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Control and analysis of crucial parameters for an automatic boiler unit in a chemical industry

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Abstract

A boiler plays a significant role in a processing industry, particularly in chemical industry. It requires proper adoption of control techniques for supplying accurate temperature, pressure, steam, and water flow to produce chemicals. An uncontrolled boiler can shut down the whole process. Therefore it requires a continuous monitoring system for avoiding such shutdown. In the past few decades, relay logic, embedded or process card systems were used for controlling the boiler system. In the conventional system, the controlling scheme was also complex for troubleshooting because process cards are used only once. In order to overcome this type of problem Supervisory Control and Data Acquisition (SCADA) and Programmable Logic Controller (PLC) system helps to collect data and information about the flow of boiler from various sensors. In this paper, SCADA and PLC assist in controlling crucial parameters using Proportional Integral Derivative (PID) control. PID controller used in this paper is programmed according to the boiler operation's need, and the data can be stored and analyzed using the SCADA system. The results in this paper help the industrial personnel for boiler automation, allowing the plant operator to observe the crucial parameters for increasing boiler efficiency and reducing the financial losses.

Keywords: PLC, SCADA, PID Controller, Industrial Boiler, Cost Analysis.

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1. Introduction

Industries like sugar mills, oil refineries, power, chemical, and many other industries require a boiler for a specific operation. The primary operation of the boiler is to generate steam for various process operations or applications mainly used in the heating application. A boiler has various fitting components and accessories, making it capable of supplying steams for industrial application. The steam flow rate, drum pressure, steam-water separator, pressure water level in drum or separator, the temperature on drum wall, superheat steam pressure, superheat steam temperature, reheat steam pressure, feed water pressure, and temperature are the principal operations of a boiler unit (*IEEE Recommended Practice for Operation of 300 MW to 600 MW Pulverized Coal-Fired Boiler, 2021*). As these boiler operations are critical and complex, they require automation of the boiler unit. A boiler is a closed packet unit where water or fluids are heating up for generating steam for industrial use (Wang *et al*, 2021). In (Tatem, John A, *et al* 1979) author shows five different types of boilers (i.e., sectional, vertical, water–tube, horizontal, and packaged boilers) used in the industry. In sugar mills, the bagasse, cane top, and molasses help to produce electricity for self-consumption, making them self-reliant. The sugar industry can sell electricity if its boiler is more efficient to simulate the burning process. In (Torres Agredo *et al*, 2014) Electricity production correlates with the boiler efficiency index. In (Zuberi *et al*, 2019), the pharmaceutical and chemical industry is top among all industries, with 22% and 25% CO2 in Switzerland. Adequate boiler technology can help in reducing CO2 emissions. Suppose a boiler is efficient enough to produce high-pressure steam. In that case, electricity production can be double, and extra heat can be used for other processes. Therefore, in (Rosen, *et al*, 2004), the authors investigate some technical factors that enhance the steam supply for industrial heating. A mid-size oil refinery spends approximately $7 million/year on steam production used for several processes like driving pumps and turbine generators. Therefore in oil-refinery, if boiler efficiency is maintained, it can reduce the operational cost (Al-Moubaraki *et al*, 2021).

