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Parametric Optimization of Medical Plastic Wastes Conversion into Transportation Fuel using Mamdani Fuzzy Inference Systems (FIS)

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Abstract: ***Rapid growth of medical plastic wastes required attention for its scientific disposal along with conversion into value added products. Pyrolysis method is found suitable process for such conversion of such wastes into liquid oil. The experiment was carried out with the medical plastic wastes collected from local medicals and treated in a batch reactor taking appropriate range of temperature change and use of Calcium bentonite (CB) and Zeolite-A (ZA) as catalysts. The yield of liquid oil, gas and char produced from the process are collected in scale. The yield of liquid fuel in this process was influenced by factors such as temperature, catalyst concentration and acidity of catalyst. It was observed that yield of liquid fuel in this process were significantly dependent on temperature, nature of catalyst and catalyst concentration. The maximum yield of oil reported at 500 C and even increased by adding 20% by weight of CB as catalyst and 10% by weight of Z-A. In this study, Mamdani Fuzzy inference System (FIS) is used in order to measure the performance of the process and can be analyzed with more objectives, oriented through mathematical modelling and simulation. Mamdani Fuzzy inference was also introduced to identify the significant factors affecting the response and helps to determine the best possible factor level of combination. Finally, a regression model for liquid fuel from catalytic degradation of medical plastic wastes has been developed and mapped as a function of process parameters.***

Keywords: ***Medical plastic wastes, thermo-catalytic degradation, batch reactor, Mamdani Fuzzy inference System (FIS)***

I. INTRODUCTION

Modern life becomes secured with the availability of good numbers of multifacilty hospitals in the city. The growing rate of hospitals substantially solves the health issues but simultaneously creating another acute challenge for medical waste disposal. Medical waste is limited to infectious, hazardous, and any other wastes that are generated from health care institutions, such as hospitals, clinics, dental offices, and medical laboratories According to National income level, volumes of medical waste generation are mainly dependent on the usage and income standard of the people. According to the survey made by World Health Organization (WHO) in 1999, the figure reported for medical waste generated and remained indisposed in worldwide is a matter of concerned.

The amount of untreated medical wastes generated in developed countries like North America, Western Europe, Latin America, Eastern Asia and India are 09-10kg, 3-6kg, 3kg, 2.5kg and 08kg/bed respectively. They include mainly discarded surgical gloves, surgical instruments, syringe and Saline bottles [1].

Various modern waste management strategies have been adopted to dispose medical wastes for a sustainable, scientific, cost effective and low risk manner. In some of the countries, Incineration was used as a common method for medical waste treatment. However, recently some modern techniques are being introduced for disposal of such wastes reducing the pollution aspects but do not provide any resource from the wastes. So, to reduce the volume of such waste, some appreciable attempts could have been taken to reuse, recycle, segregate, and better management with minimum impact on the environment and ecosystem.

Pyrolysis is a promising technique used in the experiment for sustainable management of medical wastes. Pyrolysis or cracking processes break down polymer chains into useful lower molecular weight compounds. This can be achieved by the application of heat at atmospheric pressure in the absence of oxygen, which can be either thermal or catalytic cracking. The process is influenced by chemical composition of the feedstock, cracking temperature, heating rate, operation pressure, reactor type, residence time and application of catalyst[2,3].In this context, we studied the performances of thermo-catalytic conversion of medical plastic wastes into liquid oil at various operational conditions. In the present experiment, we studied the influence of temperature and catalysts (CB and Z-A) concentration on production of liquid oil from medical plastic wastes in a batch reactor [2, 3]. Mamdani Fuzzy derivation System is utilized to enhance the oil estimation under different information parameters taken from proposed input list. In order to calculate the best oil yield, a set of 9 rules are also incorporated into the Fuzzy Inference System (FIS). A substantial investigation has been done in the proposed FIS in order to attain the exactness of oil computation as well as to set an improved standard of oil.

When a process is carried out with multiple conflicting factors influencing the result, Statistical modeling or optimization techniques are preferred for implementation in order to enhance the accuracy of the process.

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From the literature survey, it can be concluded that, during the past decade fuzzy logic has found a variety of applications in various fields including industrial-process control, medical diagnosis, securities in trading, control non-linear, time-varying, ill-defined systems to control systems whose dynamics are exactly known, such as servomotor position control, robot-arm control and to manage complex decision-making or diagnosis systems.

The literatures explaining the application of Mamdani Fuzzy Inference System (FIS) have been summarized as follows.

