Artificial Intelligent Control for a Novel Advanced Microwave Biodiesel Reactor

W. A. Wali1, K. H. Hassan, J.D. Cullen, A. I. Al-Shamma’a, A. Shaw, S.R. Wylie

Built Environment and Sustainable Technologies Institute (BEST), School of the Built Environment, Faculty of Technology and Environment Liverpool John Moores University, Byrom Street, Liverpool L3 3AF, U.K.

E-mail: w.wali@2009.ljmu.ac.uk

Abstract. Biodiesel, an alternative diesel fuel made from a renewable source, is produced by the transesterification of vegetable oil or fat with methanol or ethanol. In order to control and monitor the progress of this chemical reaction with complex and highly nonlinear dynamics, the controller must be able to overcome the challenges due to the difficulty in obtaining a mathematical model, as there are many uncertain factors and disturbances during the actual operation of biodiesel reactors. Classical controllers show significant difficulties when trying to control the system automatically. In this paper we propose a comparison of artificial intelligent controllers, Fuzzy logic and Adaptive Neuro-Fuzzy Inference System(ANFIS) for real time control of a novel advanced biodiesel microwave reactor for biodiesel production from waste cooking oil. Fuzzy logic can incorporate expert human judgment to define the system variables and their relationships which cannot be defined by mathematical relationships. The Neuro-fuzzy system consists of components of a fuzzy system except that computations at each stage are performed by a layer of hidden neurons and the neural network’s learning capability is provided to enhance the system knowledge. The controllers are used to automatically and continuously adjust the applied power supplied to the microwave reactor under different perturbations. A Labview based software tool will be presented that is used for measurement and control of the full system, with real time monitoring.

1. Introduction
Biodiesel is becoming an environmentally friendly fuel due to its non-toxic and biodegradable characteristics [1]. With increasing world crude oil prices, the focus of research is to produce biodiesel fuels from very poor quality, waste cooking oil. Fig.1 shows the production of biodiesel from waste oil.

![Image of biodiesel production process](Fig1.jpg)
Energy consumption studies show that the continuous-flow preparation of biodiesel using microwave heating proves to be more energy efficient than the conventional synthesis of biodiesel in large tank reactors\[2\]. Microwave technology offers the prospect of better conversion and separation processes\[3\]. The multipurpose microwave reactors developed by Radio Frequency group of Liverpool John Moores University were used to assist the rate of separation of the methanol and oil phases to produce biodiesel from waste cooking oil and animal fats as shown in Fig.2.

![Microwave Reactor](image1)

**Fig.2** Novel microwave laboratory reactor heating system.

The biodiesel reaction step has the largest effect on the quality and quantity of the final product. An unsuccessful reaction step due to any disturbances or changes in the reaction conditions leads to incomplete conversion of the triglycerides it is therefore advantageous to be able to control and monitor the transesterification reaction until the completion. When dealing with the problem of continuous transesterification reactor control, we need to consider the nonlinear nature of the process, operational, safety limitations imposed on manipulated variables\[4\], and system is subject to many unexpected disturbances . In this work, the intelligent control methods, Fuzzy logic and Adaptive Neuro-Fuzzy Inference System(ANFIS) were successfully applied to maintain high performance under various operational conditions. Automated the monitored and controlled system was developed using laptop computer and National Instrument’s Data Acquisition(DAQ) as shown in Fig.3, with Labview software tool. Labview as shown in Fig.4, stands for Laboratory Virtual Instrument Engineering Workbench, and is a graphical programming language which was use to receive the signals from the transducers through the DAQ, process the signals and send the output signals to the equipment to be controlled. The physical quantities of the system to be automated are sensed by the biodiesel system sensors as shown in Fig.5.

