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Usage of Industrial Effluent Water for Generator Cooling and Boiler Feed Water Systems with Fuzzy Logic Control

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Abstract- Various Industrial sectors, such as pharmaceuticals, food processing, textiles, and power generation, generate a massive volume of Water for operation, which can be treated for reuse. Particularly, Pharmaceutical product manufacturing generates wastewater, which is defined as effluents containing diverse organic and inorganic contaminants originating from active ingredients, excipients, and process residues. These effluents can cause damage to the Environment and humankind if not adequately treated before use or release into the open air. To treat these waters, there are physical, chemical, and biological processes which are combinedly operated in an Effluent Treatment Plant (ETP. The Treated Water has many applications within the industry as recycled Water. Among multiple application scopes, this Study proposes an integrated, experimental approach to reuse treated wastewater for boiler feedwater and generator cooling system applications. The application is modeled using a Fuzzy Logic Design system of the Mamdani type to achieve precise, adaptive, and robust outcomes. The proposed methodology demonstrates the potential to reduce freshwater consumption, improve resource efficiency, and support sustainable industrial water management.

Keywords: Effluent Water, Purification system, Generator Cooling, Boiler Feed Water System, Fuzzy Logic Control.

I. Introduction

Since the Fourth Industrial Revolution,[1] the industry sector is expanding through diversity. Nowadays, there are so many industries worldwide. Among all these types of Industries, most are manufacturing-based, and one term is ubiquitous: "Industrial Waste". Any solid, semi-solid, liquid, or other form of material released from manufacturing sites can be termed industrial Waste [2]. There are many classifications based on types of Waste, such as solid, liquid, and gas. These wastes have a significant impact on the Environment, humans, and animals. Liquid Waste poses the highest risk among the three waste types, as it can quickly spread and contaminate water sources [3].

Industrial Waste, or effluent water, is Water released from various industrial activities, such as manufacturing and cleaning. Wastewater has a significant impact on Human Life and the ecological balance, as it causes severe pollution [4]. Most industries are located near water sources, such as rivers and sea areas, where there is less local population density if the disposal system of wastewater is designed in such a way that it is connected to the river or water source [5], which can result in an adverse effect because those water sources are the primary source of drinking water for people [6]. Industrial effluent water typically contains a complex mixture of microbial contaminants, organic compounds, dissolved salts, and suspended solids originating from diverse operational processes [7]. In pharmaceutical manufacturing facilities that operate continuously and at high production capacity, wastewater volumes are particularly substantial due to extensive cleaning, processing, and material handling activities.

Across industrial sectors, wastewater may arise from production areas, sanitation facilities, equipment washing operations, and auxiliary services. If discharged without adequate treatment, such effluents pose significant risks to human health and the surrounding Environment. Therefore, the establishment and proper functioning of an Effluent Treatment Plant (ETP) is essential and is mandated by environmental regulatory authorities.

An Effluent Treatment plant is designed to treat industrial wastewater by removing physical, chemical, and biological contaminants accumulated during manufacturing and cleaning activities [8]. Through a series of treatment processes, the ETP converts polluted wastewater into a form suitable for safe discharge or potential reuse within the industrial facility. The stages involved in converting the wastewater to treated Water in the Effluent Water Treatment system. Those are: wastewater collection, Aeration, Segregation, clarifier and settler, sludge storage, and distribution of treated Water [9].

There are several uses of treated Water across large, medium, and small-scale applications in various sectors. Initially, studies showed that treated Water can be used for Agricultural Irrigation, but as industrial advancements progressed, analyses were also conducted on industrial reuse. One use of the treated Water is to meet the industry's potable water requirements. Other uses can be mentioned, such as in boiler feed and cooling towers [10].

In this Paper, the industry considered for the Study is a Pharmaceutical Company. This company is located in Gazipur, which is an Industrial area of Bangladesh. The Reason for considering the pharmaceutical company is the wastewater generated from various production floors; it is evident that the wastewater contains the highest levels of contaminants. The main Reason behind this idea is that the raw materials used for manufacturing pharmaceutical products are of various types, like natural, synthetic, and biotechnology, which are formed with a lot of contaminants [11]. That is why it has been identified that a combination of Physical, Chemical, and biological treatment is the best approach to get reusable effluent water.

The pharmaceutical industries need a Boiler to generate steam. This steam is then used in various applications, such as process machines, water treatment plants, and laundry machines, to create high temperatures [12]. In operation, the boiler requires Water as feed water. Hence, the effluent Water is a good source to use rather than being wasted by draining from the system.

Another usage for this Water can be found in industrial generators. Industrial generators need a cooling system for smooth operation. There are two central cooling systems. One is a radiator, and the other is a cooling tower. In the cooling tower system, Water enters the cooling tower. It is then cooled to the desired Temperature by an axial fan, providing Water for the generator's jacket water line as an external cooler.

