COST SAVINGS FROM ENHANCED NOISE REDUCTION BASED BOILER BLOWDOWN CONTROL FOR STATE PHARMACEUTICALS MANUFACTURING CORPORATION (SPMC)

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Department of Electronic and Telecommunication Engineering

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Thesis submitted in partial fulfillment of the requirements for the degree Master of Science in Electronics and Automation

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Name of the supervisor: **Dr. Upeka Premaratne**

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ABSTRACT

Boilers are widely used in most of the processing industries like Pharmaceuticals Manufacturing, for the heating applications. State Pharmaceuticals Manufacturing Corporation (SPMC) is the one of the largest Pharmaceuticals Manufacturing Plant in Sri Lanka. In Pharmaceuticals Industries Boiler is mainly used for the steam generation. In an industry normally a 4% of heat energy [1] is wasted through Blowdown.
For every Boiler there is a defined limits allowable TDS in the Boiler Drum. The Boiler feed water has a certain TDS. The maximum allowable TDS in process Boilers is 3500 ppm.

The steam is generated from the Boiler the TDS contained in the Boiler drums starts to increase. Therefore some amount of the high TDS water needs to be removed from the Boiler drum. This removal of high TDS water from the Boiler drum is called blowdown. By doing Boiler blowdown able to maintain the TDS in the Boiler drum to its optimal desired levels.

The process of blowdown is that most of the time the blowdown is done by manually. Therefore that extract amount of blowdown required is never done. Many times excess of blowdown is done and many times sub optimal blowdown is done both these are harmful. Excess amount of blowdown contributes to the blowdown loss.

Automatic blowdown control system sensors the actual TDS level in the Boiler drum and does the blowdown only when it is required to do so.

When the TDS level in the Boiler go beyond desired set point the blowdown valve will opens and brings down the TDS to the desired level.

High TDS level in the Boiler drum not only cause scaling within the Boiler drum and on the Boiler tubes. But these scales particles also get carried away with the steam and formed deposits on the downstream equipment and piping.

High TDS levels in the Boiler drum also results in moisture carryover which means steam coming out of the Boiler has a high moisture contained and this is detrimental to the equipment downstream of the Boiler. It also results poor heat transfer in the process equipment and cause high steam consumption.

An automatic blow down control can keep the blow down rate uniformly close to the maximum allowable dissolved solids level, while minimizing blow down and reducing energy losses.

The Boiler Blowdown analysis and energy savings analysis has been carried out at SPMC Plant. The objective of this research work is the blowdown analysis in the plant and analyze the annual savings obtained from Automatic Blowdown Control Intervention. The study was revealed that changing from manual blowdown control to automatic blowdown control monitory savings **Rs 202873.11** a boiler’s energy use by annually. Purchasing TDS sensor, pneumatic blowdown valve, PLC and related accessories fabrication cost can be a 3 year payback period on the investment.

ACKNOWLEDGEMENT

I owe my profound gratitude to my supervisor, Dr. Upeka Premaratne; who has always been at the forefront, extending relentless guidance by way of providing much needed supervision throughout the research. I am also heartily thankful to course coordinator of the MSc programme in Electronics and Automation; Dr. Chamira U.S. Edussoriya for his precious advices on related technical and nontechnical topics throughout the research. Additionally, I want to acknowledge the course assistant; Mr. Damith Kandage for providing timely needed assistant on various matters from the start to successful completion of the thesis. Finally, I would like to thank all the academic staff members, supportive staff and undergraduate students who supported me throughout the research by way of extending kind hands, whenever necessary.

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CHAPTER 1

INTRODUCTION

Chapter 1 reveals the motivation and ground floor behind the overall research. It gives a quick insight to the initialized roots of the research as a master thesis. The project is set to develop a control scheme to automate a Boiler Blow down control system at SPMC. Background and motivation of the thesis is discussed in section 1.1. Section 1.2 precisely defines the research work in terms of initial approach and objectives of the thesis. Section 1.3 reveals the limitations and key assumptions of the project. Further, contribution of the research to the State Pharmaceuticals Manufacturing Corporation is discussed in Section 1.4. Lastly, Section 1.5 outlines the rest of the remaining chapters of the report.

State Pharmaceuticals Manufacturing Corporation is the largest pharmaceutical manufacturer in Sri Lanka [figure 1]. SPMC manufactures a broad range of branded generic products in oral solid dosage forms. SPMC was established in 1987 as a wing of the SPC on Japanese financial aid and functions under the Ministry of Health, Sri Lanka. Currently the SPMC is working again with The Japan International Cooperation Agency (JICA) for further expansion of existing production capacity.

Figure 1: State Pharmaceuticals Manufacturing Corporation

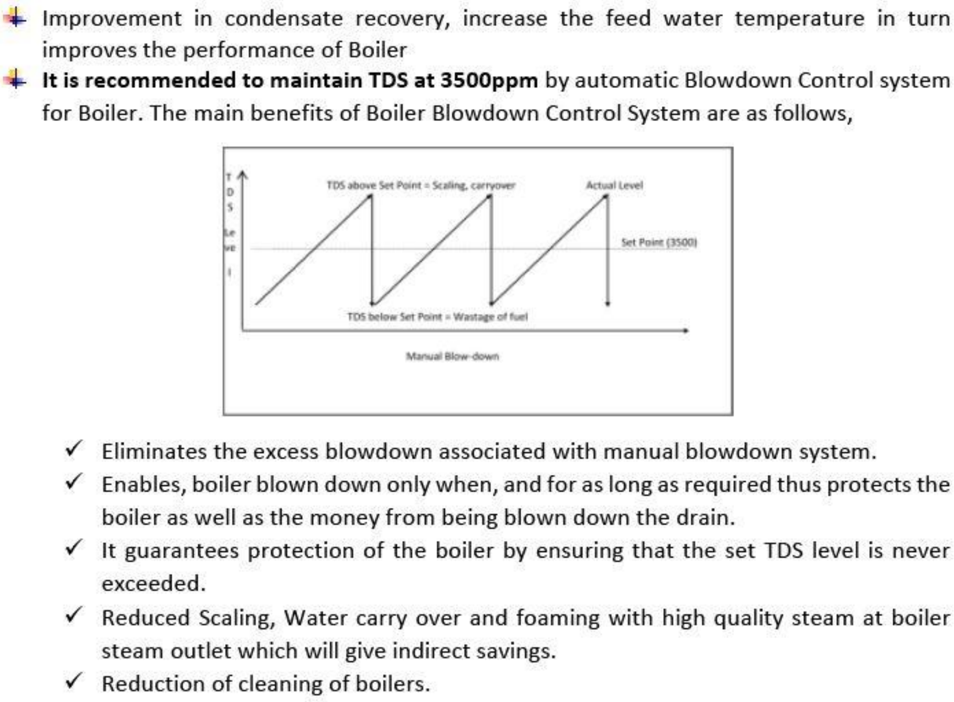
Figure 2: product packing line process in SPMC

Further, the Government of Japan has agreed to provide a loan amounting to JPY 1,244 million through JICA for the improvement of the SPMC by installing new manufacturing machines, refurbishment of production zone and construction of stores building with the intention of enhancing the production capacity up to 4,000 million tablets and capsules [figure 2], [figure 3] per annum to meet with the pharmaceuticals requirement of Sri Lanka. The project will be completed by 2019.

Figure: 3 Quality control process in SPMC

1.1 Background and Motivation

In the Energy Audit of Steam and Condensate System was conducted by Forbes Marshall Private Limited in Indian company from 12th June 2018 to 19th June 2018. Further audit report is recommended Boiler Blowdown Automation and it is illustrated in Figure 4 that extract from audit report.



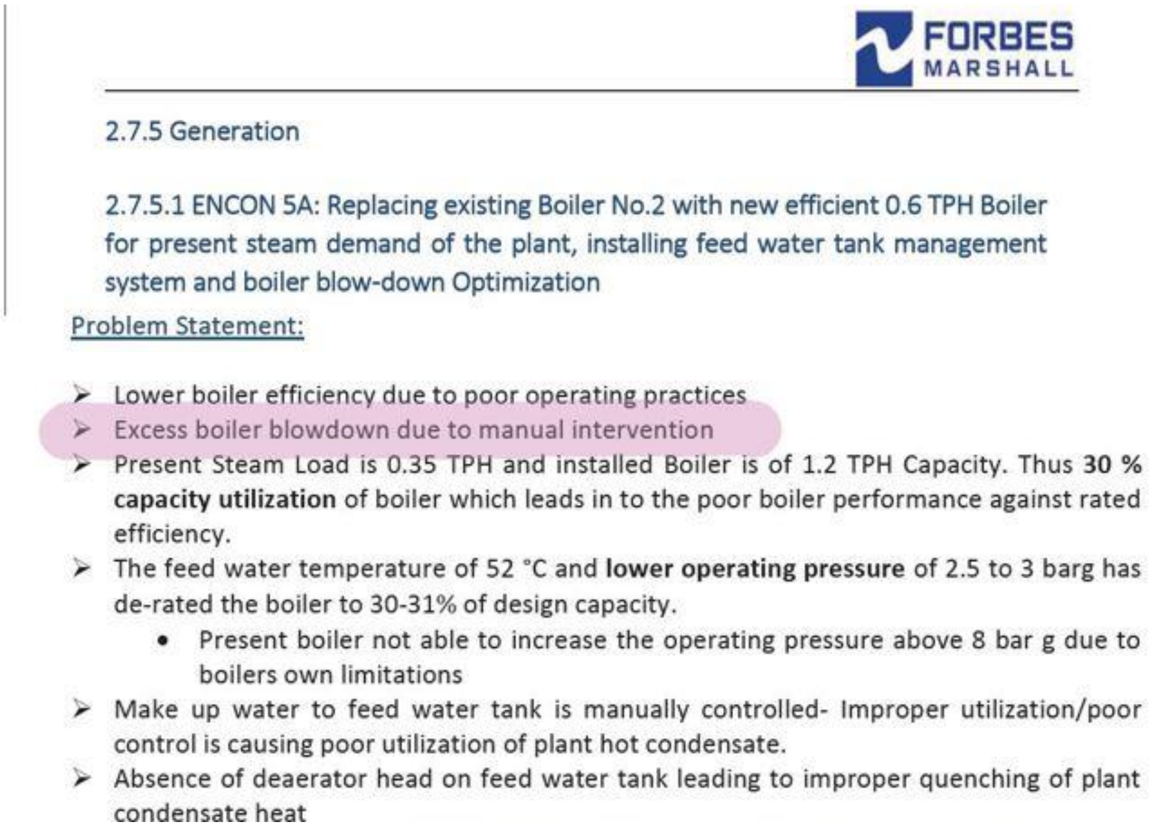
- Improvement in condensate recovery, increase the feed water temperature in turn improves the performance of Boiler
- **It is recommended to maintain TDS at 3500ppm** by automatic Blowdown Control system for Boiler. The main benefits of Boiler Blowdown Control System are as follows,

  - ✓ Eliminates the excess blowdown associated with manual blowdown system.
  - ✓ Enables, boiler blown down only when, and for as long as required thus protects the boiler as well as the money from being blown down the drain.
  - ✓ It guarantees protection of the boiler by ensuring that the set TDS level is never exceeded.
  - ✓ Reduced Scaling, Water carry over and foaming with high quality steam at boiler steam outlet which will give indirect savings.
  - ✓ Reduction of cleaning of boilers.

Figure 4: Extract from audit report
Source: Energy Audit Report SPMC

1.2. Problem Definition

The problem was identified Energy Audit Report and extraction shown in figure 5 that excess boiler blowdown due to manual intervention.



FORBES MARSHALL

2.7.5 Generation

2.7.5.1 ENCON 5A: Replacing existing Boiler No.2 with new efficient 0.6 TPH Boiler for present steam demand of the plant, installing feed water tank management system and boiler blow-down Optimization

Problem Statement:

- Lower boiler efficiency due to poor operating practices
- Excess boiler blowdown due to manual intervention
- Present Steam Load is 0.35 TPH and installed Boiler is of 1.2 TPH Capacity. Thus **30 % capacity utilization** of boiler which leads in to the poor boiler performance against rated efficiency.
- The feed water temperature of 52 °C and **lower operating pressure** of 2.5 to 3 barg has de-rated the boiler to 30-31% of design capacity.
    - Present boiler not able to increase the operating pressure above 8 bar g due to boilers own limitations
- Make up water to feed water tank is manually controlled- Improper utilization/poor control is causing poor utilization of plant hot condensate.
- Absence of deaerator head on feed water tank leading to improper quenching of plant condensate heat

Figure 5: Energy Audit Report problem statement page
Source: Energy Audit Report SPMC

1.2.1. Thesis Definition and Objectives

The main objective of master’s thesis is bound to research and develop a suitable control scheme which could autonomously operate boiler blowdown optimization to avoid excess boiler blowdown due to manual intervention. In the research, using the best setting of the plant behavior and its parameters, suitable control system is investigated. Proposed scheme is validated by comparing the results and performance of its operation.

1.2.2. Goals

The research work is intended to achieve following goals when presenting an appropriate solution.

Main Goal

I. Development of a suitable control scheme to guarantee the autonomous operation of boiler blowdown.
II. Much better set point control as compared to manual blowdown.
III. Results in Energy Savings which directly translates to fuel savings.
IV. By controlling recommended Total Dissolved Solids (TDS) will help to enhance the life of the Boiler.

Sub Goals

i. Development of Mathematical Model for the boiler blowdown system.
ii. Development of Simulink (Mat Lab) simulation model
iii. Installation of Total Dissolved Solids (TDS) sensor to logging data of blowdown TDS water to simulate real data with developed Simulink model.
iv. Implementation of the proposed control scheme in a PLC control with necessary hardware and software components.
v. Field testing, fault diagnosis and validation of the PLC controller.

1.3. Limitations

- Proposed method is based on heuristic analysis of local data. Therefore the control scheme is only valid for the SPMC boiler plant.
- An accurate heuristic controller demands analysis of data over long period of time, perhaps several years. In this research, data is not gathered over several years.
- Final implementation more sophisticated high-tech TDS sensor, pneumatically Actuated on-off valve etc, to guarantee the durability under extreme environment conditions.

1.4. Contributions to the SPMC

The thesis work demonstrates an approach to control auto blow through boiler blow down control system to maintain the drum Total Dissolved Solids (TDS) value recommended set point by the boiler manufacture avoiding unnecessary blow down cycles for savings energy consumption of the plant.

1.5. Report Outline

The remaining part of the thesis is organized as follows. Chapter 2 discusses some of literature on understanding Boiler Blow Down and related theoretical backgrounds and existing control mechanisms developed for boiler blow down systems and other similar applications. Chapter 3 introduces Boiler House Behavior at SPMC. Chapter 4 explains Mathematical Modeling Boiler Blowdown System. Chapter 5, explains Matlab Simulink Modeling and Simulation of the Boiler Blowdown System. Chapter 6 explains hardware selection and control design. Chapter 7 explains System Design and Hardware Implementation, Chapter 8 explains Test and Result Discussion, Lastly Chapter 9 explains Proposed Maintenance Guidelines, Finally, Chapter 10 includes conclusion and future work.

CHAPTER 2
LITERATURE REVIEW

2.1 Understanding Boiler Blowdown

Water inside the Boiler gets continuously evaporated due to steam generation. The concentration of dissolve solids, inside the drum increases and reach beyond the limits, so carryover of solids along with steam can occur. To prevent Boiler tube choking and overheating of the Boiler tubes the blowdown is necessary. The blowdown is the water removed from Boiler to maintain the solids level in the Boiler drum.

When a Boiler generates steam, any impurities which are in the Boiler feed water and which do not boil off with the steam will concentrate in the boiler water [7]. As steam is raised from a boiler the concentration of Total Dissolved Solids (TDS) in the boiler water increases. This leads to scale deposits on the fire tubes surfaces in the boiler resulting in reduced heat transfer. This means increased fuel consumption and decreased boiler efficiency as well as corrosion. Thus need to control the TDS level in a Boiler. This do that by "Blowing Down". Very simple put, Blow Down is the process by which water in the boiler is periodically emptied in order to prevent the TDS level from overshooting the desired limit by manual intervention or automatically intervention. Blow down, therefore protects boiler surface from severe scaling or corrosion problem that can result otherwise. Further, Boiler water blowdown is carried out to remove some of the concentrated water (suspended solids) from the pressure vessel while it is under pressure. Blowdown is a wastage of ENERGY. Blowdown is to be carried out as less as possible.

The importance of boiler blowdown is often overlooked. Improper blowdown can cause increased fuel consumption, additional chemical treatment requirements, and heat loss. In addition, the blowdown water has the same temperature and pressure as the boiler water. This blowdown heat can be recovered and reused in the boiler operations [2]. The basic diagram of boiler operation is in Figure 6.

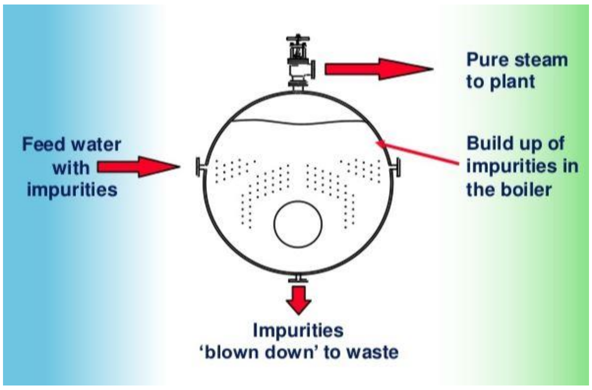


Figure 6: Basic Diagram of Boiler Operation

2.2 Boiler Blowdown Benefits

- Less water, fuel and treatment chemicals needed [2];
- Less maintenance and repair cost (minimized carryover and deposits) [2];
- Saves manual supervision for other tasks (with automatic control) [2];
- Cleaner and more efficient steam [2];
- Reduced operating cost (reduction in consumption, disposal, treatment and heating of water) [2];
- Minimized energy loss from boiler blowdown can save about 2 percent of a facility's total energy use with an average simple payback of less than one year [2].

2.3 Best Operating Practices for Boiler Blowdown

Carryover of form and water in large scale boiler water into the steam or the formation of deposits on boiler tubes. Excessive blowdown wastes energy, water and treatment chemicals. The blowdown amount required is a function of boiler type, steam pressure, chemical treatment program, and feed water quality. The optimum blowdown amount is typically calculated and controlled by measuring the conductivity of the boiler water [2]. Conductivity is a viable indicator of the overall Total Dissolved Solid (TDS) concentrations. Typically, blowdown rates range from 4 – 8 percent of boiler feed water flow rate, but can be as high as 20 percent with extremely poor quality feed water [2].

2.4 TDS Measurement Conductivity Method

The electrical conductivity of water depends on the type and amount of dissolved solid constrained [7]. The relationship of TDS and conductivity as shown in equation below [7];

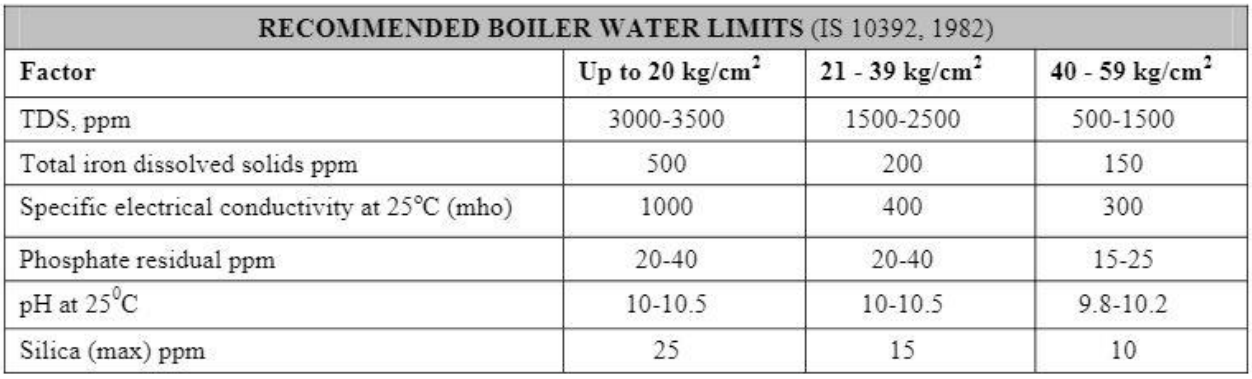
$$TDS\ (PPM) = (conductivity\ in\ \mu S/cm) * 0.7$$

*Conductivity = (measured conductivity * cell constant)* $\mu S/cm$ [8]

This relationship is only valid for a neutral sample at 25 ^{0} C [7].

2.5 The Maximum Recommended Concentration Limits

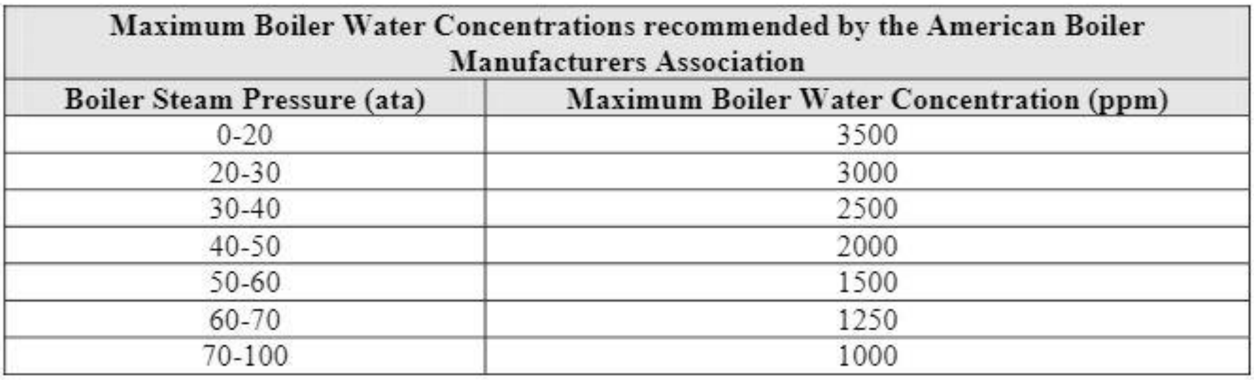
The main idea of blowdown is to maintain the solids concentration of the Boiler water within certain acceptable limits. Table 1 and Table 2 shows these maximum recommended concentration limits in the water of an operating Boiler according to American Boiler Manufactures Association (ABMA) [9].



RECOMMENDED BOILER WATER LIMITS (IS 10392, 1982)

Factor	**Up to 20 kg/cm^2**	**21 - 39 kg/cm^2**	**40 - 59 kg/cm^2**
TDS, ppm	3000-3500	1500-2500	500-1500
Total iron dissolved solids ppm	500	200	150
Specific electrical conductivity at 25°C (mho)	1000	400	300
Phosphate residual ppm	20-40	20-40	15-25
pH at 25^{0}C	10-10.5	10-10.5	9.8-10.2
Silica (max) ppm	25	15	10

Table 1: Recommended Boiler Water Limits
Source: www.asme.org



Maximum Boiler Water Concentrations recommended by the American Boiler Manufacturers Association	
Boiler Steam Pressure (ata)	Maximum Boiler Water Concentration (ppm)
0-20	3500
20-30	3000
30-40	2500
40-50	2000
50-60	1500
60-70	1250
70-100	1000

Table 2: Maximum Boiler Water Concentration by ABMA
Source: www.asme.org

The blowdown rate is set to control the Boiler water within these ABMA recommended limits. The continuous blowdown system will constantly monitor Boiler water conductivity (Solids concentration of TDS level) and adjust the blowdown rate to maintain the control range. If the Boiler water exceeds the recommended limits potential problems can occur.

2.6 Manual Vs Automatic Blowdown

Blowdown is achieved either by manual or automatic system. In the manual operation, blowdown is achieved by manually opening a bore valve at the bottom of the drum. However this practice can be highly wasteful. As the period of blowdown is not related with either boiler steam load or feed water purity, the TDS level in manual methods can vary greatly, causing an average TDS level much lower than the allowable limits, leading to excess blowdown and huge heat losses. An automatic blowdown control system, based on TDS measurement and subsequent corrective action can maintain a TDS level much closer to the set point , resulting in considerable fuel saving.

2.7 Calculating the Blowdown Rate

The following information is required [7]:

- The required boiler water TDS in parts per million [7].
- The feed water TDS in parts per million [7].

An average value may be obtained by looking at water treatment records, or a sample of feed water may be obtained and its conductivity measured [7]. As with boiler water TDS measurement, conductivity (µS/cm) x 0.7 = TDS in parts per million (at 25°C) [7].

Note: the sample of feed water that is required is from the boiler feed line or from the feed tank and is not a sample of the make-up water supplying the feed tank [7].

- The quantity of steam which the boiler generates, usually measured in kg/h. For selecting a blowdown system, the most important figure is usually the maximum quantity of steam that the boiler can generate at full-load [7].

When the above information is available the required blowdown rate can be determined using Equation [7];

$$Blowdown\ rate = \frac{FS}{B - F}$$

Where:

F = Feed water TDS (ppm)
S = Steam generation rate or Steam consumption (kg/h)
B = Required boiler water TDS (ppm)

2.8 On/Off Boiler Blowdown Valves

There is an advantage to using a larger control device with larger clearances, but only opening it for some of the time [7]. Clearly, moderation is required if the boiler TDS is to be kept between reasonable values, and DN15 and 20 valves are the most common sizes to be found [7].

A typical arrangement would be to set the controller to open the valve at, for example, 3000 ppm, then to close the valve at 3000 – 10% = 2 700 ppm. This would give a good balance between a reasonable sized valve and accurate control [7].

The type of valve selected is also important:

- For small boilers with a low blowdown rate and pressures of less than 10 bar g, an appropriately rated solenoid valve will provide a cost-effective solution [7].
- For larger boilers with higher blowdown rates, and certainly on boilers with operating pressures over 10 bar g, a more sophisticated valve is required to take flashing away from the valve seat in order to protect it from damage [7].

Valves of this type may also have an adjustable stroke to allow the user the flexibility to select a blowdown rate appropriate to the boiler, and any heat recovery equipment being used [7].

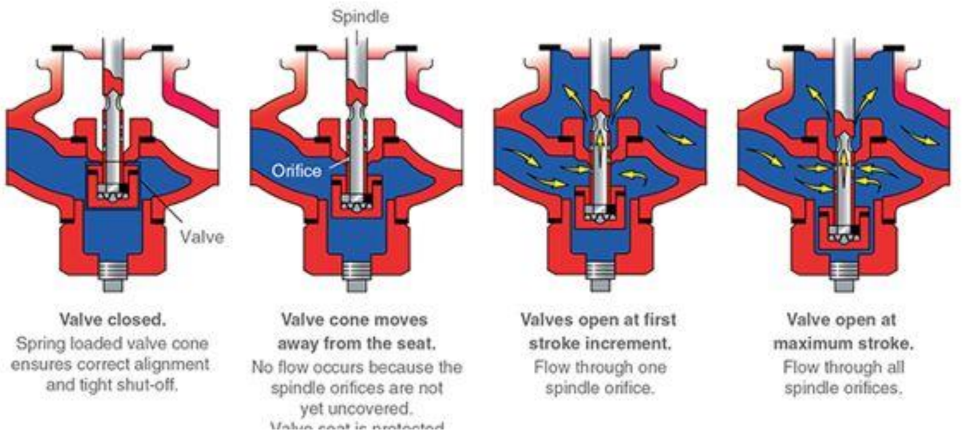


Figure 7: Modern Blowdown Control Valve
Source:http://pointing.spiraxsarco.com/resources/steam-engineering-tutorials/the-boiler-house/controlling-tds-in-the-boiler-water

2.9 Closed Loop Electronic Control Systems

These systems measure the boiler water conductivity, compare it with a set point, and open a blowdown control valve if the TDS level is too high [7].

A number of different types are on the market which will measure the conductivity either inside the boiler, or in an external sampling chamber which is purged at regular intervals to obtain a representative sample of boiler water [7]. The actual selection will be dependent upon such factors as boiler type, boiler pressure, and the quantity of water to be blown down [7].

These systems are designed to measure the boiler water conductivity using a conductivity probe sensor [7].

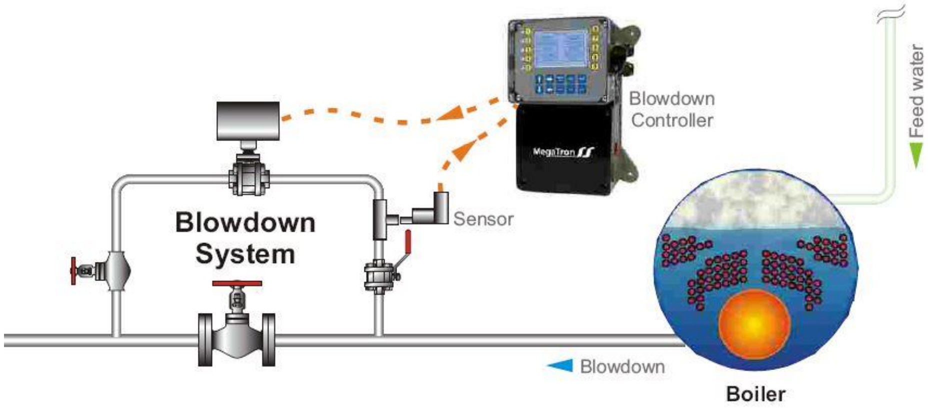


Figure 08: Close Loop Electronic TDS Control System
Source: www.ari-steamline.com

The measured value is compared to a set point programmed into the controller by the user [7]. If the measured value is greater than the set point, the blowdown control valve is opened until the set point is achieved. Typically, the user can also adjust the 'dead-band' [7].

As mentioned earlier, an increase in water temperature results in an increase in electrical conductivity [7]. Clearly if a boiler is operating over a wide temperature/pressure range, such as when boilers are on night set-back, or even a boiler with a wide burner control band, then compensation is required, since conductivity is the controlling factor [7].

2.10 Manual Blowdown Controls

In the manual method, blowdown is achieved by opening a large bore valve at the bottom of the drum (or on the side of the drum in case of continuous blowdown). However, this practice can be highly wasteful [3]. As the period of blowdown is not related with either boiler steam load or feed water purity, the TDS level in manual methods can vary greatly, causing an average TDS level much lower than the allowable limit, leading to excess blowdown and huge heat losses [3].

The commonly used method for regulating the amount of TDS is usually by blowing down the boiler for a few minutes at the end of every shift or some similar method. The below Figure 09, graph illustrates such a cycle in graphical form manual blowdown [4].

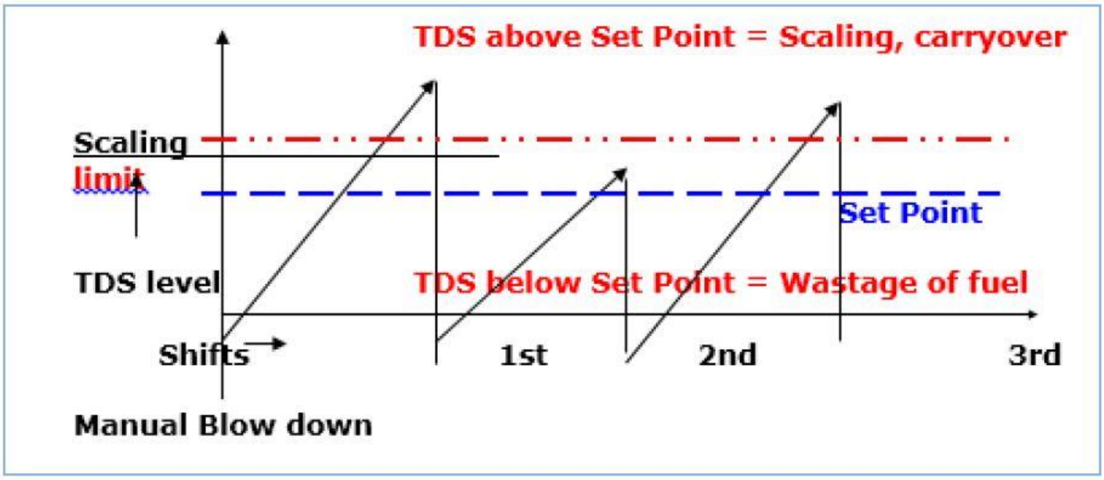


Figure 09: Manual Blowdown
Source: Energy Audit Report

Where the present method is solely manual blowdown from the bottom of the boiler, it may be possible by looking at past water treatment records, to obtain some idea of how much the boiler TDS varies over a period of weeks [7]. By inspection, an average TDS figure can be established [7]. Where the actual maximum is less than the maximum allowable figure, the average is as shown [7]. Where the actual maximum exceeds the maximum allowable, the average obtained should be scaled down proportionally, since it is desirable that the maximum allowable TDS figure should never be exceeded [7].

2.11 Automatic Blowdown Controls

Changing from manual blowdown control to automatic control can reduce a boiler's energy use by 2 – 5 percent and reduce blowdown water losses by up to 20 percent [2].

On the other hand, an automatic blowdown control system, based on TDS measurement and subsequent corrective action, can maintain a TDS level much closer to the set point, resulting in considerable fuel savings [3].

The blow down is only effective for the first few seconds of the blow down. Blow down of long duration create a great deal of turbulence in the mud drum "Stirring up" the sludge level. With the sludge in suspension from this action, it can be swept up the generating tubes where it can bake onto the tube surfaces, resulting in deposits [4].

With the automatic blow down control system, the TDS of the boiler water is checked at fixed intervals of say 30 minutes & hence leading to small blow down rates avoiding the formation of any turbulence in the shell [4].

Maintaining the boiler water cycles of concentration as close to the recommended limit as possible minimizes energy loss through blow down. This can be best accompanied only by automating the boiler blow down [4]. Scale causes fuel wastage typically up to 2% for water-tube boilers and up to 5% in fire-tube boilers. As a rule of thumb, one millimeter of scale build-up can increase fuel consumption by 2%. Since the blowdown water is at boiler working pressure and temperature, the blowdown quantity is higher than the required one it may also result in the loss of fuel [6]. Blowdown losses also include the losses through the additional cost for makeup water supplied and its softening costs. [6]
The Figure 10 shows automatic blowdown the dead band is very close to the set point compared to the manual blowdown system.

