

Optimizing the Demineralizer Water Control System Centrally in Waste Heat Recovery Power Generation by Applying the PDCA Cycle

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Abstract— The cement production process consumes a significant amount of energy, particularly during the clinker burning stage. This stage generates high-temperature exhaust gases. Waste Heat Recovery Power Generation (WHRPG) technology captures this waste heat from the kiln to generate electricity; however, its efficiency largely depends on the quality of demineralized water. This study focuses on improving demineralized water quality through the implementation of a centralized control system based on the Plan, Do, Check, Action (PDCA) method. In the Plan phase, the root causes identified were delays in performing water regeneration and manual control of the demineralization process. As an alternative solution to these dominant causes, a centralized control system was proposed for the demineralizer area, located in the control room. The results show that the centralized system effectively reduced water conductivity to below 2 $\mu\text{S}/\text{cm}$, in accordance with the required standards. This improvement led to financial benefits of IDR 300,672,000 per year through reduced water replacement and boiler damage. Additionally, it provided non-financial benefits such as simplified operations and reduced maintenance needs. The established standards for input, process, and output contribute to the continuous improvement of WHRPG operational efficiency, thereby supporting more effective energy management in the cement industry.

Keywords: Waste Heat Recovery Power Generation (WHRPG), PDCA, Centralized Control System, Better Energy Management.

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1. Introduction

The process of producing cement demands a substantial amount of energy, with each ton of cement requiring approximately 3–4 Giga Joule of energy consumption [1]. The cement manufacturing process involves three primary stages: the raw mill, where raw mix material is prepared; the combustion process, which generates clinker; and the cement mill process, which produces the final cement product. Among these stages, clinker production through combustion is the most energy-intensive. While the theoretical minimum heat required to produce one ton of clinker is 1.6 GJ, actual energy consumption in a modern, well-equipped kiln averages around 2.95 GJ per ton of cement. In certain countries, this figure can even exceed 5 GJ per ton [2].

In cement production, electrical energy contributes to 50% of the total energy consumption [3]. The rest of the energy consumption is derived from thermal energy, making up 75% of the primary energy usage [4]. Thermal energy is mainly used in the combustion process, which relies on various fuels such as coal, diesel, and alternative energy sources. During this process, the kiln temperature can rise to as high as 1,450°C.

During the combustion process, fuel is burned at extremely high temperatures, generating exhaust gases from clinker production. These gases are then directed to the electrostatic precipitator (EP). The temperature of the flue gas in the EP can reach between 300°C and 350°C [3] [5]. To make use of the heat from kiln exhaust gases, the energy is captured and converted into electrical power through a system known as Waste Heat Recovery Power Generation (WHRPG). WHRPG operates as a steam power plant that utilizes hot gases produced during the cement combustion process in the kiln [5] [6].

WHRPG utilizes two types of boilers: the Suspension Preheater (SP) boiler, which harnesses exhaust gas heat from the preheater, and the Air Quenching Cooler (AQC) boiler, which captures exhaust gas heat from the clinker cooler. The steam produced by these boilers is then used to drive a steam turbine connected to a synchronous generator, producing electrical energy [6]. The water used in the boiler to produce steam is supplied by the Water Plant at Indarung 6. Before being pumped into the boiler, the water undergoes a demineralization process to purify it by removing minerals [7] [8]. Parameters that determine good or bad water quality include pH and conductivity (electrical conductivity) [7] [9]. If any of these water parameters are outside the acceptable range, it can reduce the steam boiler's effectiveness and cause damage, such as corrosion or scaling [10] [11].

In the WHRPG unit, the process relies on a wide range of instruments that are automatically controlled via the DCS. These instruments are highly sensitive and calibrated, and they are connected to the PLC, including motorized valves, control valves, sensors, and transmitters. In contrast, the initial control in the demineralizer area was local. However, this local control system encountered several issues, leading to poor water quality in the boiler. To address this problem, a centralized control system was implemented in the control room [12].

The aim of this study is to evaluate the success of controlling the demineralizer process in a centrally controlled room. To assess this success, the Plan, Do, Check, Act (PDCA) cycle method is used. The PDCA cycle is compared to a ball that needs to be pushed towards a predetermined target [13]. To improve quality, various efforts are needed to ensure that the PDCA cycle continues to drive continuous quality improvement [14].

