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Reconfigurable Fuzzy for Cassava Starch Modification Process in Biodegradable Plastics and Pharmaceutical Applications

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Abstract: In this paper, we build up a Fuzzy Inference System (FIS) to support the operator working in cassava starch chemical modification process. The designed fuzzy logic controller considers four input parameters of cassava native starch pH, viscosity, temperature and moisture to evaluate three output chemical ratios of sodium hydroxide, hydrochloric acid and maleic anhydride or phthalic anhydride essential to mix with the native starch in modified starch manufacturing process. Sugeno fuzzy logic model designed, simulated and implemented in re-configurable FPGA architecture using system generator would load the necessary program to fire specific fuzzy rules according to the type of starch modification process, especially being used for manufacturing modified starches in the process of biodegradable plastic and tablet manufacturing applications.

Keywords: Cassava Starch Modification, System Generator, Pharmaceutical, Bio-degradable Plastics, Sodium Hydroxide (NaOH), Hydrochloric Acid (HCl), Maleic Anhydride (MA-$C_4H_2O_3$), Phthalic Anhydride (PA-$C_8H_4O_3$)

1 Introduction

Native starch obtained by crushing the Cassava raw material through washing, refining, drying and rasping process alternatively named as Tapioca. Native starch modified for many industrial applications like plastic, pharmaceutical, food, and paper industries to overcome its inability to withstand processing conditions such as extreme temperature, high adhesiveness, insoluble property, and storage at lower pH values. In order to improve on the desirable functional properties and overcome its limitations through chemical modifications, native starches are often modified for diverse applications through the critical selection of modifying agent, concentration, starch composition, and environmental conditions [1]. This section deals with the literature review on the cassava starch modification process and research gaps to be considered.

Modified starches obtained through various modification techniques like physical, chemical, and enzymatic treatment are used for improving texture, high nutritional claim, stabilizer, emulsifier, thickening agent, binder, fat replacement, and temperature stability, etc. Among the modification methods, chemical means to be the most frequently-used modification process. New starches with novel functional characteristic value demanded by the industry produced within a short span time through chemical modification methods such as esterification, cross linking, etherification, oxidation, and grafting of starch should have a suitable monitoring process to ensure the safety as well as health of the consumers and environment [2].

The cause for the slowdown of cassava process and its product commercialization to exhibit its full potential in Uganda revealed that Cassava cultivation improved the livelihood of farmers through the commercial potential opportunities of cassava products finding diverse applications in industrial fields of paper, pharmaceutical, textile, alcohol, plywood, bakery, and food industries with Cassava transformed into high value-added commercial products [3]. Cassava starch modification by cross-linking four different reagents produces four grades of modified starches exhibiting better functional properties of pH, swelling volume, solubility, moisture and ash content with viscosity variations [4].

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Attention towards biodegradable plastic manufacturing increases recently due to significant reduction in the environmental toxic wastes. The optimum parameters of modified cassava starch with hydrochloric acid and sodium hydroxide at different temperature by cross-linking maleic acid used to manufacture biodegradable plastic with good stability, shelf life and strength would save the environment [5]. Cassava starch modification is carried through maleic anhydride insoluble in acidic and soluble in basic solution at elevated temperatures. The elasticity and the hardness of the plastic sheets are decided by the maleic anhydride concentration [6]. The direct contact bio-degradable safety outer covering cassava starch trays for strawberry packaging along with poly lactic acid (PLA) and maleic anhydride had the least yeast growth and provides efficient moisture absorption barrier [7]. Polypropylene obtained through blending of maleic anhydride has improved tensile properties due to enhanced inter facial adhesion viewed through scanning electron microscopy [8].

The low non-starch component of tuber starches from an Irish potato or cassava had improved morphological and mechanical properties [9] used in non-toxic biodegradable plastic manufacturing, making them a good raw material for plastic film formations [10]. Modified tapioca starch through esterification with various concentrations of maleic anhydride along With hydrochloric acid and sodium hydroxide lowers thermal stability [11] used for biodegradable plastic formation. The variations in the characteristics of biodegradable plastic with respect to the change in the temperature and drying of the modified cassava starch is subjected to 50° C temperature with 5 hours of drying time produce better tensile strength [12].

Enteric-coated tablet produced by a process of pre-gelatinization of cassava starch and esterification using phthalic anhydride improves the film forming capability of starch successfully used for outer layer tablet coating and for the controlled diverse drug release and carrier systems of bio-active agents in stomach [13] during solid unstable drug hydrolyzed at acidic circumstance [14] with pH variations through sodium hydroxide and hydrochloric acid concentration variations. The obtained Pragelatinized cassava starch phthalate was more soluble in alkaline medium than in acidic medium [15].