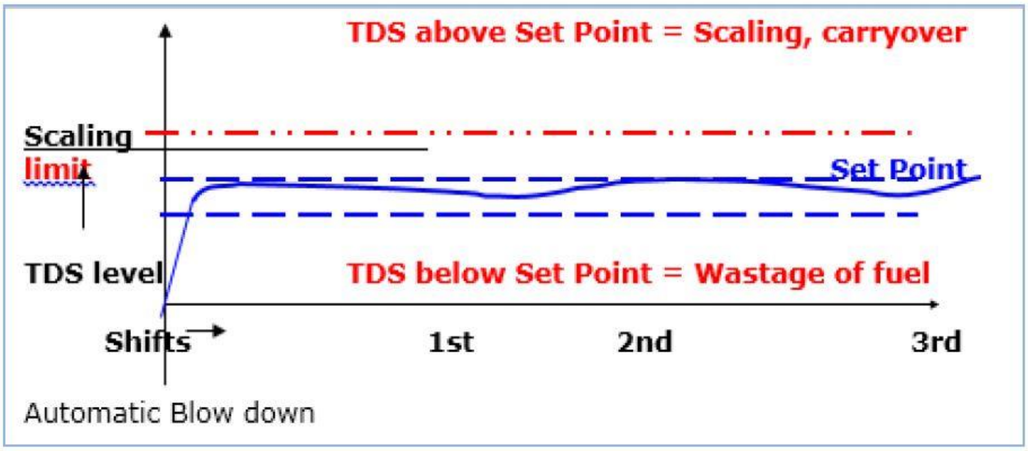


Figure 10: Automatic Blowdown
Source: Energy Audit Report

Automatic Blow down; the biggest advantage of these systems is that the amount of blow down becomes controlled automatically, thus eliminating the mistakes caused by the human factor. This ensures that the blow down quantity is always optimum, so that you neither exceed the Set TDS level, nor waste money [4].

There are two sources of blow down from a steam boiler; bottom blow down and surface blow down. Bottom blow down is the removal of the sludge which accumulates in the bottom of a fire tube boiler, or in the mud drum of a water tube boiler. The sludge is removed regularly to prevent build up which could foul the heat transfer surfaces and lead to vessel or tube failure. Bottom blow down is always done on an intermittent basis, usually once a day or once a shift. The valve(s) is opened manually for a brief period of time to allow the accumulated sludge to pass from the vessel [5].The Bottom blowdown and Surface blowdown are illustrated in Figure 11 and Figure 12 respectively.

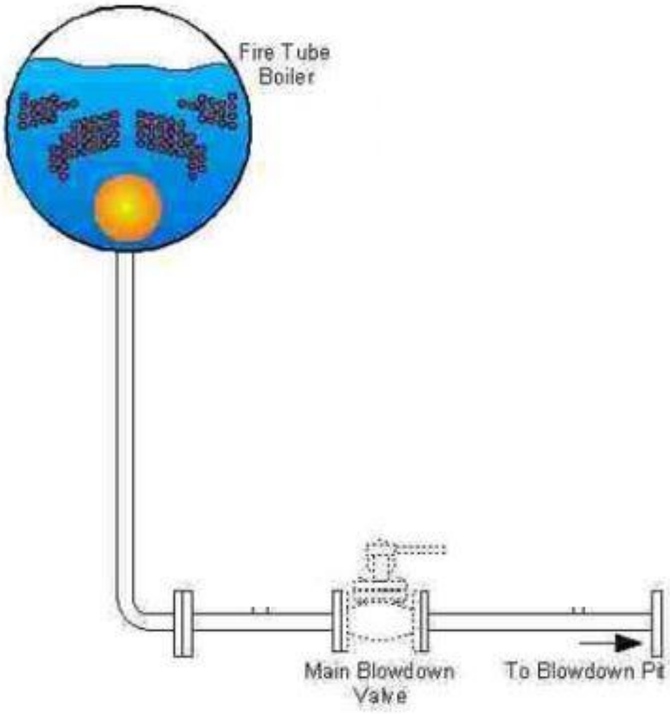


Figure 11 Bottom Blowdown
Source: www.ari-steamline.com

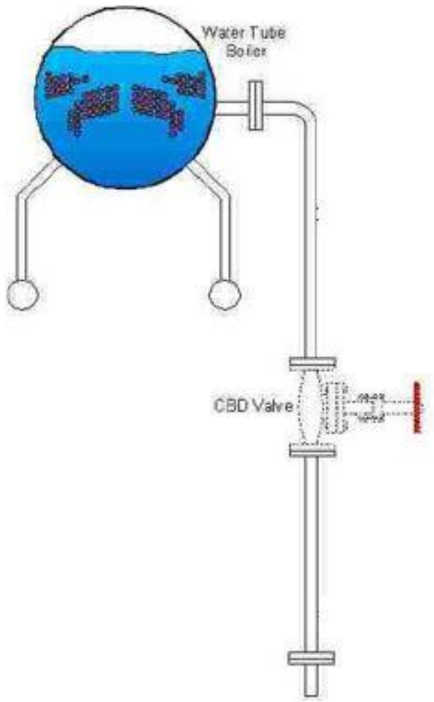


Figure 12 Surface Blowdown
Source: www.ari-steamline.com

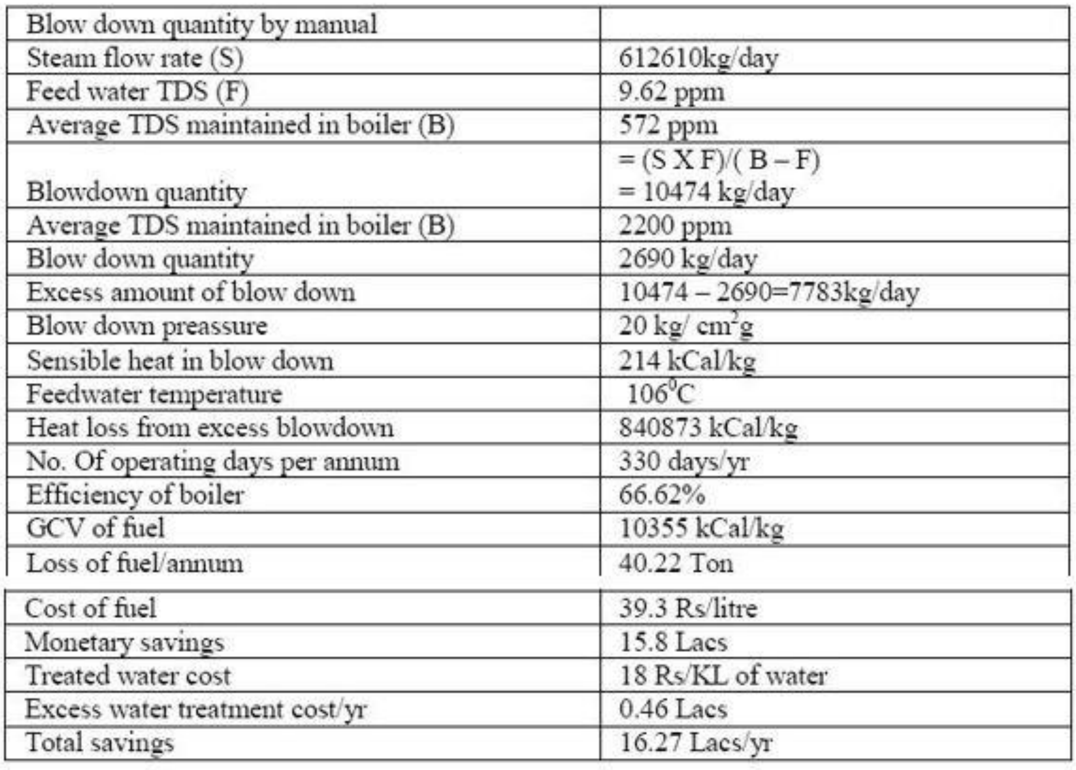
2.12 Boiler Blow down Analysis in an Industrial Boiler [5]

A reduction in boiler water blowdown can result in significant fuel and water savings [5]. In some installations, boiler water solids are lower than the maximum level permissible [5]. Through improved control methods, including automatic boiler blowdown equipment, boiler water blowdown can be reduced to maintain the solids close to but not above the maximum level permissible [5]. The rate of blowdown required depends on feed water characteristics, load on the boiler, and mechanical limitations [5]. Variations in these factors will change the amount of blowdown required, causing a need for frequent adjustments to the manually operated continuous blowdown system [5]. Even frequent manual adjustment may be inadequate to meet the changes in operating conditions [5]. The boiler water analysis is carried out at the 33TPH water tube boiler at Kerala Minerals & Metals Ltd, Kollam [5]. Presently the boiler water TDS is being controlled manually [5]. The 33 TPH boiler has the 25NB continuous blow down line [5]. This valve is kept crack open to maintain the TDS level in the boiler [5].

From last one month it is obvious that the average TDS level maintained in the boiler is about 572ppm which is lower than the recommended level of 2200ppm [5]. Since the system is being done manually without any actual online measurements, the boiler water TDS varies [5]. Since the condensate recovery from the plant varies and steam demand also leading to variation in requirement of blow down quantity [5]. Low level of boiler water TDS means higher the heart loss. Also considering the good quantity feed water of 10ppm, will generate lower boiler water TDS [5]. An effective automatic blow down control system works to measure the TDS of the blow down continuously and maintains the boiler water TDS near to the optimum/recommended level avoiding any bad effect on boiler tubes or on heat loss [5]. The following calculations indicate the savings that could be achievable [5].

The actual dissolved solids concentration at which foaming may start will vary from boiler to boiler [5]. Measurement of the dissolved solids may be done by chemical methods, by accurate density measurement using a hydrometer or by measuring the electrical conductivity of the boiler water using a conductivity meter [5]. Here we use the conductivity method to detect the TDS measurement [5]. The electrical conductivity of water depends on the type and amount of dissolved solids it contains [5]. Since acidity and alkalinity have a large effect on the electrical conductivity, it is necessary to neutralize the sample of boiler water before measuring its conductivity [5]. The procedure is as follows [5]:

- Add a few drops of phenolphthalein indicator solution to the cooled sample (< 25°C) [5].
- If the sample is alkaline, a strong purple color is obtained [5].
- Add acetic acid (typically 5%) drop by drop to neutralize the sample, mixing until the color disappears [5].



Blow down quantity by manual	
Steam flow rate (S)	612610kg/day
Feed water TDS (F)	9.62 ppm
Average TDS maintained in boiler (B)	572 ppm
Blowdown quantity	= (S X F)/(B – F) = 10474 kg/day
Average TDS maintained in boiler (B)	2200 ppm
Blow down quantity	2690 kg/day
Excess amount of blow down	10474 – 2690=7783kg/day
Blow down preassure	20 kg/ cm^{2}g
Sensible heat in blow down	214 kCal/kg
Feedwater temperature	106^{0}C
Heat loss from excess blowdown	840873 kCal/kg
No. Of operating days per annum	330 days/yr
Efficiency of boiler	66.62%
GCV of fuel	10355 kCal/kg
Loss of fuel/annum	40.22 Ton
Cost of fuel	39.3 Rs/litre
Monetary savings	15.8 Lacs
Treated water cost	18 Rs/KL of water
Excess water treatment cost/yr	0.46 Lacs
Total savings	16.27 Lacs/yr

Figure: 13 Blowdown Energy Analysis
Source: [5]

Where the present method is solely manual blowdown from the bottom of the boiler, by looking at past water treatment records it may be possible to obtain some idea of how much the boiler TDS varies over a period of weeks [5]. By inspection an average TDS figure can be established [5]. Where the actual maximum is less than the maximum allowable figure, the average is as shown [5]. Where the actual maximum exceeds the maximum allowable, the average obtained should be scaled down in proportion, since it is desirable that the maximum allowable TDS figure should never be exceeded [5]. Figure 14, below, shows that the average TDS with a well operated manual bottom blowdown is appreciably below the maximum allowable [5]. For example the maximum allowable TDS may be 2200 ppm and the average TDS only 572 ppm [5]. This means that the actual blowdown rate is much greater than that required [5]. The comparison between present manual blowdown and future installed automatic blowdown is shown below graphically [5]. The blowdown rate for each case was calculated using average and feed water TDS values [5]. And the difference between them was about 1.28% approximately [5]. From the observation result we strongly recommended the implementation of automatic TDS system to the 33TPH boiler in KMML having 25NB blowdown line [5]. So we have to increase the boiler efficiency, mainly indirect efficiency to the rated level. From the calculation and survey, it should be clearly about 70% [5].

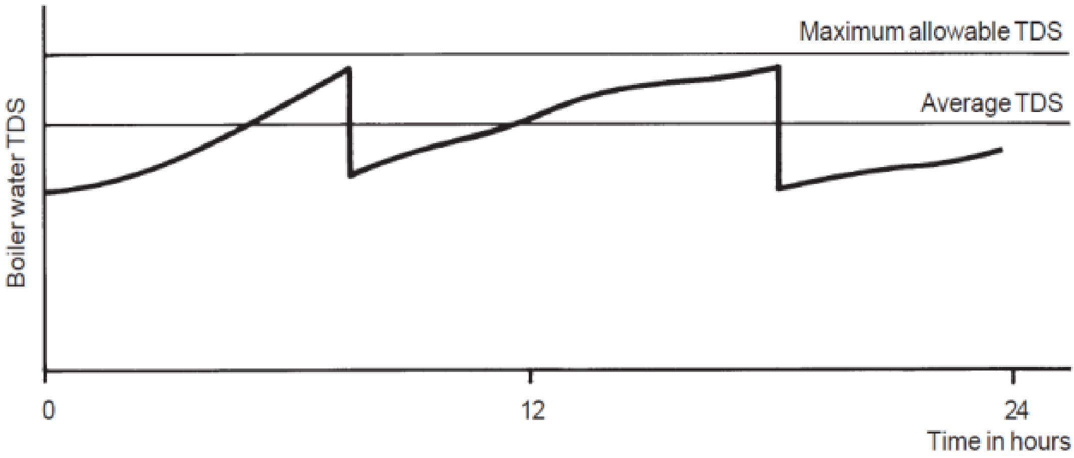


Figure: 14 Manual Blowdown
Source: [5]

Calculation of blow down rate [5]

Average TDS = 572 ppm [5]

Feed water TDS = 9.62 ppm [5]

Blow down rate = 9.62 x 100 % / (572−9.62) = 1.71% [5]

By installing an automatic TDS control system the average boiler water TDS can be maintained almost equal to the maximum allowable TDS as shown below [5].

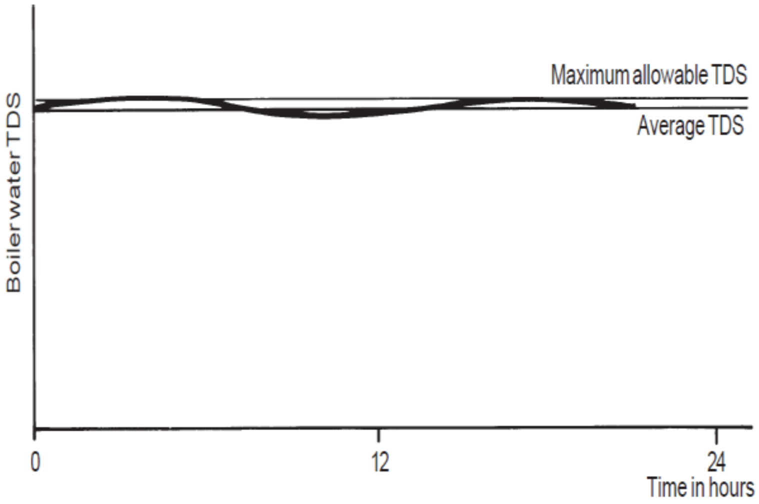


Figure: 15 Automatically Blowdown
Source: [5]

Calculation of blow down rate [5]

Average TDS = 2200 ppm [5]

Feed water TDS = 9.62 ppm [5]

Blow down rate = $9.62\ x\ 100\%\ /\ (2200-9.62)$ = 0.43% [5]

The blowdown rate is reduced by 1.28 percentage points by raising the average boiler water TDS [5].

The blowdown rate required for a particular boiler depends on the boiler design, the operating conditions, and the feed water contaminant levels [5]. In many systems, the blowdown rate is determined according to total dissolved solids [5]. In other systems, alkalinity, silica, or suspended solids levels determine the required blowdown rate [5]. An automatic blowdown control system continuously monitors the boiler water, adjusts the rate of blowdown, and maintains the specific conductance of the boiler water at the desired level [5]. This details about the blow down energy conservation analysis of KMML on January 2015 [5]. Based on our survey it is recommended to have the implementation of automatic blow down control system for the 33 TPH boiler to maintain the boiler water TDS to the recommended level [5]. This will ensure the boiler to operate near to its rated efficiency [5].

2.13 Example Analysis of Blowdown Calculation [7]

Figure 13 shows that the average TDS with a well operated manual bottom blowdown is significantly below the maximum allowable [7]. For example the maximum allowable TDS may be 3 500 ppm and the average TDS only 2 000 ppm [7]. This means that the actual blowdown rate is much greater than that required [7]. Based on a feed water TDS of 200 ppm, the actual blowdown rate is [7]:

$$\frac{200\, ppm\ feedwater\ TDS}{2\ 000\, ppm\ avarage\ boiler\ TDS - 200\, ppm\ feedwater\ TDS} * \frac{100}{1} = 11.1\%$$

By installing an automatic TDS control system the average boiler water TDS can be maintained at a level almost equal to the maximum allowable TDS as shown in Figure 14 [7].

2.14 Evaluating Savings by Reducing Blowdown Rate [7]

If a boiler is to supply a given amount of steam, the water blown down must be in addition to this amount [7]. The energy that is lost in blowdown is the energy that is supplied to the additional amount of water that is heated to saturation temperature, and then blown down [7].

A close approximation can be obtained using steam tables [7].

If the boiler had been operating at 10 bar g, steaming at 5 000 kg/h and had a feed water temperature of 80°C (hf = 335 kJ/kg), the change in energy requirement could be calculated as follows [7]:

Condition 1, manual TDS control: Blowdown rate = 11.1% [7]

To achieve a steaming rate of 5 000 kg/h, the boiler needs to be supplies with:

$$\text{Flow rate of water supplied to the boiler} = \frac{5\ 000\ \mathrm{kg/h} * (100+11.1)}{100}$$

$$\text{Flow rate of water supplied to the boiler} = 5\ 555\ \mathrm{kg/h}$$

All of this water will be raised to saturation temperature from feed water temperature hf = 782 kJ/kg at 10 bar g saturation temperature: hf = 335 kJ/kg at 80 °C

$$\text{Energy required} = \frac{5\ 555\ \mathrm{kg/h} * (782+335)\ \mathrm{kJ/kg}}{3\ 600\ \mathrm{second/hour}}$$

$$\text{Energy required} = 960\ \mathrm{kW}$$

5 000 kg/h of this is evaporated to steam for export
hfg = 2 000 kJ/kg from steam tables:

$$\text{Energy required} = \frac{5\ 000\ \mathrm{kg/h} * 2\ 000\ \mathrm{kJ/kg}}{3\ 600\ \mathrm{second/hour}}$$

$$\text{Energy required} = 2\ 778\ \mathrm{kW}$$

Total energy used to generate 5 000 kg/h of steam = 690 kW + 2 778 kW

Total energy used to generate 5 000 kg/h of steam = 3 468 kW

Condition 2, automatic TDS control [7]

Blowdown rate = $\frac{200 * 100\%}{3\ 500-200} = 6.1\%$

To achieve a steaming rate of 5 000 kg/h, the boiler needs to supply with:

Flowrate of water supplied to the boiler = $\frac{5\ 000\ \mathrm{kg/h} * (100+6.1)}{100}$

Flowrate of water supplied to the boiler = $5\ 305\ \mathrm{kg/h}$

All of this water will be raised to saturation temperature from feed water temperature hf = 782 kJ/kg at 10 bar g saturation temperature: hf = 335 kJ/kg at 80°C

Energy required $= \frac{5\ 305\ \mathrm{kg/h} * (782-335)\ \mathrm{kJ/kg}}{3\ 600\ \mathrm{second/hour}}$

Energy required = $659\ \mathrm{kW}$

5 000 kg/h of this is evaporated to steam for export:

Energy required = $\frac{5\ 000 \mathrm{kg/h} * 2\ 000\ \mathrm{kJ/kg}}{3\ 600\ \mathrm{second/hour}}$

Energy required = $2\ 778\ \mathrm{kW}$

The total energy used to generate 5 000 kg/h of steam = $659\ \mathrm{kW} + 2\ 778\ \mathrm{kW}$

The total energy used to generate 5 000 kg/h of steam = $3\ 437\ \mathrm{kW}$

Since fuel must have supplied the energy used to generate the steam, the reduction in energy used must represent a saving in fuel:

Reduction in energy = $3\ 468\ \mathrm{kW} - 3\ 437\ \mathrm{kW}$

Reduction in energy = $31\ \mathrm{kW}$

This, in turn, can be expressed as a percentage saving in the boiler fuel cost:

Reduction in energy cost = $\frac{31\ \mathrm{kW}}{3\ 468\ \mathrm{kW}} * \frac{100}{1}$

Reduction in energy cost = $\mathbf{0.9\%}$ saving fuel cost

2.15 Boiler Blowdown Optimization Analysis

Too low a TDS leads to unnecessary loss of hot Boiler water whereas operating at higher TDS levels will interfere with Boiler blowdown. The consequences of Too Little blowdown or High TDS are:

(a). Causes foaming and carryover.

(b). Alters boiling patterns in tubes leading to deposits.

(c). High TDS is leading to form scale on boiler parts in the water side such as tubes, shell, back plates etc.

The consequence of too high blowdown rates or maintaining low TDS value will always be resulting in Better health, but that will come at the cost of draining of excessive water heated around 180 centigrade from cold condition of 40 centigrade to 60 centigrade and that too with expensive fuels.

The same results can be achieved by optimizing the blowdowns with the help of Boiler blowdown control system by maintaining the TDS concentration as close to the recommended limit as possible.

CHAPTER 3
BOILER HOUSE BEHAVIOUR AT SPMC

3.1 Boiler House Parameter Observation

This chapter explains the behavior of the boiler house at State Pharmaceuticals Manufacturing Corporation (SPMC) with respect to its parameters. The Plant has two 1.2 TPH diesel fired boilers to cater the plant steam demand. The Boiler basic details is as below table 3 is illustrated.

Parameters	Units	Values	Values
Boiler Make – Hirakawa Iron Works LTD ,JAPAN		**Boiler No1**	**Boiler No2**
Boiler Design Capacity	TPH	1.2	1.2
Boiler Design Pressure	Kg/cm2g	10	10
Boiler Present Operating Pressure	Kg/cm2g	2.5	2.5
Boiler Type		Smoke Tube	Smoke Tube
Fuel Used		Diesel	Diesel
GCV of Fuel	Kcal/kg	10800	10800
Stack temperature	Deg C	198-289	340-341
Make Up Water		Soft Water	Soft Water
Chemicals Used		Yes	Yes
Type of Blowdown		Manual	Manual
Frequency		Two times per day	Two times per day
Blowdown valve size	mm	40	40
Blowdown Pressure	Kg/cm2g	2.5	2.5
Drain of hot blowdown		Local drain	Local drain

Table 3: Boiler House Observations Parameters
Source: Energy Report SPMC

The name plate details of a Boiler is shown in Figure 16.

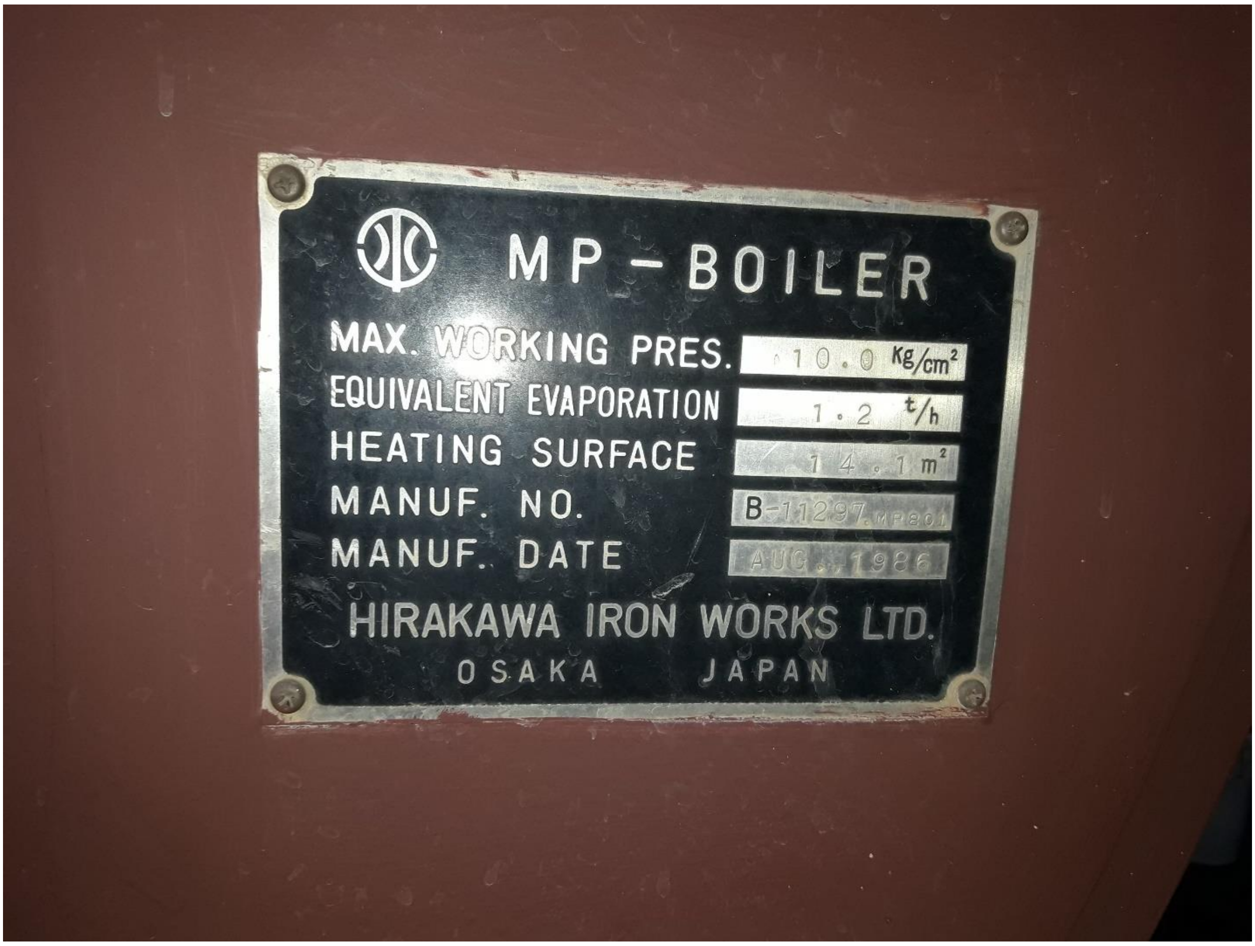


Figure 16: The Name Plate Detail of a Boiler

3.2 Overview of Boiler Steam Consumption Analysis

In order to get average steam consumption of the Plant during Energy Audit it was revealed that average steam consumption around 4383 kg/day including some loss exists at the plant (steam leakages, un-insulation loss, trap loss etc) that would be reduced with audit proposals up to 3891 kg/day. Right now steam consumption is taken as 4383 kg/day for the blowdown saving calculation for the automation system. The Table below is the present Heat and Mass Balance of the plant was revealed during energy audit and extract image is in Figure 17.

Section	Equipment	Steam Pressure (barg)	Present steam consumption (Kg/day)
General Drug Zone	Paste Preparation Kettle-1&2	2.5	67
	Heating fan unit (Equipment drying)	0.4	101
	FBD	2.5	484
	Film Coater-1	2.5	681
	Hot water generator	0.4	32
	AHU-1	0.4	673
	AHU-2	0.4	683
	Steam dryer (Laundry)	2.5	161
Penicillin Zone	Heating fan unit (Equipment drying)	0.4	199.5
	Steam dryer (Laundry)	2.5	161
	Hot water generator	0.4	32
	AHU-1	0.4	403
	Steam Washer- Maintenance office	0.4	0
Miscellaneous	Steam leakages	0.4/2.5	42
	Insulation/Un-insulation loss	0.4/2.5	523
	Trap Loss	0.4/2.5	141.8
Total (Kg/day)			**4383**

Figure: 17 Present Heat and Mass Balance (Steam Consumption) of the Plant
Source: Energy Report SPMC

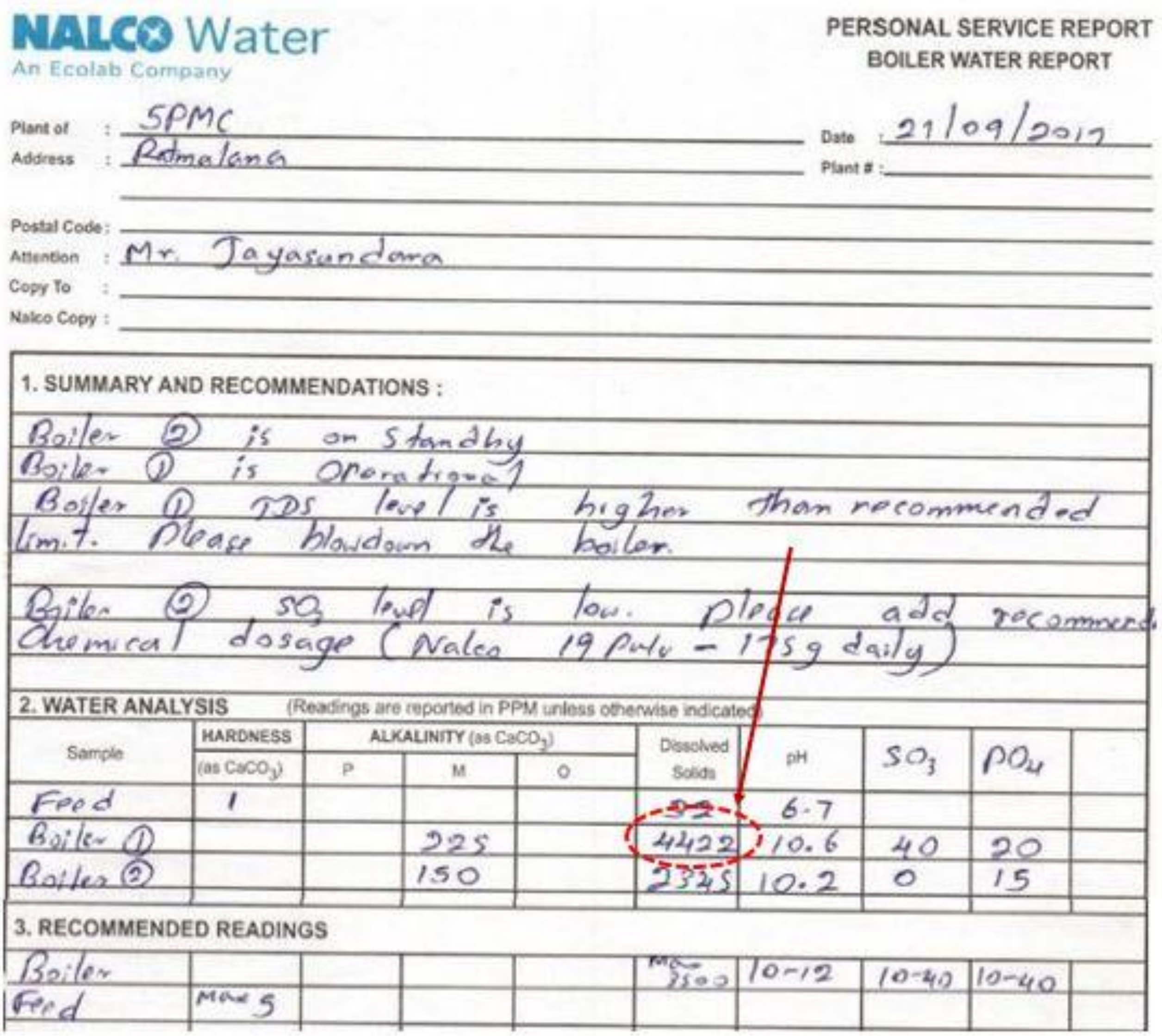
3.3 Present Manual Blowdown Practice of the Boiler House

At present blowdown is done manual intervention and two times a day Morning Shift and Evening Shift for the period of 1-2 minutes each time. Figure 18 is shown manual blowdown done by the plant Technicians.

Figure: 18 Manual Blowdown at State Pharmaceuticals Manufacturing Corporation

3.4 Water TDS Level Analysis

The Chemical Supplier providing water analysis report monthly to maintain the health of the Boiler for that requires to maintain recommended data for the Boiler operation. The sample copy of report is illustrated in Figure 19.



NALCO Water
An Ecolab Company

PERSONAL SERVICE REPORT
BOILER WATER REPORT

Plant of : SPMC
Address : Ratmalana
Date : 21/09/2017
Plant # :
Postal Code :
Attention : Mr. Jayasundara
Copy To :
Nalco Copy :

1. SUMMARY AND RECOMMENDATIONS :

Boiler ② is on Standby
Boiler ① is Operational
Boiler ① TDS level is higher than recommended limit. Please blowdown the boiler.

