Automation of the burner of a pirotubular boiler to improve the efficiency in the generation of steam

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Article Info

Article history:

Received May 21, 2020
Revised Jul 23, 2020
Accepted Aug 10, 2020

Keywords:

Automation
Burner
Efficiency
Fire tube boiler
Human machine interface
Oxygen percentage
Programmable logic controller
Steam generation
Variation of oxygen

ABSTRACT

The purpose of this article is to describe the automation developed by means of a programmable logic controller for the burner of a fire tube boiler, in order to improve the efficiency in the process of generating steam quantified through the percentage of oxygen generated. The implementation was developed under a control strategy based on the use of servomotors that allow to gradually open or close the solenoid valves that dose the amount of air and fuel; Considering that there are multiple elements, I limited the analysis to one of its main components, called the burner. After developing this automation, it was possible to demonstrate the decrease in the variability of the oxygen percentage in relation to the optimal or desired value in the boiler. The experimentally obtained data of the oxygen percentage, were subjected to a statistical analysis of dispersion, in which the value of the Pearson's correlation coefficient was determined, whose value was equal to 0.298; This result allowed to conclude that the degree of variability of the indicator in analysis with respect to time is very low, which means that the variable maintains a constant value, equal to the desired value, after automating the fire tube boiler.

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1. INTRODUCTION

After James Watt's inventions and improvements, steam engines became the first choice for energy conversion [1]. The boilers were also subject to technological improvements, driven by seeking a heat source, without the drawback of burning coal [2]. Currently the trend is to refer to these machines as steam generating equipment, referring to the combination of heat production or recovery and additional heat transfer to a working fluid [3].

On the other hand, the combination of higher energy consumption and the wide availability of fossil fuels, added to the lack of knowledge about renewable resources, led many countries to adopt energy supply using thermoelectric plants [4]. This contributed to a significant increase in the number of boilers in production processes [5]. However, over the years, the cost of fuels increased and environmental problems became important concerns for modern society [6]. Thus, professionals related to the flush of boiler manufacturing concentrated efforts on improving the efficiency of the steam generated [7].

Currently, due to various improvements and increasing industrial production, steam is still used in different activities, such as cleaning, heating and as an input for production processes, in addition to power generation [8]. Although several international agreements have been signed to preserve the environment, many boilers remain operating under inappropriate control configurations, with efficiencies considerably far from the manufacturer's specifications [9]. One of the ways to quantify this lack of efficiency in the boilers is through the percentage level of oxygen measured in the chimney of a boiler [10].

Fire tube boilers are characterized by the circulation of the combustion gases inside the tubes, while the water to evaporate surrounds the outside surface of said tubes [11]. The entire assembly, water and multitubular heat transfer package, is located inside the boiler body, formed by a cylindrical body with a horizontal arrangement, which has an upper chamber for the formation and accumulation of steam [12]. To ensure maximum efficiency in the operation of this type of boiler, it is essential to maintain a correct air/fuel ratio, which guarantees that combustion is complete within the design limits [13]. Another important aspect is to ensure that the exact amount of fuel is burned at all times, which makes it possible to keep the outlet steam pressure within the required limits, regardless of variations in load [14]. These requirements cannot be guaranteed without an effective control system for the boiler combustion process.

Technological advance brought with it that industrial automation is seen as an alternative that allows optimizing production processes, always seeking to reduce the use of inputs, improving the quantity and quality of production [15]. The solution to the quest to contribute to the reduction of fuel use is based precisely on the functionalities and advantages offered by using a programmable logic controller [16]. The programmable logic controller algorithms provide security to the process or machine, thus guaranteeing system shutdown in the event of communication failure between servers [17].

