

Comparative Analysis on Cost and Benefit of The Rejected Brine Valorization Technology for Sustainable Brine Management: An Indonesia Case Study

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Abstract

When disposed of improperly, rejected brine, a byproduct of the desalination process used in power plants, can negatively affect the environment. However, because it includes compounds that companies require, rejected brine may be a useful resource. Sustainable brine management is crucial to ensure environmental and human safety due to dynamic and complex requirements for its composition and purification. The valorization strategy changes the paradigm of rejected brine from waste into resources for various purposes. This technology can produce a NaCl solution from rejected brine to be used as an alternative raw material for the Chlor-alkali industry, especially for Indonesia company. This paper aims to compare the cost and benefit of the rejected brine valorization technology from membrane-based technology, that is, electrodialysis (ED), reverse osmosis (RO), and osmotically assisted reverse osmosis (OARO). There are three schemes to be analyzed, named scheme 1 (UF-ED), scheme 2 (UF-NF-UF-RO), and scheme 3 (UF-NF-RO-OARO). The result shows that all the schemes gave a negative net benefit in each case. The total cost for scheme 2 was lower than another scheme. However, the total benefit for scheme 3 is higher than another scheme. Furthermore, it can be seen that scheme 3 has more economical and environmental benefits than scheme 1 and scheme 2.

Keywords

Cost-Benefit Analysis, Valorization, Rejected Brine, Sustainable Management.

1. Introduction

The rejected brine is a by-product of various industries such as desalination plants, oil and gas, petrochemical, textile, and steel industries. It contains salinity of $1.6x - 2x$ when compared to seawater salinity (Gude, 2018; Panagopoulos et al., 2019). The average rejected brine per day is 45-70% of the feed seawater (Ogunbiyi et al., 2021). Brine is usually discharged into the environment through ocean/surface water discharge, evaporation ponds, sewage discharge, and other options (Arafat, 2017; Viader et al., 2021; Ziolkowska and Reyes, 2017). Regardless of the type of desalination plant, disposal of rejected brine from desalination plants into seawater is an important environmental concern because effluents contain high salinity, high temperatures, and toxic and non-toxic residual chemicals from the pre-treatment process. Consequently, the rejected brine has the potential to cause damage to marine and underground habitats, eutrophication, pH fluctuations, and an increase in heavy metals in the marine environment (Alameddine and El-Fadel, 2007; Heck et al., 2016, Petersen et al., 2018). At present, several treatment methods have been applied. However, these methods are unsustainable today (Panagopoulos, 2022).

The rejected brine is considered a potential source because it contains valuable compounds, such as Na^+ and Cl^- (Panagopoulos and Giannika, 2022). Sustainable brine management is very important to ensure environmental and human safety because brine can be one of the most challenging to treat or dispose of because its composition and purification requirements are dynamic and complex (Giwa et al., 2017; Panagopoulos et al., 2019). The valorization strategy changes the paradigm of rejected brine, which is a waste into a resource for various other purposes and applications (De Buren and Sharbat, 2015). Many process industries require brine as part of their processes, such as

hydrometallurgy, sodium hypochlorite, lithium carbonate, and the chlor-alkali industry (Ariono et al., 2016). Some facilities even use rejected brine for irrigation or deicing (SAMCO, 2019).

Brine adaption for industrial uses for example is the reuse of rejected brine as an alternative raw material in the chlor-alkali industry has high potential due to its high salinity level (Casas Garriga, 2011). Desalination plants can offset costs and even minimize the cost of the desalination process if they utilize the rejected brine, by selling pure brine to other industries (Morillo et al., 2014; Wenten et al., 2017). In addition, valorization of rejected brine can achieve circular economy targets and sustainable waste management (Ogunbiyi, 2021; Cipolletta et al., 2021). Currently, endeavors to extend the supply of renewable vitality have gotten to be a worldwide motivation (Sakti et al., 2022). In Indonesia, using rejected brine as raw material for the chlor alkali industry can potentially reduce salt imports because the raw material for salt for this industry is obtained from imports.