Cassava starch is the most common binder in the ibuprofen tablet formulations [16]. Tapioca starch modified at molecular levels through annealing followed by enzyme hydrolysis acquires functional filler-binder micro crystalline tapioca superior starch that is used to prepare softer tablet of moisture sensitive [17] with pH adjustments. The cassava starches with pH values 8.1 to 9.9, 15% moisture content and less than 1% ash values along with low viscosity property had superior mechanical property in the drug formation used in paracetamol tablet and the breakdown period of the tablets lowered with increase in cassava starch concentration [18].

Raw Cassava roots and peels, along with nutrition contain cyanogenic glucosides are decomposed with naturally present enzyme, liberating hydrogen cyanide avoiding its direct raw consumption. Cassava varieties classified as either sweet or bitter signify the existence of toxic levels and proper monitoring is essential to measure the significance of the security level of consumers, environments, and workers exposed to cyanide residue in the cassava-based food product consumption [19].

Fuzzy inference system is predominantly recognized as a feasible tool to implement solutions to real-world problems with the uncertainties and flexibilities in managing partial information. Sugeno fuzzy inference systems are implemented to derive the mechanical properties of tapioca starch under the influence of PLA, composite foams of different clay contents, temperature, and pressure to derive the outputs radial expansion ratio, and density [20]. The triangular membership function preference for each of the input variables having superior performance than other shapes of membership functions [21]. Fuzzy logic controller synthesis on FPGA significantly reduced the design time of the processor for real-time applications [22, 23].

Present scenario in Chemical starch modification process, employ manual chemical addition for modification process can be overcome through the support of research works to implement inference system on this area to meet the diverse applications of various industries in pharmaceutical and plastic industries, etc. To reduce the manual involvement in the chemical modification of starch process, controller design with re-configurable preference is required to maintain its quality with safety measures to feed accurate proposition of various chemicals for diverse applications in a single plant. Section 2 deals with the potential of cassava in India whereas Section 3 and Section 4 discuss the design of fuzzy logic controller for modified cassava starch production in pharmaceutical and plastic applications. Section 5 explains the implementation of Fuzzy Logic Controller in FPGA platform using SysGen environment with its results in Section 6.

2 Cassava Status in India

Policy restrictions on imports of starch from USA, Indonesia, Malaysia, and Singapore during Second World War aid the growth of the sago starch industries in Tamil Nadu [24]. The household consumers consume cassava in fresh form with lack of knowledge towards the market information for processing value-added products. Cassava rapidly becomes a major industrial crop and Tamil Nadu occupying the first position in cassava production during 2012–13 with 57% of the total production in India. India exports cassava and its value-added products in the form of flour, and sago to the nearly 45 countries like United

Arabic Emirates, Nepal, Saudi Arabia, Kuwait, Netherland, European nations, and USA. The demand for cassava starches increase in food and pharmaceutical sectors made research efforts in non-traditional areas with technology upgradation of equipment towards starch processing technologies to manufacture diverse value-added products in India. In South Asia, India plays a key position to provide food security through 98% of the national output cassava production predominantly from the major cultivation states of Kerala and Tamil Nadu.

The shift in cassava demand to focus towards the production of sago attained rapid growth with the number of the sago processing units from 168 to 1000 units after Sago Serve started its function in the Salem region especially during 1982 to 1995 with liberal Indian policies. Cassava production had a gradual decline in India, as farmers choose to farm high return remunerative crops like rubber, pepper, and coffee. However, there is a significant fall in the number of operating units to 308 units in 2016 and would likely to persist for next four years in order to compete with the international market towards cassava value chain modernization, quality concerns and smaller chemical usage [25]. Even though increasing investment on the modified starch industries with modern equipment for up gradation in manufacturing modified starch process, still it is lagging in auto selection of required chemicals with its concentration level for various diverse applications of modified starch manufacturing.

3 Proposed Work

Modified starch replacing native starch needs proper state-of-the-art technology to acquire various ratios of two or more various chemicals added in right proportion according to the necessity of plastic and pharmaceutical applications as shown in Fig. 1 need multiple fuzzy logic controllers for each modified starch production.

Present scenario in chemical starch modification employs manual chemical addition of chemicals in critical food sectors which can be overcome through the support of research work to implement inference system on this area. The proposed work is to examine the suitability of fuzzy technique to control the quality of modified starch and implant the experience of the quality assurance persons to employ computers in determining the required amount of chemical proportions that have to be added during the process of modified starch production for preferred industrial applications.