The use of mechanisms based on manual control, has shown in the operation of a boiler the lack of precision and with them the inefficient use of inputs (air and fuel) used in the production of steam [18]. Another important aspect of the manipulation of operators in the control of a boiler is the error in measurement of the operation indicators, since they express variation in what is needed and what it offers in terms of inputs [19]. To automate a power plant and minimize human intervention, it is necessary to develop a PLC (Programmable Logic Controller) and SCADA (Supervisory Control and Data Acquisition) system to help reduce errors in order to improve dosing and improve the precision of operation indicators through sensors and actuators that allow self-regulation of the piruitubular boiler [20]. Likewise, the SCADA system includes operation interfaces, communication systems and instrumentation and control system equipment, that is, it is a set of software applications specially designed to work on production control computers, with access to the plant through communication digital with instruments and actuators [21].

In this sense, the purpose of this article is to describe the automation developed by means of a programmable logic controller for the burner of a fire tube boiler, in order to improve the efficiency in the process of generating steam quantified through the percentage of oxygen generated. The implementation will be carried out under the control strategy based on the use of servomotors that allow gradually opening or closing the solenoid valves that dose the amount of air and fuel, being monitored from an HMI panel (Human-machine interface).

2. PROCEDURE

The following describes initially the control logic on which the programmable logic controller will be programmed; for which the elements to be sensed (percentage of oxygen and vapor pressure) were identified inciclamente, and on the other hand to identify the actuators that will allow to actuate the elements that will allow to regulate the dosage of air and fuel in the fire tube boiler. Once what was controlled by the automation was identified, the requirement provided regarding the desired values for each of the variables under analysis was transferred to the PLC programming; Table 1 shows the control logic. Figure 1 shows the schematic of the connection architecture of the sensors and actuators with the programmable logic controller, which reflects the logical conditions defined in Table 2.

Table 1. Control logic according to the percentage of oxygen and vapor pressure

Variables to control	Present value of the variable (pv)	Servomotor 1 (air damper)	Servomotor 2 (fuel damper)
Oxygen percentage	pv < 3%	For every 0.1% below it must close 3 °	For every 1% below it must close 5 °
	pv >= 3%	For every 0.1% above it must be opened 3°	For every 1% above it must open 5 °
Vapor pressure	pv < = 125 psi	For every 1 psi below it must open 2 °	For every 1psi below it must open 2.4 °