The rejected brine valorization as raw material for the chlor-alkali industry can be categorized as waste reuse. Treatment technology is needed to increase the concentration of rejected brine into a NaCl solution with a saturation of 250mg/L. This valorization is a promising and sustainable alternative, but its implementation is still on a limited scale due to the many technological gaps that must be overcome to make it economically viable (Adham et al., 2007). The use of several technologies that are quite dangerous if they are produced in high intensity can even result in health issues, acid rain, and climate change (Farizal et al., 2022; Idris et al., 2022). Therefore, a systematic assessment approach should be applied to estimate the sustainability and feasibility of investment by looking at a technological point of view and considering the economic, social, and environmental benefits. Implementing new technology requires a lot of money, so decision-makers need to look at other benefits derived from the planned implementation. When benefit and cost can be outlining, it can be used as a monetization method to measure direct and indirect impacts on social and environmental aspects (Carolus et al., 2018; Khoirun et al., 2020). Most of the literature on valorization technology for the rejected brine as raw material for the chlor-alkali industry also has not taken into account the combined cost analysis and benefit analysis of the technology used so that the application of this method in the saltwater waste sector, especially the valorization of rejected brine, is still limited.

This research focuses on processing the rejected brine into raw material for the Chlor-alkali industry using rejected brine from the steam power plant. The appropriate rejected brine valorization technology developed in Indonesia is analyzed with determined the costs and the benefits.

1.1 Objectives

This paper aims to compare the cost and benefit of the rejected brine valorization technology for sustainable brine management in Indonesia. A broader goal of this research is to provide policymakers with a comprehensive economic analysis of rejected brine reuse as alternative raw materials for the Chlor-alkali plant. Nevertheless, the results are expected to be of broader relevance, particularly to other salt-scarce regions facing similar brine management issues.

2. Literature Review

Molinos-Senante et al. (2011) presents a cost-benefit analysis of water reuse projects for environmental purposes with an economic assessment of environmental externalities. The results show that the greatest environmental benefit is the prevention of nitrogen and phosphorus release as these nutrients are primarily responsible for the eutrophication problem in inland water bodies. Analysis of water reuse, for internal gain only, shows that some factories are not financially viable. However, if external benefits from these projects are also included, the economic feasibility analysis gives positive results for all water reuse projects in the study. Therefore, for an objective evaluation of a water reuse project, an economic feasibility study should include all parameters including economy, environment, and resource availability.

Arborea et al. (2017) analyzed benefit and cost as a tool to consider two alternative scenarios for reuse of treated irrigation water, namely for new irrigated land and as an alternative to current groundwater sources. The methodological framework is presented for a cost-benefit comparison carried out taking into account the effects of scale from plant size. The results show that the economic convenience of reusing wastewater can be calculated because the cost of processing wastewater reuse is highly dependent on the quality of the incoming wastewater and the size of the plant, while the value of the benefits is quite stable.

Ohemeng and Ekolu (2020) investigated the costs and benefits of producing natural and recycled concrete aggregates for use in concrete. The study found that the net profit from producing natural or recycled concrete aggregate was negative in each case. However, the production costs for recycled concrete aggregates are lower than for suitable natural aggregates. In addition, the environmental related costs arising from the production of recycled concrete aggregates, are much lower than those of natural aggregates. Therefore, commercial production of recycled concrete aggregates from waste concrete should be promoted as a cost-effective and environmentally friendly approach for use by the construction industry.

Garcia and Pargament (2015) developed a cost and benefit methodology for wastewater reuse systems for irrigation purposes. This approach is carried out with five steps and three scenarios. A five-step approach, including selection and evaluation of a water reuse plan, estimation of internal costs (investment costs and OandM), estimation of external trade-offs (costs and benefits), implementation, and sensitivity analysis. The scenarios analyzed are pessimistic, base-case and optimistic. This literature confirms that the relevant externality benefits have a strong impact on the economic viability of wastewater reuse projects.

By outlining the costs and benefits can also show that a project may not be feasible economically, but has benefits that need to be considered. However, the definition and selection of calculated benefits were not homogeneous across studies. The selection and quantification of external benefits can have a strong impact on evaluating the feasibility of a project (Garcia and Pargament, 2015). Therefore, this research aims to analyze the utilization of the valorization technology, which considers the total costs required and the total benefits obtained, both directly and indirectly, which are nominally in monetary terms.

