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Study and Analysis on The Application of Cleaner Production in The Urea Fertilizer Industry (PT X) in Sumatera

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Abstract— Cleaner production is an environmental management strategy that is preventive, integrated and continuously applied to every process. The urea fertilizer industry certainly produces waste and allows for problems or constraints in the processing process. This study aims to obtain a cleaner production strategy to increase the efficiency of urea production. This research was studied at a urea factory in Sumatera with a high production capacity of 114,584 kg/hour. The cleaner production strategy was preventive maintenance for the CO_2 compressor (B/C 1.91), cleaning demister on dust recovery prilling tower (B/C 3.62), making automatic door closer (B/C 84,54), addition wire mesh on air exhaust (B/C 91,96), add a condensate drop container overall (B/C 1,51) and make repairs to existing dehumidifier in bulk storage (B/C 30,94). Determining the priority of cleaner production alternatives using the MPE method results in the highest priority net production alternative being making automatic doors closer. If all alternatives are implemented, there will be savings in energy consumption of 2.052 kWh/tonne/day. Percentage of urea and NH_3 loss can be reduced up to 20% so that the prilling unit production efficiency increased by 0.24% and the savings to be obtained range from 620 thousand - 45 billion rupiah/year.

Keywords: Cleaner production, MPE, urea fertilizer industry, waste minimization.

1. Introduction

Indonesia's population in 2020 has reached 270,203,917 people [1]. Indonesia's increasing population growth will result in a high demand for agricultural products. The high demand for agricultural products will also result in the expansion of agricultural land. Along with this, fertilizer production is needed to support agricultural productivity. Based on data from the Indonesian Fertilizer Producers Association (APPI), the amount of urea fertilizer production from 2014 to 2021 has the highest value compared to the amount of production of other types of fertilizers, reaching 7,968,504 tons/year in 2021 [2]. The large production capacity of urea fertilizer can have a negative impact on the environment along with the production process. Along with the increase in the amount of waste generated, an effective and efficient waste handling strategy is needed to reduce the waste output.

Waste generated can be in the form of liquid, solid, or gaseous waste, as well as noise. Liquid waste can pollute river water, groundwater, and other waters, causing aquatic biota to become sick and even die due to water pollution [3]. Solid waste from urea factories, the majority of which contains B3, can pollute the environment and have an impact on human health [4]. Gas waste in the form of ammonia can cause acid rain and CO_2 can damage ozone and cause greenhouse gases [5]. And noise can have an impact on the health of related human resources. Currently, the management and monitoring of waste quality have been carried out by implementing the ISO-14001 Environmental Management System and in accordance with the quality standards of Minister of Environment Decree Number P.17/MENLHK/SETJEN/KUM.1/4/2019. Further management improvement is still needed

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even though the environmental management system has been implemented, with the aim of minimizing waste and loss due to production activities. This encourages the formation of waste minimization strategies with other alternatives, one of which is cleaner production.

Cleaner production can be applied to all types of industries, including the urea fertilizer industry. A preventive, integrated, and sustainable environmental management strategy that is applied to every activity related to the production process, products, and services from upstream to downstream in order to increase the efficiency of the use of natural resources, reduce the formation of waste from its source, and minimize the risk to human health and safety and environmental damage is called cleaner production [6]. Efforts to improve environmental conditions due to industrial activities with waste management that have been formed (end-of-pipe treatment) in reality still cause environmental pollution problems, therefore the emergence of preventive or preventive efforts called the principle of cleaner production as an operational and integrated strategy. Cleaner production methods must be used sustainably throughout the production process and product life cycle to reduce risks to humans and the environment [7].

Research related to cleaner production applied at the Kaltim-3 ammonia plant and how it is applied at the PT Kaltim-2 ammonia plant. Pupuk Timur, Kalimantan, Tbk., found that the implementation of cleaner production can provide positive benefits from a specific, monetary and ecological perspective. The implementation of cleaner production reduced energy consumption per ton of ammonia by 5.88 MMBTU. The benefits to the economy are in the form of significant annual cost savings. Ammonia production increased by about 18% per day. Flue gas emissions decreased by about 67%, from 39,000 NM^3 per hour to 12,500 NM^3 per hour. The cleaner production alternatives in the study obtained eight recommendations, namely: 1) Recovery of continuous blowdown from the ammonia plant steam drum for use as boiler feed water, 2) Recovery air sealing system at the atmospheric pressure safety valve of the turbine condenser for recycling to the raw water tank for use as boiler feed water, 3) Recovery of water content from condensation in process air during compression for use as an air-based fire hydrant, 4) Utilization of waste ammonia from separator 1-S-434 for use as urea feedstock in a urea plant, 5) Utilization of oil leaked into reservoir oil from dry seal gas of refrigerant compressor 1-K-405, 6) Application of Benfield solution to the CO_2 removal system after use for sampling, 7) Waste return to the CO_2 removal system using Benfield solution waste and 8) Program for segregation [8].