In (Khajavi *et al*, 2007), the author investigates if an abnormality in the boiler operation can lead to corrosion, leading to frequent failure of processes. In (Khajavi *et al*, 2007), the author observed that increasing the load can show deflection in the upper and lower limits of sodium phosphate ratio, which requires accurate monitoring of the boiler system. In (Dugué, 2017), the author investigates that the leading causes of hazards in the oil and gas industry are failure in heaters, petrochemical furnaces, and boilers. In (Varma *et al*, 2015), the author in the cement industry has proposed a cogeneration plant design for heat recovery. In (Varma *et al*, 2015), this design, the water is pumped through the deaerator to the boiler pressure, which is then supplied to different associate pipelines of flow control to recover waste heat. In the above literature, it is found that the usefulness of a boiler is significant in industries. Therefore, making the boiler more efficient requires proper operation and a continuous monitoring system. In (J L Goa, 2019) , the temperature and pressure of the industrial boiler is controlled by a fractional PID algorithm to ensure the safety of the boiler system. Automation in the industry depends upon the supervisory system. In (Brandin, 1996) shows that modular and centralized supervisory control is adopted for the small manufacturing industry. To provide smooth operation and control to the gas burner system PLC is used in (Bhowmik *et al*, 2012). The PLC is programmed with a self-protection scheme in SIMATIC STEP 7-Micro/WIN programming software. The PLC is the most sensitive equipment so that a small disturbance PLC can trip or malfunction the boiler operation (Behera C *et al*, 2018) (Behera C *et al*, 2020). As the PLC is essential for automatic operation, its control plays an important role; otherwise, the industry will face substantial financial loss (Behera C *et al*, 2020) (Behera C *et al*, 2019). From the above literature, boiler automation requires a proper controller and supervisory system to operate smoothly without and failure. If any failure occurs, it will lead to considerable financial losses. Therefore, in this paper, SCADA monitors the boiler operation, and PLC is used to control the boiler operation by implementing the set of logical instruction, sequencing, timing, counting, and arithmetic operation. The proposed model helps to monitor and control the essential recruitments like temperature, steam pressure, and drum level using PID. The set of logical statements used in the PLC can be modified for increasing efficiency and safety operation. The Sx programmer expert (D300 Win) software is used to program the PLC.

Apart from introduction section-1, the remainder of this paper has been organized as follows: Section 2 presents the component of automatic boiler system. Section 3 discusses the overview of boiler. Section 4 presents the case study analysis. Finally, conclusion has been discussed in Section 5.

2. Component of Automatic Boiler System

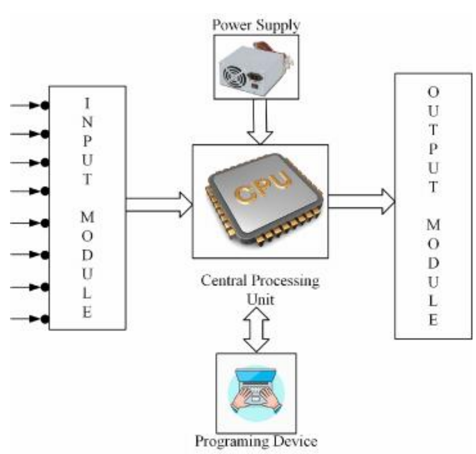

Figure 1. Major Components of PLC

A medium-size boiler produces a very high temperature (i.e., 1200°C) to boil liquid and convert it into steam; therefore, controlling the vapor and drum level at such a higher temperature is a hazardous critical task. Therefore, the automatic boiler unit must minimize human mistakes and increase a boiler's efficiency. There are three modes of operation in a boiler that need to be controlled simultaneously. The first mode of operation monitors and maintains the drum level.

In the second mode of operation, the logical unit is activated to send the signal to the boiler to start. If a sufficient amount of heat is produced, then the monitoring and control of steam are easier. In the third mode of operation, the steam pressure is maintained to be properly utilized for further industrial applications. All the mode of operation is operated through the PLC unit shown in Figure.1.

2.1 Programmable Logic Controller (PLC): The significant component of PLC is shown in Figure.1. The PLC uses an input module to collect analog or digital field data to execute the program accordingly.