Boiler ② SO_3 level is low. please add recommend. Chemical dosage (Nalco 19 Pulv – 175 g daily)

2. WATER ANALYSIS (Readings are reported in PPM unless otherwise indicated)

Sample	HARDNESS	ALKALINITY (as $CaCO_3$)			Dissolved Solids	pH	SO_3	PO_4	
	(as $CaCO_3$)	P	M	O					
Feed	1				32	6.7			
Boiler ①			225		4422	10.6	40	20	
Boiler ②			150		2345	10.2	0	15	

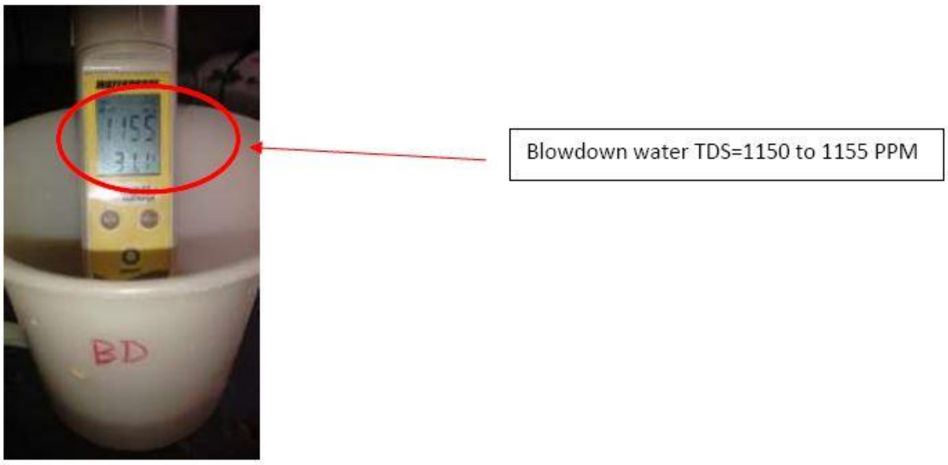
3. RECOMMENDED READINGS

Boiler					Max 3500	10-12	10-40	10-40	
Feed	Max 5								

Figure 19 Boiler Water Report

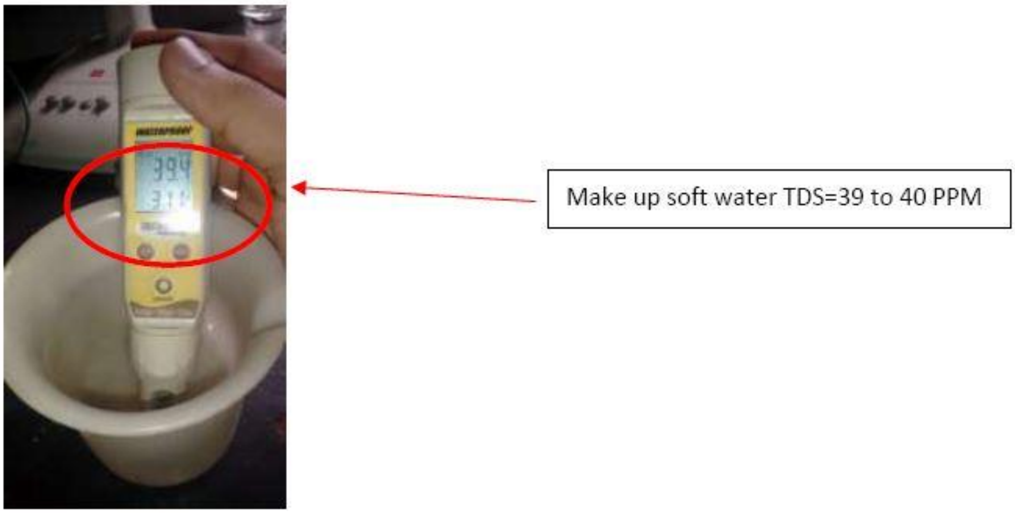
This image of water report was taken on 21 Sep 2017 after inspection of Boiler water and Boiler No 1 drum Boiler water has been exceeded recommended value of 3500 ppm and around TDS level 4422 ppm. So keeping Boiler drum water with high side TDS than recommended or maximum allowable set point of 3500 ppm, means this leads to scale deposits on the fire tube surfaces resulting in reduced heat transfer as well as corrosion. Further high TDS which would causes dirty steam, product contamination (would be effected quality of product being produced using steam) and blocked steam traps in the steam distribution network.

During Audit water quality parameters TDS was checked and was to be ranging from 1150 – 1155 PPM shown in Figure 20 and make up feed water shown in Figure 21 respectively.



Blowdown water TDS=1150 to 1155 PPM

Figure 20 Boiler Blowdown Water Check during Energy Audit



Make up soft water TDS=39 to 40 PPM

Figure 21 Make up Feed Water Check during Energy Audit

3.5 Boiler Drum Water TDS Analysis

The monthly Boiler water TDS data report was analyzed in tabular format and graphs were illustrated respectively. The Monthly Boiler Water Reports is attached in **Appendix – A**

Date	TDS Boiler Drum Level (ppm) Boiler No 1
19/09/2016	4360
05/12/2016	1650
26/05/2017	2680
15/06/2017	3886
20/07/2017	4152
31/08/2017	4020
21/09/2017	4422
07/11/2017	2850
16/01/2018	2546
19/02/2018	3183
15/05/2018	1750
16/07/2018	2010
30/08/2018	3310
10/10/2018	2850
16/11/2018	2950
Average TDS	3061

Table 4: Monthly Boiler Drum Water TDS reading past years to date – Boiler No1

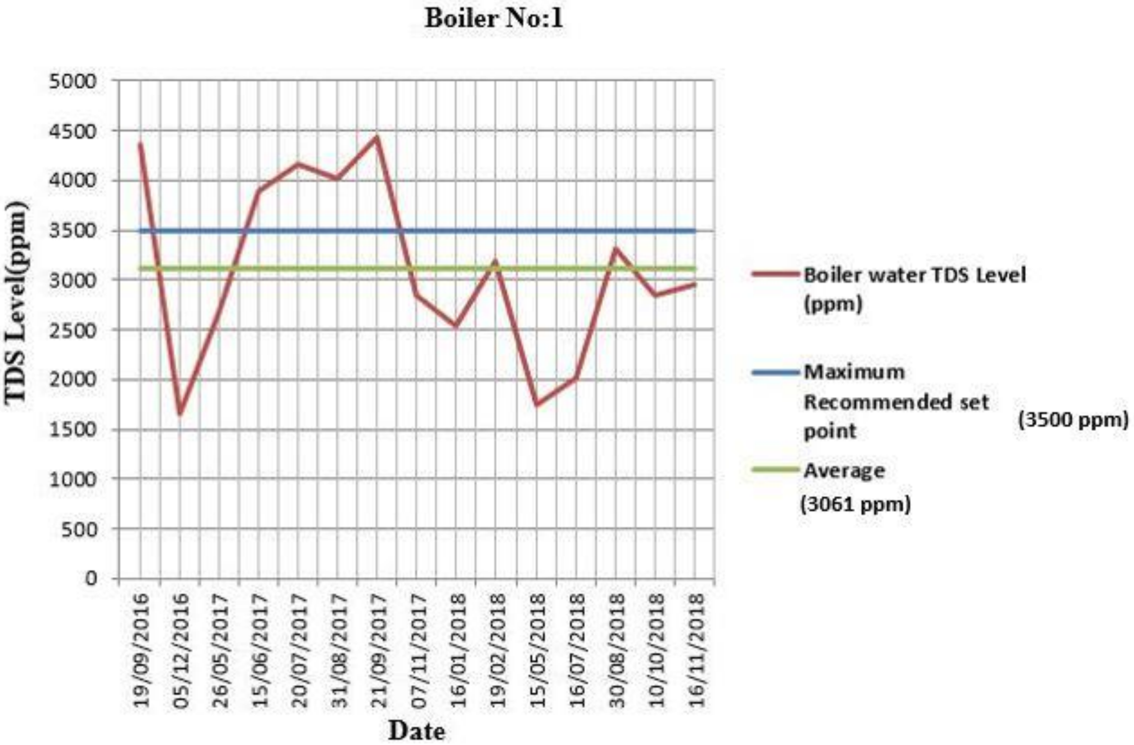


Figure 22 Boiler Water TDS variation Monthly- Boiler No1

From the above graph it's clear that TDS Level varied upper region and lower region compared to the maximum recommended set point at present due to manual blowdown intervention of the plant of from the past year to date No 1 Boiler. The para 3.3 explained drawback of high side of TDS and Boiler water with lower side TDS sufficient level well below the specific maximum allowable limits as per the graph than recommended set point 3500ppm means excessive blowdown and waste of energy.

The data of Boiler No 2 is illustrated as follows:

Date	**TDS Boiler Drum Level (ppm) Boiler No 2**
19/09/2016	4412
05/12/2016	2600
26/05/2017	968
15/06/2017	3216
20/07/2017	3752
31/08/2017	2456
21/09/2017	2345
07/11/2017	1860
16/01/2018	2010
19/02/2018	351
15/05/2018	1738
16/07/2018	1765
30/08/2018	2165
10/10/2018	2710
16/11/2018	2175
Average TDS	2302

Table 5: Monthly Boiler Drum Water TDS reading past years to date – Boiler No2

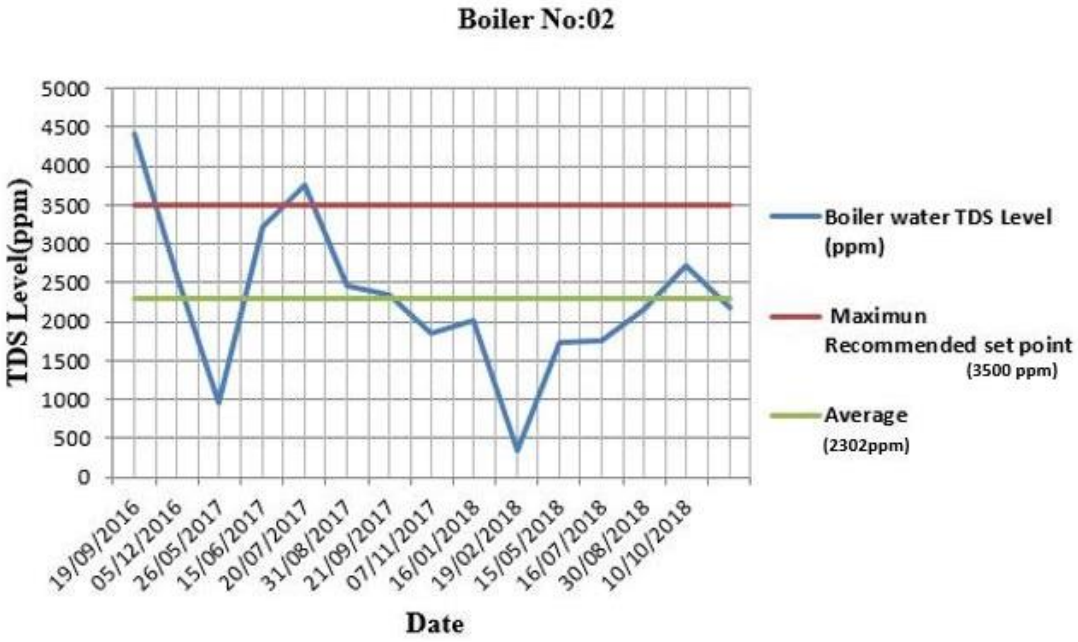


Figure 23 Boiler Water TDS variation Monthly –Boiler No2

From the above graph it’s clear that Boiler No2 TDS level varied lower region most of the time and a few overshoots year Sep 2016 and Jul 2017 respectively. So the average TDS level maintaining lower region sufficient level well below compared to set point. In this scenario excessive blowdown of Boiler No2 and waste of energy due to manual blowdown innervation to date.

At present, the manual blowdown system is operated once per shift to reduce the Boiler Total Dissolved Solids (TDS) to a sufficient level well below the specific maximum limits, this can be seen by analyzing data provided by monthly chemical water analysis graph in Figure 22, Figure 23 respectively. The TDS are allowed to build up during the next shift until they reach the maximum level again.

The continuous blowdown system can be achieved fully automatic by installing a TDS monitoring sensor facility and blowdown valve operates input from TDS sensor reading close to the maximum allowable set point of TDS. Hence manual blowdown cycle can be reduced by introducing fully automatic blowdown control base system where that automatic system blowdown will take place when reaches TDS value to the set point that reduces the number of frequency of Boiler blowdowns which in turn save energy on steam Boiler.

3.6 Boiler Feed Water TDS Analysis

The monthly Boiler feed water data report was analyzed in tabular format and graph was illustrated respectively.

Date	TDS Level (ppm)
19/09/2016	28
05/12/2016	35
26/05/2017	31
15/06/2017	35
20/07/2017	34
31/08/2017	38
21/09/2017	32
07/11/2017	38
16/01/2018	41
19/02/2018	61
15/05/2018	45
16/07/2018	31
30/08/2018	32
10/10/2018	44
16/11/2018	94
Average	41

Table 6: Monthly Boiler Feed Water TDS reading past years to date

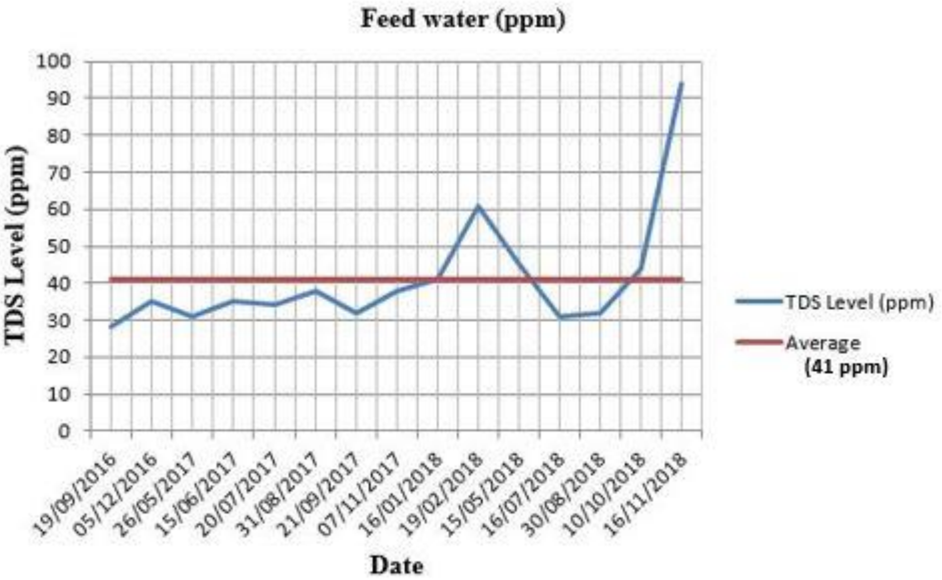


Figure 24 Boiler Feed Water TDS variation monthly

3.7 Calculating Blowdown Quantity

The Blowdown quantity can be calculated by using following formula [10]

F – Feed Water TDS (ppm)
S – Steam Consumption or Generation rate (kg/day)
B – Required Boiler Water TDS (ppm)

$$\text{Amount to be Blowdown} = \frac{\text{F x S}}{\text{B} - \text{F}}$$

Parameters	Qty	Unit
Steam Consumption (S) as per Figure 19	4383	kg/day
Blowdown Boiler Water TDS (B) as per Figure 22	1155	ppm
Feed Water TDS (F) as per Figure 23	40	ppm
Amount to be Blowdown as per the above formula	157.2	kg/day

Table 7: Blowdown Quantity Calculation in Manual Blowdown Method

In the Table 7 shows that Blowdown hot water amount 157.2 kg/day could be wasted with the TDS data analysis that we did blowdown at lower TDS region as recommended TDS level. At present blowdown was given manually 2 times a day for a 1-2 minutes each to maintain TDS level avoiding TDS level goes high. By introducing automatic blowdown control system would be optimized of Boiler blowdown considerably.

3.8 Boiler Blowdown Optimization Calculation with Automation

Description	Boiler No 1& Boiler No 2
Steam Consumption (S) as per Figure 19	4383 kg/day
Average Boiler Water TDS (B) would be maintained valve open at TDS 3500 ppm and Valve close at 3400 ppm by automation	3450 ppm
Average Feed Water TDS (F) as per Figure 23	40 ppm
Proposed Amount to be Blowdown as per the above formula	51.4 kg/day
Difference Manual vs Automatic Blowdown	105.8 kg/day
The amount of saving due to Automatic Blowdown intervention	105.8 kg/per

Table 8: Optimization of Blowdown Calculation

In automatic TDS control system can be maintain the Boiler TDS near the maximum allowable to minimize heat losses and water treatment chemical costs. Provide always with the minimum of manual attention. The dead band of TDS control can be optimized in automatic blowdown system and this can be compared with Figure 27 is given below.

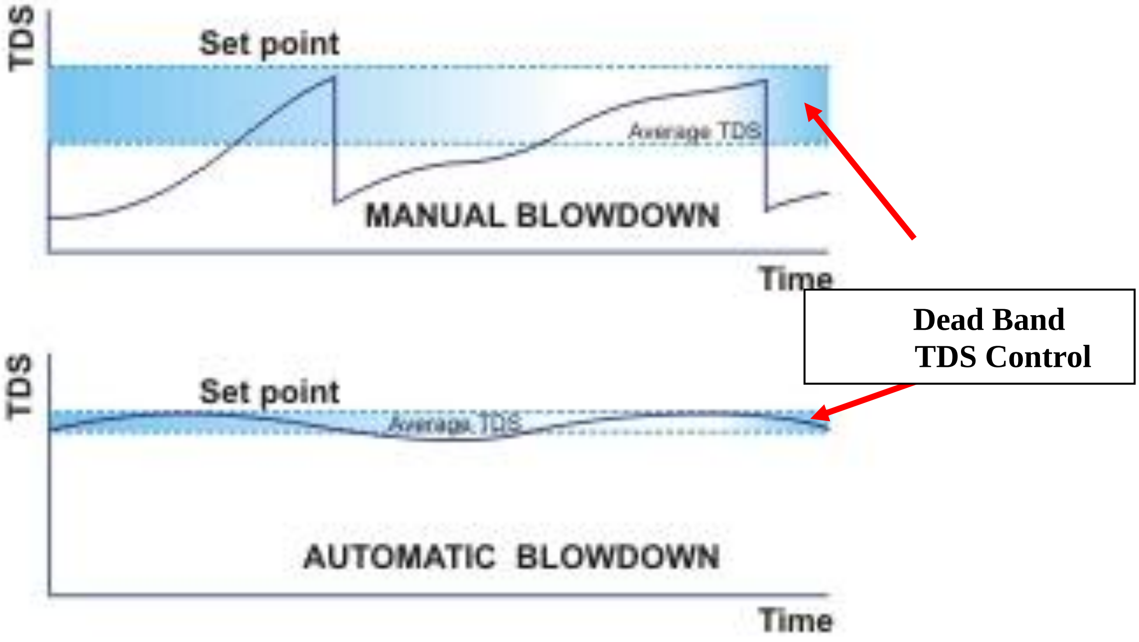
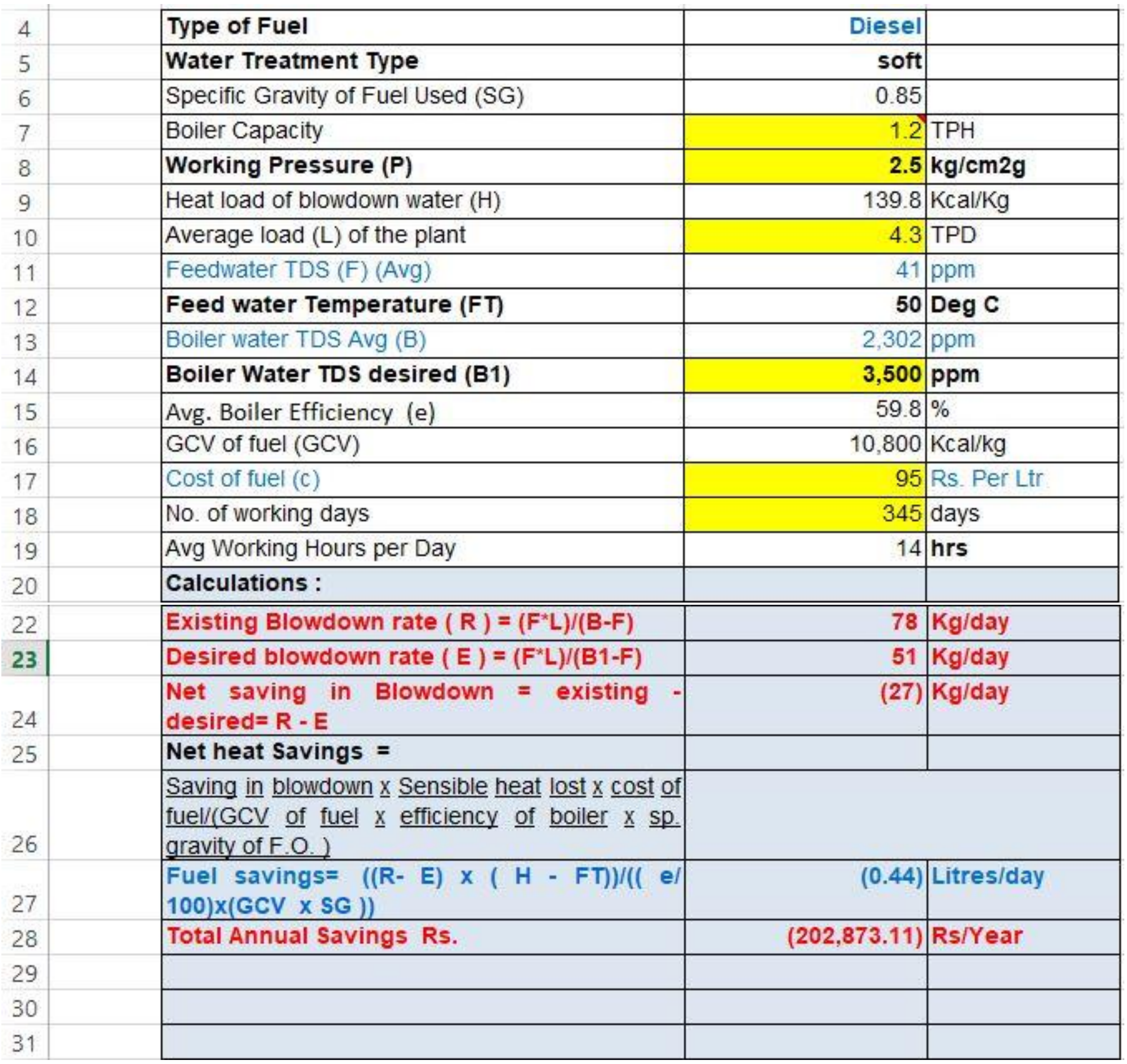


Figure 25 TDS control Manual Blowdown Vs Automatic Blowdown

3.9 Boiler Blowdown Energy Recovery Optimization Calculation at SPMC

The detail anaylisis calculation based on present Boiler data gathered from the energy audit and average TDS based on Boiler No2 (Figure 23) / avarage feed water TDS (Figure 24) are given in excel format calculation in Figure 26. This energy savings can be obtained with automatic blowdown control system average annually. This for fuel cost saving in addition to saving cost of water and chemical also adding considerable amount annualy.



4	**Type of Fuel**	**Diesel**	
5	**Water Treatment Type**	**soft**	
6	Specific Gravity of Fuel Used (SG)	0.85	
7	Boiler Capacity	1.2	TPH
8	**Working Pressure (P)**	**2.5**	**kg/cm2g**
9	Heat load of blowdown water (H)	139.8	Kcal/Kg
10	Average load (L) of the plant	4.3	TPD
11	Feedwater TDS (F) (Avg)	41	ppm
12	**Feed water Temperature (FT)**	**50**	**Deg C**
13	Boiler water TDS Avg (B)	2,302	ppm
14	**Boiler Water TDS desired (B1)**	**3,500**	**ppm**
15	Avg. Boiler Efficiency (e)	59.8	%
16	GCV of fuel (GCV)	10,800	Kcal/kg
17	Cost of fuel (c)	95	Rs. Per Ltr
18	No. of working days	345	days
19	Avg Working Hours per Day	14	**hrs**
20	**Calculations :**		
22	**Existing Blowdown rate (R) = (F*L)/(B-F)**	**78**	**Kg/day**
23	**Desired blowdown rate (E) = (F*L)/(B1-F)**	**51**	**Kg/day**
24	**Net saving in Blowdown = existing - desired= R - E**	**(27)**	**Kg/day**
25	**Net heat Savings =**		
26	Saving in blowdown x Sensible heat lost x cost of fuel/(GCV of fuel x efficiency of boiler x sp. gravity of F.O.)		
27	**Fuel savings= ((R- E) x (H - FT))/((e/ 100)x(GCV x SG))**	**(0.44)**	**Litres/day**
28	**Total Annual Savings Rs.**	**(202,873.11)**	**Rs/Year**
29			
30			
31			

Figure 26: Annual Savings with Automatic Blowdown Control System.

3.10 Hypothetical Analysis TDS Control Effects for Energy Savings Boiler Blowdown Operation

As steam evaporated the concentration of TDS increases in the Boiler water. The Boiler, prevention of scale formation or TDS concertation can produce substantial energy savings. The scale formation can be best dealt with controlling the TDS levels in the Boiler.

In Figure 27 is illustrated present Boiler loading pattern at SPMC Boiler House (Extract form Energy Audit conducted this year 12th June to 19th June 2018).

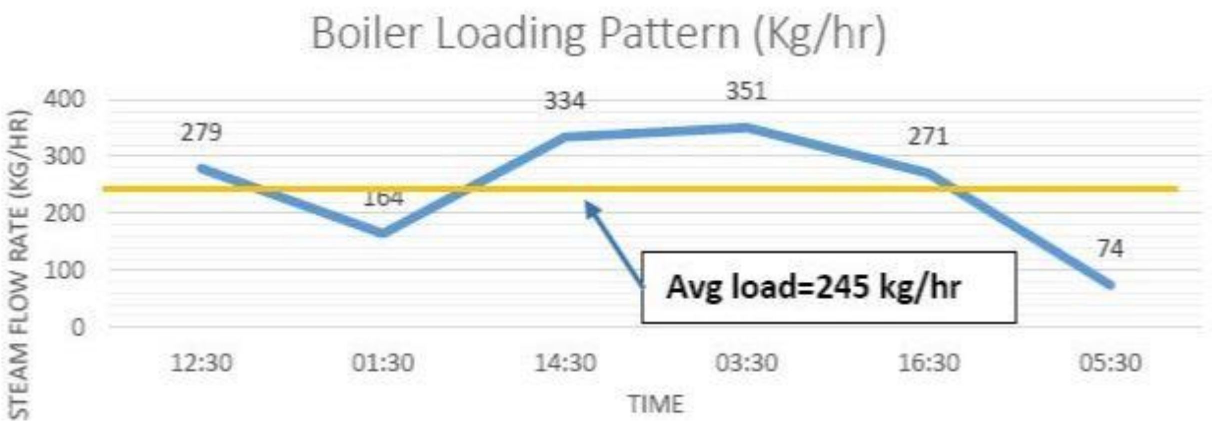


Figure 27: Boiler Loading Pattern
Source: Energy Report SPMC

From the above graph it’s clear at present peak boiler load is 351 Kg/hr considering operating machines as observed during audit period.

The overall view of plant present and future steam demand analysis is shown in Table 9.

Section	Equipment Name	Present Steam Load in Kg/hr	Future Steam Load in Kg/hr
General Drug Zone	Paste Preparation Kettle	117	117
	Heating fan unit (Equipment drying)	11	11
	Fluid Bed Dryer	117	117
	Film Coater-1	85	85
	Hot water generator-1	136	136
	Air Handling Unit-1	75	75
	Air Handling Unit-2	78	78
	Steam dryer (Laundry)	23	23
Penicillin Zone	Heating fan unit	13	13
	Steam dryer (laundry)	23	23
	Steam oven	60	60
	Hot water generator	136	136
	Air Handling Unit	55	55
F- Zone	Air Handling Unit-1	50	50
	Air Handling Unit-2	58	58
	New Fluid Bed Dryer	-	168
AB- Zone	New Film Coater	-	122
E-Zone	Air Handling Unit-1	30.3	30.3
	Air handling Unit-2	30.3	30.3
Total (Kg/hr)		**1098**	**1388**

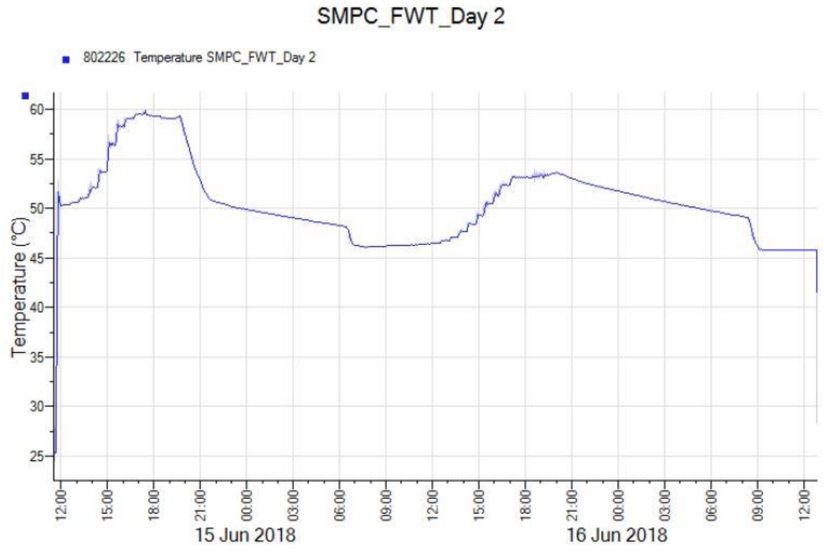
Table 9: Plant Present & Future Steam Demand
Source: Energy Report SPMC

All the above Figure 28 steam load is estimated as per machine designed parameters as given by the plant. Since Paste Preparation section operates generally once in day with 1-2 batches (early morning).Thus by excluding this section the peak demand will take Total as **(1388 -117) Kg/hr** and that is Total Peak Load **1271 Kg/hr.** By considering the present peak demand of 351Kg/hr (Figure 29), the additional of 920 Kg/hr of steam load would lead to the future peak demand of 1271 Kg/hr.

To control Boiler blowdown rate is needed to find out steam generation rate of the Boiler and that calculation obtained from energy audit report. Following data extract from audit report.

The peak demand of the plant is shown above as 1271 Kg/hr and need to find out feed water temperature for the calculation of steam generation rate of the plant considering future demand.

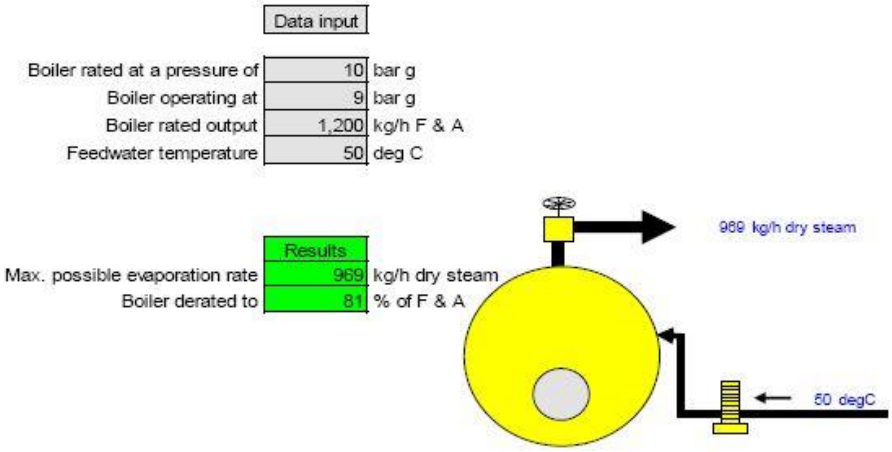
The average feed water temperature was at ranging 51 deg. C to 59 deg. C captured during plant full load condition is shown in Figure 31.



Max= 59 deg.C & Avg= 51 deg.C

Figure 28: Feed Water Temperature at Plant Full Load Condition
Source: Energy Report SPMC

By input these data as shown in Figure 32 calculated steam generation rate is 969 Kg /hr based on plant condition and extract from energy audit report.



Data input

Boiler rated at a pressure of	10	bar g
Boiler operating at	9	bar g
Boiler rated output	1,200	kg/h F & A
Feedwater temperature	50	deg C

Results

Max. possible evaporation rate	969	kg/h dry steam
Boiler derated to	81	% of F & A

Figure 29: Steam Generation Rate Calculation
Source: Energy Report SPMC

We take some hypnotical data for analyzing TDS control effect of Boiler blowdown energy savings. For an estimate of the Boiler blowdown rate use formula below. [10]. The Steam generation rate would be 969 Kg/hr as per the above calculation in Figure 29.

F – Feed Water TDS (ppm)
S – Steam Consumption or Generation rate (kg/day)
B – Required Boiler Water TDS (ppm)

$$\text{Blowdown Rate} = \frac{\text{F x S}}{\text{B} - \text{F}}$$

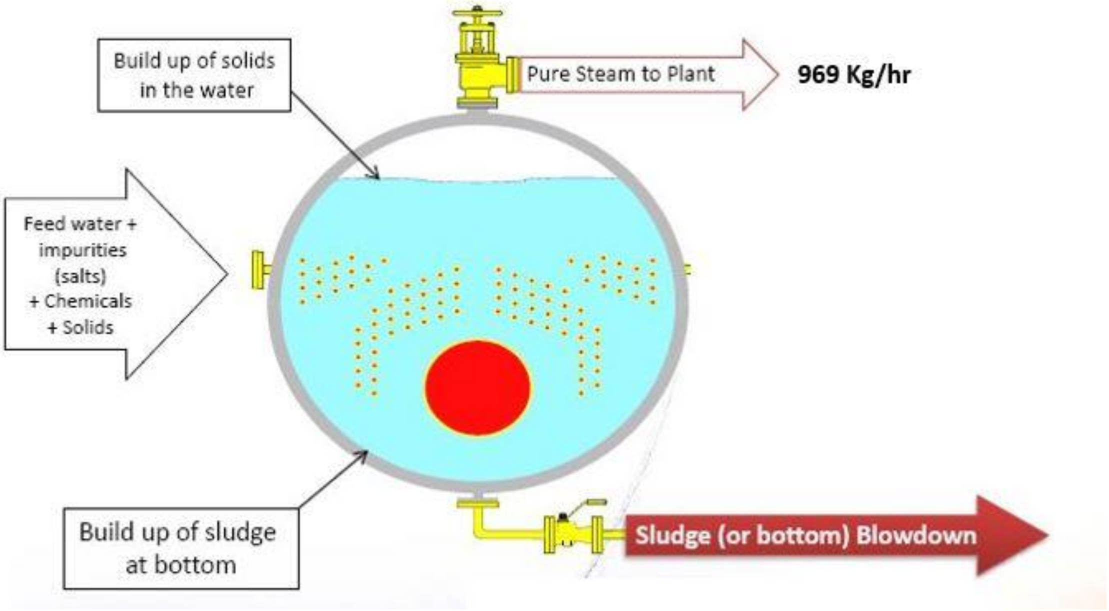


Figure 30: Boiler Blowdown Rate Analysis

The Boiler blowdown rate can be obtained using above formula and data given at table 10. So we take hypothetical example that feed water TDS value ranging from 20 to 91 in table 10. By introducing automatic blowdown system then Boiler water TDS level would be maintained at constant level as given at table 10 and blowdown rate will varying 5.6 Kg/hr to 25.9 Kg/hr that is low blowdown rate when compares with manual blowdown TDS Boiler water level in table 11.

