Adaptive Neuro-Fuzzy Inference System Prediction Method for Percentage Fatalities of Jet Fire Incident in Methanol Production Plant

Mohd Aizad Ahmad, Zulkifli Abdul Rashid

Abstract*: This research highlights on development of simpler prediction method for percentage fatalities occurred during jet fire incident in methanol production plant. A lot of parameters involved before fatalities can be determined using consequence model analysis. The parameters involved needed to calculate surface emitting power, view factor, transmissivity and area affected footprint to determine estimated fatalities. HYSYS software used to simulate density of mixture, mass and volume fraction of each component resulting from carbon dioxide and hydrogen reaction. These values used as input in ALOHA simulation to estimate area footprint. Affected area footprint then calculated in MARPLOT, which in turn used for estimating percentage fatalities. These resulting fatalities used as ANFIS prediction analysis to predict percentage fatalities, then compared to the simulation data from ALOHA and MARPLOT. The selected input data was operating pressure, volume, mass, size of leakage and wind speed. The predicted data from ANFIS attained R^2 at 0.9998 for both membership function used, triangular and Gaussian while for capabilities test, R^2 of 0.998 was achieved using Gaussian. Therefore, simpler method to predict percentage fatalities for the event of jet fire in methanol plant was successful.

Index Terms: **ANFIS, jet *fire, methanol, prediction method.***

I. INTRODUCTION

Methanol economy proposed firstly by George Olah [1] has identified as the solution for reduction of carbon dioxide emission, boost for renewable energy usage and mass-adoption for hybrid fuel- electric vehicles [2]. Small scale plant of methanol (MeOH) production integrated with power and carbon capture plant was operated firstly by Carbon Recylce Internation (CRI) using geothermal power plant [3]. The project by EU called MefCO2 granted CRI to boost production of renewable methanol, thus will see such technology to produce methanol from renewable source put into first place. These highlight the importance of such mass production of carbon to methanol production within 10-15 years to come [4]. Researchers produce various analytical assessments on the economic, financial, energy, carbon reduction as well as methanol yield and selectivity. The lab experimental scale was focused on development of customized catalyst to produce higher methanol yield and selectivity [5]–[10] whereas on larger scale, simulation on the methanol plant has been conducted through assessment on another aspect which are economic, financial, energy analysis and optimization through response surface methodology (RSM) [3], [11]–[14].

The progress of lab scale methanol synthesizes using high pressure shows that there are possibilities future plant of carbon to methanol production will have higher pressure condition (as high as near 500 bar),no recycle stream (one pass full conversion) and design with much reduced reactor volume. Current lab scale experiments absolutely are not focused on the safety aspect in term of fatality consequences as lab scale experiments have much smaller size equipment, focusing more on design of catalyst and methanol yield. However, the question arise on how the effect of chemical release to fatality for large scale production operated at high pressure up to 500 bar, with recent assessment of carbon to methanol plant only involved for financial and energy. Furthermore, the pressure condition of reactor only selected at 76- 80 bar. There are no assessment studies for medium to large scale plant operated high pressure condition except one energy study from Tidona et al.[7]. The perception of high pressure condition can lead to more disaster compare to low pressure must be assessed scientifically with systematic method to verify the perception. The importance and significances of safety study for high pressure must be addressed for this time being as this carbon to methanol plant attracts more researcher attention by the day.

Thus, established method of using quantitative risk analysis has been developed for methanol plant accident scenario. One of the possible scenario chemical releases in production plant is jet fire event. Jet fire is a fire of rapid dispersion, released of chemical fluid from a leak in vessel or pipe and immediately ignited [15]. As discussed in Purple Book [16], probability of jet fire event for MeOH is 0.2 for instantaneous release of MeOH below 1000 kg but if the release quantity is between 1000 to 10,000 kg, the probability of this event become 0.5, which is higher and more dangerous to workers inside the plant. Hazard associated with a jet fire event is thermal radiation, has a unit of kilowatt per meter square (kW/m^2). The equation that relates chemical release, thermal radiation and fatality required many parameters involving four main parameters which are actual surface emitting power, view factor, atmospheric transmissivity and calculated footprint area affected.

Revised Manuscript Received on October 30, 2019.

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In order to determine surface emitting power, radiation fraction, heat of combustion, burning rate and total surface area must be estimated. The calculation of total surface area is considered as the shape of a conical frustum including disc which consists of length of the flame, L_B, effective source diameter, D_s, velocity of the fuel in the jet, u_j, angel between axis of the hole and axis of the flame, α (°), the lift-off of the conical frustum, b (m), length of the frustum, R_L (m), frustum base width, W_1 (m) and frustum tip width, W_2 (m). D_s can be determined from parameters involved density of the gas, ρ_j, density of air, ρ_{air}, mass discharge rate, $\dot{m}$ (kg/s), temperature inside vessel, T_s, ratio of specific heats, γ_g, static pressure at the exit orifice, P_c, atmospheric pressure, P_o, and molecular weight of the gas, W_{gk}. View factor, F_{view} is calculated as a function of horizontal, F_h and perpendicular contribution, F_v. The equation to determine F_{view} consists of the area of radiating surface, Aj, angle between the normal to the receiving element and the line between the element and the radiating surface, β_i, the angle between the normal to the radiating surface at a point and the line between that point and the receiving element, β_j and the distance between the point on the radiating surface and the receiving element, r. The third element, atmospheric transmissivity is based on empirical expression including constant c_4, partial water vapor pressure, P_w, the distance of the receptor from the fire, X and radius of fire, R [17].

