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Mixing Washer Optimization for Salt Purification

Endro Wahju Tjahjono[1,2*], Suwarno[1*], Hens Saputra[2], Bambang Iskandriawan[3], Novi Syaftika[2], Dorit Bayu Islami Nuswantoro[2], Ridho Dwimansyah[2], hamzah[2], Muhammad Arif Darmawan[2]

[1]*Department of Mechanical Engineering, Institut Teknologi Sepuluh Nopember (ITS), Indonesia*
[2]*Research Center for Process and Manufacturing Industry Technology, BRIN, Indonesia*
[3]*Faculty of Creative Design and Digital Business/Lecture, Institut Teknologi Sepuluh Nopember (ITS), Indonesia*

*enwacah2014@gmail.com; warno@me.its.ac.id

ABSTRACT

Conventional salt production from seawater and solar evaporation has the drawback of containing various impurities such as magnesium, calcium, and mud. A purification process is necessary to achieve the standard quality requirements for both consumption and industrial use. This study explores a simple salt purification process using a saturated salt solution in a mixing washer. This research focuses on the design and optimization of the mixing washer. During the washing process, baffles act as flow restrictors to reduce swirling and promote vertical fluid circulation. This equipment is mainly used for mixing and suspending solids in vertical cylindrical tanks, where vortex formation is common regardless of the impeller type. The strength of the wooden baffle was tested and validated using CFD simulation, confirming its suitability for use in a mixing washer with a diameter of 850 mm. The optimum mixing and washing process was achieved at 200 rpm for 10 minutes. As a result, the purity of coarse salt increased from 88% NaCl to 98%, while magnesium content was reduced to 0.7%.

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INTRODUCTION

The demand for industrial salt in Indonesia is very high and cannot yet be supplied by domestic production. In Indonesia, salt is produced through the crystallization of seawater using a solar evaporation system, commonly referred to as "coarse salt." However, this coarse salt has low quality, with a sodium chloride (NaCl) content of approximately 88%, and contains impurities such as magnesium sulfate ($MgSO_4$), magnesium chloride ($MgCl_2$), potassium chloride (KCl), calcium sulfate ($CaSO_4$), and soil contaminants [1], [2]. To address this issue, various programs have been implemented, including PUGAR (salt program for SMEs (Small and Medium Enterprises)), Optimization Model for Improving the Efficiency of Traditional Salt Ponds. These initiatives aim to improve the productivity of locally produced salt by developing the raw salt industry through washing and purification processes, ultimately improving both quality and yield [3], [4].

***Corresponding Author | Endro Wahju Tjahjono|✉ warno@me.its.ac.id**

Raw salt purification for industrial-grade applications employs various methods such as washing, membrane separation, leaching, adsorption, and recrystallization. While recrystallization can achieve NaCl purity above 99%, it requires significantly more energy than other methods. In contrast, the washing process is simpler and more cost-effective for producing industrial-grade salt [5], [6]. A saturated brine solution is used as the cleaning medium to prevent NaCl from dissolving during the purification process, ensuring that only impurities are removed [7]. The typical raw salt washing system consists of a screw conveyor, followed by a mixing washer, and concludes with drying process which generally involves involves a centrifuge and a heater.

The mixing washer is a device consisting of a tank equipped with an agitator and baffle plates designed to mix raw salt with saturated brine [8],[9]. During the mixing process, the raw salt is simultaneously cleaned as impurities dissolve in the brine, while the salt itself remains undissolved.

The process of refining coarse salt into industrial-grade salt commonly applied in small-scale industries typically utilizes hydro-extraction technology [10]. This technology is based on simple yet effective mechanical equipment for salt purification [11]. It is relatively inexpensive in terms of both investment and maintenance. In industrial applications, the hydro-extraction process generally utilizes a modified screw conveyor. This conveyor transports the raw salt while simultaneously spraying it with saturated brine during the initial washing stage. The raw salt is then transferred from the screw conveyor to a mixing washer – a vertical cylindrical container equipped with an agitator with blades for mixing and washing, as well as baffles along the inner walls. The baffles help reduce vortex formation in the rotating liquid caused by stirring [12]. To meet industrial standards, additional washing steps are often applied to further reduce Mg^{2+} content. The final stage of the process is drying, ensuring the production of high-purity salt with low moisture content.

