A Fuzzy Model for the Optimization of Cross Flow Cooling Tower using Mamdani Rule Modelling

S.Vijila[1], S.Ananthalakshmi[2], M.Kalaiselvi[3]

[1]*Assistant Professor, Department of Mathematics, Bishop Caldwell College, Maravanmadam, Thoothukudi, Tamilnadu, India & Research Scholar (Reg. No.19122072092001), Govindammal Aditanar College for women,Tiruchendur-628 215, Tamilnadu, India.*
Affiliated to Manonmaniam Sundaranar University, Tirunelveli-627 012, Tamilnadu, India.
[2]*Assistant Professor, Department of Mathematics, Annai Hajira Women's College, Tirunelveli-627 005, Tamilnadu, India.*
[3]*Associate Professor, Department of Mathematics, Govindammal Aditanar College for Women, Tiruchendur-628 215, Tamilnadu, India.*

---***---

Abstract-*Nowadays in a medium scale industry, optimization of working cross flow of a cooling tower in a captive power plant is more challengeable. In the cooling tower optimization process is done in terms of high effectiveness and outlet water temperature, which has been brought out using mamdani type fuzzy rule modelling. Optimization is done by analyzing certain input parameters such as relative humidity, dry bulb temperature, inlet water temperature and liquid to gas ratio and is carried out with the help of MATLAB fuzzy logic toolbox. In the present situation it is very difficult to conduct experiments for the industrial cooling tower. Therefore, a Fuzzy model is developed. The model is made with specified dimensions and the readings were taken for various time intervals. The reliability of the fuzzy model was checked and the error percentage is within 6%. The predicted results are found to be in concurrence with the experimental results which confirm reliability of the proposed fuzzy model.*

Keywords - Cross flow-cooling Tower, Outlet water temperature, Flow rate and Fuzzy model.

1. INTRODUCTION

The design of power plant includes various subsection among them the most important section is cooling tower. At low temperature cooling tower is responsible for extracting waste heat into the air through the cooling of water stream. Though it has many applications, cooling tower used for electric power generation is the major one.

G.Ganand S.B.Riffat [21] evaluated the performance of a closed wet cooling tower for chilled ceiling systems. It was found that for prediction and optimization of thermal performance, operation and design of the cooling tower CFD (Computational fluid dynamics) is most appropriate tool for chilled ceiling. Nenad and Pertti [20] derived a mathematical model based on one dimensional heat and mass balance equations for a counter flow wet cooling tower with the help of measured heat transfer coefficients.

Prasad [19] proposed a method for economic up gradation of a cooling tower by replacement of fill, starting with the worst affected then replacing in sequential manner. Tower performance will be decreased, while increase in L/G Ratio was showed by Farhad Gharagheizi et al. [14]. M. Hosozet al. [15] revealed that for modeling the cooling tower ANN is an alternate method. ANN Reliability is proved in terms of Mean Relative Error. The cooling range will be more for lower liquid to gas ratio values.

M. Lemouari, M. Boumaza and I.M. Mujtaba, [16] in their research it is found that the best water cooling is obtained because of higher inlet water temperature and low water flow rate. E. Hajidavalloo et al. [12] found that increase in inlet air wet bulb temperature increases the outlet water temperature. Similarly, increase in dry bulb temperature at constant wet bulb temperature, increases the evaporation rate. M. Serna-González et al. [11] revealed that for an optimal design of cooling towers factors like L/G Ratio, Inlet water temperature, Wet bulb temperature, Water outlet temperature, Water loss by evaporation must be considered simultaneously.

E. Rubio-castro et al. Cabrera [10] presented an optimal design algorithm for counter flow wet cooling towers based upon rigorous poppe model and mixed – integrated nonlinear programming (MNLP). R.Ramkumar and A.Ragupathy [8] discussed the application of Taguchi method in assessing maximum cooling tower effectiveness for the counter flow cooling tower which is done using expanded wire mesh packing.

M. Khamis et al. [5] developed an innovative correlation for effectiveness-NTU of counter flow cooling tower. Arash et al. [6] developed a rotational splash type packing cooling tower. In this paper, he revealed that when the rotational splash type packing rotates at higher velocity more heat rejection takes place from water. Thirapong et al. [17] in his research the performance of the water jet cooling tower using experimental and numerical simulation is analyzed and tabulated. Energy and second law efficiency is affected by reasonable variation in droplet diameter, tower spray zone height, L/G ratio.N. Tao et al. [7] reported that increase of L/G ratio will decrease the tower characteristic.