As a lot of input parameters need to be examined only for one leaking condition at one specific pressure and temperature condition, there is concern of finding simpler way for predicting percentage fatalities if various pressure condition with three categories of leakage need to be examined. Thus, prediction model using Artificial Intelligent proposed to be used with the best capabilities of predicting the output close to the original simulation data. Therefore, an Adaptive Neuro Fuzzy Inference System (ANFIS) has been develop and simulate in this study as simpler method for predicting percentage fatalities in the incident of jet fire event. The learning capabilities of ANFIS can be used to address relationship between significance input parameters and output [18]. The application of AI techniques prediction model has been widely used in environmental modeling, water quality assessment and concentration of heavy metal [19] . However, there are few studies using AI prediction model in area of quantitative risk assessment, specifically for determination of percentage fatalities. Thus, this study focused on developing prediction model using ANFIS for achieving percentage fatalities in simpler method.

II. METHODOLOGY

A. Consequences Model Method

Percentage fatalities data of chemical release from vessel leakage in methanol production plant was determined using ALOHA and MARPLOT software. The release of chemical is in the form of gas, consist of MeOH, which has flammable characteristic and can initiate jet fire incident [15], [20]. Production of MeOH involved reaction of CO_2 and H_2 to produce MeOH and water with unwanted by-product of reactor is carbon monoxide, unreacted H_2 and unreacted CO_2 [12]. Ten different pressure conditions were applied to the reactor vessel which is 76.4, 100, 150, 200, 250, 300, 350, 400, 450 and 500 bar. The different of operating pressure condition change the composition of mixture in the reactor. Thermodynamic equilibrium of the mixture was studied using HYSYS software for each pressure condition with same operating temperature of 288°C and reactor volume of 7.6m^3. Resulting mixture has different density for each pressure condition while volume and weight fraction of every component in the reactor also not similar. Resulting density of mixture for each operating pressure was multiply to reactor volume to get mass of mixture. Calculation of MeOH mass in mixture was using mass fraction multiply to the mass of mixture, while volume of MeOH determined by calculating volume fraction multiply the volume of reactor, 7.6 m^3. The different of volume and mass for MeOH resulting different consequences in term of burn rate and total amount burned, thus affect the resulting area footprint and percentage fatalities. The simulation study also conducted at two different conditions which are day and night, where at day condition, the wind speed is at 2.23 m/s and 1.03 m/s for night condition. The release scenario simulated for three different size of leakage, 10 mm and 25 mm represent continuous release and 160 mm for instantaneous release. The resulting scenario produced affected area footprint which divided into three zoning threat – red, orange and yellow. Red zone threat area received thermal radiation of 10 kW/m^2 and above, while orange zone threat classified thermal radiation between 5 kW/m^2 to 10 kW/m^2 and yellow threat zone receptor gets thermal radiation between 2 kW/m^2 to 5 kW/m^2. Thermal radiation in red zone can potentially cause lethality (death) within 60 seconds, while second degree burns and pain within 60 seconds subjected to orange and yellow zone respectively [17], [21]. The calculation of percentage fatalities only considered person or workers in the area of red zone by dividing area footprint to the processing plant area section [20]. In this research study, the processing plant area has covered 300, 562 square feet (ft^2) while other location such as workshop, utilities and administration building not included for the affected area calculation.

The site location and the atmospheric data for 10 different plants are similar. The location of the plant situated at Manjung , Perak where chosen building plant assume as an unsheltered double storied, resulting building air exchange per hour of 0.29 at day and 0.23 during night condition. Atmospheric data was taken from Sitiawan weather point location, which has data of wind speed, humidity, wind direction and average air temperature. Table I describes site data and atmospheric data of the methanol plant.

Table I: Site and atmospheric data of methanol production plant

Site Data		
Location	Manjung, Perak, Malaysia	
Building air exchange per hour (unsheltered double storied) and time	Day	0.29 and 1500 hours ST
	Night	0.23 and 2300 hours ST
Atmospheric Data		
Wind speed and stability class	Day	2.23 m/s and stability class B
	Night	1.03 m/s and stability class B
Ground roughness	Urban or forest	
Cloud cover	5 tenths	
Air temperature	29°C	
Inversion Height	No	
Relative Humidity	84%	

B. ANFIS Prediction Method

A group of simulation data producing area footprint for methanol release in methanol production plant using ten different pressure conditions was used to develop and test the ANFIS analysis. The input data consists of five main parameters; operating pressure of reactor, mass of methanol in the mixture, volume of methanol in the mixture, size of hole leakage and wind speed and the output data were the percentage fatalities, which estimate from area affected footprint produced in MARPLOT software. The ANFIS analysis was performed in an ANFIS programmed interface using MATLAB and the predicted data was generated. Fig. 1 depicts the flow diagram of conducting ANFIS analysis.