Laboratory-scale process equipment research is an essential initial step before implementing the process on the industrial scale [14]. This research focuses on washing equipment, especially mixing washers for small-scale industries. This equipment was key technology to ensure the product complies with market standards. Salt farmers could implement the simple mixing washer result.

In this study, a washing process simulation was designed and applied to coarse salt. The composition of raw coarse salt was analyzed before and after processing in the mixing washer. This research aims to design, test, and evaluate the effectiveness of the washing process in increasing NaCl purity and reducing impurities, particularly magnesium (Mg^{2+}) ions. To meet industrial salt standards, the Magnesium content must be reduced to 0.06% or lower [13].

METHODOLOGY

In this study, coarse salt from conventional salt production was used as the raw material. The specifications of the raw salt and the Indonesian National Standard (SNI) industrial salt are shown in Table 1.

Table 1. Composition of coarse salt [14]

Component	Composition (%)	
	Coarse Salt	**Industrial Salt**
NaCl	89.2	97
Ca^{2+}	0.35	0.06
Mg^{2+}	0.80	0.06

The design of the equipment dimensions in this research was based on a capacity of 1 ton/day. According to the composition of the coarse salt, as shown in Table 1, the NaCl content increases to 97%, while the magnesium content decreases to 0.07%, which nearly meets the industrial salt standards. The first step involved calculating the mass balance, which serves as a reference for determining the equipment dimensions. Based on the mass balance results, a design for the mixing washer was created using SolidWorks Flow Simulation software. This marks the initial phase in simulating the coarse salt washing and mixing process using brine water.

The first step in the CFD process is to determine the type of flow that occurs, followed by defining the computational domain to restrict the analysis to the region of interest. Next, boundary conditions are established, including the flow rate of coarse salt and brine water, as well as environmental temperature and pressure.

Meshing in SolidWorks Flow Simulation involves dividing the computational domain (geometry) into smaller elements. The addition of local smoothing and refined meshing improves the accuracy of numerical fluid flow simulations. Boundary conditions are then defined to describe how the model interacts with external loads, environmental conditions, constraints, and other influences. These conditions can be customized to replicate real-world scenarios, ensuring accurate simulation results. The CFD simulation is conducted by varying the blade angle and rotation speed while measuring velocity and pressure, as these parameters are most relevant to the analysis [15].

RESULTS

a. Design a washing mixer

Mass balance accurately calculates all substances that enter, accumulate, and exit a system during a specific period. According to the law of conservation of mass, mass cannot be created or destroyed. The basic principle of mass balance involves a set of equations where the number of equations must correspond to the number of unknown mass compositions [16]. In the coarse salt-washing process, the total mass of the components mixed and washed equals the mass of the salt suspension exiting the system under atmospheric conditions (temperature 25°C). The materials entering the mixing washer include coarse salt and a saturated salt solution as the washing medium.

The process that takes place in the mixing washer is as follows:

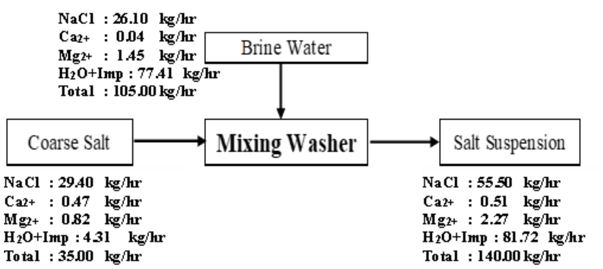


Fig. 1. Mixing Washer Mass Balance

Some general design guidelines for mixing tanks with agitators suggest that the ratio of diameter to height for a vertical cylindrical tank should range between 1:1 and 1:1.5. In other words, if the tank diameter is 1 meter, the tank height should be between 1 and 1.5 meters. For intensive mixing applications, the D/H ratio can approach 1:1, while for lighter mixing applications, a higher ratio may be used (Fig.2 below) [11].

