RULE-BASED MAMDANI-TYPE FUZZY MODELING OF PERFORMANCE OF HYDROXY (HHO) DRY CELL WITH 12x12 PLATE COMBINATION

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Abstract— *The fossil fuels and the natural gas reserves that have undertaken the role of the locomotive of the industrial period are limited. It is also the biggest factor in environmental problems. All these reasons lead to the need for alternative fuels or resources. Hydrogen is the candidate to be one of these alternatives; is an unlimited clean and efficient fuel. Hydrogen may assume the role of carrier in the process of storage of other alternative energy sources. Today, interest in hydrogen energy is increasing. One of the reasons for this is that hydrogen can be produced from renewable energy sources such as water, biomass, wind and sun as well as hydrogen from primary energy sources. There is no polluting gas emissions when hydrogen is used as fuel. The HHO dry cell is a device that converts water into HHO (oxyhydrogen) gas. In this study, performance of HHO dry cell with 12x12 plate combination was experimentally investigated and modeled with a Rule-Based Mamdani-Type Fuzzy (RBMTF) modeling technique. Input parameters are; plate number, time, current; output parameter is mass flow rate. The coefficient of multiple determination (R^2=98.5) for the mass flow rate. RBMTF results indicated that RBMTF can be successfully used in HHO dry cell with 12x12 plate combination.*

KEYWORDS*:* FUZZY LOGIC MODELLING, HHO DRY CELL, HYDROGEN,

1. Introduction

Hydrogen is the simplest element. An atom of hydrogen consists of only one proton and one electron. It's also the most plentiful element in the universe. Despite its simplicity and abundance, hydrogen doesn't occur naturally as a gas on the Earth - it's always combined with other elements. Water, for example, is a combination of hydrogen and oxygen (H_2O). Hydrogen is also found in many organic compounds, notably the hydrocarbons that make up many of our fuels, such as gasoline, natural gas, methanol, and propane. Hydrogen can be separated from hydrocarbons through the application of heat - a process known as reforming. Currently, most hydrogen is made this way from natural gas. An electrical current can also be used to separate water into its components of oxygen and hydrogen. This process is known as electrolysis. Some algae and bacteria, using sunlight as their energy source, even give off hydrogen under certain conditions [1].

In 1918 Charles Frazer, a North American inventor, patented the first water electrolysis machine act as a hydrogen booster for internal combustion engines. Yull Brown, a Bulgarian born Australian inventor patented and attempted to popularize Browns Gas as a cutting gas and fuel additive during the 1970's and 80's. HHO is an enriched mixture of hydrogen and oxygen bonded together molecularly and magnetically. HHO gas is produced in a common-ducted electrolyser & then sent to the intake manifold to introduce into combustion chamber of the engine. HHO gases will combust in the combustion chamber when brought to its auto-ignition or self-ignition temperature [2-4].

Zadeh in 1965 introduced fuzzy concept to develop a mathematical framework for imprecisely presented data. It is a generalized form of interval analysis, where parameters are defined with lower and upper values. In a traditional set theory, an element is defined as a member of a set. If the element is in the set, the membership grade is unity, otherwise it is zero. A fuzzy set is an extension of the traditional set theory in which the element has certain degree of membership l (0–1) in the set. Fuzzy set establishes relationship between uncertain data and the membership function l, which ranges from 0 to 1 [5, 6].

Fuzzy logic is a superset of Boolean-conventional logic that has been expanded to handle the concept of partial truth and truth values between "completely true" and "completely false." Fuzzy theory should be seen as a methodology to generalize any specific theory from crisp to continuous. Fuzzy modeling opens the possibility for straightforward translation of statements in natural language verbal formulation of the observed problem into a fuzzy system. Its functioning is based on mathematical tools [7].

In this study, performance of HHO dry cell was investigated experimentally and modeled by fuzzy logic method. The performance parameter is the mass flow rate. The highest value of the mass flow rate was 0.261 x 10^{-3} kg /h.