2. Method

This research begins by identifying the problems found in the WHRPG. In the Plan stage, the priority of the problems is determined, the root causes are identified, and from these causes, the dominant root cause is selected. If obstacles are encountered during the Do stage, a repair plan is developed in the Plan stage. In the Do stage, the improvement is implemented. If problems arise, the process returns to the Plan stage for a repair plan; if not, it moves on to the Check stage. In the Check stage, the results of the improvement are evaluated, followed by the final stage, the Action stage. In this stage, a new standard is established based on the improvements that have been implemented. After some time, the WHRPG unit should continue to make improvements, ensuring that the PDCA cycle remains sustainable [15]. The method used in this research can be illustrated in the Figure 1:

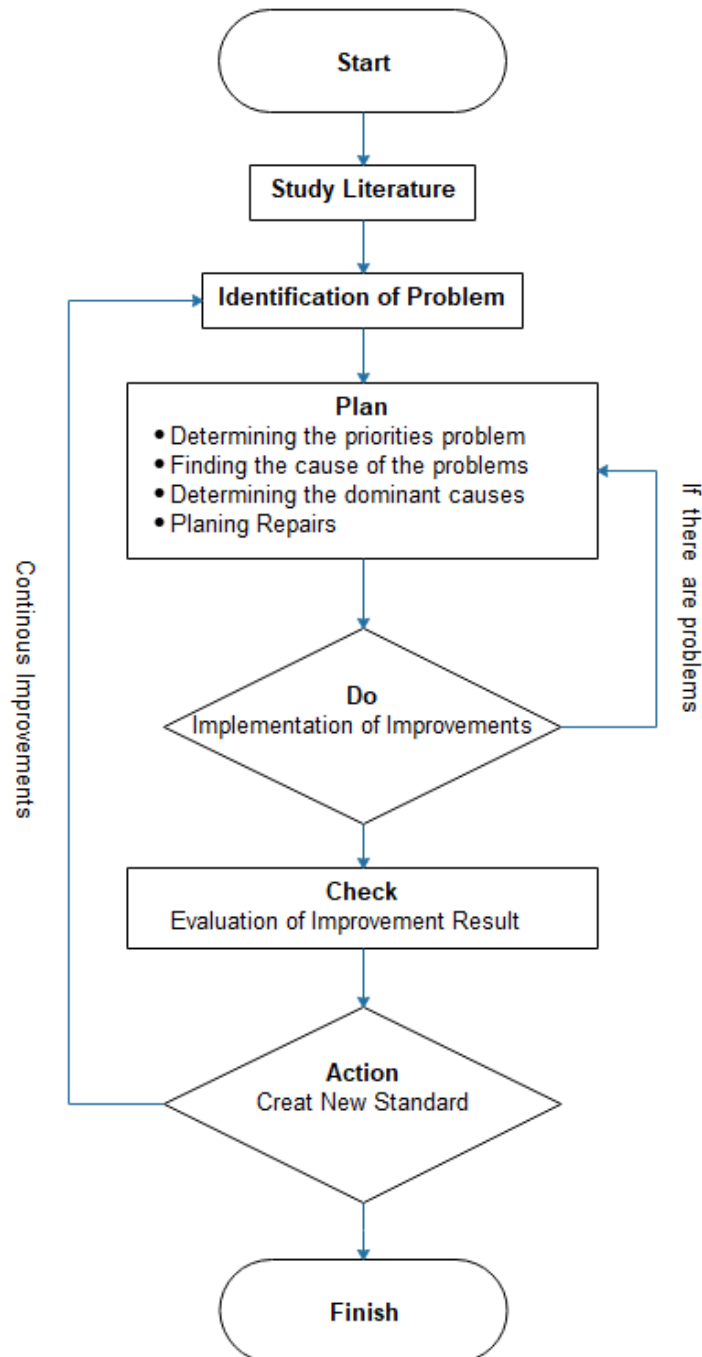


Figure 1. Research Methodology Flowchart

2.1 Research object profile

A power plant with a capacity of 8.5 Megawatts (MW) is a Waste Heat Recovery Power Generation (WHRPG) system that utilizes exhaust gas from the kiln of the Indarung V factory. The WHRPG project aims to conserve energy and reduce CO₂ emissions through the Clean Development Mechanism (CDM), which is a clean development initiative.