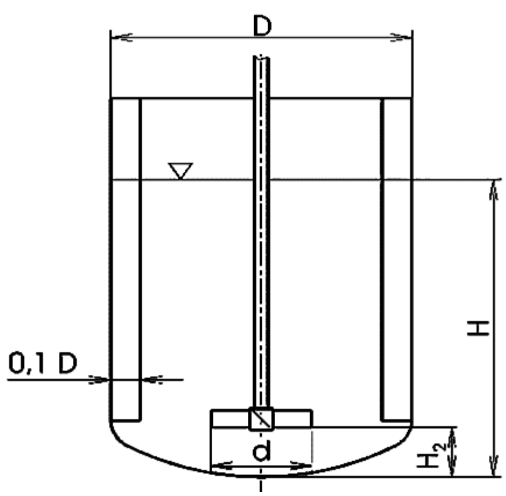


Fig. 2. Standard Mixing Tank

D = Tank Diameter mm
H = Max. liquid level mm
d = Blade Diameter = D/2
h = Blade Width =D/5
H_2 = Blade Distance to Bottom Tank
B = Baffle width = D/10

In the design of the mixing washer, the tank diameter and height are first determined based on the planned flow rate for the mixing process [10]. Based on these criteria, the technical specifications of the mixing washer tank are as follows.

P	= Operation Pressure	= 1 atm = 14.7 psi.
T	= Tank Inside Dia.	= 400 mm
H	= Tank Heigh	= 600 mm
D	= Blade Dia.	= 200 mm
H	= Blade width	= 40 mm
L	= Baffle Length	= 530 mm
B	= Baffle Width	= 20 mm
C	= Blade distance to Bottom tank = D/3 = 66,6666 ~ 70 mm	

b. Simulation Results

The simulation results of the process flow and pressure in the mixing washer equipment are shown in Fig. 3, 4 and 5 belows. The simulation was conducted with variations in blade rotation speed at 150 rpm, 200 rpm and 250 rpm.

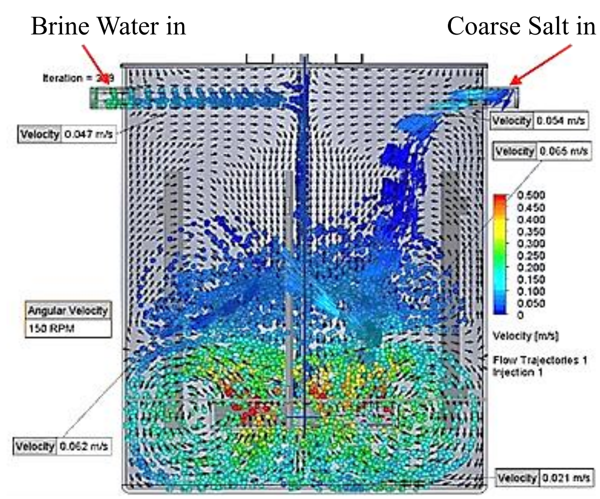


Fig. 3. Velocity Flow Contour projection blade rotation 150 rpm

Based on the simulation results above, the system was installed in the lab, and its performance was tested [8]. The appearance of the salt before and after the washing process is shown in Figures 6(a) and 6(b). The brownish color of the coarse salt indicates the presence of impurities. Previous studies have reported that contaminants in coarse salt include dirt, dust, minerals, and microorganisms. These impurities originate from the evaporation and crystallization process.