2. Materials and Methods

Hydrocarbon fuel is one of the sources of energy used for electrical power generation, heating and transportation in the world. But they have negative side effects like polluting emissions, large scale oil spill, etc. Due to its widespread dependence and difficulties in getting other alternatives the use of hydrocarbon fuel could not be eliminated. To mitigate the above problems and to reduce the use of hydrocarbon fuel, hydrogen gas can be supplemented. Hydrogen gas to air intake of a combustion process will improve flame speed, lean burn ability and flame quenching distance. But scarcity and production cost makes it more difficult to implement. Hydrogen rich gas produced from electrolysis of water called the Brown's Gas or HHO could solve the potential difficulties [4, 8].

Fuzzy inference system consists of a fuzzification interface, a rule base, a database, a decision-making unit, and finally a defuzzification interface. The function of each block is as follows. A rule base containing a number of fuzzy IF–THEN rules, a database which defines the membership functions of the fuzzy sets used in the fuzzy rules, a decision-making unit which performs the inference operations on the rules, a fuzzification interface which transforms the crisp inputs into degrees of match with linguistic values and a defuzzification interface which transforms the fuzzy results of the inference into a crisp output. Mamdani's method is the most commonly used in fuzzy inference system, due to its simple structure of 'min-max' operations [9].

In this study, performance of HHO dry cell with 12x12 plate combination was experimentally investigated (Fig.1) and modeled with a RBMTF modeling technique. The experimental setup used in this study is illustrated in Fig.1.

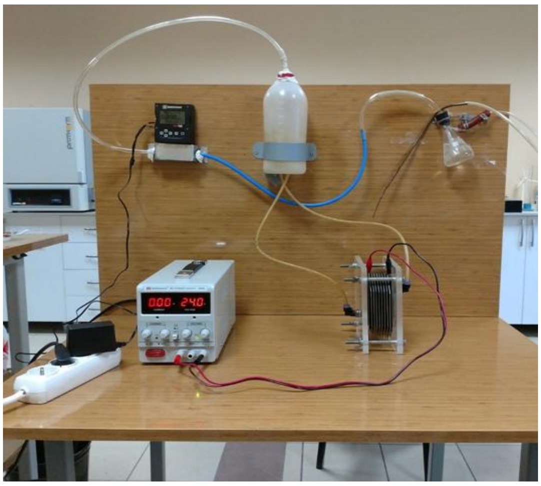

Fig.1. *Experimental system*

In the same way, the used experimental procedure can be presented as follows:

- First the plates are assembled.
- The water outlet of the water tank is connected to the water inlet of the HHO cell.
- The gas inlet pipe of the water tank is fixed to the gas outlet part of the HHO cell.
- Place water in the water tank in such a way that each combination of water level is the same.
- To supply electricity to the HHO cell, the DC power supply is connected to the electric plates of the HHO cell.
- The end of the temperature measuring instrument is attached to the HHO cell plates
- The DC power supply is started and the voltage is fixed at 24 volts.
- Every minute, the current in the DC power supply, the temperature in the temperature meter, and the mass flow rate of the HHO gas read from the mass flow rate are recorded.
- The DC power supply is turned off when the specified time for each experiment is over.
- The gas mixture in the HHO cell is drained.

General structure of RBMTF model developed (three input, one-output) is given in Fig. 2. Input parameters are; plate number (PN), time (t), current (C); output parameter is mass flow rate (MFR).

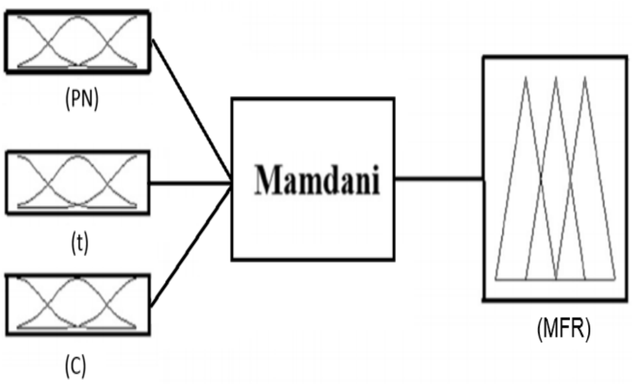

Fig.2. *Designed RMBTF structure*

A fuzzy model expresses a complex system in the form of fuzzy implications. Mamdani model can be built by using these implications (linguistic relationships) and observed data. The Mamdani-based fuzzy models use excessive number of rules for system modeling. Let X be input (regression) matrix and g an output vector defined as Eqs. (1) and (2).

