Development of a Salt Production Apparatus

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ARTICLE INFORMATION

Article History:
Received: August 3, 2017
Received in revised form: November 8, 2017
Accepted: February 21, 2018

Keywords:
Salt production, salt, solar drying

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ABSTRACT

This study designed and fabricated a salt-producing apparatus capable of operating in all seasons and be able to produce salt in a short duration of time, and, of quality comparable to traditional solar drying. For an average brine salinity of 3.27 percent (by weight), the average production output was 325.84 grams of salt from an input of 8.5 liters. For three hours of operation 15.08 kilograms of fuel was used, with drying chamber operating temperature ranging from 29 to 108 degrees Celsius. From data obtained, the drying performance was 82 %. Cost analysis showed a payback period of 2.5 years. The salt production apparatus is highly recommended for use by the local community, and perhaps by massive salt producers.

Introduction

Salt is one of the largest products of developing countries where there are areas that are typically hot, dry, and sunny. It is a low-price commodity with good profitability due to its ever increasing demand in the local and in the international market. The word *salary* itself is associated with salt. The use of salt in our everyday life such as food seasoning, coconut fertilizer in agriculture, manufacturing of food as seasoning and as preservative, are some of the needs we may identify with salt.

Annually, more than 200 million tons of salt are produced globally. Based on statistics, top salt exporters are Canada, the Netherlands, and Germany while top importers are the United States, China and Japan (Pariona, 2017). *Business Mirror* (May, 2017 issue) cites Occidental Mindoro as one of the biggest salt producers in the Philippines. Salt production increased in the year 1990 to about 60,000 metric Tons or 18% of the country's 338,000 metric Tons annual requirement. According to Pacific Farms, Inc., salt production is a vibrant industry in the Philippines. From the same reference, almost 85% of the country's annual salt requirements could be supplied by the provinces of Bulacan, Pangasinan, Occidental Mindoro, and Cavite.

The sources of brine in the production of salt are mainly seawater and inland sub-terrain waters while the marine salts are from sub-terrain or lake waters. In the history of salt production, traditional methods are associated with the landscape and patrimonial values. (Rodriguez et. al., 2011).

The traditional method of producing salts is through solar radiation and the wind. Water vaporizes from the brine until it dries leaving a crystal residue. This has the disadvantage of uncontrolled product quality due to dust, insects, and other contaminants. Production is also limited during rainy seasons. The importance of traditional method of producing salt lies on its contribution to the labor industry; creation of support industries such as basket-making, ceramic tile-making; industry for dike construction, maintenance, and repair, packaging , iodizing hauling of salts, etc. (PCSP, 2009).

In the Philippines, there is no known portable salt-producing machine or apparatus such that this researcher found the need to develop and fabricate a portable, agricultural waste fuel-fired, year-long production, and easy-to-operate salt producing system.

Preparing the students for the science and technology of the 21st century means the integration of technology and inquiry-based teaching into their instruction of the current science education (American Association for the Advancement of Science, 1993; National Research Council [NRC], 1996, 2000). The National Science Education Standards [NSES] define *inquiry* as "*the diverse ways in which scientists study the natural world and proposed explanations based on the evidence derived from their work.*" [NRC, 1996, p. 23]. The NSES encourage teachers to apply "*a variety of technologies, such as hand tools, measuring instruments, and calculators [as] an integral component of scientific investigations*" to support student inquiry [p. 175]. The *inquiry-based* science classroom allows the learners to work as scientists by utilizing technology tools (Novak & Krajcik, 2006, p.76).

This salt-making apparatus may be able to address the teacher education effectiveness, by way of improving the quality of *K-12 Science, Technology, Engineering, and Mathematics (STEM)* program specifically on engineering and technology. The scientific principles and applied technology where the design of this systems were based may motivate students' potential for higher learning and eventually aid in solving the problems currently faced by society. The technology of this salt-producing apparatus allow the students to practice the NSES definition of *inquiry-based teaching* thereby addressing the needs of teacher education.

The tools used for presentation of the final design are Solidworks software and Autocad.

Objects of this study was to devise a machine that can be operated in all seasons, shorter production time, portable, a better concentrated salt quality having less particulate contaminants, efficient, economically viable, and can be related to teacher education needs. Comparison will be made for this apparatus versus traditional method of salt production in terms of correlated variables, that is,

Purposes of the Research

The main purpose of this study is to devise an alternative system of producing salt. Other purposes are to allow the use of agricultural waste as alternative source of energy (or fuel), provide mobility to the system, to decrease the production time (as compared to traditional solar drying), and provide an aid to the needs of teacher education program.