![DAQ System](image2)

**Fig.3** Compact DAQ for the biodiesel system

![Labview Interface](image3)

**Fig.4** Biodiesel system in Labview

![Biodiesel Sensors](image4)

**Fig.5** Biodiesel sensors .
2. Experimental system setup
The automated microwave system has been used as a heating source for the reactor to produce biodiesel from waste cooking oil and animal fats. Microwaves at a frequency of 2.45GHz were used to reduce the chemical reaction time, from hours under conventional heating, to minutes for the same volume of waste input. This novel microwave reactor is capable of operating at commercial production rates (kg/hr) instead of laboratory scale (g/day). A Labview-based microwave biodiesel reactor control system as shown in Fig.6 was built in order to implement the Fuzzy logic and Neuro-Fuzzy Inference System (ANFIS) online. All the changes in the control system could be observed in real time and user commands could be accepted during the process.

![Biodiesel system](image)

3. Controllers
3.1. Fuzzy Logic controller design
Fuzzy logic control incorporates human knowledge to describe a system without requiring a mathematical model. A Fuzzy controller is composed of three calculation steps[5]: **Fuzzification:** the function of accepting input values and determining the degree of membership to some pre-selected linguistic terms. **Fuzzy Inference:** consists of determining the relationships based upon If-Then rules used to obtain more weighted outputs. These outputs are also linguistic variables in nature and have a nonlinear relationship. **Defuzzification:** involves converting the output term into a crisp value such that it is compatible with the system. The Fuzzy controller was based on the Mamdani Fuzzy logic Labview Toolkit. The first Fuzzy input represents the error between the measured temperature and the setpoint. The second Fuzzy input represents the change in error. Fig.7 shows the membership functions, (a) for the error and (b) for the change of error over the range of input variable values and linguistically describes the variables universe of discourse. Five membership functions were selected with triangle shape as follows: large positive, small positive, zero, small negative, large negative. The universe of discourse for the error and the change of error were -18 to 18 and -12 to 12 respectively. The left and right half of the triangle membership functions for each linguistic label was chosen to provide a membership overlap with adjacent membership functions.

![Membership functions](image)

**(a)**

**(b)**

**Fig.7** Fuzzy inputs membership functions for (a) error and (b) change of error.
The Fuzzy logic controller output delivered power which applied to the microwave reactor. Fig. 8 shows the membership functions of the output linguistic variables of Fuzzy output.

The output variable was chosen in the interval from -100 to 100 with seven triangle membership functions; large positive, medium positive, small positive, zero, small negative, medium negative, large negative. The rule base of the fuzzy controller decides which of the five membership functions have to fire. The rule evaluation part has 25 fuzzy rules. Table 1 shows the Fuzzy logic control rules developed for the proposed system.

### Table I

| $\Delta e$ | Lg neg | Sm neg | Zero | Sm pos | Lg pos |
|-----------|--------|--------|------|--------|--------|
| Lg neg    | Lg neg | Med neg| Med pos| Med neg| Sm pos |
| Sm neg    | Med neg| Sm neg | Sm pos| Zero   | Sm pos |
| Zero      | Sm neg | Zero   | Sm pos| Sm pos | Med pos|
| Sm pos    | Sm neg | Zero   | Sm pos| Med pos|
| Lg pos    | Sm neg | Sm pos | Zero | Med pos| Lg pos |

