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Application of an online fuzzy logic remote condition monitoring on water tube boilers- Babcock and Wilcox (British) and La Mont (French) boilers (Anonymous Company in Zimbabwe)

Mayahle Leanmark[1], Mugwindiri Kumbirayi[2] and Mushiri Tawanda[3]

[1]Undergraduate Student, Department of Mechanical Engineering, University of Zimbabwe, P.O. Box MP167, Mt Pleasant, Harare, Zimbabwe

[2]Postgraduate Coordinator, Department of Mechanical Engineering, University of Zimbabwe, P.O. Box MP167, Mt Pleasant, Harare, Zimbabwe

[3]Mechanical Engineering Lecturer, Department of Mechanical Engineering, University of Zimbabwe, P.O. Box MP167, Mt Pleasant, Harare, Zimbabwe

ABSTRACT

A LaMont boiler is a type of forced circulation water-tube boiler in which the boiler water is circulated through an external pump through long closely spaced tubes of small diameter. The mechanical pump is employed in order to have an adequate and positive circulation in steam and hot water boilers. A water tube boiler is a type of boiler in which water circulates in tubes heated externally by the fire. Fuel is burned inside the furnace, creating hot gas which heats water in the steam-generating tubes. In smaller boilers, additional generating tubes are separate in the furnace, while larger utility boilers rely on the water-filled tubes that make up the walls of the furnace to generate steam. Condition Based Maintenance using fuzzy logic was used to control the temperature and pressure entrance into the boiler. Any excess in the entry will have negative effects like corrosion of parts and also rupture of the boiler. The research here addresses this issue. Fuzzy logic was used with MATLAB software for the boiler to be controlled intelligently. Rules were generated and came up with a solution. The results predict that pressure should be maintained at between 450 – 850 psi and temperature should be monitored at 800^{0}F for these types of boilers.

Keywords: Fuzzy logic, condition based maintenance, water tube boilers

1. INTRODUCTION

Boiler feed pumps fail due to numerous reasons. These include eroded impellers, electric motor failure; worn out bearings, check valve failure etc. At this local power station after looking at the general performance information it is evident that poor water treatment and monitoring has contributed to some of the pump failure. The impellers and check valves are eroded due to corrosive minerals in the hard water. Failure of check valves has led to back flow of the super-hot condensate from the boiler thereby causing cavitation. Bearings have been worn out due to contaminated oil or lubrication. The worn out bearings have led to the motor over heating resulting in motor failure.

1.1 CONDITION BASED MAINTENANCE AS A SUBSET OF RELIABILITY CENTRED MAINTENANCE

The major reductions in routine operations and scheduling leads directly to large reductions in operations cost (Kiinigsmann 1996), htt://www.ct@consulting.com.au/MaintEng.htm. This is because equipment can revert to systemic failure even after maintenance has been carried out if due regard to maintenance instructions is not adhered to. Reliability Centred maintenance is much more than just another way to do maintenance. In a nutshell, it's a way of looking at system performance in terms of the impact of a failure and then mitigating those results by design, detection, or effective maintenance (Wheeler, 2007). RCM develops a comprehensive data base of maintenance requirements, skills required and stocks that should be held (Zhongwei, 2010). In addition, RCM also has an important role in overall system safety management (Rausand, 2008). Within RCM, the optimal reliability threshold is determined by minimizing the cumulative maintenance cost per unit time in the residual life of the system (Xiaojun. 2007).

Multi-skilling is one such approach which bridges the gap of corporate and individual interest (Huselid, 1995). Each group member should also have been trained in RCM and is thoroughly equipped with team working skills (Hackman, 2002). Maintenance management has found new vigor and purpose to increase equipment capacity and capability due to increasing focus on lean manufacturing (lean) in today's competitive environment. Tremendous efforts have been made to develop different types of maintenance strategies for enhancing the performance of equipment (Sawhney, 2009) but equipment continues to fail. From a review of present maintenance policies in electric utilities, it is concluded that maintenance at fixed intervals is the most frequently used approach, often augmented by additional corrections (Endrenyi. 2001). General preventive maintenance, which does not return equipment to the as new condition, is appropriate for equipment subject to constant failure rate (Levitt, 1988).

Failures in traditional maintenance has the potential for being disastrous for the equipment as opposed to CBM as there is ample time to analyze the potential failure and execute a recovery plan (Kiinigsmann, 1996). Condition based maintenance is a relatively new method and is based around monitoring a parameter or parameters that will indicate the condition of the equipment (Whistlecroft, 1998).

Condition based maintenance is a management philosophy that posits repair or replacement decisions on the current or future condition of assets (Raheja, Llinas, Nagi, and Romanowski, 2006); it recognizes that change in condition and/or performance of an asset is the main reason for executing maintenance (Horner, El-Haram, and Munns, 1997).