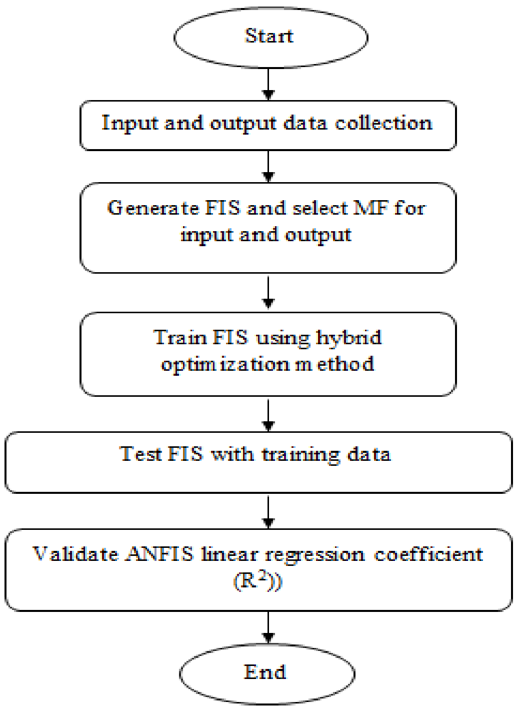

Fig. 1: Flow diagram of ANFIS analysis

ANFIS algorithm combined system of artificial neural network (ANN) and fuzzy inference, where the type of fuzzy using Takagi-Sugeno. Every rule output is the product of linear combination of input and constant term. Architecture of ANFIS comprises of five layers which is fuzzification layer –layer 1, product layer – layer 2, normalized layer –layer 3, defuzzification layer – layer 4 and output layer – layer 5 as illustrated in Fig. 2. Fuzzification layer is where the input x_i is allocated to membership function within range specified for that input. Product layer consist of weight function, w_i which is the product of different inputs membership function. The third layer, normalized layer includes all fixed nodes, which the output of the layer is the fraction of the weight function, label as $\overline{w}_i$. Defuzzification layer connect output and the input multiplied with linear parameters of p_i, q_i and r_i to become $\overline{w}_i f_i$ where $f_i = (p_i x_i + q_i x_i + r_i), i = 1,2$. The fifth layer, output layer combined all inputs component as follow: $f\,(i) = \sum \overline{w}_i f_i,\ \ i = 1,2$ [18], [22] This study chose 5 input parameters as x_1, x_2, x_3, x_4 and x_5.

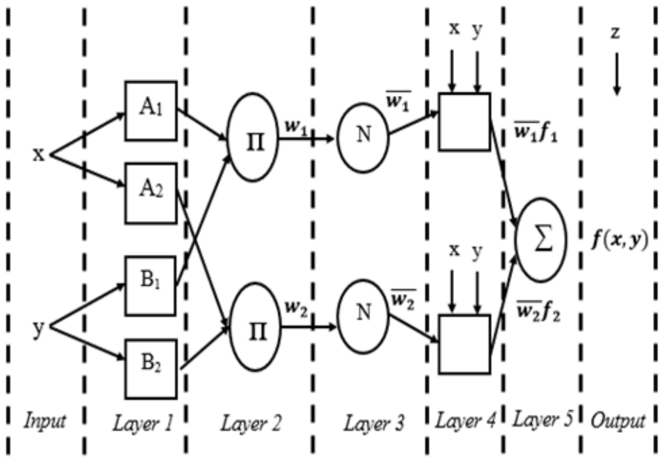

Fig. 2: ANFIS model architecture

Computation of data for ANFIS consists of training using the gradient descent and least square method and predicting the output. There are four steps to develop prediction model using ANFIS. The first step is loading the input data from file. The second step is generating fuzzy inference system, which assigned the fuzzy membership function (MF) to all inputs and output. Then, the data is train and collect data error for the third step. The last step is the prediction of outputs within the range. Two shape of fuzzy MF applied in the study which are triangular and Gaussian MF. Regression number, R^2 measures the accuracy of the model with simulation data where the highest accuracy value of R^2 close to 1 is the best [23]. The equation for R^2 is displayed in (1), as the following,

$$R^2 = 1 - \frac{\sum_{i=1}^{N}\left(Y_i^{pred} Y_i^{sim}\right)^2}{\sum_{i=1}^{N}\left(Y_i^{sim} \overline{Y}_{ave}^{sim}\right)^2} \quad (1)$$

where N is the number of data and $\overline{Y}_{ave}^{sim}$ is value for average simulation value.