Both the boiler and the Generator system require Water for operation. The Water that will be segregated from the Effluent treatment plant is proposed to be used for the Boiler Feedwater and Generator Cooling system. There are two parts in the designed system. In the first part, the wastewater is treated using ETP for use in the boiler and Generators, and the analytical data is reported. In the Second Part, the control system, designed for water flow and temperature monitoring through control logic, is presented with illustrative simulation modelling and results.

II. Literature review:

Table 1. Summary of Previous Studies on Industrial Effluent Reuse and Fuzzy Logic Control for Cooling and Boiler Feedwater Systems

Reference No. in the Paper	Author(s) and Year	Research Focus	Method	Research Gap
[13]	Chen et al. (2024)	Cooling tower water quality control	Fuzzy-PID controller	Not applied to industrial effluent reuse systems
[14]	Gupta & Verma (2018)	Boiler feedwater treatment	Demineralization and RO	Effluent reuse not studied
[15]	Gómez et al. (2021)	Industrial wastewater reuse	Catalytic treatment	No intelligent control strategy
[16]	Eshbobaev et al. (2024)	Wastewater treatment automation	Fuzzy logic control	Limited industrial-scale application
[17]	Lee et al. (2021)	Reverse osmosis water reuse	Fuzzy inference system	Application to industrial effluent reuse limited
[18]	Sharma et al. (2018)	Wastewater reuse in thermal power plants	Integrated treatment system	Real-time optimization missing

III. Materials and Methodology:

This Study established a systematic process flow that describes the steps involved from wastewater analysis to control system modelling. The overall approach consists of steps, some of which are physically verified and others based on simulation-based data analysis. Every step is described with a relative data table and a figure. The steps are outlined in a workflow Diagram in the following sections. Every step is described.

3.1 Work Flow Diagram Chart:

There are several steps to be followed for this system. Those are given as block chart in Figure 1:

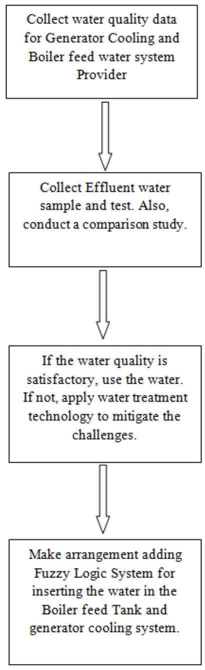

Figure 1. Process Flow Chart for the waste water Management and Fuzzy logic Control system describes each step from Water collection to Fuzzy Logic Modelling.

3.2 Collect water quality data for the Generator Cooling and Boiler Feed Water System.

In this Paper, water quality data for generator cooling and boiler feed water systems were collected from the manufacturers, as this is standard data. Those data were analyzed and written in Table 2:

Table 2. Properties of Standard Water to be used for Boiler Feedwater and Generator Cooling System.

Parameter	**Expected Specification**
Conductivity	0.1 to 1 µS/cm
pH	6.5 to 7.5
Total Dissolved Solids	Less than 10 mg/L
Nitrate	Very low
Chloride	0
Sulfate	Less than 250 mg/L
Total Hardness	0
Iron	0
Copper	0
Free Chlorine	0

3.3. Collect Effluent Water sample and test. Also, conduct a comparison study

As the water study is based on a company, with permission from the authority, water sample was collected from the effluent Treatment plant. Water sample was collected on seven consecutive days, and each day the Water was tested in the Microbiology Lab. Based on several days' results, a table is prepared that lists the worst data from the test results.

Table 3. Laboratory Test data (Worst Sample) of water Collected from the Effluent Water Storage Tank.

Parameter	**Found Results in the Lab**
Conductivity	1353 µS/cm
pH	7.75
Total Dissolved Solids	679 mg/L
Nitrate	0.4 mg/L
Chloride	200 mg/L
Sulfate	37 mg/L
Total Hardness	80 mg/L
Iron	0.16 mg/L
Copper	0.24 mg/L
Free Chlorine	0

The table below presents a comparative study of the required parameters for Usable Water and the parameters found in testing the Effluent Plant water sample.

Table 4. Comparison Table for Standard Water Sample Data and Laboratory Tested Worst Water Sample Data.

Parameter	**Effluent Treatment Plant Sample Water Data**	**Standard water Requirement Data**
Conductivity	1353 µS/cm	0.1 to 1 µS/cm
pH	7.75	6.5 to 7.5
Total Dissolved Solids	679 mg/L	Less than 10 mg/L
Nitrate	0.4 mg/L	Very low
Chloride	200 mg/L	0
Sulfate	37 mg/L	Less than 250 mg/L
Total Hardness	80 mg/L	0
Iron	0.16 mg/L	0
Copper	0.24 mg/L	0
Free Chlorine	0	0

From the comparison table it is clearly observed that the waste water should contain low conductivity with lesser pH, TDS and chloride.

3.4. If the water quality is satisfactory use or apply water treatment technology to mitigate the challenges

The comparative study indicates clearly that conductivity, pH, TDS, and chloride are the focus parameters. Various studies indicate that the Reverse Osmosis Process [19] is one of the best solutions for reducing conductivity, Total Dissolved Solids, and pH—chloride from Water.