The working principle of Waste Heat Recovery Power Generation (WHRPG) generally involves utilizing exhaust gases from the kiln to heat water in a boiler, converting it into high-temperature steam that drives a turbine and generates electricity through a generator [16]. The process scheme of the WHRPG system can be seen in Figure 2.



The cooling tower functions as a cooling facility to lower the temperature of hot water coming from the vacuum condenser. Water from the cooling tower is pumped to the oil cooler, vacuum condenser, and turbine generator using a cooling water circulating pump. After being used in the cooling process, the water is returned to the cooling tower to be cooled again before being reused.

The demineralizer consists of three main processes: the Feed Water Tank, the Multimedia Filter, and the Mixed Bed. The purified water produced through this system meets boiler water quality standards and is stored in the demineralizer water tank. From there, it is pumped to the vacuum condenser to be combined with the condensate produced from the cooling of steam from the steam turbine. The resulting mixture is collected in the hot well, then pumped to the flasher, and subsequently to the Boiler Feed Pump (BFP), which delivers it to the economizer.

Steam enters the turbine at a pressure of 1.18 MPa. If the pressure becomes excessive, the steam is redirected to the vacuum condenser. Before entering the vacuum condenser, the steam is moistened with water from the flasher. The steam that drives the turbine is converted into electrical energy by the generator, then transmitted to a step-down transformer, followed by transmission lines, and finally delivered to the PT Semen Padang Substation.

2.2 PDCA cycle implementation

The PDCA model has been widely used in quality management approaches and business process reengineering [17]. The study demonstrated that the PDCA model can serve as an effective framework for integrating technical and strategic processes in the manufacturing sector. By adapting a similar approach, this research develops the application of PDCA in the control system of a water demineralizer in a waste heat recovery power generation (WHRPG) plant. A systematic approach to optimizing the demineralizer control system can be seen in table 1.

Table 1. Implementation of the PDCA Cycle in a Systematic Approach to Optimizing the Demineralizer Control System

Stages	WHRPG Applications
Plan	Identification of inefficiency causes in the demineralizer control system (e.g., sensor data, alarms, or response delays)
Do	Development of a centralized control solution
Check	Evaluation of new performance indicators (control accuracy, water/chemical consumption, downtime)
Action	Standardize the new system and develop operational procedures.

2.3 Problem Identification

The problems that arise from this background are listed in Table 2.

Table 2. Problem Identification

No	Problem Identification	Information
1	Water conductivity > 2μS/cm	The conductivity value of water after demineralization is greater 2μS/cm
2	Water pH > 9	The pH value of the water after the demineralizer is greater than 9
3	Water pH < 6	The pH value of the water after the demineralizer is less than 6

The results of demineralizer water testing in the laboratory in march 2023 can be seen in the Table 3.

Table 3. The Results of Demineralizer Water Testing before Improvement.

March											
Date	1	2	3	4	5	6	7	8	9	10	
pH	5,9	8,5	9	5,8		9,7	9,5	9,8	9,7	5,7	
Temperature	25	27	27	25		25,8	25	25	26	25	
Conductivity μS/cm	95	78	90	87		99	78	76	79	89	
March											
Date	11	12	13	14	15	16	17	18	19	20	
pH	9,5		8,3	8,3	9,37		8,9	9,3		8,8	
Temperature	25		25	24	25,6	Regen	26	27		26	
Conductivity μS/cm	90		75	73	74		35	88		75	
March											
Date	21	22	23	24	25	26	27	28	29	30	31
pH	9,4	8,8	8,8	9			8,6	8,2	9,1	9,3	
Temperature	25	27	24	26	Regen		27	25	26	25	Regen
Conductivity μS/cm	32	9	15	9			0,2	7	11	10	

3. Result and Discussion

The Results and Discussion section presents a detailed analysis of all the PDCA cycles carried out in this study. The first cycle starts with the planning stages.

3.1 Plan stages

The Plan stage is the initial stages of the PDCA cycle. It begins with identifying the priority of the problems, analyzing their root causes, and developing an improvement plan.