III. RESULTS AND DISCUSSIONS

A. Consequences Model Analysis

The input and output data for percentage fatalities were extracted from the simulation data of ALOHA and MARPLOT prepared in Table II. Calculation of percentage fatalities for consequences analysis determined by ratio of affected area to the processing plant area multiplied by 100.

Table II: Percentage fatalities data from consequence model analysis

Operating Pressure (bar)	Volume (m^3)	Mass (kg)	Leakage (mm)	Wind speed (m/s)	% fatalities
76.4	0.39	16.7	10	2.23	0.00
76.4	0.39	16.7	25	2.23	1.12
76.4	0.39	16.7	160	2.23	1.11
100	0.56	31.8	10	2.23	0.00
100	0.56	31.8	25	2.23	1.11
100	0.56	31.8	160	2.23	1.12
150	0.94	80.2	10	2.23	0.00
150	0.94	80.2	25	2.23	1.12
150	0.94	80.2	160	2.23	1.11
200	1.35	155.3	10	2.23	1.12
200	1.35	155.3	25	2.23	1.11
200	1.35	155.3	160	2.23	1.23
250	1.83	272.6	10	2.23	1.12
250	1.83	272.6	25	2.23	1.11
250	1.83	272.6	160	2.23	1.92
300	2.5	492.8	10	2.23	1.12
300	2.5	492.8	25	2.23	1.27
300	2.5	492.8	160	2.23	3.41
350	4.19	1501	10	2.23	1.11
350	4.19	1501	25	2.23	2.20
350	4.19	1501	160	2.23	9.87
400	4.43	1753	10	2.23	1.12
400	4.43	1753	25	2.23	2.54
400	4.43	1753	160	2.23	11.44
450	4.54	1889	10	2.23	1.12
450	4.54	1889	25	2.23	2.75
450	4.54	1889	160	2.23	12.29
500	4.61	1990	10	2.23	1.12
500	4.61	1990	25	2.23	2.95
500	4.61	1990	160	2.23	12.91
76.4	0.39	16.7	10	1.03	0.00
76.4	0.39	16.7	25	1.03	1.12
76.4	0.39	16.7	160	1.03	1.11
100	0.56	31.8	10	1.03	0.00
100	0.56	31.8	25	1.03	1.11
100	0.56	31.8	160	1.03	1.12
150	0.94	80.2	10	1.03	0.00
150	0.94	80.2	25	1.03	1.12
150	0.94	80.2	160	1.03	1.12
200	1.35	155.3	10	1.03	1.12
200	1.35	155.3	25	1.03	1.11
200	1.35	155.3	160	1.03	1.14
250	1.83	272.6	10	1.03	1.12
250	1.83	272.6	25	1.03	1.11
250	1.83	272.6	160	1.03	1.78
300	2.5	492.8	10	1.03	1.12
300	2.5	492.8	25	1.03	1.19
300	2.5	492.8	160	1.03	3.17
350	4.19	1501	10	1.03	1.11
350	4.19	1501	25	1.03	2.12
350	4.19	1501	160	1.03	9.25
400	4.43	1753	10	1.03	1.12
400	4.43	1753	25	1.03	2.44
400	4.43	1753	160	1.03	10.75
450	4.54	1889	10	1.03	1.12
450	4.54	1889	25	1.03	2.65
450	4.54	1889	160	1.03	11.57
500	4.61	1990	10	1.03	1.12
500	4.61	1990	25	1.03	2.80
500	4.61	1990	160	1.03	12.13

There are 60 data produced from various scenarios of leakages with different pressure condition and wind speed. Different operating pressure of reactor resulted different volume and mass of methanol in the mixture product. For example, operating pressure of 76.4 bar has 0.39 m^3 volume and 16.7 kg of mass while operating pressure of 500 bar has 4.6 m^3 volume and 1990 kg mass. Leakage of 160 mm for both operating pressure caused 1.11 % and 12.91% fatalities although received same wind speed. At higher pressure, the density of mixture is increased and more MeOH is produced with more volume. Therefore, there is more MeOH release to atmosphere when leakage occurred for 500 bar compare to76.4 bar, leading more chemical could release and burned compare to lower pressure condition. Size of leakage also give significant different of percentage fatalities as 160 mm leak caused 4-6 times more effect compare to 25 mm leak at operating pressure 350 bar and above. Wind speed was observed has little effect of fatalities for jet fire event as almost every operating pressure produced similar result using different wind speed. For example, at 500 bar, as wind speed is 2.23 m/s, the resulting fatalities occurred was 1.12, 2.95 and 12.91 for 10 mm, 25 mm and 160 mm leak while at 1.03 m/s, the consequence was 1.12, 2.8 and 12.13 for 10 mm, 25 mm and 160 mm leak. However, different wind speed here also represents day or night condition and stability class used. 2.23 m/s indicated day condition using B stability class while 1.03 m/s represent night condition for F stability class, indicating its importance as input parameters. Therefore, the parameter consists of operating pressure, volume, mass, size of leakage and wind speed was chose as input parameter to the ANFIS prediction method. Other input data in ALOHA which are cloud cover, inversion height, air temperature, ground roughness and relative humidity is constant for all operating pressure studied and therefore, not selected as input to the ANFIS.