Methodology

Research Design

The research is an experimental study conducted in two phases. The first phase is the fabrication of the salt production machine and the second phase is the testing and evaluation of the performance of the machine in producing concentrated salt.

Components Design Details

A. Furnace

Figure 1. Furnace

1. Design Function
    a. The furnace is the component of the system where the fuel is to be burned.

2. Design Requirements
    a. Furnace volume is to be designed as to hold and efficiently combust the type of fuel (dried twigs).
    b. Furnace should be provided with durable refractory materials capable of resisting erosion and wear.
    c. Insulation must be provided to prevent excessive heat losses.
    d. Low-cost and locally-available materials should be selected.
    e. The furnace as a whole must be capable of maintaining the required temperature for a spontaneous combustion to occur.
    f. Instrument must be provided for high-temperature measurement.
    g. A means of monitoring the fire must be provided.

B. Air-tube Heat Exchanger

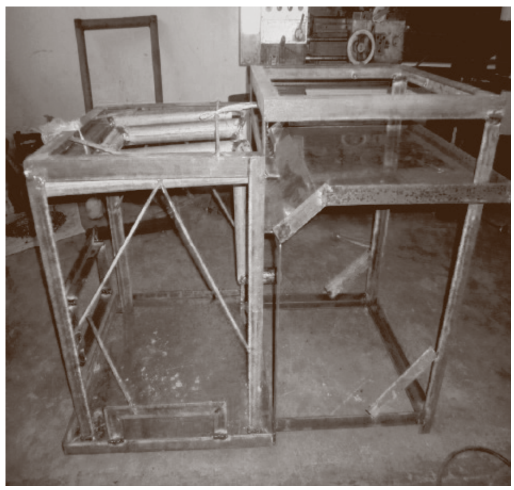

Figure 2. Air-tube Heat Exchanger

1. Design Functions
    a. The air-tube heat exchanger is to convey the right amount of hot air necessary to dry the salt.

2. Design Requirements
    a. Tube size should be capable of conveying the right amount of air required.
    b. Tube material must have a sufficient thermal conductivity to transfer the necessary heat rate to crystallize the salt contained in the charge.
    c. The tubular heat exchanger must have a sufficient surface

area for heat transmission.

d. Tube material must be capable of withstanding high furnace temperatures.

e. Tube material should be structurally strong at the design temperature of the furnace.

f. Tube joints must be welded.

g. Instruments must be provided to indicate incoming cold-air and outgoing hot-air temperature as a means of measuring the efficiency of the heat exchanger.

C. Boiling Chamber.

Figure 3. Boiling Chamber

1. Design Function

a. The boiling chamber is the systems component where water in the brine is evaporated to form a concentrated brine.

2. Design Requirements

a. The boiling chamber must have full-capacity of 21 liters of brine.

b. Material should be corrosion resistant.

c. Material must possess a high thermal conductivity.

d. The boiling chamber must provide the proper brine surface area for evaporation to take place.

e. The Boiling chamber must be structurally strong.

f. A means of sampling must be provided to monitor the brine concentration and chamber temperature

g. A sight glass must be provided.

h. The boiling must be situated at such a height that it can be easily accessed by the operator.

D. Drying Chamber

Figure 4. Drying Chamber

1. Design Function
   a. The drying chamber is the systems component where the concentrated brine will be final demoisturized to form crystallized grains of salt.

2. Design Requirement
   a. The drying chamber must have a capacity of 12.5 liters of concentrated brine.
   b. The drying chamber must have the necessary volume to contain the tubular heat exchanger.
   c. A sight glass must be provided for monitoring.
   d. A temperature gauge should be provided to monitor the chamber temperature.
   e. The drying chamber must be located at a height so as to be easily accessed by the operator.

E. Smokestack.

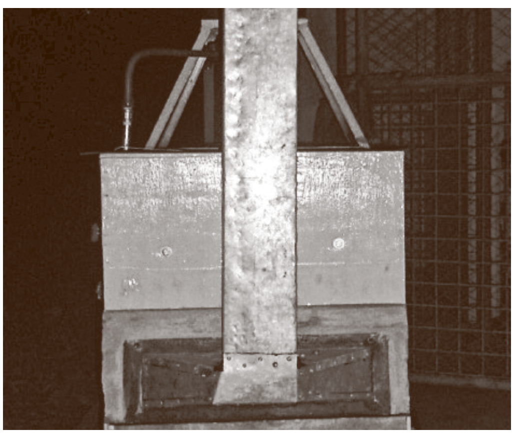

Figure 5. Smokestack

1. Design Functions.

   a. The smokestack is the systems component to exhaust and disperse the gases over a wide area to lessen its concentration in the environment.