D Nazari and M Hassan have used Mamdani Fuzzi logic to control and optimize the trajectory tracking of wheeled mobile robot. The performance of the Robot trajectory using this technique was desirable as reported [4]. Xianhua et al (2005) identified the performance and prediction of Robot position allocation and controlled using Fuzzi logic. This is due to the imperative efficacy of the techniques used for non-linear parameters of a system [5].Berg et al. (2006), developed PSO algorithm to optimize real world problems. However compare to GA and PSO, Mamdani Fuzzi was quite impressive due to its simple concept, easy implementation and fast convergence Keneddy et al. (1999) [6].Arshdeep et al. (2012) studied the effect of air cooling and its optimization in air conditioning system using Mamdani-Type and Sugeno-Type Fuzzy Inference Systems. They have reported that Mamdani FIS has a significant performance in achieving the maximum output [7].K.P. Mohandas and S. Karimulla ,(2001) explained the classical theory of Fuzzi logic and its significance to control a plant without designing a mathematical modeling for process optimization and control [8].According to T. J. Ross (2010), Fuzzi systems have been undertaken as a standard tool to illustrate complex problem that leads to a fast, accurate and imperative solution [9].

In this work, attempt has been taken to use Mamdani Fuzzy rules to improve and validate the dataset of oil production under various parametric conditions. The proposed model prediction results are compared with a set of reliable experimental information accessible in the literature for the validation of fuzzy model and it is discovered that proposed fuzzy model gives the outcomes which fit well in experimental results.

II. MATERIALS AND METHODS

A. Materials

The materials used in this experiment comprise of waste surgical syringe and saline bottles were collected from local medicals and municipalities bin. The waste materials collected subjected to sterilization, drying and shredding into chips around 3-4 mm size. The shredded materials are taken into the semi-batch reactor for thermal degradation. From a detailed survey about the types and quantity of medical plastic wastes generated in different hospital bins located at Bhubaneswar City, Odisha, it is found that the quantity of used syringe and exhausted saline bottles are the two major plastic wastes being accumulated in addition to other items in small fractions. Again the saline bottle and used syringe are in the ratio of about 70:30. So it is decided to carry out the pyrolysis of these wastes in the same proportion. In this context, these two plastic waste materials are collected from different hospitals and subjected to drying and then shredded into small pieces of around 2-4 mm size and subjected to pyrolysis in 70:30 (Saline bottles: Syringe) proportion.

Fig. 1 Medical Wastes collected and Shredded

Two different catalysts such as Zeolite-A and acid treated calcium bentonite are used in this experiment. Detergent grade Zeolite A [$Na_2O(AlO_2.SiO_2.)_{12}$ $27H_2O$] procured from NALCO Damonjodi Odisha is used as catalyst in the experiment. The XRF composition of this catalyst is Al_2O_3: 27.98, Fe_2O_3:0.0, TiO_2:0.0, SiO_2: 32.87, Na2O: 16.98, CaO: 0.0, P_2O_5 :0.0,V_2O_5 :0.0, MnO:0.0, LOI: 22.19. It is a white free flowing powder with average particle size 4-6 micron particle size and high surface area 350 to 1000 m^2/g have high thermal and hydrothermal stability can withstand temperature upto 800°C even in presence of steam [10]. Thermo-Acid treated calcium bentonite reported in other work [11] is used as one of the catalysts in this experiment. The parent material calcium bentonite (Al_2O_3:20.34,Fe_2O_3:9.39,TiO_2:1.14, SiO_2:53.02, Na_2O:0.03.98,CaO :4.85, P_2O_5 :0.03, V_2O_5 :0.09, MnO:0.08, LOI: 10.72) is refluxed with 3M H_2SO_4at about 80°C for 4 hours followed by calcining the filtered product at 500^{o}C for 1h. The XRF composition of acid treated calcium bentonite (CB) sample is Al_2O_3 :15.34, Fe_2O_3 : 4.65, TiO_2 :1.26, SiO_2 :65.04, Na_2O:0.36, CaO:0.0, P_2O_5 :0.03, V_2O_5 :0.09, MnO:0.08, LOI: 13.15. The BET surface area of the sample is found to be 290 m^2/g.

B. Pyrolysis in semi batch reactor

The pyrolysis of the shredded plastic samples are carried out using a semi batch reactor made of stainless steel (SS) tube sealed at one end and an outlet tube at other end already reported in our other work [l2].

The SS tube is heated externally by an electric furnace associated with a thermocouple and a PID controller to control the desired temperature. Shredded mixed plastic wastes of 50g were loaded in each pyrolysis reaction. In the catalytic pyrolysis, a mixture of catalyst in different concentration and the plastics samples were subjected to pyrolysis at the desired temperature.

The reaction time was calculated from the start time when the reactor with sample was inserted into the furnace chamber at room temperature and allowed temperature rise up to the desired temperature until end of the reaction when no more oil comes from the outlet tube.The condensable liquid products were collected through the condenser and weighed. After pyrolysis, the solid residue left out inside the reactor was weighed. Then the weight of gaseous product was calculated from the material balance. Reactions were carried out at different temperatures ranging from 400-550°C. Reproducibility of the experiments are ascertained by repeating each of the significant experiments three times.

C. Proposed algorithm

Step-1. The system considering with two different input values, one Temperature and other Zeolite Catalyst from the input parameter set. Then the oil production is calculated.

Step-2. Set the different variance of mamdani fuzzy input and output variables are like { very very low (VVL), very low(VL), low (L), medium low (ML), medium (M), medium high(MH), high (H), very high (VH), very very high (VVH)} and{Far, Intermediate, Near} represented in the optimization process.