Ritwick et al. [4] found that cooling tower evaporation loss account for one of the foremost sources of industrial water loss and explores the possibility of fog capture from cooling tower plume. Pooriyasahalai et al. [3] proposed some standards to attain optimum operating conditions of wet cooling tower. Elazm et al. [13] studied a cross flow induced draft cooling tower theoretical and experimentally and found a correlation in order to achieve efficiency in wet bulb operation. For this study, a cross flow cooling tower which is positioned in a captive power plant in a medium scale industry is selected. Immanual et al. [2] developed a new software that will help to predict the Thermal Performance of a cross flow-cooling tower which is situated in a medium scale industry in various districts across India. Rafat and Behnia [18] predicted the thermal performance of the natural draft wet cooling tower which can be enhanced, when the cross wind velocity is higher than 7.5 m/s.

Fuzzy logic [22, 24] is one of artificial intelligence models that involves phonological variables and experimental associations to match with the human reasoning and intuition. Fuzzy is well-known for its ability to solve complex problems with several conditions. It is a suitable tool for combining reckonable factors with qualitative interactive concepts. Fuzzy logic is a superset that works between completely false and true values. The controlling stages of any fuzzy systems involve fuzzification, decision making and de-fuzzification.

Tarik A. Rashidand Haval et.al, have performed modelling and planning a student management system based on gross point average using fuzzy concepts and the accuracy of results were appreciable [9]. T. Takagi et.al [23] found that the fuzzy models have superior qualities than the numerical models since the interpretation was nearer to human thinking and also its ease of viability to work with nonlinear systems. The present inputs (inlet water temperature, dry bulb temperature, relative humidity, liquid to gas ratio) from the site were used to check the reliability of the fuzzy model. The parameters are optimized using mamdani type fuzzy rule modelling. Alagumalai Malairajan et al. [1] proposed a mathematical model for the optimization of the cross flow-cooling tower using taguchi-grey analysis.

2. PROPOSED WORK

2.1 Mamdani-Type Fuzzy Rule Modelling

Zadeh has acquaint with fuzzy logic to build a numerical framework for the data that were presented vaguely, which was a common form of interval analysis with high and low values. In set theory, the variable is considered to be a part of a set. The rank of the variable is assumed to be one if it lies inside set otherwise it is taken as zero. Fuzzy is a non-conventional set theory wherein the elements have a certain degree of membership function. The output values of fuzzy set gives the correlation between the indeterminate data and the membership function whose value ranges from 0 to 1. The fuzzy implications illuminate a multifaceted fuzzy system. The above stated implications along with the experimental data can be developed as a mamdani model. The system planning can be done by mamdani models which use more number of rules. The input matrix (X) and the output vector (g) of a fuzzy system are defined as follows:

$X = [x1 , x2 ,……., xn]^T$ & $g = [g1 , g2 ,…….., gn]$

The propositions of the fuzzy mamdani system include both the antecedent and consequent. A common form of if-then rule of fuzzy is given by, Ri: if x is Ai then y is Bi, I = 1, 2,….., k.

In the above expression, the rule number is expressed by Ri, the sets are represented by Ai& Bi, and both the antecedent and consequent variables are represented by x, y. Fuzzy set of input and output variables are represented in table 1.

Table - 1: Fuzzy set of input and output variables

	L/G	DRYT	RH	IWT	OWT
1	0.8	30	45	46	24.83
2	0.8	32	55	48	27.17
3	0.8	34	65	50	29.75
4	0.8	36	75	52	32.59
5	1	34	45	48	28.64
6	1	36	55	46	30.79
7	1	30	65	52	29.11
8	1	32	75	50	31.15
9	1.25	36	45	50	31.61
10	1.25	34	55	52	32.06
11	1.25	32	65	46	31.42
12	1.25	30	75	48	31.62
13	1.5	32	45	52	32.15
14	1.5	30	55	50	31.94
15	1.5	36	65	48	34.86
16	1.5	34	75	46	34.5

The process of obtaining unique value by converting the fuzzy outputs is termed as de-fuzzification which is done by any one of the commonly available approaches including COG, Weighted-Average approach. In this paper four parameters liquid to gas ratio, dry bulb temperature, relative humidity, inlet water temperature and outlet water temperature in the cooling water are considered and the rules for each parameter is indicated in the table 2.