2. CAUSES OF BOILER FAILURES

Boiler tubes fail due to numerous reasons which include failure due to overheating, failure due to corrosion and several other reasons. When tube failures occur due to overheating, a careful examination of the failed tube section reveals whether the failure is due to rapid escalation in tube wall temperature or a long-term, gradual buildup of deposit. When conditions cause a rapid elevation in metal temperature to 1600°F or above, plastic flow conditions are reached and a violent rupture occurs. Ruptures characterized by thin, sharp edges are identified as "thin-lipped" bursts. Violent bursts of the thin-lipped variety occur when water circulation in the tube is interrupted by blockage or by circulation failure caused by low water levels. Thin-lipped bursts occur in super heater tubes when steam flow is insufficient, when deposits restrict flow, or when tubes are blocked by water due to a rapid firing rate during boiler start-up.
Various corrosion mechanisms contribute to boiler tube failure. Stress corrosion may result in either intercrystalline or trans granular cracking of carbon steel. It is caused by a combination of metal stress and the presence of a corrosive. The presence of corrosive substances is usually due to poor water treatment. This is true assessing the data gathered from the power station general performance, whereby it was mentioned that the water treatment plant was not monitored properly in 2008 and thereafter a series of tube failures occurred. As a result the buildup of the corroded metal causing scaling in the tubes, with the final result being tube rapture or bursting. Pressure of the water tube boilers should range between 450 - 850psi (**Babcock and Wilcox (British) and La Mont (French) boilers)**. In this research, temperature and pressure control are to be worked upon.

3. EARLY ANOMALY DETECTION

It is the abnormally hot spots that are detected by the system and it manages to do this by making use of infrared cameras which give real time temperature parameters of the boiler tubes, economizer tubes, condenser tubes etc. These temperature irregularities on the surface of the tubes are detected by the infrared camera by measuring the thermal energies that are produced by the tube surfaces. The infrared cameras are capable of detecting temperatures within 300 ℃- 1600℃.
Now in the event of rapture the system is still capable of detecting a leak. This comes from the fact that compressed fluid forced through a small opening creates turbulence with strong ultrasonic components on the downstream side of the opening producing a particular sound signal and pattern at a particular frequency. It is this frequency which is detected by acoustic measuring devices and analyzed to assess the nature of the leak. The devices are capable of picking up frequencies within the range of 3Hz-20 KHz and will filter any background noise.

4. MANUFACTURER OF THE WATER TUBE BOILERS

Babcock and Wilcox (British) and La Mont (French), all are water tube boilers that use pulverized coal operating on a Rankine thermal cycle and are used at this anonymous company.

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5. CONDITION BASED MAINTENANCE IN ONLINE MONITORING

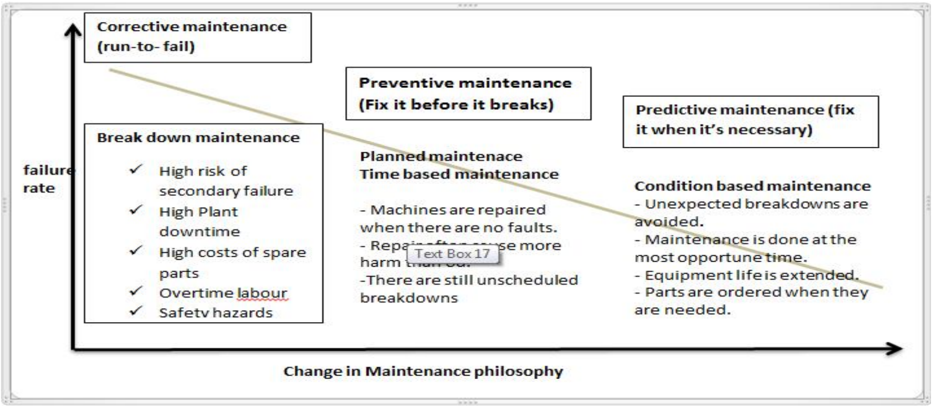

Figure 1 Change in maintenance philosophy:

Condition-based maintenance (CBM), shortly described, is maintenance when need arises. This maintenance is performed after one or more indicators show that equipment is going to fail or that equipment performance is deteriorating.

This concept is applicable to mission critical systems that incorporate active redundancy and fault reporting. It is also applicable to non-mission critical systems that lack redundancy and fault reporting.

