International Journal of Industrial Engineering & Production Research September 2024 Vol. 35, No. 3: 1-17
DOI: 10.22068/ijiepr.35.3.2058

RESEARCH PAPER

Process Design and Feasibility Study of Food-Grade Salt Production from Crude Solar Salt in Madura, Indonesia

Makhfud Efendy[1]*, Nizar Amir[2], Kritsana Namhaed[3], Muhammad Yusuf Arya Ramadhan[4], Mochamad Yusuf Efendi[5], Mohamed Kheireddine Aroua[6] and Misri Gozan[7]

Received 5 May 2024; Revised 13 July 2024 ; Accepted 6 August 2024;

ABSTRACT
The production of food-grade salt from crude solar salt has been rigorously evaluated through a comprehensive techno-economic analysis. This study aimed to investigate a salt factory to assess its technical and economic aspects, identify precise parameters for enhancing the quality of food-grade salt, and develop a cost-effective and novel method for processing high-quality food-grade salt. The factory's primary processes include grinding, washing, draining, drying, and fortification, supported by equipment such as brine management systems, conveyors, sieves, and packaging machinery. The proposed salt plant, designed for a daily output of three tons over 15 years, requires 30 months for construction and a 4-month startup period. The total capital investment is USD 1,921,000, with USD 310,000 allocated for technology and equipment. Economic indicators, including a Net Present Value (NPV) of USD 7,862,000, an Internal Rate of Return (IRR) of 46.48%, a payback period of 1.56 years, and a Return on Investment (ROI) of 64.28%, demonstrate its feasibility. Furthermore, this research provides a detailed production process and layout of the plant, which is crucial for all stakeholders. Moreover, it emphasizes the critical need for designing an effective organizational structure and addressing identified safety issues to maximize efficiency and safety in food-grade salt factories. Therefore, establishing a salt plant in Indonesia supports food-grade salt production, stabilizes solar salt prices, and enhances the welfare of traditional salt farmers. Ultimately, the results of this study offer valuable insights for all stakeholders regarding the feasibility of establishing a food-grade salt production plant in Indonesia.

KEYWORDS: Food-grade salt; Crude solar salt; Salt processing; Salt plant; Techno-economic analysis.

1. Introduction

Salt has become a vital commodity in various global economic and industrial sectors [1]. Over the years, the demand for salt has steadily increased, primarily due to its applications in industry, human consumption, and pharmaceuticals [2]. In 2022, the Indonesian Ministry of Industry reported that out of the country's total salt demand of 4.5 million tons, only 800 thousand tons were allocated for household consumption [3]. Over the past several years, Indonesia has experienced a rising trend in salt imports, with the volume increasing from 2.5 million tons in 2017 to 2.75 million tons in 2022 [4], amounting to a total value of USD 124.4 million. One of the main drivers of this increased

* **Corresponding author: Makhfud Efendy**
makhfud.espi@trunojoyo.ac.id

1. ***Department of Marine Science, Universitas Trunojoyo Madura, Bangkalan, East Java, 69162, Indonesia***.
2. ***Research Centre for Carbon Dioxide Capture and Utilisation (CCDCU), School of Engineering and Technology, Sunway University, No. 5 Jalan Universiti, Bandar Sunway, Selangor, Petaling Jaya, 47500, Malaysi & Second Address Department of Mechanical Engineering, Universitas Trunojoyo Madura, Bangkalan, East Java, 69162, Indonesia.***
3. ***Laboratoire de Génie Chimique, Université de Toulouse, CNRS, INPT, UPS, Toulouse, France.***
4. ***Chemical Engineering Department, Universitas Indonesia, Kampus UI Depok, Depok 16424, Indonesia.***
5. ***Research Center for Biomass Valorization, Faculty of Engineering, Universitas Indonesia, Kampus Baru UI, Depok, 16424, Indonesia.***
6. ***Research Centre for Carbon Dioxide Capture and Utilisation (CCDCU), School of Engineering and Technology, Sunway University, No. 5 Jalan Universiti, Bandar Sunway, Selangor, Petaling Jaya, 47500, Malaysia and Second Address Department of Engineering, Lancaster University, Lancaster, LA1 4YW, United Kingdom.***
7. ***Research Center for Biomass Valorization, Faculty of Engineering, Universitas Indonesia, Kampus Baru UI, Depok, 16424, Indonesia.***

demand for salt is the rapid population growth [5]. As the population expands, the need for salt as a primary food ingredient and a fundamental element in various industries has significantly increased [6].

Table salt, also known as food-grade salt, used as a flavor enhancer in various foods, contributes positively to the agricultural and food sectors [7]. Additionally, salt plays a crucial role in the industrial sector, including the chemical and pharmaceutical industries [8]. It frequently serves as a primary raw material for producing a wide range of products in manufacturing processes. In the pharmaceutical sector, salt is vital in manufacturing medicines and various medical products [9]. Several vital stages are involved in the processing of food-grade salt [10], which require careful investigation. For instance, an essential step is fortifying salt with iodine or other beneficial nutrients to ensure it provides these vital elements crucial for human health [11]. These stages significantly impact both the quality and quantity of the salt produced.

To meet the demands for high-quality and cost-effective food-grade salt, a comprehensive understanding of salt production techniques and the proper selection of processing methods are required. To study the production process of food-grade salt, we employed SuperPro Designer software to develop and simulate system performance. This powerful tool aids research by identifying optimal performance in both technical and economic terms. Numerous studies have utilized SuperPro Designer to develop and simulate industrial production processes before presenting the findings to government and industry stakeholders to initiate projects, as explained below.

This study [12] utilized SuperPro Designer software to simulate and evaluate the techno-economic performance of a metal recovery process, focusing on molybdenum, vanadium, nickel, and alumina from discarded hydroprocessing catalysts. The simulation included layout design, optimized reaction conditions with Ethylenediaminetetraacetic acid (EDTA) as the leaching agent, and economic assessments, such as total investment costs, unit production costs, internal rate of return, net present value, and project payback time. The findings indicated that using EDTA for metal recovery is economically viable. The process generated minimal waste and emissions while efficiently recovering valuable solvents. These results support the economic feasibility of recycling spent hydroprocessing catalysts and provide insights for industrial-scale valorization, aiding stakeholders and decision-makers in investment and policy decisions.

Another study [13] also utilized SuperPro Designer software to conduct comparable simulations, examining the economic aspects of an herbal ice cream product derived from longevity spinach. The formulation includes longevity spinach (5%), skim milk (69.75%), flavor extract (0.6%), sugar (3.25%), salt (1%), lecithin (20%), and food coloring (0.4%). The plant can produce 57,734 jars per day, each priced at Rp 5,066. The initial investment is Rp 10,305,160,564, with an annual revenue of Rp 77,216,401,229 and an internal rate of return (IRR) of 46%. The net present value (NPV) is Rp 21,819,500,900, and the payback period is 2.24 years. The product's performance is sensitive to the selling price and raw material costs. From the literature, it is evident that simulation can offer a detailed overview before actual implementation in developing an industry. This approach helps prevent losses during implementation by identifying potential mistakes and optimizing plant design, equipment, and technical parameters. Consequently, this enhances the economic perspective and overall feasibility of the project. This can be explained that the simulation and economic analysis are highly effective methods extensively applied across diverse disciplines to comprehend and forecast complex systems and their behaviors. Combining these approaches offers significant benefits, including valuable insights and improved decision-making processes. A notable advantage of this integration is its ability to assess the competitive impacts of mergers [14].