Related research was also conducted by Rachman [9] on the management of urea dust emissions with reference to clean production principles, which resulted in the application of the method, which can save the inclusion of urea dust raw materials scattered in the prilling tower and granulator units, resulting in savings in equipment painting costs due to significant exposure to urea dust. The study also showed that the application of the method can reduce expenditures due to a reduction in investment costs and an acceleration of the payback period. Prasetyaningsih *et al.* [10] conducted research on measuring eco-efficiency in the implementation of cleaner production using the activity-based costing method (a case study in the urea fertilizer industry). The research showed that the application of the method can reduce the output of liquid waste in the WWTP by 15 m^3/hour, so that it provides financial benefits, namely a reduction in waste treatment costs. PT X is a urea fertilizer industry in Sumatra with a production capacity of 114 tons of urea/hour. Cleaner production has many advantages for an industry, including reducing production costs, reducing waste, increasing productivity, reducing energy consumption, minimizing waste disposal, including waste handling, and increasing the value of by-products [7]. These benefits will also be obtained in the urea fertilizer industry of PT X when implementing cleaner production. Based on this, further analysis and studies are needed towards a more environmentally friendly urea fertilizer industry according to cleaner production principles.

The objectives to be achieved in this research are: 1) Identifying the types and amounts of waste formed in the urea fertilizer production process and the handling of waste carried out, 2) Identifying cleaner production alternatives that can be applied to reduce waste formed in the urea fertilizer formation process, 3) Analyzing the feasibility of cleaner production activities in the urea fertilizer industry technically, financially, and environmentally, 4) Determining the priority scale of the recommended cleaner production activities in the urea fertilizer industry.

2. Method

This research was conducted from May 2022 to October 2022. The research was conducted in the urea fertilizer industry in Sumatra.

2.1 Data Collection Method

Data collection methods in this study were observation, direct measurement, laboratory analysis, literature study, and interviews with respondents who are related industry experts. The data was collected in the form of primary data obtained from observations, interview results, direct field measurements, and laboratory analysis results. Secondary data is obtained from various literature sources, including industrial report data, books, journals or proceedings and others relevant to the research topic. Data collection is carried out by determining the flow of urea production from raw materials to final products and waste products in the IIB urea plant and then determining the mass balance.

2.2 Identification of Process Flow and Material Cycle

At this stage, an assessment is carried out on five components, namely raw materials, process technology, production processes, final products, and waste products.

a) Assess and present all available information on the operating unit, raw materials, products, water, and energy use with mass balance analysis. This assessment is carried out using direct measurement methods, laboratory analysis, observation, and interviews with respondents who are related industry workers. At this stage, a mass balance analysis will be carried out with input, output, and waste streams.
b) Explaining the source, quantity, and type of waste generated by direct measurement methods, laboratory analysis, observation, and interviews with respondents who are related industry workers.
c) Identifying process inefficiencies and areas where there are mistakes in terms of management using the observation method and interviews with respondents who are related industry workers.

2.3 Identification of Cleaner Production Opportunities

The formation of waste and loss in the urea fertilizer production chain is a consideration in determining cleaner production opportunities. Raw material substitution, technology modification, good layout, product modification, and onsite reuse are potential alternative opportunities for improvement. This identification was done by the literature study method and discussed with workers and related industry experts by interview [11].

2.4 Feasibility Evaluation of Cleaner Production Opportunities

Evaluate cleaner production opportunities technically, financially, and environmentally. Technical feasibility refers to the process, raw materials, equipment, and labor. The financial feasibility test is carried out to determine the benefits and savings opportunities obtained after implementing cleaner production alternatives; therefore, this study only focuses on calculating the payback period and B/C ratio. The environmental feasibility test is used to evaluate the cleaner production option to be selected. The benefits or impacts on the environment resulting from the use of cleaner production methods are covered in this feasibility test. The environmental feasibility test was conducted descriptively using the literature study and observation method [12].

