American Journal of Computer Science and Technology
2023; 6(2): 80-95
http://www.sciencepublishinggroup.com/j/ajcst
doi: 10.11648/j.ajcst.20230602.15
ISSN: 2640-0111 (Print); ISSN: 2640-012X (Online)

Expert System for Control and Maintenance of Steam Package Boiler Drum and Feed Water Using Rule-Based Fuzzy Logic Techniques

Boye Aziboledia Frederick, Daniel Matthias, Onate Egerton Taylor

Department of Computer Science, Rivers State University, Port Harcourt, Nigeria

Email address:

bayelsaforprogress2022@gmail.com (Boye Aziboledia Frederick), matthias.daniel@ust.edu.ng (Daniel Matthias), taylor.onate@ust.edu.ng (Egerton Onate Taylor)

To cite this article:

Boye Aziboledia Frederick, Daniel Matthias, Onate Egerton Taylor. Expert System for Control and Maintenance of Steam Package Boiler Drum and Feed Water Using Rule-Based Fuzzy Logic Techniques. *American Journal of Computer Science and Technology*. Vol. 6, No. 2, 2023, pp. 80-95. doi: 10.11648/j.ajcst.20230602.15

Received: May 18, 2022; **Accepted**: October 5, 2022; **Published**: June 27, 2023

Abstract: Expert system as a branch in artificial intelligence have impact greatly in many fields of discipline experimentally with various applications. This paper presents research work for expert system for steam package boiler control and maintenance using rule-base fuzzy logic technologies. The system handles cause of boiler errors in terms of control and maintaining the level in boiler drum and feed water variables. The methodology used was quantitative and qualitative as the system validates the consistency, correctness, and its precision on the test value cases, with twenty-one (21) boiler domain practitioners on dynamic simulation. The boiler variables with less or higher test value worst-cases validates the system, indicating red on the boiler's panel, while on test value best-cases, validates the system, indicating green on the boiler's panel as end users entered the right values. The steam package boiler system prevents damaged and controls its alkalinity, scaling, chemical corrosion, forming, correct pH values and then conductivity which deals with the feed boiler water and monitored the level in the boiler drum using the industry process parameters, pressure, temperature, level, and flow. The system mean (μ) error on auto run mode was computed as 1.5. The system can be deployed in chemical plants, oil, and gas industry etc. where steam package boilers are needed for steam generation and to reduced need for draughting.

Keywords: Expert System, Rule-Base System, Fuzzy Logic, Steam Package Boiler, Dynamic Simulation

1. Introduction

The discovery and development of expert systems recorded since in the early 1970s until today. Expert systems are an offspring of the more general area of study known as artificial intelligence (AI) [19]. Going further, [20] Turing was regarded as the father of artificial intelligence with his simple computer, known as Turing machine, he was able to manipulate symbols and numbers back in 1936. ES then is a computer program that contains a significant portion of the specialized knowledge of a human expert in a specific, narrow domain, and emulates the decision-making ability of the human expert, also in addition that expert system is one area in AI that is designed to simulates human expert in acts and activates [12], by the system's capability to find new facts from available facts and render advice, to teach and execute intelligent tasks [15]. Expert system answer to questions about specific problems by inference, including inference of human knowledge that is experts in the field. Expert systems should be able to explain the reasoning process and conclusion for the final user contributed [21]. In expert systems, the knowledge to develop the system is derived from human experts [9]. One of the principal attractions of expert systems is that they enable computers to assist humans in many fields. These systems are rule-based systems are used to store and manipulate knowledge to interpret. A rule consists of two parts: condition (antecedent) part and conclusion (action, consequent) part, i.e.: IF (conditions) THEN (actions) Antecedent part of the rule describes the facts or conditions that must exist for the rule to fire. Consequent describes the facts that will be established, or the action that will be taken or conclusion that will be made. Information in a useful way, used in artificial intelligence applications and research [19]. Knowledge is the key success in the performance of an expert system. Acquisition of the desired knowledge for the problem domain was obtained from intelligent human experts, said [12]. assist in solving set of various problems, for instance, expert systems for designing and planning, classification & identification, prediction, Repairs, forecasting, discovery, diagnosis, monitoring control [22] etc. and implies into the engineering and manufacturing process can provide greatest assistance for operational workers during perform and deal the critical and important tasks. However, expert system for control and maintenance of steam package boiler is new as this was not benefitted and so specifically deployed in fertilizer plants.

2. Literature Review

A survey with different works has been done earlier in different ways using Expert System (ES) for various areas and various applications of expert systems of knowledge that had used in real world. The survey includes the following areas: Medical, Education, Automobile and Agriculture for duration from 2010 to 2014 in different countries [10].

Researchers acknowledged that development of artificial intelligent (AI) technology system can be a wide scope; for an instant, there are rule-based, frame-based, fuzzy logic expert systems, etc. deploying the merge technology, rule-based expert system, the time to search and execute rule is longer, while fuzzy logic allows you deal with imprecise knowledge, trace the error and defect in the various phases in the development processes [15]. Furthermore, interactive system that responds to questions, asks for clarification, makes recommendations, and generally aids the decision-making process [2], which is hoped to prevent the losses or the wastes source of materials, producing times, labor, facilities, and utilities invested by a company to manufacture a product [26].

Also, as citizens need to make sure AI programmers are keeping things on the level, we should be sure they are doing the job correctly, so that no future accidents occur, the principal attractions of expert systems is that they enable computers to assist humans in many fields [19], in another explanation, AI is being used in maintenance programs of industrial plants from common malfunctions to rarely emergency situations, it captures efficiency of problem solving expertise from the domain experts; guides the human operator [13], since boiler operator is responsible for operating and maintaining the boiler in a safe and efficient manner with sound engineering practices and manufacturer's specified maintenance procedures [6]. Boiler domain operator expertise is generally capable of reacting to faults and performing corrective measures, guidance using expert systems which will improve operation and reduce downtime [14]. Also, boiler chemical components or impurities captured during boiler operations depend on the untreated feed water quality, and the treatment process and the boiler operating procedures can be control and maintained using an expert system with rule-based fuzzy logic technologies on the boiler drum and feed water utility variables [1]. In another development, an expert system for fault diagnostics in condition-based maintenance and the goal of the system is provided to the non-experts in industrial maintenance with a list of possible failure modes [8]. A group of authors also worked on the development of user centered design approach to situation awareness which if applied to boiler systems will certainly aid the operations of the system, this can be verified in [17].

For further research works, authors exploit the enhancement of expert systems in engineering, and therefore, an expert system implies into the engineering and manufacturing process can provide greatest assistance for operational workers during performances and deal with critical and important tasks [20]. In another research, a comprehensive expert system that assists in power plant boiler failure analysis and the maintenance planning subsystem automatically and prepares daily repair schedules, a work estimation plan, and work specifications was developed as in [8], showing that expert systems are very advantageous for steam turbine unit (STU) diagnosis. The system also employs the experience of experts [12].

Similarly, still on ES, ovation expert system was designed to help achieved operational excellence and create a sustainable competitive advantage, with standard hardware platforms, operating systems, and network architectures [25]. Another author proposed a fuzzy expert system, using fuzzy control design a simulation system of fuzzy logic controller for water tank level control by using simulation package which is Fuzzy Logic Toolbox and Simulink in MATLAB [11]. It is showed that on boiler temperature and water control, designing an expert system, using fuzzy logic on FLC based boiler control, the proposed method consists of two sections. First section is to develop a steam temperature monitoring and control system and the second section consists of water level control. For both sections Fuzzy Logic Control will be used [4]. and in a similar way a proposed modeling and control of a 200 MW power plant using the embedded fuzzy approach was developed. The embedded fuzzy based boiler control consists of models, and the output of the network is the interpolation of the models' using memberships [6].

In line with power evaluation and control, a fuzzy based expert system named Nuclear Power Plant Operator Evaluation Expert System (NPPOEX) is one of the latest expert systems which shows the use of expert system techniques in the personal evaluation process [18]. Another proposed was design and implementation of a web based fuzzy expert system that focused on the monitoring and fuzzy fault diagnosis of aeroengine [7]. Also, one of the systems developed by Chubu Electric Power Company and Mitsubishi Heavy Industries, Ltd. in Japan. a comprehensive expert system that assists in power plant boiler failure analysis and maintenance planning. The failure diagnosis reports the most probable causes for failure, guidelines for inspection, the items to be investigated, repair methods, and suggested preventive maintenance. The maintenance planning subsystem automatically prepares daily repair schedules, a work estimation plan, and work specifications [5].

In another research, a proposed expert system (ES)– Smart Solutions for Power Plants that can support operators and engineers in different areas was developed. Monitoring systems like SR: EPOS enable continuous gathering and analyzing of data and thus can help to detect various problems very fast to avoid a reduction of efficiency or damages [28] and two occasion, publications, agreed that control remains the center of operations in the industries as in [23, 21].

3. Methodology

When conducting research or degree projects, methods and methodologies are essential to plan and steer the work to achieve proper, correct, and well-founded results, and on disciplines within computer sciences, the focus is often on the work with the research rather than methods [3].

To produce a good system that will meet both functional and non-functional requirement, performance for users in package boiler control and maintenance for various chemical plants, the researcher brought in his computing and instrumentation engineering knowledge geared towards his working experience of more than ten (10) years alongside with the utility boiler domain practitioners in fertilizer plant to understand more of the activities of its operations. To attain these task or objectives, is by integrating action research method and object-oriented development for the modelling.

3.1. Action Research Method

Action research is “an approach in which the action researcher and a client collaborate in the diagnosis of the problem and in the development of a solution based on the diagnosis. One of the main characteristic traits of action research relates to collaboration between researcher and member of organization to solve organizational problems [23], and this is in line with the quantitative and qualitative research approach proposed by [24]. and the method has advantages as describe in [23].