Reverse Osmosis (RO) is a membrane-based demineralization process to separate dissolved solids from the Water and make the Water usable for various purposes [20]. The RO process purifies Water. Actually, as the process is named, it's a reversal action of the general osmosis process. Osmosis typically allows Water to flow from a low-concentration solution to a high-concentration solution through a semipermeable membrane. Reverse Osmosis is the cross-flow operation of osmosis, which involves a higher-pressure stream. Cross-flow filtration has an influent stream called the feed and two effluent streams: permeate, which flows after filtration to the forward way, and concentrate, which remains as the rejected stream [21].

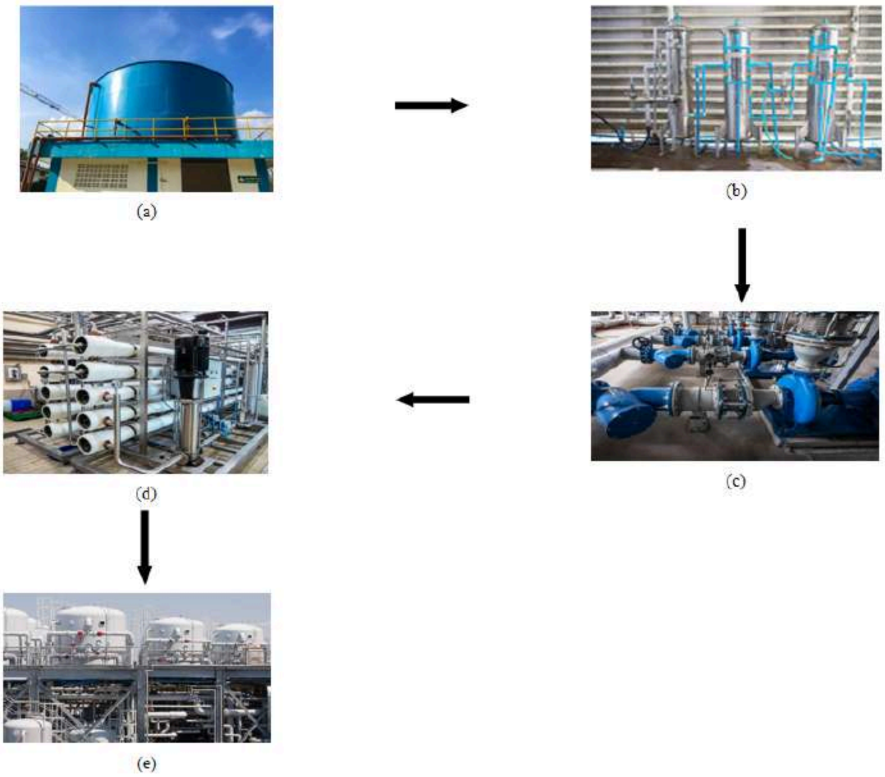

Figure 2. Process Flow for Waste water Treatment with Real time images for Demonstration (a) Waste Water Storage in Water Storage Tank (b) Pretreatment Filtration System to eliminate low particle Size solid materials (c) Pump Unit for water flow to the Reverse Osmosis Unit (d) Reverse Osmosis to segregated the water as Permeate Water to flow towards the next step and Concentrate water to flowback to the tank (e) Treated Water Storage Tank [22].

3.5. Make Arrangement adding Fuzzy Logic System for inserting the water in the Boiler feed tank and Generator Cooling System

The controllable parameters are Water and Temperature. To monitor the Water and Temperature, two input sensors are proposed. Those are water-level and Temperature monitoring sensors. Reading from these sensors is demonstrated to control the Water flow valve, heater, and water drain unit. The control unit in this Paper is designed using a fuzzy logic controller. A fuzzy logic controller is a control system based on input-output membership functions.

In this Study, MATLAB's Fuzzy Logic Toolbox is used. Fuzzy logic offers control actions via fuzzy sets and rules [23]. The interface system selected for this proposed system is the Mamdani fuzzy Interface system. There are several fuzzy logic systems. Mamdani and Sugeno are the most used in Fuzzy logic control systems. Mamdani is used because it is based on the center-of-gravity defuzzification technique [24].

A Fuzzy controller depends on information provided by domain experts through membership functions. A fuzzy logic system (FLS) converts the nonlinear mapping of an input data set to a scalar output data. Fuzzy logic systems use mainly crisp inputs and outputs, but also consider errors such as differential, integral, and time-related errors. Various considerations for Inputs and outputs are [25]: AND Method: Min; OR Method: Max; Implication: Min; Aggregation: Max; Defuzzification: Centroid; Type: Triangular, Trapezoidal.