- a. Identifying the priority of the problem.

Based on the measurement results and analysis of the WHRPG demineralizer in Table 2, a Pareto diagram was used to determine the priority of the problem. The priority issue of this research is presented in Table 4 and Figure 3. According to the Pareto diagram, the primary problem identified in this research is water conductivity exceeding 2 $\mu\text{S}/\text{cm}$.

Table 4. Priority of the Problem

No	Problem Identification	Frequency of occurrence	Presentation (%)	Cumulation
1	Water conductivity > 2 $\mu\text{S}/\text{cm}$	24	65	65
2	Water pH > 9	10	27	92
3	Water pH < 6	3	8	100
Total		37	100	

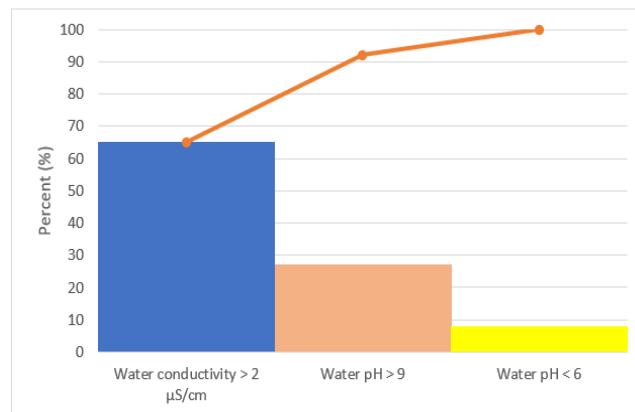


Figure 3. Pareto Diagram of the Problem Priority

- b. Determine the root cause

After identifying the priority problem, the root cause is analyzed using a fishbone diagram to determine its underlying factors [18] [19]. This research identifies six root causes: human factors, tools, environmental factors, methods, procedures, and materials [20]. A detailed breakdown of these root causes is illustrated in the fishbone diagram in Figure 4 below.

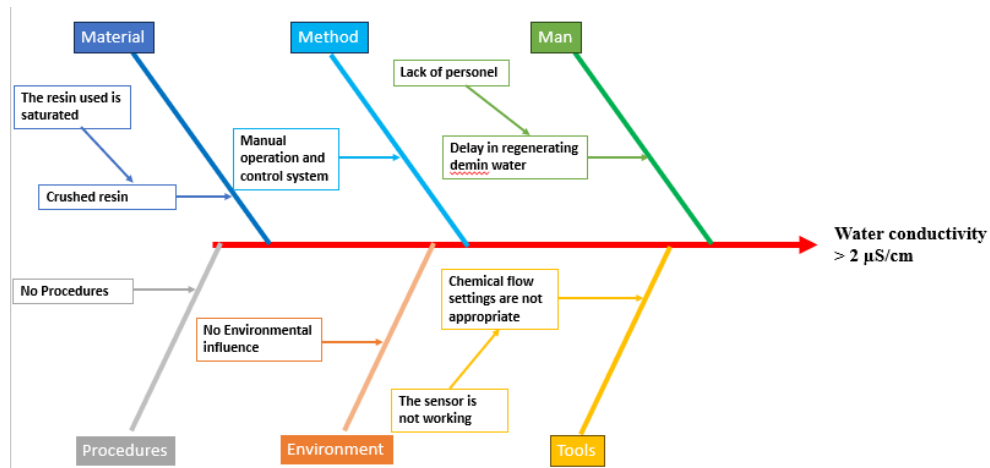


Figure 4. Fishbone Diagram of the Root Cause Analysis

c. Determine the dominant root cause

In determining the dominant cause, the team employs the nominal group technique (NGT) tool [21]. As presented in Table 5.