2.5 Prioritization of Cleaner Production Activities with MPE

One method of prioritizing cleaner production activities is the Exponential Comparison Method (MPE). According to Bolman and Helmi [13], with several criteria, MPE is one of the Decision Support System (SPK) methods for ranking alternative decisions. Depending on the knowledge of the person evaluating and making decisions based on the quantification of one or more opinions on a certain scale, the difference in value between the criteria can be distinguished. The following are the stages of using MPE: 1) Compilation of preferred opportunity options; 2) Listing of important considerations or decision-making criteria and comparing them; 3) Determination of the significance of each criterion or criterion consideration in a decision; 4) Evaluation of each option based on each criterion; 5) Calculation of the total score or value of each option; 6) Prioritization of decisions using the score or value of each alternative.

The greater the Total Score (TN) of the alternative, the higher the priority ranking. The score value with an exponential function makes the priority order of decision alternatives more real. Using MPE can help reduce bias in the alternative selection analysis process, which is an advantage. The assessment criteria consist of technical and technological, financial, human resources, and environmental aspects, with each weighted score of 1–5 as in Table 2. The assessment of clean production opportunities against the criteria uses a rating scale of 1 (unfavorable) to 10 (excellent). The MPE equation is [14]:

$$(TN_i) = \sum_{j=1}^{m} (RK_{ij})^{TKK_j} \quad (1)$$

TNi : Total score of the i-th alternative
RK ij : Degree of relative importance of criteria j in decision-making
TKKj : Degree of importance of the jth decision criterion; nTKKj> 0; rounded
n : Number of decision options
m : Number of decision criteria

Respondents involved in the analysis of alternative determination with this method are the superintendent of the IIB urea plant, a senior process engineer, the vice president of the environment, a maintenance assistant, and the head of the environmental damage control section of the local Provincial Environmental Agency, for a total of five respondents.

3. Result and Discussion

The urea manufacturing process uses CO_2 and NH_3 liquid feedstock supplied from the ammonia plant. In general, the material flow stages of the urea processing process can be seen in Figure 1.

3.1 Synthesis Unit

The most important component of the urea plant, the synthesis unit, is responsible for the reaction of liquid NH_3 and CO_2 gas in the urea reactor. In this unit, there are two reaction stages involved in the urea synthesis process. The first exothermic and fast reaction is the formation of carbamate from liquid NH_3 gas and CO_2 gas. The second reaction, which is slow and endothermic, is the reaction that forms urea from carbamate. The reaction equation is as follows:

2 NH3 + CO2 ↔ NH4OCONH2 ↔ NH2CONH2 + H2O
(Ammonium Carbamate) (Urea)

The recyclencarbamate solution from the recovery unit is also input into the reactor. The operating pressure in the synthesis unit is 175 kg/cm^{2}G. In the stripping process by CO^2, there is still excess ammonia in the ammonium carbamate solution produced from the reaction process, so the solution is sent to the purification unit.