To review the food-grade salt production process, it is essential to understand the primary stages involved. The process begins with transforming crude salt into fine salt, typically through size reduction. One study [15] investigated the grinding process in detail, comparing wet and dry grinding methods. This process usually utilizes a disc mill or hammer mill to reduce the salt's size. The choice of material for the equipment is crucial for durability, with stainless steel often used due to its rust-preventing properties. However, dry grinding can still induce rust even with stainless steel, necessitating the introduction of the wet grinding method. Despite its advantages, the wet method has drawbacks, such as higher quantity reduction due to salt dissolution in brine water. Following grinding, the next step involves thoroughly washing the salt to remove impurities and contaminants. This involves draining to remove excess water, followed by drying to eliminate any remaining moisture, resulting in dried salt. This method enhances the salt's shelf life and overall quality, making it crucial to understand the relevant parameters. According to the literature [16], reducing the water content in salt requires two types of equipment: draining and drying equipment. Draining typically utilizes a centrifugal hydroextractor, which effectively reduces high water content, while drying commonly employs rotary, fixed, or fluidized bed dryers. These dryers reduce the salt's water content to the lowest levels, with fixed or fluidized bed dryers being particularly effective in producing high-quality salt [17]. Proper salt processing requires not only appropriate equipment but also carefully selected parameters [18]. Accurate processes, equipment, and parameters provide stakeholders with a clear investment overview, ensuring the salt industry can achieve feasible results [19].

However, for the literature, there is currently a lack of research investigating salt factories to analyze their technical and economic aspects and determine precise parameters for improving the quality of food-grade salt. This research is crucial for providing new insights to fill this knowledge gap and for proposing practical implementation strategies to the government and industry to develop high-quality, cost-effective salt. Therefore, in this paper, we proposed a detailed design for a food-grade salt production plant with an estimated capacity of 3 tons of crude solar salt per hour. This design was created using SuperPro Designer 9.5 to develop and simulate the industrial production processes. The evaluation encompasses the production line and technical parameters necessary for producing food-grade salt from crude solar salt. Furthermore, the study also analyzed the economic aspects, including production costs, investments, and engineering benefits. The objective of this study is to develop a cost-effective method for processing high-quality food-grade salt and to evaluate it in terms of technical and economic factors. Ultimately, the study provides a comprehensive overview of how to establish a high-quality, cost-effective food-grade salt processing industry. It contributes to practical knowledge and offers guidelines for all stakeholders before real implementation.

The remaining part of this paper is structured as follows: Section 2 explains the experimental procedures, simulation, process description, and economic analysis. The results and discussion are presented in Section 3, detailing the mass and energy balance of food-grade salt from crude solar salt, as well as the capital and production cost analysis, cash flow, and profitability. Finally, Section 4 provides the conclusion of the study and offers recommendations to all stakeholders.

2. Experimental Procedures

2.1. Simulation and process description

In this study, a proposed plant for food-grade salt production, with an estimated capacity of 3 tons per hour of crude solar salt, was designed. The primary source of this crude solar salt was obtained from local traditional saltworks around Madura Island, East Java Province, Indonesia. This acquisition served two purposes: firstly, to support local traditional salt farmers by purchasing their salt products, and secondly, to minimize transportation costs. The plant was designed to be located in Pamekasan Regency, with an expected productive lifespan of 15 years, including a developmental phase of 30 months and a startup period of 4 months. The production line was planned to operate on a daily schedule of eight hours, six days a week, to achieve optimal operation. The maintenance schedule for equipment included bi-weekly maintenance sessions. Evaluations of mass and energy balance were simulated using SuperPro Designer 9.5 to ensure optimal process conditions. Furthermore, profitability analysis was conducted using Microsoft Excel 2019. To provide a reference for technical feasibility, the process design in this study was developed based on a previous literature review study.

Figure 1 presents a detailed process flow encompassing five primary stages: grinding, washing, draining, drying, and fortification. The secondary processes include transferring, represented by belt and screw conveyors, sieving, represented by a vibrating screen; and packaging, represented by a filler. The grinding process reduces the size of crude solar salt to its smallest particle size. At this stage, the washing procedure is crucial to remove impurities effectively. The washing process uses saturated brine water to eliminate soluble and insoluble impurities in the crude solar salt. Removing soluble impurities enhances the purity of sodium chloride while eliminating insoluble impurities like mud, plastic, and sand improves the salt's physical quality. The draining process reduces the water content of the salt after washing, preparing it for the subsequent drying stage. The drying process aims to reduce the water content to the lowest level, meeting Indonesian national standards for food-grade salt. Finally, the fortification process adds potassium iodate (KIO_3) to provide the necessary iodine content in the salt.

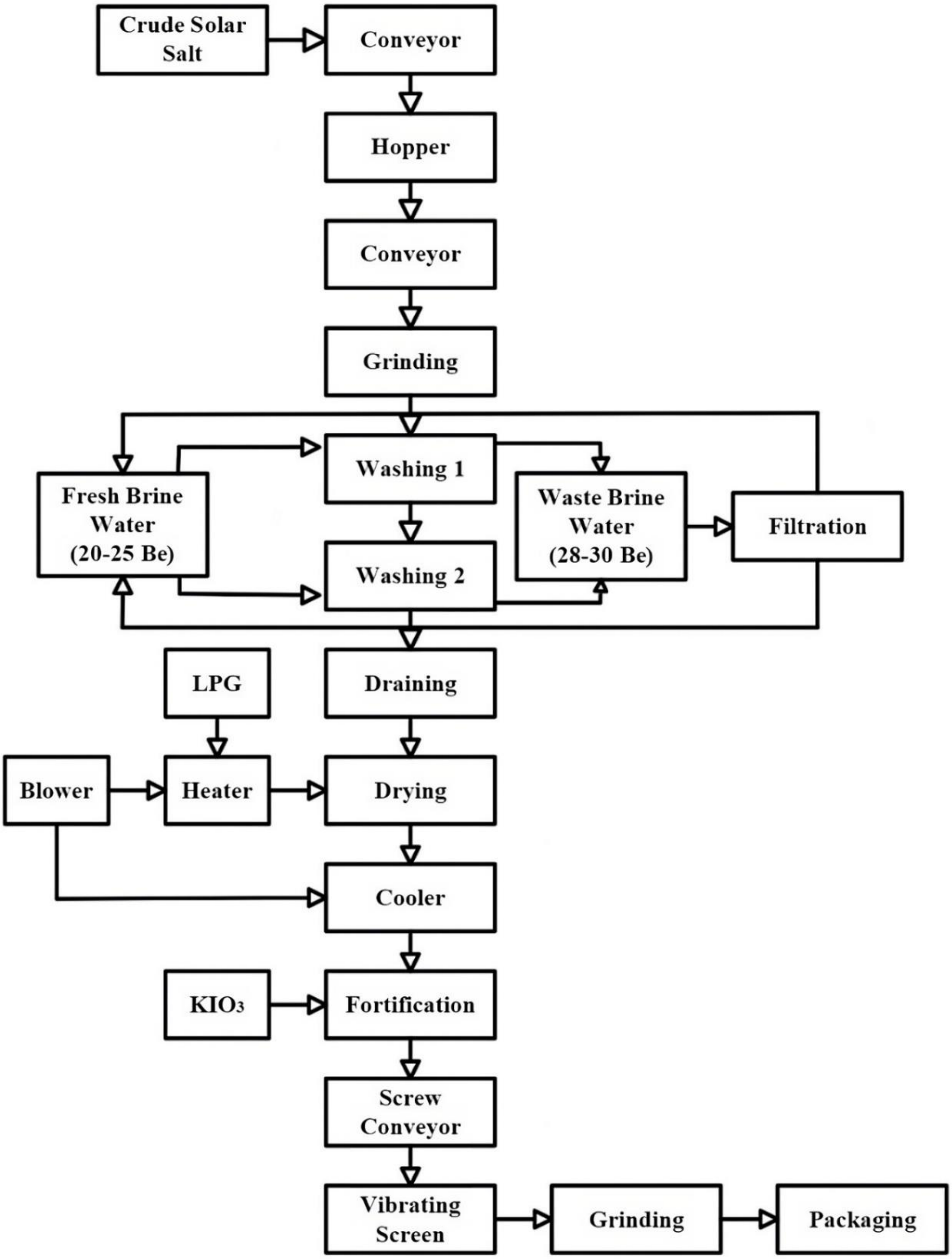

Fig. 1. Block flow diagram of production of food-grade salt from crude solar salt.