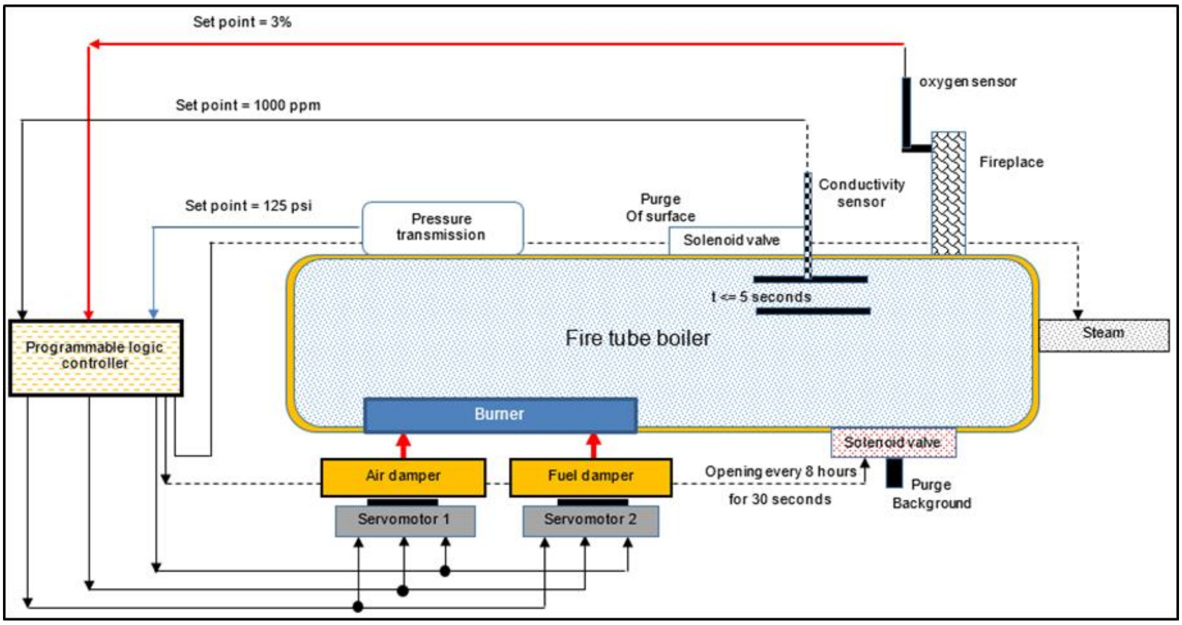


Figure 1. Sensor and actuator connection architecture with the programmable logic controller

Table 2. Drive logic for the bottom and top blowdown of the boiler

	Drive Logic
Bottom Blowdown	Valve will open every 8 hours for 30 seconds
Superior Purge	Particulate level per million> 1000, purge valve opens for 30 seconds

From the control logic shown in Table 1 and Table 2, and as outlined in Figure 1, the programming of the programmable logic controller is then performed; below is a summary of some programming windows.

In Figure 2, the first segment of the Organization Block OB1 programming is shown, the "Start" input is defined, in which the normally open button (% I0.0) will be connected, it will be used to start the process. The "Stop" input is also defined, in which the normally closed button (% I0.1) will be connected, whose function is to stop the process at any moment. Additionally, the inputs for turning on (% M1.3) and turning off (% M1.4) the HMI panel (Human Machine Interface) were defined.

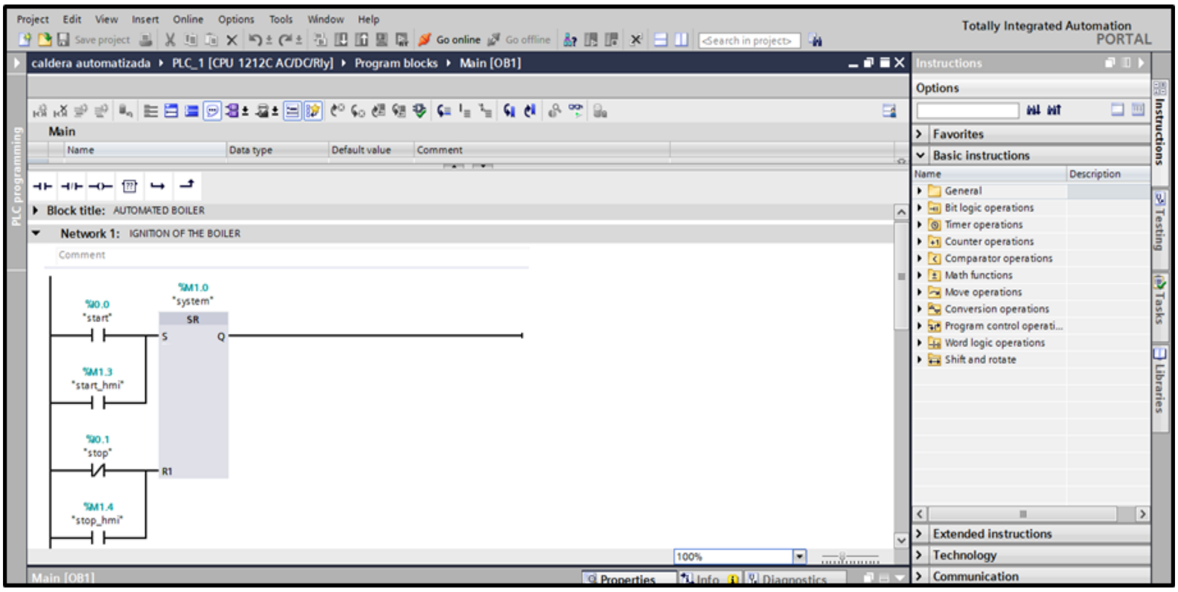


Figure 2. Defining the start and stop inputs of the automated boiler and the HMI panel