Here primarily Sugeno FLC designed with weighted average method evaluates the three output chemicals ratio of sodium hydroxide ,hydrochloric acid and maleic anhydride or phthalic anhydride for manufacturing of modified starches for plastic and pharmaceutical application based on the input native starch properties pH, temperature, viscosity and moisture along with

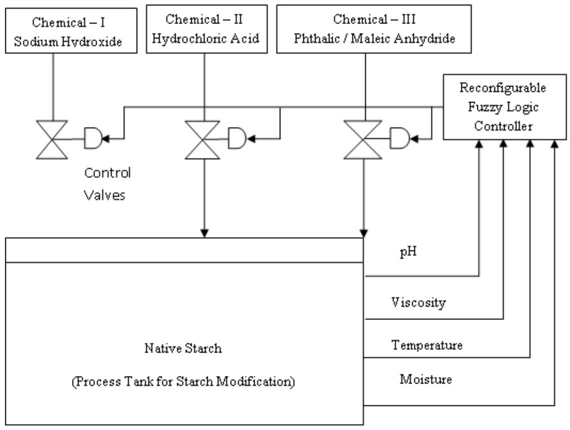

Fig. 1: Starch Modification Process

application specific input. The chemicals such as sodium hydroxide in the range of (0–20%) and hydrochloric acid in range of (0–8%) is used to maintain required pH level whereas maleic anhydride in the range of (0–40%) is used to control the moisture content in plastic manufacturing process and phthalic anhydride in the range of (0–16%) that is added to maintain viscosity values of modified starch for tablet coating in pharmaceutical applications. Along with native starch parameters, when the application selection inputs value zero, the fuzzy rule derives the maleic anhydride concentration value required for manufacturing biodegradable plastic applications and value one corresponds to phthalic anhydride concentration for tablet manufacturing process through mux control.

4 Fuzzy Logic Controller (FLC)

The problems encountered in agro-industrial engineering and technology applications can be resolved with the highest level of accuracy through fuzzy systems, dealing with imprecise, uncertain and complex data. Since it is very complex to have a mathematical model to starch modification process, fuzzy logic controller is employed to find the optimum range of chemicals added with the native starch in the manufacturing process of modified starch for plastic or pharmaceutical applications. Based on the knowledge of pharmaceutical and plastic industry, the membership ranges for the input parameters are partitioned and specified in Table 1

System Generator is a powerful design tool to support the auto generation of HDL code for particular FPGA processor from the designed model of integration of various Xilinx blocks set available in the MATLAB simulink environment and provide rapid method to implement real-time application through Hardware generator HDL model. The designed SysGen model interface of MATLAB simulink and Xilinx environment through System Generator token involves integration of

Table 1: Fuzzy input membership range

Input range	Very Low (VL)	Low (L)	Medium (M)	High (H)	Very High (VH)
pH (5–9)	5–6.5	5.5–7	6.5–7.5	7–8.5	7.5–9
Viscosity (0–2800 CPS)	–	0–1400	700–2100	1400–2800	–
Moisture (10–14%)	–	10–12	11–13	12–14	–
Temperature (40–80 °C)	–	40–60	55–70	65–80	–
Application Selection (0 or 1)	Modification Type: Plastic (0) / Pharmaceutical applications (1)				

various Xilinx blocks components between gateway blocks. The black box block supports the way to include the existing hardware description language files into a model and take part during co-simulation. System generator token is used to select the FPGA board with its configuration settings and generate the HDL file in the Xilinx environment. The developed system generator structure for both plastic and pharmacy industry application is shown in Fig. 2 which integrates different tools for simulation, verification, rapid design and concurrent synthesis of complex fuzzy controllers with hardware/software co-simulation process. In combination with Xilinx and MATLAB tool environment, this provides an easy approach for synthesis of fuzzy inference systems on FPGA. The developed system structure contains four native starch input parameters such as pH, viscosity, moisture and temperature along with the type of application of modified starch manufacturing for plastic or pharmaceutical industries. The output parameter is the ratio of three chemicals (Sodium Hydroxide, Hydrochloric acid and Maleic Anhydride or Phthalic Anhydride). The input pH membership function is partitioned as Very Low (VL), Low (L), Medium (M), High (H) and Very High (VH) whereas membership function for viscosity, moisture and temperature are partitioned as Low (L), Medium (M), and High (H) as per Table 1.

The output membership functions sodium hydroxide, hydrochloric acid, and phthalic anhydride or maleic anhydride partitioned as singleton in the three regions Low (L), Medium (M), and High (H). The min–max rule developed in VHDL language makes easy implementation of Sugeno model in FPGA using Sysgen environment. The input and output port names linked with the program are tabulated in Table 2.

