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Extraction and characterization of distilled water from by-product of salt refinery processing

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ABSTRACT

Salt-making is a major agro-industry in the coastal municipalities and cities of Pangasinan, Philippines. During salt refining, vapor with corrosive properties is released as a by-product, contributing to infrastructure deterioration in surrounding communities. This study aimed to develop a salt-making machine with a built-in distillation system to capture and utilize this vapor by converting it into distilled water. A prototype salt-making machine equipped with an integrated distiller was fabricated and operated under typical refining conditions. Distilled water produced during the refining process was collected and subjected to laboratory analysis to evaluate its chemical quality. Results showed that the recovered water contained measurable amounts of magnesium, potassium, sodium, calcium, chlorides, and bicarbonates, indicating incomplete removal of dissolved ions during distillation. While the system effectively recovered water vapor and refined salt simultaneously, the chemical composition of the collected distilled water did not meet the purity requirements for direct use in automotive radiators or lead-acid batteries. The distilled water, however, may be suitable for other non-automotive applications following appropriate treatment. The findings highlight the potential of vapor recovery in salt refining as a sustainable practice, while emphasizing the need for further purification to expand the utility of the recovered water.

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INTRODUCTION

Salt has long been recognized as an essential commodity in both domestic and industrial contexts. In Filipino culture, it holds both symbolic and practical significance, where traditional beliefs emphasize that a new household must contain three fundamental items—a jar of rice, a jar of water, and a jar of salt-which collectively symbolize abundance, sustenance, and prosperity (Hills *et al.*, 2023). Beyond its cultural importance, salt plays a vital role in food preservation and preparation, making it indispensable in households and food industries worldwide.

The increasing demand for iodized salt, driven by public health campaigns and nutritional requirements, has contributed to the steady growth of the salt refinery industry in the Philippines. While this expansion supports economic development, it has also introduced environmental and infrastructural challenges affecting surrounding communities. One of the most critical concerns is the vapor generated during the salt refining process. This vapor, containing high concentrations of saline particles and chlorides, is released into the atmosphere and has been observed to accelerate corrosion of metal roofing in nearby residential and industrial structures. Such corrosion leads to increased maintenance and repair costs, compromises structural integrity, and raises concerns about long-term environmental degradation.

The corrosive effects of salt vapor and saline aerosols on metal structures are well documented. Corrosion is an electrochemical process in which water vapor, oxygen, and salts such as sodium chloride (NaCl) and sodium sulfate (Na_2SO_4) accelerate metal oxidation. Tang *et al.* (2020) demonstrated that pure iron exposed to solid Na_2SO_4 deposits in a humid, oxygen-rich environment exhibited significantly enhanced corrosion due to combined chemical and electrochemical reactions producing acidic by-products. Similar findings have been reported in industrial and high-temperature environments, where sodium salts promote deterioration of refractory materials and metal components. These studies support observations in salt refinery communities, where salt-laden vapor settles on exposed metal surfaces and accelerates roofing corrosion.

In response to these challenges, there is increasing interest in sustainable strategies for capturing and repurposing vapor emissions generated during salt production. Converting this industrial by-product into a useful resource aligns with principles of environmental sustainability and circular economy. One potential application is the recovery of distilled water from condensed vapor. Distilled or deionized water is widely valued for its low mineral content and minimal dissolved solids, making it suitable for technical applications such as automotive cooling systems and lead-acid batteries. In radiator systems, distilled water reduces scale formation and sediment buildup compared with tap water, although its lack of corrosion inhibitors necessitates careful use, typically in combination with commercial coolants (Vehicle Service Pros, 2017; CarFromJapan, n.d.). For lead-acid batteries, strict standards require high-purity water, as impurities can interfere with electrochemical reactions, reduce battery efficiency, and shorten service life. International standards such as EAS 121:1999 and BS 4974 specify the use of distilled or deionized water for battery maintenance (East African Standard, 1999; British Standards Institution, 1975).