Table 5. NGT table

No	Root Cause	Team Facilitator	Team Leader	Team Secretary	Team Member 1	Team Member 2	Total
1	Delay in regenerating demin water	5	5	5	5	5	25
2	Chemical flow setting are not appropriate	4	4	2	2	3	15
3	Manual operation and control system	6	6	6	6	6	30
4	No environmental influence	2	2	3	3	1	11
5	No Procedures	1	1	1	4	2	9
6	Crushed Resin	3	3	4	1	4	15

The NGT value from table 5 can be obtained by calculating it using the equation (1)

$$\begin{aligned}
 \text{NGT} &= (\frac{1}{2} \times N \times V) + 1 \\
 \text{NGT} &= (\frac{1}{2} \times 6 \times 5) + 1 \\
 \text{NGT} &= 16
 \end{aligned}
 \tag{1}$$

Where: N is Number of Issues
V is Number of Voters

As a result, the team agreed to focus on solving the dominant issues scoring ≥ 16 , particularly causes number 1 ("Delay in regenerating demin water") and 3 ("Manual operation and control systems").

Based on the identified dominant causes, a solution has been developed to overcome them: creating a centralized demineralizer control system in the Control Room.

d. Repair plan

To achieve optimal results, the repair plan is developed using the 5W and 2H methods: What, Why, When, Where, Who, How, and How Much. This plan is further supported by the involvement of competent personnel who are capable of effectively implementing the improvements.

3.2 Do Stages

The second stage of the PDCA cycle is the 'Do' stage, which involves a series of problem-solving activities. The first activity is the preparatory phase, beginning with identifying the problem, followed by collecting the necessary data, designing the equipment, procuring the required materials and equipment, and, finally, sharing knowledge with team members.

Once the preparations are complete, the next activity is implementation. This phase begins with the installation of equipment and materials according to the design. After installation, testing or commissioning is carried out. If the commissioning is successful and aligns with the final design, a new standard for the improvement is established.

3.3 Check Stages

The check stage is the third phase in the PDCA cycle. During this stage, an evaluation of the improvements made is conducted. The improvement implemented in this research involved centrally controlling the demineralizer process from the control room. Prior to this improvement, the demineralizer process was operated locally by the operator.

Table 2. shows the results of measuring the conductivity value of demineralized water before the improvement. It can be seen in the table that the water conductivity value is above 2 micro siemens. After the improvement, the water conductivity value was reduced to below 2 micro siemens, as shown in the results presented in table 6. Therefore, the improvements made in this research were successful, as they reduced the water conductivity value to meet the standards allowed for boiler water.

Table 6. The Results of Demineralizer Water Testing after Improvement.

June										
Date	1	2	3	4	5	6	7	8	9	10
pH	6,7		8,7		7,6	8,9	7,5	8,7	9,1	Regen
Temperature	26,7	Regen	25,7		26,8	25,7	25,3	25,8	26,7	
Conductivity $\mu\text{S/cm}$	1,3		1,4		1,4	2	1,6	1,5	1,9	
June										
Date	11	12	13	14	15	16	17	18	19	20
pH		8,2	7,9	8,6	6,9	8,7			7,7	8,2
Temperature		25,8	26,7	26,9	25,9	26,9	Regen		25,3	26,2
Conductivity $\mu\text{S/cm}$		1,1	1,5	1,3	1,6	1,4			1,2	1,4
June										
Date	21	22	23	24	25	26	27	28	29	30
pH	7,8	7,6	7,9	7,5			7,3	8,1	8,7	8,8
Temperature	26,1	27,5	26,5	25,7		Regen	25,9	27,1	25,9	26,4
Conductivity $\mu\text{S/cm}$	1,7	1,6	1,3	1,5			0,9	1,3	1,2	1,7

Once the boiler water conductivity value meets the standard, the benefits gained by the WHRPG include both financial and non-financial advantages.

a. Financial Benefits

Due to the high conductivity results, the demineralizer water must be replaced twice a year. Each replacement requires 48,000 liters of water, with the cost of 1,000 liters of demineralized water being Rp 7,000. Therefore, the benefit obtained from replacing the demineralized water is IDR 672,000. Additionally, replacing leaking boiler pipes due to rusting costs IDR 300,000,000. Thus, the total gain from this innovation is IDR 300,672,000 per year

b. Non-Financial Benefits

The non-financial benefits of this innovation include ease of operation and reduced maintenance requirements.

After the check stage is completed, the next stage is the action stage.

3.4 Action Stages

The action stage is the final stage in the PDCA cycle. In this stage, standards are established after improvements have been implemented. These standards are categorized into three types: input standards, process standards, and output standards.

a. Input standards

Input standards are the criteria used as inputs for the improvements made. These input standards are shown in Table 7.