The AND Method describes how the INPUT conditions are combined. There are Two Possibilities for the AND Method. Those are MIN and PROD. MIN is used to consider the minimum values of the Membership INPUTs. Moreover, PROD uses the Product of the membership functions [26]. For this Paper, the MIN is considered. The OR Method describes how multiple inputs are combined, and it triggers multiple rules [27]. In this Paper, the MAX is regarded for the OR Method.

The Implication describes how the truth value of the membership functions will affect the output values [26]. The MIN considers truncating the output membership function at the rule's truth level. Aggregation combines all possible output rules into a Single most appropriate OUTPUT [26]. MAX is considered to evaluate all considerations. Defuzzification converts the aggregated fuzzy output set into a crisp (numerical) output. Centroid is the most commonly used Defuzzification system, which considers the center of gravity inside the Curve. There are three types of Membership functions. Those are Triangular, Trapezoidal, and Gaussian. In this Paper, the Triangular and Trapezoidal types are considered, as we have evaluated each value in a MIN or MAX state, thereby focusing on the most appropriate output. The trapezoidal type is considered to yield a linear boundary function.

It is stated that Fuzzy Logic Design is based on an input-output function. Considering all possible factors, this Paper proposes TWO INPUTs and THREE OUTPUTs. The First Input is the water level, which is separated into three Membership functions. Those are Low, Normal, and High. The division is done over a range of 0 to 100%, meaning the level.

Table 5. Water Level ranges as INPUT in the Fuzzy Logic Control System. There are two types (Trapezoidal and Triangular) for three level of the values.

Water Level	Type	Range
Low	Trapezoidal	0 10 20 30
Normal	Triangular	25 50 80
High	Trapezoidal	75 84 93 100

The other Input is Temperature, which is also split into three Membership Functions. Those are Low, Normal, and High. As the suitable Temperature for Generator Cooling and Boiler Feed water ranges from 70 to 85 °C, the Membership functions are designed as shown in the table below:

Table 6. Temperature ranges as INPUT in the Fuzzy Logic Control System. There are two types (Trapezoidal and Triangular) for three level of the values.

Temperature	Type	Range
Low	Trapezoidal	0 25 47 70
Normal	Triangular	65 73 85
High	Trapezoidal	80 87 93 100

Based on the Inputs, the Paper proposes three Outputs. The outputs are: Water Control Valve (controls a Pump), which controls the flow of Water from the storage Tank; and Heating System, which generates heat if the Temperature drops below the normal range. Also, a drain valve is included in the system to maintain the water flow if it occurs.

Table 7. Water Control Valve ranges as OUTPUT in the Fuzzy Logic Control System. There are two types (Trapezoidal and Triangular) for Four level of the values considering Maximum Complexity.

Water Control Valve	Type	Range
OFF	Triangular	0 5 10
ON First Stage	Trapezoidal	8 13 22 35
ON Second Stage	Trapezoidal	30 40 50 60
ON Final Stage	Triangular	55 72 100

Water control ranges are set in an OFF-ON mode, with a range from 0 to 100%, where 0 means the control valve is completely OFF and 100% means the valve is fully ON.

Table 8. Heating System ranges as OUTPUT in the Fuzzy Logic Control System. There are two types (Trapezoidal and Triangular) for Four level of the values considering Maximum Complexity.

Heating System	Type	Range
OFF	Triangular	0 5 10
ON First Stage	Trapezoidal	8 13 19 25
ON Second Stage	Trapezoidal	20 35 48 60
ON Final Stage	Triangular	55 78 100

Heating System ranges are set in an OFF-ON mode, from 0 to 100%, where 0 means the heating system is completely OFF, and 100% means the Heating system is entirely ON.

Table 9. Drain Valve ranges as OUTPUT in the Fuzzy Logic Control System. There are two types (Trapezoidal and Triangular) for Four level of the values considering Maximum Complexity.

Drain	Type	Range
OFF	Triangular	0 8 15
ON First Stage	Trapezoidal	10 15 22 30
ON Second Stage	Trapezoidal	25 37 48 60
ON Final Stage	Triangular	55 78 100

Drain ranges are set in an OFF-ON based on a range from 0 to 100% where 0 means the drain is completely OFF and 100% means the drain is fully ON.
The Ranges are put in the Fuzzy Logic system through Mamdani Type 1 interface system.

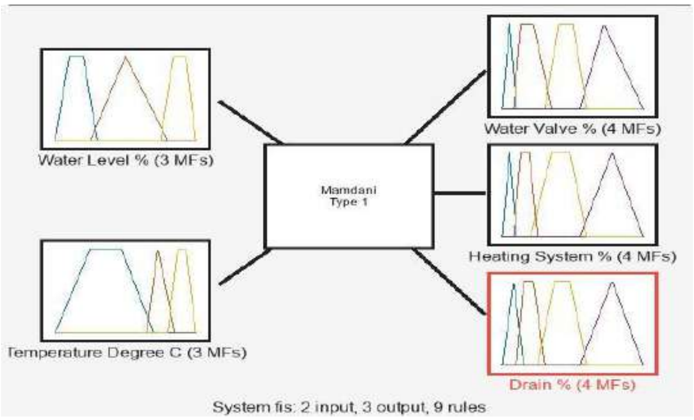

Figure 3. Fuzzy Logic System Interface Plot Designed in MATLAB System considering Two INPUTs and Three OUTPUTs.

