.8

A. Simulation Graphs Discussion

This system was simulated for the given range of input variables. The given value of: volume = 48 lies in the region 3 of range 40-60, viscosity = 15 lies in the region 1 of range 0-20, and item selection = 27 lies in the region 2 of range 20-40. The eight rules were applied for MATLAB simulation according to this range scheme.

In this design model rotating motor speed, grinding motor speed and amount of heating / cooling depend upon the value of viscosity required.

Rotation time, grinding time, heating / cooling time and valves open time depend upon the amount of volume required. Whereas, the number of valves selection depends on item-select input variable. The simulated and calculated results are according to the dependency scheme.

Fig. 16(a) shows that the rotating motor speed is inversely proportional to viscosity and it does not depend upon the volume.

Fig. 16(b) represents that the rotating time is directly proportional to the design range of volume and it does not depend upon the selected value of viscosity.

Fig. 16(c) supports the design view and shows that the grinding speed is inversely proportional to the viscosity and does not depend upon volume.

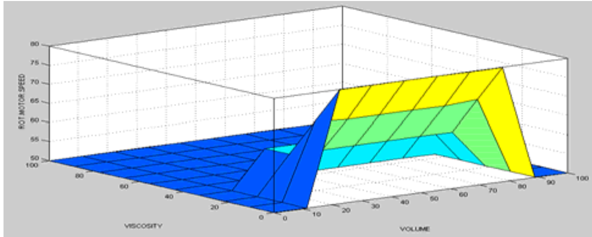
Fig.16 (d) shows that the grinding time is directly proportional to given range of volume and it does not depend upon viscosity.

The operational design view of the system that the amount of temperature is inversely proportional to the viscosity and does not depend on volume is supported by Fig. 16(e).

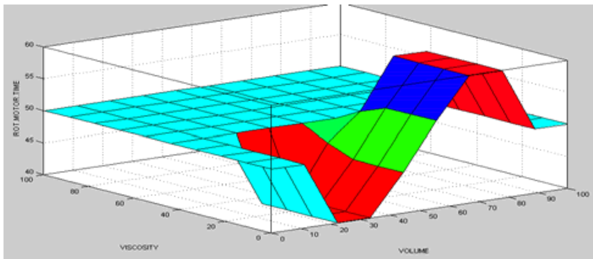
Fig. 16 (f) explains that the cooling or heating time depends on the amount of volume and does not depend upon the value of viscosity for the given design range.

Fig. 16 (g) shows the design view point that the number of valves selection is directly proportional to the item selection and it does not depend upon the viscosity for the given range.

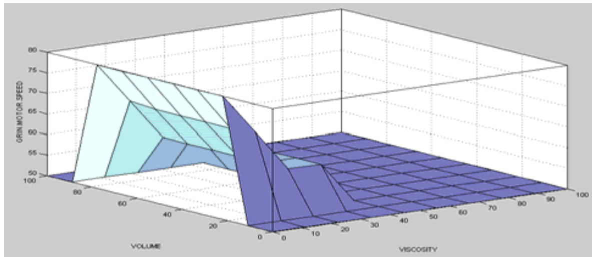
Fig. 16 (h) supports the design and shows that the valves open time is directly proportional to the amount of required volume and it does not depend upon viscosity for this design range.



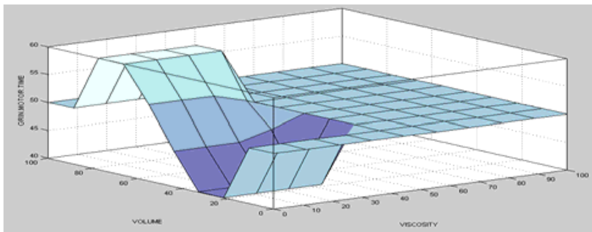
(a) Plot between volume-viscosity-rotating speed



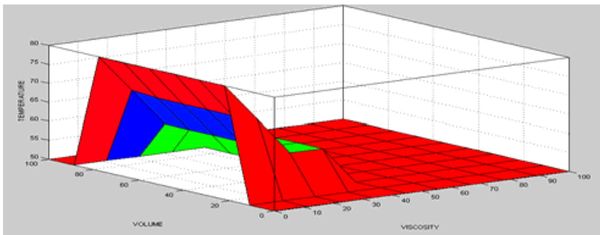
(b) Plot between volume-viscosity-rotating time



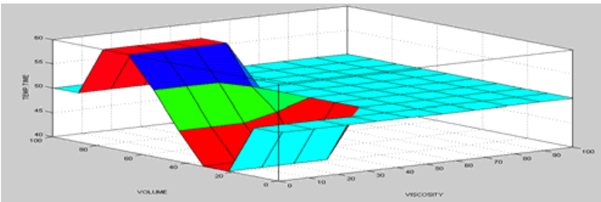
(c) Plot between volume-viscosity-grinding speed



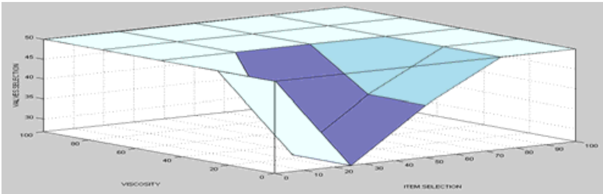
(d) Plot between volume-viscosity-grinding time



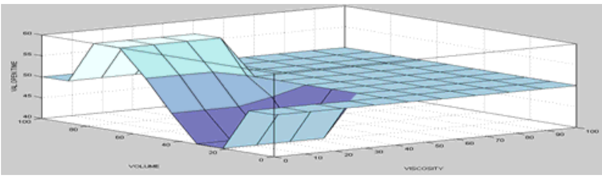
(e) Plot between volume-viscosity-temperature



(f) Plot between volume-viscosity-temperature time



(g) Plot between viscosity-item selection-valves selection



(h) Plot between volume-viscosity-valves open time

Fig. 16 (a to h) Simulation plots

VI. CONCLUSION AND FUTURE WORK

Design model of liquids mixing fuzzy logic time control system provided the results completely in agreement with the simulated results. This system can be extended for any time control system to overcome the time control issues and achieve better performance without the burden of extra load for time control. This system is better than the other systems because it provides the time control management for a system without the complexity.

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 high tech micro-electronics based FPGAs for the 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 using concepts of multi-agents.

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