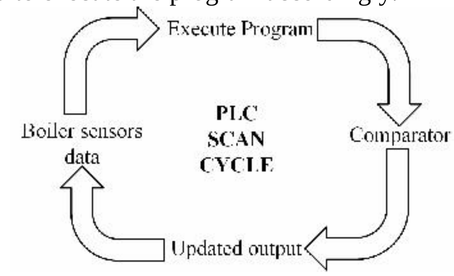

Figure 2. Scan Cycle of PLC operation

Then from the output module, the data are sent to the field through an analog or digital module. The PLC has a scan cycle that executes its operation, with the boiler sensors data as the input to the scan PLC scan cycle. Then the logic program is executed then with the help of a comparator, and the signal is compared with the old signal if required. The new signal is generated and passes to the updated output. The program length should be less so that it can be executed within a few milliseconds, and the PLC scan cycle is shown in Figure.2. So the scan cycle of PLC first scans the output status, updates the program, and executes the output. Another major component of PLC is its Central Processing Unit (CPU) and the brain of any PLC. The CPU performs all the arithmetic and logical operation. The power fed to the CPU is the first filter for providing a controlled DC supply. The programing device or monitor is connected to the PLC circuit; all the logic is programmed and monitored with this programming unit.

2.2 Operation of PID Controller: The operator must control crucial parameters like temperature, pressure, feeder speed, and drum level in an industrial boiler. In a boiler, the fuel feeder and furnace require fuel at a constant rate, and air respectively requires an accurate control technique. So without a proper control technique, the boiler operator has a switching option (i.e., “ON” and “OFF”), which makes a very critical task for the operator. When the operator controls these crucial parameters with the PID controller, it operates smoothly, and the efficiency of the boiler increases. More than 95% of boiler automation, controller, PI, PD, and PID, are used for the control process application. As the PID controller is simple in operation, it has been widely used in the process industry. The sample block of the PID controller used in the boiler is shown in Figure.3.The boiler sensor data are converted to analog input set points of the PID controller shown in Figure.3. After entering the set point, the PID starts to operate according to its logic and provides 100% output it means the PID is in operating condition. The 100% output of PID helps the process to maintain its threshold limit for the required operation. After some time, when the process value starts to go above the set value, then the PID controller starts decreasing from 100% to 0% to achieve the set desired set point. If the process value goes below the process value, PID operates and increases the value up to 100%. So if an operator can control the speed of Variable Speed Drive (VFD), then the temperature of the furnace can be controlled. Similarly, the drum level requires maintaining the water level at a certain point for the smooth operation of the boiler. So with a proper PID controller, the analog signal of the drum level can be fed to the PID controller module and through the SCADA monitoring unit so that the operator can get the exact set point values to maintain the water at the drum level.

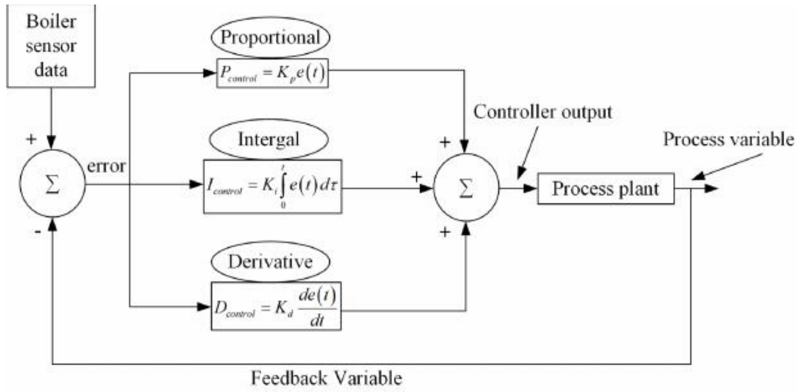

Figure 3. Schematic block for PID controller used for boiler

2.3 Supervisory Control and Data Acquisition (SCADA): The SCADA system gets information from processes that are needed to control. The SCADA can monitor the industrial process located at a far distance. The telemetry mode of communication is used to send the instruction or program and obtain the desired output at the monitoring unit from the remote location. The PLC and SCADA are interconnected through a communication cable, and it has some communication protocols like RS485, RS232, Ethernet, and Modbus. The SCADA is a supervisory control; if an operator wants to change any analog set value for further process, it needs to change the set value through SCADA to the PLC. The SCADA also helps to give the graphical representation of various outputs so that it is helpful for smooth operation. The SCADA unit record data of the analog signal, which will further help in future expansion and cost estimation of any product. The sample block of the operation of the SCADA monitoring unit is shown in Figure.4.