Step-3. Generate the fuzzy if-then-rule by help of defined input variables, with help of different linguistic variable represented in the system defined in step-2 and the prediction and yields of oil as output in the system.

Step-4. Fuzzification and bins are constructed based on if-then- rule. By considering dynamic matrix which holds fuzzy output variable in column and number of trials in rows in the system.

Step-5. Performed the defuzzification process by following the if-then-rule and bin construction process by using Jacobi's defuzzifier technique.

Step-7. By considering the number of iterations the value of oil prediction and accuracy is defined until it converges with minimum error value in the system.

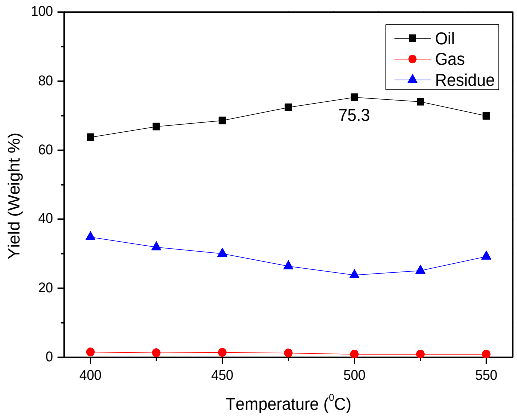
III. RESULTS AND DISCUSSION

A. Experimental optimization of the pyrolysis process

The pyrolysis experiments carried out at different temperatures from 400-550°C showing considerable alteration in the product distribution with change in temperature (Figure-2). Oil being the major product at all the temperatures, increases from a lower yield of 63.7% at 400°C to a maximum value of 75.3% at 500°C and gradually decreases with further increase in temperature. The yield of gaseous fraction shows a decreasing trend from 400°C to a lowest value of 23.8% at 500°C and increases further beyond this temperature. The residue fraction (char like) is lowest (<2%) among all the three fractions. The product distribution pattern with temperature can be explained due to the change of reaction time. Higher reaction time facilitates the secondary cracking of the primary reaction oligomers to lighter fractions yielding high gaseous product at lower temperature. With increase in temperature, the oligomers get sufficient energy to come out of the reactor and escape secondary cracking. After an optimum temperature of 500°C, the very high initial thermal energy cause severe cracking of the polymer mostly to gaseous fraction. As the objective of the experiment is to optimize the condition for higher yield of oil fraction, so the experimental results show that, 500°C is the optimum condition of temperature for maximizing the oil yield. The reaction kinetics has been interpreted in terms of the time of completion of the reaction carried out at a specific temperature. The rate of reaction increases or the time of completion of reaction decreases with increase in temperature. Both the catalysts show significant effect on the product yield and kinetics of the reaction, and the Zeolite A is found better in both aspects as compared to acid treated calcium bentonite catalyst (Figure 3).The pyrolysis product distribution with catalyst concentration is summarized in the (figure 4). A maximum oil yield of 79.2% is found with 10% Zeolite A catalysts and decreased with increase in catalyst concentration to 20%, simultaneously increasing the gaseous fraction. Whereas in Calcium bentonite based catalytic reaction maximum oil yield of 83.2% is found with 20% catalyst concentration which decreases with further increase in catalyst concentration increasing the gaseous fraction. A significant change in the basic physical properties of the oil such as density and viscosity also is observed in presence both the catalysts (Table 1). The above result infers that both the catalysts enhances the reaction rate and improve the product quality. This may be due to the presence of high surface area and surface acidity (Calcium bentonite)/basicity (Zeolite A) that facilitates the cracking of plastic sample. The high activity of Zeolite-A catalyst at lower concentration can be explained due to its very high surface area. Similarly the catalytic activity of acid treated calcium bentonite is attributed due to higher surface acidity (high Si/Al value) but require more catalyst due to lower surface area. The acid treated calcium bentonite is more effective for selective production of low density and low viscous oil as compared to Zeolite A catalyst owing to higher acidity.

Table 1 Results of pyrolysis experiments at 500°C

Pyrolysis Reaction	Oil yield (%)	Reaction Time (min.)	Density of oil at 15°C(g cc^{-1})	Viscosity of oil at 30°C (cSt)
Thermal	75.3	62	0.83	3.92
Zeolite A catalysed	79.2	55	0.74	2.42
Acid treated CB catalysed	83.2	52	0.78	2.18



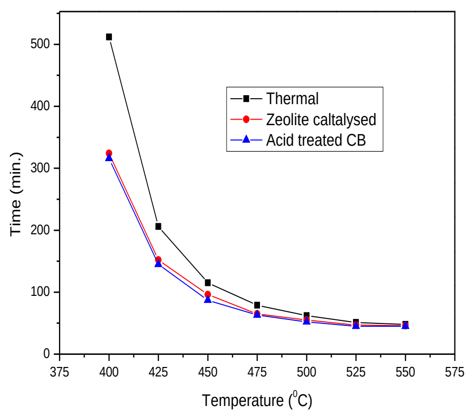


Fig 1 Effect of Temperature on oil yield **Fig 2 Effect of Temperature on product distribution**