Condition-based maintenance was introduced to try to maintain the correct equipment at the right time. CBM is based on using real-time data to prioritize and optimize maintenance resources. Observing the state of the system is known as condition monitoring. Such a system will determine the equipment's health, and act only when maintenance is actually necessary. Developments in recent years have allowed extensive instrumentation of equipment, and together with better tools for analyzing condition data, the maintenance personnel of today are more than ever able to decide what is the right time to perform maintenance on some piece of equipment. Ideally condition-based maintenance will allow the maintenance personnel to do only the right things, minimizing spare parts cost, system downtime and time spent on maintenance.

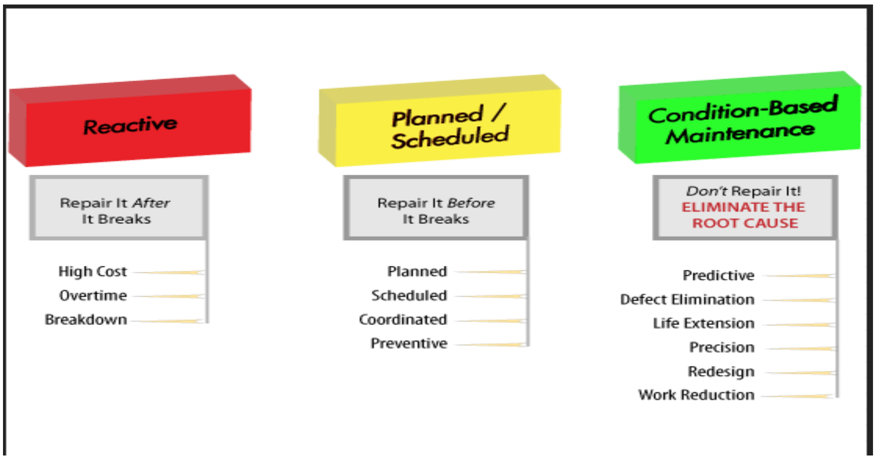

Figure 2 Condition Based Maintenance (CBM) Adapted from www.puradyn.com

6. CBM WITH FUZZY LOGIC

Although condition monitoring is, in most cases, better than waiting for a breakdown, CBM isn't the ideal solution. Wherever possible, implement automated control systems, as they minimize human error and significantly improve service levels.

For example, suppose a critical piece of equipment is monitored continuously to ensure that some temperature is within an acceptable range. If the temperature rises above the upper limit, a control loop can activate a fan to cool the overheated area until the temperature returns to an acceptable range.

This is clearly superior to a condition-monitoring system that merely alerts a human that the temperature was too high. It's then up to the human to eliminate the variance condition effectively and efficiently.

However, it isn't always possible to determine the root cause of a variance automatically. Nor is it always possible or cost-effective to take automatic action. In such cases, human intervention is desirable, making a condition-monitoring system preferable over an automated control system (http://www.plantservices.com/articles/2006/199.html).

This then leads us to concentrate on artificial intelligence with CBM. A **fuzzy control system** is a control system based on fuzzy logic, a mathematical system that analyzes analogue input values in terms of logical variables that take on continuous values between 0 and 1, in contrast to classical or digital logic, which operates on discrete values of either 1 or 0 (true or false respectively) (www.sccs.swarthmore.edu/users/)

7. BOILER DRUM-LEVEL CONTROL

Boiler drum-level control is critical. Too low a level may expose boiler tubes, which overheats and damages them. Too high a level may interfere with separating moisture from steam, which reduces boiler efficiency and carries moisture into the process or turbine. The drum-level controller maintains the level at constant steam load. There are three options for drum-level control single-element, two-element and three-element drum-level control.

Single-element control is the simplest but least effective form of control (see Figure 3). A proportional signal or process variable (PV) signal generates a correction that's proportional to the deviation from set point. The output controls the boiler's feedwater valve. Single-element control requires one analog input and one analog output. Because there's no relationship between drum level and steam or feedwater flow, it can be applied only to a single feed pump on a single boiler supplying a relatively stable load. Also, the swell effect may render control inadequate.

7.1 Easiest way

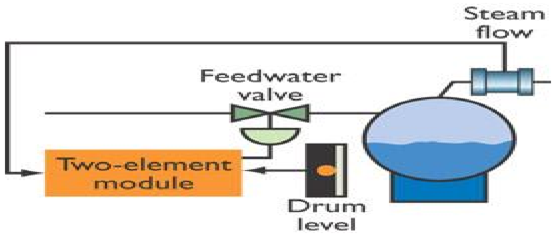

Figure 3 Drum-level control with a single-element module (http://www.plantservices.com/articles/2004/180.html).

7.2 Typical

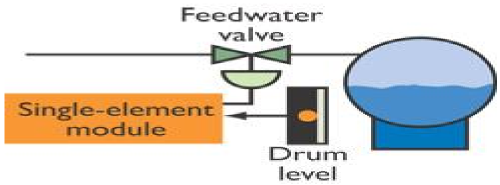

Figure 4 Drum-level control with a two-element module (http://www.plantservices.com/articles/2004/180.html).