Table – 2: Rules followed in the fuzzy model to determine percentage of error

L/G	DRYT	RH	IWT	OWT
1	1	1	1	1
1	1	1	1	2
1	2	2	2	2
1	3	3	3	4
1	2	1	1	2
1	3	1	1	3
1	1	2	3	2
1	1	3	2	3
2	3	1	2	3
2	2	1	3	4
2	1	2	1	3
2	1	3	1	3
3	1	1	3	4
3	1	1	2	3
3	3	2	1	5
3	2	3	1	5

3. RESULTS AND DISCUSSIONS

In this paper, MATLAB fuzzy logic toolbox is used for Rule-based Mamdani model is used for optimization of cross flow cooling tower. For the optimization four parameters such as liquid to gas ratio, dry bulb temperature, relative humidity and inlet water temperature are considered as inputs and outlet water temperature is taken as output. The fuzzy triangular membership functions for two input and output variables are shown in Figure 1(a) and (b) respectively.

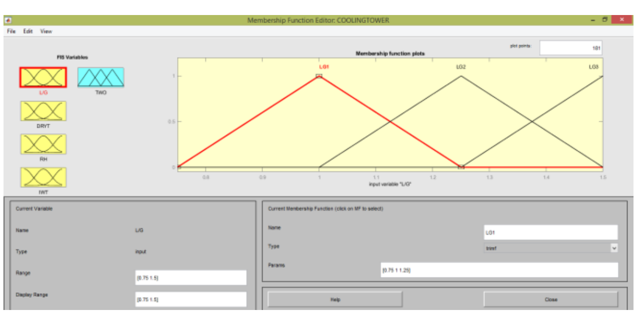

Fig -1.a: Fuzzy triangular membership function for liquid to gas ratio

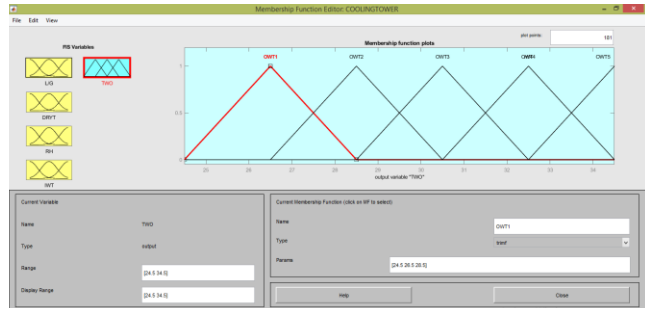

Fig -1.b: Fuzzy triangular membership function for outlet water temperature

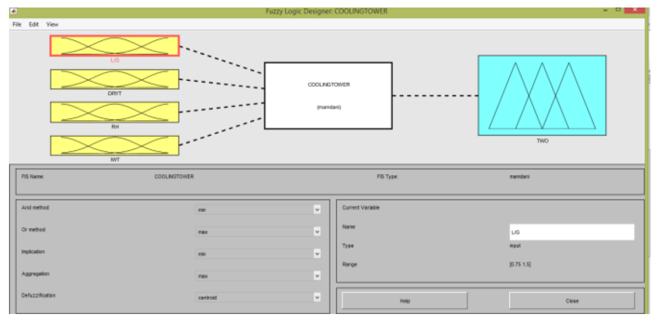

Fig – 2: General layout of fuzzy model using mamdani type rule modelling

Fig 2. Shows the mamdani type fuzzy rule model of the experimental setup. This model is constructed by considering four input parameters liquid to gas ratio, dry bulb temperature, relative humidity and inlet water temperature in the cooling water. Based on these input values using mamdani model outlet water temperature is noted and percentage of the error is predicted.

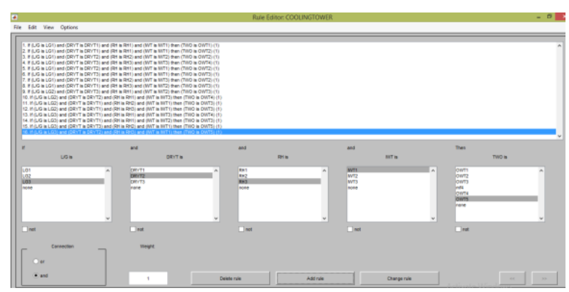

Fig – 3: Mamdani Rule editor of the cooling tower representing input and output variables

Table 3 represents the comparison of outlet water temperature between mathematical model and mamdani type fuzzy rule modelling for different sets of input parameters. The percentage of error and its efficiency is predicted using mamdani type fuzzy model.