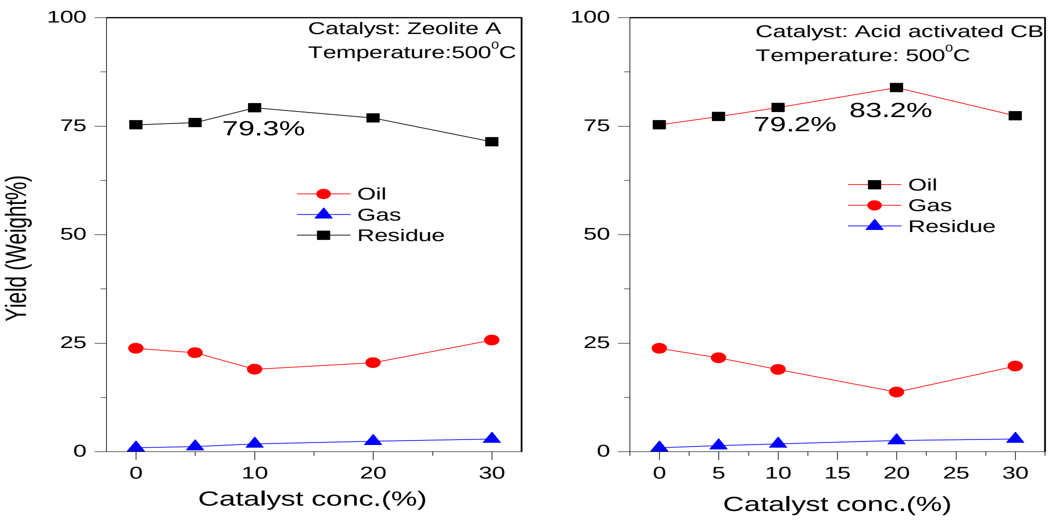


Figure 3 Effect of catalyst concentration on product distribution

B. Development of Mamdani type FIS

Such model has been developed using Mamdani Fuzzy Interface System where all the Node location are determined by centroid method. Temperature (TP), CB and Zeolite A Catalyst(ZC) as input andoil production as output for simulation using fuzzy system. The Mamdani fuzzy takes TP, CB and ZC value as input in order to map the output as oil yield. The input parameters for the mamdani system is provide as TP,CB and ZC values.. Figure 4 described that Mamdani fuzzy inference system by taking three inputs such Temperature of reaction, Catalyst Calcium bentonit and Catalyst Zeolite denoted as TC, CB and ZC and it explains the optimum output of oil yield.It

is represented in nine different membership function such as very very low (VVL), very low (VL), low (L),medium low (ML), medium (M), medium high (MH), high (H), very high (VH), very very high (VVH) is given in Figure5,Figure 6 and Figure 7. Range of input membership functions varies [ZC_{min},ZC_{max}] and [TP_{min},TP_{max}],where ZC_{min},TP_{min}stands for minimum and ZC_{max}, TP_{max}stands for maximum values of ZC and TP.Also input membership functions varies [CB_{min},CB_{max}] and [TP_{min},TP_{max}], where CB_{min}, TP_{min}stands for minimum and CB_{max}, TP_{max}stands for maximum values of CB and TP.