Both the numerical values for the quantitative and non-numerical values for the qualitative were all under technical, practical, and emancipatory action research. The numerical values are from the boiler drum recommended quality and feed water recommended quality, whereas the non-numerical entails the boiler problems and causes extracted from the O&M of fertilizer plant manual. Also, the researcher conducted one-on-one interview with twenty-one (21) of the boiler plant domain practitioners, carrying out dynamic simulations during the design of system, changes were made based on their recommendations on the application on consistency, correctness, and its precision. The dataset numeric values are corresponding to the physical or chemical state of the boiler system, control measures such as shutdown, bidirectional or one directional flow, open on excess fluid, or close on excess fluid can be used to control the performance of the boiler system to keep it in a workable condition.

The performance and health of the steam package boiler drum and feed water can be control, measured and monitored using process measuring, control and sensing devices such as pressure gauges, temperature sensor (transducers), flow and level gauges, actuating valve etc. which are incorporated in the system designed. The idea is to take all the useful dataset from the boiler manual according to its performance and capability in different operation points to model a more efficient system for plant control and maintenance as stated in [16]. The same system performance capability is applied in the user centered design approach to situation awareness as describe in [17].

3.2. Object-Oriented Development Approach

Object-oriented (OO) approach can be described as a system development methodology that follows an iterative and incremental approach to systems development. In each increment or phase, the developers move through the activities of gathering requirements, analyzing the requirements, designing the system, implementing the design, and testing the system [21]. Object-oriented approach models its processes using objects, that is, the solution of problems can be seen as a set of objects or computations performed in the context of objects. Data and the processes that act on the data are encapsulated within every object. Each object’s data (attributes or states) are the properties that relate to the object [2].

Object-oriented development approach (OODA) using a set of diagramming techniques known as the Unified Modeling Language or UML, and it focuses on the three architectural views of a system: functional, static, and dynamic, makes use of iterative and incremental steps, it gives opportunity to manage changes as they occur to user requirements. So, it is more prone to user satisfaction. In this research work, the steam package boiler is object to be controlled, monitored, and maintained. The Java programming language is suitable for the system development because each module in the system is seen as classes, and this gives the environment to develop a user interface for interaction with the system [22].

4. Expert System Architecture

The expert system architecture of the boiler drum and feed water rule-based fuzzy logic technology is shown in Figure 1. It shows the encoded knowledge of the domain expert put into the system’s database where the inference engine would make use of it to process and determine the working state and errors of the system. When the system runs on the manual operation mode (MOM), the user enters the required value which enable a corresponding output from the input signal and expected value of the affected plant system as authorized by plant operations manager. In the expert system shell, data flow bi-directional to check values from plant (field instruments) and from field operator or process system engineer navigating the system.

The description of the system architecture as shown in figure 1, has the processes of both fuzzification and defuzzification, which plays major roles in the expert system architecture. The fuzzy logic is found in the part of the inference engine, where the software system converts rules to code and codes back to rules.

Domain Expert: The domain expert is the personnel either designing the ES shell or putting in his/her knowledge into the system. It has a ready and mostly accurate knowledge and experience on the proposed system shell to be designed. The expert then encodes their knowledge into the system, by making it understandable for the machine to read by fuzzification.

Knowledge Base (KB): The is the part of the expert system shell which holds the encoded expert knowledge where the inference engine gets its own knowledge. It is knowledge warehouse or library of the entire expert system shell.

Datasets/Software Mechanism: This is the process of converting a fuzzy system statement or expression into a software usable or understandable language. The fuzzified expression or language is in the form of a fuzzy system membership form. This is the process where the software makes use of the datasets in the system as encoded by the domain expert.

Plant Datasets: The plant datasets are then extracted from the inference engine (core of the fuzzy system) to be used for proper working of the plant. This process is bi-directional where the plant gets its datasets from the inference engine and gives its current datasets working condition to the inference engine for control.

User interface: this is the part of expert system architecture that helps the user to be in contact with the system so we can consider it as the main engine of expert system.

The Users: The user (Field operator/Panel engineers etc.) login into the main system with an authenticated username and password, carried out required corrections of the system errors on the interface when the system is running on manual mode and monitor and maintained the progress of the system on AMOs.

Steam Package Boiler Drum and Feed Water Rule-Base Fuzzy Logic:

The system has an inference kernel and a knowledge-based linked. The inference kernel (engine) is executed periodically to determine the system output based on current system input. The knowledge-based contains membership functions and rules.

Fuzzification: The current input values are compared against stored input membership functions, usually in a program loop structure to determine the degree to which each linguistic variable of each system is true.

Defuzzification: Dissolves multiple degree ambiguous by putting raw fuzzy outputs into a composite numerical output.

Rule-Base Evaluation: On the rule-base evaluation, this process has a list of rules from the knowledge-based using current fuzzy input values to produce a list of fuzzy output linguistic variable.

Therefore, the system has the processes of both fuzzification and defuzzification, which plays major role in the expert system architecture. The fuzzy logic is found in the part of the inference engine, where the software system converts rules to code and codes back to rules.

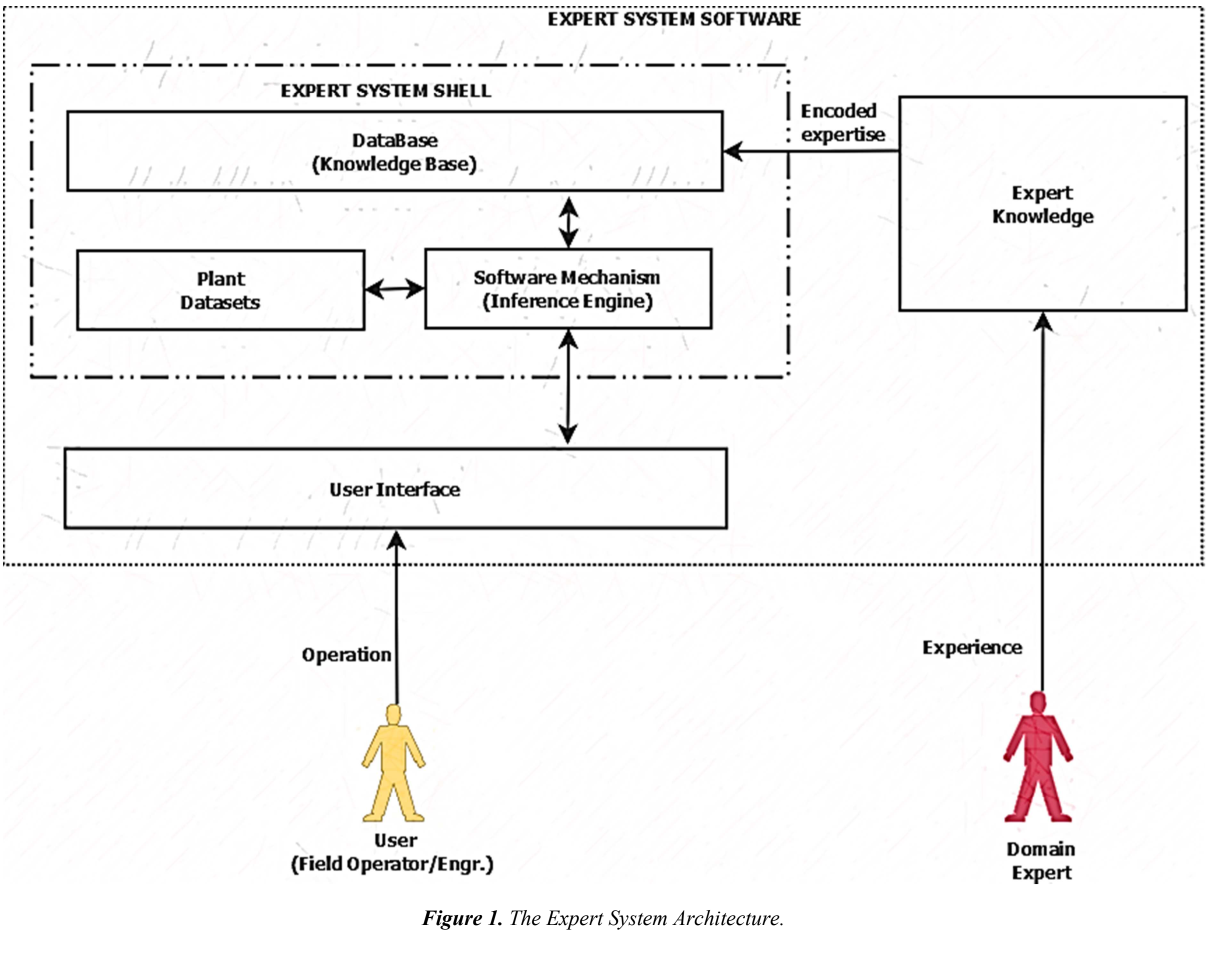

Figure 1. *The Expert System Architecture.*

5. The Expert System Design

The process of building or designing expert systems as knowledge engineering. The components and their interaction will be refined over the course of numerous meetings of the knowledge engineer with the experts and users [26], which reflect on the researcher's expert system architecture in figure 1.

5.1. Datasets

The datasets used are extracted from Section C of the boiler manual and these boiler drum water and feed water recommended qualities datasets are used for the design of the fuzzy logic system [27]. The impurities found in boiler water depend on the untreated feed water quality, the treatment process used and the boiler operating procedures. As a rule, the higher the boiler operating pressure, the greater will be the sensitivity to impurities. The boiler safety, emergency procedures datasets are used because that area is where fault solutions are placed [1]. The datasets are placed in a tabular form as shown below in tables 1 and 2.

Table 1. *Boiler Drum Water Recommended Quality.*

Parameters	Unit	Value
pH value	-	10.8 - 11.4
Alkalinity as $CaC0_3$	ppm	190
Sodium Phosphate as PO_4	ppm	29 - 34
Total Dissolved solids	ppm	143
Silica $Si0_2$	ppm	4
Oil and Organic matters	ppm	Nil

Table 2. *Feed water recommendation quality.*

Parameter	Unit	Value
General appearance		Clear and Colourless
Total hardness as $CaCo_3$	ppm	Commercial zero
Total Fe	ppm	<0.025
Total Cu	ppm	<0.02
Oil and Organic	ppm	<0.1
pH value at 25°C	ppm	8.5 - 9.5
Total dissolved solid	ppm	<1.5
Reactive SiO_2 max	ppm	<0.20

5.2. System Use Case Diagram

The use case diagram in figure 2 gives simple overview of an interaction of the user with the system. This use case diagram shows the field operator/engineer's interaction with the system, here the user engaged the system and get the expected results/output. This detail can either be a simple textual, a structural description in a table or a sequence diagram and it is used to support requirement elicitation.