3. Methods

3.1 Valorization Technology of Rejected Brine to Produce a NaCl Solution

The object of this research is the valorization technology of rejected brine to produce a NaCl solution that can be used as an alternative raw material for the Chlor-alkali industry. Several commercial technologies for the valorization of rejected brine that can produce NaCl solutions (>200 mg/l) analyzed in this article are membrane-based technologies that have been commercialized, including electrodialysis (ED), reverse osmosis (RO), and osmotically assisted reverse osmosis (OARO). A multi-stage OARO system developed by Hyrec successfully concentrated SWRO brine at a final TDS concentration of 250,000 mg/L (WDR, 2018). The processes proposed by Turek (2003a, 2003b) are especially indicated for areas with seawater availability and lack of freshwater resources, fossil fuels and land. In Japan, ED is actually used in a commercial sense to concentrate seawater to a TDS of 200 g/L, which is then followed by thermal concentration and salt crystallization. A commercial EDR system called the non-thermal brine contractor, created by General Electric, can treat brackish water reverse osmosis brine solutions and recover up to 99% of the freshwater (General Electric Company, 2013). Similar to this, Saltworks Technologies Inc. created a number of commercial EDR systems that could be used to treat and concentrate reverse osmosis brine solutions to a TDS concentration as high as 180,000 mg/L (Saltworks Technologies Inc., 2019).

The valorization technology to reuse rejected brine as raw material for the Chlor-alkali industry in this research consists of Scheme 1 comprising ultrafiltration (UF) and electrodialysis (ED) sub-systems (Ogunbiyi et al, 2021). Scheme 2 consists of ultrafiltration (UF), nanofiltration (NF), ultrafiltration (UF), and reverse osmosis (RO) (Wenzlick and Siefert, 2020). Scheme 3 consists of sub-systems of ultrafiltration (UF), nanofiltration (NF), reverse osmosis (RO), and osmotically assisted reverse osmosis (OARO) (PTSEIK, 2021). In scheme 1, the output produced is only NaCl solution. While in scheme 2 and scheme 3, the output produced is NaCl solution and demineralized water. The schematic of the technology analyzed in this article is shown in Figure 1-3.

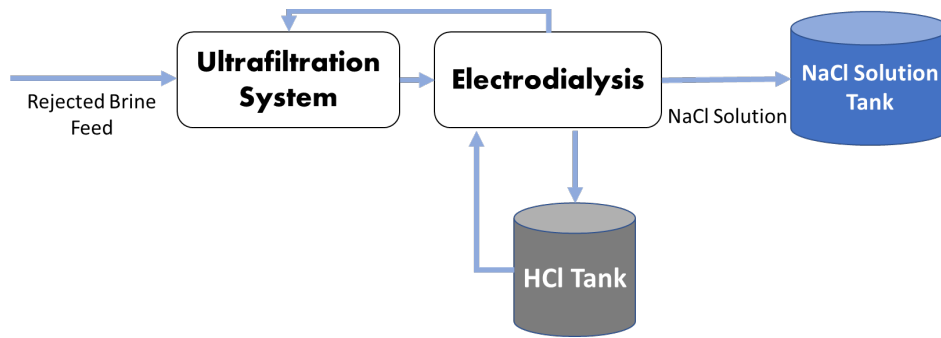


Figure 1. Scheme 1 (UF-ED) (Ogunbiyi, 2021)

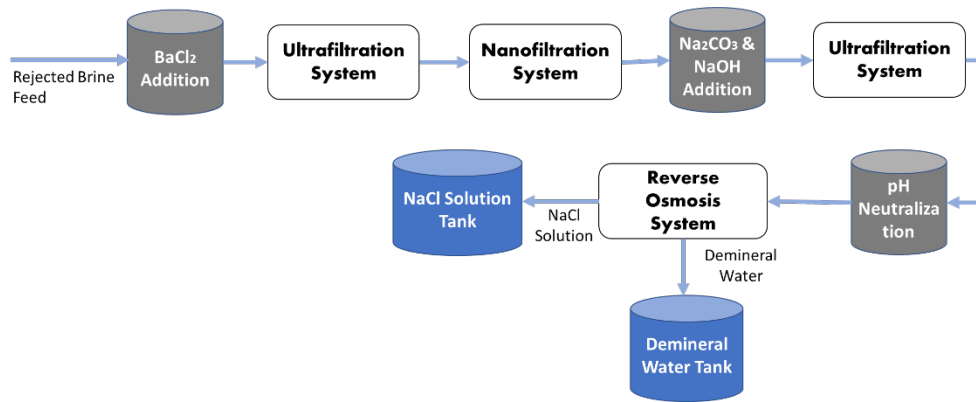


Figure 2. Scheme 2 (M. Wenzlick and N. Siefert, 2020)