In this study, the simulation of the production line and technical parameters for producing food-grade salt from crude solar salt using SuperPro Designer 9.5 is explained as follows. The process begins by transferring the crude solar salt from storage using a conveyor belt with a 5-ton/h capacity. It is then placed into a hopper for temporary storage. Next, the crude solar salt is moved to a grinder, where it undergoes size reduction using hammer mill equipment. The expected output size is approximately 0.3 mm, with a processing capacity of 3 tons/h. The grinding process is designed to produce a uniformly sized salt product that meets quality standards, with negligible losses assumed in the transferring and grinding stages. Following grinding, the salt is washed using saturated brine water with a salinity level of approximately 20-25 degrees Baumé in the washing equipment. The washing process is conducted twice to maximize impurity removal. The estimated amount of saturated brine water used in a single washing process is 9,000 L/h. The use of saturated brine water aims to limit the loss of salt content due to dissolution. Therefore, in this simulation, washing losses are assumed to be negligible.

The washing process is expected to increase the sodium chloride content in the salt from 88% to 94%. Additionally, it enhances the physical characteristics of the salt, leading to improved whiteness and purity. The brine management system addresses water management issues and promotes environmentally friendly processes by handling the saturated brine water. This system is designed to deliver clean, saturated brine water to the washing system through multiple filtration steps before recycling it for use in the washing process. All waste generated from the brine management system is collected and stored in the waste treatment plant. After washing, the moist salt is moved to the draining phase to remove any remaining water through centrifugation. During this process, the salt is estimated to have an 11% water content on a wet basis. The draining process is more effective in reducing higher water content in materials that the drying process cannot efficiently manage.

The drying process was conducted using a rotary dryer to reduce the water content to its lowest possible level. The salt's water content was estimated to be approximately 1% to 3%, meeting the minimum percentage requirement specified by Indonesian standards for food-grade salt. The drying temperature was maintained at 100 to 110°C to maximize water evaporation without compromising the quality of the salt. Before entering the fortification process, the salt is cooled to an estimated temperature of 25°C using an ambient air blower. Lower salt temperature is advantageous for the fortification process with KIO_3, as higher temperatures can lead to the evaporation of KIO_3, resulting in lower iodine content.

The fortification process is carried out in a 100L mixing tank, where iodine in KIO_3 is added to the salt to achieve a final concentration of 45 ppm. Iodine is added using a dosing pump with a flow rate capacity of 5 to 8 L/min. The product then passes through a vibrating screen to ensure uniform salt particle size. Afterward, it is moved to salt storage before being packed. The packaging process involves using a machine capable of handling 40 packs per minute, with each pack weighing 250 g. These packs are made of polyethylene plastic and weigh 5 g each.

The process simulation used SuperPro Designer V9.5 to generate mass balance, energy balance, and an economic report. SuperPro Designer V9.5 was utilized to calculate specifications for several preliminary plant research designs [20-22]. Equipment prices were obtained through a local manufacturing vendor, and raw material prices were sourced from local salt warehouses and vendor companies. The price for packed salt was set at IDR 1,200 to match the market price. The USD to IDR conversion rate used in this study is IDR 15,610.95 per USD 1 (as of October 5, 2023). The flow diagram design in the SuperPro Designer V9.5 interface and the detailed parameters of the equipment technology are presented in Figure 2 and Table 1, respectively.

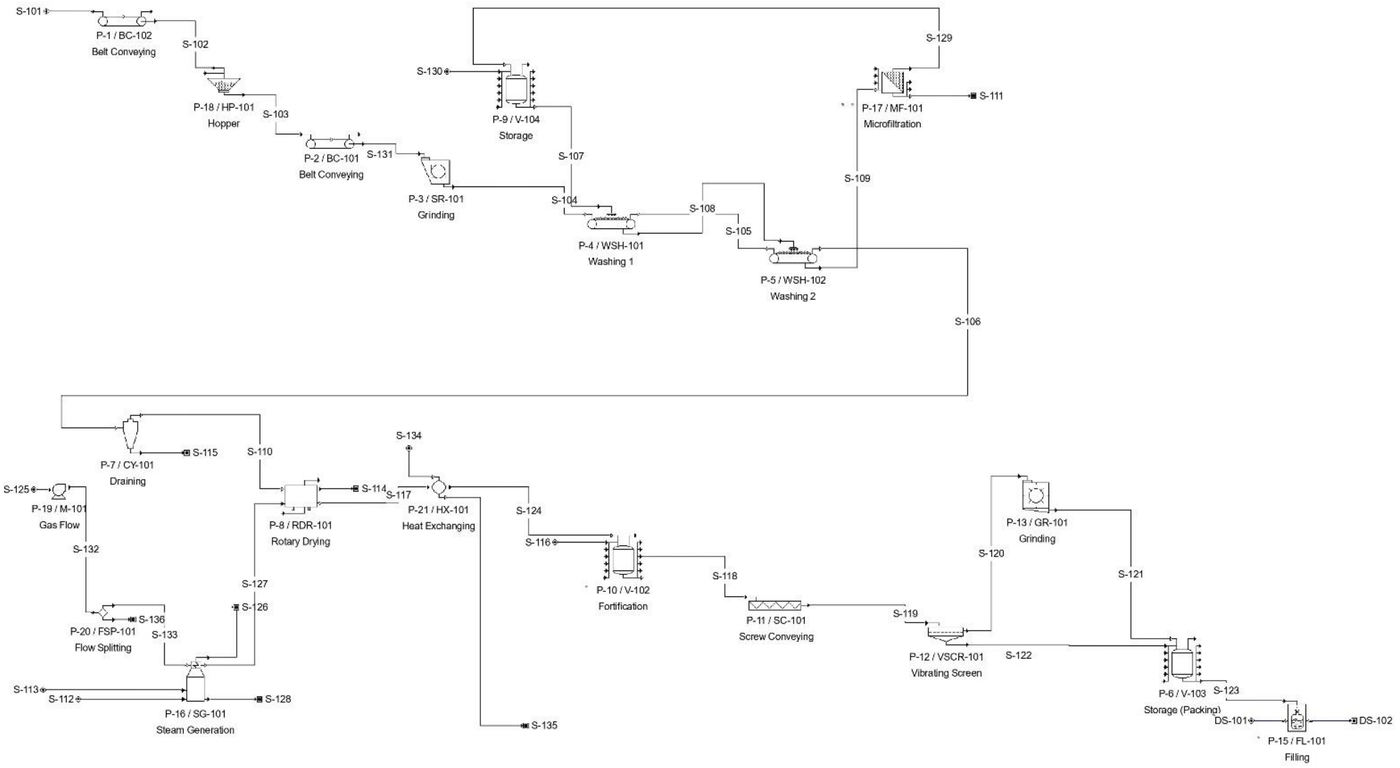

Fig. 2. Process flow diagram of food-grade salt production in SuperPro Software.

Tab. 1. The detailed parameters for each equipment in the salt plant

Items	Capacity (tons/h)	Power (kW)	Size (mm)
Main Equipment			
Belt conveyor	± 5 tons/hours	1.48 kW	6900 x 600 x 2450
Hopper Storage	± 5 tons/hours	2.22 kW	1200 x 1200 x 1500
Belt conveyor	± 5 tons/hours	1.48 kW	600 x 830 x 5000
Hammer mill	± 3 tons/hours	7.4 kW	1480 x 980 x 1850
Washing 1	± 3 tons/hours	2.22 kW	3900 x 1200 x 1690
Washing 2	± 3 tons/hours	2.22 kW	3750 x 1220 x 2510
Centrifuge	± 4 tons/hours	22.5 kW	24600 x 12860 x 10300
Screw centrifuge	± 6 tons/hours	1.48 kW	3400 x 600 x 1700
Screw input dryer	± 6 tons/hours	1.48 kW	4400 x 600 x 1800
Rotary dryer	± 3 tons/hours	2.22 kW	8900 x 950 x 1680
Dryer heating stove	-	0.74 kW	-
Screw assembly + cooling	± 5 tons/hours	1.48 kW	3400 x 280 x 450
Dry salt screw + cooling	± 6 tons/hours	1.48 kW	4400 x 280 x 450
Gyro sieve	± 3 tons/hours	-	-
Disk mill	± 3 tons/hours	7,5 kW	1480 x 980 x 1850
Elevator grader	± 3 tons/hours	1.48 kW	600 x 830 x 5000
Elevator silo	± 3 tons/hours	1.48 kW	600 x 830 x 5000
Silo storage	± 2.5 ton	-	-
Screw silo salt	± 3 tons/hours	1.48 kW	3400 x 280 x 450
KIO_3 tank	± 0.1 ton	0.06 kW	-
Packing machine	± 25-40 pack/min	0.75 kW	-
Digital scales	± Max 0.2 ton	0.006 kW	420 x 500 x 1080
Supporting Equipment			
Primer water pump	-	0.75 kW	·
Brine water pump	± 6 tons	0.75 kW	·
Resevoir tank	± 0.2 ton	-	·