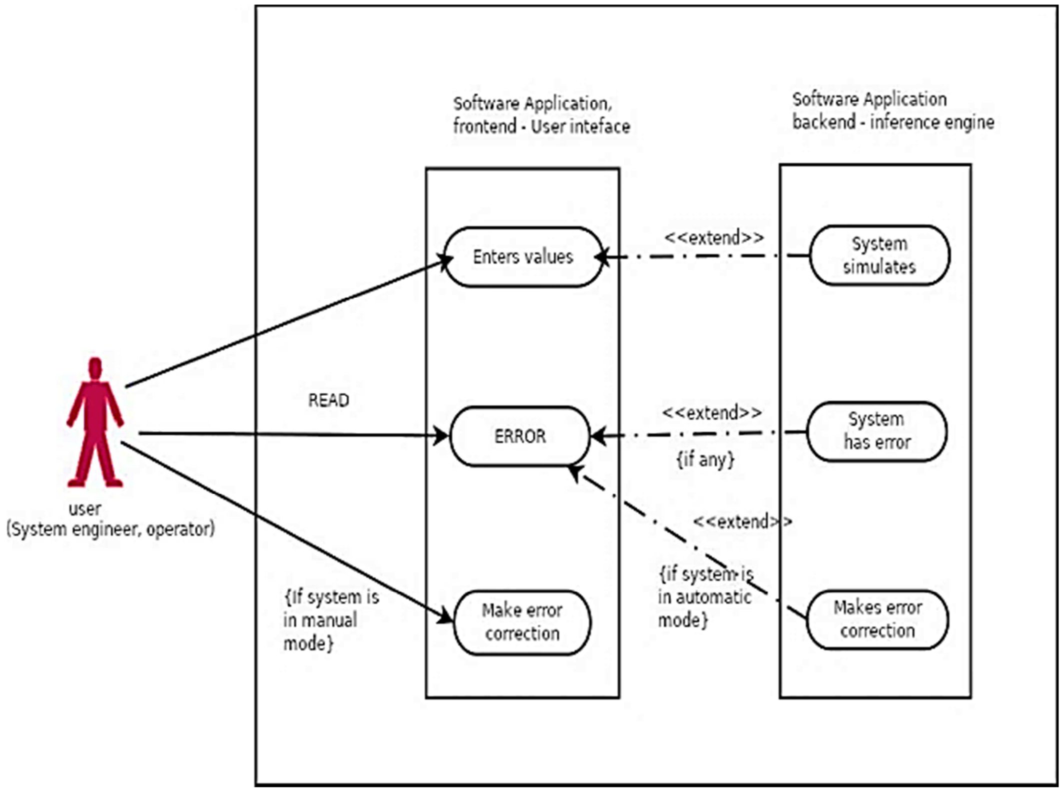

Figure 2. *Use Case Diagram of the System.*

The system use case diagram reflects on the actor(s) and its performance as the actors navigate the system. The users (operator/panel engineer) enter correct values as required for the boiler to work efficiently, this kept the system on control, maintaining the setpoints of variables of both the boiler drum and feed water etc., reduced downtime and boiler damages. When the boiler panel indicator shows red due to drift on boiler setpoints, the user read this information on the console, navigate, and effect changes. The boiler system on manual mode, enable the users to make more changes on boiler panel variables, on the other hand, when the boiler system runs on auto mode, the system correct errors as they drift from their setpoints which effect system and makes changes to keeps the boiler works efficiently. The backend of the application lies the inference engine.

5.3. System Activity Diagram

The activity diagram reveals the events of the user (Field operator/Engineer) using the system. The user opens the main application, view on the system values on the boiler panel. if the boiler runs with correct values as per design specifications, then the system is running efficiently well, otherwise, the user inputs the required parameter setpoint values to control and maintain the boiler drum and feed water parameters (variables).

This system using the rule-based fuzzy logic techniques, was designed to run in two modes (phase), manual operation mode (MOM) and automatic operation mode (AOM). The auto run was selected due to faster and quicker response (real-time) for equipment operations as the plant instrument air is on fail to close or fail to open (FO/FC) condition.

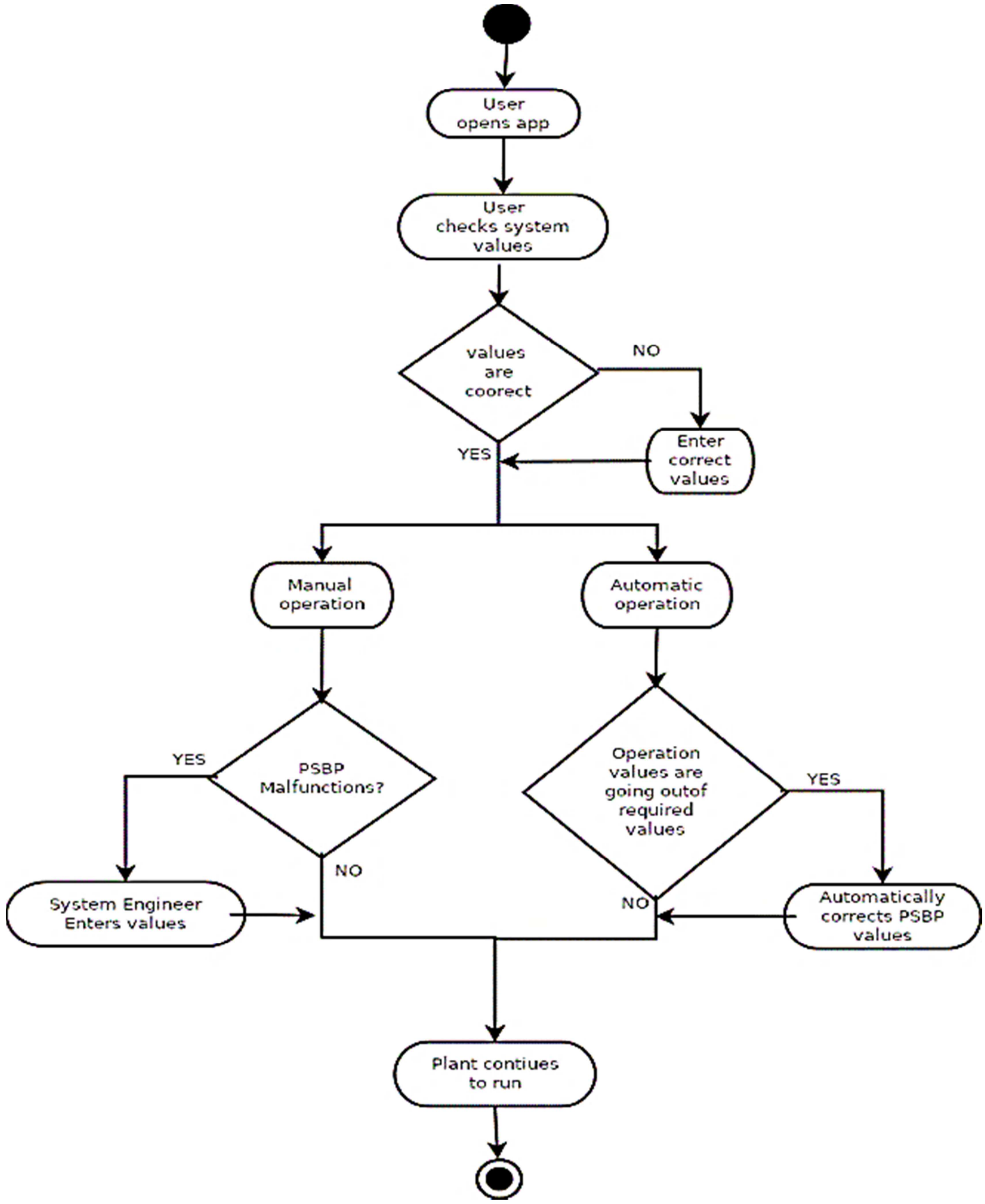

Figure 3. *System Activity diagram.*

On MOM, when the system detect an error (erratic) by a drift in boiler drum and feed water parameters setpoints, the user (Field Operator/Engineer) inputs values for corrections which enables the smooth control and maintenance of the boiler device, otherwise, the plant operations manager (POM) will request for the maintenance team with an issuance of permit to work (PTW) comprising of Mechanical, Electrical and Instrument to carry out physical (field) maintenance in the plant by bye-passing required field equipment's. But, if the system runs on AOM, and there are erratic detections, the system will automatically assume control of the boiler drum and feed water parameters, make corrections which aid the continues running of steam package boiler device.

The process of designing this system, is aimed at providing detailed dataset as shown in Table 1 and Table 2 and other system elements that enable the development and its implementation of the system reliable. The system is designed is such a way that, the output variables or condition of the boiler system controls its input variables or condition of the boiler device. The pH value at 25°C in the table above has a range of value suitable for the application of fuzzy logic system. The FLS is designed as follows.