2. Design Requirements.
   a. Material of construction must be durable enough to withstand erosion and corrosion due to flue gases.
   b. It must be capable of exhausting all the flue gases produced by combustion of the fuel.
   c. It must be structurally strong.
   d. It must be constructed in such a way that it may easily be replaced.
   e. A provision for systems cleaning must be provided.

Construction of the Apparatus

The furnace is supported by welded angular steel bars and then lined with fireclay bricks for proper insulation. Leakage of combustion gases is prevented by the provision of plain sheet enclosure. The stoker-type of fuel burner is situated below the combustion chamber. The drying chamber is placed directly above the furnace with the air-tube heat exchanger between them. The flow of combustion gases was streamlined such that it passes and heats the boiling chamber, and out to the atmosphere via a smokestack or steel chimney. One forced-draft fan forces the air to pass through the air-tube heat exchanger. Another forced-draft fan was installed for conveying the required combustion air to the furnace. The extractable brine pan was fabricated for placement into the boiling chamber. A vent between the boiling chamber and the drying chamber was provided to ensure no overcooking of the salt can take place. The evaporated water (or steam) from the two chambers is exhausted to the atmosphere by natural convection through a vent made particularly for it. Concentrated brine are collected from the bottom of the boiling pan and transferred to the drying pan via a conduit. A valve was provided with this conduit for control of flow. Systems components such as the furnace, firetube heat exchanger (or evaporator), fans, drying chamber, measuring instruments, and chimney were assembled to the frame with the necessary instruments and wiring. See Figures 6 and 7

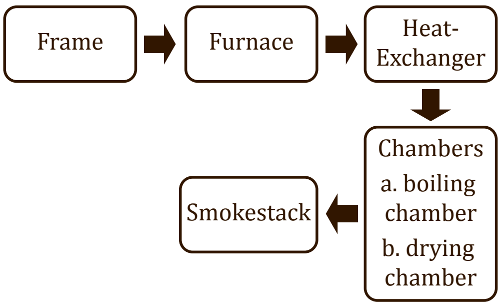

Figure 6. The Fabrication or Assembly Process

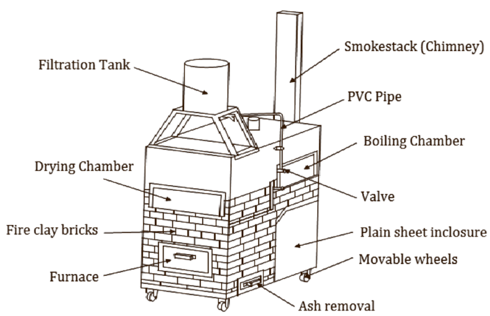

Figure 7. Isometric view of salt production apparatus

Data Collection and Analysis

The data gathered are analyzed using:

Rate of Salt Recovery:

$$\text{Rate of Salt Recovery} = \frac{\text{Grams of salt produced}}{\text{Hour x Liter brine input}}$$

Dying efficiency:

$$\text{Drying efficiency} = \frac{\text{mass of moisture removed x latent heat of water}}{\text{total heat enter to the chamber}}$$

Payback Period:

The economic value analysis of the apparatus is the period of time recovered the investment cost is recovered. This is the initial cash outflow from the cash inflows generated by the investment

Results and Discussion

Systems Operation

The machine operates starting from collecting brine into shallow pond or ocean then filtering the brine that takes place at the filtering tank. The insoluble impurities such as sand, rubbles and slightly soluble impurities such as calcium carbonate settle at the bottom of the filtering tank. Secondly, the brine passes through the PVC pipe entering the boiling pan in the boiling chamber where evaporation begins as the temperature range from 90˚C to 100˚C. The temperature in the boiling chamber is controlled all through out with the speed of blower fan and the amount of fuel (dry twigs) that feed in the furnace. Thirdly, as the brine evaporates, the boiling brine from the boiling chamber moves into a drying pan in the drying chamber, which is heated to a temperature of 108.7˚C and above until the brines forms as crystal salt. Lastly, as the salt forms completely in the drying pan the salt crystal are then collected. See Figures 8 and 9