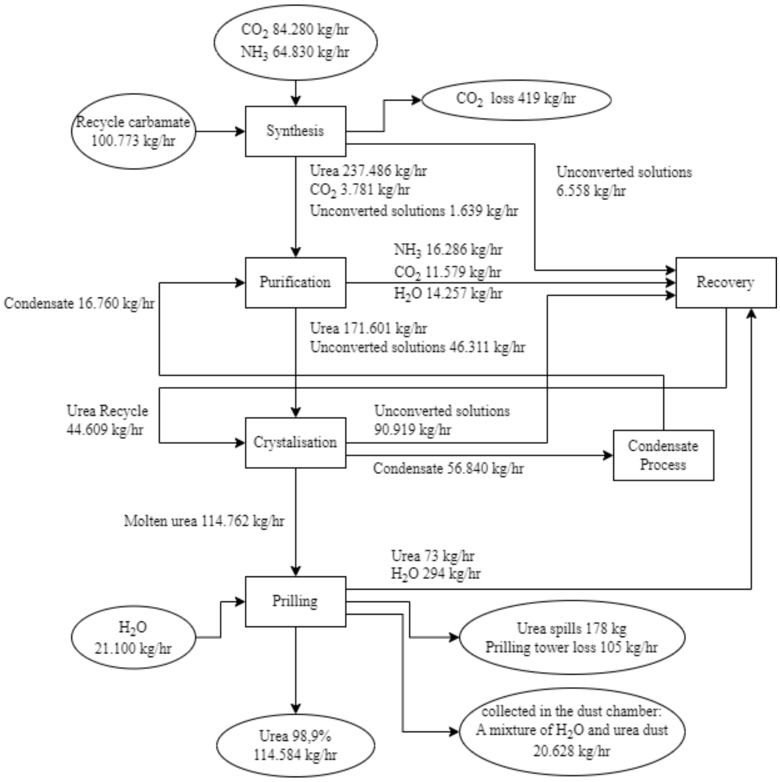

Figure 1. The material flow stages of the urea processing

In the synthesis unit, there is CO^2 loss in the CO^2 compressor tool caused by the tool's performance. Based on an interview with the senior engineer of the factory, in a multi-stage compressor, there is a process of enthalpy and entropy, which is a change in the density of a substance due to a compression process that is linear between pressure and temperature. To keep the compression process stable, the fluid formed must be separated by condensation through the intercooler and knock-out dum. It is expected that the gas entering each stage is pure gas fluid, so the results of condensation in the form of condensate will be discharged automatically to the knock-out dum, which makes CO^2 carry away even in small quantities.

3.2 Purification Unit

In this unit, there is a purification process by decomposing and separating the unconverted ammonium carbamate solution and excess ammonia levels in the solution. Purification in this unit also aims to separate other unwanted components, namely water and CO_2, so that the urea concentration becomes 65-75%. The separation process is carried out by heating and two steps of pressure reduction at 17 kg/cm^{2}G and 22.2 kg/cm^{2}G. After the separation process, the urea solution is sent to the crystallizer unit. The excess CO_2 and NH_3 gases in the solution are sent to the recovery unit. In the direct observation process, several leaks were found in the condensate water pipe in the purification unit, resulting in rust on the steel grating around the droplets. However, at several leakage points, handling has been carried out in the form of a container to accommodate water droplets so that no rust occurs in the drip area. This problem is related to the maintenance of the equipment as well as its age.

3.3 Crystallizer Unit

In this unit, the crystallization process occurs in the urea solution sent from the purification unit. The crystallization process is triggered by raising the temperature. The sensible heat of the urea solution provides the heat required to evaporate the water, while the heat required to crystallize the urea slurry is generated by circulating it to the HP absorber in the recovery unit. The crystallizer unit has not experienced any problems for a long time; the few problems that occur in this unit are only related to maintenance on the equipment as it ages.

3.4 Prilling Unit

In this unit, the urea granulation process occurs. Hot air is used to dry the urea crystals coming out of the centrifuge to 99.8% by weight. The urea crystals are then transported to the top of the prilling tower, where they are liquefied and distributed evenly to all distributors before being stored in the granulated urea reservoir at the bottom of the tower. During the process, air from the environment is also introduced into the system. The urea product is then sent to bulk storage by belt conveyor. The prilling unit is the unit that has the most problems compared to the other units. The first problem is that there is still a lot of urea and urea dust scattered around the conveyor belt in the process of transporting granules to bulk storage. This is due to the vibration of the conveyor belt that makes the urea prill dusty, and the dust drifts to the area around the conveyor (tools and floor).

The next problem is the urea dust that accumulates on the doors of the prilling tower and the wind flow window on the tower. Although handling has been carried out in the form of making urea and urea dust scattered shelters in the scattered area, there are still many scattered urea dust particles that have hardened and have not been treated further, resulting in a reduction in the weight of the urea mass sent to bulk storage.

3.5 Recovery Unit

Ammonia gas and CO_2 gas separated in the purification section are sent back to the recovery unit. This process involves two-step absorption using mother liquor as an absorbent, which is then recycled back to the synthesis section. The recovery unit has not experienced problems for a long time; some of the problems that occur in this unit are only related to maintenance on equipment as it ages.

3.6 Condensate Process Unit

Water vapor that has been evaporated and separated from the crystallizer unit undergoes a cooling and condensation process in this unit. The stripper and hydrolizer separate small amounts of urea, NH_3, and CO_2, which are also sent to this unit. The purification section receives the separated CO_2 and NH_3 gases for reuse. The utility unit receives the condensate water temporarily. The condensate process unit has not experienced any problems for a long time; the few problems that occur in this unit are only related to the maintenance of the equipment as it ages.

3.7 Water Use and Energy Requirements

Water requirements for the Urea production process are in accordance with the amount of raw material processed (Majid 2019). Water use at the II-B Plant of the Urea Fertilizer Industry in Sumatra includes use for condensate water systems in ammonia plants by 39.35% and urea plants by 23.29%; demin plants in utilities by 6.09%; housing and offices by 25.72%; and reverse osmosis (RO) reject water to condensate water Steam Turbine Generator (STG) by 5.54%. Water usage in the urea fertilizer industry of PT X can be seen in Table 1.