Despite extensive documentation on salt vapor corrosion and the importance of high-purity water in automotive and industrial applications, applied research on capturing and reutilizing vapor emissions from salt refinery processes remains limited, particularly in tropical and developing-country contexts. Moreover, while established standards define permissible impurity levels for battery water, fewer guidelines exist for distilled water intended for radiator use, highlighting the need for localized assessment of water quality parameters such as pH, electrical conductivity, and dissolved ionic content.

There is a lack of practical, field-based studies that integrate salt refining and vapor recovery systems to both mitigate environmental damage and evaluate the usability of recovered distilled water as an industrial by-product. Specifically, limited evidence exists on the chemical quality of distilled water recovered directly from salt refinery vapor and its suitability for automotive applications.

This study aims to design and fabricate a salt-making machine with an integrated distillation system to capture vapor emissions during salt refining, extract distilled water as a by-product, and evaluate its chemical quality to assess its potential suitability for use as radiator coolant and refill water for lead-acid car batteries.

MATERIALS AND METHODS

Research design

This study employed an experimental research design to develop, operate, and evaluate a salt-making machine integrated with a vapor distillation system. An experimental approach was selected because it allows controlled observation of process performance, systematic manipulation of operational conditions, and direct measurement of output quality, particularly for engineering and process-based innovations (Computer-Aided Applications in Pharmaceutical Technology, 2013; Montgomery, 2017). The focus of the experiment was to assess both the functional efficiency of the fabricated system and the chemical quality of the distilled water recovered as a by-product of salt refining.

Design and fabrication of the salt-making machine with built-in distiller

A salt-making machine equipped with a built-in distillation unit was designed and fabricated locally using commonly available materials to ensure practical applicability in small-scale salt refinery settings. The system consisted of a cooking pan for brine evaporation, a vapor collection chamber, a condenser assembly, and a distilled water collection vessel. The design allowed vapor generated during the salt refining process to be directed through the condenser, where it was cooled and converted into liquid water.

Charcoal was used as the primary fuel source to simulate typical conditions in small-scale salt production environments. The machine was constructed to allow simultaneous salt crystallization and vapor condensation, enabling continuous recovery of distilled water during the refining process. The overall design emphasized simplicity, durability, and ease of operation to reflect conditions commonly encountered in rural and coastal salt-producing communities.

Salt refining and vapor collection process

Brine solution (salt water) was prepared and measured prior to each experimental run. For each trial, approximately two liters of brine were placed into the cooking pan of the salt-making machine. The system was then heated using charcoal fuel under open atmospheric conditions. As the brine temperature increased, water vapor was generated and directed toward the condenser unit.

Initial condensation of vapor occurred approximately 20 minutes after heating commenced, marking the onset of distilled water collection. The salt refining process continued for approximately two hours, during which refined salt gradually crystallized and solidified in the cooking pan. Throughout this period, condensed vapor was continuously collected as distilled water. After completion of heating, the refined salt was allowed to drain further to improve product quality and shelf life.

Sample collection and preparation

Two water samples were collected for laboratory analysis. The first sample represented the original brine solution prior to processing, while the second sample consisted of distilled water collected from the condenser during the salt refining operation. All samples were collected in clean, contamination-free containers and properly labeled. Care was taken to minimize exposure to external contaminants during collection, storage, and transport to ensure the reliability of analytical results (APHA, 2017).

Water quality analysis

Chemical analysis of the collected water samples was conducted at the Regional Soils Laboratory, Department of Agriculture, Philippines, using standard laboratory procedures. Parameters analyzed included pH, electrical conductivity, and concentrations of major dissolved ions such as sodium, potassium, calcium, magnesium, chlorides, bicarbonates, sulfates, phosphorus, and ammoniacal nitrogen. These parameters were selected because they are commonly used indicators of water purity and suitability for technical applications such as automotive cooling systems and lead-acid batteries (APHA, 2017; East African Standard, 1999).

Electrical conductivity was measured to assess the overall ionic content of the samples, while pH values were determined to evaluate acidity or alkalinity. Ionic concentrations were quantified to determine the extent of residual mineral content in the distilled water relative to the original brine solution.