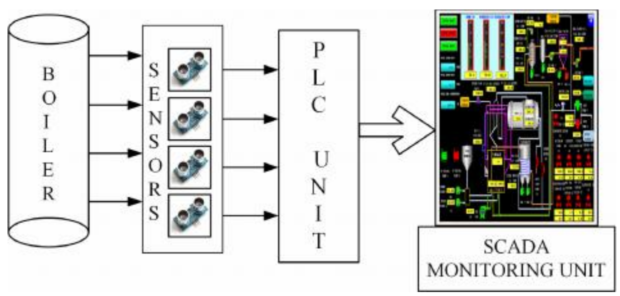

Figure 4. Sample block diagram of SCADA system

The SCADA unit consists of field instrumentation, field controller, network connectivity, and database in boiler automation. All types of sensors connected to the boiler are fetching to the SCADA unit through field instrumentation. The controller data like PLC or connected to the field controller are fetching to the SCADA unit. Different protocols are connected through network connectivity

3. Overview of Boiler

In this paper, boiler automation is done for the chemical industry. The boiler is attached with different types of sensors listed in Table.1. The sensor values are fed to the PLC, and with the help of the SCADA system, the boiler can be operated smoothly. The boiler has three-stage of operation, which need the proper monitoring system. Stage 1 is the boiler water flow system shown in Figure.5. In stage 1, the water is stored in the client tank for the boiler process. In the client, tank water is treated to avoid the tank's corrosiveness. Then water is stored at the treated water storage tank. Then with the help of a make-up pump, it forced the water to flow into the deaerator tank through the control valve. The PID controller uses these control valve values to maintain the drum deaerator tank level.