Table - 3: Comparison of outlet water temperature between mathematical model and mamdani type fuzzy model

	L/G	DRYT	RH	IWT	OWT	FUZZY PREDICTED OWT	ERROR	ERROR (%)
1	0.8	30	45	46	24.8	29.5	4.67	19
2	0.8	32	55	48	27.2	27.5	0.33	1
3	0.8	34	65	50	29.8	28.5	1.25	4
4	0.8	36	75	52	32.6	32.5	0.09	0
5	1	34	45	48	28.6	29.5	0.86	3
6	1	36	55	46	30.8	29.5	1.29	4
7	1	30	65	52	29.1	29.5	0.39	1
8	1	32	75	50	31.2	30.5	0.65	2
9	1.25	36	45	50	31.6	29.5	2.11	7
10	1.25	34	55	52	32.1	32.5	0.44	1
11	1.25	32	65	46	31.4	29.5	1.92	6
12	1.25	30	75	48	31.6	29.5	2.12	7
13	1.5	32	45	52	32.2	29.5	2.65	8
14	1.5	30	55	50	31.9	29.5	2.44	8
15	1.5	36	65	48	34.9	33.9	0.96	3
16	1.5	34	75	46	34.5	29.5	5	14

Figure 4 represents the surface viewer of the cooling tower and figure 5 represents Mamdani Rule viewer of the cooling tower representing input and output variables

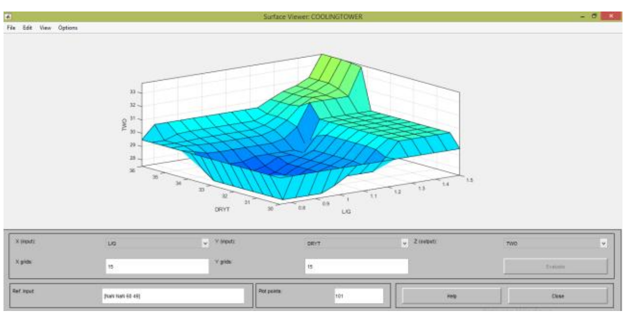

Fig – 4: Surface view of the cooling tower

Fig – 5: Mamdani Rule viewer of the cooling tower representing input and output variables

4. CONCLUSIONS

The objective of the present work develops the mathematical model to optimize the cross flow of the cooling tower in a medium scale industry. For this stated objective, various research articles are reviewed and the mamdani type fuzzy model is chosen for further analysis. By using MATLAB fuzzy logic toolbox mamdani model is created. The output temperature values are predicted for the developed mamdani fuzzy model using MATLAB fuzzy logic toolbox and the percentage of error between the mathematical and mamdani model is found to be 6% which can be used to conclude that the predicted values of fuzzy model are in strong correlation with the actual values. Hence, the mamdani rule-based fuzzy model can be employed to optimize the performance of the cross flow cooling tower. From the surface plot, it is clear that the maximum outlet temperature is attained and the error percentage is reduced to 6%.Thus, the proposed system can be very much useful in optimizing the performance of the cross flow cooling tower. In future, this system can be clubbed with intelligent systems.

REFERENCES

[1] Alagumalai Malairajan, Immanual Rajkumar, S. Daniel Selvakumar and P. Rajaram, “A Novel Method in Optimization of the Cross Flow-cooling Tower Using Taguchi-grey Analysis”, International Journal of Printing, Packaging & Allied Sciences, Vol. 5, No. 1, 2017.

[2] Immanual R, Paul Vinofer B, Chokkalingam B, Varun B, Oswalt Manoj S, Raja V, and Dhinesh Kumar M, “Prediction of Cooling Tower Thermal Characteristics using Newly Developed Software for a Chemical Industry”, International Journal of Chem Tech Research, Vol.10 No.12, pp 344-350, 2017.

[3] Pooriyasahalai, M. Rahmati, S. R. Alavi and A. Sedaghat, “Experimental study on improving operating conditions of wet cooling towers using various rib numbers of packing”, International Journal of Refrigeration, 2015.