5.3.1. Algorithm

1. Define linguistic variables and terms (start)
2. Construct membership function for the terms (start)
3. Construct knowledge base of the rules (start)
4. Construct crisp data into fuzzy datasets using membership functions (Fuzzification).
5. Evaluate rules in the Rule Base (Inference Engine)
6. Combine results from each rule (Inference Engine)
7. Convert output data into non-fuzzy values (Defuzzification)

5.3.2. Development

1. State(s) = {very-low, low, normal, high, very-high}
2. Constructing membership function

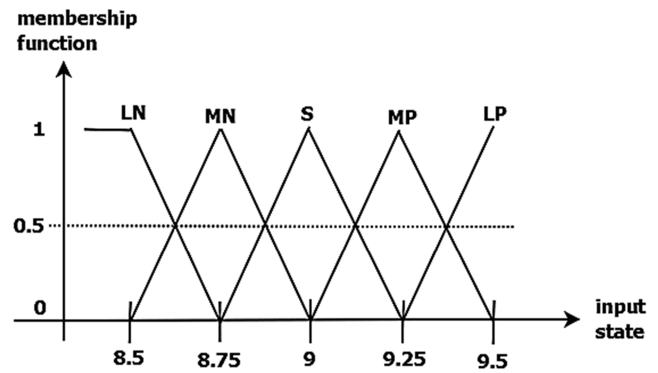

Figure 4. *A graph of membership function of pH value at 25°C ranging between 8.5ppm (Mini value) to 9.5ppm (maxi value). 1and 4. Constructing a Knowledge Based Rule from the membership function.*

Table 3. *pH Value at 25°C Showing Membership Values.*

M/Class	Class/R	Grade
LP	x = 9.5	L/value
MP	x = 9.25	H/Average
S	x = 9	Average
MN	x = 8.75	Lower/Average
LN	x = 8.5	Smallest/Value

The above table 3 has been used to design a membership function graph for the membership values in the table, as calculated with the datasets of pH value at 25°C ranging between 8.5ppm (actual minimum value) to 9.5ppm (actual maximum value).

Table 4. *Membership function table -membership function replaced with actual numeric values. The actual rule from the inference engine will be as follows.*

State	Target (s)				
-	Very/Low	Low	Normal	High	Very/High
Very/L	No/C	8.75	9	9.25	9.5
Low	8.5	No/C	9	9.25	9.5
Normal	8.5	5.75	No/C	9.25	9.5
High	8.5	8.75	9	No/C	9.5
Very/H	8.5	8.75	9	9.25	No/C

From the boiler drum water recommended quantity and following the same steps of 1**,** the pH value (10.8 - 11.4) and the Sodium Phosphate as PO_4 (29 - 34) rule-based fuzzy logic system will be developed using the parameters from table 1.

The steps in the algorithm of 1a are followed in the system design and development of the pH value and Sodium Phosphate as PO_4 membership function and fuzzy logic rule base system.

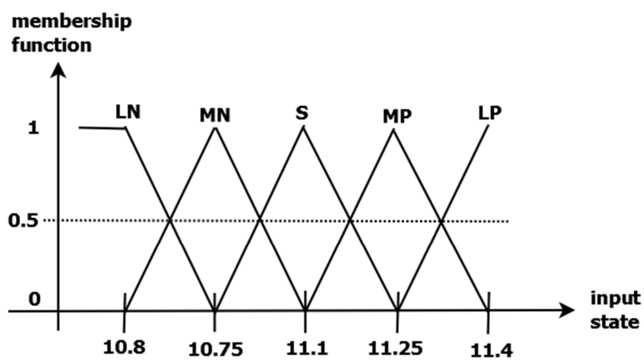

Figure 5. *Show above is a graph of the membership function of pH ranging between 10.8 ppm (min value) to 11.4 ppm (maxi value).*

R1: IF STATE= (10.8 OR 10.75) AND TARGET =
11. THEN ALERT
R5: IF STATE= (10.8 OR 10.75 OR 11.1 OR 11.25) AND TARGET =11.4 THEN ALERT
Listing 5.a
R1: IF STATE= (10.8 OR 10.75) AND TARGET = 11.1 THEN SET STATE=11.1
R5: IF STATE= (10.8 OR 10.75 OR 11.1 OR 11.25) AND TARGET = 11.4
THEN SET STATE=11.1
Listing 5.b

Listing 5. Listing 5.a Manual mode, and Listing 5.b Automatic mode, are both the final Rule-Base System used in the Inference Engine of Sodium Phosphate as PO_4 ranging between 10.8ppm (mini value) to 11.5ppm (maxi value).

***Table 5.** Membership Function of Numeric Values of pH Ranging Between 10.8 ppm (mini value) to 11.4 ppm (maxi value) table.*

State	Target(s)				
-	V/Low	Low	Normal	High	V/High
V/Low	No/C	10.75	11.1	11.25	11.4
Low	10.8	No/C	11.1	11.25	11.4
Normal	10.8	10.75	No/C	11.25	11.4
High	10.8	10.75	11.1	No/C	11.4
V/High	10.8	10.75	11.1	11.25	No/C

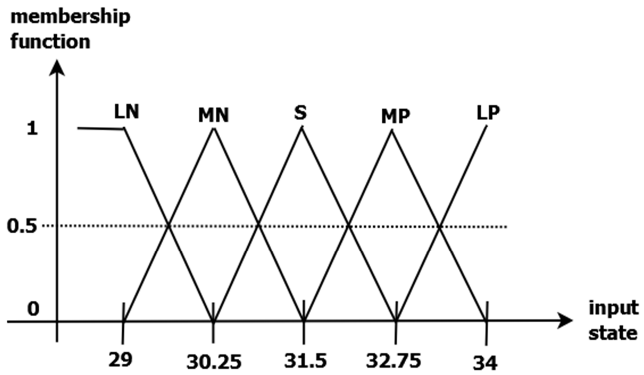

***Figure 6.** A Graph of Membership Function of Sodium Phosphate as PO_4 ranging between 29ppm (minimum value) to 34ppm (maximum value).*

***Table 6.** Membership Function of Numeric Values of Sodium Phosphate as PO_4 Ranging between 29ppm (Min value) to 34ppm (Maxi value).*

State	Target(s)				
-	Very/low	Low	Normal	High	Very/high
V/Low	No/C	30.25	30.5	32.75	34
Low	29	No/C	30.5	32.75	34
Normal	29	30.25	No/C	32.75	34
High	29	30.25	30.5	No/C	34
V/High	29	30.25	30.5	32.75	No/C

R1: IF STATE= (29 OR 8.5) AND TARGET = 9 THEN ALERT

R5: IF STATE= (29 OR 8.75 OR 9 OR 9.25) AND TARGET =9.5 THEN ALERT

Listing 6.a

R1: IF STATE= (29 OR 30.25) AND TARGET = 30.5 THEN SET STATE=30.5

R5: IF STATE= (29 OR 30.35 OR 30.5 OR 32.75) AND TARGET =34

THEN SET STATE=30.5

Listing 6.b

Listing 6. Listing 4.a Manual mode, and Listing 4.b Automatic mode, are both the final Rule Base System used in the Inference Engine of pH value at 25°C ranging between 29ppm (mini value) to 34ppm (maxi value)..

5.4. System User Interface

The main purpose of this application user interface is to enhances the field operator/engineers with less effort to navigate and received maximum desired outcome from the system. The boiler drum and feed water expert system graphical user interface is menu-driven type and as shown in figure 7, and the system functions carried out with a dynamics simulation process during this research work.

Both *manual and auto* operations take place on this UI, it shows the window style view of the entire structure of the system. schematically it shows the drum water quality and feed water quality panels, boiler drum, water level, temperature, flow, pressure, console etc. on its panel.

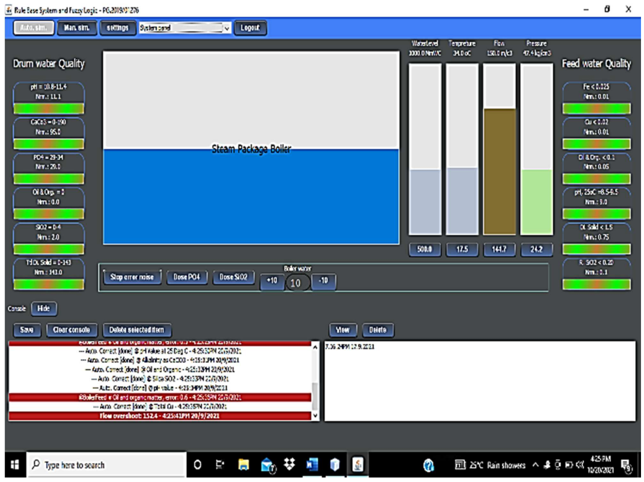

***Figure 7.** System User Interface.*

5.5. Admin and User Login Interface

This is the interface for both admin authorization and user login to have access to the main application. The UI is design to enable an admin to provide his login details before the end-user (field operator/engineers) can gain access to the main application. the Exit button is clicked to exit the application. When credentials are correct the system gives access to the user to access the main application screen as shown in figure 8 below.

***Figure 8.** Admin and User login Interface.*

5.6. User Registration Window

On the registration window, the admin double clicking on the ExpertSystem icon on the Desktop as installed by the system architect and splash up of the *user access point window* comprising *of register and exit button*.

The system is design for an admin to grant access to the end-user before gaining access to the main system. Evaluated and validated window result for a successful registration process of a New User (Field operator/Process or panel Engineer) carried out by the admin is shown in figure 9 below:

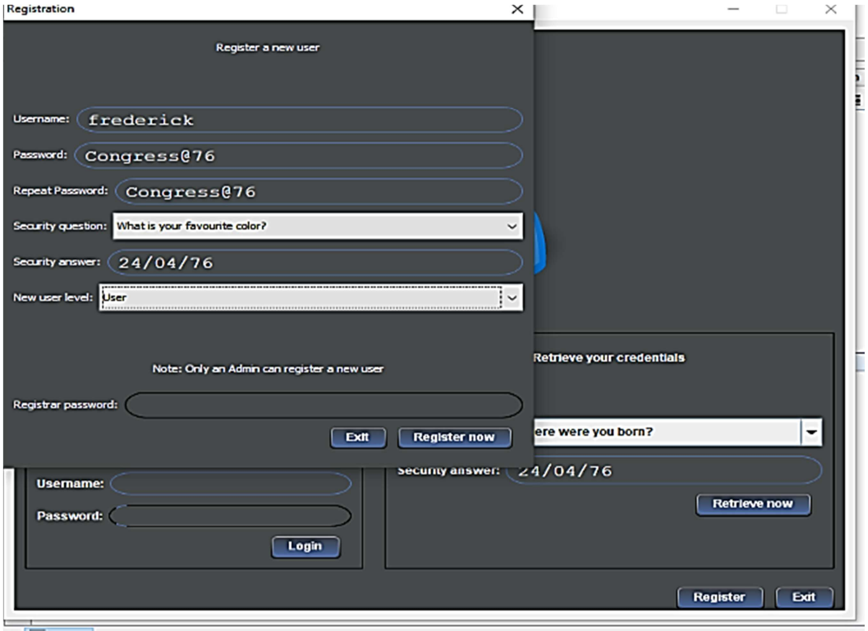

Figure 9. *User Registration Window.*

Admin authorization window: This comprises of the following's components, Admin password and authorize button, the username's, password, and login button. Retrieve your credentials window: it also comprises of the text boxes, security question, security answer and retrieve now button.