In Figure 3, the lower purge stage is shown, it operates every 8 hours by means of a TON timer (timer with delay in connection), which is programmed for 24 hours, the same that will activate the solenoid valve every 8 hours by means of the comparator blocks (equal to 8 hours, 16 hours, 24 hours) that are subject to the timer and have a working time of 30 seconds which works with a TON timer, a counter was placed in order to reset the first TON timer when it arrives at its maximum time (24 hours), and the counter is reset after the first 1 hour of the first TON timer. So that there is no conflict in time since you have a permanent work time.

In Figure 4, it is shown that the upper purge stage works through the conductivity sensor, which the sensor was scaled using a NORMA_X block, which has a digitization range of 0-27648, and then this digitization is converted to the other block. which is SCALE_X with a range of 500-1500 PPM (particles per million), which is considered as a reference for installation in the boiler, when the conductivity sensor reaches its Set Point (1000 PPM), solenoid valve 2 is activated by a comparator block (equality), with a working time of 30 seconds, which is programmed by means of a TON timer.

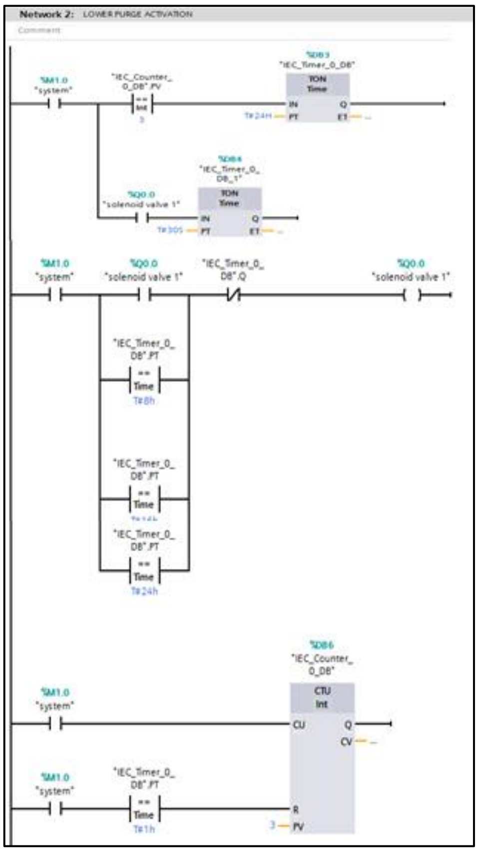


Figure 3. Scheduling the lower purge stage

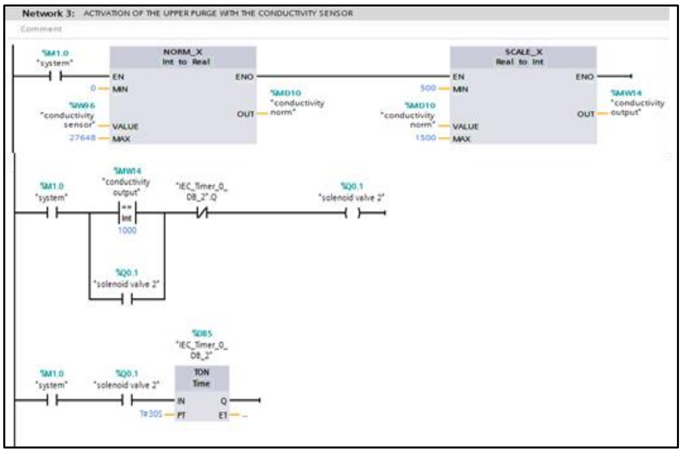
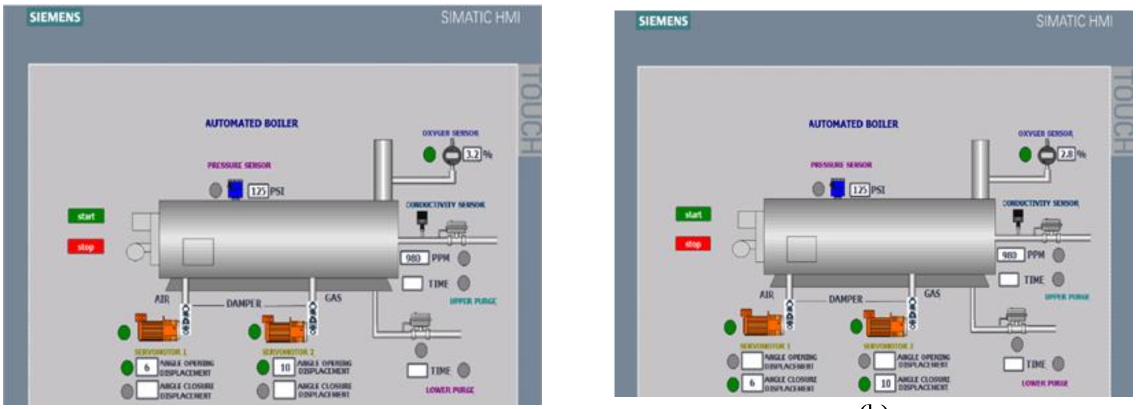