Panel control washing unit	-	-	.
Panel control drying	-	-	.
Blower and cyclone	-	2.22 kW	.
Cooling tower and pump	-	1.51 kW	.
Daughter station CNG	-	-	-
Electricity	-	64 kW	-

2.2. Economic analysis

2.2.1. Estimation of capital cost

Capital costs are one-time expenses associated with project development, encompassing expenditures for construction, land clearing, mechanical and electrical equipment, installation, and acquiring assets such as land. The projected total area for the salt plant is approximately 5,100 m². Detailed insight into the plant layout and the specific allocation of this area are presented in Figure 3. This project aims to establish a collaboration with the government to improve traditional salt farmers' welfare. Consequently, the expense associated with land acquisition was excluded from this calculation, as the government will supply it. The primary capital cost is allocated to the construction of the salt plant, which includes civil, mechanical, and electrical work, equipment technology development, equipment site installation, and other contingency costs. Local contractors and supplier companies provided all quotations for the project's development.

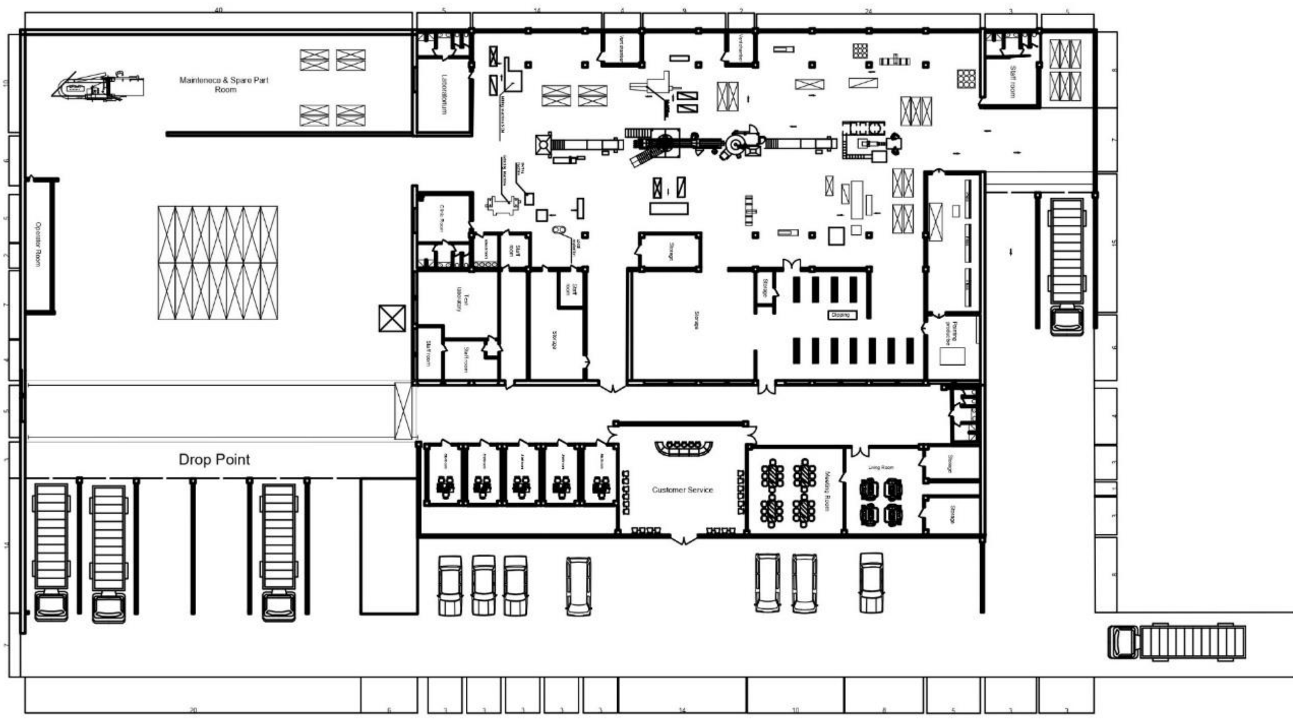

Fig. 3. The two-dimensional (2D) layout of the salt plant.

2.2.2. Estimation of production cost

Production costs refer to the total expenses incurred throughout the entire process of manufacturing a product, including the costs related to its distribution to the market. These costs encompass expenses for raw materials, payroll, administration, facilities, consumables, and utilities. Crude solar salt is purchased from a local traditional saltworks, with the price covering both the purchase and delivery to the project location. Payroll expenses are determined by the minimum wage regulations in the local area, while administration costs include expenses related to office and business operations. Facilities costs cover electricity, water, gas, maintenance, repairs, insurance, and taxes. Additionally, laboratory, consumables, and utilities costs are associated with maintaining optimal business operations.

2.2.3. Estimation of economic and profitability

The economic analysis of this plant involves a two-step process. Firstly, the capital cost is determined by applying the purchase cost factor on default settings while excluding unlisted equipment. Subsequently, the production cost is assessed using SuperPro Designer V9.5 with necessary adjustments. This approach allows for a comprehensive evaluation of the facility's economic profitability. Calculating income and cash flow is essential when analyzing profitability. Income is computed as the revenue from salt product sales, taking into account all production costs, taxes, and depreciation. Cash flow is determined by subtracting all expenses from income. A cash flow analysis was conducted using SuperPro, considering the project's lifetime without financing options for investment. The project lifetime is 15 years, with a construction period of 30 months and a startup period of 4 months. Based on the calculated cash flow, the plant's profitability can be analyzed by calculating the NPV, IRR, payback period, and return on investment (ROI) [23]. NPV illustrates the disparity between the present value of incoming cash flows and the present value of outgoing cash flows over a specified time frame [24]. As NPV is the outcome of calculations, it also determines the current worth of future payments, considering the appropriate discount rate. Projects with a positive NPV are generally judged feasible, while those with a negative NPV are discouraged. The IRR serves as a financial metric employed in assessing the potential profitability of investments [25]. IRR represents the discount rate that, in a discounted cash flow analysis, results in the NPV of all cash flows being precisely zero. The payback period refers to the time required to recover the initial cash investment [26]. ROI is a primary ratio that calculates the net profit of an investment divided by its cost [27].

3. Result and Discussion

3.1. Mass and energy balance of food-grade salt from crude solar salt

By following several processes, including grinding, washing, draining, drying, and fortification, crude solar salt can be purified, ultimately resulting in the successful production of food-grade salt. Table 2 provides an overall mass balance in kg/year for producing food-grade salt from crude solar salt. This simulation demonstrated that crude solar salt can be efficiently and feasibly purified into food-grade salt. The purification process is estimated to result in a maximum loss of 10%, primarily occurring during the removal of soluble and insoluble impurities in the crude solar salt during the washing process. This process results in the production of high-quality food-grade salt. The washing process requires 2,595 L/day of brine water and is expected to generate approximately 50 kg of waste daily. This waste, known as salt slag, contains significant quantities of magnesium and calcium minerals, rendering it a valuable resource for these elements. These minerals can be utilized as sources of magnesium and calcium for dietary supplements in shrimp aquaculture feed [28]. Consequently, this could provide additional income for the industry.

Tab. 2. Overall mass balance in kg/year.