7.3 Best way

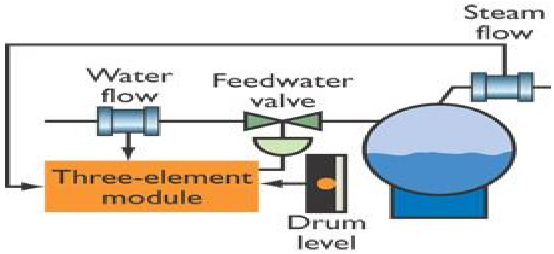

Figure 5 Drum-level control with a three-element module (http://www.plantservices.com/articles/2004/180.html).

Two-element drum-level control can best be applied to a single drum boiler if the feedwater is at a constant pressure. Two-element control (see Figure 4) includes the same level element used for the single-element configuration but has an added steam-flow element that provides a density-corrected mass flow-rate signal to control the feedwater flow. Two elements offer tighter control of drum level. The steam flow acts as a feed-forward signal to allow faster level adjustments. This gives an immediate feedwater response to load changes while the level controller corrects any imbalance between steam mass flow and feedwater flow that arises from:

- Blow down variations caused by changes in dissolved solids.
- Variation in feedwater supply pressure.
- Steam leaks in the steam circuit.

Three-element drum-level control is suited for handling variable feedwater pressure or multiple boilers with multiple feedwater pumps (see Figure 5). The three elements in this system handle level, steam and feedwater flow. The level and steam elements correct for unmeasured disturbances arising from boiler blow down, as well as leaks in the boiler and super heater tubes. The feedwater flow element responds rapidly to variations in feedwater demand that arise from the steam flow-rate feed-forward signal and feedwater pressure or flow fluctuations.

8. WATER TUBE BOILER OPERATION

The pulverized coal is put in boiler furnace. Boiler is an enclosed vessel in which water is heated and circulated until the water is turned in to steam at the required pressure.

Coal is burned inside the combustion chamber of boiler. The products of combustion are nothing but gases. These gases which are at high temperature vaporize the water inside the boiler to steam. Some times this steam is further heated in a super heater as higher the steam pressure and temperature the greater efficiency the engine will have in converting the heat in steam into mechanical work. This steam at high pressure and temperature is used directly as a heating medium, or as the working fluid in a prime mover to convert thermal energy to mechanical work, which in turn may be converted to electrical energy. Although other fluids are sometimes used for these purposes, water is by far the most common because of its economy and suitable thermodynamic characteristics.

In these boilers water is inside the tubes and hot gases are outside the tubes. They consist of drums and tubes. Feed water enters the boiler to one drum. This water circulates through the tubes connected external to drums. Hot gases which surround these tubes will convert the water in tubes in to steam. This steam is passed through tubes and collected at the top of the drum since it is of light weight. So the drums store steam and water (upper drum).The entire steam is collected in one drum and it is taken out from there. As the movement of water in the water tubes is high, so rate of heat transfer also becomes high resulting in greater efficiency. They produce high pressure, easily accessible and can respond quickly to changes in steam demand. These are also classified as vertical, horizontal and inclined tube depending on the arrangement of the tubes. These are of less weight and less liable to explosion. Large heating surfaces can be obtained by use of large number of tubes. It can attain pressure as high as 125 kg/sq. cm and temperatures from 315 to 575 centigrade.

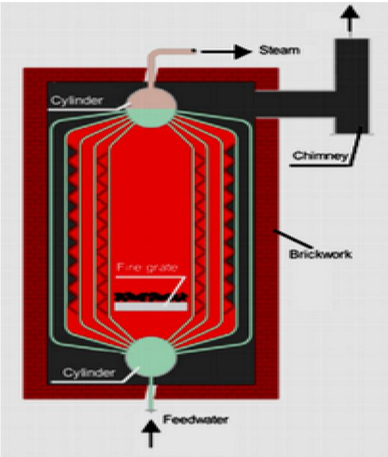

Figure 6 Water tube boiler

9. METHODOLOGY

9.1 TWO FUZZY SETS PRESSURE, P AND TEMPERATURE, T

Union of the two fuzzy sets is defined as the maximum of the two individual membership functions. This is called the maximum criterion, **μ_{PuB} = maximum (μP, μT)**

- Intersection of the two fuzzy is defined as the minimum of the two individual membership functions. This is called the minimum criterion. $\mu_{P\cap T}$ **= minimum (μP, μT)**

  Intersection of two fuzzy can also be defined as the product of the two individual membership functions. This is called the product criterion. $\mu_{P\cap T}$ **= μP × μT**

9.2 RULE-BASE DEVELOPMENT

Fuzzy *IF- THEN, or IF, AND - THEN* rules are the heart of fuzzy logic control system in this design. These rules relate the antecedent part of the FLC to the consequent part of the FIS, input variables and membership functions are called antecedent part of FLC and output variables and output membership functions are called consequent part of FLC.