The relation between all inputs and outputs is established through Fuzzy Rules. The rules are defined using an if-else statement. The statements are formed based on the probability of the events. Every event has a probability matrix, from weak to substantial or from least probable to most probable, based on the factor (s) that have a direct or indirect impact on the event. The strong one is based on certainty and obligation, and the weak one is based on feasibility and possibility [21]. As a fuzzy system is built up based on a set, the membership functions are not limited to binary truth 0 or 1 of crisp logic; instead, they are built up in such a logic that they can be part of two states [28] Every rule is based on the probability and complexity of the input/s and output/s.
In this Paper, the two most possible inputs are identified as water Level and Temperature. As there are Three Membership functions for each input, the potential rule number will be three (3) multiplied by three (3), which means nine (9).

Table 9. Truth Table for Fuzzy Rules based on designed Membership Functions of the INPUTs-OUTPUTs.

Inputs		**Outputs**		
Water level	Temperature	Water Control Valve	Heating System	Drain
Low	Low	ON Final Stage	ON Final Stage	OFF
Normal	Low	ON First Stage	ON Final Stage	OFF
High	Low	OFF	ON Final Stage	ON Second Stage
Low	Normal	ON First Stage	OFF	OFF
Normal	Normal	OFF	OFF	OFF
High	Normal	OFF	OFF	ON Final Stage
Low	High	ON Final Stage	ON	ON
Normal	High	OFF	OFF	ON First Stage
High	High	OFF	OFF	ON Final Stage

IV. Results and Discussion

The results are collected from MATLAB simulation. Several types of results are generated from the simulation. The type of results which are discussed and analyzed in the paper are: Rule Interface Results, Control Surface Results, and Contour Plot Results.

4.1. Rules Interface Results

The first component of the analysis presents the Rule Interface Results. As previously stated, a total of nine (09) possible rules has been defined; however, for illustrative purposes, three representative rules are discussed in this section. Corresponding rule interface images are included to facilitate clearer interpretation of the rule-based decision process. Three different state rules are discussed.

Considering the two input parameters, the first rule is activated when both inputs are in the *Low* state. In this case, the water level is measured at 21.67%, which is classified as *Low*, and the temperature is recorded as 17.42 °C, also categorized as *Low*. Based on the predefined rule table, the corresponding outputs are triggered in accordance with.

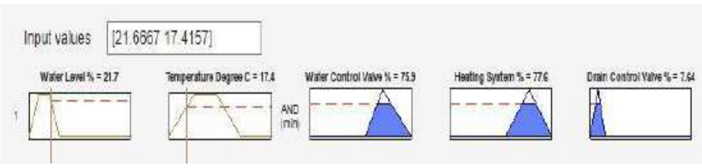

Figure 4. Rule Interface Considering Both INPUTs are Low.

Under this rule condition, the **water control valve** operates in the *ON – Final Stage*. The rule interface results indicate that the valve opening reaches 75.9%, which is consistent with the predefined rule set. Similarly, the **heating system** is activated in the *ON – Final Stage*, with an output value of 77.6% as obtained from the rule interface, confirming compliance with the preset control rules. In contrast, the **drain control valve** remains in the *OFF* state, as dictated by the corresponding rule conditions and validated by the rule interface results.

The second operating condition considers the scenario in which both input variables are in the *Normal* state. In this case, the water level is measured at 51.5%, while the temperature is recorded as 76.3 °C.

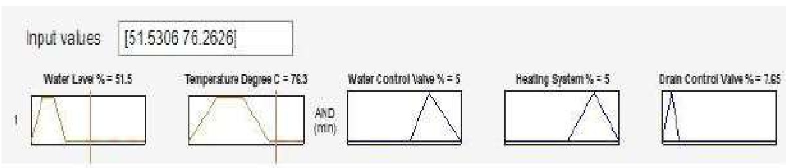

Figure 5. Rule Interface Considering Both INPUTs are Normal.

Under this operating condition, the **water control valve** remains in the *OFF* state. The rule interface results indicate a valve activation level of 5%, which is consistent with the predefined control rules. Similarly, the **heating system** operates in the *OFF* state, with an output value of 5% as obtained from the rule interface, confirming adherence to the preset rule base. The **drain control valve** also remains *OFF*, and the rule interface output of 7.6% further validates compliance with the established rule conditions.

The final operating condition considers the scenario in which both input variables are classified under the *High* state. In this case, the water level is measured at 89.3%, while the temperature is recorded as 90.4 °C.