Component	Initial	In	Out	Final	In-Out
Ash	0	74,880	74,880	0	0
Carb. Dioxide	0	0	312	0	- 312
Nitrogen	3,924	77,509,036	77,509,036	3,924	- 0
Oxygen	1,191	23,530,242	23,529,856	1,191	386
Polyethylene	0	150,834	150,834	0	0
Pottasium Iodat	0	340	340	0	0
Propane	0	105	0	0	105
Sodium Chloride	0	7,987,200	7,987,200	0	0
Water	0	2,670,720	2,668,378	0	2,342
TOTAL	5,115	111,923,356	111,920,835	5,115	2,521
Overall Error:					0.002%

Following the washing process, the draining stage is critical in eliminating excess water from the salt. This method reduces the salt's water content by more than 25%, yielding saline water. The brine water can be reused in subsequent washing procedures, improving overall brine water management efficiency. Additionally, the brine can serve as a feed for traditional solar salt production using the evaporation method proposed in [29]. This synergy between industry and traditional solar salt production benefits solar salt farmers and mitigates the harmful impact of brine waste on marine life. Consequently, this approach supports Sustainable Development Goal 14, which focuses on preserving aquatic life [30]. During the drying process, a constant flow of hot

Archive of SID.ir

air is fed into the rotary dryer to remove the remaining water content, ensuring that the salt meets food-grade quality standards. The drying stage is a crucial step in producing high-quality food-grade salt, requiring proper equipment and parameters. Another study found that the most efficient method for producing high-quality dried salt involves combining drying, grinding, and separating into a single stage [31]. This method can significantly reduce costs while maintaining high quality. However, the solar salt input must meet certain requirements, such as having a water content of less than 10% [32]. The dried salt then proceeds to the fortification process, where 1.1 kg/day of KIO_3 is added to achieve a minimum KIO_3 level of 45 ppm. These successive processes produce a food-grade salt with a minimum sodium chloride content of 95% and a KIO_3 level of at least 45 ppm. The detailed mass and energy balance for each stream, generated using SuperPro software, are presented in Tables 3a - 3d. Ultimately, the integrated process of grinding, washing, draining, drying, and fortifying crude solar salt efficiently converts it into high-quality food-grade salt, achieving minimal impurity loss while generating valuable waste products that support sustainability and provide economic benefits to the industry.

Tab. 3a. The mass and energy balances for each stream.

Stream Name	S-101	S-102	S-103	S-131	S-104	S-125	S-132	S-133
Source	INPUT	P-1	P-18	P-2	P-3	INPUT	P-19	P-20
Destination	P-1	P-18	P-2	P-3	P-4	P-19	P-20	P-16
Stream Properties								
Temperature (°C)	25.00	25.00	25.00	25.00	25.00	25.00	26.35	26.35
Pressure (bar)	1.01	1.01	1.01	1.01	1.01	1.01	1.03	1.03
Density (g/L)	1,804.01	1,804.01	1,804.01	1,804.01	1,804.01	1.18	1.20	1.20
Total Enthalpy (kW-h)	66.06	66.06	66.06	66.06	66.06	142.38	150.06	0.15
Specific Enthalpy (kcal/kg)	16.24	16.24	16.24	16.24	16.24	6.05	6.38	6.38
Heat Capacity (kcal/kg-°C)	0.65	0.65	0.65	0.65	0.65	0.24	0.24	0.24
Component Flowrates (kg/h)								
Ash	30.00	30.00	30.00	30.00	30.00	0.00	0.00	0.00
Nitrogen	0.00	0.00	0.00	0.00	0.00	15,534.14	15,534.14	15.53
Oxygen	0.00	0.00	0.00	0.00	0.00	4,715.86	4,715.86	4.72
Sodium Chloride	3,200.00	3,200.00	3,200.00	3,200.00	3,200.00	0.00	0.00	0.00
Water	270.00	270.00	270.00	270.00	270.00	0.00	0.00	0.00
TOTAL (kg/h)	3,500.00	3,500.00	3,500.00	3,500.00	3,500.00	20,250.00	20,250.00	20.25
TOTAL (L/h)	1,940.13	1,940.13	1,940.13	1,940.13	1,940.13	17,172,344.73	16,916,080.80	16,916.08

Tab. 3b. The mass and energy balances for each stream (Continued).

Stream Name	S-136	S-113	S-112	S-126	S-127	S-107	S-105	S-108
Source	P-20	INPUT	INPUT	P-16	P-16	P-9	P-4	P-4
Destination	OUTPUT	P-16	P-16	OUTPUT	P-8	P-4	P-5	P-5
Stream Properties								
Temperature (°C)	26.35	25.00	25.00	200.00	110.00	28.46	26.42	28.11
Pressure (bar)	1.03	1.01	1.01	1.01	1.03	1.01	1.01	1.01
Density (g/L)	1.20	1.80	1.18	0.73	0.94	993.44	1,904.54	994.85
Total Enthalpy (kW-h)	149.91	0.00	0.01	0.11	0.63	342.45	63.08	345.40
Specific Enthalpy (kcal/kg)	6.38	99.46	6.05	118.14	26.68	28.57	16.66	28.16
Heat Capacity (kcal/kg-°C)	0.24	0.40	0.24	0.27	0.24	1.00	0.63	1.00

Component Flowrates (kg/h)								
Ash	0.00	0.00	0.00	0.00	0.00	0.00	3.00	27.00
Carb. Dioxide	0.00	0.00	0.00	0.12	0.00	0.00	0.00	0.00
Nitrogen	15,518.60	0.00	0.56	0.56	15.53	0.00	0.00	0.00
Oxygen	4,711.15	0.00	0.17	0.02	4.72	0.00	0.00	0.00
Sodium Chloride	0.00	0.00	0.00	0.00	0.00	0.00	3,200.00	0.00
Propane	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00
Water	0.00	0.00	0.00	0.07	0.00	10,312.05	54.00	10,527.04
TOTAL (kg/h)	20,229.75	0.04	0.73	0.77	20.25	10,312.05	3,257.00	10,554.04
TOTAL (L/h)	16,899,164.72	23.36	618.97	1,059.53	21,640.83	10,380.13	1,710.12	10,608.67

Tab. 3c. The mass and energy balances for each stream (Continued).

Stream Name	S-106	S-109	S-129	S-111	S-117	S-134	S-124	S-135
Source	P-5	P-5	P-17	P-17	P-8	INPUT	P-21	P-21
Destination	P-7	P-17	P-9	OUTPUT	P-21	P-21	P-10	OUTPUT
Stream Properties								
Temperature (°C)	27.13	27.98	28.76	28.76	105.00	26.35	31.35	54.73
Pressure (bar)	1.01	1.01	1.01	1.01	1.01	1.03	1.01	1.03
Density (g/L)	1,918.80	995.04	993.33	1,007.53	1,894.44	1.20	1,931.84	1.09
Total Enthalpy (kW-h)	63.91	344.57	319.11	35.05	230.40	149.91	68.79	311.52
Specific Enthalpy (kcal/kg)	17.04	28.01	28.87	28.13	65.61	6.38	19.59	13.25
Heat Capacity (kcal/kg-°C)	0.63	1.00	1.00	0.97	0.63	0.24	0.63	0.24
Component Flowrates (kg/h)								
Ash	0.00	30.00	0.00	30.00	0.00	0.00	0.00	0.00
Nitrogen	0.00	0.00	0.00	0.00	0.00	15,518.60	0.00	15,518.60
Oxygen	0.00	0.00	0.00	0.00	0.00	4,711.15	0.00	4,711.15
Sodium Chloride	3,200.00	0.00	0.00	0.00	3,021.38	0.00	3,021.38	0.00
Water	27.00	10,554.04	9,512.05	1,041.99	0.00	0.00	0.00	0.00
TOTAL (kg/h)	3,227.00	10,584.04	9,512.05	1,071.99	3,021.38	20,229.75	3,021.38	20,229.75
TOTAL (L/h)	1,681.78	10,636.81	9,575.87	1,063.98	1,594.86	16,899,164.72	1,563.98	18,500,394.81

Tab. 3d. The mass and energy balance for each stream (Continued).