The above registration window also aids the end-user's a forgotten login credentials retrieval, all users are expected to choose a security question and type the answer in the given textbox and click the *"Retrieve Now*" button as shown in figure 9.

5.7. Settings Button Interface Window

The setting button interface window in figure 10 enable flexibility in navigation for the end user, mainly the company deploying the system. All the boilers' drum and feed water recommended qualities in tables 1 and 2 (parameters) can be change based on the design requirement and specifications of the industry or company deploying this system. These parameters changes are carried out at the backend of the expert system application.

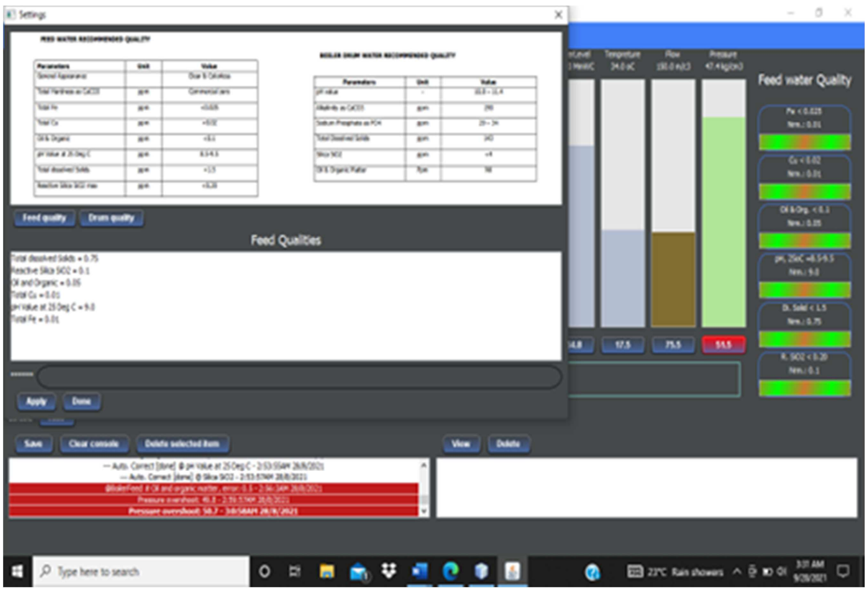

Figure 10. *Setting Button Interface Window.*

5.8. The Main System Control Panel Interfaces

The main control utility (steam) boiler interface panel is where the users (operators/engineers) will navigate, monitor, controlled, and maintained the real-time conditions and readings (default parameters of the utility boiler expert system with their operating setpoints for better operational efficiency, reliability, performance, and product throughput. The system comprises of seven (7) panels as shown in steam package UI in figure 7.

The Top Control Panel
The Drum Water Quality Display Panel
The Feed Water Quality Display Panel
The Level, Temperature, Flow and Pressure Bars
The Utility Boiler Drum
The Bottom Control Panel

Each of these operational panels are describe below for better understanding.

5.8.1. The Top Control Panel

This is menu situated on top of the main utility boiler application comprising of simple "Automatic and Manual Sim" buttons", "Setting" button, Panel Selection Drops Down Menu Bar, and "Logout" button. The Automatic Simulation button is used to run and navigate the Utility Boiler in an auto mode (AM) where all errors are corrected by the designed fuzzy logic system. While on manual mode (MM). Operators/engineers effect required changes to keep the system operational.

5.8.2. The Drum Water Quality Display Panel

This steam boiler drum panel on the main application displays the real-time parameter values of the Total Hardness as $CaCO_3$ in ppm, TI (ppm Fe), TC (ppm Cu), Oil & Organic, pH value at 25 Deg. C, total dissolved solids (ppm TDS), and the Reactive Silica max (ppm SiO_2) of the water in the boiler drum, in their respective range of values. When there are low or high values in the drum water quality parameters as calibrated setpoints desired for running of the steam package boiler ES, the green horizontal bars on the drum water panel turned red or green as shown Figure 8. Also, the boiler drum water quality should be continuously monitored and suitable adjustment in *blowdown* is carried out to maintain the drum water real-time values as per the utility boiler system design specifications. With the calculation carried out, the quantity of blowdown required to control boiler water solids concentration is calculated by using the following formula.

Blow down (%) = Feed water TDS x % Make up water / Maximum Permissible TDS in Boiler water.

If maximum permissible limit of TDS as in a package boiler is 3000 ppm, percentage make up water is 10% and TDS in feed water is 300 ppm, this can be express as follows.

TDS in PB =3000 ppm
TDS in FW = 300 ppm
Make up H_2O = 10%
Then the percentage Blow down is given as:

$$= 300 \times 10/3000$$

$$= 3000/3000 = 1\%$$

Therefore, Blow down = 1%
If boiler evaporation rate is 3000 kg/hr., then required blow down rate is.

$$= 3000 \times 1/100$$

$$= 30 \text{ kg/h}$$

Good utility (steam) boilers blow down control can significantly reduce treatment and operational costs that include:

1. Lower pre-treatment costs
2. Less make-up water consumption
3. Reduced maintenance downtime
4. Increased boiler life
5. Lower consumption of treatment chemicals [1]

5.8.3. The Feed Water Quality Display Panel

Boiler performance, efficiency, and service life are direct products of selecting and controlling feed water used in the boiler. The feed water panel on the main utility (steam) boiler system displays real-time values of the running plant with setpoints of pH value, CaCO3 in ppm, Sodium Phosphate as PO_4, Total Dissolved Solids (ppm TDS), Reactive Silica max (ppm SiO2), and Oil & Organic matters present in the feed as it goes into the boiler drum, in their range of values as system requirement specifications. When there are low or high values in the feed water quality parameters as setpoints desired for the functional operation and running of the boiler system, correct or error values will be detected on the horizontal bar indicator and turned either red or green on the feed water quality panel [1].

5.8.4. The Boiler System Industry Process Parameters

The four (4) bars on the main system interface represent four main industry process parameters, water Level in the drum (1000 MmWc), Temperature of the drum (34 Deg. C), Flow of the feed water (150 m/c^3), and the Pressure that is built up in the drum as it is heated up (47.4 kg/cm3). These are seen on the main utility boiler interface as shown in figure 7. Each industry process parameters values on the bar can be reset by mouse clicking the button below to get an input popup textbox. The operator/panel engineer entering the right values into the textbox will removed the red colour indicating on any of the parameter bars as required, which then maintained the boiler system under control and healthy operations.

5.8.5. The Steam Package Boiler Drum

The utility boiler is one the main facilities in every chemical plant (fertilizer) situated at the utility section and is monitored during operations. The boiler system drum can be seen on the main application interface. The water level is monitor with the result obtained from the four industry process measurement parameters vertical bars representing pressure, temperature, level, and flow as seen in figure 7.

5.8.6. The Bottom Control Panel

This panel comprises of the "Stop Error Noise" used to stop any error noise during boiler operations, the noise is coming due to system error, "Dose PO_4" and "Dose SiO_2" buttons are used for dosing as required to maintain feed & boiler water qualities at a desirable level, on clicking either of this button will bring a pop-up window with an input textbox which receives the value from any of the user (field operator/engineers) of the system. The boiler system keeps running as right values are entered into the system by these domain practitioners.

6. Evaluations and Results

The performance of every system after design and installation will be monitored to check if it's working properly, meaning to check if the system meets the system design specifications. In other to evaluate, validate the correctness of system by the boiler domain practitioners, the following variable were used for dynamic simulation, Actual minimum range, actual maximum range, test values worst-case and test values best-case and tested with the following conditions.

Actual values (Max or Min): These value range are the boiler parameters from minimum to the maximum required limits of the system design specification. The healthy, proper, and effective performance on control and maintenance of the utility (steam) boiler system depends on these operating parameters within the required range and limits as shown table 7 of worst-case and best-case test values.

Test Values: There are two type of test values used in this discussion, the Worst-case and the Best-case test values.

Worst-Case The worst-case value are the values outside the expected functional range setpoints of the required plant parameters value. This worst-case value is used to monitor, examine, and evaluate the behaviour of the utility boiler system if the water chemical component quality exceeds or falls below the required set value.

Best Case: The best-case values are the values which are set within the required functional range or setpoints of the plant water chemical components.

Table 7. *Parameters Test values (Worst-case/Best case) used for the dynamic simulation process to validate the system consistency, correctness, and its precision.*

Parameters	AMR	AMR	TestV WorstC	TestV BestC
BDWQ			**I**	**I**
pH value	10.8	11.4	10	11.2
PO_4 (ppm)	29	34	43	32
Silica SiO_2	0	4	6	2
FWQ			I	I
Total Fe	0	0.025	2	0.010
pH@25Deg C	8.5	9.5	8.2	8.9
TDS (ppm)	0	1.50	1.8	1.2

6.1. Dynamic Simulation of Operational Boiler Drum Water Quality Parameters

The researcher explores a dynamic simulation process alongside twenty-one (21) boiler domain practitioners using three (3) steam package boiler drum recommended qualities as displayed on the drum water panel of the steam package boiler system comprising of pH value, Sodium Phosphate (PO_4) and Silica max (SiO_2 parameters.