Figure 4. Programming of the upper purge stage

Thus, programming and configuration were also carried out to moniotrogate the process through the HMI panel (Human Machine interface); in Figure 5, one of the HMI windows showing the data capture from the pressure sensors and the oxygen sensor are shown as a system. In Figure 5(a), the scenario is evident when the oxygen sensor is 0.2% above our set point (3.2%). Servo motor 1 has an opening angular displacement of 6 ° for the opening of air, and the servo motor 2 has an opening angular displacement of 10° for the gas, so that the system finds its stability and the oxygen sensor returns to its set point (3%). So also in Figure 5(b), the scenario is evident when the oxygen sensor is 0.2% lower than the set point (2.8%), which means that our servo motor 1 has a closing angular displacement of 6 ° to the air, and the servomotor 2 has a closing angular displacement of 10 ° for the gas, so that the system finds its stability and the oxygen sensor returns to its set point (3%).



(a) (b)

Figure 5. Programming of the HMI, actuation stage of the servomotors - Oxygen sensor

3. RESEARCH METHOD

3.1. Design and level of research

The research design carried out in this article is the Experimental one, since it is intended to manipulate the initial conception of the air and fuel dosage of a fire tube boiler, in order to experience improvements in the percentage of oxygen; In other words, it seeks to generate an effect by manipulating the control process that governs the boiler burner [22]. The purpose of the experimental designs is to determine how the variation of a group of factors called variables affect the behavior of a system that is tested under controlled conditions [23].

The level of research addressed in this article is descriptive / correlational. Descriptive because it initially seeks to describe the control strategy, relying on the operation of a fire tube boiler and the dosage form of the indusmos (air and fuel), which generate the steam [24]. And it is correlational because it seeks to subject the collected data to a statistical test in order to obtain the Pearson's correlation coefficient, which will help us identify the degree of variability of the indicator in the “oxygen percentage” analysis, with respect to time [25].

3.2. Population and sample

In the present investigation, the population coincides with the sample because only one unit of analysis is analyzed, which is the fire tube boiler [26].

3.3. Data collection

The data collection will be carried out through technical reports, in which it is intended to carry out the data captures, in a time interval of two minutes for the period of one hour, in a single day; the data associated with the investigation is the percentage of oxygen, before and after the development and implementation of the automation [27].

4. RESULTS AND DISCUSSION

4.1. Results

In relation to the objectives of this research, which aims to improve the efficiency of a fire tube boiler from its automation through a programmable logic controller, the results obtained are shown below, from the data collected experimentally through reports. It is important to specify that the quantitative indicator under analysis is the percentage of oxygen measured at the outlet of the boiler chimney. Figure 6 shows the variability of the oxygen percentage.