$$X = [x_1, \ldots, x_2]^T = \begin{bmatrix} x_{11} & x_{12} \\ x_{21} & x_{22} \\ \vdots & \vdots \\ x_{n1} & x_{n2} \end{bmatrix} \quad (1)$$

$$g = [g_1, \ldots, g_n] \quad (2)$$

where upper script T denotes the transpose. In the Mamdani fuzzy model, both the antecedent and consequent are fuzzy propositions. A general form of linguistic fuzzy if-then rule is given as Eq. (3).

$$R_i : \text{if } x \text{ is } A_i \text{ then } y \text{ is } B_i;\ i = 1,\ 2, \ldots, K \quad (3)$$

where Ri is the rule number, Ai and Bi are the fuzzy sets, x is the antecedent variable representing the input in the fuzzy system, and y is the consequent variable related to the output of the fuzzy system [10].

In this study, numerical parameters of input and output variables were fuzzificated as linguistic variables: very very low (L_1), very low (L_2), low (L_3), negative medium (L_4), medium (L_5), positive medium (L_6), high (L_7), very high (L_8) and very very high (L_9) linguistic classes (Fig.3).

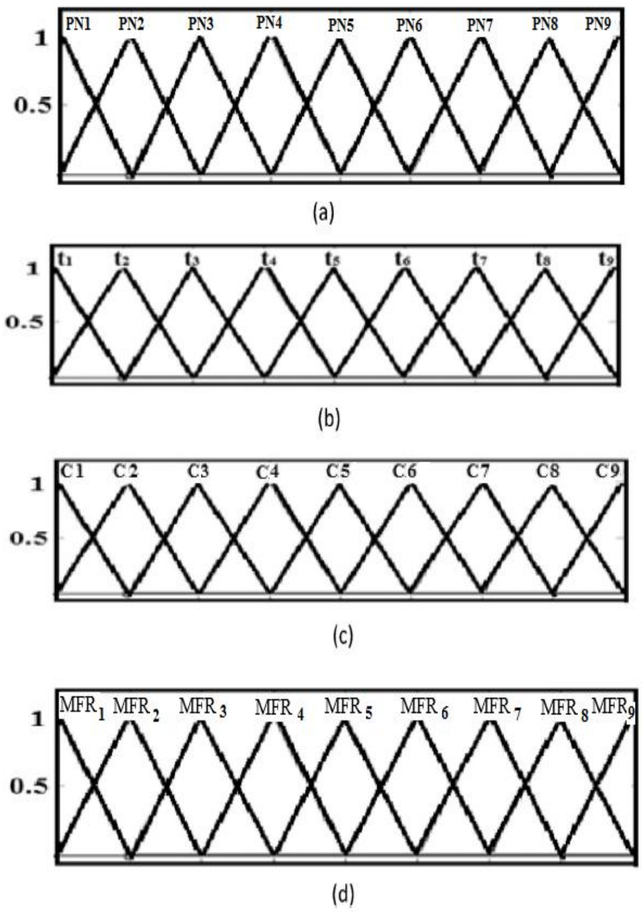

Fig. 3. *Fuzzy membership functions for three input variables and one output variable: (a) PN fuzzy set graphic, (b) t fuzzy set graphic, (c) C fuzzy set graphic, (d) MFR fuzzy set graphic*

3. Results and Discussion

HHO gas has substantial advantages when compared to the gasoline due to its high diffusivity. First two of these advantages is rate of formation of homogenous mixture is greater since HHO diffuses faster in mixture. Secondly, HHO can dilute quite fast under circumstances of leakage. Several researches show that 1866 litres of HHO gas is obtained from 1 liter of water, after ignition, the HHO gas returns to original volume after combustion [11, 12].

The HHO dry cell with 12x12 plate was tested in this study for temperature, current, mass flow rate (Figs. 4-6). According to the experimental results;

- The highest temperature value was found at 5 minutes in the 12-9 plate combination.
- The highest temperature value was measured as 25.5 °C.
- The highest temperature value occurred at 1.01 A.
- The temperature increased when the current increased.
- The mass flow rate increased when time increases.
- The highest value of the mass flow rate was 0.261 x 10^{-3} kg /h. This value was measured in a 9 plate combination and on the 1st minute.