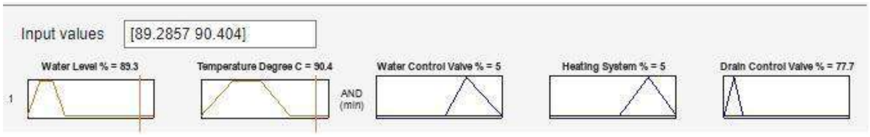

Figure 6. Rule Interface Considering Both INPUTs are High.

The Water control Valve will be in "OFF" and from the rule interface results it is being seen that the water control Valve is 5% which is as per preset rule.

The heating System will be in "OFF" and from the rule interface results it is being seen that the Heating system is 5% which is as per preset rule. The Drain Control Valve will be in "ON Final Stage" and from the rule interface results it is being seen that the result is 77.7% which is as per preset rule.

4.2. Control Surface Results

The Next Result Analysis is based on the control Surface results which are generated from the simulation.

In the result plot, X axis is the Water Level % and Y axis is the Temperature Degree C. All the outputs are will be in the Z Axis. There are three Basic colors in the plot which describes the Three State (LOW, NORMAL, HIGH) which varies with value changes.

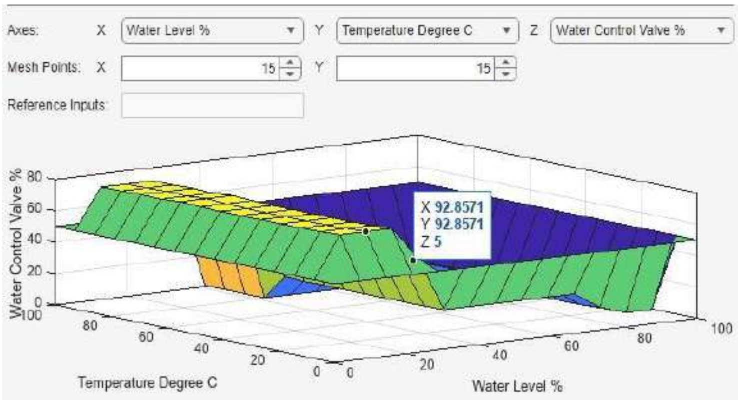

Figure 7. Control Surface Result for Water Control Valve %

The surface represents how the fuzzy controller adjusts the water control valve based on temperature and water level. As the Temperature and Water Level both input values are HIGH, so the Water Control valve should be in OFF which is represented by the value.

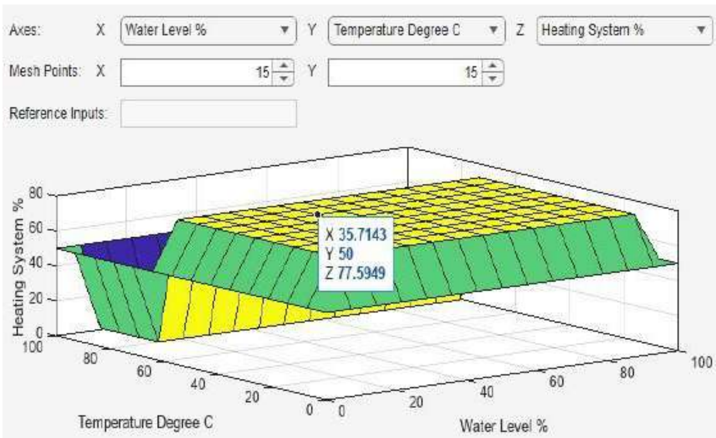

Figure 8. Control Surface Result for Heating System %

The surface represents how the fuzzy controller adjusts the Heating system based on temperature and water level. As Water Level is in LOW and Temperature is in LOW state as per value, the Heating system is in ON state with Final Stage as the output Value is in the Range of "ON Final Stage".

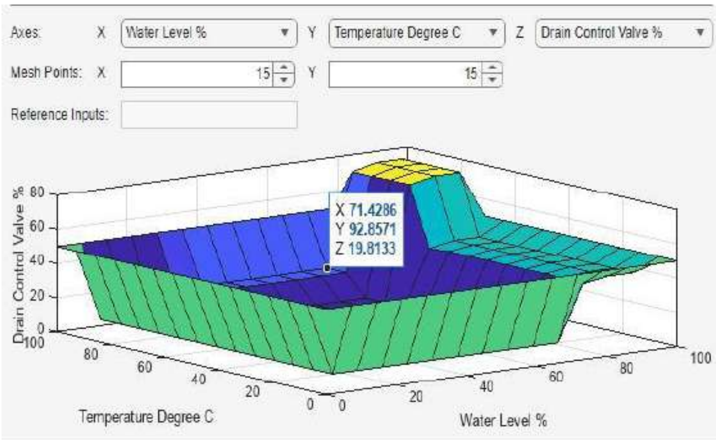

Figure 9. Control Surface Result for Drain %

The surface represents how the fuzzy controller adjusts the drain Valve based on temperature and water level. As water level is intended to be HIGH and Temperature is HIGH, so the drain valve is in "ON First Stage" which is represented by the value.