5 FPGA Implementation of Fuzzy Logic Controller

The maximum development of fuzzy logic applications leads to the need of finding a competent way to implement the hardware model. Field Programmable Gate Array (FPGA) is the significant tool for hardware implementation due to high computational capability, re-configurable property, low power consumption, high operating speed and sampling rate support with large data storage capacity. FPGA device contains the matrix of

Table 2: SysGen I/O port mapping

Gateway	Input/ Output Mapping
gateway_in (3:0)	First input (pH)
gateway_in1(10:0)	Second input (Viscosity)
gateway_in2(3:0)	Third input (Moisture)
gateway_in3(6:0)	Fourth input (Temperature)
gateway_in4(1:0)	Fifth input (Application Selection)
gateway_out(4:0)	First output (Sodium Hydroxide)
gateway_out1(3:0)	Second output (Hydrochloric acid)
gateway_out2(6:0)	Third output (Maleic Anhydride)
gateway_out3(4:0)	Third output (Phthalic Anhydride)

re-configurable logic blocks to program the functionality connected to I/O blocks through series of mux and memory elements. Signals are routed within FPGA matrix with programmable interconnect switch. FPGA Spartan-3 is employed to meet the design and works through 90 nm process technology with efficient multiplexers.

Since prototyping of Sugeno model in FPGA environment is very flexible and re-configurable option is necessary to load the appropriate rules at required instance and that would avoid very complex design model for modified starch applications. Out of various modified starch production in an industry for various industrial applications, at a time only one particular type of modified starch is manufactured with same hardware facility by adding necessary chemicals according to the customer specification.

The fuzzy rules would become more complex if all the different application requirements are made in single fuzzy logic controller. So, a set of fuzzy rules required for particular industry is loaded into the re-configurable FPGA architecture according to the type of modified starch production.

Among the different types of membership functions used in fuzzy, triangular membership functions is framed by two points with two slope values. The membership function is divided into two segments with an upward slope and downward slope as shown in Fig. 3. The actual value of pH is mapped in the x-axis and the corresponding membership value mapped with the y-axis degree of membership (μ) value through fuzzification with input range lying on upward slope or downward slope.

The degree of membership in Y-axis ranges varies between 0 (Hexadecimal: 00_H) and 1(Hexadecimal: FF_H) depending on on the position of the input value with