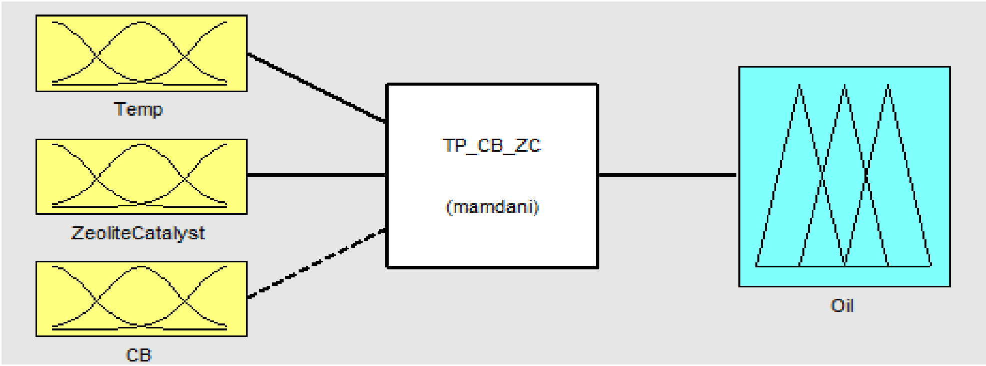


Figure 4System model of Mamdani FIS

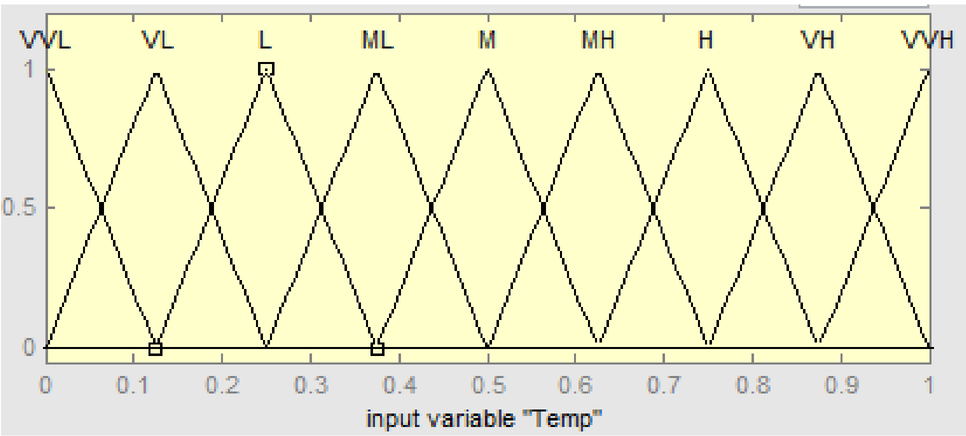


Figure 5. Temperature Membership function

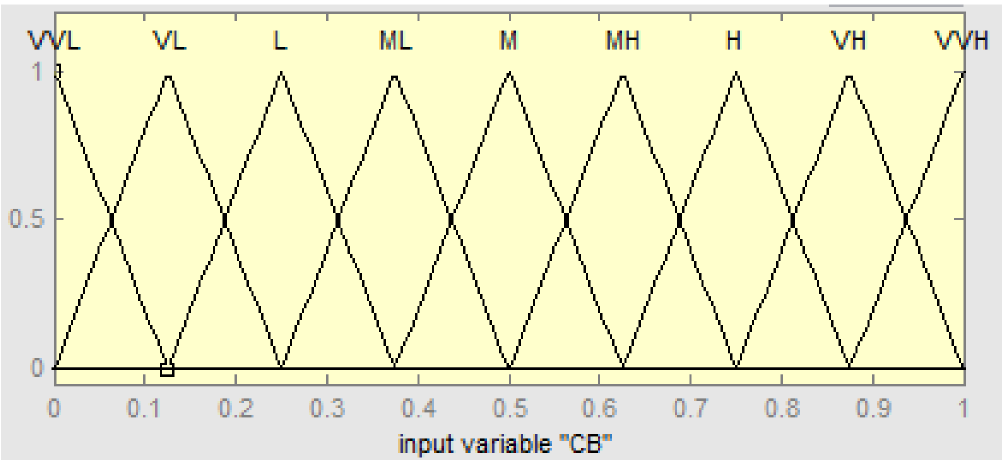


Figure 6.Calcium Bentonite (CB) Membership function

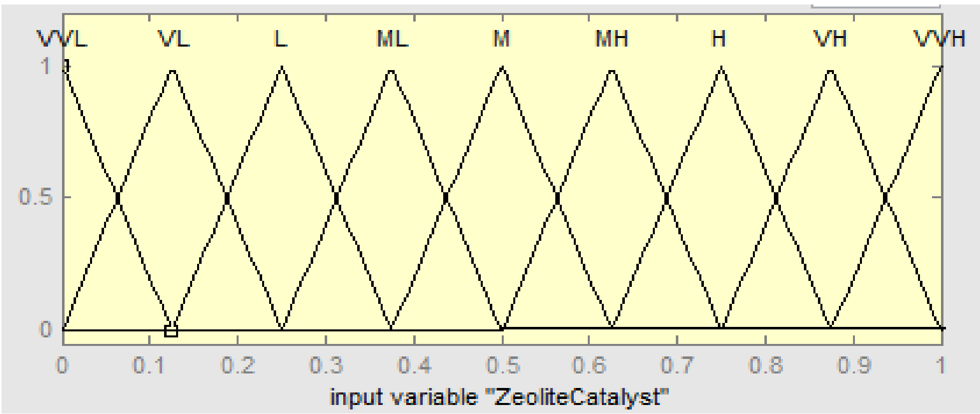


Figure 7. Zeolite -AMembership function

Figure (8 and 9) represents the surface view of input and output parameter in efficient ways using Mamdani fuzzy system. It gives the better performance of the system during the oil calculation by this three input as TP, CB and ZC. It is obvious from the given diagram shows that Zeolite Catalyst, where temperature is high, then oil-estimation is more and when temperature shows low values for same range of pressure, yield is also gradually decreasing in nature. The surface representation generated by Zeolite A Catalyst, temperature and oil-yield are featured in this figure. At the upper and lower range of Zeolite A Catalyst, the high temperature as shown in figure, produces high range of oil-yield and a low oil-yield is achieved at low temperature, during the high range of Zeolite A Catalyst. It also represents that at higher range of CB, where temperature is high, there oil-yield is high and when temperature is low for same range of pressure, yield is also gradually decreasing in nature.