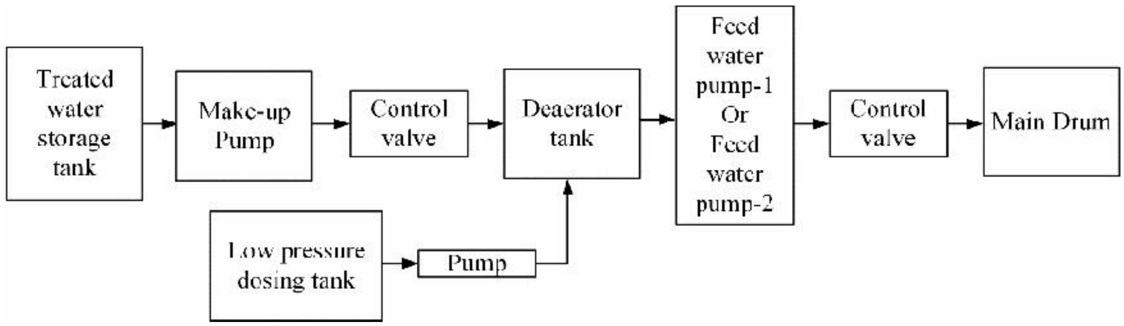

Figure 5. Stage 1 of boiler water flow system

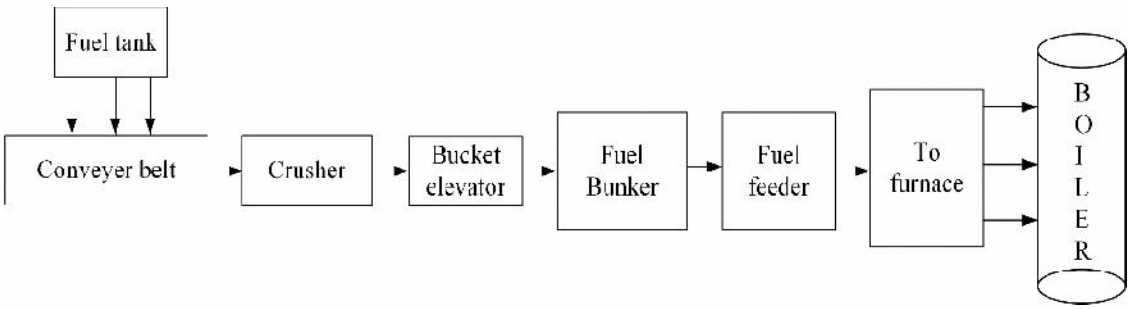

Figure 6. Stage 2 Fuel handling system

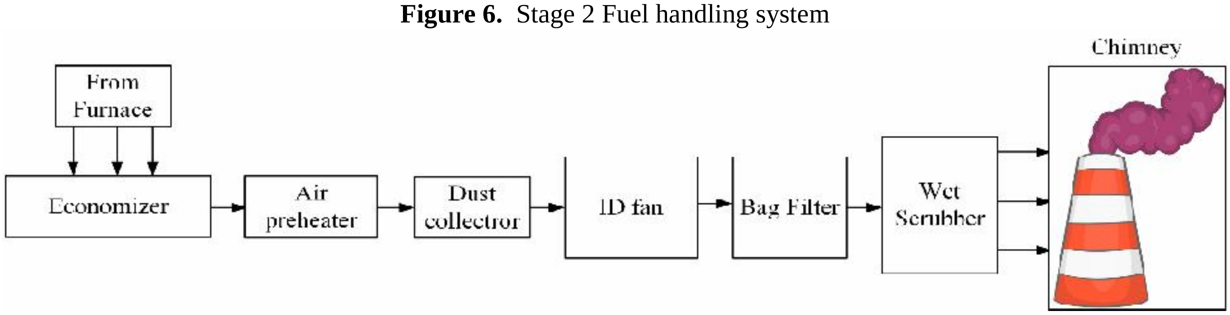

Figure 7. Stage 3 fuel gas flow structure

Table 1. Lists of major sensors for boiler operation

Sensors	**Range**	**Unit**	**Sensors**	**Range**	**Unit**
Water flow transmitter	0 - 5000	MMWC	Level transmitter	0 - 100	-
Steam flow transmitter	0 - 5000	MMWC	Pressure transmitter	0 - 35	BAR
Thermocouple	0 - 1200 (K TYPE)	°C	Oxygen analyzer	0-100	-
Resistance temp detector (RTD)	0 - 600	°C	Total dissolve solid (TDS)	0-100	-
Floaty switch	ON/OFF	-	Proximity	ON/OFF	-

Table 2. Component boiler at stage 2

Component	**Rating**	**Component**	**Rating**
Induced draught (ID)fan	40 HP	Rotary actuator valve (RAV)	1 HP
Forced draught (FD) fan	60 HP	Belt Conveyer	3 HP
SFD	7.5 HP	Bucket elevator	5 HP
Feed Pump	30 HP	High pressure dosing pump	1 HP
Feeder	1 HP	Low pressure dosing pump	0.5 HP

A low-pressure dosing pump is used when the deaerator tank encounters low pressure. The deaerator tank water flows to the main drum through feed pump-1 or pump-2 through the control valve. The main drum capacity is 2000 liters to maintain the drum level with the help of the PID operator. Stage 1 has two feed pumps for uninterrupted water supply to the main drum where the steam is generated. Stage 2 is the fuel handling shown in Figure.6. In stage -2, coal is used as fuel, which is crushed into the appropriate shape to be done at a higher efficiency. After proper sizing of the coal, the bucket elevator helps the coal gets into the fuel bunker. The fuel bunker has a nozzle at the end, which ensures the fuel feeder's flow onto the fuel feeder or screw feeder to fuel the furnace where the coals are burning. The significant component of stage 2 is listed in Table.2. Stage-3 shown in Figure.7, is the flue gas flow where the coal is burned in the furnace and produces huge amounts of carbon dioxide, polluting the environment. Then from the furnace, fuel gas goes to the economizer where the heat is recovered. From the air preheater, the heat is extracted from the hot fuel gases then goes to the dust collector, where ash particles are collected. The ID fan extract that gases from the furnace go into the bag filer where the dust is collected and goes out from the lower end of the bag filter. The fuel gases goes in to the wet scrubber, which absorbs both air and solid pollutants from that gases then the fuel gas is free to out to the atmosphere.