Stream Name	S-116	S-118	S-119	S-120	S-122	S-121	S-123	DS-101	DS-102
Source	INPUT	P-10	P-11	P-12	P-12	P-13	P-6	INPUT	P-15
Destination	P-10	P-11	P-12	P-13	P-6	P-6	P-15	P-15	OUTPUT
Stream Properties									
Temperature (°C)	25.00	31.35	31.35	31.35	31.35	31.35	31.34	25.00	30.37
Pressure (bar)	1.01	10.35	10.35	10.35	10.35	10.35	10.35	1.01	1.01
Density (g/L)	3,104.50	1,931.88	1,931.88	1,931.85	1,931.88	1,931.85	1,931.88	368.91	55.82
Total Enthalpy (kW-h)	0.00	68.78	68.78	0.69	68.09	0.69	68.78	1.87	70.65
Specific Enthalpy (kcal/kg)	2.61	19.59	19.59	19.59	19.59	19.59	19.59	26.62	19.72
Heat Capacity (kcal/kg-°C)	0.10	0.62	0.62	0.63	0.62	0.63	0.62	1.07	0.62
Component Flowrates (kg/h)									

Polyethylene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	60.43	60.43
Pottasium Iodat	0.14	0.14	0.14	0.00	0.14	0.00	0.14	0.00	0.14
Sodium Chloride	0.00	3,021.38	3,021.38	30.21	2,991.16	30.21	3,021.38	0.00	3,021.38
TOTAL (kg/h)	0.14	3,021.51	3,021.51	30.21	2,991.30	30.21	3,021.51	60.43	3,081.94
TOTAL (L/h)	0.04	1,564.03	1,564.03	15.64	1,548.39	15.64	1,564.03	163.81	55,211.67

3.2. Capital cost analysis

Capital investment in technology and equipment is vital for developing a salt plant. Selecting the appropriate technology is crucial to transform purified crude solar salt into food-grade salt. Failure to select suitable technology may lead to the manufacture of salt that fails to meet the requirements set by Indonesia. Table 4 presents the detailed capital costs for the equipment and technology used in the salt plant. The most expensive technology is the centrifuge, accounting for 16.2% of the total technology and equipment cost. This technology cannot be developed domestically and relies on imported technology from overseas. It is essential to consider future research and development efforts for domestic centrifuge production. Following this, the rotary dryer represents 5.6% of the total technology and equipment cost. This technology has the capability for local development, boasting a 100% domestic component level. However, implementing this technology results in slightly higher costs due to its complexity and the need for precise development. The complexity of this technology arises from the precise design of the heating and cooling processes and the timing considerations. Additionally, the use of stainless steel 316 as a critical material for this technology increases expenses.

Tab. 4. The detailed capital cost for the equipment and technology in the salt plant.

Items	Quantity	Cost (USD)	Percentage
Main Equipment			
Belt conveyor	1	5,773	1.6 %
Metering hopper	1	6,288	1.7 %
Elevator input 5 m	1	5,736	1.5 %
Hammer mill	1	5,792	1.6 %
Washing 1	1	8,647	2.4 %
Washing 2	1	8,101	2.2 %
Centrifuge	1	58,460	16.2 %
Screw centrifuge	1	4,331	1.2 %
Screw input dryer	1	5,133	1.4 %
Rotary dryer	2	20,415	5.6 %
Dryer heating stove	2	4,706	1.3 %
Screw assembly + cooling	1	5,001	1.3%
Dry salt screw + cooling	1	5,135	1.4 %
Gyro seive	1	11,609	3.2 %
Disk mill	1	5,773	1.6 %
Elevator grader	1	5,554	1.5 %
Elevator silo	1	5,554	1.5 %
Silo	1	7,217	2.0 %
Screw salt silo	1	4,987	1.3 %
Chlorine tank	1	2,871	0.7 %
Packing machine	1	8,625	2.3 %
Digital scales		242	0.06 %
Supporting Equipment			
Primer water pump	1	1,004	0.2 %
Brine water pump	1	1,004	0.2%
Resevoir tank	1	5,748	1.5 %
Panel control washing unit	1	6,903	1.9 %
Panel control drying	1	8,205	2.2 %
Blower and cyclone	1	3,684	1.0 %
Cooling tower and pump	1	2,824	0.7 %
Station house CNG	1	51,771	14.3 %
Electricity 80 KVA	1	21,964	6.1 %

Finally, the washing process requires careful consideration. All components within the washing process, including the equipment for brine water management and instrumentation, collectively account for nearly 10% of the total technology and equipment cost. The washing process plays a vital role in enhancing salt quality without significantly reducing salt quantity during the washing stage. The reduction in salt quantity is mainly due to inaccuracies in providing the correct brine water salinity. In the salt washing process, higher brine water salinity reduces the capability to remove impurities but also minimizes salt loss.
Conversely, lower brine water salinity allows for better impurity removal but leads to higher salt loss. Therefore, effective management of brine water in salt washing is essential. The complete breakdown of the capital cost calculation can be seen in Table 5. In addition to the cost of technology and equipment, a significant portion of the capital investment is allocated to the construction and installation of the salt plant. Due to the hygroscopic properties of salt, precise engineering and design of the building are essential. Specific processing areas necessitate particular consideration in their design. For instance, the washing processing area should seamlessly integrate with the brine water management systems. Inappropriate design of the washing processing area can lead to increased costs for the salt washing process, thereby raising overall capital and production expenses.
Furthermore, the design of the drying process area must be carefully considered, as it can produce fine salt particles. These fine particles tend to adhere to the walls and roof of the factory, leading to corrosion of the metal structures and equipment. Therefore, the drying process area should be isolated from other processing areas to minimize this risk. Additionally, the storage area for food-grade salt products should be located far from other processing areas and maintained under optimal environmental conditions, including temperature and humidity. This precaution helps to avoid any deterioration in the salt product’s quality.

Tab. 5. The complete breakdown of the capital cost calculation.

Component	Cost (USD)
1. Technology & equipment cost	310,000
2. Installation	152,000
3. Process piping	108,000
4. Instrumentation	124,000
5. Insulation	9,000
6. Electrical	31,000
7. Buildings	139,000
8. Yard improvement	46,000
9. Auxiliary facilities	124,000
10. Engineering	261,000
11. Construction	365,000
12. Contractor's fee	84,000
13. Contingency	167,000
Total	1,921,000

3.3. Production cost analysis

Raw materials account for a significant portion of the production cost, exceeding 50% of the expenses. This overview emphasizes the importance of selecting high-quality crude solar salt. Failure to select high-quality crude solar salt might result in a decline in the final product’s quality, raising production expenses. Based on the results of this study, it is recommended that the government adopt a consistent operational method at the saltworks level. This process would serve as a reference for traditional salt producers in Indonesia to produce high-quality crude solar salt [33]. Moreover, it is essential to emphasize the necessity of a facility that ensures the appropriate cleaning and draining of crude solar salt before its transit to the salt plant or storage in the salt warehouse [34]. The cleaning and draining process accounts for more than 40% of the production expenses for food-grade salt, mostly due to the need for diverse energy sources and extended operational durations. Additionally, the substantial water usage during operations contributes to the elevated facility expenses. The detailed production costs and their respective percentages are presented in Table 6.

Tab. 6. Total detailed production cost and its percentages.

Cost Item	Cost (USD)	Percentage (%)
Raw Materials	439,000	50.58
Labor-Dependent	5,000	0.56
Facility-Dependent	370,000	42.66
Laboratory/QC/QA	2,000	0.08
Consumables	2,000	0.28
Utilities	51,000	5.84
Total	868,000	100.00

3.4. Cash flow and profitability

The cash flow analysis for food-grade salt production over a 15-year operational period is detailed in Table 7. Sales revenue is primarily generated from salt product sales, amounting to an annual total of USD 2,413,000. Notably, the salt plant is expected to experience negative cash flow during the initial three years due to a 30-month development phase and a 4-month startup period. However, positive cash flow is anticipated in the subsequent years. It is critical to highlight that the salt plant can potentially enhance its cash flow and generate supplementary income by efficiently utilizing waste salt slag and implementing effective saline water management [35]. Consequently, these practices contribute to achieving sustainability. A profitability analysis was conducted to assess the economic viability of the salt plant, with results presented in Table 8. The analysis indicates positive economic indicators, making the project feasible. The annual revenue generated totals USD 2,413,342, with a net profit income of USD 1,388,000. In addition, the salt plant provides a substantial gross margin exceeding 60%, as depicted in Table 8. Other economic parameters also show positive outcomes, including an NPV of USD 7,862,000, an IRR of 46.48%, and a relatively short payback period of 1.56 years. Ultimately, these results can be achieved by implementing the strategies proposed in this study [36]. These include incorporating vertical competition to enhance supply chain efficiency, maintaining product freshness to ensure customer satisfaction, and introducing initiatives such as return policies, discounts, and credit periods to incentivize retailers. These measures collectively optimize operational performance and market responsiveness, thereby ensuring the projected economic outcomes.