B. ANFIS Prediction Analysis

The input and output data was generated, trained and tested using ANFIS in MATLAB. Grid partition using three triangular and Gaussian membership functions for each input data was selected to generate Fuzzy Inference System (FIS) while output data are using constant MF. Hybrid optimization method was used to train FIS with error tolerance of 0 and 3 epochs. The tested FIS was plot against training data which resulting an average testing error of 0.043433 for triangular MF and 0.038344 for Gaussian MF. Fig. 3 shows relationship between input and output data. Resulting ANFIS structure have 524 nodes, 243 linear parameters and 243 fuzzy rules for both MF, while 45 and 30 of nonlinear parameters for triangular MF and Gausssian MF respectively.

Retrieval Number: A3060109119/2019©BEIESP
DOI: 10.35940/ijeat.A3060.109119

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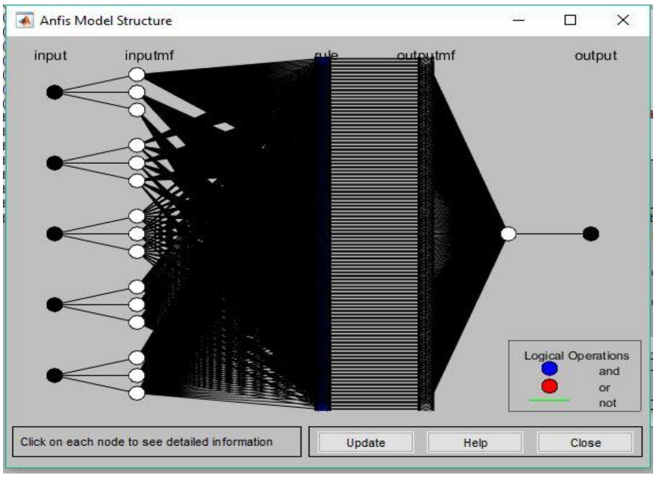

Fig. 3: ANFIS structure for percentage fatalities prediction

Simulation data and ANFIS predicted output data using both triangular and Gaussian MF was compared as listed in Table III.

Table III: Comparison of simulation data and ANFIS predicted output

Simulation (%)	ANFIS Predicted - triangular MF (%)	ANFIS Predicted - Gaussian MF (%)
0.0000	-0.0002	0.0213
1.1166	1.1000	1.1500
1.1119	1.1000	1.1000
0.0000	-0.0320	-0.0811
1.1119	1.1300	1.0800
1.1166	1.1000	1.1100
0.0000	0.1030	0.1180
1.1166	1.0000	1.0300
1.1142	1.1000	1.1000
1.1166	0.9820	1.0100
1.1119	1.2100	1.1700
1.2287	1.2000	1.2000
1.1166	1.1600	1.1300
1.1142	1.0500	1.0700
1.9247	1.9000	1.9000
1.1166	1.0900	1.0900
1.2656	1.3100	1.3100
3.4109	3.4000	3.4000
1.1119	1.1000	1.1000
2.2042	2.2000	2.2000
9.8745	9.9000	9.9000
1.1166	1.0900	1.0900
2.5353	2.5100	2.5100
11.4366	11.4000	11.4000
1.1166	1.1100	1.1100
2.7535	2.7900	2.7900
12.2923	12.3000	12.3000
1.1166	1.1000	1.0900
2.9475	2.9000	2.9100
12.9135	12.9000	12.9000
0.0000	-0.0006	0.0209
1.1166	1.1000	1.1500
1.1142	1.1000	1.0900
0.0000	-0.0318	-0.0809
1.1119	1.1300	1.0800
1.1166	1.1000	1.1200
0.0000	0.1040	0.1190
1.1166	1.0000	1.0300
1.1166	1.0900	1.0900
1.1166	0.9810	1.0100
1.1059	1.2200	1.1700
1.1415	1.1100	1.1000
1.1166	1.1600	1.1400
1.1142	1.0400	1.0700
1.7817	1.8000	1.8000
1.1166	1.0900	1.0900
1.1904	1.2100	1.2100
3.1747	3.2000	3.2000
1.1142	1.1000	1.1000
2.1220	2.1000	2.1000
9.2530	9.3000	9.3000
1.1166	1.0900	1.0900
2.4384	2.4100	2.4100
10.7479	10.7000	10.7000
1.1166	1.1100	1.1100
2.6540	2.6900	2.6900
11.5670	11.6000	11.6000
1.1166	1.1000	1.0900
2.8000	2.8000	2.8100
12.1343	12.1000	12.1000