Feed Water TDS(ppm)	Steam Generation (Kg/hr)	Maximum Allowable Boiler Water TDS (ppm)	Blowdown Rate (Kg/hr)
20	969	3500	5.6
35	969	3500	9.8
38	969	3500	10.6
41	969	3500	11.5
47	969	3500	13.2
52	969	3500	14.6
62	969	3500	17.5
74	969	3500	20.9
86	969	3500	24.4
91	969	3500	25.9

Table 10: Boiler Blowdown Rate Calculation with Maximum allowable TDS in Automation

Feed Water TDS(ppm)	Steam Generation (Kg/hr)	Available Boiler Water TDS (ppm)	Blowdown Rate (Kg/hr)
20	969	1155	17.1
35	969	2010	17.2
38	969	2434	15.4
41	969	3010	13.4
47	969	2680	17.3
52	969	2101	24.6
62	969	2720	22.6
74	969	3134	23.4
86	969	2331	37.1
91	969	1980	46.7

Table 11 Boiler Blowdown Rate Calculation with Available TDS in Manual

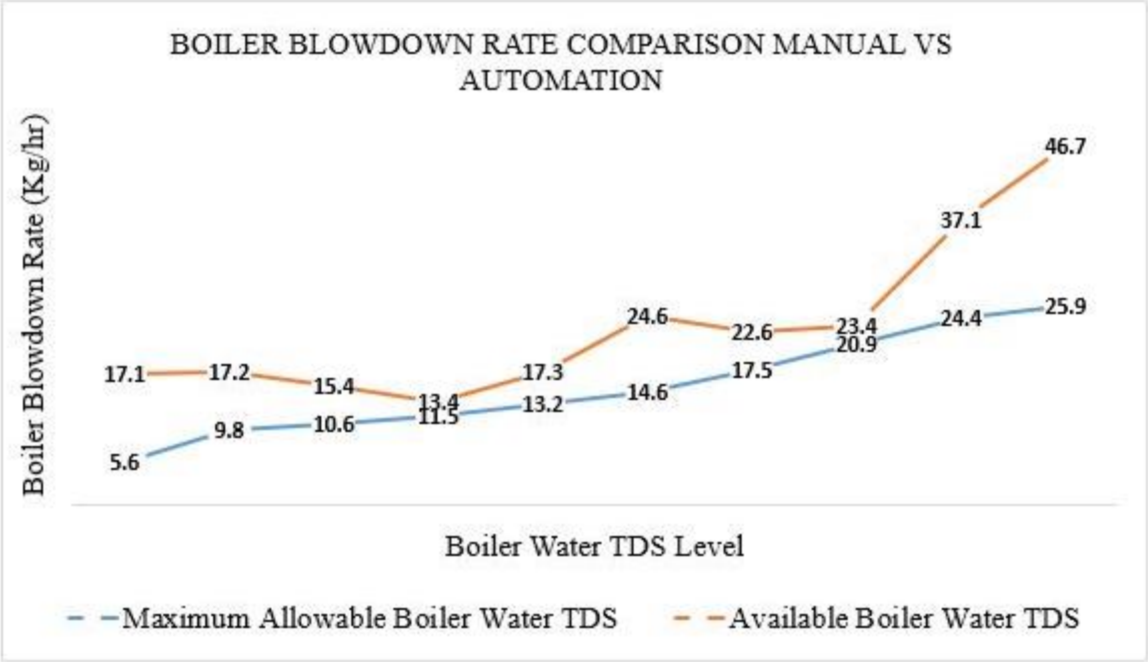


Figure 31: Boiler Blowdown Rate Comparison

By comparison of Figure 31 graph it’s clear that Boiler blowdown rate optimum with automatic blowdown system that lead to considerable amount of energy savings in Boiler blowdown operation.

CHAPTER 4

MATHEMATICAL MODELING BOILER BLOWDOWN SYSTEM

The Mathematical model of the Boiler Blowdown System is described in this section where two main equation has been obtained. Both equations consider as state variables and obtain using mass and energy balance of the boiler system.

The Following Assumptions are made this Model:

The heat exchange surface between vapor and liquid planar

The water in both phases (liquid and vapor) at the drum is at the saturated conditions

Steam out is constant and Steady State

4.1 Description of the System Model of Boiler Blowdown

The Figure 32 is illustrated mathematical modeling of Boiler operation and detailed abbreviated functions are mentioned here.

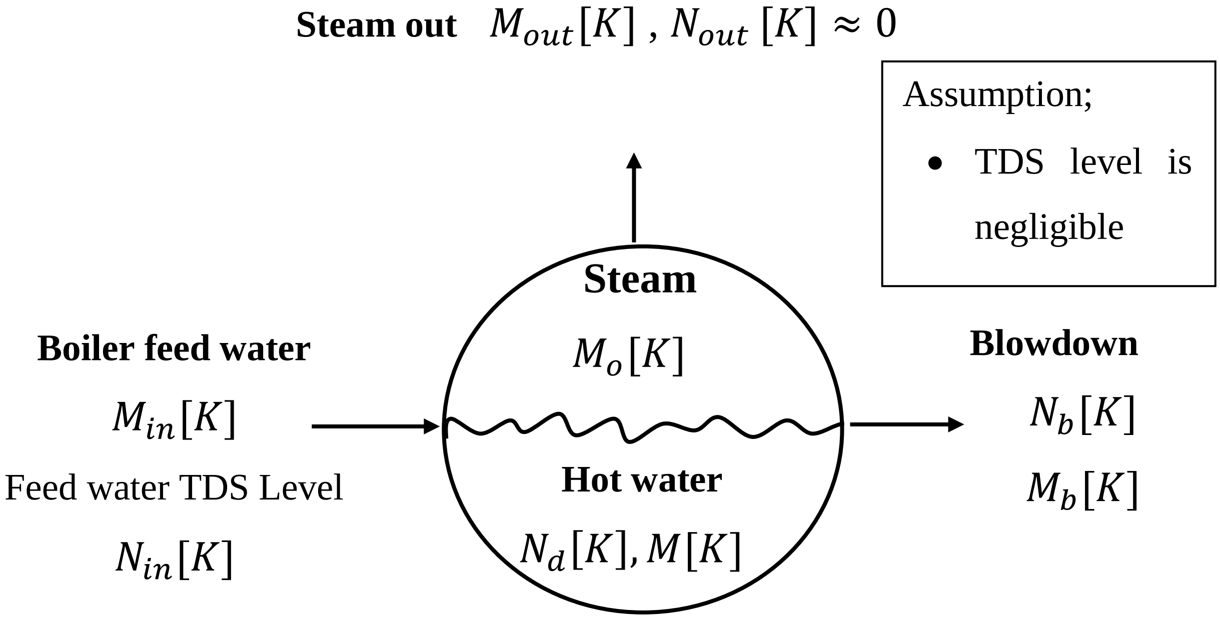


Figure 32: Mathematical Model of Boiler Operation

Feed water mass	$M_{in}[K]$
Boiler Feed water TSD Level	$N_{in}[K]$
Boiler inside mass	$M[K]$
Boiler inside steam mass	$M_o[K]$
Boiler inside TSD Level	$N_d[K]$
Boiler steam out mass	$M_{out}[K]$
Boiler Blowdown mass	$M_b[K]$
Boiler Blowdown TDS Level	$N_b[K]$

The Energy balance Equation can be written with state variables as follows

$$N_d[K] = N_d[K-1] + M_{in}[K]N_{in}[K] - uM_b[K]N_b[K]$$

Based on Energy Balance the Equitation can be simplified as

$$N_d[K] = N_d[K-1] + M_{in}[K]N_{in}[K] - uM_b[K]N_b[K] \quad \longleftarrow \quad (1)$$

$$M[K] = M[K-1] + M_{in}[K] - uM_b[K] - M_{out}[K]$$

$$E[M_{in}[K]] = E[M_{out}[K]]$$

$$y[K] = \frac{N[K]}{M[K]}$$

During Blowdown the Blowdown valve open and close will take place

$$u = \begin{matrix} 1-ON \\ 0-OFF \end{matrix}$$

$$M[K] = M[K-1] + M_{in}[K] - uM_b[K] - M_{out}[K]$$

Here u is open and close variable

So, control Low is

$$y[K] > y_t \; then \; u = 1$$

$$y[K] < y_t \; then \; u = 0$$

u is the input variable is 1(ON) when blowdown occurs otherwise 0 (OFF)

$0 < M[K] < M_0$ $\longrightarrow$ Assumption

$$\omega = \begin{matrix} 1: M[K] < M_0 \\ 0: M[K] > M_0 \end{matrix}$$

ω is input variable that disable the input feed water tank is full

$$\omega = 0 \, , otherwise \; \omega = 1$$

$$M[K] = M[K-1] + \omega M_{in}[K] - uM_b[K] - M_{out}[K] \quad \longleftarrow \quad (2)$$

$$N_d[K] = N_d[K-1] + \omega M_{in}[K]N_{in}[K] - uM_b[K]N_b[K] \quad \longleftarrow \quad (3)$$

$$E[M_{in}[K]] = E[M_{out}[K]]$$

Standard General Blowdown Formula is ;

$$M_b[\mathrm{K}] = \frac{(\text{Steam consumption})(\text{TDS in feed water})}{(\text{Max allowed TDS}) - (\text{TDS in feed water})}$$

$$M_b[\mathrm{K}] = \frac{M_{out}[\mathrm{K}]N_{in}[\mathrm{K}]}{3500 - N_{in}[\mathrm{K}]} \quad \longleftarrow \quad (4)$$

$$Blowdown\ rate = \frac{M_{out}[\mathrm{K}]N_{in}[\mathrm{K}]}{3500 - N_{in}[\mathrm{K}]} * 100$$

$$M_{out}[\mathrm{K}] = \mathrm{C}\ ; (\text{constant})$$

$$M_{in}[\mathrm{K}] \sim \mathrm{x}$$

$$\mathrm{E[x] = C}$$

The analysis done further with equation (3) of the Boiler model as derived above

$$N_d[K] = N_d[K-1] + \omega M_{in}[K]N_{in}[K] - uM_b[K]N_b[K]$$

$$N_d[K] - N_d[K-1] = \omega M_{in}[K]N_{in}[K] - uM_b[K]N_b[K]$$

In this as we are not considering the controlling of the feed water pump valve "$\boldsymbol{\omega}$"

$$\omega M_{in}[K]N_{in}[K] = 0$$

But to model a dynamic system feed water TDS level is added to the system simultaneously ($\boldsymbol{N_{in}}$)

And a constant value is added to the system as the boiler inside TDS level at the starting point of the system. ($N[K-1]$)

$$N_d[K] - N_d[K-1] = -uM_b[K]N_b[K]$$

[u - valve state (0 or 1), $N_b -$ blow down TDS level]

$$\frac{d(N_d[K])}{dt} = \quad -u\ \frac{d(M_b[K])}{dt} N_b[K]$$

Rate of change of TDS level Inside the boiler

Blow down rate

Adding the constant N(k-1) to get the

$$\frac{d(N_d[K])}{dt} \qquad = \ -u\,\frac{d(Mb[k])}{dt}\mathrm{N_b[k]}$$

$$N[K-1] - N_d[K] \ = \text{TDS level}$$

In practical scenario $N_d[K]$value is almost equal to $N_b[K]$. so in the control model the $N_b[K]$ value is updated with the relevant $N_d[K]$ value.

$$N_d[K] = \ N_b[K]$$

So in this process even though we does not require the feed water valve control to make the system dynamic we add the TDS (N_{in}) to the system whenever the Blow down valve is turned off.

$$u\begin{cases} 1: \ \ blow\ down\ valve\ is\ on \\ 0: blow\ down\ valve\ is\ off \end{cases}$$

Inputs require for the Simulink Modeling are;

Boiler Blowdown TDS Level	$N_b[K]$
Boiler Blowdown Rate	$\frac{d(M_b[K])}{dt}$
Boiler Feed water TDS Level	$N_{in}[K]$
Boiler inside mess TDS level (This value is required only in the start of the process)	N [K-1]
Blowdown Valve	u

The develop Modeling of Simulink is given below in Figure 33 and Figure 34 that Derivative Model of the Controller respectively.

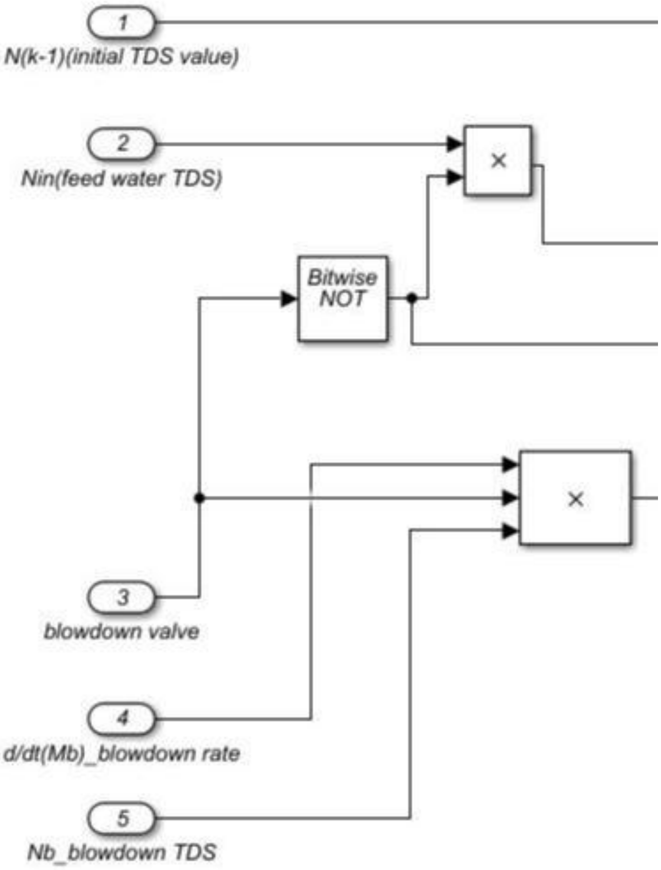


Figure 33: Inputs details of derivative Simulink Block

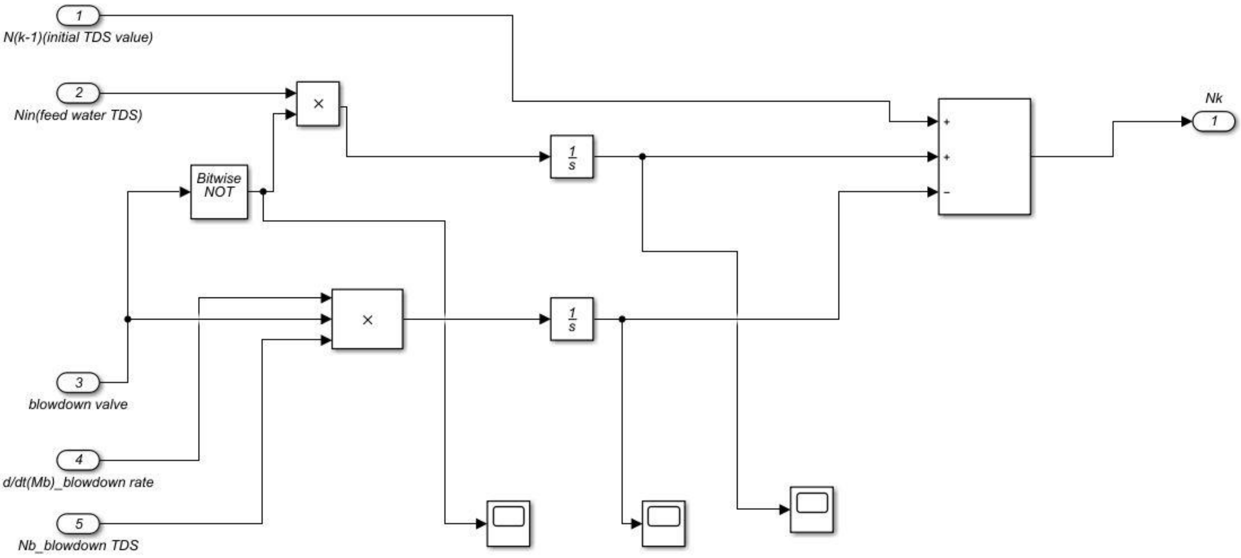


Figure 34: Derivative Simulink Model of the Controller

The Figure 34 describes Simulink Modeling of the Mathematical model which is done for the blow down process sub system. In this model the simulation is only carried out for the controlling of the blow down valve. Because in this scenario the controlling of the boiler feed water valve and the controlling of the blow down valve is identified as to independent processes.

CHAPTER 5

MATLAB SIMULINK MODELING AND SIMULATION OF THE BOILER BLOWDOWN SYSTEM

This chapter explains Simulink Modeling and Simulation of the Boiler Blowdown implement control schemes proposed in Chapter 4 Mathematical Model.

5.1. Simulation and Modeling of the Boiler Blowdown Process

The Boiler Blowdown is carried out to control the Total Dissolved Solids (TDS) level inside the boiler water. In this model we have set the range for 3400 and 3300. We have selected these two values by considering the most optimum value of TDS as 3400. (3400 ± 100) to varying Boiler inside TDS level keep within this band that blowdown valve open at TDS level reach to the value of 3400 ppm and open the valve till drop the TDS level to TDS value of 3300 ppm then close the blowdown valve, because recommended maximum allowable TDS level inside the Boiler is 3500 ppm. If we set the valve open at TDS level 3500 ppm it may overshoot due to sensor signal and valve activation delay. The Figure 38 describes Simulink Modeling which is done for the blowdown process. In this model the simulation is only carried out for the controlling of the blowdown valve in set point. Because in this scenario the controlling of the feed water and the controlling of the blowdown is identified as independent processes each other. The Figure 35 is illustrated part of the Simulink Model enlarge version for easy reference and Figure 36 is shown complete Model Block.

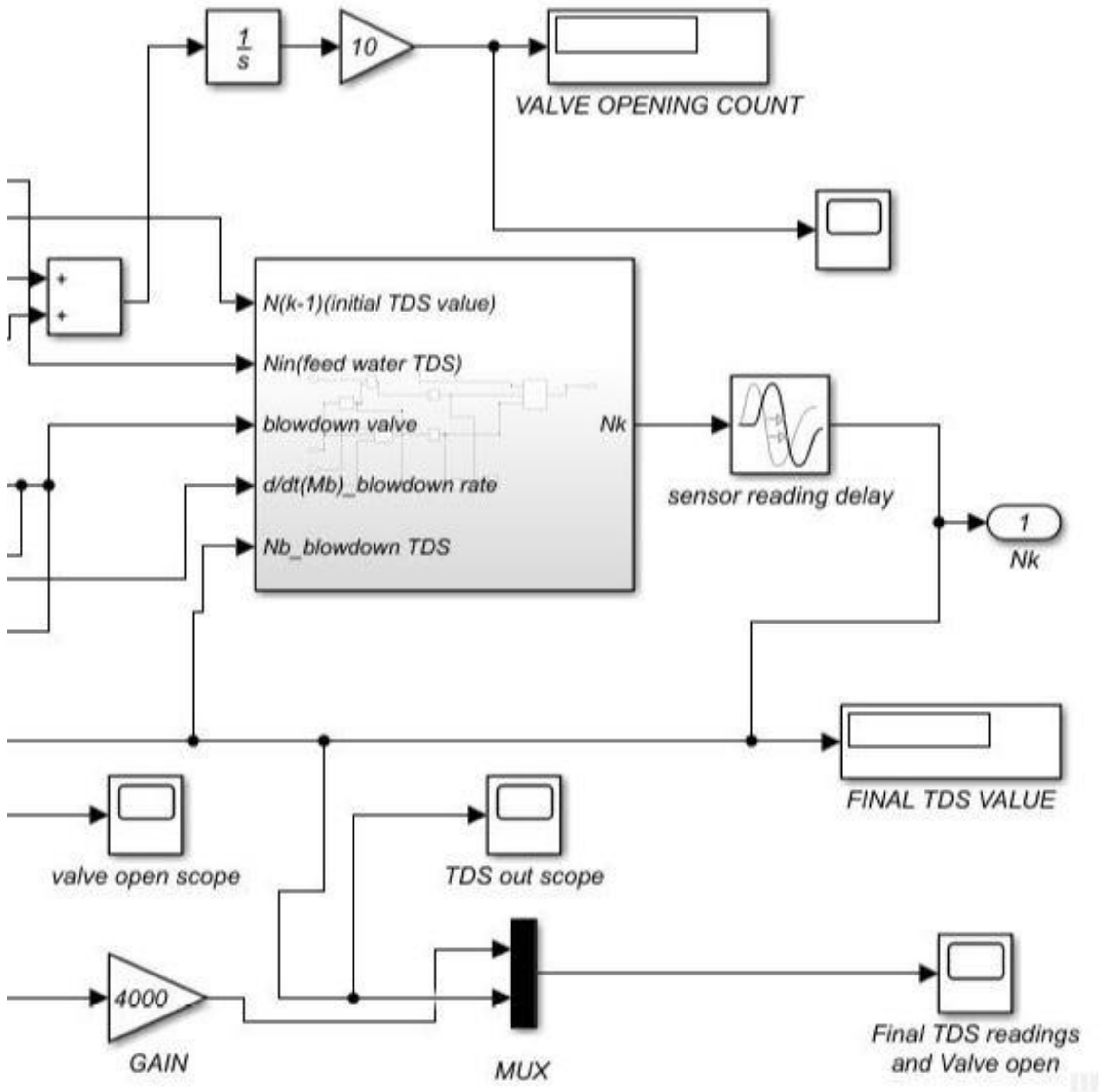


Figure 35: Part of the enlarge Simulink Model Block

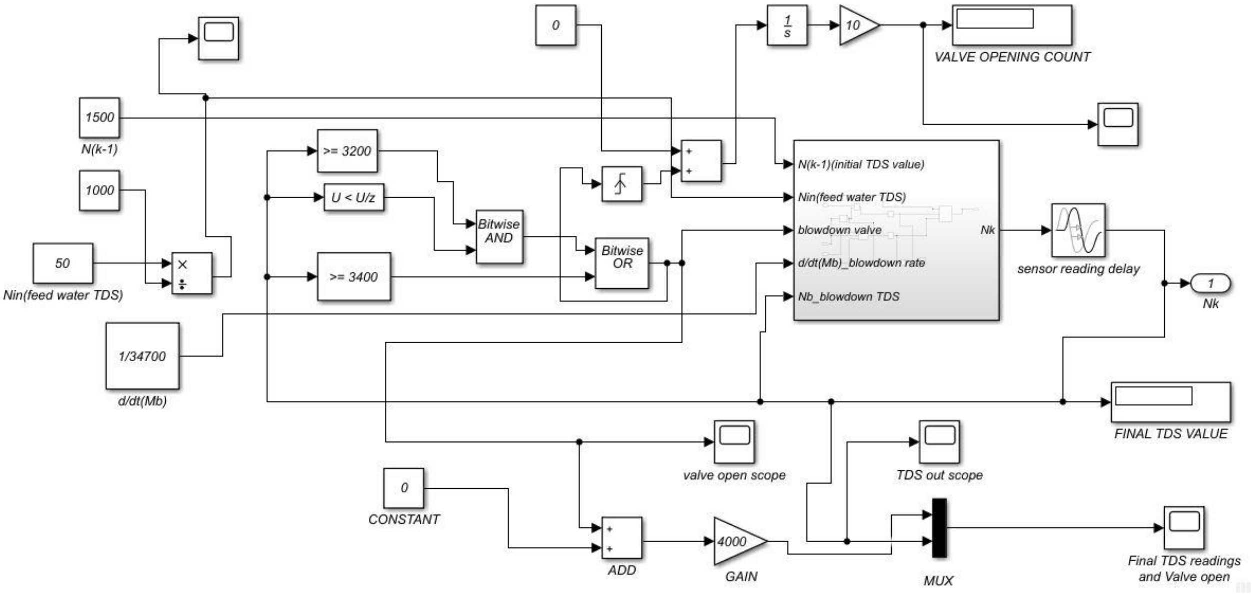


Figure 36: Boiler Blowdown Controller Simulink Simulation Model

The TDS sensor reading and blowdown valve open close simulation is given in Figure 37 with simulation time of 150000 second shown below figure.

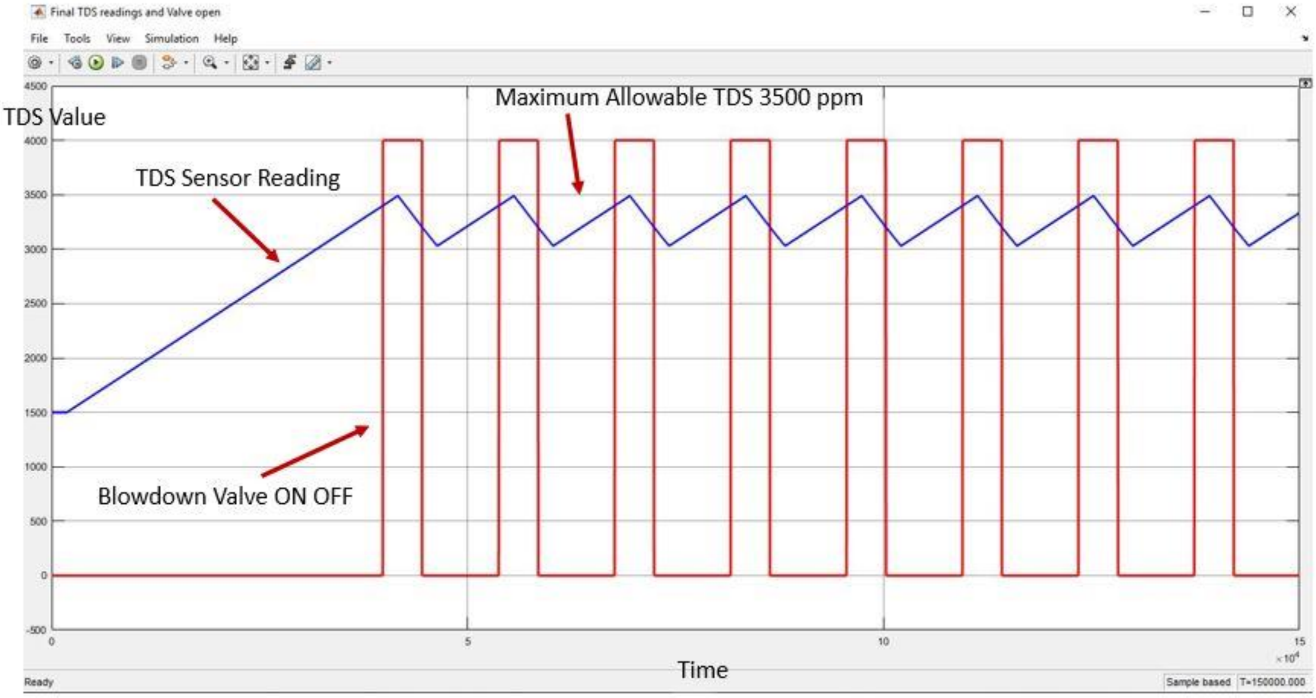


Figure 37: Blowdown Valve Open/Close Based on TDS reading set point Simulation

5.2. Modeling and Simulation TDS Sensor Noise and Disturbance Environment

In practical situation sensor would be add noise or other pickup disturbances and sensor reading will get erroneous detection ,this would lead to open the valve unnecessarily. This has to be avoided to provide proper function of the developed Boiler blowdown system. First, we see by injecting noise signal to the Modeling Block and how Simulation effects.

The Figure 38 shows that noise added simulation block.

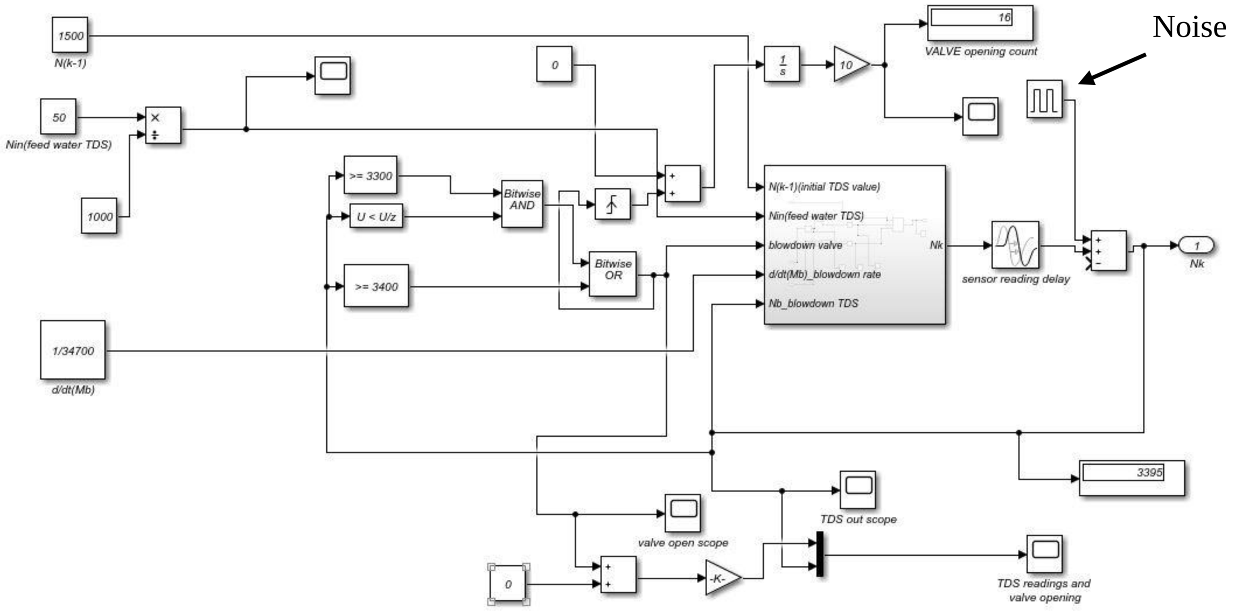


Figure 38: Noise add Simulation Block

The Simulation Output is shown in Figure 39

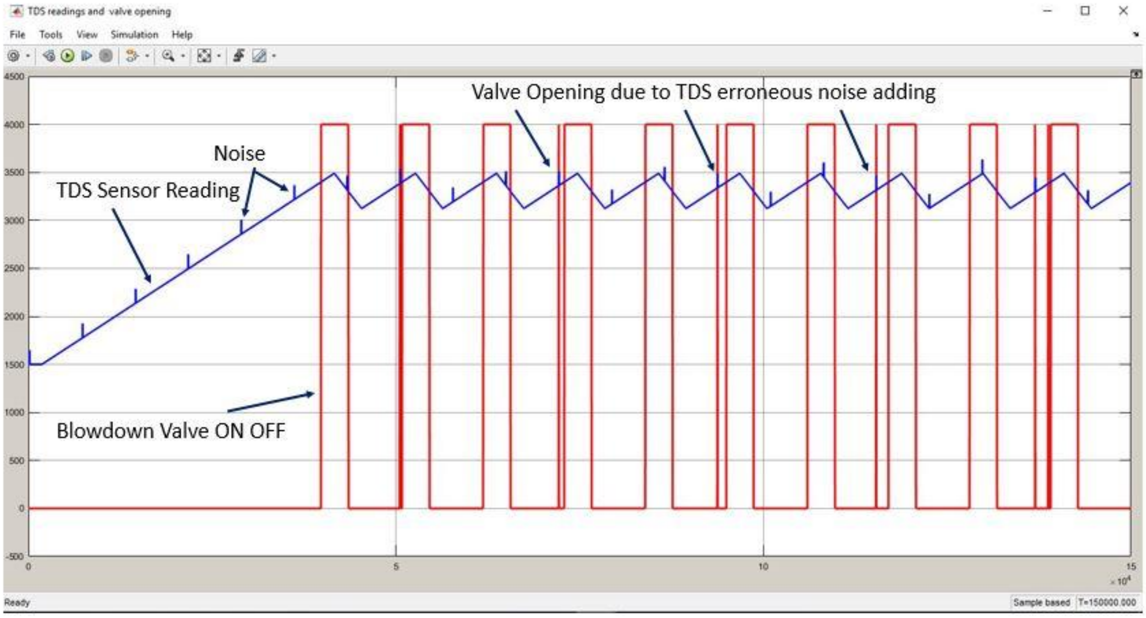


Figure 39: TDS Noise Simulation Output

5.3 Modeling and Simulation Removal of Noise of TDS Sensor

The following steps explain Modeling of Control system that removal of unwanted spike signals that can be add to the TDS sensor signal to operate valve unnecessarily.

The Figure 40 is illustrated that sensor output signal feds through a “Derivative Block” then that spike output (noise) gives fluctuating a constant value elsewhere. Then that Derivative Block output go through an “Interval Test Block” in order to identify the time internal where the spike exists. If there is a spike output gives zero else gives one.