Assessment of suitability for automotive applications

The quality of the recovered distilled water was evaluated by comparing the measured chemical parameters with established guidelines and standards for water used in automotive radiators and lead-acid batteries. Reference standards included international specifications for battery water quality and published automotive maintenance guidelines emphasizing low mineral content and minimal dissolved solids (British Standards Institution, 1975; East African Standard, 1999; Vehicle Service Pros, 2017). This comparative assessment was used to determine whether the distilled water produced by the system met the minimum purity requirements for practical automotive use or required further treatment.

RESULTS AND DISCUSSION

Performance of the salt-making machine with built-in distiller

The fabricated salt-making machine with an integrated distillation unit operated effectively under experimental conditions. The structural components of the system, including the evaporation pan, vapor conduit, condenser, and collection vessel, are illustrated in Fig. 1 (Perspective view, Front view, Side view, andExploded view. These figures collectively demonstrate the functional layout of the system and the integration of the distillation unit within the salt refining apparatus.

During operation, the system successfully enabled simultaneous salt refining and vapor recovery. Upon heating approximately two liters of brine using charcoal fuel, vapor generation commenced as the brine temperature increased. Condensation of vapor was first observed after approximately 20 minutes of heating, indicating effective heat transfer and condenser functionality. After roughly two hours, salt crystallization was completed, and refined salt was obtained while distilled water continued to be collected throughout the refining period. This dual-output performance highlights the system's potential to improve process efficiency by recovering a usable by-product that would otherwise be released into the atmosphere.

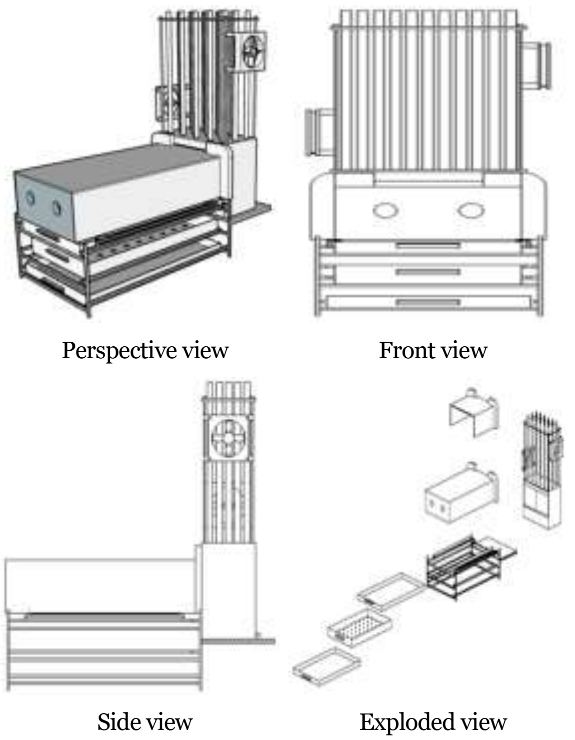

Fig. 1. Different view of salt making machine with built distiller design

Extraction and yield of distilled water

The extraction process demonstrated that vapor emitted during salt refining can be effectively captured and condensed into liquid water. The continuous recovery of distilled water during salt crystallization confirms that vapor generation is sustained throughout the refining process rather than occurring only at initial heating stages. This finding is particularly relevant for salt refinery environments, where prolonged exposure to saline vapor is known to contribute to corrosion of surrounding infrastructure.

Although the primary focus of this study was water quality rather than volumetric optimization, the consistent collection of distilled water throughout operation indicates the feasibility of integrating vapor recovery into small-scale salt production systems. Similar approaches have been suggested in industrial process optimization studies, where waste heat and vapor recovery are used to enhance resource efficiency and reduce environmental impact (Montgomery, 2017).

Chemical quality of collected water

The chemical quality of the collected water was evaluated through laboratory analysis, and the results are summarized in Table 1. Two samples were analyzed: the original brine solution and the distilled water recovered from the salt refining process.