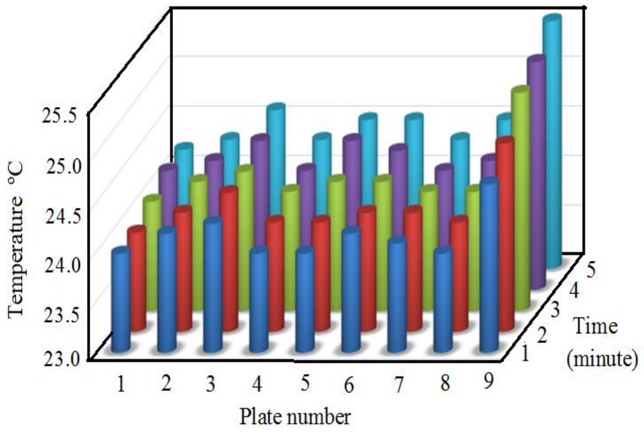

Fig.4. *The temperature values for time*

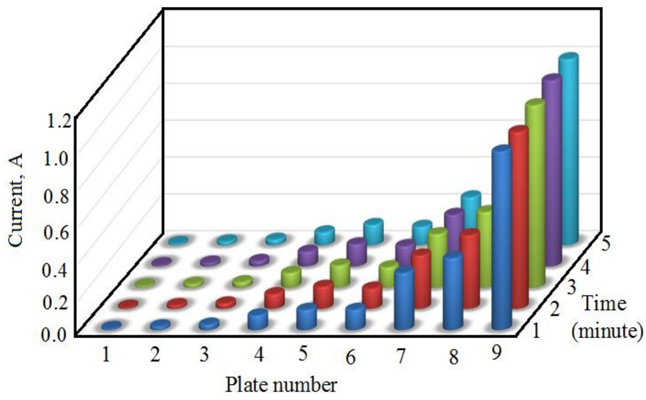

Fig.5. *The current values for time*

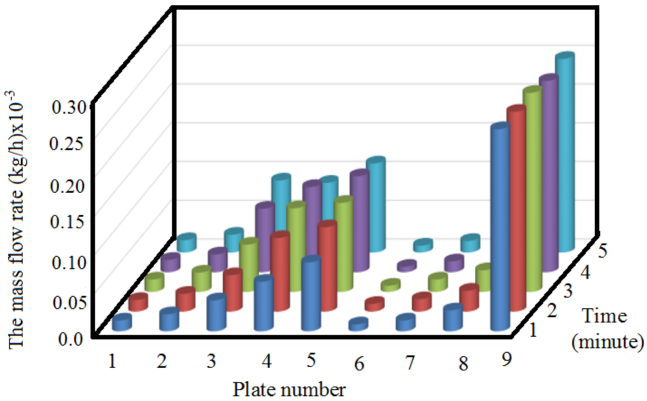

Fig.6. *The mass flow rate values for time*

The purpose of this study is to model the performance of the HHO dry cell using experimental data by the RBMTF modeling technique. The performance parameter is mass flow rate. In Table 1 shows the comparison of experimental data with RBMTF for the mass flow rate.

Table 1. *Comparison of experimental (EXP.) data with RBMTF for the variation of time with mass flow rate (MFR) for plate number (PN)*