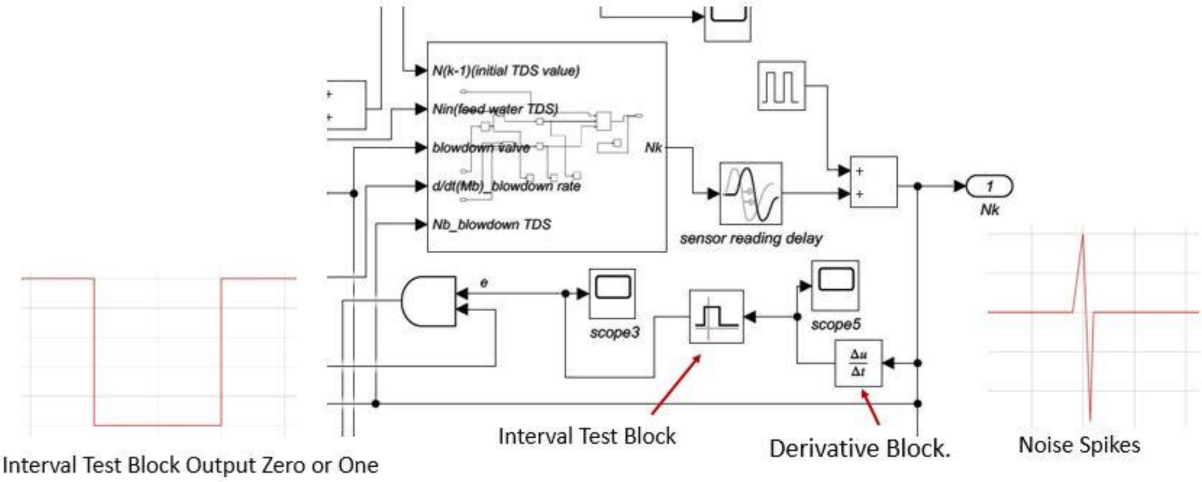


Figure 40 Modeling and Simulation of Noise Identification

The Figure 41 is illustrated that output from the range detection block of TDS sensor reading takes “ u” and output from error detection block takes as “e” and feds through an AND gate.

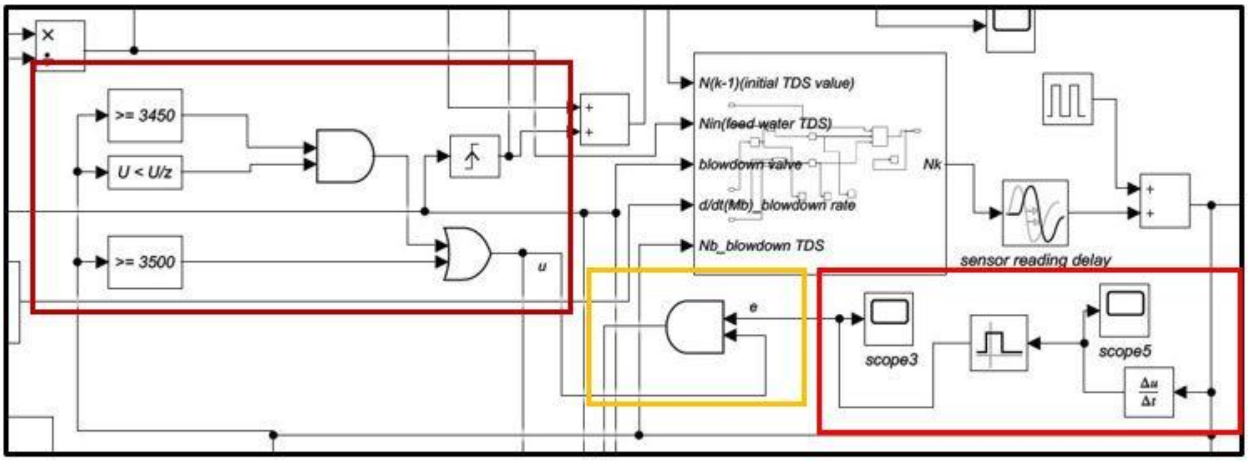


Figure 41 Error Detection Using AND Block

The output of the AND block is shown in Table 12

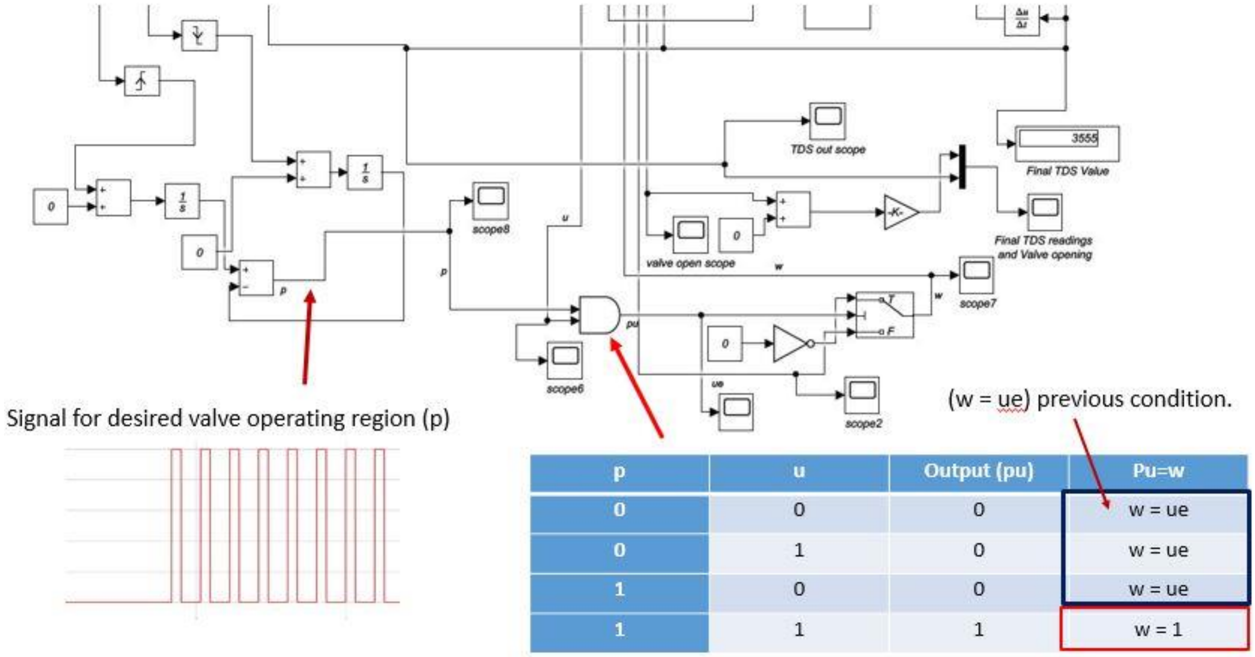
TDS Sensor Reading (u)	Error Noise Reading (e)	AND Gate Output (ue)
0	0	0
0	1	0
1	0	0
1	1	1

Table 12: AND Gate Boolean Output Based on Sensor and Noise Reading

Above Table clearly shows that AND gate output response when output is one condition that’s means our control law is when valve is opened that *u* is one else zero thereby we can remove unwanted spikes generating in the system if TDS not in the desired limits as defines in the TDS range detection block.

The error signal happen when blowdown valve is open and closing time that would be continued open the valve unnecessarily so that strategy can be removed following steps in the modeling block of simulation.

If the error occurs prior to the desired valve opening region the pervious corrective action is prevailed. If the error occurs during the desired valve opening region valve signal sets to 1 (w = 1) This signal goes to AND gate and AND gate output will satisfied w = 1 condition valve opening and closing takes place as illustrated in Figure 42.



Signal for desired valve operating region (p)

(w = ue) previous condition.

p	u	Output (pu)	Pu=w
0	0	0	w = ue
0	1	0	w = ue
1	0	0	w = ue
1	1	1	w = 1

Figure 42: Valve Opening Error Signal Removal

The complete simulation modeling block is illustrated in Figure 43 given below.

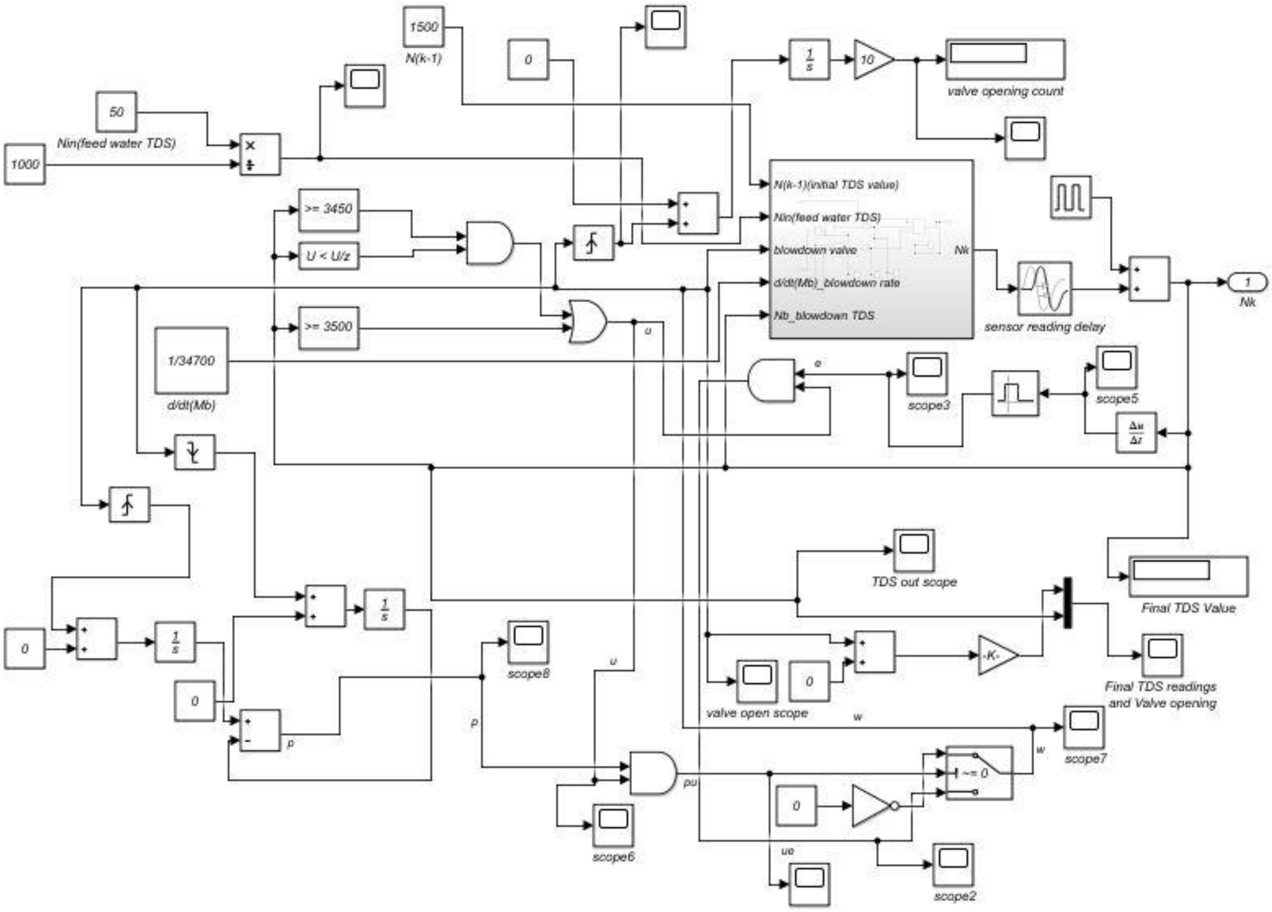


Figure 43 Noise Solution Modeling Block of Simulation

The Simulation output is illustrated in Figure 44 below.

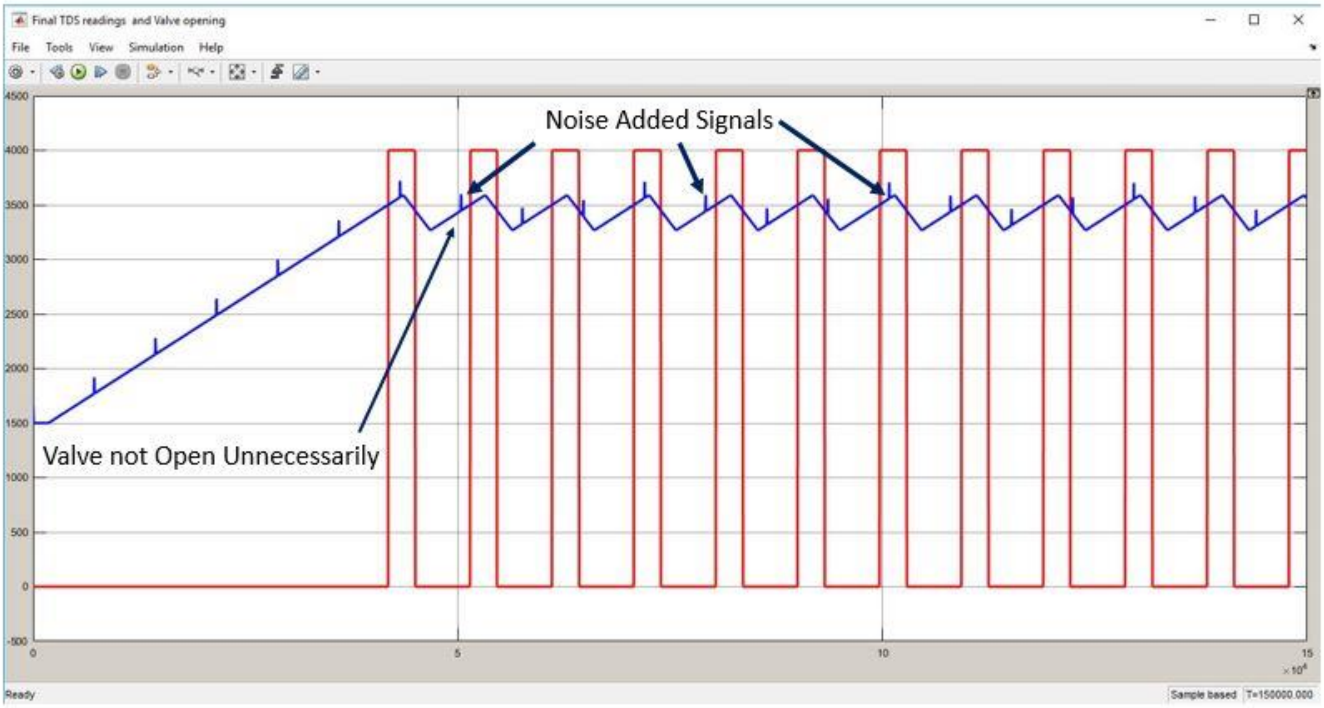


Figure 44 Simulation Output of Valve Opening and Close Blowdown

5.4 Real Data Simulation Develop Simulink Model

Before implementing hardware with PLC based controlling system that field trial was done using real data captured from one of the MAS Company Boiler house at Biyagama BOI zone. They have installed continuous online monitoring of all boiler parameters automated system of Effimax 500 manufactured by Forbes Marshall in India. Figure 45 is shown that automatic blowdown system and Supervisory Control And Data Acquisition (SCADA) system display of the plant at Biyagama BOI zone.

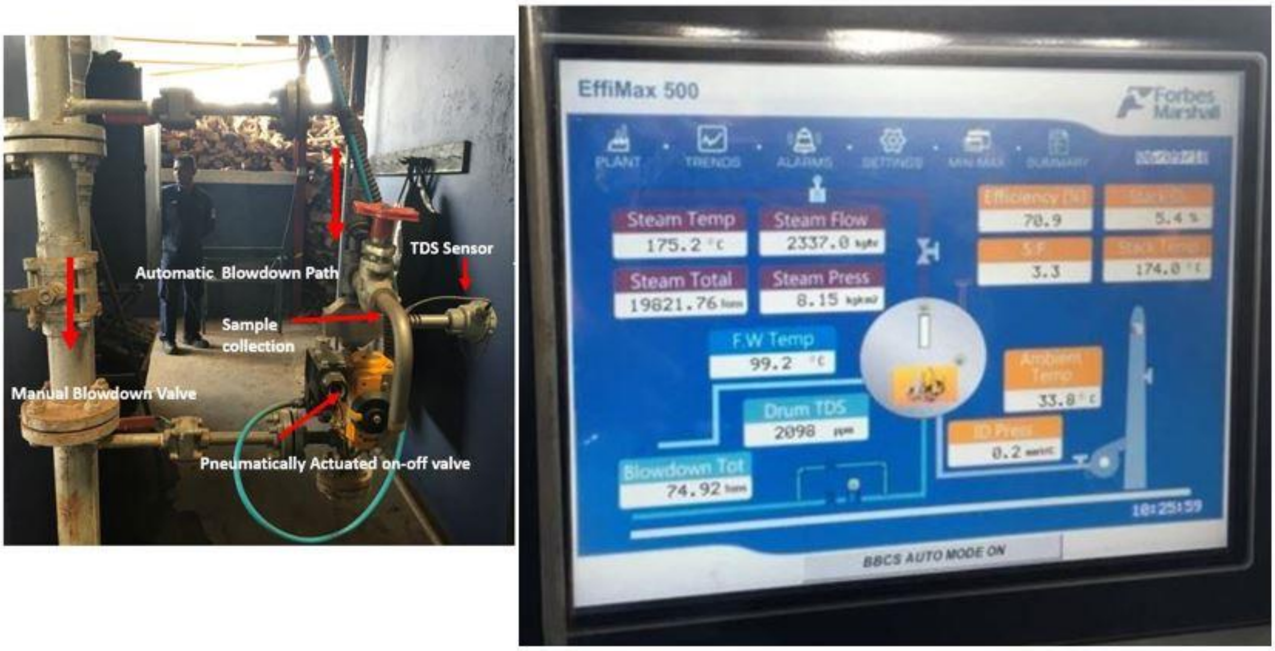
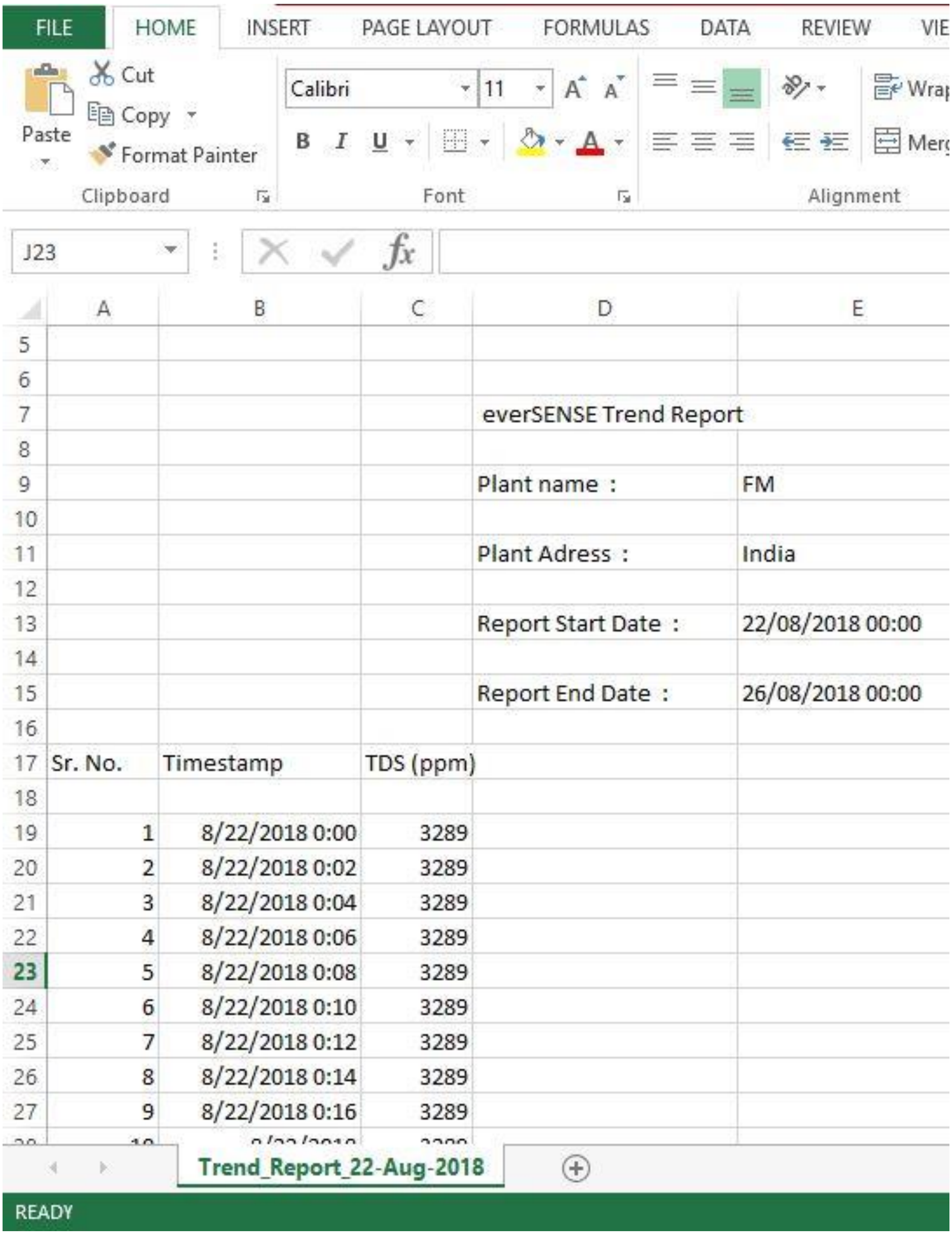


Figure 45: Automatic Blowdown and SCADA System at MAS Biyagama Plant

The system TDS data was obtained from the Boiler operating on 22 August 2018 in excel format to the pen drive that extracted data is shown in Figure 46.

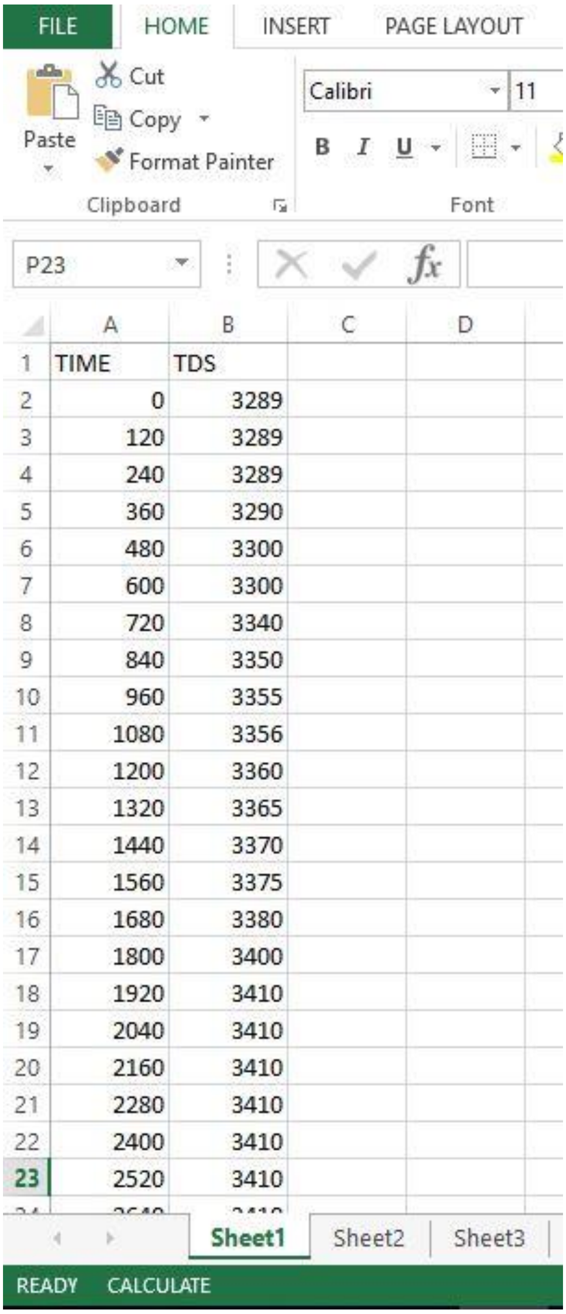


	A	B	C	D	E
5					
6					
7				everSENSE Trend Report	
8					
9				Plant name :	FM
10					
11				Plant Adress :	India
12					
13				Report Start Date :	22/08/2018 00:00
14					
15				Report End Date :	26/08/2018 00:00
16					
17	Sr. No.	Timestamp	TDS (ppm)		
18					
19	1	8/22/2018 0:00	3289		
20	2	8/22/2018 0:02	3289		
21	3	8/22/2018 0:04	3289		
22	4	8/22/2018 0:06	3289		
23	5	8/22/2018 0:08	3289		
24	6	8/22/2018 0:10	3289		
25	7	8/22/2018 0:12	3289		
26	8	8/22/2018 0:14	3289		
27	9	8/22/2018 0:16	3289		

Figure 46: TDS Sensor Reading Trend Report Taken form the Plant

The data of TDS sensor reading recorded in this system every two seconds , then simulation lookup table is prepared taking time interval 120 second time gaps of TDS sensor reading to insert data to the develop Simulink Model for this research work.

The Figure 47 is shown lookup table data for the Simulink model and this data is attached in **Appendix B.**



TIME	TDS
0	3289
120	3289
240	3289
360	3290
480	3300
600	3300
720	3340
840	3350
960	3355
1080	3356
1200	3360
1320	3365
1440	3370
1560	3375
1680	3380
1800	3400
1920	3410
2040	3410
2160	3410
2280	3410
2400	3410
2520	3410

Figure 47: TDS Sensor Reading Lookup Table

The above Lookup Table data is shown in Figure 48 to compare the simulated output.

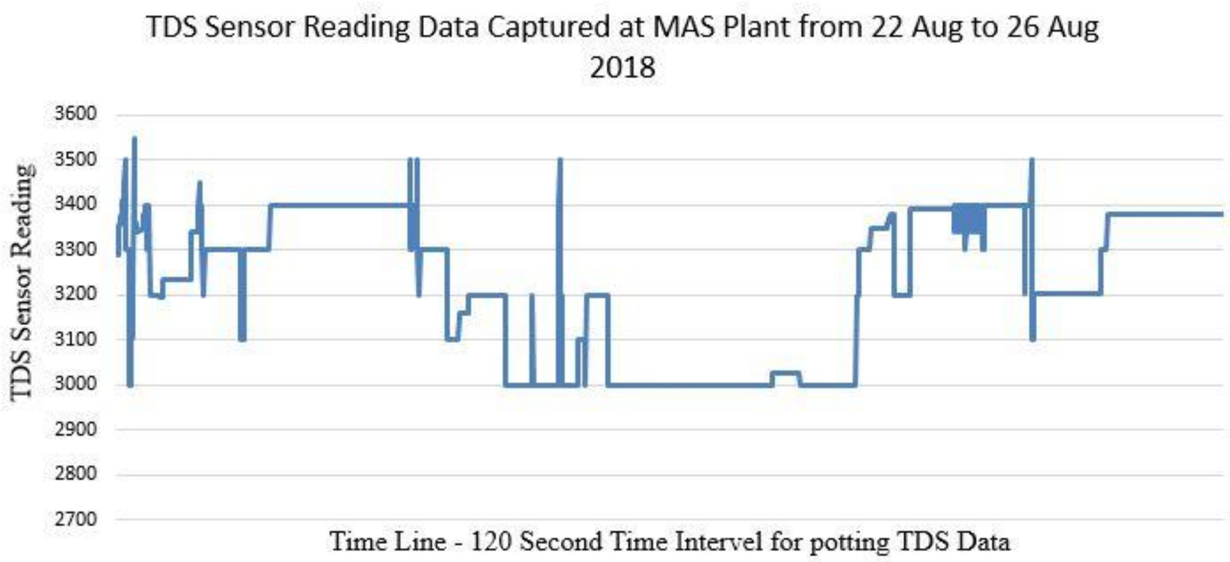


Figure 48: Boiler Water TDS Reading Graph Collected Data

The TDS captured data Simulink Model is shown in Figure 49.

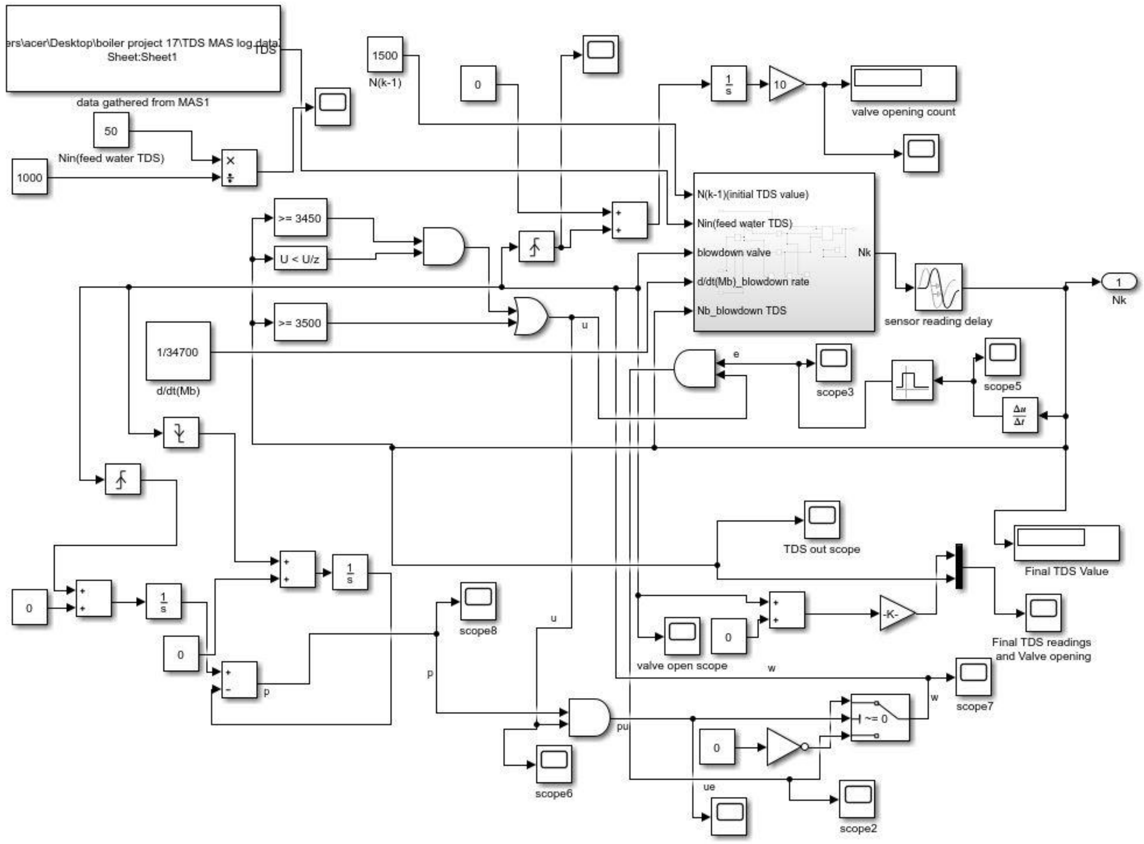


Figure 49: Simulink Modeling of Captured TDS Data

The Simulation results of TDS sensor reading data extract from above Figure 49 that output of display graph is shown in Figure 50 below.

Figure 50: TDS Sensor Reading and Valve Open / Close Display Graph

Following graph it is clear that when compares with Excel graph sensor TDS data and simulated output for validation of developed Simulink Model for the System is shown in Figure 51.

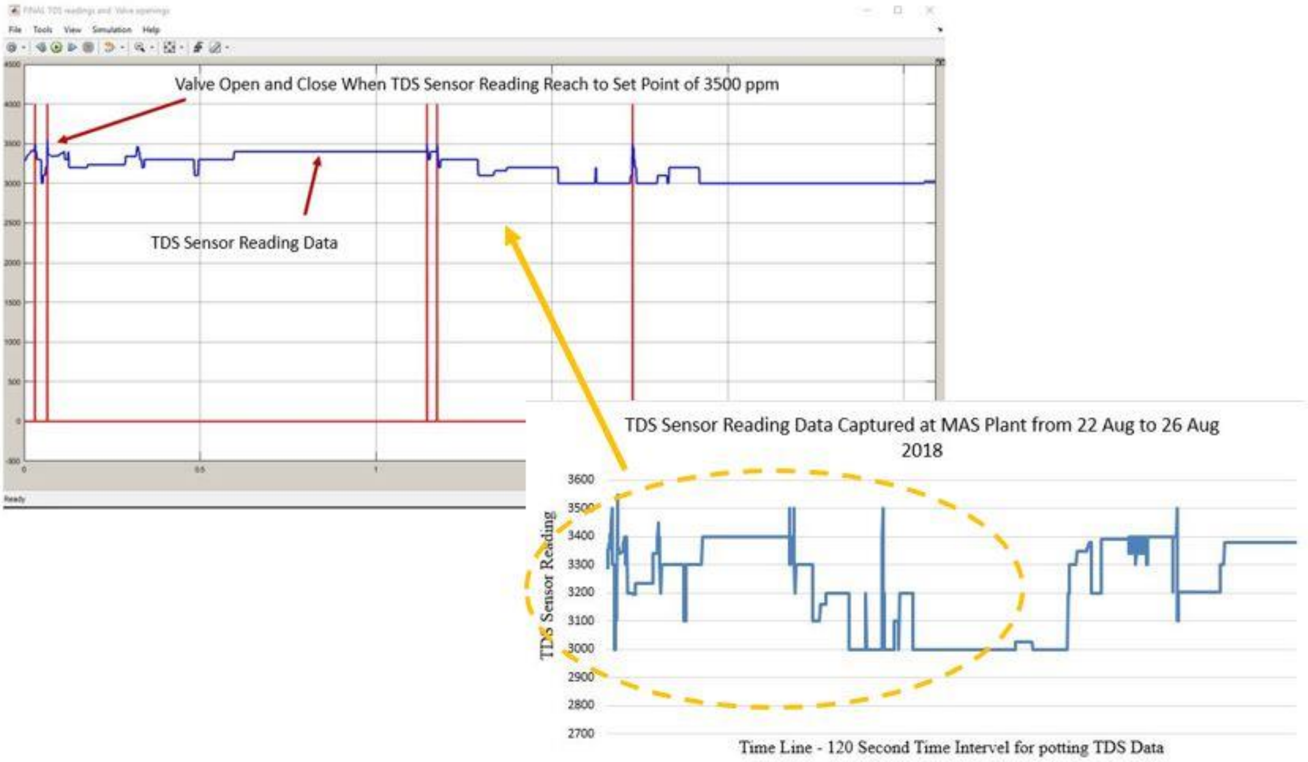


Figure 51: Data Comparison Graph

CHAPTER 6
HARDWARE SELECTION AND CONTROL DESIGN

This chapter discusses on proper TDS measuring sensor selection for this research project work and outlook on proposed heuristic control scheme.