Table 1. Water usage in the urea fertilizer industry of PT X

Urea II-B Factory	Water Usage (m^3)
Ammonia Factory (*CW System*)	2,381,541.6
Urea Factory (*CW System*)	1,409,821.4
Utility (*Demin Plant*)	368,785.5
Housing & Offices	1,556,820.8
Reject RO to CW STG	335,155.3
Water Usage Total	**6,052,124.6**

The largest use of water is in the ammonia plant. This is because water is used as system condensate in boilers, turbine engine coolers, and others. Water use at the urea plant is also allocated as system condensate water, similar to the ammonia plant. Water for housing and offices is used for daily needs. A large source of energy is needed in the urea fertilizer industry to drive machinery and other equipment. Energy use in the manufacture of urea at the IIB plant includes steam energy and electrical energy from natural gas, as well as steam boiler feed water energy. The total energy consumption of each can be seen in Table 2.

Table 2. The total energy consumption

Units at IIB Factory	Energy Consumption (kWH/ton/hari)		
	Steam	Steam Boiler	Electricity
Synthesis Unit	0.38215	4.19833	98.0691
Purification Unit	0	0.60916	0.3892
Crystalisation Unit	0	1.11053	1.0996
Prilling Unit	0.01679	0	5.27473
Recovery Unit	0.19947	0.62562	1.5779
Condensate Process Unit	1.66093	1.25460	2.9350
Energy Consumption Total	**2.25935**	**7.79824**	**109.3455**

Based on the table above, it can be seen that the highest energy use is electrical energy, which is 109.3455 kWH/ton/day. This is due to the high use of electrical energy in the CO_2 compressor located in the synthesis unit. The amount of boiler feed water energy (steam boiler) is 7.79824 kWH/ton/day. The smallest energy use is steam energy at 2.25935 kWH/ton/day. The use of steam boilers and steam energy is used to drive tools and cooling water systems for condensate water.

3.8 Identification of Cleaner Production Alternatives

The implementation of cleaner production strategies that have been applied today has reduced production problems, hazards for workers, and waste generation that arise in the urea processing process in the industry. However, with the many strategies that have been implemented, it is possible to implement other cleaner production strategies to overcome some other problems that have not been resolved in the industry. The more cleaner production strategies that are implemented, the fewer problems will arise (Aulia et al., 2023). The assessment has been carried out at the stages of the waste generation process and production inefficiencies so as to obtain the causes and alternative options that are likely to be implemented. The assessment was carried out through direct observation and interviews with factory management and related operators so that clean production options could be proposed. The main problems from the assessment results and recommended cleaner production options can be seen in Table 3.

Table 3. The main problems from the assessment results and recommended cleaner production options

No	Problems	Cause Identification				Cleaner Production
		1	2	3	4	
1.	CO_2 Loss due to wear on the piston ring and lack of air filter maintenance.		√			Preventive maintenance on CO2 compressor equipment (good housekeeping).
2.	Gas, Dust and NH_3 Loss.	√	√			Cleaning of the demister in dust recovery.
3.	Urea granules scattered around the door of the prilling tower building.	√	√	√	√	Making automatic door closer on the door of the prilling tower building (technology modification).
4.	Urea granules scattered around the air exhaust of the prilling tower.	√	√	√	√	Adding wire mesh to the air exhaust so that urea granules do not easily come out (technology modification)
5.	The provision of a condensate droplet collection container is not comprehensive and causes rust on the iron floor step.				√	Adding condensate droplet collection containers as a whole at each leak point (technology modification).
6.	Caking fertilizer due to incomplete cooling process.	√	√			Make improvements to the existing dehumidifier (good housekeeping).

Keterangan:

1 = Raw material factor	3 = Method factor
2 = Tool/machine factor	4 = Human/skill factor

In the table of problems and opportunities, there are six recommendations for clean production implementation in the form of technology modification and good housekeeping. The recommended technology modifications include the addition of several new functions to existing technology, while good housekeeping involves the repair and maintenance of equipment. The problem mentioned above is a specific problem at the IIB urea plant of the Sumatra urea fertilizer industry. The preparation of clean production recommendations is based on direct observations, literature studies, discussions, and interviews with relevant management and operators.