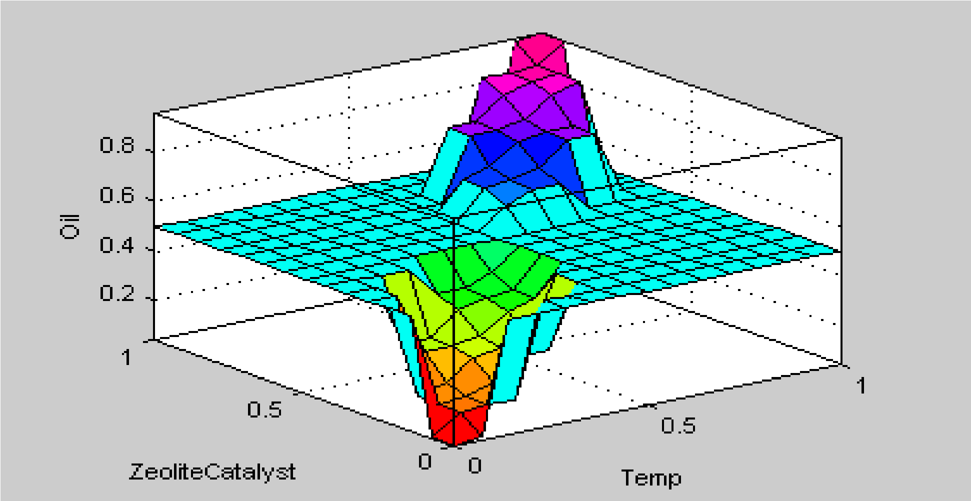


Figure 8 Surface view of Temperature, Zeolite- A Catalyst and Output Oil

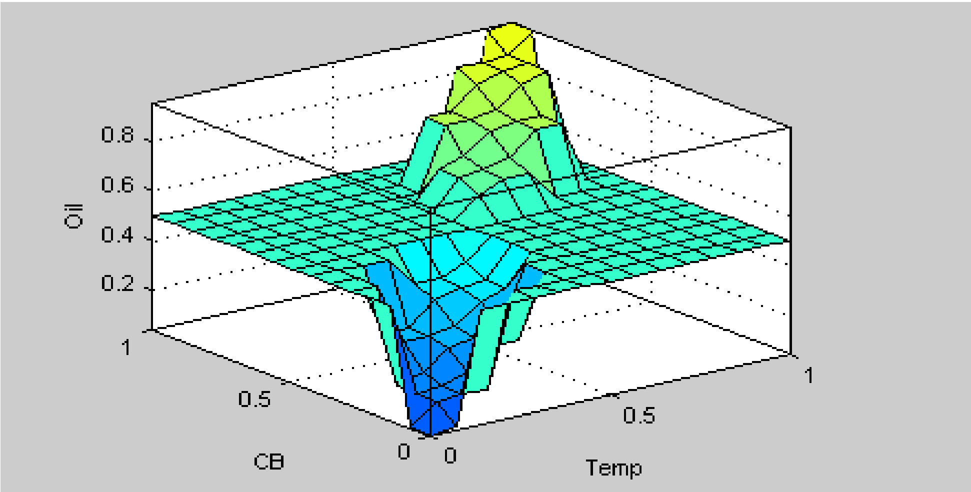


Figure 9 Surface view of Temperature, CB and Output Oil

The fuzzy membership characteristic value is divided into distinct linear characteristic parameters such as: VVL, VL, L, ML, M, MH, H,VH and VVH. The range of the input value is represented as $[0,ZC_{max}]$where ZC_{max}stands for maximum value as 1(one). The fuzzy rules are represented by Mamdani system is maintaining and based on the value of ZC.

Figure 10and Figure 11describes the fuzzy rules in efficient and dynamic manner to predict the oil yield. It also represents Rule view of input and output parameter using Mamdani fuzzy system. And derives the rules during the calculation. These 9 rules help to predict the best way to obtain high oil yield at new inputs introduce.

The Mamdani fuzzy inference Rules proposed in the process modelling are given bellow:

Rule 1. If (TP is VVL) and (CB is VVL) and (ZC is VVL) then (Oil is VVL)

Rule 2 .If (TP is VL) and (CB is VL) and (ZC is VL) then (Oil is VL)

Rule 3. If (TP is L) and (CB is L) and (ZC is L) then (Oil is L)

Rule 4. If (TP is ML) and (CB is ML) and (ZC is ML) then (Oil is ML)

Rule 5. If (TP is M) and (CB is M) and (ZC is M) then (Oil is M)

Rule 6. If (TP is MH) and (CB is MH) and (ZC is MH) then (Oil is MH)

Rule 7. If (TP is H) and (CB is H) and (ZC is H) then (Oil is H)

Rule 8. If (TP is VH) and (CB is VH) and (ZC is VH) then (Oil is VH)

Rule 9. If (TP is VVH) and (CB is VVH) and (ZC is VVH) then (Oil is VVH)

Control surface of the fuzzy system (Figure 10,11) which explains the interdependency of input, and output parameters guided by the various rules in the given system. It represents Rule view of input and output parameter using Mamdani fuzzy system. It gives the derives the rules during the oil calculation. This 9 rules help to better ways predicts oil when new input comes. This figure clearly shows that at Temp =0.5, Zeolite catalyst 0.5 and the predicted oil is 0.5 of undertaken parameters at various others values of system can also be predicted from the fuzzy models.