Table 7. Input Standards

No	Equipment	Function
1	Panel view AB	Local HMI
2	Modbus serial to fiber optic converter	A device used to convert Modbus serial communication (such as RS-232 or RS-485) into fiber optic communication and vice versa

b. Process standards

Process standards consist of Standard Operating Procedures (SOPs) and maintenance procedures, which serve as references for operators during operations and maintenance activities.

c. Output standards

The output standard is a benchmark used to determine whether the equipment is functioning properly and correctly. For this improvement, the output standard is the water conductivity value produced by the demineralizer process, which must be less than 2 $\mu\text{S}/\text{cm}$.

4. Conclusion

The cement production process, which consumes a large amount of energy, particularly during the clinker burning stage, necessitates more efficient energy management. The implementation of Waste Heat Recovery Power Generation (WHRPG) technology offers a crucial solution for utilizing waste heat from kiln combustion to generate electrical energy. However, one of the primary challenges in WHRPG implementation is maintaining the quality of demineralized water, as it directly impacts the performance of the boiler and the overall system.

This research successfully improved the quality of demineralized water by implementing a centralized control system through a control room, utilizing the PDCA method. The system effectively reduced the water conductivity value to meet the standard of less than 2 $\mu\text{S}/\text{cm}$. This improvement delivers significant financial benefits, achieving cost savings of up to IDR 300,672,000 per year, along with non-financial advantages, including simplified operation and reduced maintenance requirements. Established standards for input, process, and output ensure continuous improvement in WHRPG performance and demineralized water quality, thereby supporting enhanced energy efficiency.

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References

- [1] A. Amiri and M. R. Vaseghi, "Waste Heat Recovery Power Generation Systems for Cement Production Process," *IEEE TRANSACTIONS ON INDUSTRY APPLICATIONS*, vol. 51, no. 1, pp. 13 - 19, 2015, <https://doi.org/10.1109/TIA.2014.2347196>.
- [2] T. Engin and V. Ari, "Energy Auditing and Recovery for Dry Type Cement Rotary Kiln Systems—A Case Study," *Energy Conversion and Management Elsevier*, vol. 46, pp. 551-562, 2005.
- [3] M. Safira, . M. Latif, Z. A. . M. Muharam dan W. Njeri, "Analysis of Exhaust Gas Heat Utilization in Waste Heat Recovery Power Generator at Indarung V Factory PT Semen Padang," *Andalas Journal of Electrical and Electronic Engineering Technology*, vol. III, no. 1, pp. 23-29, 2023, <https://doi.org/10.25077/ajeet.v3i1.34>.
- [4] M. R. Vaseghi, A. Amiri and A. Pesaran, "A Review of Rnergy Efficiency and CO2 Emissions in the US Cement Industry," *Proc. 23rd IEEE-IAS/PCA Cement Ind. Tech. Conf*, pp. 1-9, 2012.
- [5] A. Rachman and B. Arianto, "Studi Eksergi Siklus Steam Flash dan Siklus Daya Kalina Pada Sistem Operasi Waste Heat Recovery Power Generation," *Jurnal Teknik Mesin Institut Teknologi Padang*, vol. 10, no. 1, pp. 16-32, 2020.
- [6] Liliana. and Delafena. I, "Analisis Kinerja Sistem Proteksi Type M-3425A pada Generator di WHRPG PT. Semen Padang," *Jurnal Sains, Teknologi dan Industri*, vol. 17, no. 2, pp. 81 - 85, 2020, <http://dx.doi.org/10.24014/sitekin.v17i2.10333>.
- [7] D. D. S. Putri and A. Purnomo, "Kajian Instalasi Pengolahan Air Demineralisasi dari Nalco Water an Ecolab Company," *JURNAL TEKNIK ITS*, vol. 12, no. 2, pp. 123 - 128, 2023, <https://doi.org/10.12962/j23373539.v12i2.120029>.
- [8] I. Nugraha, M. A. Arif and H. Setyawati, "Optimalisasi Resin Penukar Ion pada Proses Demineralisasi Air Tanah," *ATMOSPHERE*, vol. 4, no. 2, pp. 8-14, 2023.
- [9] S. Jonner and S. Maryanto, "Unjuk Kerja Sistem Air Bebas Mineral untuk Pengolahan Limbah Radio Aktif," dalam *Prosiding Seminar Nasional Teknologi Pengelolaan Limbah XV*, 2017.
- [10] A. Supriyadi and A. Masyuroh, "Proses Optimasi Desalinasi dan Demineralisasi untuk Menjamin Kuantitas dan Kualitas Air Proses dan Domestik di PT Ineos Aromatics Indonesia," *Jurnal Lingkungan dan Sumberdaya Alam (JURNALIS)*, vol. 5, no. 2, pp. 13 - 23, 2022, <https://doi.org/10.47080/jls.v5i1.1809>.
- [11] A. R. Wahyudin , A. Raihan, M. F. Adrian, R. Agustian, M. A. Darian, M. F. Ramadhan A, F. Paundra and Y. Ito, "Analisis & Perawatan pada Water Treatment Plant PLTU X," *PERWIRA JOURNAL OF SCIENCE & ENGINEERING*, vol. 4, no. 2, pp. 86-93, 2024.