6.1.1. Dynamic Simulation for Worst-Case and Best-Case Values for Drum Water Quality on pH Value

The results of the dynamic simulation process of the researcher using variable pH value range of 10.8-11.4 with worst-case pH value of 10. The system displaying less value setpoint of 10.8, turns red the utility boiler variable indicator bar, an operator/engineer clicking gives the system popup request to enter the right value to validate that the pH value of 10 is erratic. Also, the user entering a best-case functional of pH value of 11.2 validates the system and the parameter indicator bar turns green as shown in figure 11 below.

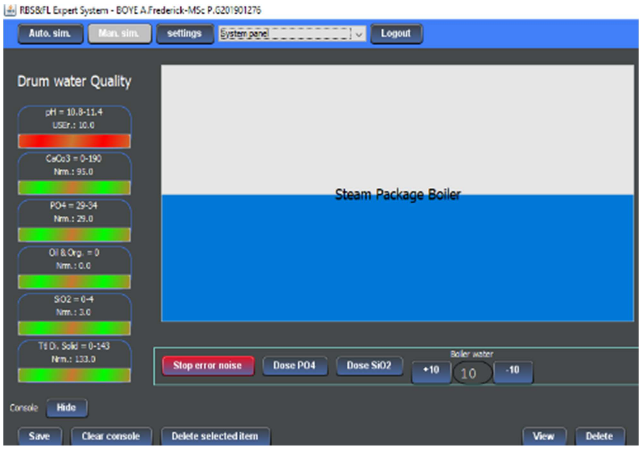

Figure 11. *pH value of 10.*

6.1.2. Dynamic Simulation for Worst-Case and Best-Case Values for Drum Water Quality on Sodium Phosphate as PO_4

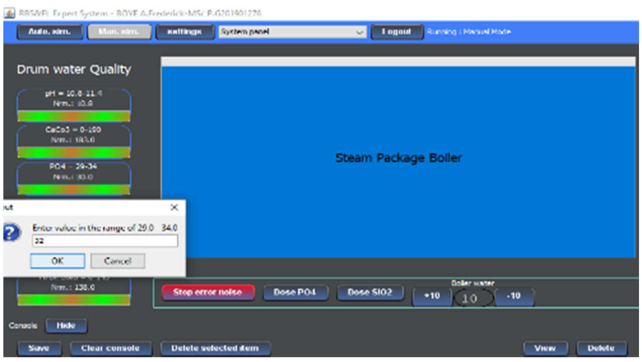

Figure 12. *PO_4 Simulation Result.*

The specified design system values of PO_4 are shown in Figure 12 to be use for the dynamic simulation process. The operator/engineer viewing on the boiler panel displaying 43ppm of PO_4 as a worst-case value, which is erratic value, turns the utility boiler indicator panel bar red. An operator/engineer enters the best-case value of 32ppm through a window popup, which turns the boiler indicator of the PO_4

parameter green, validating the utility boiler is operating in healthy condition. The PO_4 system design specification for sodium phosphate is between 29-32 ppm as shown in figure 7 and display on the boiler drum panel in figure 12.

6.1.3. Dynamic Simulations for Worst-Case and Best-Case Values for Boiler Drum Water Quality on SiO_2

Figure 13 is showing the dynamic simulation of Silica Max of 2 ppm parameter. The system requirement for the design specification of Silica max (SiO_2) is 0.0-4.0 ppm. The boiler water recommended quality must remain within its setpoint for the boiler to function effciently. The results of the simulation with a worst-case of 6ppm, shows erratic displaying on the boiler panel, viewed by the operator/engineer, verifying that SiO_2 reading is high, indicating red on the boiler system indicator bar. Its requires a user to enter the right value, 2ppm of SiO_2, which will turn the parameter indicator bar on the boiler panel green, validating the steam boiler running normally.

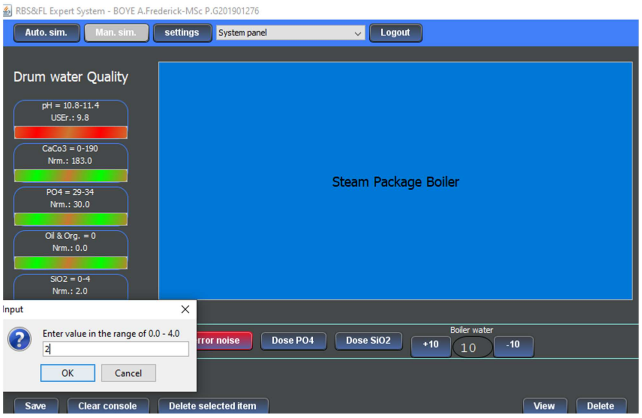

Figure 13. Silica Max Simulation Result.

6.2. Dynamic Simulation for Operational Feed Water Quality Parameters

A dynamic simulation with test value worst-case and best-cases on feed water quality for iron (Fe) ppm, pH value at 25DegC and total dissolved solid (TDS) ppm were carried out and variable displayed on the boiler panel as evaluated and verified by twenty-one (21) fertilizer boiler domain practitioners.

6.2.1. Dynamic Simulation for Worst-Case and Best-Case Test Values on Iron Fe (ppm)

The iron (Fe) as a default parameter with range of 0.0-0.025ppm was simulated, and the feed water erratically displays worst-case of 2ppm a higher value of Fe, this turns the indicator variable red. The erractic value was remove as a user clicking and system requesting right value to be entered. the user enterd a test value best-case of 0.010 Fe (ppm), which is within the variable setpoint range, and the indicator bar turns green, validating that the boiler device enable and working effeciently. The dynamic simulation with the displayed parameter of Fe ppm parameter is shown in figure 14 of the boiler feed water quality panel.

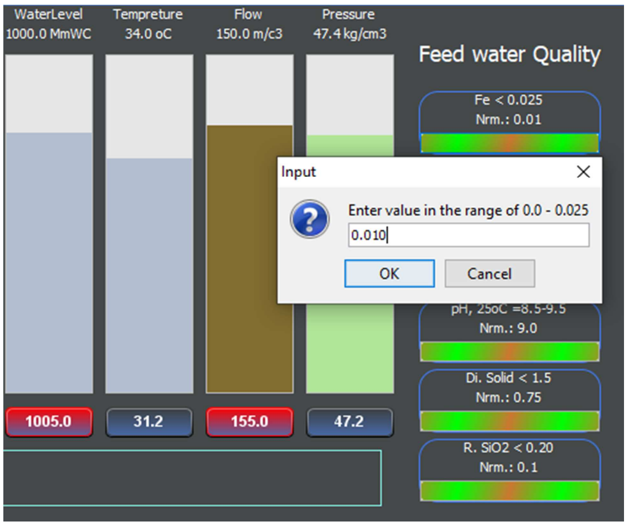

Figure 14. Fe (iron) Simulation Result.

6.2.2. Dynamic Simulation for Worst-Case and Best-Case Values on pH Value at 25DegC

The dynamic simulation results of the feed water quality for pH value at 25 DegC displaying pH value parameters of test value worst-case of 8.2-9.5 is shown below. The boiler system displaying a test value worst-case pH value of 8.2, less than the designed setpoint, turns indicator panel red, a user then clicked on the indicator bar and entered the right value range of pH value of say 8.9 to validate the system. The best-case value simulation which is a pH value of 8.9 @25DegC, turns indicator green, meaning value entered is within the boiler system designed specification. Check below for the display of the pH value at 25 Deg C parameter on the feed water indicator panel (Figure 15).

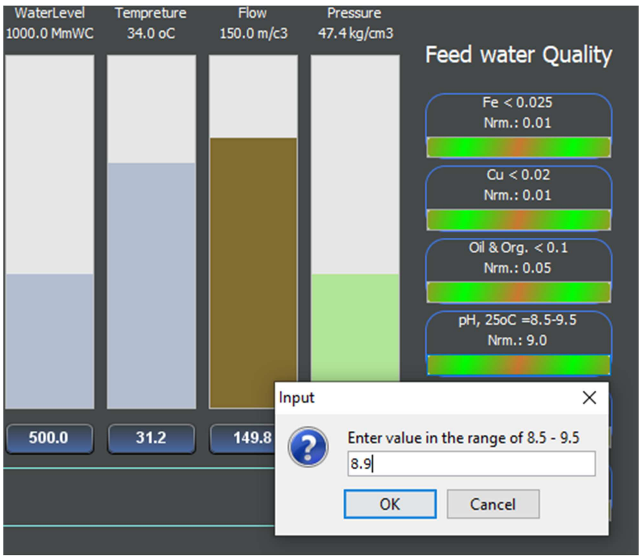

Figure 15. pH value at 25DegC simulation Result.

6.2.3. Dynamic Simulation for Worst-Case and Best-Case Values for Feed Water Quality on (TDS) in ppm

Finally, a dynamic simulation for total dissolved solid (TDS) parameter was carried out with worst-case value of 1.80ppm and best-case value of 1.20ppm TDS. The feed water TDS panel indicator bar turns red at 1.80ppm which is erratic. A user is requested to entered correct value of the feed water quality at 1.20ppm which turns the TDS bar indicator green, this keeps boiler device in healthy operation.