3.2. Adaptive Neuro- Fuzzy Inference System (ANFIS) control.

Adaptive Neuro- Fuzzy Inference Systems (ANFIS) are fuzzy Sugeno put in the framework of adaptive systems to facilitate learning and adaptation. Such frameworks make fuzzy logic more systematic and less relying on expert knowledge [6]. The objective of ANFIS is to optimize the parameters of a given fuzzy inference system by applying a learning procedure using a set of input-output training data. A combination of least square and back-propagation methods are used for training a fuzzy inference system to enhance its performance [7]. In our work, we designed the ANFIS as a first order Sugeno fuzzy model so the consequent part of the fuzzy rules is a linear equation with generalized bell-shaped membership functions of the inputs, which contain three fitting parameters; centre and half of the width and slope. Two membership functions were chosen on each input, usually this number is determined experimentally. The Initialization of the primes parameters of the ANFIS network are set so that the centers of the membership functions are equally spaced along the range of input variable, where the initial value of consequent parameters are assumed zero. The inverse model control approach was used, in which the controller is the inverse of the plant. In this method a learning task is needed to find the inverse model of the advanced biodiesel microwave.
system so ANFIS inverse learning for control purpose is performed as shown in Fig.9. The training data were obtained from real experiments to reflect input-output characteristics of the biodiesel reactor. In the application phase, the obtained ANFIS inverse model was used to generate the control action.

**Block diagram for inverse control method (training)**

4. Experimental results and Conclusion.

The (ANFIS) and Fuzzy logic were implemented online for the advanced biodiesel microwave reactor. All the experimental results are in 5sec control sample intervals and for a 300 ml/min flow rate. The controllers were subjected to a multiple set point tracking beginning from the nominal temperature value of 30°C and changing to 35°C then down to 30°C as shown in Fig.10(a). The ANFIS and Fuzzy controllers successfully tracked the reactor temperature setpoint accurately, but the ANFIS controller had no overshoot and undershoots even in setpoint tracking beginning from the inlet temperature. The ANFIS control response was faster than Fuzzy logic as shown in Fig.10(b). The controllers were then tested under an introduced disturbance in the feed to the flow rate of the reactor. After the start up of the process, the reactor temperature was left regulated by the controllers at 30°C. The disturbance was then introduced when the nominal feed in flow rate was reduced by 20%, it was observed that the (ANFIS) controller was able to bring back the process to its initial setpoint of 30°C with very small effect as shown in Fig.11. For further test under disturbance, the input flow rate was reduced 10% then sudden raised by 30%, the ANFIS controller showed a good ability to disturbance rejection and tracking performance.

**Fig.10** Neuro- Fuzzy Inference System (ANFIS) and Fuzzy logic controllers (setpoint tracking temperature).
6. Conclusion

Intelligent control techniques including Fuzzy logic and ANFIS control were designed and implemented for a novel microwave biodiesel reactor. A Labview software tool was used for real time monitoring and control for the full system. The achieved results showed that proposed ANFIS controller is more robust to parameter variations when compared to the Fuzzy controller.

6. References

[1] N. Ellis, F. Guan, T. Chen, C. Poon, “Monitoring Biodiesel Production(transesterification) Using in Situ Viscometer”, Chemical Engineering Journal, Vol.138, PP.2000-206, 2008.

[2] T. Michael, Barnard, Nicholas E. Leadbeater, “Microwave Technology and Continuous – Flow Production”, Biodiesel Magazine, october 2007 Issue.

[3] T. Michael, N. Leadbeater, M. Boucher, L. Stencel, B. White, “Continuous-Flow Preparation of Biodiesel Using Microwave Heating”, Energy & Fuels, Vol.21, PP.1777-1781, 2007.

[4] F. Mjalli, M. Hussain, “Approximate Predictive Versus Self-Tuning Adaptive Control Strategies of Biodiesel Reactors”, Ind. Eng. Chem. Res., Vol.48, PP.11034-11047, 2009.

[5] D. Ruan, “Intelligent Systems: Fuzzy Logic Neural Networks and Genetic Algorithms”, Kluwer Academic Publishers, USA, 1997.

[6] K. Assaleh, “Extraction of Fetal Electrocardiogram Using Adaptive Neuro-Fuzzy Inference System”, IEEE Transactions on Biomedical Engineering, Vol.54, No.1, PP.5968, 2007.

[7] X. K. Zhang, Y. C. Jin, and G. Guo, “ANFIS Applied to a Ship Autopilot Design”, Proceedings of The Fifth International Conference on Machine Learning and Cybernetics, Dalian. PP: 2233-2236, August, 2006.