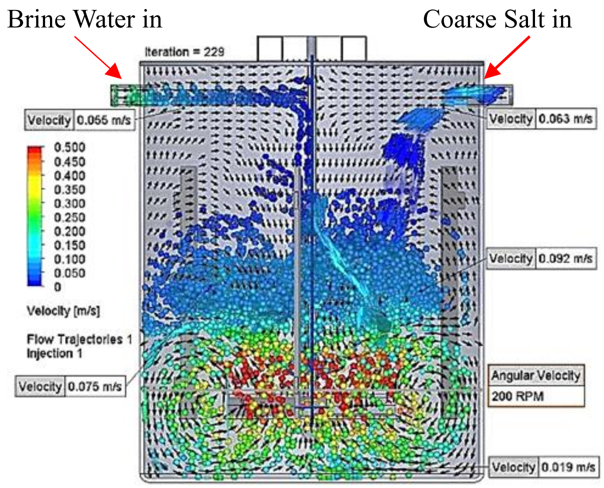


Fig. 4. Velocity Flow Contour projection blade rotation 200 rpm

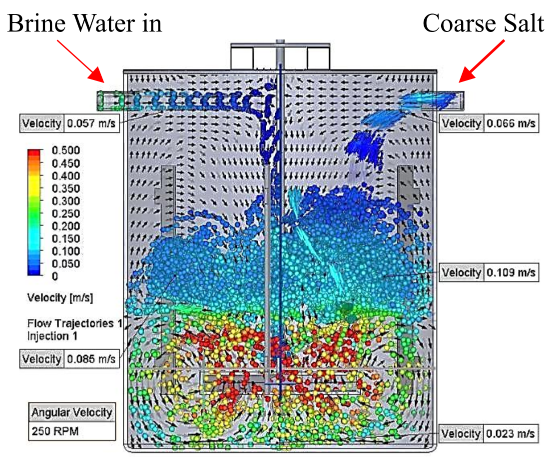


Fig. 5. Velocity Flow Contour projection blade rotation 250 rpm

(a) (b)

Fig. 6. The Visual of: (a) Coarse Salt and (b) Salt after Washing

c. Testing and Optimization

The results of the mixing washer run test are shown in Fig. 7. The NaCl purity increased as the processing time was extended. Initially, the NaCl concentration was 88%, rising to 96% after 10 minutes. The concentration continued to increase gradually, reaching 98% after a 60-minute process (Run Test 3). Run tests 1 and 2 exhibited similar trends. Based on these results, the optimal processing time in the mixing washer is 40 minutes. Considering the NaCl content, the final product is close to meeting the requirements for industrial salt.

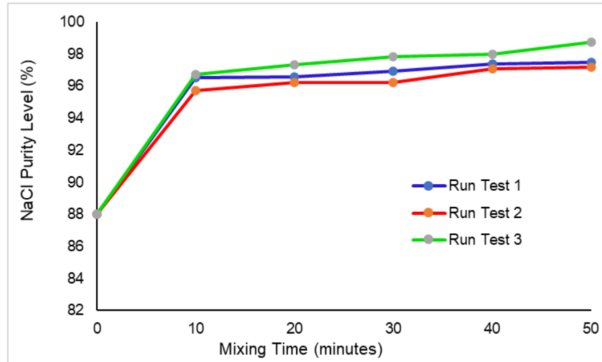


Fig. 7. Relationship between processing time in the mixing washer and NaCl purity across three run tests.

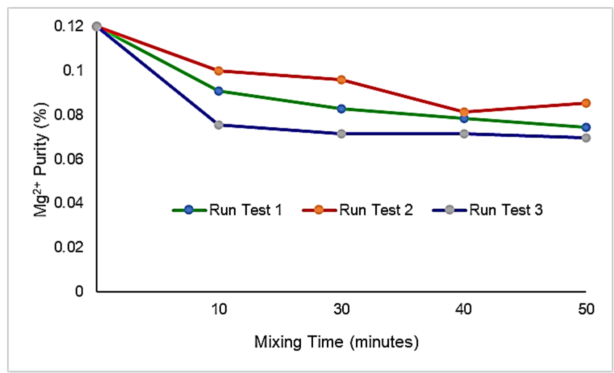
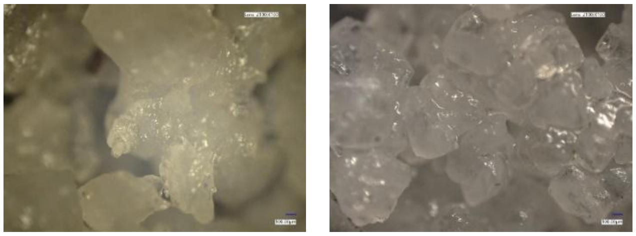


Fig. 8. Relationship between processing time in the mixing washer and Mg2+ impurity across three run tests.