3.9 Feasibility Evaluation of Cleaner Production Opportunities

3.9.1 Preventive maintenance on CO2 compressor equipment

In the process of synthesizing CO_2 and NH_3 liquid in the synthesis unit, there is a CO_2 compressor that functions to increase CO_2 pressure to the reactor operating pressure of 175 kg/cm^{2}G so that CO_2 gas conversion can be optimized. In the mass balance analysis, there is CO_2 loss in the CO_2 compressor tool, which is caused by the increasing age of the tool, so that the performance of the tool decreases. In addition, based on interviews with senior factory engineers, in multi-stage compressors there is a process of enthalpy and entropy, which is a change in the density of substances due to a linear compression process between pressure and temperature. To keep the compression process stable, the fluid formed must be separated by condensation through the intercooler and knock-out dum. It is hoped that the gas entering each stage is pure gas fluid, so the condensation results in the form of condensate will be discharged automatically to the knock-out dum, which makes CO_2 carried away even in small quantities. Preventive maintenance on CO_2 compressor equipment on a regular basis can be an opportunity to minimize CO_2 lost due to decreased tool performance [15].

Technically, preventive maintenance on CO_2 compressor equipment is quite easy to do, but further analysis needs to be done regarding the ideal cleaning schedule so as not to interfere with the production targets set by the company. This alternative can benefit the environment by reducing the level of CO_2 lost to the air from 419 kg/hour to 209.5 kg/hour and reducing the contribution of greenhouse gas emissions. This option can increase tool efficiency from 95.016% to 95.116%. The cost per year required for preventive maintenance on CO_2 compressor equipment is Rp 42,000,000. The savings obtained are IDR 45,856,650,000.00 per year, and the B/C ratio value is 1.91, which shows that the alternative is feasible to implement.

3.9.2 Cleaning of the Demister Tool Dust Recovery Prilling Tower

In the process of urea twisting in the prilling tower, a temperature drop is carried out on the urea melt by free falling from a height of more than 50 meters above the prilling tower. Along with the process of lowering the temperature, the urea melt becomes a metamorphic solid called urea prill. The small-sized urea grains (above 19 mesh) are carried by the air coming out of the induced fan at the top of the prilling tower as urea dust emissions. This is because the nature of urea at high temperatures tends to be dusty [16]. The company has a treatment to minimize the loss of dust that still contains urea and ammonia with the Modified Dust Recovery System. However, the mass balance still shows a high output. One of the causes is the demister tool in dust recovery, which tends to get dirty and is rarely cleaned. Demister is a tool that functions to separate gas and liquid fluid before exiting the induced fan output prilling tower [17]. Cleaning the demister device in dust recovery can be an opportunity to further minimize dust containing urea and NH_3 from escaping into the air.

Cleaning of the demister device in dust recovery is done by washing, which requires the device to be removed from the unit installation first. Technically, this causes the Modified Dust Recovery System to stop operating during the cleaning process. In the process of roasting urea melt, the Modified Dust Recovery System plays an important role in minimizing the loss of urea dust that flies into the air [18]. Therefore, if the system stops operating, the blending process must also stop operating. Based on the results of expert interviews, it was found that the process of disassembling, cleaning, and reassembling the demister device is estimated to take 6 working hours. Cleaning the demister tool in dust recovery can minimize urea dust loss and also provide a longer life for the tool because it avoids sticking and crystallizing urea dust, which is corrosive and can damage the tool. This option can increase production efficiency in the packing unit from 99.44% to 99.68%.

Environmental feasibility analysis of this activity selection can reduce urea dust from 32 kg/hour to 25.6 kg/hour and NH_3 loss from 73 kg/hour to 58.4 kg/hour. Technically, cleaning the demister is quite easy to do, but further analysis needs to be done regarding the ideal cleaning schedule so as not to interfere with the production targets set by the company.The cost per year required for cleaning the demister tool is IDR 7,500,000.00. The savings obtained are IDR 4,071,288,000.00/year, and the B/C ratio value is 3.62, which shows that the alternative is feasible to implement.

3.9.3 Making an Automatic Door Closer on the Prilling Tower Door

In the process of urea twisting in the prilling tower, a temperature drop is carried out on the urea melt by free falling from a height of more than 50 meters above the prilling tower. Along with the temperature reduction process, the urea melt becomes a solid form of urea called urea prill. In the blending tower building, there is a door made of iron plate to make it easier for the operator to monitor the blending process. There are urea granules that fall freely and float out through the door gap and into the tower exhaust water. The company has collected and reprocessed the scattered urea granules. However, the automatic door closer on the door of the Pilling Tower building can minimize the urea granules that come out through the door gap. Reducing urea scattering can reduce energy consumption and recovery costs [19].