Tab. 7. Cashflow analysis of food-grade salt over 15 years of operation (in thousands USD).

Year	Capital Investment	Sales Revenues	Operating Cost	Gross Profit	Depreciation	Taxable Income	Taxes	Net Profit	Net Cash Flow
1	-576	0	0	0	0	0	0	0	-576
2	-768	0	0	0	0	0	0	0	-768
3	-719	402	457	-55	182	0	0	128	-591
4	0	2,413	868	1,546	182	1,546	340	1,388	1,388
5	0	2,413	868	1,546	182	1,546	340	1,388	1,388
6	0	2,413	868	1,546	182	1,546	340	1,388	1,388
7	0	2,413	868	1,546	182	1,546	340	1,388	1,388
8	0	2,413	868	1,546	182	1,546	340	1,388	1,388
9	0	2,413	868	1,546	182	1,546	340	1,388	1,388
10	0	2,413	868	1,546	182	1,546	340	1,388	1,388
11	0	2,413	868	1,546	182	1,546	340	1,388	1,388
12	0	2,413	868	1,546	182	1,546	340	1,388	1,388
13	0	2,413	685	1,728	0	1,728	380	1,348	1,348
14	0	2,413	685	1,728	0	1,728	380	1,348	1,348
15	239	2,413	685	1,728	0	1,728	380	1,348	1,587

Tab. 8. Profitability analysis.

Component	Value
Total Revenue per Year	USD 2,413,342
Net Profit per Year	USD 1,388,000
Gross Margin	64.05%
NPV (at 7.0% interest)	USD 7,862,000
Payback Period	1.56 years
ROI	64.28%
IRR (After Taxes)	46.48%

4. Managerial and Safety Strategies

For a food-grade salt plant to run effectively, it is crucial that an appropriate organizational structure is designed and that personnel and safety procedures are determined to maximize work efficiency. This entails carefully assessing needs, comparing workloads, and following industry-specific efficiency guidelines for the industry [37]. The core staff must be selected by management after extensive background checks on their qualifications and specific requirements. A Plant Manager runs the factory with support from four department heads, namely the Head of Production, Head of Marketing, Head of Human Resources, and Head of Finance, each with well-defined responsibilities and authority. All managers should report to the Plant Manager, with responsibilities that can be either routine (scheduled) or ad hoc (as required). Accountability is maintained through regular or occasional written reports (daily and monthly) or verbal reports in planned or ad hoc meetings. The factory operates 8 hours a day for 312 days a year, with the potential for extended hours using a rotating shift system with three shifts: Shift one from 07:00 to 15:00, Shift two from 15:00 to 23:00, and Shift three from 23:00 to 07:00. This system allows for flexible scheduling to meet production demands while ensuring a structured and manageable work schedule for employees.

To prevent hazards, process safety management (PSM) is essential, encompassing management principles and systems designed to identify, understand, and control hazards arising from production processes [38]. PSM focuses on five key areas: prevention, preparation, mitigation, response, and recovery from industrial disasters, particularly relevant to companies that store, produce, or use hazardous chemicals. This comprehensive approach ensures systematic risk management, enhancing workplace safety and operational integrity. Maintaining occupational health and safety in salt factories involves implementing measures to prevent the three main causes of accidents. Managing process hazards requires considering flammable and explosive materials in the design of the physical environment and ensuring equipment compatibility with raw materials and finished products. To maintain product quality and prevent any contamination, fire stops must be installed, and drainage systems implemented for underground pipes, with proper valve arrangements and piping systems for safety. High-temperature equipment should be insulated to prevent heat loss and accidents, avoiding worker fatigue due to temperature extremes, which affects efficiency and necessitates an adequate ventilation system inside rooms.

5. Conclusion

In conclusion, establishing a salt plant for food-grade salt production on Madura Island can significantly enhance the welfare of traditional salt farmers in Indonesia. Ownership by a governmental or local firm would ensure stable prices and reliable purchasing agreements, contributing to regional or national salt cost stability. This study outlines the proper development of such a plant, detailing production processes and engineering layout. The washing and drying stages are crucial for maintaining salt quality and cost efficiency. The integrated processes of grinding, washing, draining, drying, and fortification transform crude solar salt into high-quality food-grade salt with minimal impurity loss. This approach generates valuable by-products like magnesium and calcium-rich salt slag, promotes efficient brine water management, and supports traditional solar salt production, enhancing sustainability, providing economic benefits, and aligning with the Sustainable Development Goals by reducing the environmental impact of brine waste and preserving aquatic life. Furthermore, this research underscores the importance of an effective organizational structure and addressing safety issues to maximize efficiency and safety in food-grade salt factories. Economically, the profitability analysis indicates a promising payback period of 1.56 years and an NPV of USD 7,862,000, with an ROI of 64.28% and an IRR of 46.48%. Therefore, establishing a salt plant in Indonesia is not only profitable and feasible but also enhances food-grade salt production, stabilizes solar salt prices, and improves the welfare of traditional salt farmers. This study contributes to the academic field by providing a comprehensive feasibility analysis and strategic framework for sustainable salt production. Ultimately, these findings offer valuable insights for policymakers, investors, and stakeholders, highlighting the economic and social benefits of developing the salt industry in Indonesia.

Data availability

Data will be made available upon request.

CRediT authorship contribution statement

Makhfud Efendy: Writing - original draft, investigation, data collection, and data analysis. Nizar Amir: Conceptualization, methodology, and data analysis. Muhammad Yusuf Arya Ramadhan: Methodology and formal analysis. Mochamad Yusuf Efendi: Data collection and data analysis. Kritsana Namhaed: Data analysis and writing - review & editing. Mohammed Kheireddin Aroua: Supervision and writing - review & editing. Misri Gozan: Supervision and writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

6. Acknowledgment

The authors gratefully acknowledged the research funding scheme from Universitas Trunojoyo Madura through the research grant “Skema Grup Riset 2023” (No.69/UN46.4.1/PT.01.03/2023).

References

[1] Forsythe, W., McConkey, R., Breen, C., “*Persistence and risk: salt production in post-medieval Ireland*,” World Archaeol, Vol. 58, (2022), pp. 603-19.

[2] Prabawa, F.Y., Bramawanto, R., “*The intensification of industrial salt production using the salt production house concept*,” IOP Conf Ser Earth Environ Sci, Vol. 925, (2021), p. 012031.

[3] Kemenprin, Ministry of Industry Facilitates Industry Absorption of Local Salt More than 1 Million Tons 2022, https://kemenperin.go.id (2023).

[4] BPS, Salt Imports by Main Country of Origin, (2023), pp. 2017-2022.

[5] Lestari, W, Fazlia, I.R.R., Evalina, A., Saputra, M., Irma, S.A., “*Technology Development of Salt Products Using Geomembrane Thread Filter Technology in Kajhu Village Baitussalam, Aceh Besar*,” J Phys Conf Ser, Vol. 1424, (2019), p. 012050.

[6] Yani, A.A., Herawati, N., Hajar, M.A.I., Sangkala, Thara, T., Hans, A., Hidayat, A. R., “*Environmental and social policy analysis on traditional salt production in Jeneponto Regency, Indonesia*,” IOP Conf Ser Earth Environ Sci, Vol. 343, (2019), p. 012091.

[7] Anwar, F., Omar, A.T., Al-Abassi, F.A., Kumar, V., Alhayyani, S., 2022, “*Natural sea salt in diet ameliorates better protection compared to table salt in the doxorubicin-induced cardiac remodeling*,” Journal of Taibah University for Science, Vol. 16, (2022), pp. 1213-24.

[8] Zhang, Y., Zhang, Y., Chang, L., Ji, Y., Liu, L., Feng, Y., Zhang, Y., Zou, D., Liu, Y., Su, X., “*Crystalline palmatine saccharinate pharmaceutical salt without reducing solubility and improving its hygroscopic stability with regard to palmatine chloride*,” J Mol Struct, Vol. 1230, (2021), p. 129631.