The results of the magnesium content analysis during the mixing washer process are shown in Figure 8. The test results indicate that the premium local salt used as raw material had an initial magnesium impurity content of 0.12%. After processing in the mixing washer, the magnesium content decreased from approximately 0.12% to 0.07% over a 60-minute period.

Further reduction of magnesium content would require additional equipment to remove impurities embedded within the salt crystals, such as a hydrocyclone. In this process, magnesium remaining on the surface of the salt crystals is separated using a high-speed flow of concentrated brine solution. The magnesium is then carried into a separate solution based on the density difference between the solution and the salt crystals.

Visually, the difference in color between the coarse salt before and after processing in the mixing washer is evident, as shown in Figure 6. Figure 6(a) depicts the raw coarse salt before processing, which contains numerous impurities. Figure 6(b) shows the salt after processing, appearing cleaner and whiter.



(a) (b)

Fig. 9. Visualization with 100x magnification of coarse salt (a) and washed salt (b)

Fig. 9 shows cross-sections of salt crystals before and after the washing process in the mixing washer. The coarse salt appears uneven, with some sections remaining sharp, suggesting an incomplete crystallization process. This phenomenon is due to the high presence of impurities in the coarse salt, which can impede crystal growth or alter the chemical reactions involved in crystallization, leading to smaller, irregular, or less stable crystals. However, after washing, the crystals become more uniform compared to the coarse salt, indicating improved crystallization.

Microscopic observation at 100x magnification shows that coarse salt has a crystalline structure with some sharp edges, indicating that the crystallization process is incomplete. This is due to the high impurity content in coarse salt, which can inhibit crystal growth or change the chemical reactions in the crystallization process, resulting in smaller, irregular, or less stable crystals. However, after the washing process (Fig. 9b), the salt crystals are seen to be more uniformly clear compared to the coarse salt, indicating purification through washing.

The results of laboratory-scale research have been applied at a BUMDES in Sampang, Madura, on a mini scale and have shown promising outcomes. Raw materials in the form of coarse salt produced by local farmers are known to have low NaCl content, around 84% [5]. The mixing ability of the washer can increase the NaCl level by 8–10%, based on measurements taken every 10 minutes. To ensure NaCl levels above 96% and achieve more consistent results, it is recommended that the washing process be carried out in two stages. This approach is believed to shorten the overall processing time without compromising the quality of the salt produced.

It is expected that the findings of this research can be applied to the SME industry. In order to achieve all SNI quality requirements, additional equipment such as a hydrocyclone is needed. Further development of drying technology to support SMEs should be pursued as a continuation of this achievement. In addition, further in-depth research is needed at the industrial scale, particularly focusing on blade design to enhance energy efficiency. At larger scales, variations in blade type, number, and angle can significantly impact both mixing performance and energy consumption, making this a crucial area for future investigation..

CONCLUSIONS

Based on the laboratory-scale mixing washer design simulation results, the flow pattern at 150 rpm was less uniform compared to 200 rpm and 250 rpm. At 200 rpm, a more even flow pattern was observed than at 250 rpm. The difference in flow patterns between 200 and 250 rpm was minimal; however, 200 rpm was deemed more efficient as it required less power than 250 rpm.

The result of the coarse salt experiment showed a significant improvement in the brightness of the salt color. Microscopic observation revealed that the washed salt appeared clearer, indicating a high level of purity. The NaCl purity increased to 98%, while the magnesium concentration was reduced to 0.7%

AUTHOR CONTRIBUTIONS

Endro Wahju Tjahjono: Writing-original draft, supervision, **Suwarno:** Supervision**, Hens Saputra:** Supervision, Review & editing**, Bambang Iskandriawan:** Supervision**, Novi Syaftika:** Supervision**,** Review, **Dorit Bayu Islami Nuswantoro:** simulator**, Ridho Dwimansyah:** Drafter**, Hamzah:** Formal analisys**, Arif Darmawan:** Formal analysis

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