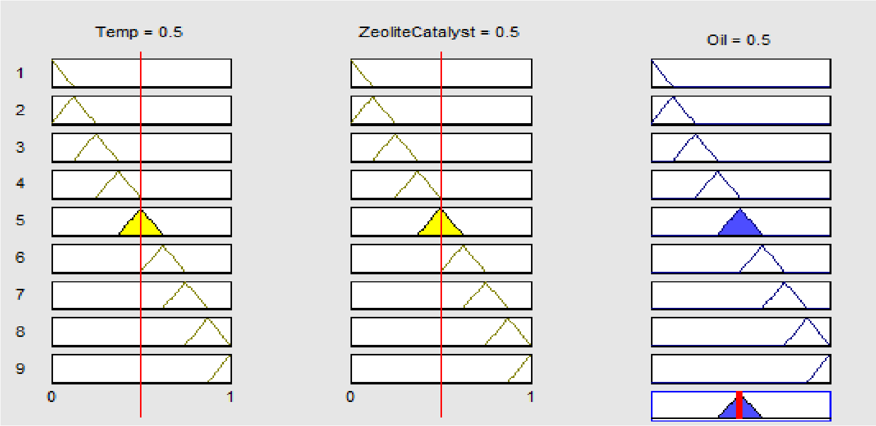


Figure 10 Rule View of control surface of Zeolite in FIS

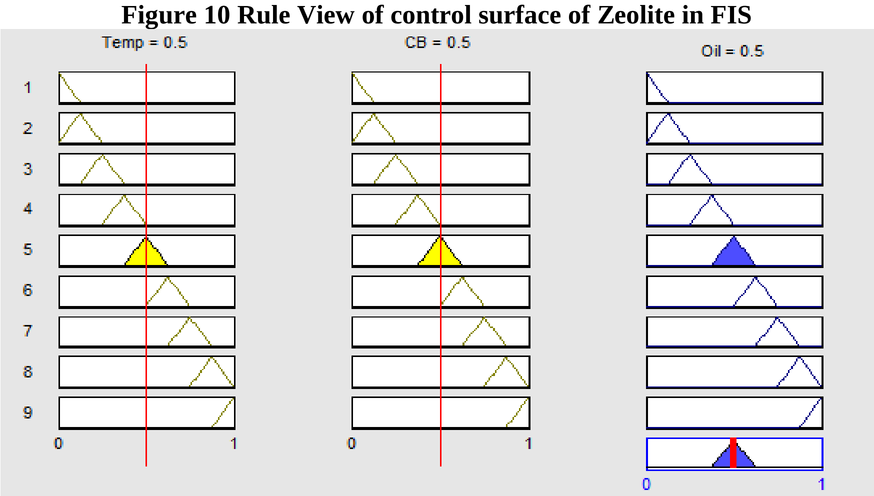


Figure 11 Rule View of control surface of CB in FIS

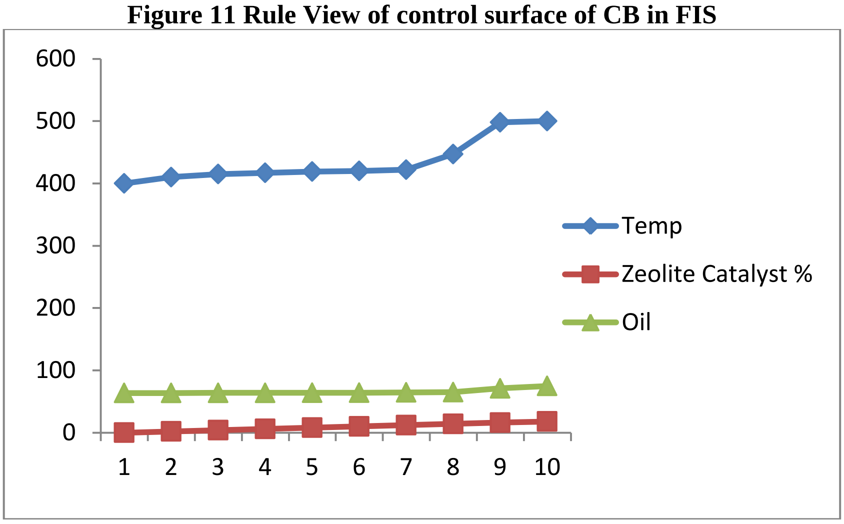


Figure 12. ZC& TP vs. Oil

Figure 12 describes the performance factors which predict the significance of maximum oil yield. It is found that oil yields become maximum during temperature of 450-500 ^{o}C with 10 % Zeolite mixed with the sample.