If premise THEN consequent or;
If antecedents AND antecedents THEN consequent
There will be "*linguistic variables*" that describe each of the time-varying controller inputs and outputs mainly in this case for temperature, pressure kiln velocity and inclined angle. Linguistic variables assume "*linguistic values*". That is, they can be described by the following values: *"Negative High (NH), Negative Low (NL), Zero, Positive Low (PL), Positive High (PH)"*. These linguistic variables to be controlled are show in the fuzzy logic base rule matrix as shown in table

- When conditions cause a rapid elevation in metal temperature to 1600°F or above, plastic flow conditions are reached and a violent rupture occurs.
- Pressure of the water tube boilers should range between 450 - 850psi

9.3 The fuzzy logic control base rule matrix

Table 1: Fuzzy logic control toolbox

		change in temperature		
		Negative	*Zero error*	*Positive*
change in pressure	*Negative*	*High rupture*	*Rupture is low*	*High rupture*
	Zero error	*Rupture average*	*Rupture is low*	*Rupture average*
	Positive	*High rupture*	*Rupture is average*	*Rupture is high*

Rules can now be written as below

1. IF (change in temperature is "positive") THEN (change in rupture is "high")
2. IF (change in temperature is "zero") THEN (change in rupture is "average")
3. IF(change in temperature is "negative") THEN (change in rapture is "high")
4. IF (change in pressure is "negative") THEN (change in rupture is "high")
5. IF (change in pressure is "zero") THEN (change in rupture is "average")
6. IF (change in pressure is "positive") THEN (change in rupture is "high")
7. IF (change in temperature is "negative") AND (change in pressure is "negative" THEN (change in rupture is " high")
8. IF (change in temperature is "zero") AND (change in pressure is "zero") THEN (change in rupture is average)
9. IF (change in temperature is "Positive" AND (change in pressure is "negative") THEN (change in rupture is "high")
10. IF (change in temperature is "negative") AND (change in pressure is "zero" THEN (change in rupture is "average")