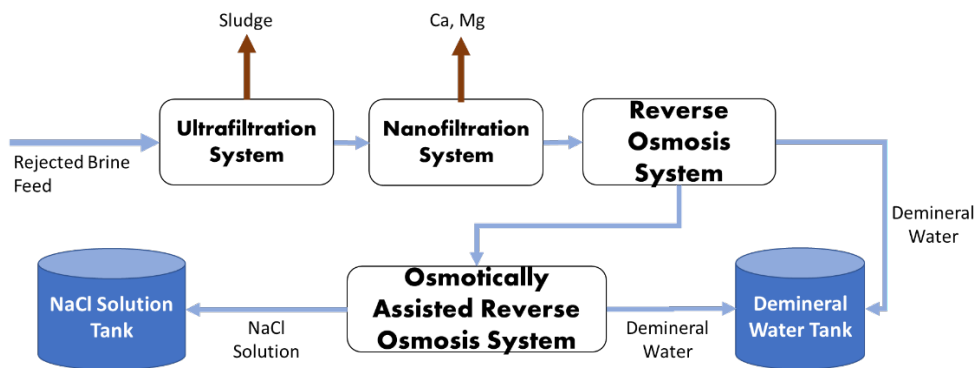


Figure 2. Scheme 2 (PTSEIK, 2021)

4.2 Methodology Step

The initial research stage begins with identifying the technology through studying the object and literature review. The next stage is the stage of data collection and data processing. Interviews and surveys were carried out at the stage of data collection. Economical and environmental aspects demonstrate sustainability in brine management. Rejected brine valorization technology's cost component consists of investment and operational costs. Investment costs consist of direct costs and indirect costs. Direct costs include equipment, instrumentation and control, installation, piping, installed electricity, ship transportation, insurance, transporting goods to the plant site, factory buildings, service

facilities and yard repairs. Meanwhile, indirect costs include engineering and supervision, contractor, and unexpected costs. The working capital investment charged is used for the purchase of the membrane. The rejected brine valorization system's operational and maintenance cost components consist of maintenance costs, chemical consumption costs, membrane replacement costs, electricity costs, direct labour costs, and other operational costs. Environmental costs incurred include the costs of emissions generated by machinery and equipment.

Benefits are also seen from the economic and environmental aspects. On the economic aspect, the benefits of building a valorization system are sales of NaCl solutions and demineralized water. In scheme 1, the output produced is only NaCl solution. While in scheme 2 and scheme 3, the output produced is NaCl solution and demineralized water. While on the environmental aspect, the benefits obtained are reduced imports of industrial salt, reduced emissions due to reduced shipping activities, and reduced damage to coral reefs. The reduced import of industrial salt is an avoided cost when developing rejected brine valorization technology. Reduced emissions from shipping activities will reduce sea transportation trips to send imported salt. This reduced transportation trip will reduce emissions generated by burning ship fuel. Meanwhile, reduced damage to coral reefs benefits from a reduced discharge of rejected brine. The benefits obtained by not discharging rejected brine into the sea are calculated based on the value of the cost of avoidable damage from the discharge of rejected brine per m³. The cost of the damage will be calculated based on the benefits lost from the damage to coral reefs. With the destruction of coral reefs, the immediate benefit lost is coral reefs as fishing grounds. Damage to coral reefs due to exposure to hot water discharges into the sea causes fish to lose their use as a habitat. With the destruction of coral reefs, the risk of abrasion increases. The next step is to compare and analyze the results of data collection. The conclusion is the last step in this research.