4. Case Study Analysis

In this section, the PID control crucial parameters like deaerator level, desuperheater temperature, drum level, steam pressure, deaerator temperature, Pressure Reduction System (PRS), steam pressure, and steam temperature for the smooth operation of the boiler. The two significant boiler components are water and steam, so to evaluate the flow, these two components following equations are used in the chemical industry.

$$Steam\ Flow = \sqrt{FT} \times Flow_{Cont} \tag{1}$$

To evaluate the steam flow equation (1) is used where $\sqrt{FT}$ is the steam flow transmitter scale, $Flow_{Cont}$ is flow constant off-set and its value 0.7-7. Now the final steam flow is given in equation (2). If the operator fails to maintain the drum level, there is an overflow of treated water, which further causes economic and production losses. The overflow of water fails to remove the dissolved gases from water, leading to the corrosion of the boiler, piping, and other necessary equipment. The amount of water flow is evaluated using equation (3).

$$Final\ Steam\ Flow = \left[\left(\frac{P_{Actual} + 1.033}{P_{deifined} + 1.033}\right) \times \left(\frac{T_{Actual} + 273}{T_{deifined} + 273}\right)\right] \times Steam\ Flow \tag{2}$$

$$Water\ Flow = \sqrt{WT} \times Flow_{Cont} \tag{3}$$

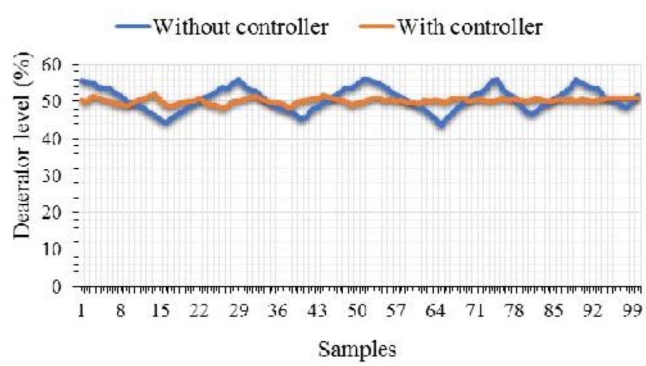

Figure 8. Boiler deaerator level control with and without controller

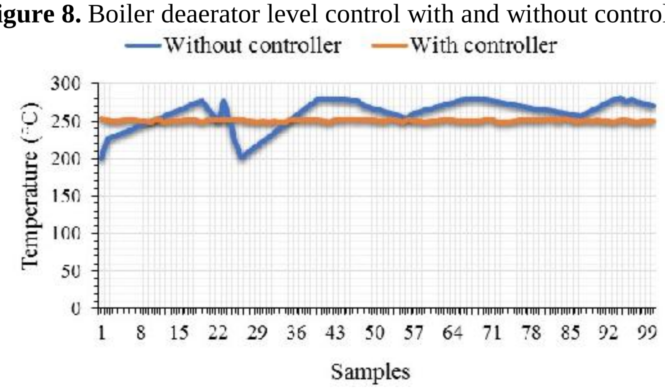

Figure 9. Boiler desuperheater temperature with and without controller.

The deaerator level is maintained to its desired value using the PID controller and the SCADA system operator monitor. In this paper, the set point for the deaerator level is 50%, the values for P, I, and D are 200, 50, and 20, respectively, depending upon the process shown in Figure.8 it has demonstrated the values before and after the drum level controller. Moreover, it is found that the fluctuation in the deaerator level before the PID controller is more. After implementing the PID controller, the deaerator level is maintained at 50%. The deaerator must keep a 50% level of the deaerator tank, which helps feed water to the main drum.The control of desuperheater temperature is shown in Figure. 9. Furthermore, the P, I, D values are 200, 100, and 20, respectively, as required. The operator needs to maintain the desuperheater temperature at 250 degrees Celsius for this system, which is possible through the PLC-based SCADA system. Desuperheater reduces the temperature of the steam generated at high temperatures and pressure. If an operator fails to maintain the desuperheater temperature, then there will be a sudden decrease in temperature, affecting the production process.