Fig. 4 and 5 illustrates regression graph between predicted and simulation data percentage fatalities for both ANFIS using triangular and Gaussian MF. The best fit has R^2 of 0.9998 for both triangular MF (trimf) and Gaussian MF (Gaussmf)

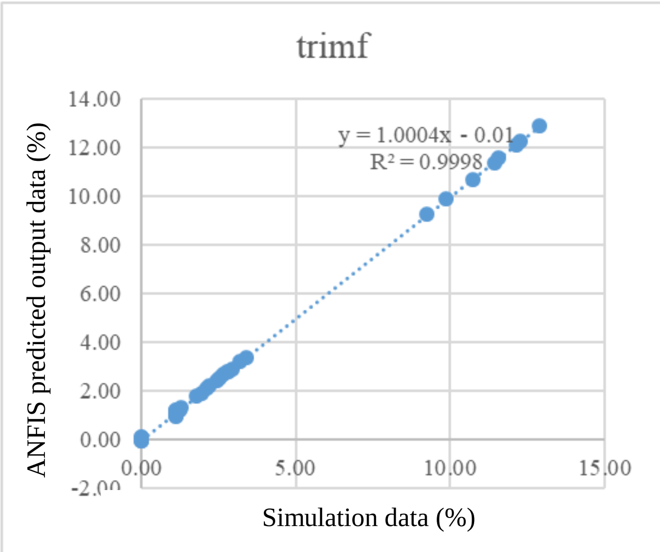

Fig. 4: Regression models of predicted output and simulation data using triangular MF

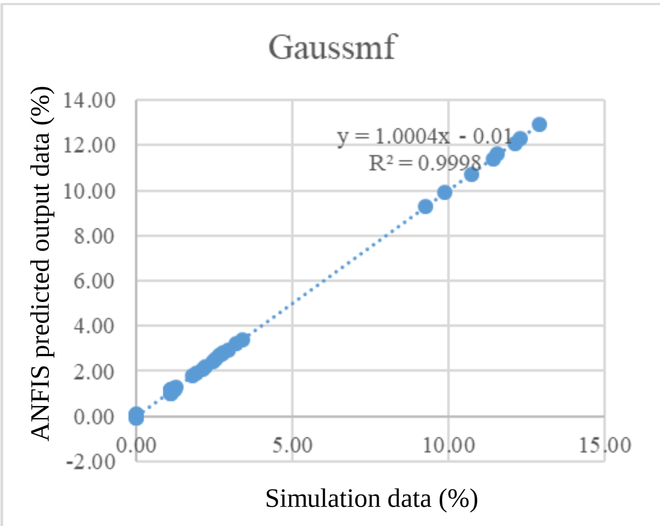

Fig. 5: Regression models of predicted output and simulation data using Gaussian MF

Prediction model using ANFIS has proved best fit regression close to 1, thus can be used as simpler method to predict fatalities. Consequence model method determine fatalities using HYSYS to get mass and volume of chemical, ALOHA and MARPLOT to determine flame length, burn rate, total amount burned and area affected footprint in order to estimate percentage fatalities. In other hand, ANFIS prediction method using HYSYS and MATLAB only in order to get the same percentage fatalities value, within range input data from consequence model method. Therefore, users have more choice to predict fatalities and test another operating pressure as they also can use ANFIS in MATLAB, albeit have similar atmospheric condition and within the range of consequence model method simulated in ALOHA and MARPLOT. For testing capabilities of ANFIS to reproduce results, another set of 24 data predicted using ANFIS first, then simulate using consequence model in ALOHA and MARPLOT was performed. The input data for operating pressure of 92, 184, 335 and 442 bar was used in HYSYS to calculate mass and volume of MeOH in mixture. This data are then used in ANFIS using triangular MF and Gaussian MF to predict percentage fatalities, as presented in Table IV. Table V tabulated the results comparison of ANFIS prediction in MATLAB and simulation data using consequences analysis in ALOHA and MARPLOT.

Table IV: Input parameters for ANFIS capabilities test

Operating Pressure (bar)	Volume (m^3)	Mass (kg)	Leakage (mm)	Wind speed (m/s)
92	0.5	26.2	10	2.23
92	0.5	26.2	25	2.23
92	0.5	26.2	160	2.23
184	1.2	127.8	10	2.23
184	1.2	127.8	25	2.23
184	1.2	127.8	160	2.23
335	4	1299.6	10	2.23
335	4	1299.6	25	2.23
335	4	1299.6	160	2.23
442	4.5	1869.9	10	2.23
442	4.5	1869.9	25	2.23
442	4.5	1869.9	160	2.23
92	0.5	26.2	10	1.03
92	0.5	26.2	25	1.03
92	0.5	26.2	160	1.03
184	1.2	127.8	10	1.03
184	1.2	127.8	25	1.03
184	1.2	127.8	160	1.03
335	4	1299.6	10	1.03
335	4	1299.6	25	1.03
335	4	1299.6	160	1.03
442	4.5	1869.9	10	1.03
442	4.5	1869.9	25	1.03
442	4.5	1869.9	160	1.03