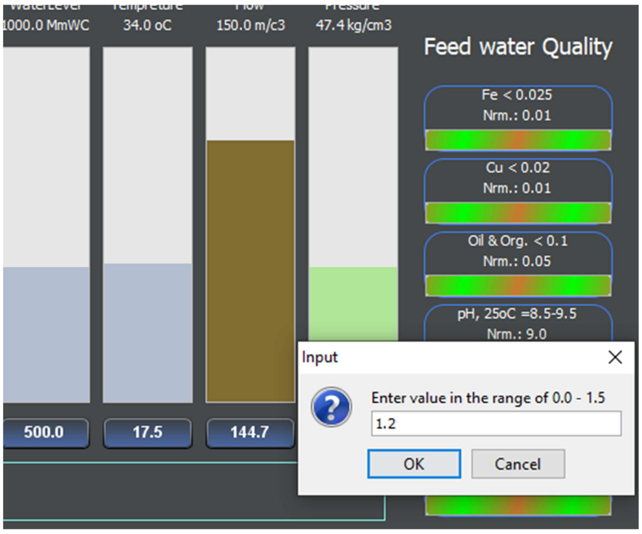

Figure 16. *TDS Simulation Result.*

6.2.4. Results for Boiler Drum Performance Using the Industry 4 Process Parameters

The industry parameter performance during auto run for the boiler drum were captured, level, flow, temperature, and pressure. The results are tabled is with respect to the effect that comes from level when any of the parameters (setpoints of pH value, CaCO3 in ppm, Sodium Phosphate as PO_4, Total Dissolved Solids (ppm TDS), Reactive Silica max (ppm SiO2), and Oil & Organic matters). The reactions or performance of each is different based on value of the parameter displays on the boiler panel during the steam package ES running, in either auto or manual, pH value, Sodium Phosphate and SiO_2. The reaction or performance is due to either high, very high, low, or very low on the industry process parameters during the steam package boiler operations.

pH Value parameter:

pH values Amin V =10.8

pH value AMaxV = 11.4

Indicator Fault value display = pH value = 10 (below, outside parameter setpoint), steam package boiler operation erratic. Because the pH value parameter was lower than design specifications.

Indicator Correct value Display = pH value = 10.2 (within parameter setpoint), boiler operation healthy

Sodium Phosphate (PO_4) Parameter:

PO_4 AminV = 29ppm

PO_4 AmaxV = 34ppm

Indicator Fault value display = 43 (higher, outside parameter setpoint), steam package boiler operation erratic.

Indicator Correct value Display = 32 (within parameter setpoint), steam package boiler operation healthy

Reactive Silica max (ppm SiO_2)

SiO_2 AminV = 0ppm

SiO_2 AmaxV = 4ppm

Indicator Fault value display = 6 (higher, outside parameter setpoint), steam package boiler operation erratic. Because there is drift from the parameter setpoint, it required an operator/panel engineer to effect changes as to keep the steam package boiler working efficiently.

Indicator Correct value Display = 2 (within parameter setpoint), steam package boiler operation healthy). Figure 17 below show the graphical interpretation of the three (3) industry parameter of the boiler drum quality.

6.2.5. Result for Feed Water Quality Performance on the Industry 4 Process Parameters

The industry parameter performance during auto run for the boiler drum were captured, level, flow, temperature, and pressure. The results are tabled is with respect to the effect that comes from level when any of the parameters (setpoints of the Total Hardness as $CaCO_3$ in ppm, TI (ppm Fe), TC (ppm Cu), Oil & Organic, pH value at 25 Deg. C, total dissolved solids (ppm TDS), and the Reactive Silica max (ppm SiO_2). The reactions or performance of each is different based on value of the parameter the steam package displays on the boiler panel, pH value, Sodium Phosphate and SiO_2. The reaction or performance is due to either high, very high, low, or very low on the industry process parameters as shown in figure 18.

Total Iron (Fe ppm) Parameter:

Fe Amin V =.0 ppm

Fe AMaxV = 0.025 ppm

Indicator Fault value display = Fe ppm = 2 ppm (value higher, outside parameter setpoint), boiler operation erratic.

Indicator Correct value Display = Fe 0.010 ppm (within parameter setpoint), boiler operation efficiently healthy

pH Value at 25 Deg Celsius Parameter:

pH at 25 Deg C AminV = 8,5

pH at 25 Deg C AmaxV = .9.5

Indicator Fault value display = 8.2 (lower, outside parameter setpoint), steam package boiler operation erratic.

Indicator Correct value Display = 8.9 (within parameter setpoint), steam package boiler operation efficiently healthy

Total Dissolved Solid (TDS) Parameter:

TDS AminV = 0 ppm

TDS AmaxV = 0.18 ppm

Indicator Fault value display = 2 (Display higher, outside parameter setpoint), steam package boiler operation erratic. Needs operator to effect changes as to keep the boiler working efficiently.

Indicator Correct value Display = 0.10 (within parameter setpoint). The boiler operation remains healthy at this point.

Below show the graphical interpretation of the three (3) industry parameter of the feed water quality in the boiler drum.

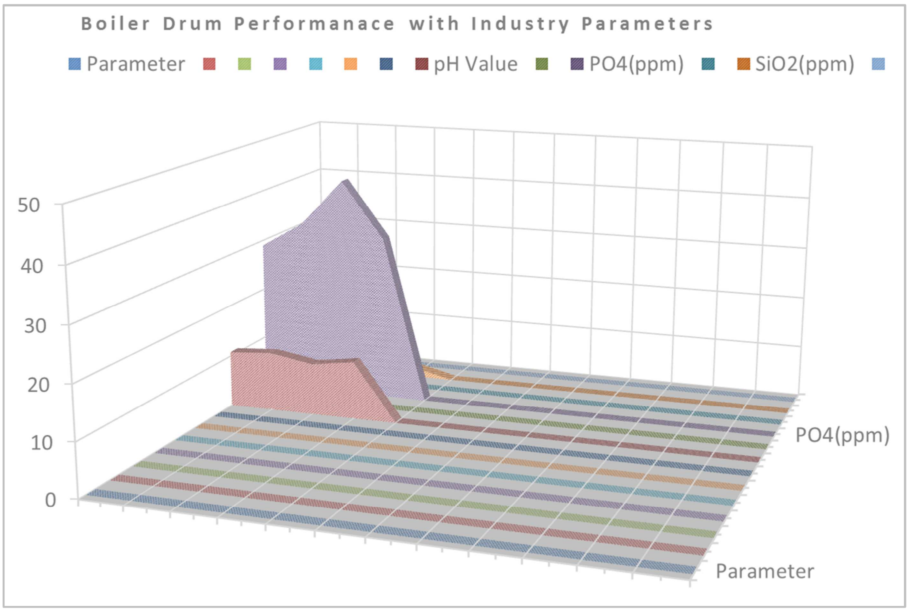

Figure 17. *Boiler Drum Performance on industry 4 parameter.*

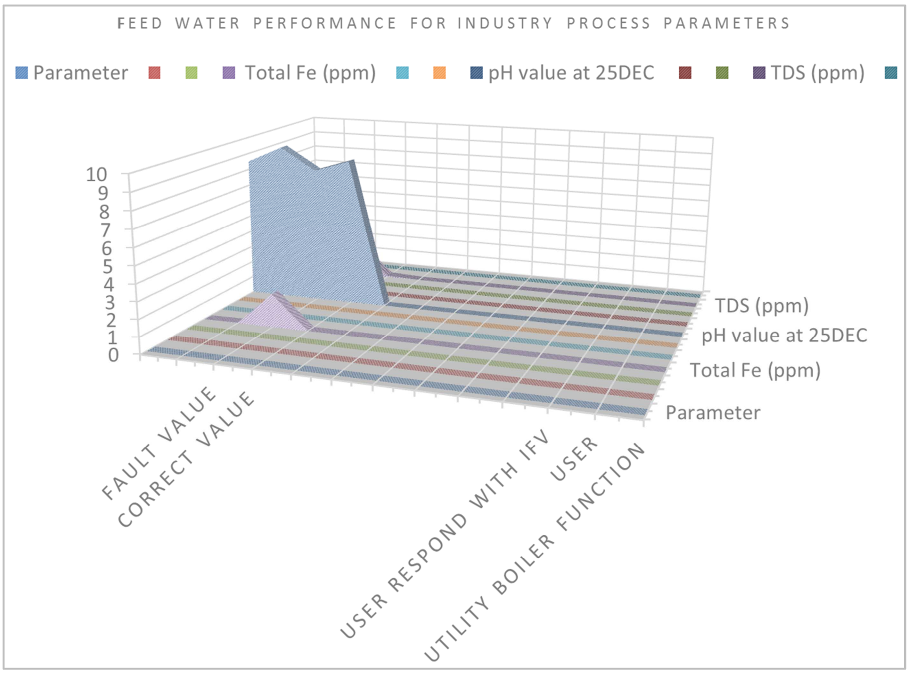

Figure 18. *Feed Water Performance on industry 4 parameter.*

6.3. System Analysis for Mean, Mean Absolute Deviation and Standard Deviation of Auto Run Errors

The researcher computes the mean, mean absolute deviation and the standard deviation errors of both manual and auto running with different time intervals to evaluate and verify which mode of the boiler system was preferable and the number of errors generated. The action research method deployed with quantitative observation of ten (10) consecutives run times of the boiler system in Table 8, comprising system error time (minutes), system running in manual and auto run. Each time corresponds with the number of errors generated.

Table 8. *System Running on Manual and Auto Errors with Time (Minutes).*

System Error Time (Minutes)	System Running on Manual	System Running on Auto
1	3	1
2	6	2
3	6	2
4	6	1
5	6	1
6	8	2
7	9	1
8	11	1
9	11	2
10	12	2

Table 9. *System Run for Mean and Mean Deviation Error on Auto Run.*

Auto Run True System Error (x)	Mean Deviation Error on Auto Run | x - μ |
1	0.5
2	0.5
2	0.5
1	0.5
1	0.5
2	0.5
1	0.5
1	0.5
2	0.5
2	0.5
Mean (μ) E = $\frac{\sum x}{n}$ = 1.5	(MAD) $\sum \| x - \mu \| = 5$

The mean (μ) error of the system running on automatic mode is computed as follows:

$$\text{Mean } (\mu) \text{ Error} = \frac{\sum x}{n} \quad (1)$$

$$= \frac{1+2+2+1+1+2+1+1+2+2}{10} = 1.5$$

Therefore, the mean (μ) error of automatic system run mode is 1.5

The mean deviation error of the steam package boiler system running on auto mode is computed as follows:

$$\text{The Mean Deviation Error} = \frac{\sum |x - \mu|}{n}, \quad (2)$$

where x is the true mean error, μ is the mean error and n the sum of system errors in auto run of the proposed system.