4. Results and Discussion

The technology for valorizing rejected brine is categorized as waste reuse. This research uses the analyzed rejected brine valorization technology to process steam power plant (PLTU) rejected brine into NaCl solution (content > 200g/l). The investment cost to build a rejected brine valorization system with ED membrane (scheme 1) is higher than the rejected brine valorization system with RO and OARO membranes (scheme 2 and scheme 3). This is in line with Tong and Elimelech (2016) and Turek et al. (2017), which state that ED is an electrically driven, relatively expensive, and energy-intensive membrane technology when processing a high concentration of the salt solution in order to produce high-purity water products. However, electro dialysis is the early commercial technology to gain more salinity from brine (Panagopoulos et al., 2019).

Figure 4 shows that the direct costs for all schemes have the largest portion, more than 80% of the total costs analyzed in this article. The equipment cost was the highest component charge of direct cost. The equipment costs for producing per m³ NaCl Solution of every scheme were 61,9%; 61,9%; and 58,3% of the direct cost or 52%; 52%; and 49% of the total investment cost, respectively. These results show that equipment cost is a critical component for cost-effective production. Total environmental costs have a low portion of total costs because membran technology used less electricity.

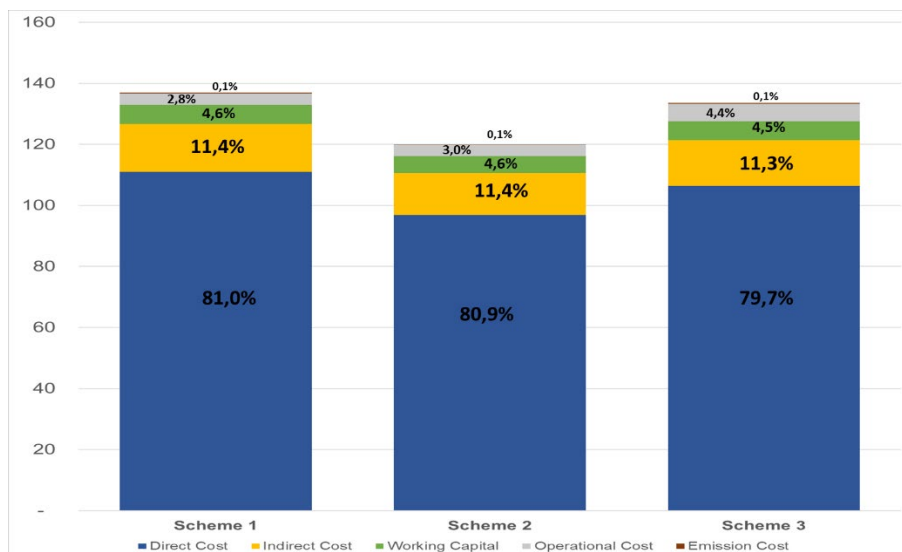


Figure 4. Total cost by component (per m³ NaCl Solution)

Implementing new technology requires no small amount of money, so decision-makers need to look at other benefits derived from the planned implementation of the technology. From figure 5, the greatest benefit value per m³ of NaCl solution is obtained by scheme 3. The largest component of the benefits is the reduced damage to marine corals. It shows rejected brine management can save marine environmental. Based on the calculation results, the value of environmental benefits from implementing rejected brine valorization technology is higher than the economic benefits.