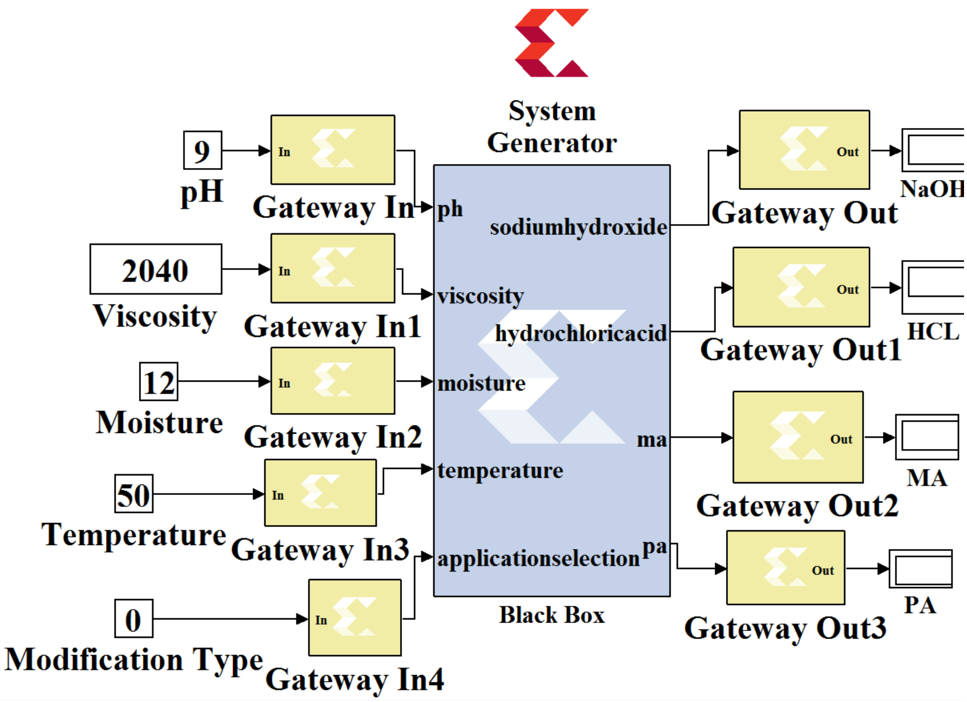

Fig. 2: MATLAB simulink SysGen fuzzy model

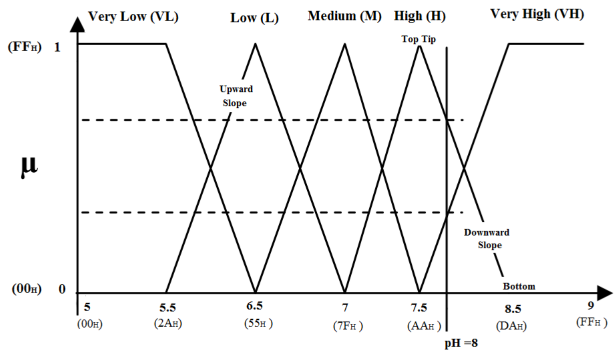

Fig. 3: pH membership range

respect to the upward slope and downward slope having maximum value 1 (FF_H) and minimum value 0 (00_H). FPGA FLC implementation using VHDL language involves each membership function that's represented by 8-bit top tip (point1) and bottom point (point 2) with upward slope and downward slope values using record type declaration.

//Membership Function

type membership_function is array(natural range < >) of membership;
constant mfs:
membership_function: = ((term => verylow,
point1 => (x"00"), slope1 => x"ff",
point2 => x"2a", slope2 => x"06"),
(term => medium, point1 => x"55", slope1 => x"06",
point2 => x"7f", slope2 => x"06"),
(term => high, point1 => x"7f", slope1
=> x"06", point2 => x"aa", slope2 => x"06"),
(term => veryhigh,
point1 => x"aa", slope1 => x"06",
point2 => x"ff", slope2 => x"FF"));
\\ Slope Calculation
slope = y2-y1/ x2–x1;
upward slope mf verylow = (ff_h–00_h)/(00_h-00_h) = ff_h
upward slope mf medium = (ff_h–00_h)/($7f_h$-55_h) =06h
upward slope mf high = (ff_h–00_h) / (aa_h-$7f_h$) = 06h
\\Output membership function (Singleton)
constant p1: std_logic_vector: = x"33" ;
constant p2: std_logic_vector: = x"66" ;
constant p3: std_logic_vector: = x"99" ;
constant p4: std_logic_vector: = x"cc" ;
constant p5: std_logic_vector: = x"ff" ;
type singletons is array(0 to 4)
of std_logic_vector(7 downto 0);
signal p: singletons: = (p1, p2, p3, p4, p5);
\\ Fuzzification
μ upward = (Input value–point 1) * slope 1
μ downward = 255-(Input value–point 2) * slope 2
It is observed from Fig. 3, If the input pH value is 8, the degree of membership value lies on downward slope of high term and upward slope of very high term.
μ downward = 255–(Input value–point 2) * slope2 $= 255-(8-7.5)*6 = FC_H$
μ upward = (Input value–point 1) * slope 1

$= (8-7.5)*6 = 3_H$
\\max-min rule
signal producta, productb, productc, productd, producte: std_logic_vector(7 downto 0);
function minimum (a, b, c, d, e: std_logic_vector(7 downto 0)) return std_logic_vector is variable min : std_logic_vector(7 downto 0): = (others => ’0’);
begin
if a < b and a < c and a < d and a < e then
min : = a;
elsif b < a and b < c and b < d and b < e then
min : = b;
end if;
return min ;
end minimum;
\\Defuzzification (Weighted Average Method)
product = (s(j) × f(j)) + product;
sum = f[j] + sum; output = product / sum;
n = quantity of output membership function;
Initially sum = 0 and j = 1 to n;
s = array of singleton output membership function;
f = array of outcome of all rule evaluations;

By integrating the min–max functions, the rules framed to acquire output <= maximum (minimum (pH (L), viscosity (L), temperature (L), moisture (L)), minimum (pH (M), viscosity (M), temperature (M), moisture (M), ...). Here, the SysGen blocks contain series of multiplexers routed through black box and mcode decision blocks. In combination with Xilinx and Simulink model, SysGen tool provides a powerful design environment at every step of design for the synthesis of fuzzy inference systems on FPGA with internal circuitry necessary for hardware/software co-simulation process. Here, Sugeno fuzzy inference model is supported through HDL code through black box tool and m-code through m-code block available in MATLAB Simulink, making the process simple in simulink environment during HDL co-simulation. The generated HDL netlist in SysGen is transferred and linked in Xilinx ISE environment through system generator token is assigned with pin configuration using plan ahead as user constraint file in Xilinx ISE environment. The synthesis of hardware model implements design and generates bit file options followed in Xilinx ISE environment to implement the HDL design in hardware and the generated bit file is downloaded into the FPGA using impact in JTAG mode. The RTL schematic view of the implemented model is shown in Fig. 4.