- [12] M. D. Surindra, “Design Simulator Fresh Water Tank di PLTU dengan Water Level Control Menggunakan Mikrokontroler,” Prosiding SNST ke 3, pp. 79 - 84, 2012.
- [13] P. Gupta, “Beyond PDCA-A New Process Management Model,” *Quality Progress*, vol. 39, no. 7, pp. 45-52., July 2006.
- [14] M. S. Arif, C. F. Putri and N. Tjahjono, “Peningkatan Grade Kain Sarung dengan Mengurangi Cacat Menggunakan Metode Kaizen dan Siklus PDCA pada PT. X,” *Jurnal WIDYA TEKNIKA* , vol. 26, no. 2, pp. 222 - 231, 2018.
- [15] R. Budiman and R. Nazir, “Electric Load Modeling for Managing Electric Energy Consumption Through the PDCA Cycle in the Library Building of Andalas University,” *Andalas Journal of Electrical and Electronic Engineering Technology*, vol. 3, no. 1, pp. 10 - 22, 2023, <https://doi.org/10.25077/ajeet.v3i1.35>.
- [16] Nugrahadhi, F. Mujayyin and L. Adi, “Penerapan Total Productive Maintenance (TPM) Pembangkit Listrik Waste Heat Recovery Power Generation (WHRPG),” *Nozzle :Journal Mechanical Engineering (NJME)*, vol. 11, no. 1, pp. 1-8, 2022.
- [17] M. N. Rajić, Z. . Z. S. Stanković, M. V. Mančić, P. M. Milosavljević and R. Maksimović, “Business Process Reengineering with a Circular Economy PDCA Model from the Perspective of Manufacturing Industry,” *Processes*, vol. 12, no. 5, pp. 1-27, 2024, <https://doi.org/10.3390/pr12050877>.
- [18] H. Kurniawan, E. Sumarya and A. Merjani, “Peningkatan Kualitas Produksi untuk Mengurangi Unit Cacat Insufficient Epoxy dengan Metode PDCA di Area DIE ATTACH,” *PROFISIENSI*, vol. 5, no. 1, pp. 44 - 50, 2017.
- [19] T. Luo, C. Wu and L. Duan, “Fishbone Diagram and Risk Matrix Analysis Method and Its Application in Safety Assessment of Natural Gas Spherical Tank,” *Journal of Cleaner Production*, vol. 174, pp. 296-304, 2018.
- [20] R. Budiman and J. Faizal, “Development of an Energy-Efficient Electrical Load Model for Optimizing Electricity Consumption in the Headquarters Building of PT Semen Padang Using the PDCA Approach,” *Andalasian International Journal of Applied Science, Engineering and Technology (AIJASET)*, vol. 5, no. 1, pp. 65-73, 2025, <https://doi.org/10.25077/aijaset.v5i1.207>.
- [21] M. V. Shahroodi, A. Mansourzadeh, S. S. Moghani and M. Saeidi, “Using the Nominal Group Technique in Group Decision-Making:A Review,” *Medical Education Bulletin*, vol. IV, no. 4, pp. 837-845, 2023, <https://doi.org/10.22034/meb.2024.434656.1090>.