11. IF (change in temperature is “zero”) AND (change in pressure is “zero” THEN (change in rupture is “low”)

12. IF (change in temperature is “positive”) AND (change in pressure is “zero” THEN (change in rupture is "average")

13. IF (change in temperature is “negative”) AND (change in pressure is “positive” THEN (change in rupture is " high")

14. IF (change in temperature is “zero”) AND (change in pressure is “positive” THEN (change in rupture is "high")

15. IF (change in temperature is “positive”) AND (change in pressure is “positive” THEN (change in rupture is “ high”)

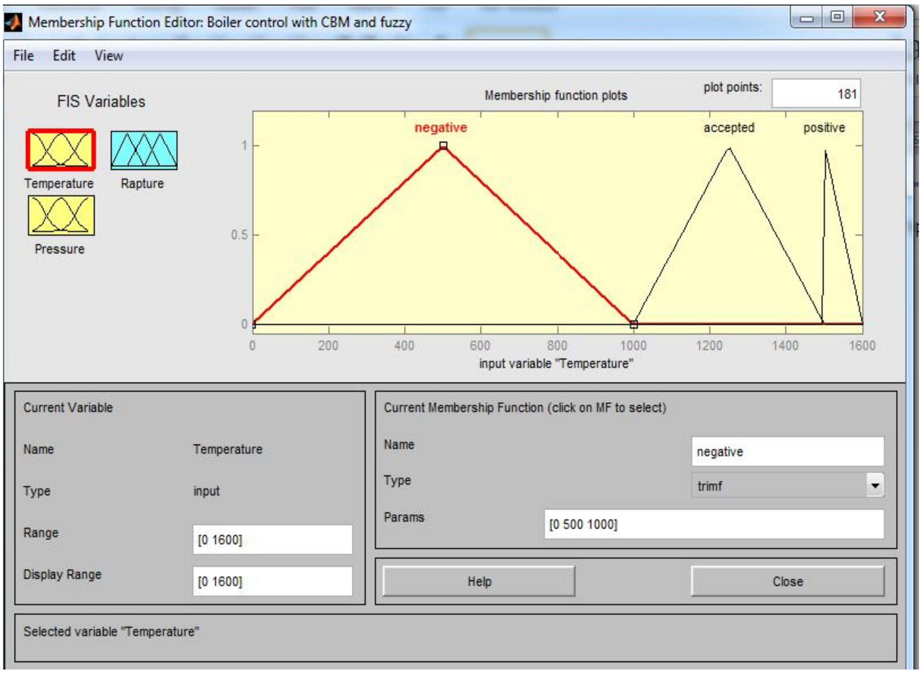

Figure 7 Membership function editor for temperature

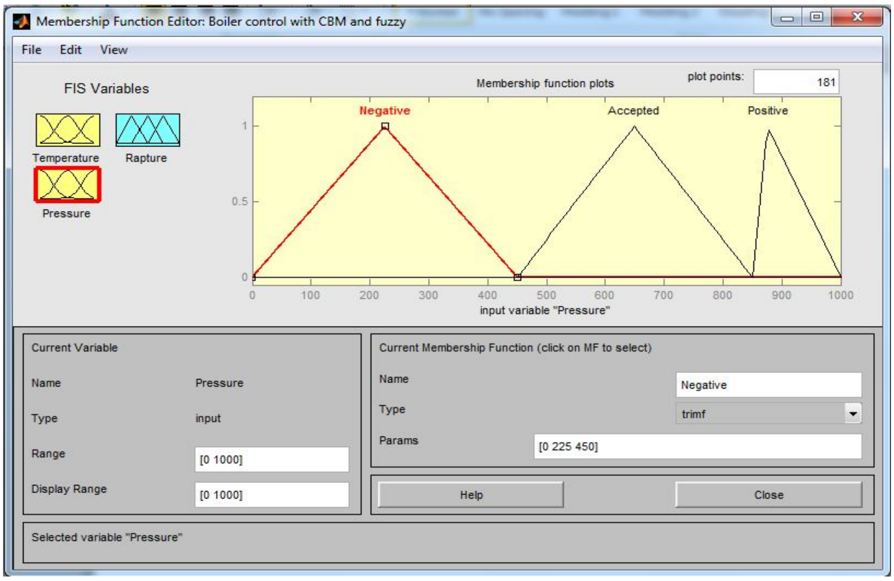

Figure 8 Membership function editor for pressure

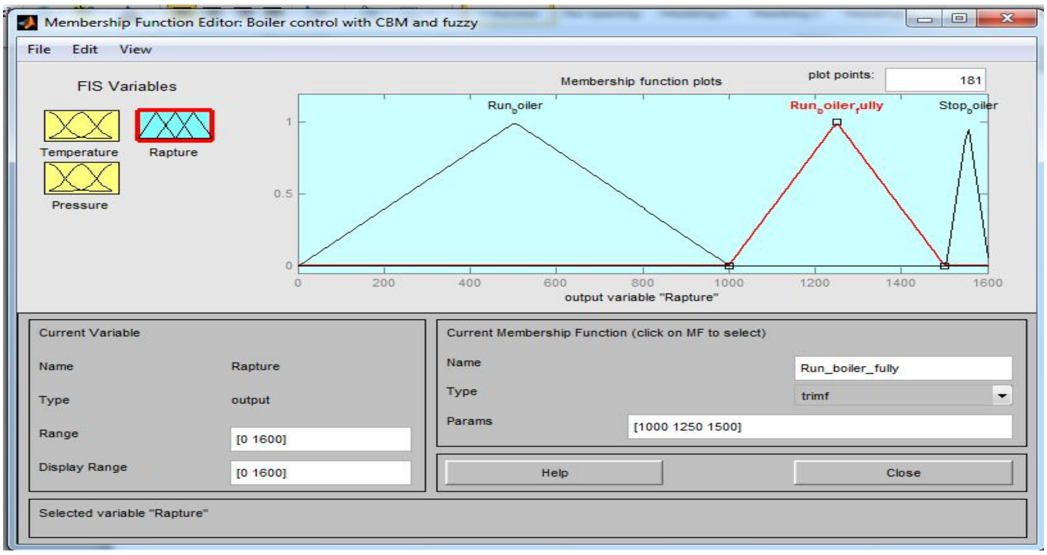

Figure 9 Membership function for the boiler

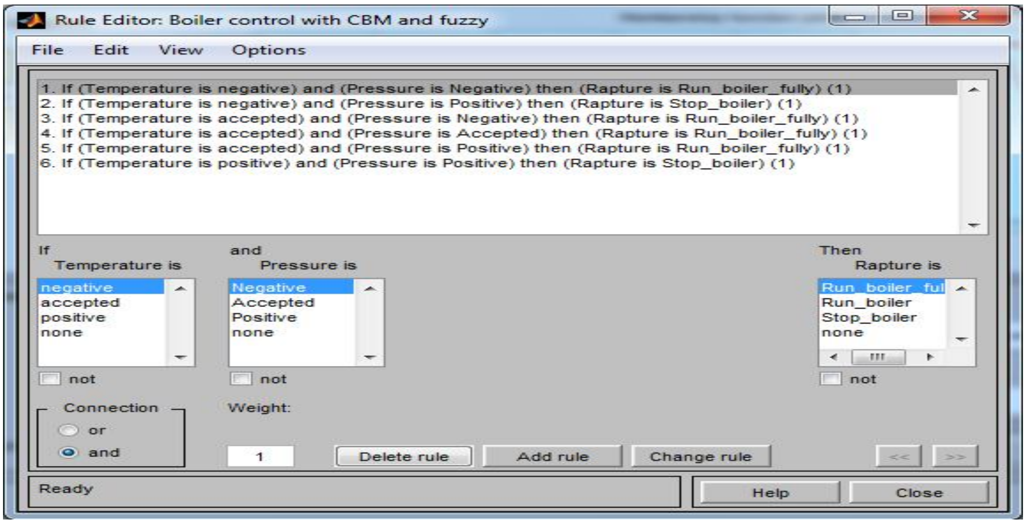

Figure 10 Rule editor for the boiler

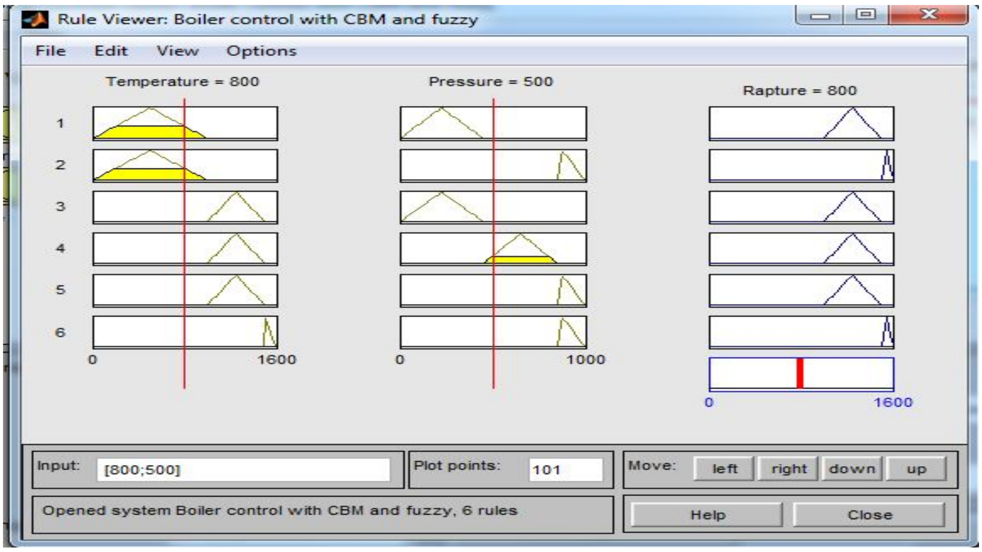

Figure 11 Rule viewer for the boiler

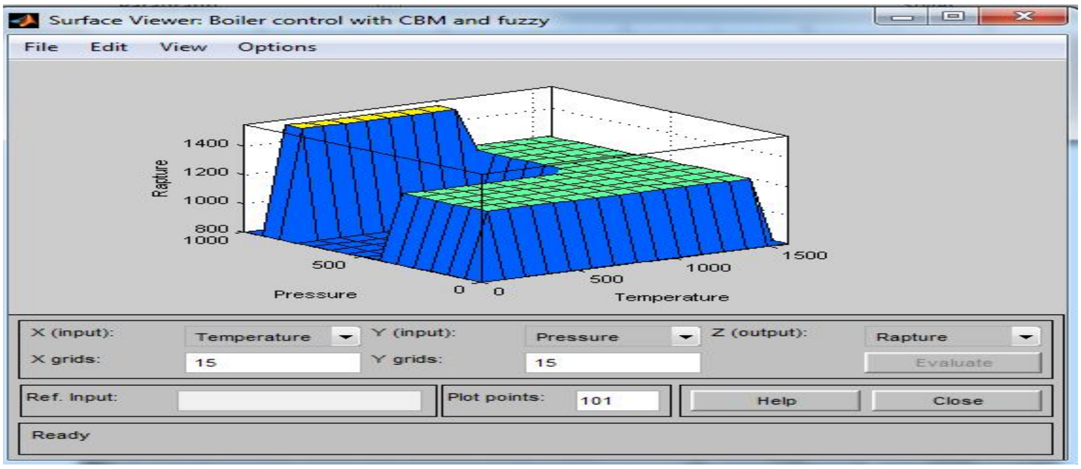

Figure 12 Surface viewer for the boiler control in temperature and pressure in 3D