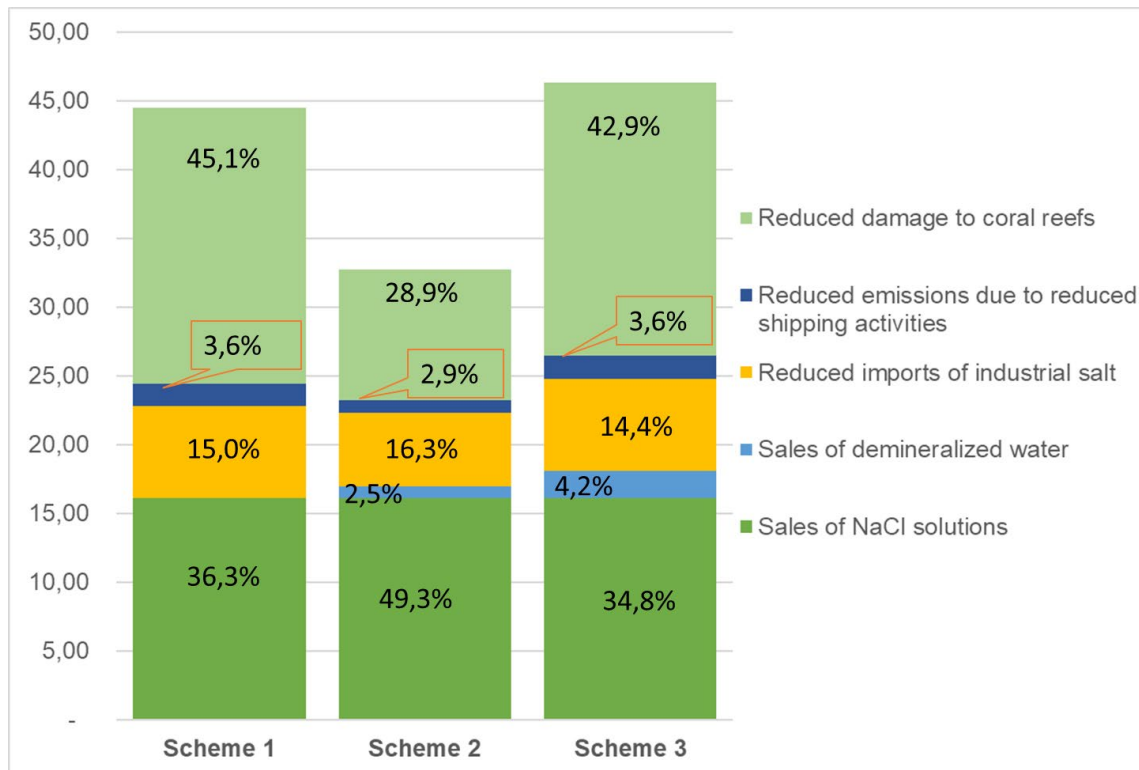


Figure 5. Total benefits by component (per m³ NaCl Solution)

The total cost for scheme 2 was lower than another scheme. Furthermore, the total benefit for scheme 3 is higher than other schemes. the ratings for net benefits sequentially include scheme 2, scheme 3, and scheme 1. It can be seen that scheme 3 has more economical and environmental benefits than scheme 1 and scheme 2. Table 1 compares the costs and benefits of valorization technology by the scheme. It can be seen that all the schemes gave a negative net benefit in each case. The net benefits for scheme 2 and scheme 3 have almost the same value. The RO-OARO membrane blend is a developing technology that converts rejected brine into NaCl solution. OARO membranes can achieve higher permeate recovery at lower costs than RO membranes alone (Mo et al., 2022). In addition, OARO membranes have flexibility in their operations under changing time conditions (Peters and Hankins, 2019). In terms of production, this technology is still classified as new and is not yet commercially available in Indonesia, so it has operational risks in its production activities. However, this has become one of the business opportunities in the membrane technology sector due to market demand for this technology. As such, scheme 3 should be promoted.

Table 1. Comparison of the costs and benefits of valorization technology by scheme (USD per m³ NaCl solution)

	Scheme 1	Scheme 2	Scheme 3
Total Cost	136,94	119,82	133,51
Total Benefit	44,47	32,71	46,29

Net Benefit	-92,47	-87,11	-87,22
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5. Conclusion

Implementing new technology requires no small amount of money, so decision-makers need to look at other benefits derived from the planned implementation of the technology. Analyzing the cost and benefits can systematically estimate the feasibility of investing in technology. However, the application of this method in the rejected brine sector, especially the valorization of rejected brine, is still limited. based on calculations, the values for net benefits for scheme 1 is USD -92,47, scheme 2 is USD -87,11, and scheme 3 is USD -87,22.

Each technology has its own advantages and drawbacks regarding water recovery rate and energy consumption. Future research should look at combining different membrane technologies to optimize brine concentration with a reasonable water recovery rate and operating cost. The recovery of value-added minerals from brine offers both economic and environmental benefits. Nevertheless, the processes need to be further optimized to improve the high precision separation of single elements from others, and boost the benefit-cost ratio.

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