[9] Elbashir, A.A., Ahmed, A.A., Ali Ahmed, S.M., Aboul-Enein, H.Y., “*1,2-Naphthoquinone-4-Sulphonic Acid Sodium Salt (NQS) as an Analytical Reagent for the Determination of Pharmaceutical Amine by Spectrophotometry*,” Appl Spectrosc Rev, Vol. 47, (2021), pp. 219-32.

[10] Li, T., Shi, J., Liu, X., He, M., Wang, J., Yan, X., Fan, Y., “*Analysis of the effect of salt processing on microplastic residues*

in crushed and washed sea salt," J Sea Res, Vol. 194, (2023), p. 102405.

[11] J.-A. B. Baxter, B. Carducci, M. Kamali, S. H. Zlotkin, and Z. A. Bhutta, "Fortification of salt with iron and iodine versus fortification of salt with iodine alone for improving iron and iodine status," Cochrane Library, Vol. 2022, No. 4, (2022).

[12] Al-Sharrah, G., Marafi, M., 2023, "*Process simulation and techno-economic evaluation of recovery of metals and alumina from spent hydroprocessing catalysts using leaching with EDTA,*" Journal of Engineering Research, (2023).

[13] Gozan, M., Ramadhan, M.Y.A., Harahap, A.F.P., Sari, C.N., Muharam, Y., Purwanto, W.W., Tristantini, D., "*Techno-Economic Analysis of Healthy Herbal Ice Cream Product*," International Journal of Technology, Vol. 11, (2020), p. 931.

[14] L. M. Froeb and G. J. Werden, "An introduction to the Symposium on the Use of Simulation in Applied Industrial Organization," International Journal of the Economics of Business, Vol. 7, No. 2, (2000), pp. 133-137.

[15] Amir, N., Efendy, M., Hidayat, R., Gozan, M., "The Effects of Dry and Wet Grinding Processes on The Salt Quality," E3S Web of Conferences, Vol. 328, (2021), p. 07011.

[16] Amir, N., Efendy, M., Hidayat, R., Gozan, M., "*Analysis and Comparison of Different Dewatering Methods On Salt Quality,*" E3S Web of Conferences, Vol. 328, (2021), p. 05007.

[17] Amir, N., Efendy, M., Yoo, Y.J., Gozan, M., "*Improved Salt Quality and Reduced Energy Consumption via Hot Air Drying,*" International Journal of Technology, Vol. 20, No. 12, (2021), pp. 592-601.

[18] Amir, N., Efendy, M., Rini, D.A.S., Gozan, M., "*Effect of Washing Operating Parameters on the Quality of Dried Salt in Salt Washing Plant,*" Journal of Biosystems Engineering, (2022).

[19] Efendy, M., Syarif, M., Amir, N., Hidayat, R., "*Economic Feasibility Case Study of Developing a Salt Production Plant,*" Eng Econ, Vol. 68, (2023), pp. 99-121.

[20] Sano Coelho, R., Cuellar, M.C., Franco, T.T., van der Wielen, L.A.M., "*Techno-economic assessment of heterotrophic microalgae biodiesel production integrated with a sugarcane bio-refinery,*" Biofuels, Bioproducts and Biorefining, Vol. 15, (2021), pp. 416-29.

[21] Alam, A., Jiang, L., Kittleson, G.A., Steadman, K.D., Nandi, S., Fuqua, J. L., Palmer, K. E., Tusé, D., McDonald, K. A., "Technoeconomic Modeling of Plant-Based Griffithsin Manufacturing," Front Bioeng Biotechnol, Vol. 6, (2018), pp. 1-13.

[22] Sayar, N.A., Durmaz Şam, S., Pinar, O., Serper, D., Sarıyar A. B., Kazan, D., Sayar, A.A., "Techno-economic analysis of caffeine and catechins production from black tea waste," Food and Bioproducts Processing, Vol. 118, (2019), pp.1-12.

[23] N. Z. Xiao and N. J. Zhang, "The Analysis of Effectiveness of Cost Control Strategy on the profitability of Coca-Cola Company from year 2015 to 2017," Management Studies, Vol. 8, No. 3, (2020).

[24] T. Shou, "A Literature review on the Net Present Value (NPV) Valuation Method," Advances in Economics, Business and Management Research/Advances in Economics, Business and Management Research, (2022).

[25] N. Amir, M. Gozan, M. Lee, and K. Winarso, "Techno-economic and environmental analyses of a grid-connected renewable energy power system in Madura, Indonesia," International Journal of Ambient Energy, Vol. 44, No. 1, (2022), pp. 317-333.

[26] J. P. Andrew and H. L. Sirkin, "Using the cash curve to discuss and discipline innovation investments," Strategy & Leadership, Vol. 35, No. 4, (2007), pp. 11-17.

[27] E. C. Nwude, "A review on the calculation of return on investment," International Journal of Advanced and Applied Sciences, Vol. 3, No. 9, (2016), pp. 110-119.

[28] N. Amir, M. Efendy, and A. F. Hidayat, "Effects of dietary Salt-Based Minerals and phosphorus supplements on mean body weight, survival rate and feed conversion ratio of white shrimp reared in brackish water," Rekayasa, Vol. 14, No. 3, (2021), pp. 340-347.

[29] N. Amir, M. Efendy, and M. N. L. Azmi, "Experimental investigation of a convection - improved solar salt evaporation system," Technium, Vol. 16, (2023), pp. 237-242.

[30] THE 17 GOALS | Sustainable Development." https://sdgs.un.org/goals.

[31] N. Amir, M. Efendy, M. Z. Mahasin, and M. Gozan, "Development of a novel salt processing technology and its performance and economic evaluation: an experimental study," Australian Journal of Mechanical Engineering, (2024), pp. 1-11.

[32] N. Amir, V. R. Febriyanti, M. M. Aminullah, and T. Prasetyo, "Effect of operating parameters on the quality of solar salt in novel salt processing technology," AIP Conference Proceedings (2024).

[33] N. Amir and M. Efendy, "Analisa Kelayakan Penggunaan Garam Rakyat Madura Sebagai Solusi Kesehatan, Kesejahteraan dan Ekonomi Masyarakat di Masa Pandemi COVID-19," Amir | Prosiding Seminar Nasional Penanggulangan Kemiskinan, Vol. 25, (2021).

[34] A. Gabriel-Santos et al., "Increasing the performance of a Salt Washing Machine through Axiomatic Design," IOP Conference Series. Materials Science and Engineering, Vol. 1174, No. 1, (2021), p. 012024.

[35] V. Somashekar, A. V. Anand, V. Hariprasad, E. M. Elsehly, and M. Kapulu, "Advancements in saline water treatment: a review," Water Reuse, Vol. 13, No. 3, (2023), pp. 475-491.

[36] A. Aazami and M. Saidi-Mehrabad, "A production and distribution planning of perishable products with a fixed lifetime under vertical competition in the seller-buyer systems: A real-world application," Journal of Manufacturing Systems, Vol. 58, (2021), pp. 223-247.

[37] Z. Abdalfatah, E. Elbeltagi, and M. Abdelshakor, "Safety performance evaluation of construction projects in Egypt," Innovative Infrastructure Solutions, Vol. 8, No. 9, (2023).

[38] A. Petrone, L. Scataglini, L. La Rosa, C. Salvador, L. Frattini, and G. Manfredi, "Implementing a disciplined process safety framework in mature assets: two case studies on onshore sour field," Paper Presented at the Abu Dhabi International Petroleum Exhibition and Conference, Abu Dhabi, UAE, (2015).

Follow this article at the following site:

Makhfud Efendy, Nizar Amir, Kritsana Namhaead, Muhammad Yusuf Arya Ramadhan, Mochamad Yusuf Efendi, Mohamed Kheireddine Aroua and Misri Gozan. Process Design and Feasibility Study of Food-Grade Salt Production from Crude Solar Salt in Madura, Indonesia. IJIEPR 2024; 35 (3) :1-17
URL: http://ijiepr.iust.ac.ir/article-1-2058-en.html