Table 1. Physicochemical properties of brine and distilled water collected from the salt refinery process

Parameter	Result	
	Brine	Seawater
pH	7.92	7.98
Electric Conductivity, mS/cm	0.39	0.31
Ammoniacal + Nitrate N, %	0.01	<0.01
Phosphorous, ppm	0.07	<0.01
Sodium, ppm	15.76	7.97
Potassium, ppm	3.83	7.48
Calcium, ppm	4.37	11.12
Magnesium, ppm	0.55	1.07
Carbonates, ppm	<0.01	<0.01
Bicarbonates, ppm	111.92	81.36
Chlorides, ppm	27.48	7.09
Sulfates, ppm	<0.01	<0.01
Sodium Adsorption Ratio (SAR)	1.89	0.61
Residual Sodium Carbonate (RSC)	1.57	0.69

The pH values of both samples were near neutral, indicating neither acidic nor highly alkaline conditions. While the distilled water showed a slight increase in pH relative to brine, both values remained within ranges generally acceptable for industrial water use. Electrical conductivity, however, remained relatively high in the distilled water compared with what is expected for pure distilled or deionized water. This elevated conductivity suggests the presence of residual dissolved ions that were not fully removed during single-stage distillation.

Notably, although mineral concentrations were reduced in the distilled water compared with the brine sample, measurable amounts of sodium, potassium, calcium, chlorides, and bicarbonates persisted. The presence of these ions indicates incomplete separation of dissolved salts during the distillation process. Similar observations have been reported in studies where single-stage or low-efficiency distillation systems were used, particularly when vapor entrainment or condenser contamination occurs (APHA, 2017).

Implications for automotive radiator use

Water used in automotive cooling systems must have very low mineral content to prevent scale formation, corrosion, and blockage within the radiator and engine components. While distilled water is generally preferred over tap water due to its reduced mineral content, it must still meet strict purity requirements or be used in combination with corrosion inhibitors (Vehicle Service Pros, 2017; CarFromJapan, n.d.).

In this study, the distilled water exhibited significantly lower mineral concentrations than the original brine; however, the remaining ionic content and elevated conductivity exceed typical expectations for radiator-grade distilled or deionized water. The presence of calcium and bicarbonates is of particular concern, as these ions are known contributors to scale formation at elevated temperatures. Consequently, the recovered distilled water, in its current form, is not suitable for direct use as a radiator coolant without further purification or chemical treatment.

Implications for lead-acid battery applications

Lead-acid batteries require water of exceptionally high purity to maintain electrochemical stability and prolong battery life. International standards specify strict limits for dissolved salts, metals, and ionic contaminants in battery refill water (East African Standard, 1999; British Standards Institution, 1975). Even trace amounts of certain ions, such as chlorides or calcium, can adversely affect battery performance.

Although the distilled water produced in this study showed reduced impurity levels relative to brine, detectable concentrations of sodium, calcium, chlorides, and bicarbonates remain above recommended limits for battery-grade water. These findings indicate that the distilled water does not meet the purity requirements for safe use in lead-acid batteries. Similar conclusions have been reported in battery maintenance literature, which emphasizes that only fully deionized or multi-stage purified water is appropriate for such applications (Crown Equipment Corporation, n.d.; Battery Builders LLC, 2025).

CONCLUSION

This study demonstrated that the fabricated salt-making machine with a built-in distillation system is operationally effective and capable of recovering distilled water from salt refinery vapor. The integration of vapor recovery into the salt refining process represents a meaningful step toward reducing environmental exposure to saline vapor while improving overall resource efficiency in salt production.

However, chemical analysis revealed that the recovered distilled water does not yet meet the purity requirements for direct use in automotive radiators or lead-acid batteries. The presence of residual dissolved ions indicates that additional treatment is necessary before such technical applications can be considered. These findings highlight the importance of incorporating post-distillation purification processes, such as deionization, activated carbon filtration, or reverse osmosis, to achieve water quality standards suitable for automotive and industrial use.

Overall, the study provides a practical foundation for sustainable salt production practices and demonstrates the potential for converting an environmental by-product into a valuable resource through further system refinement.

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