6.1 TDS Sensor Characteristics and Selection

Before discussed TDS Sensor Characteristics and Suitable Sensor selection of this application, theoretical back ground of controlling TDS in Boiler water and measurement of TDS in Boiler water.

6.1.1 Controlling Total Dissolved Solids (TDS) in Boiler Water

As a steam generates steam, any impurities which are in the Boiler feed water and which do not boil off with the steam will concentrate in the Boiler water [13]. As the dissolved solids become more and more concentrated, the steam bubbles tend to become more stable [13]. There comes a point (depending on Boiler pressure, size, and steam load) where a substantial part of the steam space in the Boiler becomes filled with bubbles and foam is carried over into the steam main [13]. Careful control of Boiler water TDS together with attention to these other factors should ensure that the risks of foaming and carryover are minimized [13].

6.1.2 Boiler Water Sampling

The Boiler water TDS may be measured either by; taking a sample and determine the TDS external to the Boiler, or by a sensor inside the Boiler providing a signal to external monitor [13]. The manual Boiler blowdown line, possible to obtain a representative sample from this location [13].

6.1.3 Conductivity Method

The electrical conductivity of water also depends on the type and amount of dissolved solids contained [13]. Measured conductivity is typically measured in milliSiemens (mS) or microSiemens (µS) [12]. When using a contacting conductivity sensor, conductivity cell geometry affects the conductivity reading [12]. In order to ensure standardization of electrical conductivity measurements, units of specific conductivity are used [12]. Specific conductivity is expressed as milliSiemens per centimeter (mS/cm) or microSiemens per centimeter (µS/cm) [12]. The TDS in ppm is approximately as shown in equation [13] below.

TDS (ppm) = (Conductivity in µS/cm) x 0.7 [13]

This relationship is only valid for sample at 25 °C [13]

6.1.4 Conductivity Measurement in the Boiler

It is necessary to measure the conductivity of the boiler water inside the boiler or in the blowdown line [13]. An increase in temperature results in an increase in electrical conductivity [13]. For Boiler water , the conductivity increases at the rate of approximately 2% (of the value at 25°C) for every 1°C increases in temperature [13].A conductivity sensor is used to measure the concentration of TDS in Boiler water. Usually there is a roughly linear relationship between conductivity and the concentration of irons in a solution, at least until very grate ion concentration are attained [11]. Conductivity depends on both ion concentration and ion mobility [11]. A mobility generally increases with temperature, conductivity measurements are temperature dependent [11], increase in temperature [11]. The measured conductivity can be temperature compensated with an equation of the following form [13]:

$$\boldsymbol{\sigma(T) = \sigma(T_o) \{ 1 + \alpha (T - T_o)\}} \qquad [13]$$

Where,
σ (T) is the measured conductivity at any temperature T (µS/cm) ;
$\sigma(T_o)$ is the conductivity at a reference temperature T_o, usually 25°C;
(T) is the measured temperature and,
α is the temperature coefficient in $°C^{-1}$.

{Typically a value of α =2% $°C^{-1}$ or 0.02 $°C^{-1}$ is often used}.

This means that the effects of the temperature have to be allowed for in the blowdown controller, either by automatic temperature compensation, or by assuming that the boiler pressure (and hence temperature) is constant [13]. The small variations in boiler pressure during load variations have only a relatively small effect, but if accurate TDS readings are required on boilers which are operated at widely varying pressures then automatic temperature compensation is essential [13].

The effect of temperature on increased and consequently this lead to an increase in its conductivity [16]. Therefore it is mandatory to always associate conductivity measurements with a reference temperature, usually 20°C or 25°C [16]. The Automatic Temperature Compensation (ATC), instrument or sensor applies a temperature coefficient of variation to the measured conductivity and reports what conductivity would be at the reference temperature as illustrated in Figure 52 [16].

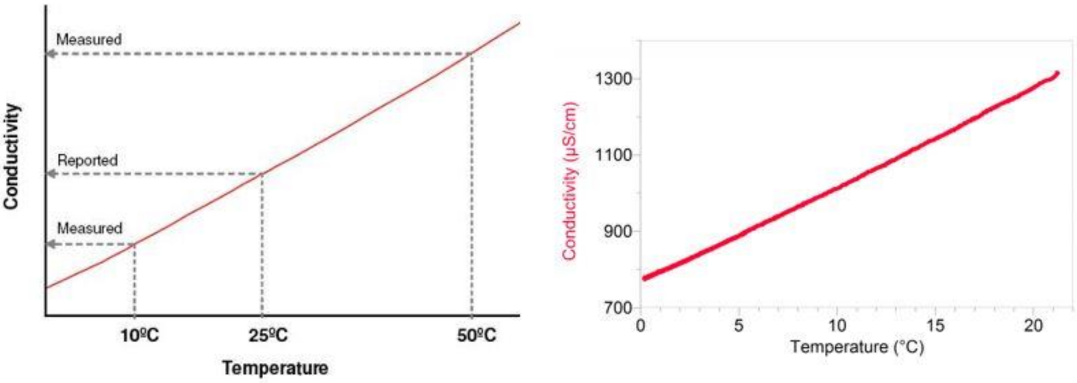


Figure 52: Temperature Compensation uses a Temperature Coefficient of Variation to convert the Conductivity Measured at a Specific Temperature to that at the Reference Temperature (25°C)[16]

This is known as linear temperature compensation and can give a good approximation to the true conductivity when the temperature of the measured solution is close to the reference temperature [16].

6.1.5 Cell Constant

A Probe used to measure the conductivity of a liquid has a ‘Cell Constant’ [13]. The value of this constant depends on the physical layout of the sensor Probe and electrical path through the liquid [13].

Conductivity compensates for variations in conductivity cell geometry by multiplying measured conductivity by a factor called the cell constant [12]. Cell constant (k) is directly proportional to the distance separating the two conductive plates and inversely proportional to their surface area [12].

Measured conductivity [σ (T)] * Cell Constant (k) [12]

For solutions with low conductivities the electrodes can be placed closer together or made larger so that the cell constant is less than one [14]. This has the effect of raising the conductance to produce a value more easily interpreted by the meter [14]. The reverse also applies, in high conductivity solutions, the electrodes are placed farther apart or made smaller to reduce the conductance of the sample [14]. By using the appropriate probe, K=0.1 for low conductivity solutions, K=1 for normal solutions and K=10 for high conductivity solutions, accurate measurements across the full range of conductivity values can be made [14].

Therefore we can be taken sensor reading at any temperature in Boiler water TDS reading with temperature compensated with conductivity measurement and relationship to the reference temperature conductivity based on above theoretically explain formulas.

$\sigma(T) = \sigma(T_o) \{ 1 + \alpha (T - T_o)\}$ extract from para 6.1.4 where $\sigma(T)$ measured conductivity

Measured conductivity [σ (T)] * Cell Constant (k) extract from para 6.1.5

$\sigma(T) = \sigma(T_o) \{ 1 + \alpha (T - T_o)\}$* Cell Constant(k)

$\sigma(T_o) = \sigma(T) / \{ 1 + \alpha (T - T_o)\}$ where $\sigma(T_o)$ reference conductivity at 25°C

TDS (ppm) = (Conductivity)*(Cell constant [k])*(0.7)

The cell constant can be obtained from sensor specifications.

6.1.6 Suitable TDS measuring Sensor Selection

The suitable sensor selection is very critical in the application project. Because that Autonomous Blowdown System totally depend on TDS sensor reading to control blowdown valve open and close to required set point of TDS level in the Boiler.

The sensor conductivity depend on temperature when measuring Boiler water TDS level, if we select temperature around room temperature effect sensor then the sensor has to be cooled to get correct sensor readings and this type of system found when accessing in website is illustrated in Figure 53.

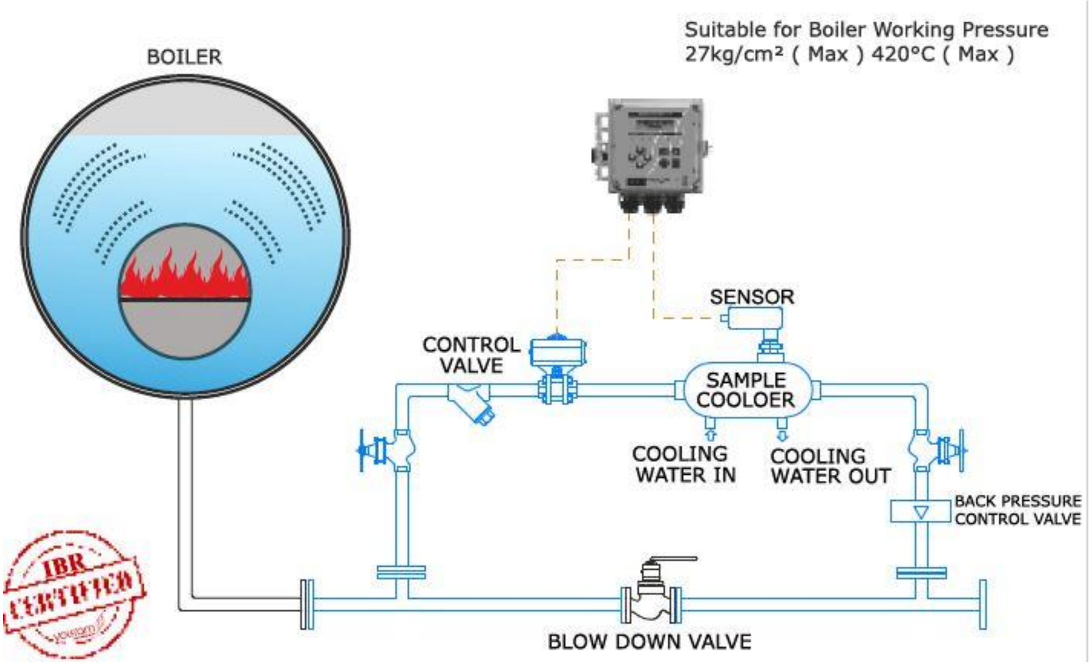


Figure 53: Sensor placing cool position system
Source: www.volfram.in

This type of sensor selection would be created disadvantage that sensor cooling is an additional work to the system. Further the sensor reading conductivity may get error reading if required cooling is not maintained.

Therefore, this type of application requires a sensor that temperature around 100°C to 200 °C because blowdown pipe steam will flow above temperature in the Boiler averagely and automatic temperature compensation conductivity measurements are temperature compensated to ensure the highest accuracy.

The following explains suitable temperature compensated conductivity sensors for Boiler application. The Figure 54 and 56 are illustrated conductivity sensor and conductivity transmitter Figure 55 that could be connected to a PLC for advance control system respectively.

Industrial Contacting Conductivity Sensors

Heavy duty electrodes for boiler applications

Available with ATC for most makes and models of conductivity transmitters or controllers

0.1, 1.0 and 10.0 cell constants available (see details below)

Extended length version for mounting in cross

Sensorex manufactures a quality line of industrial grade conductivity electrodes for submersion or in-line mounting. All electrodes are constructed with stainless steel bodies and pins (316SS) and PEEK insulators. As an added option, automatic temperature compensation is available. Model CS650TC is well suited for ultra-pure water applications while CS675HTTC and CS676HTTC are well suited for boiler applications. All "HTTC" models are supplied with 6" PTFE coated wires for customer convenience.

Figure 54: Conductivity Sensor for Boiler Application
Source: www.sensorex.com

Sensorex

CX3100 INTELLIGENT (HIGH TEMP) CONDUCTIVITY TRANSMITTER

PRODUCT SPECIFICATION SHEET

Monitor Conductivity, TDS, Resistivity or Salinity

Programmable Hi/Hi, Hi/Lo, Lo/Lo Relays

2 analog 4-20mA outputs

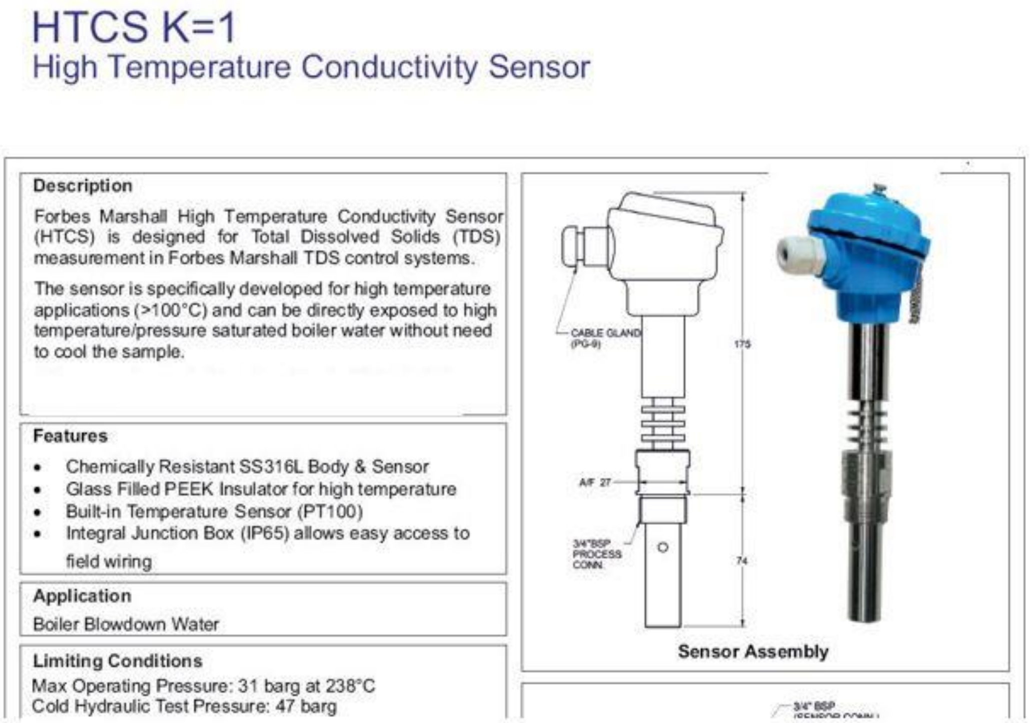
Automatic temperature compensation up to 200°C

User friendly text and graphical illustrations

The CX3100 replaces the Sensorex CX3000 as our conductivity, resistivity, TDS, and salinity monitoring instrument in a ½ DIN size.

This transmitter / controller is ideal for boiler applications, providing accurate temperature compensated readings up to 200°C (the highest of any of our instruments). With PT1000 temperature compensation, the CX3100 is compatible with Sensorex's best in class stainless steel boiler conductivity probes (CS675, CS676, and CS875).

Figure 55: Conductivity Transmitter with analog output connected to a PLC
Source: www.sensorex.com



HTCS K=1
High Temperature Conductivity Sensor

Description

Forbes Marshall High Temperature Conductivity Sensor (HTCS) is designed for Total Dissolved Solids (TDS) measurement in Forbes Marshall TDS control systems.

The sensor is specifically developed for high temperature applications (>100°C) and can be directly exposed to high temperature/pressure saturated boiler water without need to cool the sample.

Features

- Chemically Resistant SS316L Body & Sensor
- Glass Filled PEEK Insulator for high temperature
- Built-in Temperature Sensor (PT100)
- Integral Junction Box (IP65) allows easy access to field wiring

Application

Boiler Blowdown Water

Limiting Conditions

Max Operating Pressure: 31 barg at 238°C
Cold Hydraulic Test Pressure: 47 barg

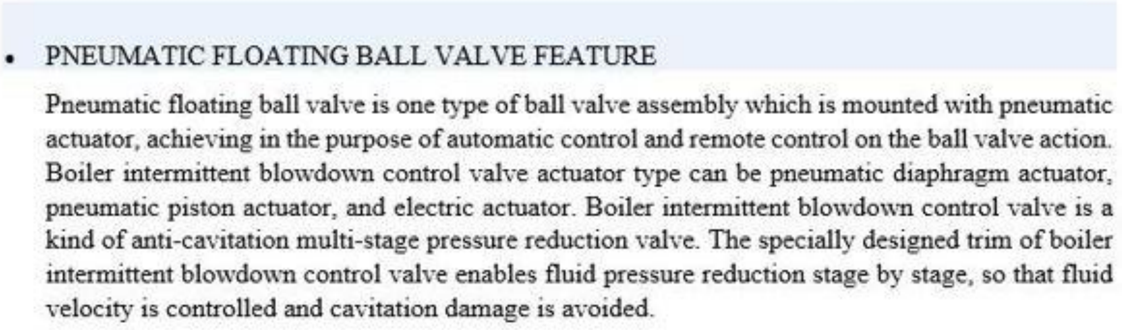
Figure 56: High Temperature Conductivity Sensor
Source: Forbes Marshall Sensor

6.1.7 Suitable Blowdown Valve Selection for the System

The valve has a two different types that electrical actuated valve or pneumatically actuated valve. The Boiler blowdown application is suitable to use pneumatically actuated valve than electrically actuated valve due to following reasons;

The Boiler water during blow down high pressure will release so it is suitable to handle that type of pressure pneumatically actuated valve than electrically actuated valve and valve life cycle and reliability is more this type of application to use pneumatically actuated valve.

The Figure 57 shows market available valve extract from website for the Boiler applications.



- PNEUMATIC FLOATING BALL VALVE FEATURE

Pneumatic floating ball valve is one type of ball valve assembly which is mounted with pneumatic actuator, achieving in the purpose of automatic control and remote control on the ball valve action. Boiler intermittent blowdown control valve actuator type can be pneumatic diaphragm actuator, pneumatic piston actuator, and electric actuator. Boiler intermittent blowdown control valve is a kind of anti-cavitation multi-stage pressure reduction valve. The specially designed trim of boiler intermittent blowdown control valve enables fluid pressure reduction stage by stage, so that fluid velocity is controlled and cavitation damage is avoided.

Figure 57 Boiler Blowdown Valves
Source: www.penumaticballvalve.com

6.2 Proposed Control Scheme

The control system is required to be designed to achieve autonomous open and close of Boiler Blowdown valve. In this design is used Figure 57 shown High Temperature Conductivity Sensor to measure TDS readings and sensor need to be measured reading accurately because this whole autonomous process is purely depend on correct TDS sensor reading to activate the Blowdown valve to function the system.

The proposed controller is a PLC based designed to maintain the steam boiler water TDS level within limits specified by Boiler manufacture. Usually 3500 ppm maximum allowable limits for Boiler capacity of our Boiler.

6.3 Development of Control Architecture

The algorithm for writing Ladder Programmed as follows;

The sensor is used to measure conductance and temperature of water sample collected in sensor chamber to measure Boiler drum TDS level and accuracy of the TDS reading is very important to take control decision autonomously, therefore maintain every 45 minutes water sample at sensor chamber will be refresh opening control valve for a period of 1 seconds using inbuilt timer to maintain correct TDS reading at Boiler drum inside.

The blowdown valve will open based on TDS sensor reading whenever the measured TDS reading reach to exceeding set point of 3500 ppm ,the blowdown valve will open until the TDS reading falls below the set point of 3400 ppm and close the blowdown valve. This is done intermittent rather than continuous using inbuilt timer mentioned in below and this avoids sudden drops of water level in boiler for the safety.

After opening blowdown valve with TDS reading at 3500 ppm and keep open 30seconds using inbuilt timer and close valve. If TDS not reach to below lower set point of 3400 ppm again opens for a 30 seconds periods until TDS level drops to lower set point of 3400 ppm, this steps continuous. If TDS level drops within 30 seconds time period then the blowdown valve will be closed and not wait till 30 seconds to close the valve. This time period would be adjusted to suitable time after analyzing collected data in the future to get optimizing proper times.

CHAPTER 7

SYSTEM DESIGN AND HARDWARE IMPLEMENTATION

This chapter explains designing of a hardware platform to implement control schemes proposed in Chapter 6, para 6.2 and 6.3 respectively. The overall design presents describes in this Chapter.

7.1 Introduction to Design

This section proposes hardware and software approaches to automate Boiler blowdown control system with suitable mechanical and electrical designs. The design is used as platforms to implement the proposed control scheme in Chapter 6. A cost effective Programmable Logic Controller (PLC) is used as main controller to write Ladder Programme for implementing the automatic control algorithm.

7.2 Designing of Control System

The Electrical/Electronics/Mechanical and Control System is designed to facilitate the blowdown in automatic mode is shown in Figure 58. For operation necessary sensor, pneumatic actuated valve and PLC controller are shown.

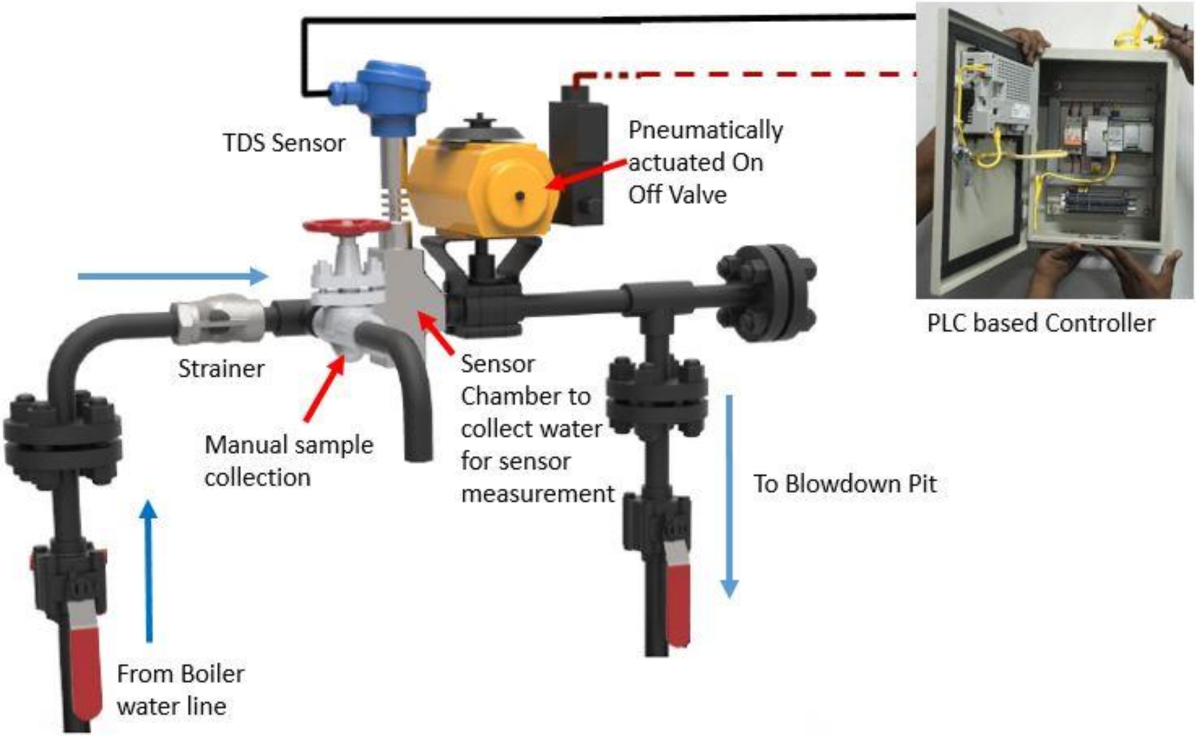


Figure 58: Design Blowdown Automatic Control System

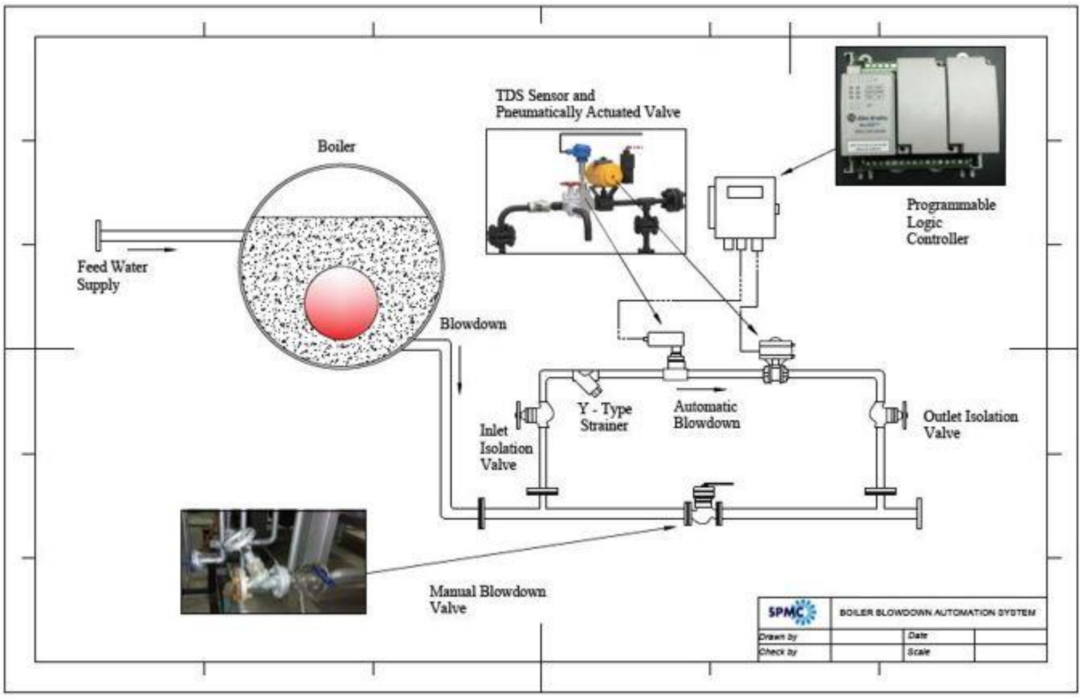


Figure 59: Boiler Blowdown System

A conductivity sensor is used to obtain TDS level online in the Boiler drum by installing sensor as shown in Figure 61 above and take dominant control decisions are presented in Chapter 6. The control system should be able to provide control signals for the described blowdown valve and sensor. A programmable logic controller (PLC) is selected as the main controller by considering required level of operations and the reliability. The selected Allen Bradley Micro 820 Controller should fulfill input and output requirement.

The TDS sensor reading is used to drive blowdown valve to actuate open and close as set point on PLC commands. A Human Machine Interface (HMI) is used to facilitate user access by way of displaying status of the blowdown system as shown in Figure 60.

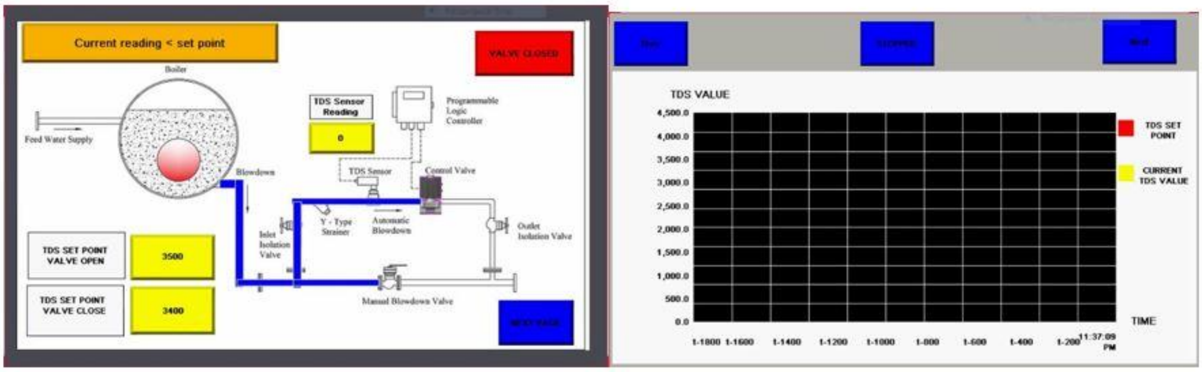


Figure 60: HMI Interface

The Figure 61 and Figure 62 shows wired key components of the proposed system.

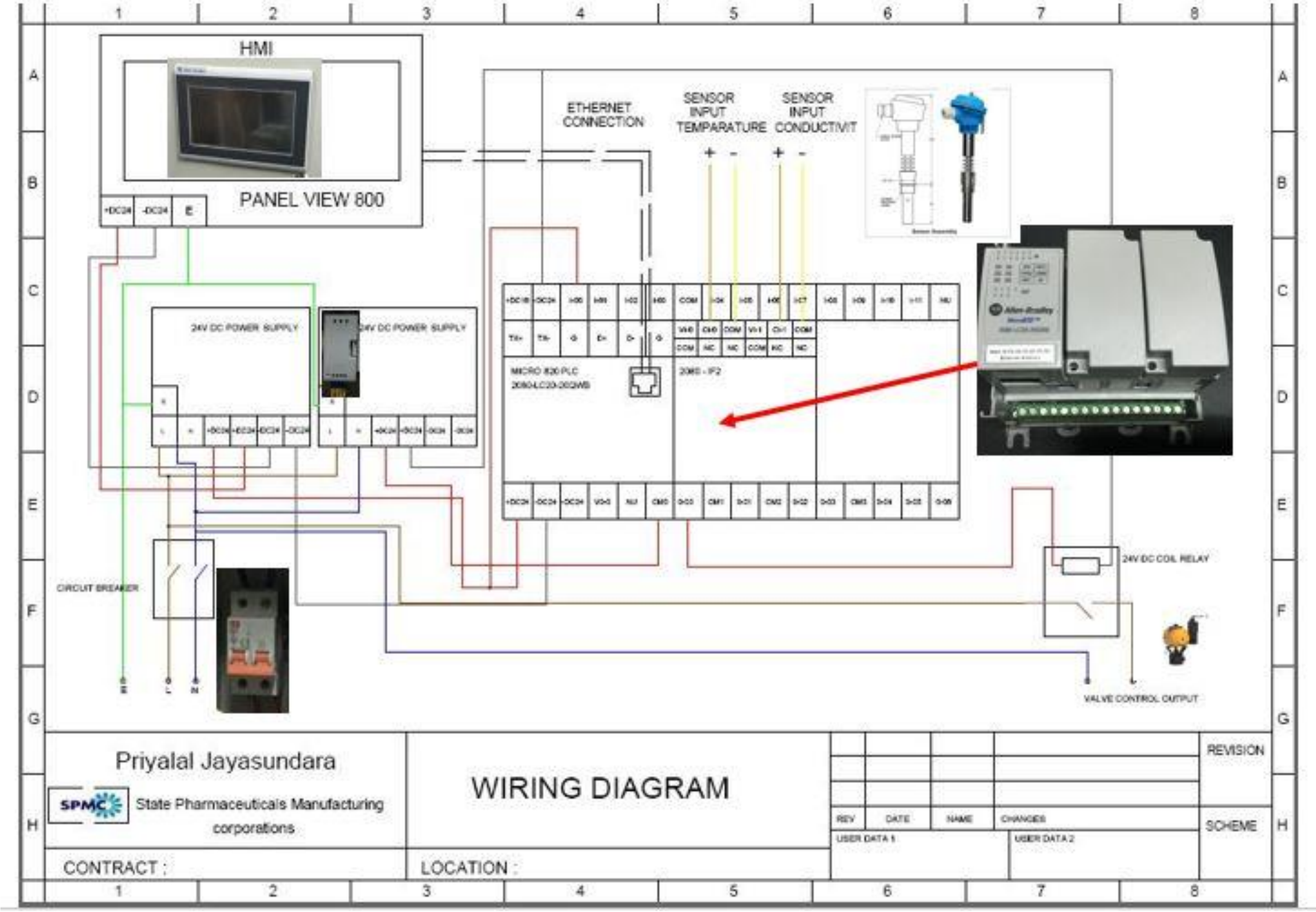


Figure 61: PLC/ Input / Output / Electrical Breaker Component Drawings

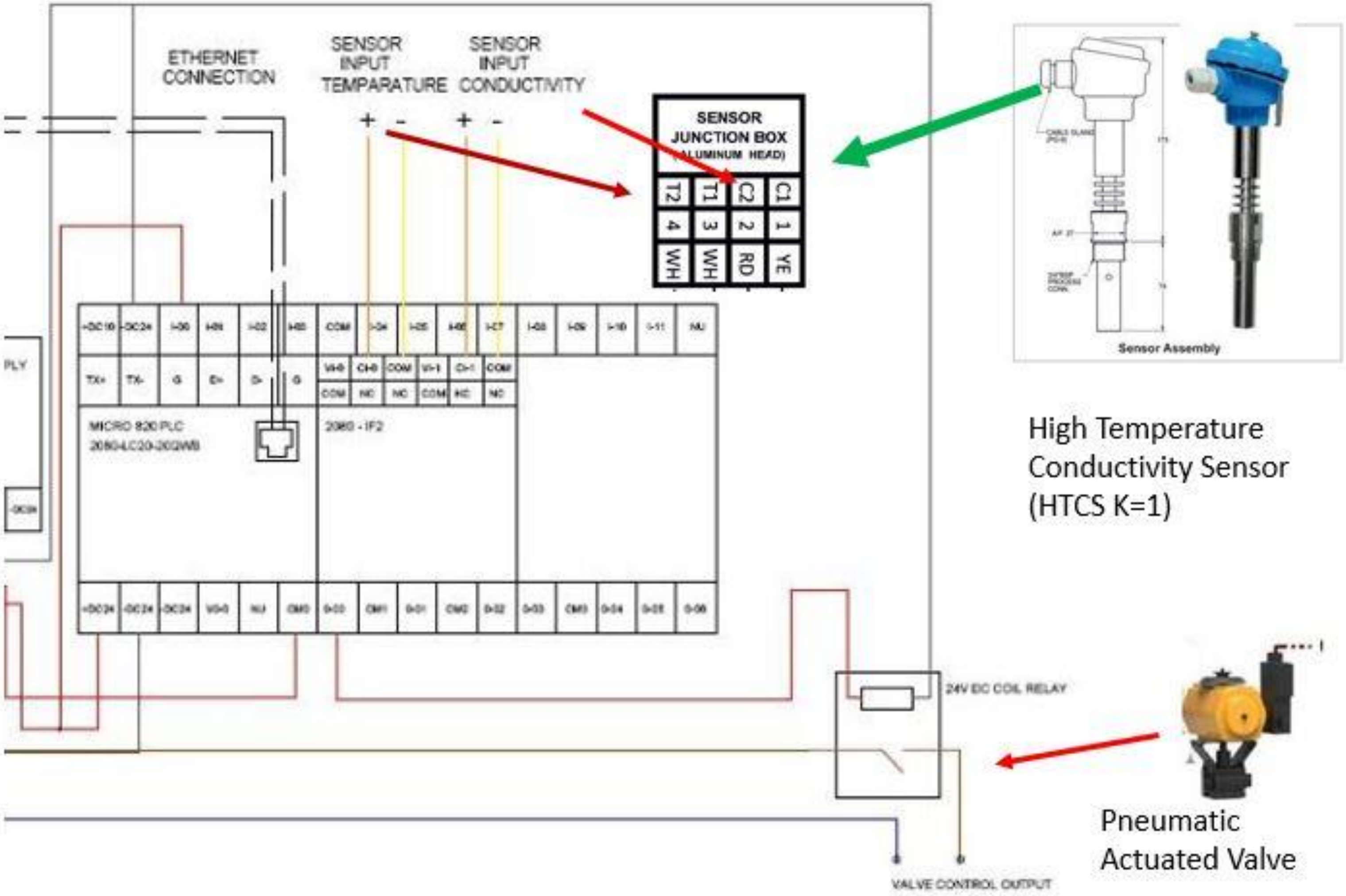


Figure 62: Sensor and Valve Connection Diagram to PLC Controller

7.3 Selected Sensor and Pneumatic Valve Secifications

According to the manufacutre’s product specific technical information sheet (TIS) as follows;

a. Sensor Measurment
   - i. TDS Range : 700 to 7000 ppm ,Resolution 10 ppm
   - ii. Temperature Range : 0 to 250 °C , Resolution 0.1 °C
   - iii. Cell Constnat : k = 1

b. Pneumatic Valve
   - i. Maximum Operating Pressure : 31 kg/cm2(g)
   - ii. Maximum Operating Temperature 238 °C
   - iii. Instrument Air Supply : 4 to 6 kg/cm2(g)
   - iv. Electrical Supply : 110 or 230 VAC ,50/60 Hz

Figure 63: Sensor and Connection View of the Selected Sensor for the Project

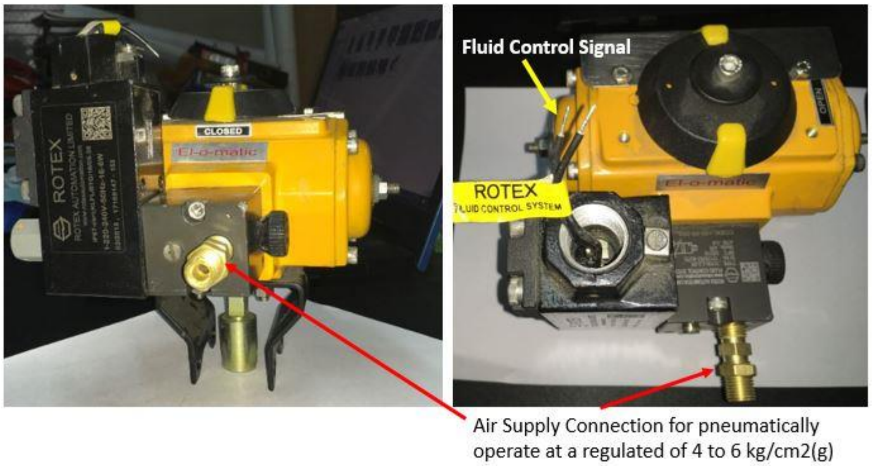


Figure 64: Selected Air Operated Blowdown Valve

The above Figure 62 and 63 are shown Sensor and Blowdown Valve used this project.