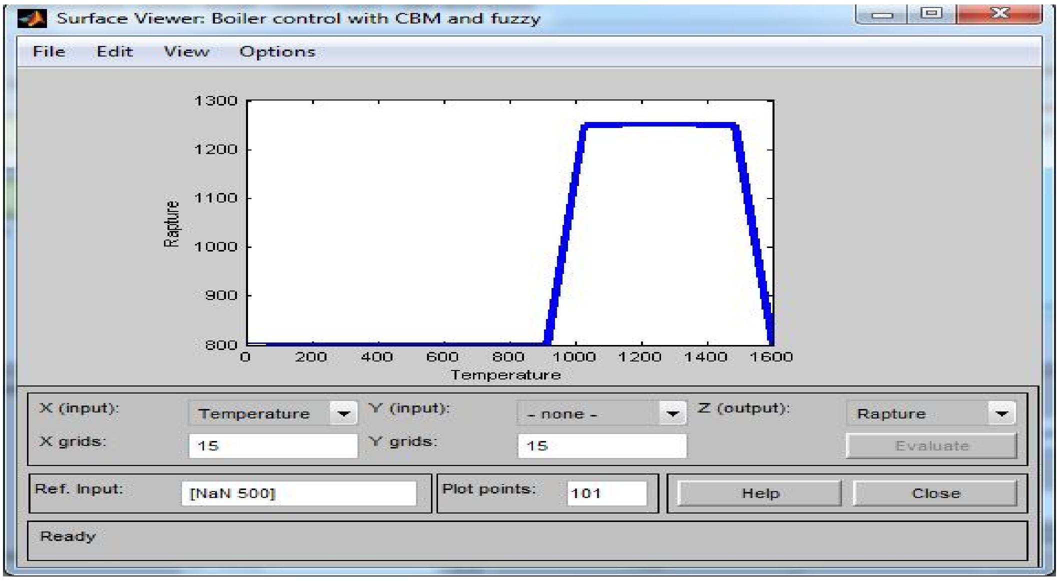

Figure 13 Surface viewer for the boiler control in temperature

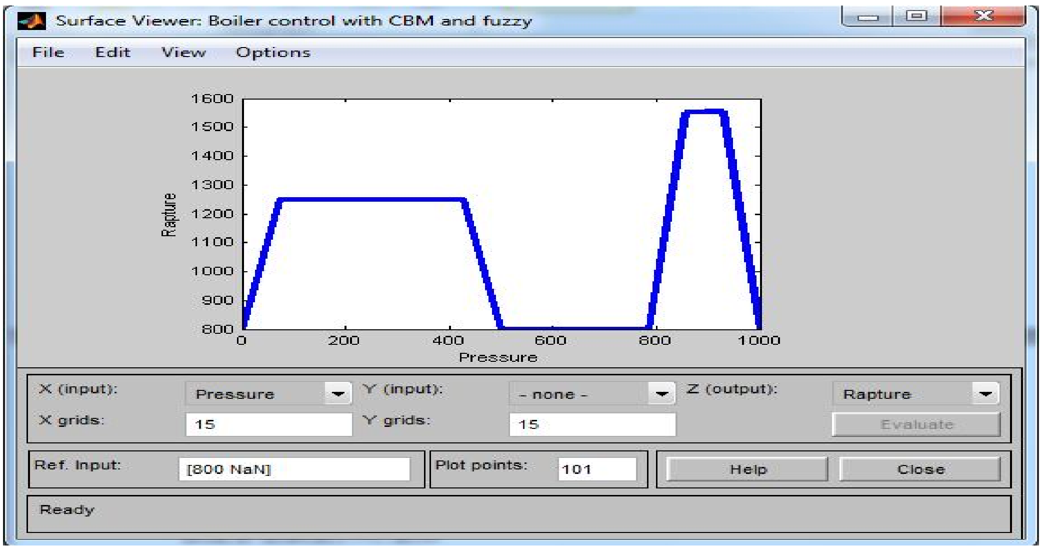

Figure 14 Surface viewer for the boiler control in pressure

10. RECOMMENDATIONS

The results predict that pressure should be maintained at between 450 – 850 psi and temperature should be monitored at 800^0F.

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AUTHOR

Tawanda Mushiri received the B.Sc. (Hons) in Mechanical Engineering and M.Sc. Manufacturing Systems and Operations Managaement degrees from University of Zimbabwe in 2008 and 2012, respectively. During 2008 – 2010, he went on to do a Graduate Trainee Learner ship from an Oil Company under the Ministry of Energy and Power Development in Zimbabwe. He also worked as a Graduate Teaching Assistant at Chinhoyi University of Technology from 2011 to early 2013 teaching machine intelligence and advanced control and robotics. He is now a lecturer at the University of Zimbabwe from March 2013 to date teaching Engineering dynamics and design.