From Figure 7, we can interpret that before the automation, the oxygen percentage showed greater variability with respect to the desired value; The oscillation range before automation turned out to be between 2.5% and 4.5%; whereas after automation the oscillation interval is almost entirely centered on the desired value; this is understood that the programmable logic controller through the sensors and actuators allow to open and close the dampers in a timely manner, correctly dosing the combination of inputs for the production of steam.

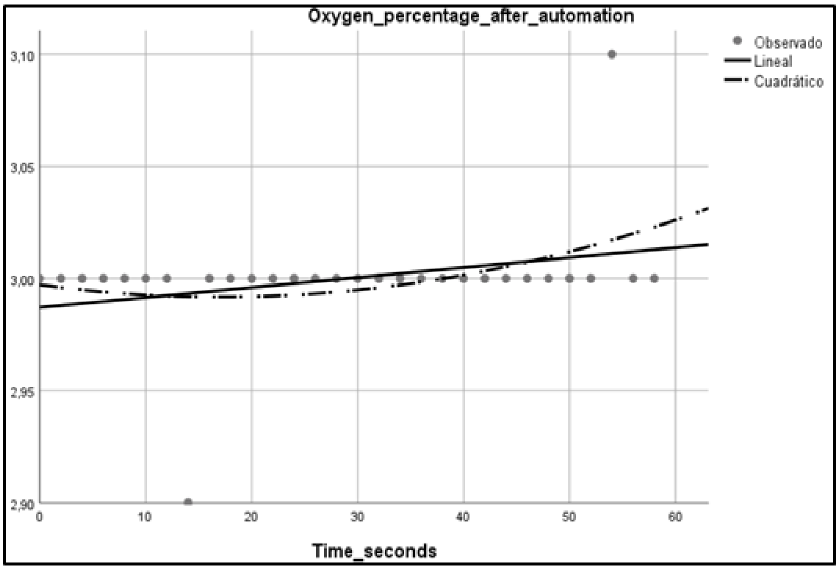


Figure 6. Dispersion model of the collected data

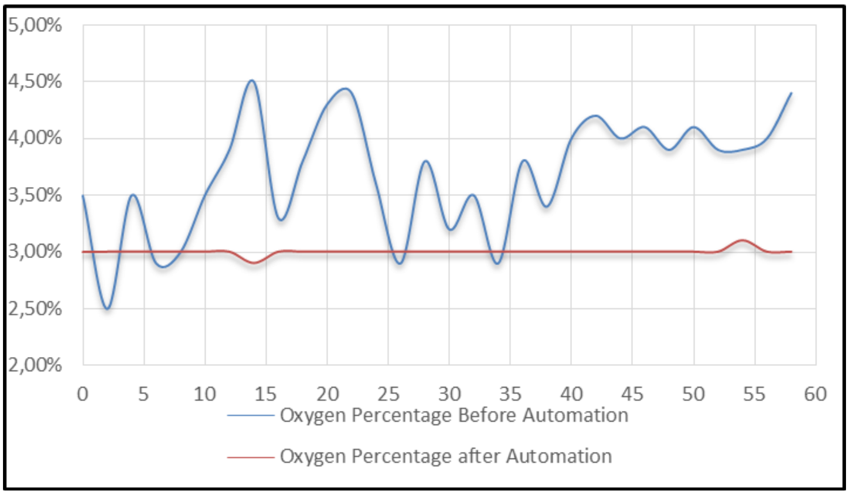


Figure 7. Variation of the percentage of oxygen measured before and after the automation

Now I will determine the average of measured values of the percentage of oxygen before and after automation. This is due to the fact that the optimal control of the air and fuel ratio leads to obtaining optimal results in terms of fuel consumption; in this sense, we define boiler efficiency using (1) [28].

$$eficiencia = \frac{PPODA-PPOAA}{PPOAA}\ x\ 100\% \tag{1}$$

where:
PPODA= Average percentage of oxygen after automation.
PPOAA= Average percentage of oxygen before automation.
Based on the data obtained above, the results will be replaced in (2):

$$\text{eficiencia} = \frac{3-3.69}{3.69}\ \text{x}\ 100\%$$

$$\text{eficiencia} = 18.69\% \tag{2}$$

According to the results, automation improves efficiency in steam generation, by 18.69%.