[4] R. Ghosh, T. K. Ray and R. Ganguly, “Cooling tower fog harvesting in power plants-A pilot study”, Energy, Pp. 1–11, 2015.

[5] M.K. Mansour and M. A. Hassab, Innovative correlation for calculating thermal performance of counter flow wet-cooling tower”, Energy, Vol. 74, Pp. 855–862, 2014.

[6] ArashLavasani, Zahra NamdarBaboli, Mohsen Zamanizadeh, MasoudZareh, “Experimental study on the thermal performance of mechanical cooling tower with rotational splash type packing”, Energy Conversion and Management 87:530–538, 2014.

[7] N. Tao, C. Daotong, J. Mingxiao, W. Jinshi and Y. Junjie, "Experimental investigation on the performance of wet cooling towers with defects in power plants", Applied Thermal Engineering, 2014.
[8] R.Ramkumar and A.Ragupathy, "Optimization of cooling tower performance analysis using taguchi method", Thermal Science, Vol. 17, No. 2, Pp. 457–470, 2013.
[9] Tarik A. Rashid, Haval Abdulkarim Ahmed (2012): Revised General Test/Gross Point Average System via Fuzzy Logic Techniques, Journal of Computer Science and Engineering, Volume 16, Issue 1, November 2012.
[10] E. Rubio-castro, M. Serna-gonzález, J. M. Ponce-ortega and M. A. Morales-cabrera, "Optimization of mechanical draft counter flow wet-cooling towers using a rigorous model", Applied Thermal Engineering, Vol. 31, Pp. 3615-3628, 2011.
[11] M. Serna-González, J.M. Ponce-Ortega and A. Jiménez-Gutiérrez, "MINLP optimization of mechanical draft counter flow wet-cooling towers", Chemical Engineering Research and Design, Vol. 88, No. 5, Pp. 614-625, 2010.
[12] E. Hajidavalloo, R. Shakeri and M.A. Mehrabian, "Thermal performance of cross flow cooling towers in variable wet bulb temperature", Energy Conversion and Management, Vol. 51, Pp. 1298–1303, 2010.
[13] Mohamed Mahmoud ABO ELAZM and Ahmed Farouk ELSAFTYT, "Theoretical And Experimental Study Of A Cross-Flow Induced-Draft Cooling Tower", Thermal Science, Vol. 13, No. 4, Pp. 91–98, 2009.
[14] F. Gharagheizi, R. Hayati and S. Fatemi, "Experimental study on the performance of mechanical cooling tower with two types of film packing", Energy Conversion and Management, Vol. 48, Pp. 277–280, 2007.
[15] M. Hosoz, "Performance prediction of a cooling tower using artificial neural network", Energy Conversion and Management, Vol. 48, Pp. 1349–1359, 2007.
[16] M. Lemouari, M. Boumaza and I.M. Mujtaba, "Thermal performances investigation of a wet cooling tower", Applied Thermal Engineering, Vol. 27, Pp. 902–909, 2007.
[17] Thirapong Muangnoi, Wanchai Asvapoositkul, Somchai Wongwises, "An energy analysis on the performance of a counter flow wet cooling tower", Applied Thermal Engineering 27(5-6):910-917, 2007.
[18] R. Al-waked and M. Behnia, "CFD simulation of wet cooling towers", Applied Thermal Engineering, Vol. 26, Pp. 382–395, 2006.
[19] M. Prasad, "Economic up-gradation and optimal use of multi-cell cross flow evaporative water cooling tower through modular performance appraisal", Applied Thermal Engineering, Vol. 24, Pp .579–593, 2004.
[20] Nemad Milosavljevic and Pertti Heikkila, "A comprehensive approach to cooling tower design", Applied Thermal Engineering, V. 21, Issue-9, pp 899-915, 2001.
[21] G. Ganand S.B. Ri, "Numerical simulation of closed wet cooling towers for chilled ceiling systems", Applied Thermal Engineering, Vol. 19, Pp. 1279-1296, 1999.
[22] C. Lee "Fuzzy logic in control systems: fuzzy logic controller. I", v. 20, Issue: 2, 1990.
[23] T. Takagi, T. Sugeno, Fuzzy identification of system and its applications to modelling and control, IEEE Trans. Syst. Man Cybern. 15 (1985) 116e132.
[24] L. A. Zadeh, "Fuzzy logic and approximate reasoning", Synthese, V. 30, Issue 3–4, pp 407–428, 1975.