7.4 Hardware Fabrication and Installation of Main Control Panel Board.

Explains designing of Hardware platform to implement control schemes proposed in Chapter 6. The overall design a mechanical structure and an electrical, PLC control system which are required to achieve blowdown automatic operation are described this chapter.

7.4.1 Designing of Mechanical System for Sensor Chamber

Firstly, Sensor Chamber is need to design to keep Sensor to collect Boiler water to measure the TDS measurement to activate the Blowdown valve at required set point by the PLC controller. According to the sensor diameter and the sensor height initial two dimensional design is done in Auto CAD drawing and same thing is developed using Solid Works platform is shown in Figure 65. Refer to Appendix “D”.

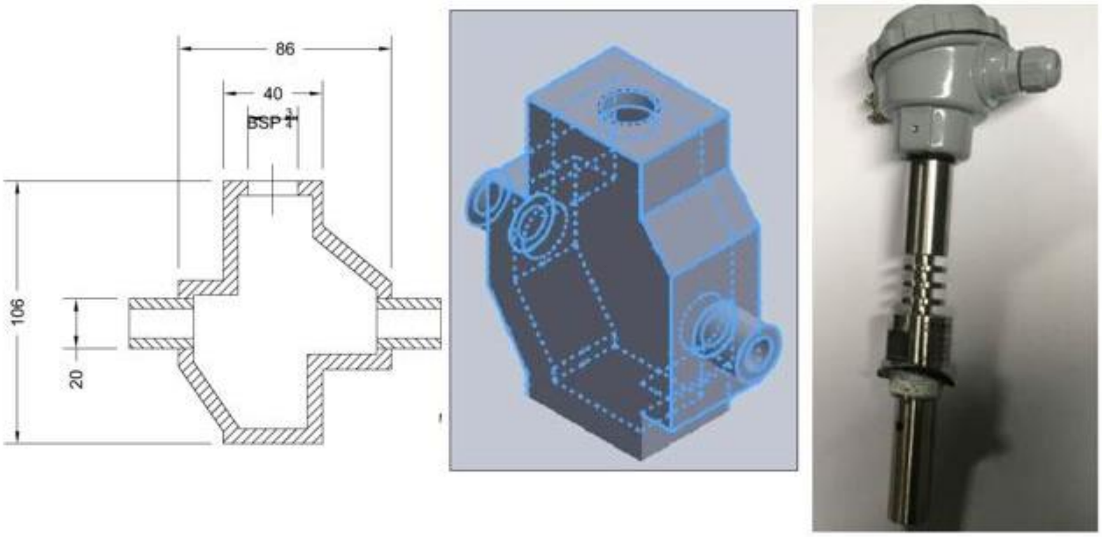


Figure 65: Design Sensor Chamber Structure of 2D and 3D View

The designed sensor chamber structure and its structure are verified various condition of Boiler water operating such as pressure and temperature verification of mechanical structure for failures by analyzing with SOLID WORKS simulation software platform is illustrated in Figure 66. Refer Appendix “E”

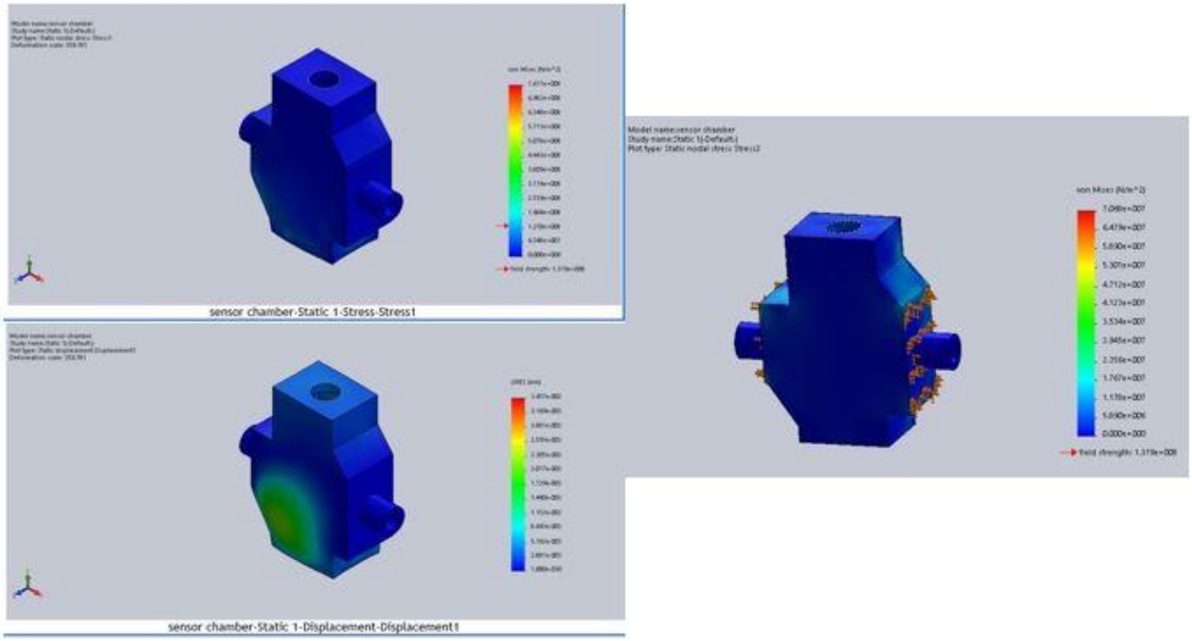


Figure 66: Designed Sensor Chamber Analyzed with Solid Works Simulation

It is proposed to fabricate the sensor chamber using stainless steel (ASTM SS 316) 40 mm by doing wire cut EDM machine fabrication method to design a sensor chamber. After fabricating with above measurement and material is used and figure 67 shown below.

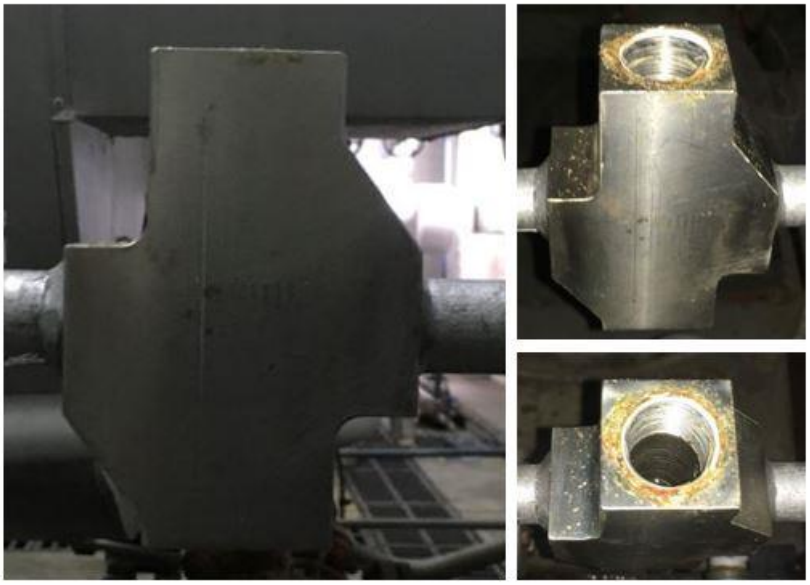


Figure 67: Fabricated Sensor Chamber using ASTM SS 316 Material for this Project

7.4.2 Design of Boiler Automatic Blowdown Kit

Initially developed the Piping and Instrumentation Diagram (P&ID) and it is illustrated in Figure 68. The Piping and Flange are used DN 25 & DN 40 for the fabrication. Refer Appendix “F”.

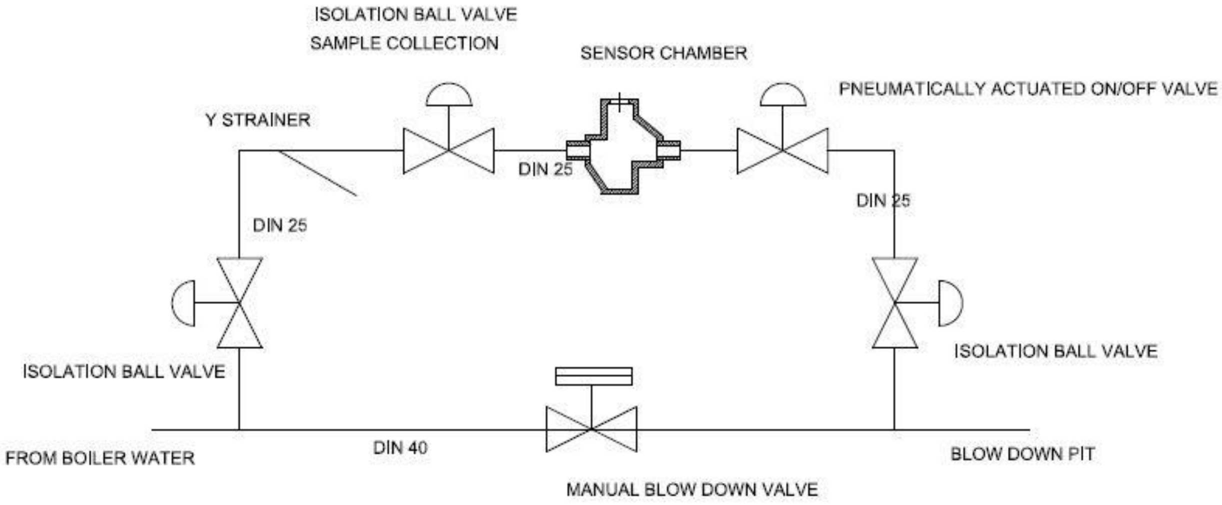


Figure 68: Piping and Instrumentation Diagram of Boiler Automatic Blowdown Kit

7.4.3 Implementation of Mechanical Installation Blowdown Kit

The designed is fabricated using 1’’ B1 Schedule Pipe (Black Iron), Flanges and installed at the Boiler House and Shown in following Figures.

Figure 69: Removal of Existing Manual Blowdown Piping

Figure 70: Fabricating of Flanges for Design Blowdown Kit

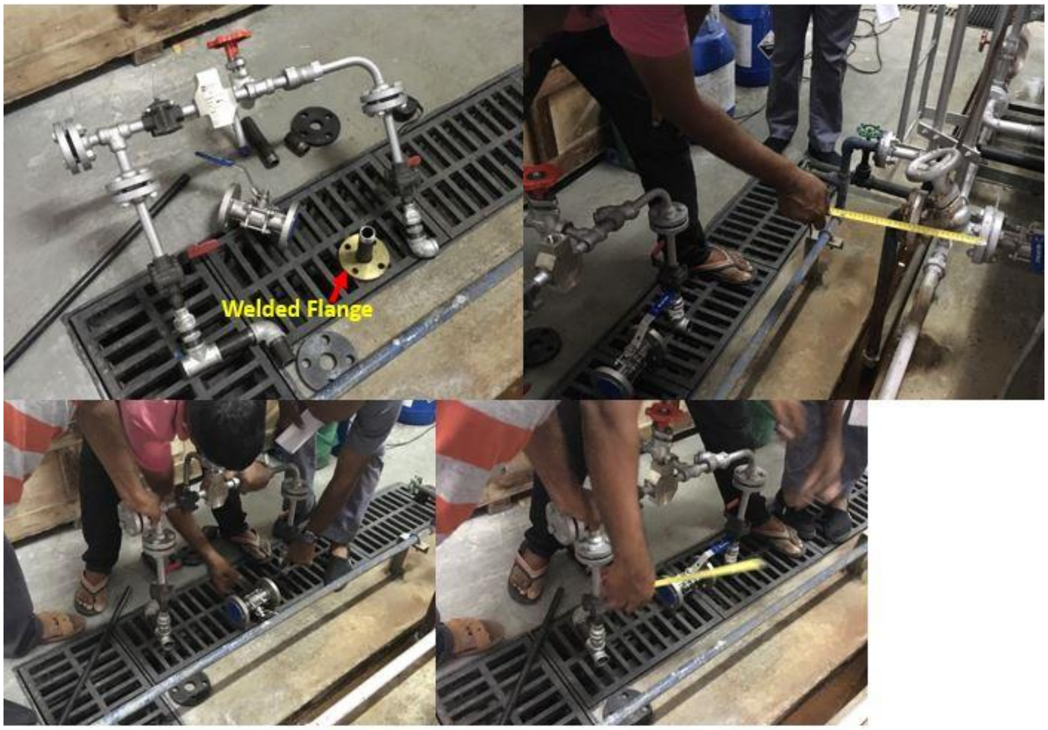


Figure 71: Installation of Design Blowdown Control System

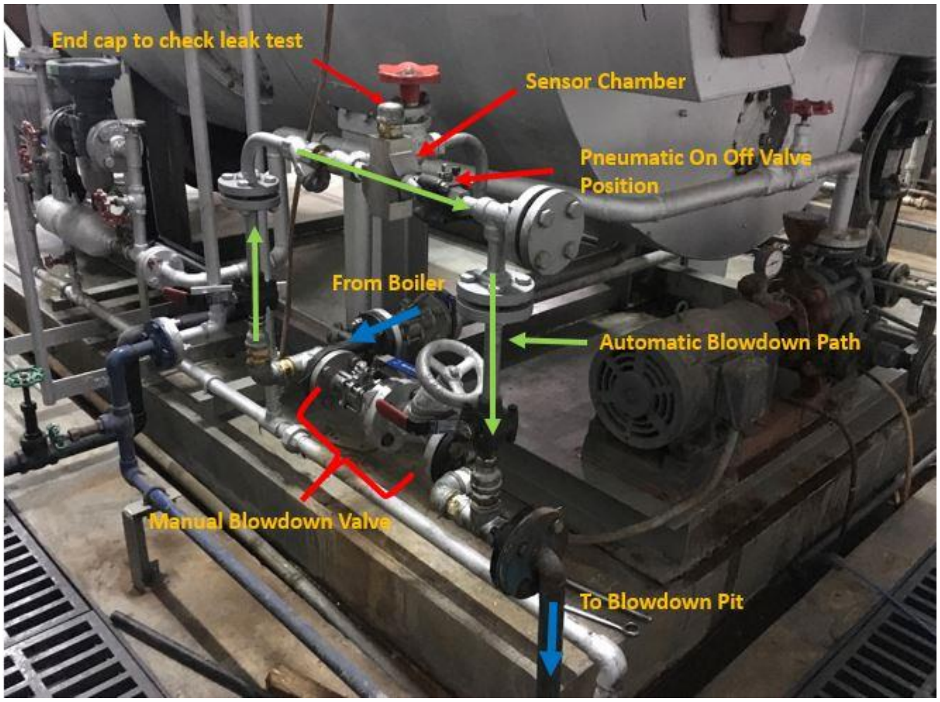


Figure 72: Completion of Blowdown Control System Installation

After installing above blowdown kit was checked a period of one week any leaks and material condition of piping, design sensor chamber and related valves for pressure and temperature when operating boiler before installing sensor and pneumatically activated blowdown valve to the system. This is done by keep opening isolating valves on automatic path and doing normal procedure of manual blowdown by activating manual blowdown path during above mentioned period after installing the new blowdown kit to the system.

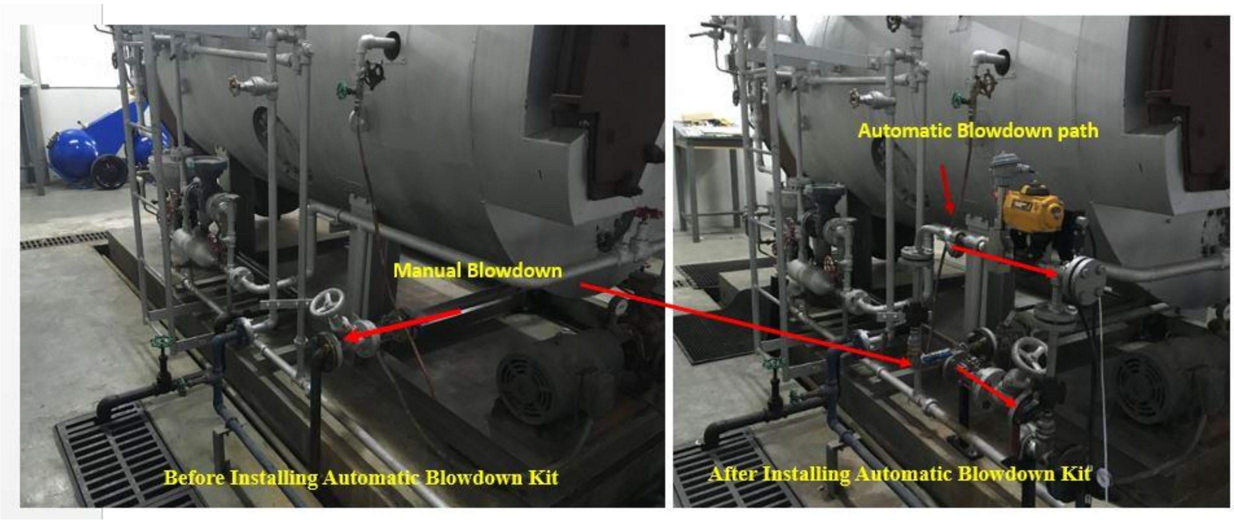


Figure 73: Before and After Installation of Blowdown Kit

Above Figure 73 shows before and after installation of automatic blowdown kit to the boiler.

7.5 Control Panel

Table 13 presents a summary of key components used in panel board controller design components are graphically related with the fabricated control panel is shown in Figure 74.

No.	Components	Symbol	Specification
01	PLC	PLC	Process the input control signals and provides commands to the actuator (Allen-Bradly, Micro 820,2080-LC20-20QWB)

02	2080-IF2	AI-M	2-Channel analog input module
03	Power supply	PS	24V DC power supply, to power up the PLC and the HMI
04	Circuit Breaker	CB	Act as the input power isolation device
05	HMI	HMI	Human machine interface, used to set specific values and to observe essential outputs(interface between the operators and the controller)
06	Incoming power	IP	Terminals for the incoming power(230V AC power)
07	Input and output terminals	I/O	Terminals used to connect the sensor inputs and the valve control outputs.

Table 13 Summary of Key Components used for Design Controller

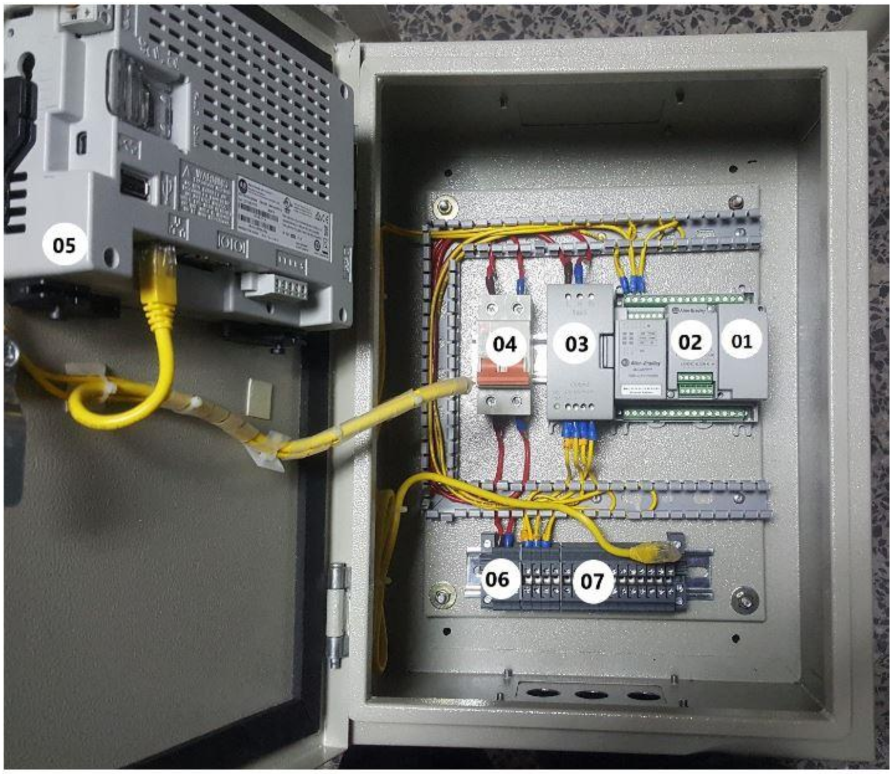


Figure 74 Components Layout Control Panel Board

7.6 Software Implementation

The Mathematical algorithms can be easily implemented in user friendly platforms like, Matlab, Arduino, and Raspberry –Pi etc. In this particular application, use of these open source platforms is disqualified by the fact that the Boiler operation system would be entirely running in a environment under temperature fluctuations. In the industrial environment, Programmable Logic Controller (PLC) has a good reputation for the cost effectiveness and the durability. After analyzing the developed control algorithms, a reliable PLC is selected for writing codes. The compatible software platform is provided by the PLC manufacturer and Ladder Logic is used as the Programming Language.

“Connected Components Workbench (release 11.0)” – Rocwell PLC program tool [15] is used to write and download PLC codes. It is the compatible software platform for the Connected Components (Release 11.0) PLC. The Figure 75 shows the software page. The Appendix –G presents a Ladder Program implemented proposed control approach.

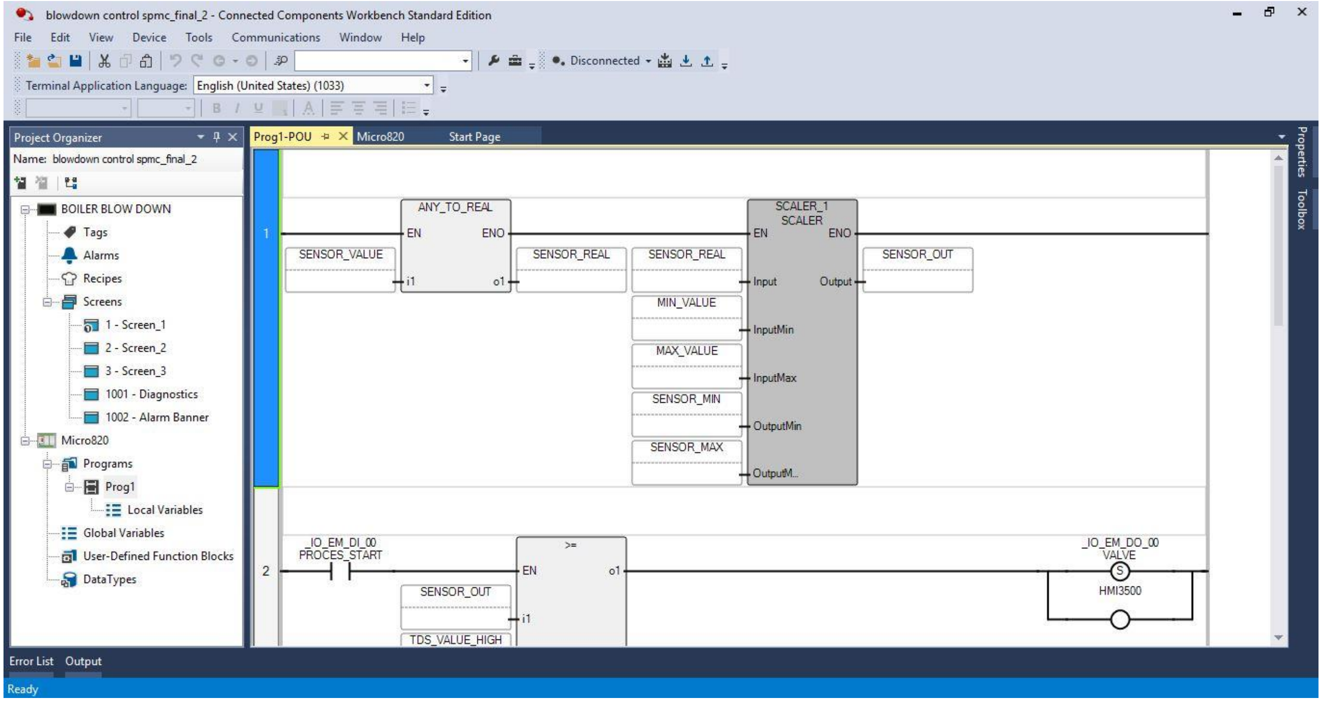


Figure 75: Connected Components Workbench Standard Edition Software Tool

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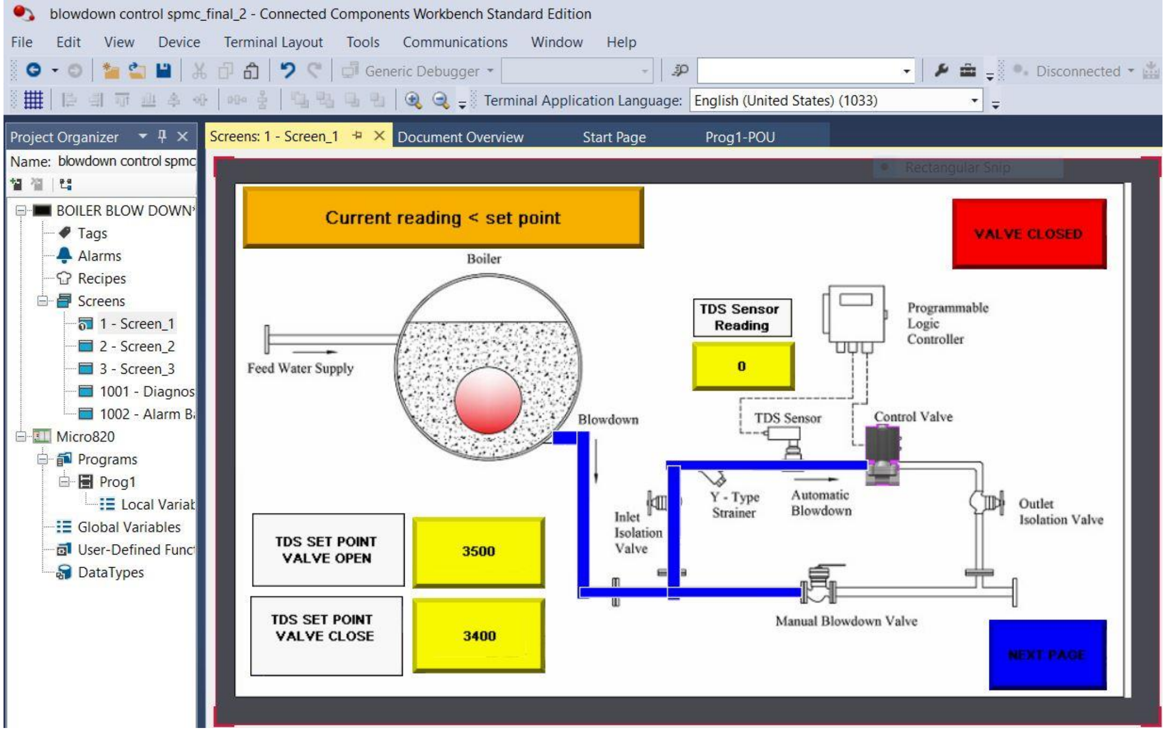
The Figure 76 and Figure 77 shows Human Machine Interface (HMI) developed displays using software tool respectively.



Terminal Application Language: English (United States) (1033)

Name: blowdown control spmc

TDS Sensor Reading: 0

TDS SET POINT VALVE OPEN: 3500

TDS SET POINT VALVE CLOSE: 3400

Figure 76: HMI Display Develop using Software Tool

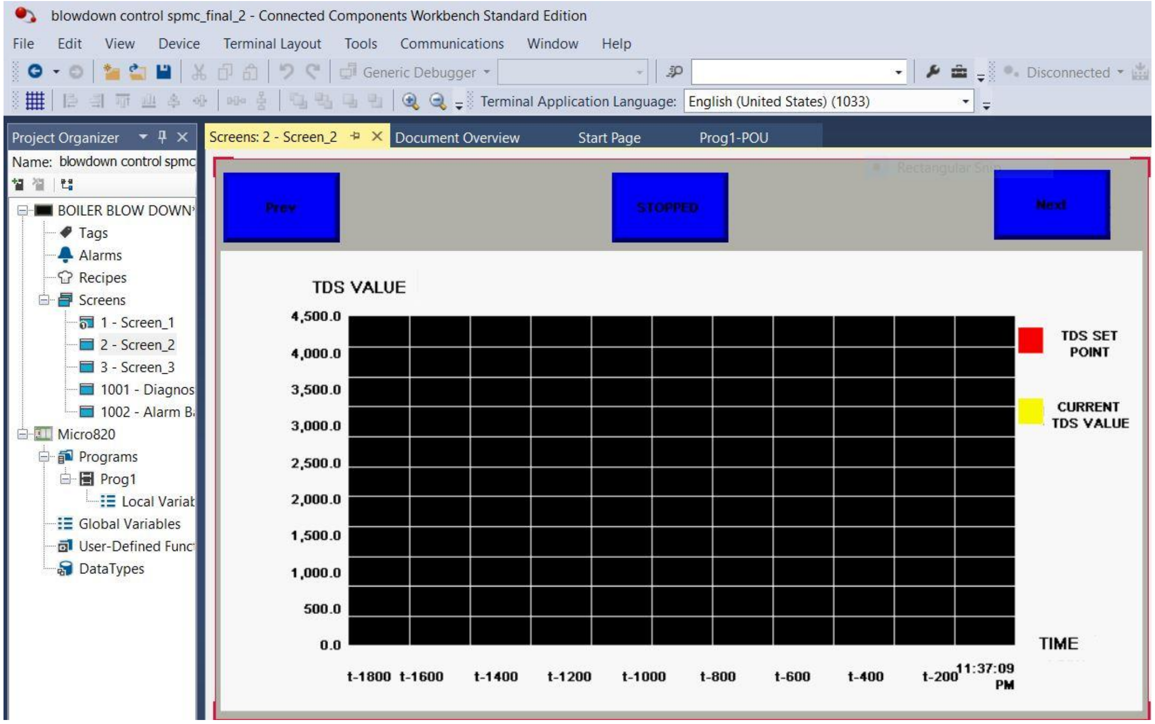


Figure 77: HMI Display Develop using Software Tool

7.7 Ladder Program Function and Operation

The PLC parameters and a sample ladder program is illustrated in Appendix G and function as follows;

Rung 1

Current conductivity value is fed to the PLC as a 0-20mA signal through the 2080- IF2 analogue plug in module. The value is then read as a UINT value through the module.