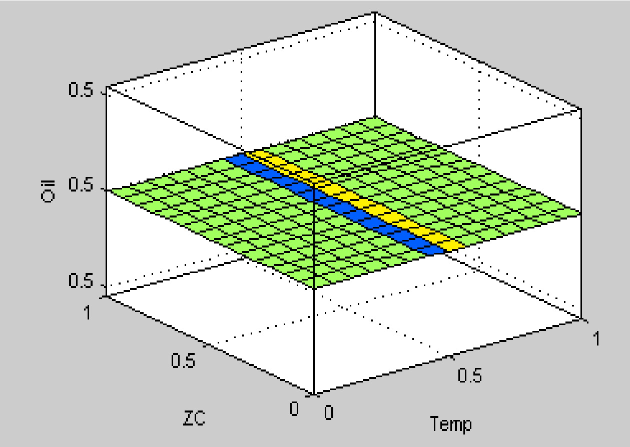


Fig 13 Surface View of Mamdani type of FIS

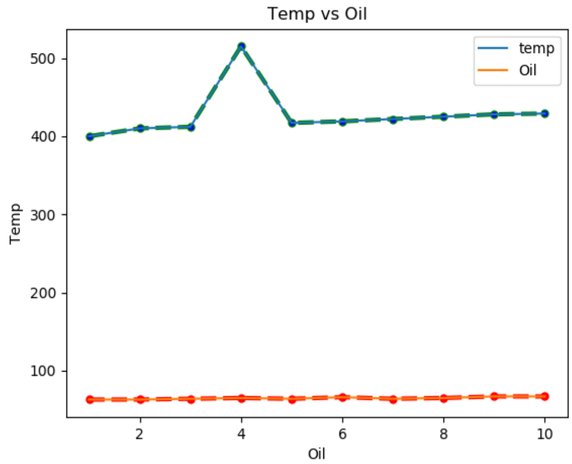


Figure.14 Oil yield Vs Temperature

Figure 13 describes the surface view of Mamdani FIS. It predicts the performance simulation of volume of oil yield. It also explains the volume of oil production dependent on two input parameters using Mamdani fuzzy system. It helps to validate better performance by optimising temperature and concentration of CB Catalyst.Figure.14 shows the effect of temperature on oil yield and it is found that when temperature at 500°C gives oil production ratio better in system. The systems have been compared with the experimental results for its validation in the different temperature value

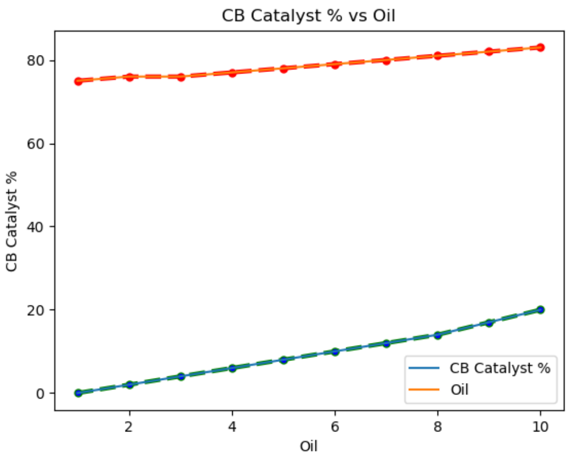


Figure.15 Oil Vs Calcium Bentonite (CB)

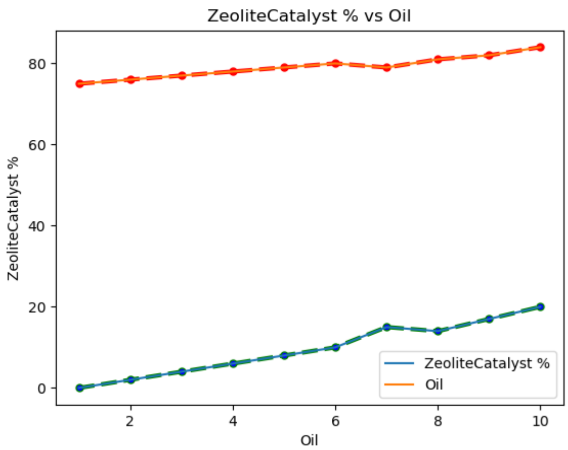


Figure.16 Oil Vs Zeolite Catalyst(ZC)

Figure.15 shows when Calcium bentonite value totally reflects in the oil production. The system shows that ratio of CB and Oil is directly proportional to each other, when CB value increases, then oil production increases up to 20%.Figure.16 represents that Oil prediction value depends directly upon the Zeolite A Catalyst value. This result shows that ratio of ZC and Oil is proportional to each other when ZC value increase then oil production increases up to 10%.

IV. CONCLUSION

In the current work, a better utilization of fuzzy logic system in optimization process of oil extraction from Waste Medical wastes has been addressed where TP, ZC and CB are used as input parameters. The fuzzy rule based system explained the significance of the new method introduced in the simulation process. During the oil yield prediction process, Mamdani fuzzy model represented a key role to define a system where input parameter made a path to calculate the maximum productivity of oil.The extent of accuracy in result calculation process of oil was found depended on the inputs value. Hence, the proposed fuzzy system has been proven a sustainably analyzing the sample and established the efficiency of oil extraction process.

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