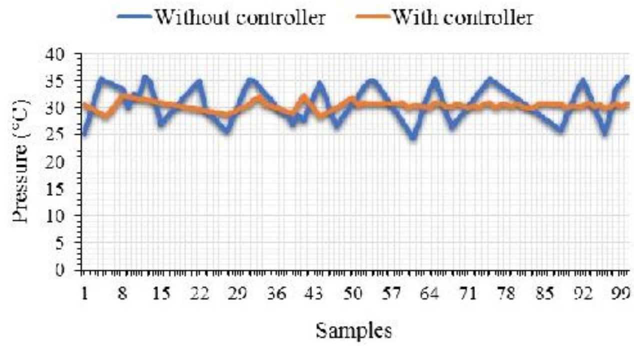

Figure 10. Boiler steam pressure with and without controller

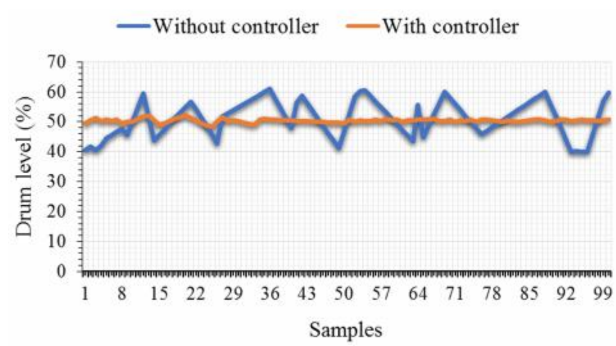

Figure. 11. Boiler drum level with and without controller

The boiler's steam pressure in this work needs to be maintained at 30 bar, shown in Figure.10. If the operator fails to maintain the steam pressure, the excess steam can damage the steam pipe and the turbine equipment. The PID values for Figure.10 are 170,100, 20, respectively, for maintaining moisture at 30 bar. The boiler's Drum level needs to maintain at 50% where the steam is generated. If an operator fails to maintain the drum level, then the boiler's efficiency decreases. Therefore, to maintain the drum level, the PID values in this work are 200, 100, and 10. A lower efficiency boiler leads to heat wastage, leading to economic losses. The drum level with and without the controller is shown in Figure.11. The PRS steam pressure needs to be maintained at 10 bar in this work. The PID values for controlling PRS steam pressure are 200, 100, and 20, respectively. If an operator fails to maintain the PRS steam pressure, then immense pressure will release due to the low pressure at the steam tank, which is not suitable for the turbines. This low steam pressure is not helpful for the turbines. Moreover, the wastage of steam pressure production of electricity hampers leads to financial losses. The PRS steam before and after control is shown in Figure. 12. The steam temperature of the boiler in this work needs to maintain at 250 degrees Celsius. If an operator fails to maintain the steam temperature, moisturized steam can reduce boiler efficiency. Which also causes corrosion of the pipes lines, further affecting a boiler's life. The PID values for this work are 200,100, and 20, respectively. The boiler steam pressure with and without a controller is shown in Figure. 13. From Figure.8 to Figure.13 it is found that boiler automation helps the plant operator maintain the boiler unit's desired level for the boiler's smooth operation. The financial analysis with and without a controller is given in Table. 3.