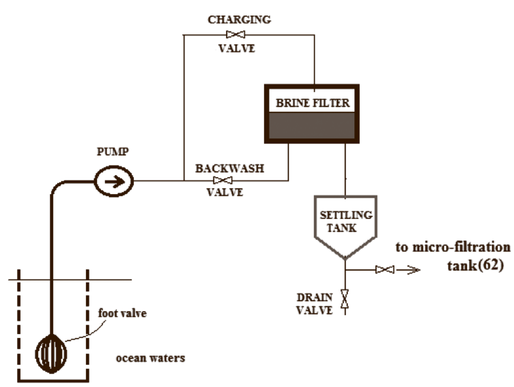

Figure 8. Filtration Process

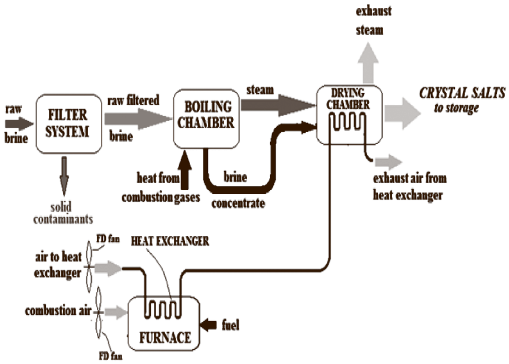

Figure 9. Salt production process

Sampling Procedure

The 8.5 liters of raw brine charge was weighed before filtration. The salinity and pH number of the charge were measured before and after the filtration process. The determination of the salinity and pH number of samples were done in the laboratory.

The weight of the fuel charge and the final weight of salt produced, the time duration to produce the product salt from the 8.5 liters of raw brine were all measured and recorded.

Based on the salinity previously measured, the maximum salt that can be produced from the samples are calculated and included as a secondary data.

A total of three (3) trial runs were made in order to evaluate the performance of the system.

Based on the average salinity values of the data collected (see Table 1), the target salt production was predetermined.

Since there is a certain correlation between volume, drying time, weight of salt produced the calculated rate of salt recovery from the input of 8.5 liters of raw brine is as follows:

$$\text{Rate of Salt Recovery} = \frac{\text{Grams of salt produced}}{\text{Hour x Liter brine input}}$$

$$= \frac{325.84}{3.04\ (8.5)}$$

$$= 12.61\ \frac{g}{h \cdot l}$$

Table 1 shows the apparatus is largely dependent on the effectiveness of the heat exchange surfaces and the amount of heat input to the system is indicated in the third trial. The data gathered during the first and second trial runs indicate that the amount of salt produced increases as the fuel input is increased. The third trial shows a decrease in the salt produced with a further increase in fuel input.

Table 1

Data Collection

QUANTITY	TRIALS				
	1	2	3	TOTAL	MEAN
Volume of Raw Brine (L)	8.5	8.5	8.5	25.5	8.5
Mass of Raw brine, (g)	8712.5	8712.5	8712.5		
Salinity before filtration (kg/l)	0.0329	0.0327	0.0326		0.0327
Salinity after filtration (kg/l)	0.033	0.0327	0.0328		0.0328
pH Number before filtration	7.98	7.97	7.79		7.91
pH after filtration	7.95	7.94	7.86		7.91
Mass of fuel used (kg)	14.50	15.25	15.5	45.25	15.08
Mass of salt produced (g)	132.54	374.49	470.49	977.52	325.84
Production Time (h)	3h 7 min	2 h 50 min	3 h 10 min	9 h 7 min	3.04 hours
Dry salt content (g)	280.5	277.95	277.10 g		278.52
Maximum Projected Salt Production (g)					327.67

Payback Period.

The payback period based on the cost analysis made are as follows:

$$\text{Payback Period} = \frac{\text{Php } 27{,}057.45}{\text{Php } 10{,}786.85}$$

$$= 2.5 \text{ years''}$$

- Initial investment (machine cost) Php 27,057.45
- Total annual gross income,
- Prevailing price of non-iodized salt, Php 5.00/kg (www.ncp.ph)

The viability of the salt production apparatus that was devised using an alternative and cheap fuel in the form of dried twigs is justified by the payback period of 2.5 years.