Technically, making an automatic door closer is quite easy to do by buying a set of automatic door closer tools and having them installed by a third party. The manufacture of automatic door closers can be done without disrupting the production process and does not take a long time. An automatic door closer will be installed on 8 units of parking tower building doors. In the environmental feasibility analysis, the selection of modifications by making an automatic door closer can reduce the urea splashing out of the prilling tower door gap from 178 kg/hour to 142.4 kg/hour and provide energy savings of 2.052 kWh/ton/day for the recovery process of recovered urea. The investment cost required to make an automatic door closer on the door of the parking tower building is IDR 11,500,000. The investment is the cost of purchasing and installing an automatic door closer from a third party. The profit obtained is Rp693,376,000/year, assuming a 20% urea loss can be overcome (based on the results of expert interviews). The B/C ratio value is 84.54, which shows that the alternative is feasible to implement with a payback period of 0.017 years.

3.9.4 Adding Wire Mesh to Air Exhaust

In the process of urea melting in the prilling unit, there is a decrease in temperature or cooling by utilizing atmospheric air absorbed from the air exhaust located on several sides of the prilling tower building wall. Since the urea granules fall freely from a height of more than 50 meters, there are urea granules that drift out through the gaps in the prilling tower air exhaust and cause mass loss sent to the bagging and storage unit. The company has collected and reprocessed the scattered urea granules. However, efforts to add wire mesh to the exhaust water can minimize the urea granules that come out. Reducing urea scattering can reduce energy consumption and recovery costs [19].

The addition of wire mesh to the exhaust water is technically easy to do by purchasing a 20-mesh wire mesh measuring 15x5m and having it installed by a third party. However, based on expert interviews, it is necessary to consider the effect of wire mesh installation on the air flow of exhaust air. Based on the results of interviews with the manager of the production planning and control section of PT X, the addition of wire mesh to the exhaust air can be done without disrupting the production process and does not take a long time. In the environmental feasibility analysis, the selection of modifications with the addition of wire mesh in the exhaust water can reduce the urea scattering from 178 kg/hour to 142.4 kg/hour and provide energy savings of 2.052 kWh/ton/day for the recovery process of recovered urea. The investment cost required to add wire mesh to the exhaust air of the parking tower building is Rp8,150,000. The investment is the cost of purchasing and installing a 20-mesh wire mesh measuring 15 x 5 meters from a third party. The profit obtained is Rp694,046,000.00 per year, assuming a 20% urea loss can be overcome. The B/C ratio value is 91.96, which shows that the alternative is feasible to implement with a payback period of 0.012 years.

3.9.5 Addition of an Overall Condensate Droplet Containment Container

In the operating unit, there is condensate water as feed water for the boiler work process. In the direct observation process, a condensate water valve leak was found, which resulted in condensate water droplets at several points. The company has handled maintenance on tools and procurement of containers under the droplets, but not thoroughly. There are several leakage points that have not been provided with a container. The procurement of a collection container as a whole can minimize the occurrence of steel gratings that are rusted and damaged by droplets of condensate water. Condensate that drips continuously can cause the steel grating to rust and be damaged [20].

The addition of a container for condensate droplets is technically easy to implement by purchasing a 122 cm x 244 cm thick 1 mm bordes iron plate. Making and welding iron plates to form a container measuring 150 cm x 25 cm x 30 cm The selection of bordes-type iron plate was carried out because the results of Utomo and Hasan's research [21] proved that this type of iron plate has a low corrosion rate of 0.08838 mm/yyear under normal conditions. In the environmental feasibility analysis, the addition of condensate droplet collection containers as a whole can extend the life of steel gratings and prevent them from rusting and being damaged by dripping condensate water.

The investment cost required to add a condensate drip container is IDR 2,032,000. The investment is the cost of purchasing a 122 cm x 244 cm 1 mm thick bordes iron plate and labor costs. The profit obtained is IDR 620,800/year, and the B/C ratio value is 1.51, which shows that the alternative is feasible to implement with a payback period of 1.309 years.

3.9.6 Existing Dehumidifier Improvements

In the final product storage warehouse, there is a dehumidifier that functions to maintain air humidity in the room. The dehumidifier has a vapor compression cooling system that utilizes the heat wasted from the condenser as a heater that is controlled according to the desired temperature and relative humidity [22]. Dehumidifiers in urea storage warehouses function to maintain warehouse humidity so that it is not too humid, which causes urea products to clump. Clumped final products can be detrimental to the company because they cannot be distributed and result in a reduction in the weight of the final product. Improvements to the existing dehumidifier equipment can maximize the performance of the dehumidifier equipment in keeping the room humidity dry and reduce the potential for lumpy end products in the storage warehouse [23].