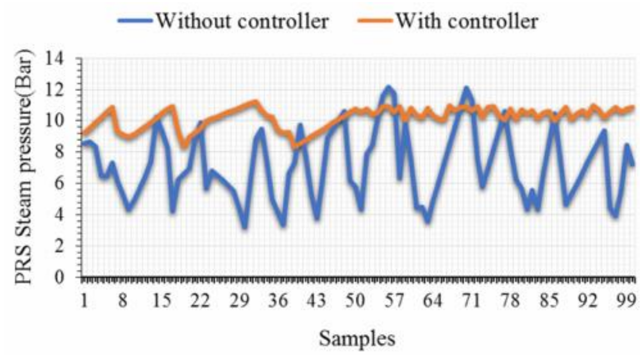

Figure. 12. Boiler PRS steam pressure with and without controller

When the SCADA-based PLC system is not adopted in the chemical industry, the essential worker needs to work at each point of the control unit, which is unnecessary. Therefore after boiler automation, the industry spends only Rs 500/day, and other employees can work at a different department. The labor cost before and after boiler operation is given in Table.3. Similarly, when automation is not done for the boiler, manual control delays the whole process, causing the boiler to increase the boiler operational cost.

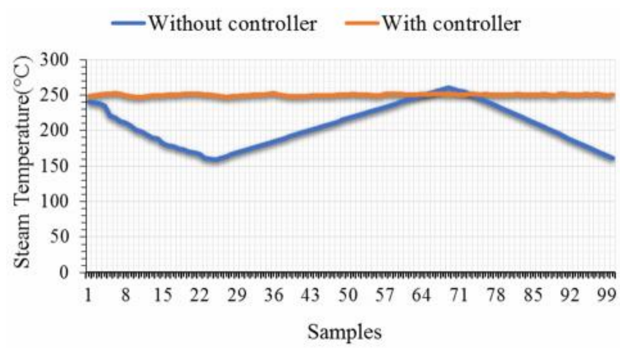

Figure. 13. Boiler steam pressure with and without controller.

Table.3. Financial analysis with and without boiler automation in a chemical industry

Sl. No.	Cost parameters	Cost Automation (INR)	Cost After Automation (INR)
1	Labor	4000/day	500/day
2	Fuel	300000/day	200000/day
3	Production waste	1388/day	0/day
4	Water waste	20000/day	0/day
	Total	**325,388/-**	**200,500/-**

The extra fuel will burn unnecessarily, which is an additional burden for the industry, so with the help of boiler automation, the fuel consumption is also less. Due to manual operation, there is a wastage of production; after automation, the production wastage becomes nearly about zero, shown in Table.3. Due to the manual process, there is an overflow of water in the control tank. Therefore industry suffers a wastage of 20-25 liters of water per day. However, it is reduced to zero after automation, given in Table.3. From the above analysis, it is found that the boiler required automation for smooth operation and which further helps in reducing operational and maintenance costs for the industry.

5. Conclusion

The boiler's automation helps the operator maintain efficiency so that other necessary operations would not hamper production. It is imperative to adopt a controller in the industry. Moreover, that controller needs to look after various objectives like superior quality, increased efficiency, high profit, and other various objectives of an industry. In this recitation, a PID controller is adopted for SCADA and PLC to control crucial parameters of the boiler such as steam pressure, steam temperature, water level, water flow, and tank level. Thus its helps to obtain better efficiency, higher production, and better safety. The expression calculates the steam and water flow for the chemical industry, which monitors the water and steam temperature before and after automation. The results show how the crucial parameters like deaerator level, desuperheater temperature, drum level, steam pressure, temperature, Pressure Reduction System (PRS), steam pressure, and steam temperature fluctuate when operated manually. The boiler deaerator level must be 50%, but it fluctuates without the controller between 40 and 60 %. Similarly, the Boiler desuperheater temperature should be 250 degrees centigrade with PID values of 200, 100, and 20, respectively. However, after implementing the controller and the SCADA system, the chemical plant operator can run smoothly and help increase the efficiency of a boiler. It can be observed from the result that when there is no boiler automation, the chemical plant suffers from the financial loss of INR 325,388/- per day, but after automation, the financial loss is reduced to INR 200,500/- per day. Therefore, this paper will significantly help the industrial personnel go for the boiler unit's automation to avoid unnecessary equipment damage, production, and financial loss.

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