Table V: Comparison of ANFIS predicted output and simulation data

ANFIS Predicted - triangular MF (%)	ANFIS Predicted - Gaussian MF (%)	Simulation (%)
0.0847	-0.047	0
1.22	1.1	1.1166
1.09	1.1	1.1142
0.0841	-0.047	0
1.22	1.1	1.1166
1.08	1.11	1.1166
0.766	0.844	1.1059
1.23	1.17	1.1166
1.13	1.1	1.1472
0.765	0.843	1.1059
1.23	1.17	1.1166
1.06	1.01	1.1166
1.4	1.32	1.1166
2.49	2.28	1.958
9.09	8.87	8.5972
1.4	1.32	1.1166
2.39	2.16	1.8925
8.79	8.46	8.0752
1.15	1.12	1.1166
2.76	2.75	2.7469
12	12.1	12.1526
1.15	1.12	1.1166
2.66	2.65	2.6400543
11.3	11.4	11.445226

The results of ANFIS capabilities to reproduce results almost similar to the consequence method have proven successful as the R^2 for both triangular and Gaussian MF is 0.9947 and 0.998 respectively. Fig. 6 and 7 shows regression graph between predicted and simulation data of percentage fatalities in ANFIS capabilities test for both ANFIS using triangular and Gaussian MF. Thus, ANFIS capabilities to reproduce results are excellent, at par with consequence model method, which shows more proof of ANFIS prediction as simpler and alternative method for prediction percentage fatalities.

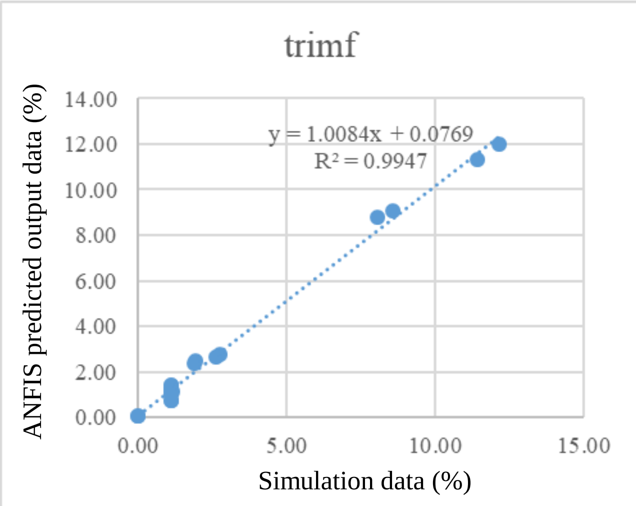

Fig. 6: Regression models of predicted output and simulation data using triangular MF for ANFIS capabilities test

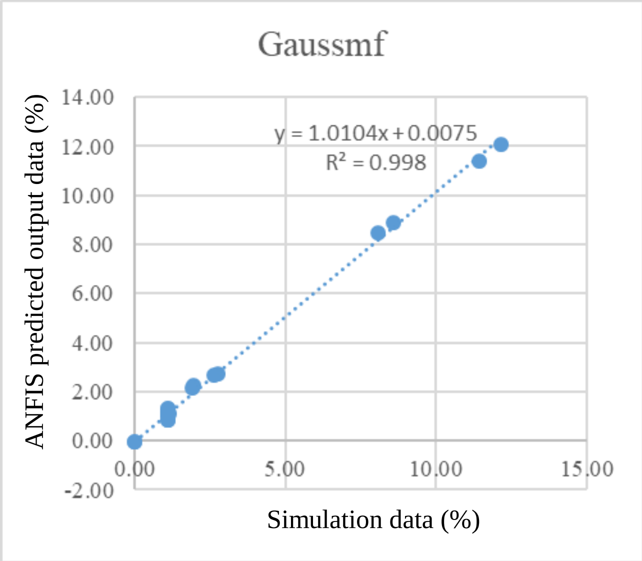

Fig. 7: Regression models of predicted output and simulation data using Gaussian MF for ANFIS capabilities test

IV. CONCLUSION

Percentage fatalities of jet fire event in MeOH production plant was estimated using consequence model method simulated in ALOHA and MARPLOT while simpler method using ANFIS prediction was developed in MATLAB. The regression model of ANFIS prediction method attained R^2 of 0.998 for both triangular and Gaussian MF constructed and capabilities test achieved R^2 of 0.9947 for triangular MF and 0.998 for Gaussian MF. Thus, ANFIS prediction method has proven as simpler and alternative way to predict percentage fatalities of jet fire incident in MeOH production plant with almost 100 % accuracy. More input parameters with more data are suggested to be implemented using ANFIS prediction method in future work.

ACKNOWLEDGMENT

The authors would like to acknowledge Faculty of Chemical Engineering, Universiti Teknologi MARA (UiTM) and the Ministry of Education (MOE) for the 600-RMI/FRGS/5/3 (0094/2016) grant, for all the funding and support given in establishing this project.