Time (min.)	MFR (kg/h)	MFR (kg/h)	MFR (kg/h)	MFR (kg/h)	MFR (kg/h)	Debi (kg/h)
	PN = 1 (EXP.)	PN = 2 (EXP.)	PN=3 (EXP.)	PN=1 RBMTF	PN=2 RBMTF	PN=3 BMTF
1	0.014 x 10^{-3}	0.022 x 10^{-3}	0.04 x 10^{-3}	0.015 x 10^{-3}	0.021 x 10^{-3}	0.05 x 10^{-3}
2	0.015 x 10^{-3}	0.023 x 10^{-3}	0.047 x 10^{-3}	0.016 x 10^{-3}	0.024 x 10^{-3}	0.048 x 10^{-3}
3	0.016 x 10^{-3}	0.025 x 10^{-3}	0.061 x 10^{-3}	0.017 x 10^{-3}	0.026 x 10^{-3}	0.062 x 10^{-3}
4	0.016 x 10^{-3}	0.023 x 10^{-3}	0.082 x 10^{-3}	0.017 x 10^{-3}	0.024 x 10^{-3}	0.084 x 10^{-3}
5	0.016 x 10^{-3}	0.023 x 10^{-3}	0.093 x 10^{-3}	0.018 x 10^{-3}	0.024 x 10^{-3}	0.095 x 10^{-3}
Time (min.)	MFR (kg/h)	MFR (kg/h)	MFR (kg/h)	MFR (kg/h)	MFR (kg/h)	MFR (kg/h)
	PN=4 (EXP.)	PN=5 (EXP.)	PN=6 (EXP.)	PN=4 RBMTF	PN=5 RBMTF	PN=6 BMTF
1	0.064 x 10^{-3}	0.089 x 10^{-3}	0.009 x 10^{-3}	0.065 x 10^{-3}	0.09 x 10^{-3}	0.010 x 10^{-3}
2	0.095 x 10^{-3}	0.109 x 10^{-3}	0.01 x 10^{-3}	0.093 x 10^{-3}	0.119 x 10^{-3}	0.012 x 10^{-3}
3	0.108 x 10^{-3}	0.115 x 10^{-3}	0.008 x 10^{-3}	0.109 x 10^{-3}	0.125 x 10^{-3}	0.009 x 10^{-3}
4	0.11 x 10^{-3}	0.124 x 10^{-3}	0.007 x 10^{-3}	0.12 x 10^{-3}	0.124 x 10^{-3}	0.008 x 10^{-3}
5	0.09 x 10^{-3}	0.115 x 10^{-3}	0.009 x 10^{-3}	0.10 x 10^{-3}	0.116 x 10^{-3}	0.0011 x 10^{-3}
Time (min.)	MFR (kg/h)	MFR (kg/h)	MFR (kg/h)	MFR (kg/h)	MFR (kg/h)	MFR (kg/h)
	PN=7 (EXP.)	PN=8 (EXP.)	PN=9 (EXP.)	PN=7 RBMTF	PN=8 RBMTF	PN=9RBMTF
1	0.14 x 10^{-3}	0.027 x 10^{-3}	0.261 x 10^{-3}	0.15 x 10^{-3}	0.0278	0.263 x 10^{-3}
2	0.16 x 10^{-3}	0.027 x 10^{-3}	0.258 x 10^{-3}	0.17 x 10^{-3}	0.027x 10^{-3}	0.259 x 10^{-3}
3	0.16 x 10^{-3}	0.028 x 10^{-3}	0.257 x 10^{-3}	0.17 x 10^{-3}	0.029x 10^{-3}	0.258 x 10^{-3}
4	0.14 x 10^{-3}	0.026 x 10^{-3}	0.247 x 10^{-3}	0.15 x 10^{-3}	0.027 x 10^{-3}	0.248 x 10^{-3}
5	0.15 x 10^{-3}	0.027 x 10^{-3}	0.25 x 10^{-3}	0.16 x 10^{-3}	0.028 x 10^{-3}	0.26 10^{-3}

4.Conclusions

In this study, a HHO dry cell with 12x12 plate was investigated experimentally and modeled by RBMTF. According to the experimental results; the highest value of the mass flow rate is 0.261 x 10^{-3} (kg /h). This value was measured in a 12-9 plate combination and on the 1^{st} minute.

The comparison between experimental data and fuzzy logic is done using statistical methods such as the R^2 are defined as follows (Eq.1),

$$R^2 = 1 - \frac{\sum_{m=1}^{n}(t_{m,m} - y_{p,m})^2}{\sum_{m=1}^{n}(t_{m,m} - \bar{t}_{m,m})^2} \quad (4)$$

where n is the number of data patterns, $y_{p,m}$ indicates the predicted, $t_{m,m}$ is the actual value of one data point m, and $\bar{t}_{m,m}$ is the mean value of all actual data points [13].In this study, the R^2=98.5 is for the mass flow rate and RBMTF can be successfully used in HHO dry cell with 12x12 plate combination.

Acknowledgment

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