4.3. Control Surface Results

A contour Plot is a surface drawing technique with similar height Z, on a two dimensional co-ordinates X & Y [29].

The Analysis of the result is based on Contour Plot of the system.

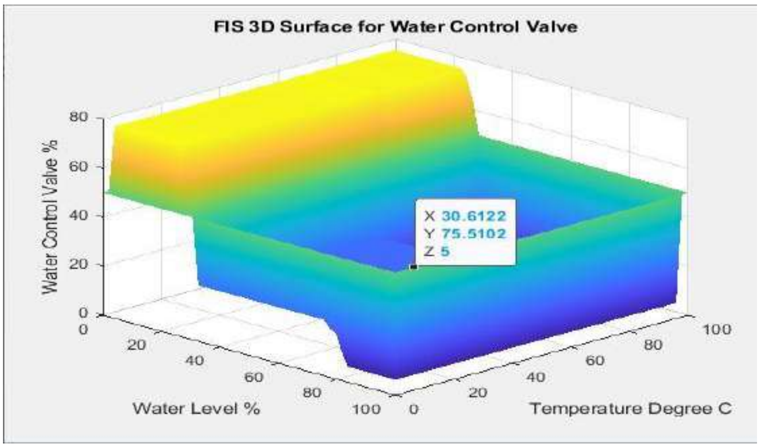

Figure 10. Contour Plot for Water Control Valve %. The water level is high and Temperature is Low, So Water Control Valve is in OFF state.

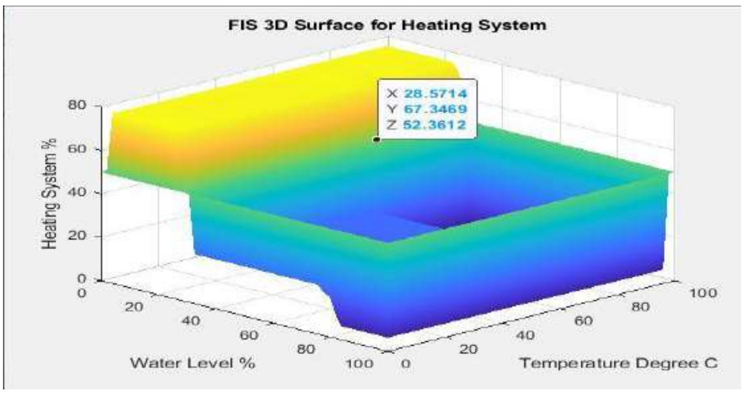

Figure 11. Contour Plot for Heating System %. The Water level is Normal and Temperature is Low, so Heating System is ON partially.

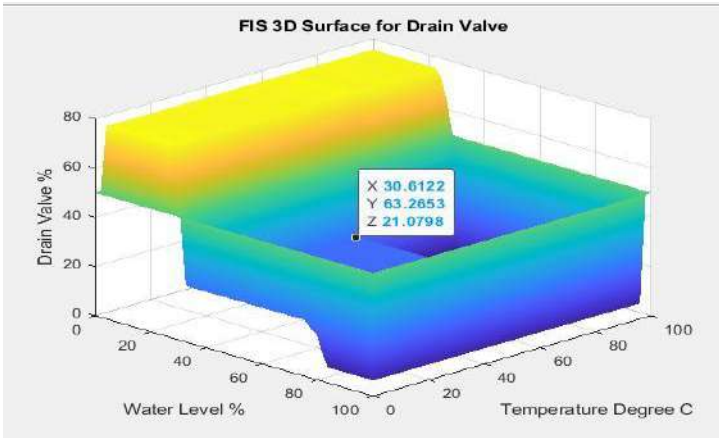

Figure 12. Contour Plot for Drain Valve %. The Water level is High and Temperature is Low, so Valve is ON partially.

V. Conclusion

This paper proposes a systematic approach for the recycling and reuse of industrial wastewater. A conventional water purification framework is adopted, with reverse osmosis incorporated due to its widespread industrial applicability and effectiveness. The subsequent stage focuses on the utilization of the treated water, which is both proposed and validated through simulation. Boilers and generators are critical components of industrial operations and require a reliable, high-quality water supply to ensure efficient, uninterrupted performance. Accordingly, the reuse of purified water is identified as a suitable and sustainable solution for meeting these operational demands. Furthermore, a fuzzy-logic–based control strategy is implemented to manage the system, offering an effective alternative to conventional control methods by employing rule-based *IF–ELSE* reasoning to handle system uncertainties and nonlinearities. All simulation results are presented and critically analyzed to substantiate the feasibility and effectiveness of the proposed methodology.