REFERENCES

1. G. A. Olah, "Beyond oil and gas: The methanol economy," *Angew. Chemie - Int. Ed.*, vol. 44, no. 18, pp. 2636–2639, 2005.
2. C. Mass-adoption and C. Mass-adoption, "Methanol : the Surprising Solution for Pollution , Global Warming and Electric Methanol : the Surprising Solution for Pollution , Global Warming , and Electric," pp. 1–21, 2019.
3. C. Bergins, K. Tran, E. Koytsoumpa, E. Kakaras, T. Buddenberg, and Ó. Sigurbjörnsson, "Power to Methanol Solutions for Flexible and Sustainable Operations in Power and Process Industries Mitsubishi Hitachi Power Systems Europe GmbH , Germany * Carbon Recycling International , Iceland," pp. 1–18, 2015.
4. G. C. C. Twitter, G. C. C. Twitter, C. R. International, and E. U. Horizon, "CRI awarded € 1 . 8M EU grant to scale CO2-to-methanol technology," pp. 1–8, 2020.
5. R. Gaikwad, A. Bansode, and A. Urakawa, "High-pressure advantages in stoichiometric hydrogenation of carbon dioxide to methanol," *J. Catal.*, vol. 343, pp. 127–132, 2016.
6. A. Bansode and A. Urakawa, "Towards full one-pass conversion of carbon dioxide to methanol and methanol-derived products," *J. Catal.*, vol. 309, pp. 66–70, 2014.
7. B. Tidona, C. Koppold, A. Bansode, A. Urakawa, and P. Rudolf Von Rohr, "CO2 hydrogenation to methanol at pressures up to 950 bar," *J. Supercrit. Fluids*, vol. 78, pp. 70–77, 2013.
8. A. B. Bansode, "Exploiting high pressure advantages in catalytic hydrogenation of carbon dioxide to methanol," Ph.D dissertation, Universitat Rovira i Virgili , 2014.
9. R. Gaikwad, "Carbon Dioxide to Methanol : Stoichiometric Catalytic Hydrogenation under High Pressure Conditions," 2018.
10. J. G. van Bennekom *et al.*, "Methanol synthesis beyond chemical equilibrium," *Chem. Eng. Sci.*, vol. 87, pp. 204–208, 2013.
11. É. S. Van-Dal and C. Bouallou, "Design and simulation of a methanol production plant from CO2 hydrogenation," *Journal of Cleaner Production*, vol. 57. pp. 38–45, 2013.
12. M. Pérez-Fortes, J. C. Schöneberger, A. Boulamanti, and E. Tzimas, "Methanol synthesis using captured CO2 as raw material: Techno-economic and environmental assessment," *Appl. Energy*, vol. 161, pp. 718–732, 2016.
13. E. S. Van-Dal and C. Bouallou, "Design and simulation of a methanol production plant from CO2 hydrogenation," *J. Clean. Prod.*, vol. 57, no. October, pp. 38–45, 2013.
14. G. Leonzio, "Optimization through Response Surface Methodology of a Reactor Producing Methanol by the Hydrogenation of Carbon Dioxide," *Processes*, vol. 5, no. 4, p. 62, 2017.
15. M. J. Assael and K. E. Kakosimos, *Fires, Explosions, and Toxic Gas Dispersions - Effects Calculation and Risk Analysis*. Boca Raton: CRC Press, 2010.
16. U. de Haag and Ale, *Guideline for quantitative risk assessment*, 3rd ed. Netherland: CPR, 2005.
17. N. Oceanic, A. Administration, and O. Response, "(AREAL LOCATIONS OF HAZARDOUS," no. November, 2013.
18. J. S. R. Jang, "ANFIS: Adaptive-Network-Based Fuzzy Inference System," *IEEE Trans. Syst. Man Cybern.*, vol. 23, no. 3, pp. 665–685, 1993.
19. Ga. O. Kordon, A. Karsi, and L. Pinchuk, "Innate Immune Responses in Fish: Antigen Presenting Cells and Professional Phagocytes," *Turkish J. Fish. Aquat. Sci.*, vol. 18, pp. 1123–1139, 2018.
20. L. Lahti, "A guideline for chemical process quantitative risk analysis," *J. Hazard. Mater.*, vol. 26, no. 1, pp. 101–102, 1991.
21. N. Oceanic, A. Administration, and O. Response, "ALOHA Example Scenarios," no. December, 2011.
22. J. S. R. Jang and E. M. Sun, *Neuro-Fuzzy and Soft Computing A Computational Approach to Learning and Machine Intelligence*. Úpper Saddle River: Prentice Hall, Inc., 1997.
23. H. Cao, Y. Xin, and Q. Yuan, "Prediction of biochar yield from cattle manure pyrolysis via least squares support vector machine intelligent approach," *Bioresour. Technol.*, vol. 202, pp. 158–164, Feb. 2016.

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