Analog input variables.

Variable name	Channel	Range for variables
_IO_Px_AI_00	0	0 to 65535, where 0 equals 0V (voltage channel), or 0mA (current channel), and 65535 equals 10V (voltage channel), or 20mA (current channel)
_IO_Px_AI_01	1	0 to 65535, where 0 equals 0V (voltage

		channel), or 0mA (current channel), and 65535 equals 10V (voltage channel), or 20mA (current channel)

Then to scale the output the UINT value is converted to a real value.
After getting the real value the maximum and minimum values of the sensor is scaled with the scaler block of CCW.

Rung 2

Current Temperature value is read through the second channel of the analogue module and scaled as described in the first Rung.

Rung 3

In this rung the received values are fed to the equation to calculate the conductivity at the temperature of 25°C.

$$C25 = C0 / (1 + \alpha (T0 - T25))$$

Using the first block the subtraction of T0-T25 is done and using the next one it is multiplied by the temperature coefficient ($\alpha = 0.02$) and the other block is used for the addition and to get this (1 + 0.02(T0 – 25)) completed.

Rung 4

Using the first block the division is done and the conductivity at 25°C is calculated. Then to convert it to the ppm value it is multiplied by cell constant in the second block. And then it is again multiplied by 0.7 in the third block.

Rung 5

The TDS value is compared to the set point of 3500 ppm and the valve is opened if the TDS value is greater than the set value of 3500 ppm.

Rung 6

Valve is kept open for 30 second and then again it is closed to stop the excessive removal of heated water.

Rung 7

Valve is kept closed for 10 minutes and again the TDS value is checked.

Rung 8

If the TDS value is lower than 3400ppm the valve is closed.

Rung 9

This rung is used for the flushing process and the valve is kept open for 2 second every 45 minutes in a loop continuously.

Rung 10

It is used to control the opening of the valve for 2 second. to count the 2 second delay.

Rung 11

This is done to count the no of blow down cycles, whenever the valve is open due to exceeding the set TDS value the count is incremented by one.

Rung 12

This is done to count the no of refresh cycles, whenever the valve is open due to refresh purpose the count is incremented by one. Separate coils are used to identify above and this process separately.

Rung 13

This is used to convert the DINT count values into REAL values.

In Figure 78 shows PLC main controller, HMI and related Electrical wiring fabrication and installation of the control panel board.

Figure 78: Fabrication and Installation of Main Control Panel Board

CHAPTER 8

TEST AND EXPERIMENT RESULTS DISCUSSION

8.1 Installation and Configurable Parameters of the System

The High Temperature Conductivity Sensor (HTCS) was mounted on sensor chamber and sensor cable is fixed length of 5 meter cable that is provided factory calibrated 4 cored shield sensor cable along with sensor by the sensor manufacturer. Pneumatically operated blowdown valve also mounted to the fabricated blowdown kit as illustrated in Figure 79.

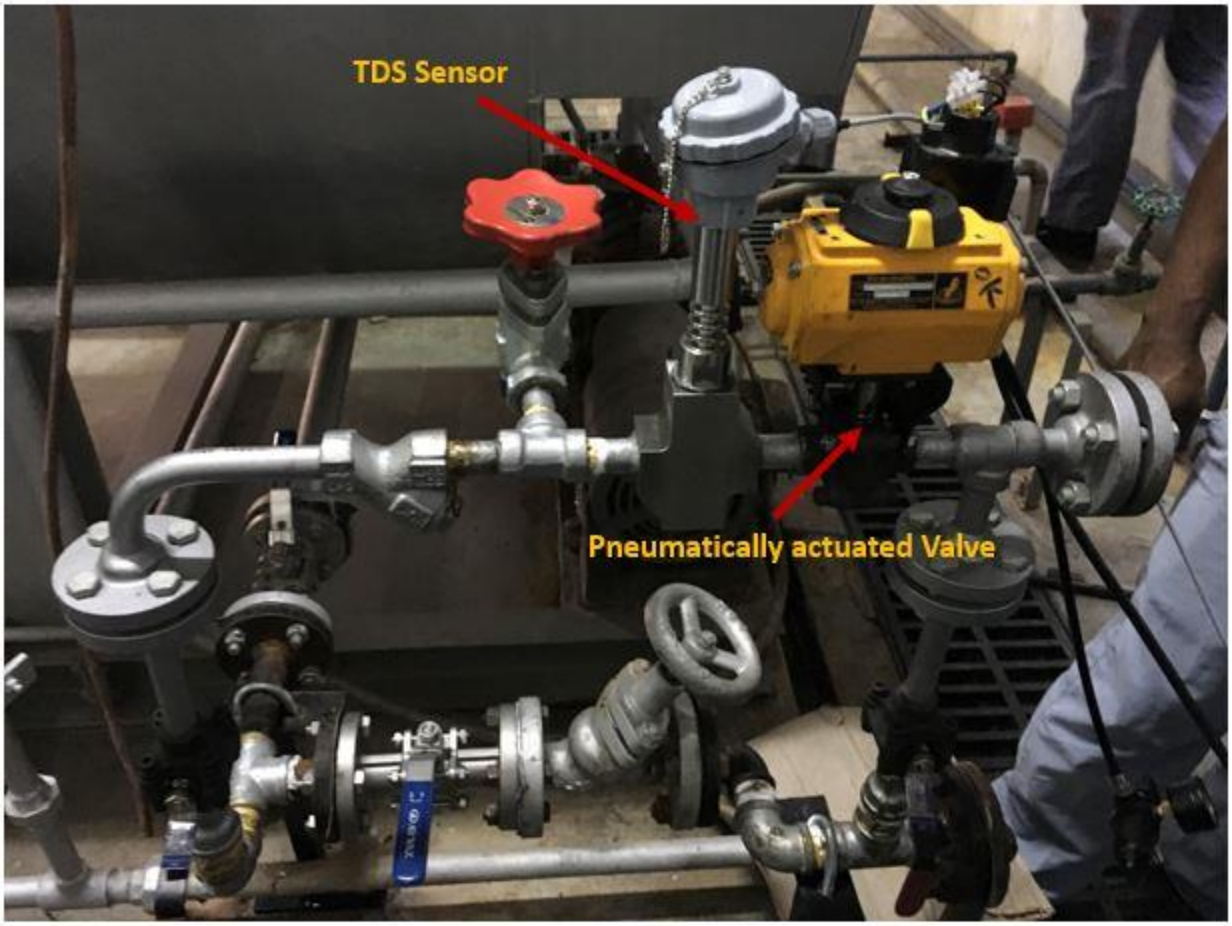


Figure 79: Sensor and Pneumatic Operated Valve Installation

The computed and displayed parameters on the ladder program of the PLC as follows in table 14.

Parameter	**Description**
TDS	TDS value of water sample present in sensor chamber.
Set point	TDS value to be maintained , configured as 3500 ppm
Purge or Refresh Cycle	Total number of Purge or Refresh Cycles that have occurred
Blowdown Cycle	Total number of Blowdown Cycles that have occurred
Purge After (Remaining time)	Time to be elapsed before next purge or refresh sensor chamber water

Table 14: Computed and Displayed Parameters

a. Configurable TDS set point – TDS value of boiler water to be maintained, specified by boiler manufacturer (here we set as 3500 ppm). if measured TDS rises above the set point , the boiler water is drained (blowdown) till TDS falls below the set point (here we set as 3400 ppm)

b. Configurable TDS factor – Factor to convert conductivity to TDS.

c. Configurable Purge Time – Duration for which Purge valve is open (same valve), allowing fresh sample of water to be collected in sensor chamber. (To keep errorless TDS reading).

d. Configurable Blowdown Time – Duration for which Blowdown valve is open, allowing water to drain in order to reduce TDS.

The following below Figure 80 and Figure 81 are illustrated testing and configuration of ladder program to the PLC system.

Figure 80: Testing and Configuration of the System

Figure 81: Testing and PLC Ladder Program Configuration

8.2 Sensor Calibration

The conductivity sensor and the temperature sensor was calibrated by considering their rated minimum and maximum value ranges. By considering the sensor input current (4mA -20mA) minimum value and the maximum value was set accordingly.

The minimum conductivity value was set for the 4mA input current and the maximum conductivity value was set to 20mA current. The same was done for the temperature sensor.

TDS values

4mA current – 700 ppm (relevant conductivity value as per the sensor specifications)

20mA current 7000 ppm (relevant conductivity value as per the sensor specifications)

Temperature readings

4mA current – 0 Celsius reading (as per the sensor specifications)

20mA current – 250 Celsius reading (as per the sensor specifications)

And then using the scaling blocks the relevant A-D to conversion values were spread out according to the resolution (13107-65535).

To get the values confirmed and to make the resolution more efficient a boiler water sample was taken and the TDS value was measured by using a portable TDS meter. The observed reading of above portable TDS meter reading recorded value is 1153 ppm at 44.8 Celsius. The displayed in the HMI that TDS value is 1171ppm at 105 Celsius. By considering the temperature compensation it showed a value which was in an acceptable range. The Figure 82 Shows the comparison of PLC controlled TDS sensor reading value and externally measure TDS reading by obtaining water sample at the blowdown kit sample collection point.

TDS
1171 ppm
Set Point
3500 ppm
Purge after 60 min

Address	Value
40001	1171.53002929688
40002	
40003	105.576400756836
40004	
40005	5.46506401086679E-44
40006	
40007	0
40008	
40009	0
40010	

Figure 82: TDS Reading Comparison of Sensor Reading and Portable Meter Reading

Results discuss the validation of the heuristic controller that after implementing control scheme in a PLC program, is tested for both purge time (refresh cycle) and blowdown cycle of operations.

This section presents outcome of experimental results is done for field test for the function of pure cycle that the purge time is set to 60 mints and tested refresh cycle valve opening and close after set time of 5 second to keep TDS sensor reading update in boiler drum water TDS for the automatic blowdown operation. The controller response during testing period is presented in Figure 83 and HMI display of next purge cycle remaining time period in Figure 84.

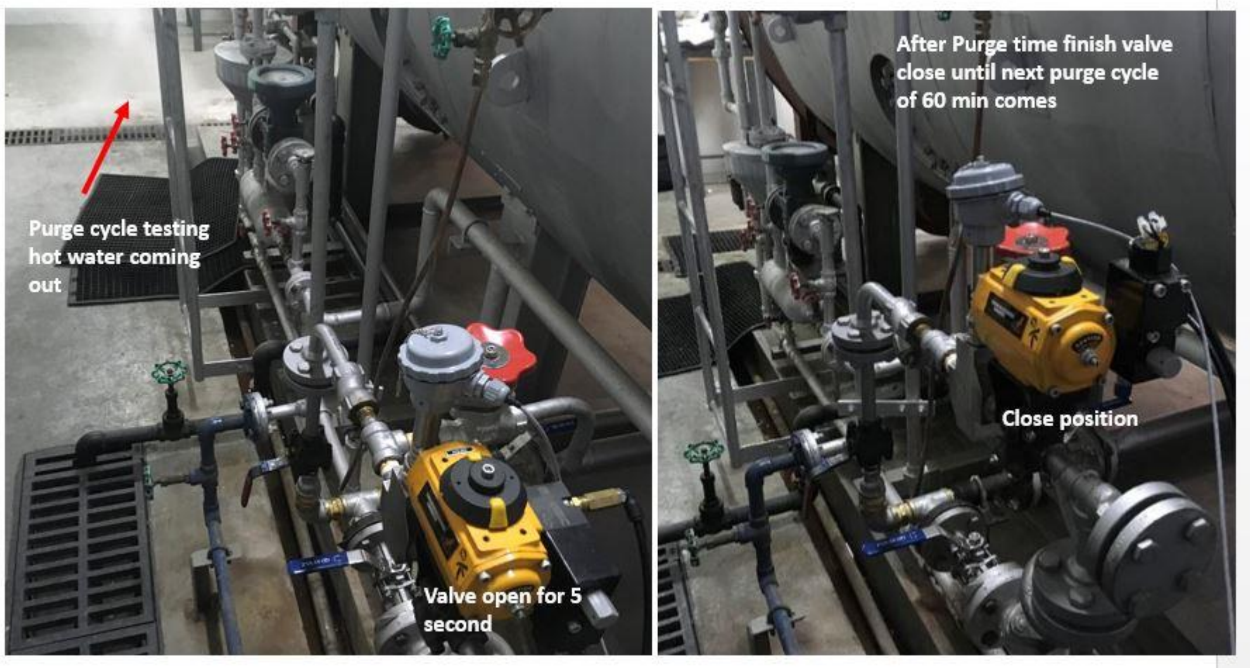


Figure 83: Purge Cycle Time Testing

TDS
1088 ppm
Set Point
3500 ppm
Purge after 59 min

Figure 84: HMI Display Showing Next Purge Cycle Remaing Time

A field testing is carried out to examine the controller’s response by observing the valve’s moment of blowdown opening and closing automatic function in order to test this function that recommended set point of 3500 ppm adjusted based on current sensor TDS reading and set as 1000 ppm set point and the controller’s response by observing the valve’s movement of blowdown opening and closing after set time of 25 second and until TDS current reading goes below the set point TDS reading in side the boiler drum water is illustrated in Figure 85.

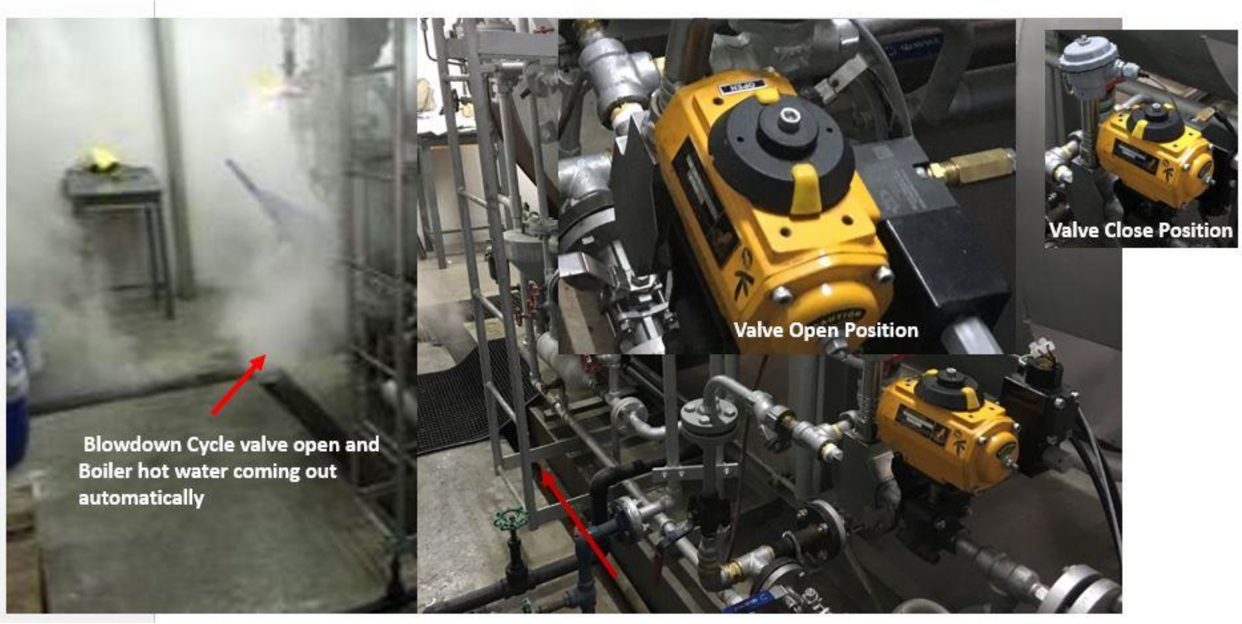


Figure 85: Testing of Blowdown Automatic Operation

It becomes quite clear that, the control scheme responds according to the information available in PLC code program and hence the valve is open autonomously positioned in purge mode and blowdown mode accordingly to the time set purge time as well as TDS sensor measurement comparing to the set point of TDS reading for blowdown valve to be opened until current boiler drum water TDS reaches to the set point by measuring TDS sensor reading with refresh cycle continuously.

The TDS measurement and Temperature reading based on drive sensor parameters Table [13] gives recorded parameters readings over random time intervals during boiler operation on 03 Jan and 04 Jan 2019. The summery of recorded sensor reading of TDS and Temperature is given table 15.

Blow-down Automated System
Poll definition: ID = 1, Function = 03, Address = 0, Scan Rate = 1000

Date and Time	TDS (ppm)	Temp C
1/3/2019 9:35	1106.00	76.65
1/3/2019 10:35	1108.53	82.67
1/3/2019 11:35	1088.34	88.32
1/3/2019 12:35	1145.00	90.23
1/3/2019 13:35	1147.00	91.45
1/3/2019 14:36	1150.00	96.12
1/3/2019 15:36	1154.57	98.00
1/3/2019 16:36	1130.12	91.23
1/3/2019 17:36	1132.10	93.12
1/3/2019 18:36	1140.00	96.34
1/3/2019 19:36	1146.00	95.65
1/3/2019 20:37	1122.43	84.43
1/3/2019 21:37	1119.62	82.00
1/4/2019 9:37	1123.00	118.50
1/4/2019 10:37	1115.12	115.32
1/4/2019 11:30	1156.00	114.70
1/4/2019 12:37	1107.00	63.10
1/4/2019 13:38	1099.32	52.60
1/4/2019 14:30	1121.34	52.60
1/4/2019 15:30	1128.00	50.70
1/4/2019 16:35	1117.34	68.80
1/4/2019 17:38	1140.00	68.50
1/4/2019 18:35	1115.00	55.40
1/4/2019 19:38	1116.12	53.40
1/4/2019 20:30	1124.00	53.90
1/4/2019 21:33	1150.00	59.70

Table 15: Summary of Recorded Sensor Reading TDS and Temperature

According to the summary results of TDS sensor reading that during these two days of boiler operation that boiler drum water not reaches to the recommended TDS reading of 3500 ppm to do the boiler blowdown, but as a practice with manual blowdown our boiler operator technician carrying out manual operation two times a day that is not necessary to do by looking a TDS sensor data recorded in PLC. Thereby energy saving can be achieved avoiding excess boiler blowdown due to manual innervation by introducing this automatic blowdown operation in the future

CHAPTER 9

PROPOSED MAINTENANCE GUIDELINES

This Chapter explains proposed maintenance guidelines for routine and preventive maintenance in order to keep system proper operation. This checks can be performed by the boiler maintenance technician in the factory after trained them. The Frequency of cleaning and inspection will depend on the quality of blowdown water, which varies time to time. Sensor removal and cleaning is very important because if any impurities in boiler water at sensor chamber with over a period of time can get scale in the sensor area, so it will be effected to the correct sensor reading.

Therefore, it is proposed following table [16] mentioned frequency for checking various parameters of the automatic blowdown system. The proposed guidelines to monitor at least one year and after that frequency of inspection and preventive maintenance would be adjusted accordingly.

Sr. No.	**Parameter to be checked**	**Frequency for checking various parameters**					
		Daily	Weekly	Monthly	Quarterly	Half year	Annually
1	Visual Inspection for Leakages	Yes					
2	Cleaning of Y Strainer in top piping		Yes				
3	Sensor in line Calibration				Yes		
4	Lubrication of piston valves				Yes		
5	Clean sensor and sensor chamber				Yes		

Table 16: Routine and Preventive Maintenance Check List

CHAPTER 10

CONCLUSION AND FUTURE WORK

10.1 Conclusion

Boiler blowdown is the removal of water from a boiler drum. Its purpose is to control boiler water parameters within prescribed limits to minimize scale, corrosion, carryover and other specific problems. TDS controlled accurately near to maximum level minimizing blowdown yet avoiding carryover and foaming cause by TDS level.

The design controller linked with conductivity sensor which monitors the TDS of boiler drum through blowdown sample chamber with purge cycle. The measured TDS value during purge time is then compared with the set point in the controller. If this value is less then the blowdown valve gets closed. If the it is more then the valve gets open in intermittent cycle till the value drops below the set point.

This controller was designed PLC based device to maintain the boiler water TDS within the safe band as specified by the boiler manufacturer. This is done by measuring the TDS value of boiler water periodically in purging cycle.

High Temperature Conductivity Sensor is used to measure conductivity and temperature of water sample collected in sensor chamber. TDS is calculated based on these measurement. This purging, measurement and blowdown cycle is repeated until the conductivity level drops below set point.

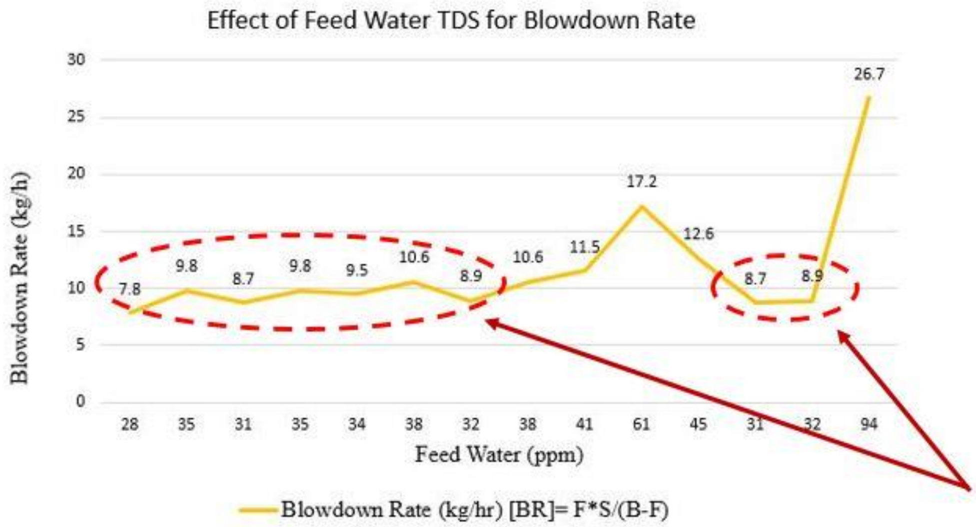
10.2 Future Work

Boiler feed water consists of return condensate plus the make-up water and chemicals added as water is converted to satisfy steam demands. When we take monthly Boiler water reports is shown in Table 17 that TDS feed water also varying from 10 ppm to 100 ppm when we analysis of Boiler feed water. Data obtain reports is in Appendix A.

Date	Feed Water TDS Level (ppm) (F)	Steam Generation (kg/hr) (S)	Max allowable TDS (ppm) (B)	Blowdown Rate (kg/hr) [BD]= F*S/(B-F)
19/9/2016	28	969	3500	7.8
5/12/2016	35	969	3500	9.8
26/5/2017	31	969	3500	8.7
15/6/2017	35	969	3500	9.8
20/7/2017	34	969	3500	9.5
3/8/2017	38	969	3500	10.6
21/9/2017	32	969	3500	8.9
7/11/2017	38	969	3500	10.6
16/1/2018	41	969	3500	11.5
19/2/2018	61	969	3500	17.2
15/5/2018	45	969	3500	12.6
16/7/2018	31	969	3500	8.7
30/8/2018	32	969	3500	8.9
16/11/2018	94	969	3500	26.7

Table 17: Boiler Feed Water Monthly Report

After Implementing Autonomous Boiler blowdown system we can maintain the maximum allowable Boiler water TDS level at almost close to TDS level at 3500 ppm that is the optimization we can achieved when compared to manual blowdown. Therefore above tabular format we can keep Boiler inside TDS level as 3500 ppm. So we can calculate blowdown rate value with plant operates average steam consumption based on Chapter 3, para 3.6.



Feed Water TDS controlling low valve then blowdown rate lesser compares high Feed Water TDS

Figure 86: Feed Water TDS and Blowdown Rate Comparison Graph

This graph clearly evidence that we can be obtained further optimization of blowdown control if we continuously monitor feed water TDS level and maintain as much as lower TDS level then, this can be achieved. So we can monitor Feed Water TDS level by installing TDS sensor at Feed Water line of the Boiler and get the feedback to control the Feed Water TDS and thereby controlling blowdown rate to desire at low rate.

REFERENCES

[1] Optimization of Boiler Blowdown and Blowdown Heat Recovery in Textile Sector. (Research Article) Sunudas T1, M G Prince2 ,**1(**PG Scholar, MES College of Engineering Calicut University), 2 (Assistant professor, Department of Mechanical Engineering, MES College of Engineering)

[2] Boiler Blowdown – Fact Sheet-P2 infoHouse (33027.pdf), *infohouse.p2ric.org/ref/34/33027.pdf* - August 2004.

[3] ARI Armaturen Steamline LLP TM • Survey No. 32/3/14, Kondhwa Budruk, Pune 411048 India Phone: + 91 20 2693 2213 • Fax: + 91 20 2963 2214
Email: sales@ari-steamline.com • Web: www.ari-steamline.com.

[4] Training Notes obtained from Forbes Marshall Pvt Ltd, Steam Engineering Centre,Pune 410501 , Maharashtra , India

[5] International Organization of Scientific Research "Boiler Blowdown Analysis in an Industrial Boiler" by Keerthi R Lekshmi & Vandana Spillai, www.iosrjen.org ISSN (e): 2250-3021, ISSN (p):2278-8719, Vol. 05, issue 07(July 2015)

[6] Research Article "Optimization of Boiler Blowdown and Blowdown Heat Recovery in Textile Sector" *Sunudas T et al. Int. Journal of Engineering Research and Applications* www.ijera.com *Vol. 3, Issue 5, Sep-Oct 2013, pp.35-38* , Sunudas T, M G Prince **(**PG Scholar, MES College of Engineering Calicut University), (Assistant professor, Department of Mechanical Engineering, MES College of Engineering).

[7] Internet Article "Controlling TDS in the Boiler Water" http://pointing.spiraxsarco.com/resources/steam-engineering-tutorials/the-boiler-house/controlling-tds-in-the-boiler-water.

[8] Internet Article "DOC316.52.93084 – conductivity of water.pdf"

[9] Energy Efficiency Guide for Industry in Asia – www.energyefficiencyasia.org Thermal Energy Equipment: Boiler & Thermic Fluid Heaters.

[10] TDS (Total Dissolved Solids). • TDS is the dissolved solids in boiler water exists because of the chemical treatment of the boiler. • As a boiler generates steam, ```mechanical-fet.weebly.com/uploads/2/7/9/3/.../tds_contro___heat_recoveryl.pdf

[11] http://www.mosaic-industries.com/embedded-systems/instrumentation/conductivity-meter/total-dissolved-solids

[12] https://sensorex.com/blog/2017/11/29/conductivity-cell-constants/ (Accessed 25 Nov 2018)

[13] http://www.spiraxsarco.com/Resources/Pages/Steam-Engineering-Tutorials/the-boiler-house/controlling-tds-in-the-boiler-water.aspx (Accessed 25 Nov 2018)

[14] http://www.jenway.com/faq_Conductivity_Meters.asp (Accessed 25 Nov 2018)

[15] https://compatibility.rockwellautomation.com/pages/search.aspx?crumb=117&q=CCW%20v11%20Feature%20Pack%20for%20Micro800%20(RAid1074871)

[16] http://www.jenway.com/adminimages/A02_001A_Effect_of_temperature_on_conductivity.pdf (Accessed 25 Nov 2018)

[17] Sonntag, Borgnakke, Van Wylen (1998). *Fundamentals of Thermodynamics (5th edition*). New York, NY: John Wiley and Sons Inc.

[18] Franklin Kreith, Mark S. Bohn (1996). *Principles of Heat Transfer (5th edition).* Boston, MA: PWS Publishing Company.

[19] Dukelow, S.G. 1991. *The Control of Boilers*, pp. 74–85 Research Triangle Park: Instrument Society of America

[20] Stultz, S.C. and J.B. Kitto. 1992. *Steam. Its Generation and Use,* 40th Edition, pp. 9 –22 to 9 – 27. Lynchburg, Va.: The Babcock & Wilcox Company.

[21] Greg Harrell , Boiler Blowdown Energy Recovery, *Energy Engineering, Volume 101, Issue 5*, 2004, pages 32-42, DOI:10.1080/01998590409509277

[22] Everett B. Woodruff, Herbert B. Lammers, Thomas F. Lammers (1998). *Steam Plant Operation (7th edition).* New York, NY: McGraw Hill.

[23]. Kerala Minerals And Metals Ltd, KMML, http://www.kmml.co.in/, January 10,2015

[24]. Bureau of Energy Efficiency Manual, Bureau of energy Efficiency, http://www.bee-india.nic.in/,
November 24, 2014

[25]. Amit Kumar Jain "An Approach towards Efficient Operation of Boilers", International Journal of Scientific and Engineering Research,(Volume 3, Issue 6, June-2012)

[26] Energy Audit Report of SPMC Ratmalana Sri Lanka for Steam Audit, 22 June 2018.

[27] www.yokogwwa.com/us

[28] www.altret.com (Blowdown Calculation for Boiler)

[29] Best Practice in Boiler Water Treatment (www.Byworth.com)

[30] Internal Journal of Scientific & Engineering Research, Volume 3, Issue 6, June-2012 , ISSN 2229-5518, www.ijser.org.

[31] International Journal of Scientific Research in Science and Technology (www.ijsrst.com), Studies and Research on Operation, Modeling and Simulation of Boilers: A Review.

[32] Y. P. Bhalerao, S. V. Patil, P. V. Vijay Babu, and S. J. Kulkarni(2011), Energy Retrofit Studies in Diethyl Thiophosphoryl Chloride (DETC) Plant, International Journal of Chemical Engineering and Applications 2(6),439-445.

[33] Sunil J. Kulkarni, Ajaygiri K. Goswami(2014), A Review on Studies and Research for Biodiesel Production from Various Feed stocks,International Journal of Engineering Research and Management 1(6), 136-138.

[34] Syed Shah Khalid, Zhang Liang and Nazia Shah(2012), Harnessing Tidal Energy Using Vertical Axis Tidal Turbine, Research Journal of Applied Sciences, Engineering and Technology 5(1) , 239-252.

[35] Sunil Jayant Kulkarni(2015),Tidal Energy: A Review, International Journal of Research (IJR) 2(1), 55-59.

[36] Sunil Jayant Kulkarni(2014), Solar Distillation: A Review, International Journal of Research (IJR) 1(11), 1171-1176.

[37] L S Blunden and A S Bahaj(2007),Tidal energy resource assessment for tidal stream generators, J. Power and Energy Proc. IMechE 221 (Part A),.137-146.

[38] Rong Panxiang, Sun Jianpeng，Liu Zhaoyu, Yu Lin And Dong Wenbo(2013), Simulation And Research Of Boiler Combustion Process Based On The Improved Rbf Neural Network, International Journal Of U- And E- Service, Science And Technology 6(5), 79-88.

[39] Rakesh Jain, Devendra Dandotiya, Abhishek Jain(2013),Performance Improvement Of A Boiler Through Waste Heat Recovery From An Air Conditioning Unit, Iinternational Journal Of Innovative Research In Science, Engineering And Technology 2(2), 405-412.

[40] T. Karuppiah, V. Sivasankaran, Dr. Azha. Periasamy, Dr. S. Muruganand(2013), Embedded System Based Industrial Power Plant Boiler Automation Using Gsm Technology, International Journal Of Advanced Research In Computer And Communication Engineering 2(8),3321-3325.

[41] Sanjoy Kumar Chakraborty,Nilotpal Manna And Surodh Dey(2014), Importance Of Three-Elements Boiler Drum Level Control And Its Installation In Power Plant, International Journal Of Instrumentation And Control Systems(Ijics) 4(2),1-12.

[42] Atul Mohod,Y.P.Khandetod, S. H. Sengar, And H. Y. Shrirame(2012), Energy Analysis Of Baby Boiler For Steaming Of Raw Cashew Nut Seeds, International Scholarly Research Network(2012), 6,Pages Doi:10.5402/2012/476702.

[43] Sunudas T, M G Prince(2013), Optimization Of Boiler Blowdown And Blowdown Heat Recovery In Textile Sector, Int. Journal Of Engineering Research And Applications 3(5), 35-38.

[44] P. Hari Krishnan, Prathyusha S(2014), Optimization Of Main Boiler Parameters Using Soft Computing Techniques, International Journal Of Research In Engineering And Technology 3 (Special Issue: 07), 553-560.

[45] G. Suresh Babu, Dr. V. Chittaranjan Das(20123), Condition Monitoring And Vibration Analysis Of Boiler,International Journal Of Scientific And Research Publications 3(6), 1-7.

[46] P.Ravindra Kumar, V.R.Raju, N.Ravi Kumar, Ch.V.Krishna(2012), Investigation Of Improvement In Boiler Efficiency Through Incorporation Of Additional Bank Of Tubes In The Economiser For Supercritical Steam Power Cycles, International Journal Of Engineering Research And Development 4(8), 94-100.

[47] S. Shahul Hamid, D. Najumnissa Jamal Murshitha Shajahan(2013), Automatic Detection And Analysis Of Boiler Tube Leakage System, International Journal Of Computer Applications 84(16), 19-24.

[48] Kim Sorensen,Thomas Condra, Niels Houbak(2003), Modelling, Simulating And Optimizing Boiler Heating Surfaces And Evaporator Circuits", The 44th Conference on Simulation and Modelling, Västerås, Sweden,September 18-19 2003,13 pages.

[49] Jaya S. Lahane, Meera A.Khandekar(2014), System Identification And Controller Design For Boiler And Heat Exchanger Set-Up, International Journal Of Advanced Research In Electrical,Electronics And Instrumentation Engineering 3(7), 10708-10715.

[50] Tomasz Turzynski, Dariusz Kardas(2013),Experimental Research On Helical Coil Biomass Boiler With Oil As A Heating Fluid, Transactions Of The Institute Of Fluid-Flow Machinery 125, 55–65.

APPENDIXES