6 Results and Discussion

Before implementation of the prototype design of the model, the precise ratio of chemicals can be verified through simulation in FPGA environment. The XILINX ISE simulator results are shown in Fig. 5 with pH value $1001_2(9_{10})$, viscosity $11111111000_2(2040_{10})$ CPS,

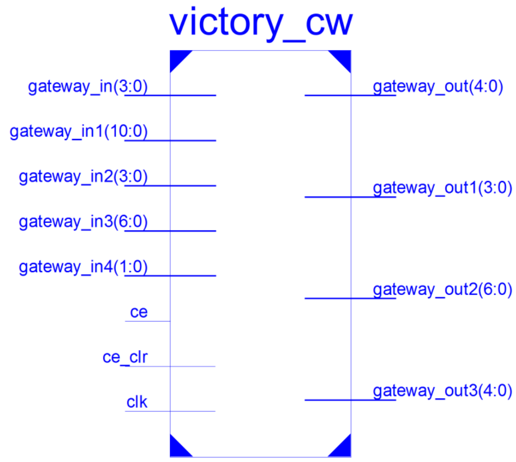

Fig. 4: RTL schematic

Table 3: FPGA-FLC chemical ratio determination for starch modification

Application Selection	Input native starch parameters	Input values	Output chemicals	Expected ratio	FPGA output	Output error
				Results in %		
1	pH	8	NaOH	0	0	0
	Viscosity	2650	HCL	5.6	6	7.14
	Moisture	10	PA	1.7	2	17.6
0	Temp.	50	MA	6	6	0
1	pH	9	NaOH	0	0	0
	Viscosity	2040	HCL	7.9	8	1.27
	Moisture	11	PA	1.9	2	5.2
0	Temp.	75	MA	5	5	0
1	pH	7	NaOH	0	0	0
	Viscosity	1462	HCL	1.8	2	11.1
	Moisture	12	PA	7.5	7	6.66
0	Temp.	50	MA	17.2	17	1.16
1	pH	5	NaOH	16	16	0
	Viscosity	240	HCL	0	0	0
	Moisture	13	PA	14.4	14	2.7
0	Temp.	75	MA	32.7	33	0.9

Moisture 1011_2 (11_{10}) and temperature 1001011_2 (75 °C) with plastic industry application selection (0_2), the required amount of chemicals added to the native starch is found to be sodium hydroxide $0000_2(0_{10})$%, hydrochloric acid 1000_2 (8_{10})% and maelic Anhydride $0101_2(5_{10})$%. The fuzzy Logic controller implemented in FPGA is shown in Fig. 6.

It is also observed from the simulation results of Fig. 5, with pH value 1001_2 (9_{10}), viscosity 11111111000_2 (2040_{10}) CPS, Moisture 1011_2 (11_{10}), temperature 1001011_2 (75 °C) and application selection changed as (01_2), the required amount of chemicals to be added to the native starch for pharmaceutical application is found to be sodium hydroxide (0_{10})%, hydrochloric