Technically, improvements to the existing dehumidifier can be easily implemented without taking a long time (based on interviews with the senior maintenance engineer at the factory). In the environmental feasibility analysis, improvements to the existing dehumidifier can reduce clumped urea products from 34,375.2 kg/day to 13,750 kg/day, improve the quality of products produced, and increase storage efficiency in bulk storage. The investment cost required to improve the existing dehumidifier is Rp6,000,000. The investment is the cost of purchasing 10 meters of dehumidifier pipe and repair wages by a third party. The profit obtained is Rp111,375,648.00 per year, and the B/C ratio value is 30.94, which shows that the alternative is feasible to implement with a payback period of 0.06 years.

3.9.7 Prioritization of Cleaner Production Alternatives

In this study, there are several alternative cleaner production strategies that arise from the results of the identification that has been done. The strategy alternatives are then ranked based on the assessments of five experts calculated by the Exponential Comparison Method (MPE) prioritization method. The expert assessment considers the criteria used, namely technical capabilities, financial aspects, and the environment. The weighting of criteria is obtained from the assessments of five predetermined experts.

There are six clean products obtained from this research, namely good housekeeping in the form of preventive maintenance on the CO_2 compressor, cleaning the demister device in dust recovery, adding an overall condensate droplet collection container, improving the existing dehumidifier in the final storage unit, and technology modification in the form of making an automatic door closer on the door of the prilling tower building and adding wire mesh to the prilling tower air exhaust. The results of the prioritization of clean product alternatives with the MPE method can be seen in Table 4.

Table 4. The results of the prioritization of clean product alternatives with the MPE method

Cleaner Production Alternatives	MPE Score	Priority
CO_2 Compressor preventive maintenance	6,12	3
Cleaning demister device at dust recovery	6,13	2
Creating automatic door closer	6,18	1
Adding wire mesh at air exhaust	5,88	6
Overall condensate drip tray	6,07	4
Existing dehumidifier improvements	6,06	5

Based on the results of the calculation of priorities in Table 4, the main priority of clean production alternatives that can be applied is the application of tool modifications in the form of making an automatic door closer on the prilling tower building door. This is because this alternative has the highest MPE value of 6.18 and a technical criteria value of 9.2. The effort to make an automatic door closer on the door of the Pilling Tower building can minimize the urea granules that come out through the door gap. Reducing urea scattering can reduce energy consumption and recovery costs [19].

This alternative is also easy to implement, can increase production efficiency, and is beneficial to the environment in the form of reducing urea spillage by 311,856 kg/year, saving production costs of Rp 57,480,333.00/month, and saving energy for the urea loss recovery process by 2.052 kWh/ton/day. Cleaner production alternatives can be implemented by urea fertilizer companies based on the priority level that has been assessed.

4. Conclusion

The results identified through mass balance analysis of the waste generated are CO_2 gas emissions of 419 kg/hour caused by a decrease in the performance of the compressor, scattered granules and urea dust of 178 kg around the door and air exhaust prilling tower, and NH_3 gas emissions of 105 kg/hhour in the prilling unit. In general, the problems found in several operating units are the lack of maintenance of tools and machinery that causes a decrease in the performance of tools that cause losses in the form of lumpy urea products and the provision of condensate collection containers that are not yet comprehensive, causing condensate to drip onto the factory floor and steel gratings.

Six clean production activities that are feasible with the needs of the factory are good housekeeping in the form of preventive maintenance on the CO_2 compressor, cleaning the demister device in dust recovery, adding a condensate droplet collection container as a whole, improving the existing dehumidifier in the final storage unit, and technology modification in the form of making an automatic door closer on the prilling tower building door and adding wire mesh to the prilling tower exhaust water.

The recommended cleaner production activities have been tested for technical, financial, and environmental feasibility. All recommended cleaner production activities are feasible to implement. The most prioritized cleaner production alternative is the creation of an automatic door closer on the door of the parking tower building, with the highest priority value of 6.18. If all cleaner production alternatives are implemented, there will be energy consumption savings in the recovery unit of 2,052 kWh per ton per day. The percentage of urea and NH_3 loss can be reduced by 20% so that the production efficiency in the prilling unit increases from 99.44% to 99.68% and the savings to be obtained range from 620 thousand to 45 billion rupiah per year.

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