The Mean Absolute Deviation

$$\text{(MAD) Error} = \frac{\sum |x - \mu|}{n} = \frac{5}{10} = 0.5$$

In computing the standard deviation of the proposed system error on auto run, we must take the square root of the mean absolute deviation (MAD) squares it, divides by the total number of system errors (n) in auto run.

$$\text{Standard Déviation} = \sqrt{\frac{\sum |x - \mu|^2}{n}} \quad (3)$$

$$= \sqrt{\frac{5^2}{10}} = \sqrt{\frac{25}{10}} = 1.58113883 \approx 1.58$$

From Table 9 of the error analysis, the auto run, minimum error is 1 in 1 minute while the maximum error is 2 in 10 minutes. The errors in minute are deduced from the log save error view button on the console and viewing the save logs screen.

On auto run, Error needed correction = overshoot + errors, this mode is subtracted from the errors correction done by the system, i.e., Correction Done-Needed correction = System errors, for instance in 2-minute, the system error gives 2 error on auto run. The overshoot was 8, error was 4, error needed correction is 12, correction was 14. This is the same with 4 minutes etc.

The manual run of the boiler system was evaluated as did the auto run which was our main purpose for the design of the expert system. the system is automated and if there is any drift in parameter range or setpoints, it will be required by the field manager to physical send the maintenance team (electrical, instrument and mechanical) for field work with permit to work (PTW) from the shift-in-charge (SIC). Although the manual run was not computed during as the auto run, the graphical representation and behaviour of the system was captured by the back end of the steam package boiler expert system as shown in figure 19 of the system error analysis on manual and auto run of the boiler system.

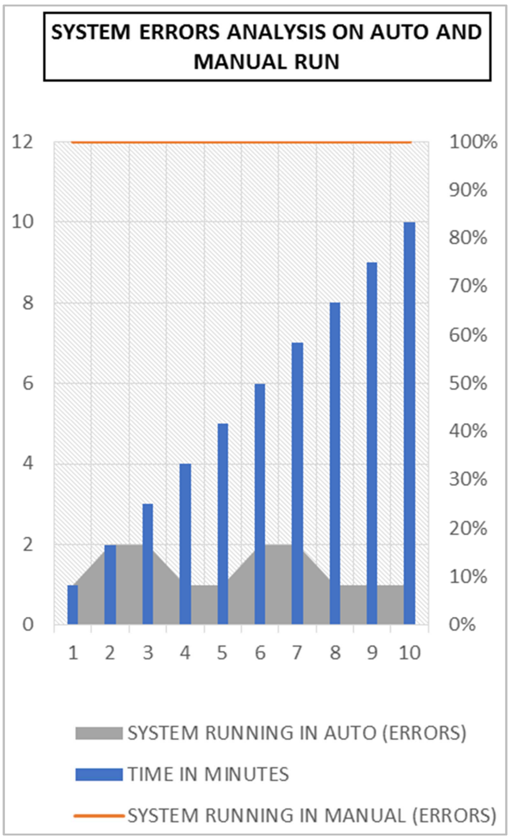

Figure 19. *System Error Graphical Analysis on Manual and Auto Run.*

The graphical system error analysis of both auto and manual run of the system is shown in figure 19. System errors are more pronounced on the manual run than auto run of the boiler expert system. The auto run error produce at the end of the dynamic simulation was two (2) errors in 10-miniute as shown on the graphical representation. The system on manual run generates between 12 to 3 errors in 10-minute.

7. Conclusion and Future Work

This paper is focused on modelling and building an expert system for control and maintenance of boiler drum and feed water using rule-based fuzzy logic technologies. A simple dynamics simulation technique was applied to show relatively the high performance of consistency, correctness, and its precision. The boiler expert system behaviour supports the auto mode as the best for running fertilizer plants, industrial and other related firms same if deployed. The system design specifications and requirements can be modified at the backend using the setting button interface window.

Future works can be done by researchers on the system, working on the knowledge base (KB) with the domain experts on its boiler operations, and build in boiler features for furnace control and maintenance into the system design and finally, also, an acceptable error margined during the system was not considered during the system design, this should be considered. The system knowledge base can be built up and it will be interested deploying it in an industrial and chemical plants, oil and gas industry, gas plants where boilers are needed for steam generation and to reduced need for draughting.

References

[1] Amit, K. J. (2012). An Approach towards Efficient Operation of Boilers. International Journal of Scientific & Engineering Research, 3 (6).

[2] Adetokunbo et al, (2012), Software Engineering Methodologies: A Review of the Waterfall Model and Object-Oriented Approach, International Journal of Scientific & Engineering Research, 4 (7).

[3] Anne Håkansson (2013), Portal of Research Methods and Methodologies for Research Projects and Degree Projects, WORLDCOMP'13 - The 2013 World Congress in Computer Science, Computer Engineering, and Applied Computing, 22-25 July 2013, FECS'13 - The 2013 International Conference on Frontiers in Education: Computer Science and Computer Engineering.

[4] Anabik, S. & Ashok, S. D. (2012). Fuzzy Logic Approach for Boiler temperature and water level. International Journal of Scientific and Engineering Research, 3 (6).

[5] Bretz, E. A. (1990), Expert System Enhance Decision Making Abilities of O&M Permission Electrical world, 39-48.

[6] Celin S, Anne Frank Joe, Rajalakshmi G, Thaj Mary Delsy T, Jamuna Rani D (2016), Embedded Fuzzy Based Boiler Control, International Journal of Robotics and Automation (IJRA), 5 (2).

[7] Emmanuel C. Ogu, Adekunle, Y. A. (2013), Basic Concepts of Expert System Shells and an Efficient Model for Knowledge Acquisition, International Journal of Science and Research (IJSR), India Online ISSN: 2319-7064, Vol. 2 (4).

[8] Edgar Amaya Simeón & Ricardo Ribeiro Gudwin, (2010), An Expert System for Fault Diagnostics in Condition Based Maintenance, ABCM Symposium Series in Mechatronics - Vol. 4 - pp. 304-313.

[9] Tripathi, K. P. (2011), "A Review on Knowledge-based Expert System: Concept and Architecture," Artif. Intell. Tech. - Nov. Approaches Pract. Appl., vol. 4, no. 4, pp. 19-23.

[10] Jabbar H. K. & R. Z.; Khan (2015), "Survey on development of expert system in the areas of Medical, Education, Automobile and Agriculture," Comput. Sustain. Glob. Dev. (INDIACom), 2015 2nd Int. Conf., vol., no., pp. 776-780, 11-13.

[11] Krishan K. (2016), Fuzzy Logic Execution in Boiler Control, IJSRD - International Journal for Scientific Research & Development| Vol. 4, Issue 05, 2016 | ISSN (online): 2321-0613.

[12] Konstantin E. Aronson, Boris E. Murmansky, Ilia B. Murmanskii & Yuri M. Brodov, (2020), An Expert System for Diagnostics and Estimation of Steam Turbine Components' Condition, Int. J. of Energy Prod. & Mgmt., Vol. 5, No. 1 (2020) 70-81.

[13] Mrudula, P. (2013). Expert System-A Review Article, International Journal of Engineering Sciences & Research Technology, 2 (6).

[14] Simin, S. S., Fatemeh, M., Fatemeh, A., Marjan, T. & Afsaneh, A. (2013). Investigate the Effect of Expert Systems Application on Management Performance. Institute of Interdisciplinary Business Research. Interdisciplinary Journal of Contemporary Research in Business, 478 4 (1).

[15] Chee T. et al., (2016), The Application of Expert System: A Review of Research and Applications, ARPN Journal of Engineering and Applied Sciences, ISSN 1819-6608, VOL. 11, NO. 4, February 2016.

[16] Michael, A. B. B. (2016). Model Predictive Fuzzy Control of a Steam Boiler, Master's degree in Automàtic and Robotics. Escola Tècnica Superior d'Enginyeria Industrial de Barcelona.

[17] Muhammad, A., Suleman, A., Humza, W. & Nuka Nwiabu, and Ibrahim Adeyanju (2012), User Centered Approach to Situation Awareness, International Journal of Computer Applications, (0975-8887), Vol. 49-No17, July 2012.

[18] Yangping Zhou, Xiang Fang and Xu Hong He (2011). "Use of an expert system in a personnel evaluation process". Proceedings of IEEE International Conference Quality and Reliability, Beijing. 2011: 15-19.

[19] Harald S and Georg H. (2015), Expert Systems – Smart Solutions for Power Plant, STEAG Energy Services GmbH, Essen, German, presented in Session 8 "Plant Optimization & Improvements I" on September 3rd, 2015, in Bangkok, Thailand.

[20] Marco, A. A., Lopez, C., Floresa, H. & Eduardo, G. G. (2003). "An intelligent tutoring system for turbine start up training of electrical power plant operators". Expert Systems with Applications, 24, 95-101.

[21] Tavira-Mondragon, Jose M. N, Jimenez-Fraustro Fernando, Orozco-Martinez Roni, (2011), Power Plant Simulators and Their Application in an Operators Training Center.

[22] Nabil, M., Ali, M. & Govardhan, A. (2012), Comparison study between Traditional and Object-Oriented Approaches to Develop all projects in Software Engineering, International Journal of Computer Science, and Information Technologies, 3 (1), 3022–3028.

[23] Bryman, A., & Bell, E. (2011). Business Research Methods (3rd ed.). Oxford: Oxford University Press.

[24] Kusumarasdyati R (2016), Qualitative and Quantitative Approaches to Action Research. Universitas Negeri Surabaya, kusumarasdyati@unesa.ac.id, Pp 139-146.

[25] Emerson Process Management Power and Water Solution Inc (2011), Emerson Process Management (online).

[26] Fundamentals of Expert Systems Pdf (Online).

[27] Installation, Operation, Maintenance Manual, Indorama Eleme Fertilizer and Chemical Limited, IEFCL TRAIN 2 Fertilizer Project (IEFCL2), DOC. NO: CXBF001-CPR-012.

[28] Harry P. G., (Online), Running head: Expert Systems and Applications.