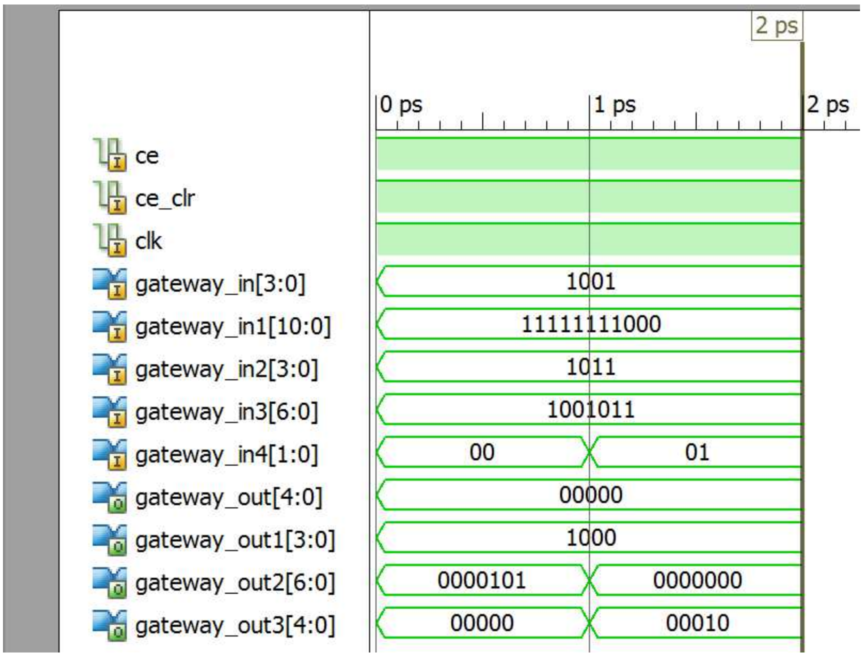

Fig. 5: Simulated chemical ratio output

Fig. 6: FPGA implementation

acid (8_{10})% and phthalic Anhydride $0010_2(2_{10})$%. It is observed from pH neutralization process, sodium hydroxide was added when pH is less than 7 and hydrochloric acid is added when pH value is greater than 7 to bring the native starch pH level nearly to neutral range.

The results obtained for various input variations are tabulated in Table 3 and it is inferred that the FPGA results obtained in hardware are nearly the same as that of the expected results. Output error is calculated by difference between the actual expected value and FPGA predicted value with percentage deviation. The maximum output error obtained in implementation of FLC for plastic and pharmacy industry application in Spartan-3 is found to be 1.16% error for maleic anhydride, 11.1% error for hydrochloric acid and 17.6% error for Phthalic Anhydride. It is observed from the table, phthalic anhydride concentration increases with lower viscosity native starch and Maelic anhydride concentration increases with more moisture content in native starch and decreases with increase in temperature level.

7 Conclusions

The main aim of this work is to find the suitability of fuzzy inference model to control the modified starch quality and embed the experience to workers to employ computers to derive required amount of chemical proportions that have to be added with native starch during the process of modified starch production for preferred industrial applications. Advanced techniques with integration of modern equipment lagging in starch modification process reported would be addressed primarily with re-configurable fuzzy logic controller considering the input parameters of native starch and evaluate the chemical ratios necessary to meet the pharmacy / plastic industrial requirements. Primarily Sugeno fuzzy logic controller model designed for manufacturing of modified starches in Cassava modified Industry application is simulated and implemented in FPGA platform successfully and that would certainly provide solution to the operators working in chemical modification process to evaluate the chemical ratios for diverse applications improving effective utilization of cassava starches and export business.

The simulation results of Xilinx ISE simulator and hardware FPGA results are compared with the expected results obtained from literature review and the results show that simulation and hardware implemented results are the same as the expected one. Re-configurable FPGA architecture would load the necessary HDL program to fire specific fuzzy rules according to the type of starch modification, and that would be the great key for the future of cassava starch modification industries.

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References

[1] A. Korma Sameh, Kamal-Alahmad, SobiaNiazi, FarahZaaboul & Tao Zhang, Chemically modified starch and utilization in food stuffs, *International Journal of Nutrition and Food Sciences*, **5**(4) 264–272. (2016).

[2] Durdica Ackar, Jurislav Babic, Antun Jozinovic, Borislav Mili, Radoslav Milicevic, Marija Rajic and Drago Šubaric, Starch Modification by Organic Acids and Their Derivatives: A Review, *Molecules*, **20** 19554–19570 (2015).

[3] W. Odongo and S. Etany, Value chain and marketing margins of cassava: an assessment of cassava marketing in northern Uganda, *African Journal of Food Agriculture Nutrion and Development*, **18**(1) 13226–13238 (2018).

[4] Akpa, Jackson Gunorubon, Dagde and Kenneth Kekpugile, Modification of cassava starch for industrial uses, *International Journal of Engineering and Technology*, **2**(6) 913–919 (2012).

[5] Thu, Shune, *Modification of Cassava Starch for Biodegradable Plastic Preparation*, Master of research thesis, University of Yangon, Myanmar (2015).

[6] Vimolvan Pimpan, Korawan Ratananarat and Mullika Pongchawanakul Preliminary Study on Preparation of Biodegradable Plastic from Modified Cassava Starch, *International Journal of Science and Technology*, **26**(2) 117–126 (2001).

[7] Marina Baratter, Eduarda Francine Weschenlfelder, Fernanda Stoffel, Mara Zeni, Luciani Tatsch Piemolini-Barreto, Analysis and Evaluation of Cassava Starch-Based Biodegradable Trays as an Alternative Packaging to Fresh Strawberry, *American Journal of Polymer Science and Technology*, **3**(4) 76–81 (2017).

[8] Henry C. Obasi, Isaac O. Igwe, Cassava, Starch-Mixed Polypropylene Biodegradable Polymer: Preparation, Characterization and Effects of Biodegradation Products on Growth of Plants, *International Journal of Science and Research (IJSR)*, **3**(7) (2014).