VI. Data Availability

Underlying data
figshare: Fuzzy Logic Control System Design Source Code
Source Code: https://doi.org/10.6084/m9.figshare.31781881

This project contains the following underlying data:
Control System Source Code

References

1. Groumpos, P.P., *A Critical Historical and Scientific Overview of all Industrial Revolutions.* IFAC-PapersOnLine, 2021. **54**(13): p. 464-471.
2. Tharakupeedikayil Abdul Majeed, S. and N. Pallath, *Industrial Waste*. 2024. p. 231-246.
3. Khoshsepehr, Z., S. Alinejad, and M. Alimohammadlou, *Exploring industrial waste management challenges and smart solutions: An integrated hesitant fuzzy multi-criteria decision-making approach.* Journal of Cleaner Production, 2023. **420**: p. 138327.
4. Hanchang, S., *Industrial wastewater-types, amounts and effects.* Point sources of pollution: Local effects and their control, 2009. **2**: p. 191.
5. Lemessa, F., et al., *Assessment of the impact of industrial wastewater on the water quality of rivers around the bole lemi industrial park (BLIP), Ethiopia.* Sustainability, 2023. **15**(5): p. 4290.
6. Saravanakumar, K., et al., *Impact of industrial effluents on the environment and human health and their remediation using MOFs-based hybrid membrane filtration techniques.* Chemosphere, 2022. **307**: p. 135593.
7. Dutta, D., S. Arya, and S. Kumar, *Industrial wastewater treatment: Current trends, bottlenecks, and best practices.* Chemosphere, 2021. **285**: p. 131245.
8. Lee, S.-H., et al., *Detection status and removal characteristics of pharmaceuticals in wastewater treatment effluent.* Journal of Water Process Engineering, 2019. **31**: p. 100828.
9. Asiwal, R.S., et al., *Wastewater treatment by effluent treatment plants.* SSRG International Journal of Civil Engineering (SSRG–IJCE), 2016. **3**(12): p. 29-35.
10. Dawood, A.H., S.Q. Aziz, and S.O. Ismael, *A review on pharmaceutical wastewater characteristics, treatment techniques and reusing.* Environmental Protection Research, 2023: p. 181-193.

11. Rathore, A.S., D. Kumar, and N. Kateja, *Role of raw materials in biopharmaceutical manufacturing: risk analysis and fingerprinting*. Current opinion in biotechnology, 2018. **53**: p. 99-105.
12. Einstein, D., E. Worrell, and M. Khrushch, *Steam systems in industry: Energy use and energy efficiency improvement potentials*. 2001.
13. Chen, Y.-S., et al., *Advanced Study: Improving the Quality of Cooling Water Towers' Conductivity Using a Fuzzy PID Control Model*. Mathematics, 2024. **12**(20): p. 3296.
14. Thalange, V.C., et al., *Thermal hydraulics of natural circulation loop in beam-down solar power tower.* Energy, 2018. **159**: p. 1088-1101.
15. Arias, B.G., et al., *Sustainable recovery of wastewater to be reused in cooling towers: Towards circular economy approach.* Journal of Water Process Engineering, 2021. **41**: p. 102064.
16. Eshbobaev, J., et al., *Control of Wastewater Treatment Processes Using a Fuzzy Logic Approach*. Engineering Proceedings, 2024. **67**(1): p. 39.
17. Galizia, A., et al., *Advanced control system for reverse osmosis optimization in water reuse systems*. Desalination, 2021. **518**: p. 115284.
18. Wadehra, S. and A. Mishra, *Encouraging urban households to segregate the waste they generate: Insights from a field experiment in Delhi, India.* Resources, Conservation and Recycling, 2018. **134**: p. 239-247.
19. Zubair, M.M., H. Saleem, and S.J. Zaidi, *Recent progress in reverse osmosis modeling: An overview.* Desalination, 2023. **564**: p. 116705.
20. Tayeh, Y.A., *A comprehensive review of reverse osmosis desalination: Technology, water sources, membrane processes, fouling, and cleaning.* Desalination and Water Treatment, 2024. **320**: p. 100882.
21. Garud, R., et al., *A Short Review on Process and Applications of Reverse Osmosis*. Universal Journal of Environmental Research & Technology, 2011. **1**(3).
22. Moraga, C., *Introduction to fuzzy logic*. Facta universitatis - series: Electronics and Energetics, 2005. **18**: p. 319-328.
23. Kaliniewicz, Z., et al., *The use of a Mamdani-type fuzzy model for assessing the performance of a boom stabilization systems in a field sprayer.* Scientific Reports, 2023. **13**(1): p. 18591.
24. Ross, T.J., *Fuzzy logic with engineering applications*. 2005: John Wiley & Sons.
25. Jain, A. and A. Sharma, *Membership function formulation methods for fuzzy logic systems: A comprehensive review.* Journal of Critical Reviews, 2020. **7**(19): p. 8717-8733.
26. Dubois, D. and H. Prade, *What are fuzzy rules and how to use them.* Fuzzy sets and systems, 1996. **84**(2): p. 169-185.
27. Saatchi, R., *Fuzzy logic concepts, developments and implementation.* Information, 2024. **15**(10).
28. Hasanah, L., et al., *Development of software for making contour plot using matlab to be used for teaching purpose.* Applied Physics Research, 2013. **5**(1): p. 78.