Also in Table 3, the result of Pearson's correlation analysis is shown, of the data collected after the process of automation of the fire tube boiler. This with the purpose of determining the reliability of the data from the dispersion analysis of the same.

Table 3. Pearson correlation analysis result

		Oxygen percentage after Automation	Time (seconds)
Oxygen percentage after Automation	Pearson Correlation	1	0.298**
	Sig. (bilateral)		0.000
	N	30	30
Time (seconds)	Pearson Correlation	0.298**	1
	Sig. (bilateral)	0.109	
	N	30	30

From the previous table it can be specified that the correlation factor is 0.298, which indicates that there is a low level of variability of the oxygen percentage with respect to time; In other words, with the automation of the fire tube boiler, the "oxygen percentage" was achieved to be constant, and equal to the desired value for an optimal boiler process.

4.2. Discussions

In relation to the results obtained before and after the development of the automation through a programmable logic controller in order to achieve effects on the indicator under study, the percentage of Oxygen, and having performed the data processing through the statistical correlation analysis, you have the following discussions:

In reference to automating a fire tube boiler by means of a programmable logic controller, it was possible to determine from the measurement of the percentage of oxyphene in the boiler chimney that it improved by 18.69%, in this respect Spinelli et al (2018), establishes that the Percentage improvement in efficiency obtained after automation was 22.8%, in this regard it can be established that said result is higher than that obtained in my research, because the boiler to which they refer uses a different controller than the one I used, from precisely they use a Proportional Integrative and Derivative PID controller [29]. Likewise, Zeasch et al (2016), points out that the percentage of improvement in the efficiency of the boiler after automating it, was 16.3% [30], in this regard this result is lower than that obtained in my research, because the type The boiler was not a fire tube, but a water tube boiler, whose operating principle is different.

In reference to the correlation of the data collected from the percentage of oxygen after automation, it was obtained that the Pearson's correlation coefficient is 0.298, which indicates that the level of variability of the variable under analysis is almost nil; In this regard, Spinelli et al (2019), established that the correlation coefficient obtained after automating a boiler through a PID controller turned out to be 0.251 [31]; which conjectured me to establish that the PID controller is more susceptible to small error signals related to the percentage of oxygen. Likewise, Bhimrao et al (2014), points out that the level of correlation obtained in their research turned out to be equal to 0.345 [32]; We can establish that its result is higher than the one obtained in my research due to the fact that in its control logic it establishes a higher setpoint value (3.5%) for the percentage of oxygen; thus generating a greater range of variability for the indicator under analysis.

5. CONCLUSION

It is concluded that it managed to automate the fire tube boiler, through the Simatic 1212C programmable logic controller, automatically regulating the servo motors that open and close the dampers that dose the burner of the fire tube boiler for the production of steam (air and fuel). Thus, before the automation, the oscillation interval of the oxygen percentage was between 2.5% and 4.5%, while after the automation in the oscillation interval it was between 2.9% to 3.1%, thus improving the efficiency of the boiler. by 18.69%.

Furthermore, it is concluded that, from the data collected during the various reports obtained during the operation of the fire tube boiler after the automation process, the Pearson's correlation coefficient was determined, whose value turned out to be equal to 0.298; which allowed us to establish that automation helped improve the variability of the oxygen percentage, measured in the chimney of the pylorotubular boiler. At a statistical level, we corroborate what was stated in the previous conclusion.

ACKNOWLEDGEMENTS

The authors wish to recognize and thank the National Technological University of South Lima for their support of this investigation and Federico Villarreal National University.

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