[9] Mopelola Abeke Omotoso, Grace Oluwadunni Ayorinde and Olakunle Alex Akinsanoye, Preparation of Biodegradable Plastic Films from Tuber and Root Starches, *IOSR Journal of Applied Chemistry*, **8**(4) 10–20 (2015).

[10] Tuty Dwi Sriaty Matondang et al., Studies about Palm Sago Starch as a Filler to Make Biodegradable Packaging Material, *International Journal of Science and Research Methodology*, **7**(1) 163–175 (2017).

[11] Pratumgaysorn Triwises, Yupaporn Ruksakulpiwat, and Chaiwat Ruksakulpiwat, The modification of tapioca starch by esterification technique, *Suranaree J. Sci. Technol.*, **23**(2) 157–165 (2016).

[12] Bambang Admadi Harsojuwono, I. Wayan Arnata Sri Mulyani, Biodegradable Plastic Characteristics of Cassava Starch Modified in Variations Temperature and Drying Time, *Chemical and Process Engineering Research*, **49** 1–5 (2017).

[13] Subhashis Debnath, V.G. Gayathri, M. Niranjan Babu, Chemically modified starches and their applications in pharmacy, *International Journal of Research in Pharmaceutical and Nano Sciences*, **2**(3) 332–344 (2013).

[14] I. M. Thakore, S. Desai, B.D. Sarawade, and S. Devi, Studies on biodegradability, morphology and thermo mechanical properties of LDPE/ modified starch blends, *European Polymer Journal*, **37** 151–160 (2001).

[15] Silvia Surini, Kurnia S.S. Putri, Effionora Anwar, Preparation and characterization of Pragelatinized cassava starch Phthalate as a ph- sensitive polymer for enteric coated tablet formulation, *International Journal of Pharmacy and Pharmaceutical Sciences*, **6**(3) 17 (2014).

[16] Judith Chitedze, Maurice Monjerezi, J.D. KalengaSaka and Jan Steenkamp, Binding Effect of Cassava Starches on the Compression and Mechanical Properties of Ibuprofen Tablets, *Journal of Applied Pharmaceutical Science*, **2**(4) 31–37 (2012).

[17] A.O. Shittu, A.R. Oyi, A.B. Isah, S.O. Kareem and M.A. Ibrahim, Formulation and Evaluation of Microcrystalline Tapioca Starch as a Filler- Binder for Direct Compression, *Int J Pharm Sci Res*, **3**(7) 2180–2190 (2012).

[18] Frank Kumah Adjei, Yaa Asantewaa Osei, Noble Kuntworbe, and Kwabena Ofori- Kwakye, Evaluation of the Disintegrant Properties of Native Starches of Five

New Cassava Varieties in Paracetamol Tablet Formulations, *Journal of Pharmaceutics*, Article ID 2326912, 9 pages, (2017).

[19] A. Fukushima, M. Nicoletti, A. Rodrigues, C. Pressutti, J. Almeida, Brandão, T, R. Kinue Ito, L. Bafille Leoni, and H. Souza Spinosa, Cassava Flour: Quantification of Cyanide Content, *Food and Nutrition Sciences*, **7** 592–599 (2016).

[20] Lee, Siew-Yoong; Hanna, Milford; and Jones, David D, An Adaptive Neuro-Fuzzy Inference System for Modeling Mechanical Properties of Tapioca Starch-Poly (Lactic Acid) Nanocomposite Foams, *Starch/Stärke*, **60**, 159–164 (2008).

[21] I.W. Ofosu, Fuzzy Modelling γ-Radiated Starches as Inactivating Agents of Nuls Lectins, *Macromol Ind J.*, **12**(3) 109 (2017).

[22] K. Virendra, Verma, Sarika Sapre, Implementation of Fuzzy Logic Controller using VHDL-A Review, *International Journal of Engineering Trends and Technology*, **24**(1) 21–25 (2015).

[23] Vuong, Philip, Madni, Asad and B. Vuong, Jim, VHDL Implementation for a Fuzzy Logic Controller. pp. 1–8, World Automation Congress (2006).

[24] T. Srinivas and M. Anantharaman, Status of Cassava in India An Overall View, Central Tuber Crops Research Institute (2013).

[25] R. Linder, A. Giuliani, K.R. Ashok and S. Arivarasan, Constraints and opportunities of the Tamil Nadu industrial cassava value chain and market, *World Academic Journal of Root and Tuber Crops Research*, **2**(2) 154–165 (2017).

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