Conclusion and Recommendation

The general objective of this paper is to devise an alternative system of producing salt. In the Philippines, there is an existing patent of salt making apparatus that can be operated indoors. These are vertical evaporator for salt production and improved salt making apparatus. This apparatus is an evaporative type utilizing heat given off by a combustion chamber but depend on the evaporative power of atmospheric air by means of sunlight and another apparatus that operated indoors enabled to produce salt during the rainy and dry season but it required of fuel using waste materials in generating the heat required by the device. The present study relates to the development of a salt production apparatus with the same function in terms heat required that utilizes waste materials or biomass fuel that used in all seasons. The present study has no impurities involved since there is a process of filtration to produce of concentrated salt. This machine has a movable type with wheels to easily transfer in other places. Also, it is easy to operate and less of maintenance. When compared in the traditional way of harvesting salt the drying process is faster and economical in terms of labor, production rate and higher salt recovery.

Based on the findings of the study, the following conclusions were drawn; [a] the researcher concludes that there is a positive correlation between the mass of salt produced, the volume of raw brine, drying time and production rate. Based on the numerical simulation and design calculation, the results of salt production rate (grams per hour) and the mass of salt per liter of brine or seawater (grams per liter) of the described salt making process using solar evaporation method increased by 36.41% and 55.34%, applied external heat of evaporation almost 100% increased and 20%, and stone boiling representing evaporation almost 100% increased and decreased of 90.53% respectively. This implies that fine-grained salt product from this apparatus can be produced in a time duration of 3 hours per batch; [b] the researchers concluded that the apparatus producing of concentrated salt with an average mean of 325.84 grams at 8.5 liters of salt water with a 15.08 kg of fuel consumed in the average of 3:04 hours of operation. This implies that the salt apparatus are efficient and effective with the use of agricultural waste as an alternative source of energy, therefore, it signifies that the apparatus was acceptable; [c] the researcher concluded that apparatus is a movable type that easily transfers to another places especially during the wet season as compared than the previous method. This implies that the present apparatus has continuous operation while the previous type is seasonally basis; [d] the researcher concluded that apparatus devised performance in terms of rate of salt recovery is 12.61 grams per hour per liter while the traditional salt production using solar radiation (Williams, 2002) has 0.5729 gram per hour per liter. This implies that the present apparatus is greater the rate of salt recovery as compared to solar drying; [e] The salt-making technology can be of use for teacher education program needs where students can do laboratory and practice inquisitive learning process.

Based on the result of the study, the following recommendations considered; 1) closer monitoring of the production variables such as temperature distribution, fuel feed corresponding to flame management, maintenance of the cleanliness of the heat transfer surfaces for good heat input to boiler and dryer, monitoring of the air-tube heat exchanger inlet and outlet temperatures are some of the concerns of operating the apparatus; 2) because the system needs skillful operators, it can be a great improvement if the apparatus is given the proper instrumentation and automation where needed. The automation leads to a decrease in the manpower; and 3) solar energy may provide the power to operate the forced draft fans.

For the further and future direction of this study, because this device is of the batch-type, future innovations are recommended especially in the matter of operating the apparatus continuously.

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Links:

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Appendices

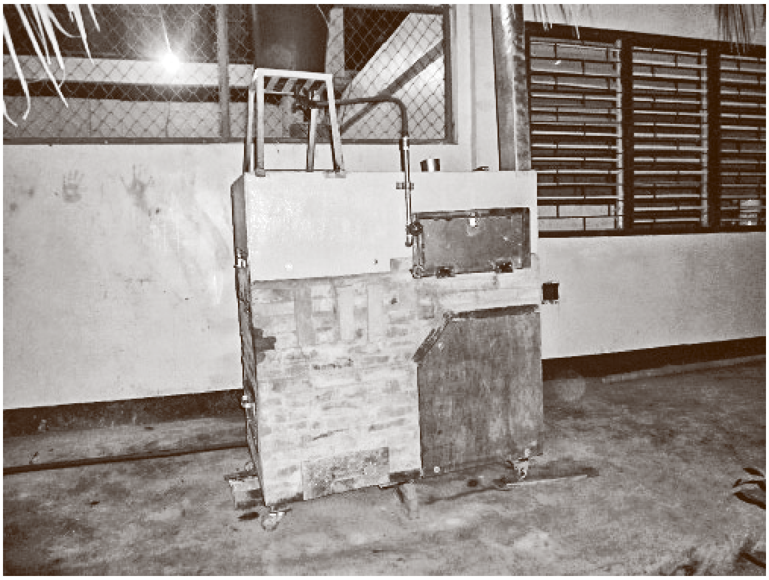

Figure 10. Isometric View of Salt Machine

Figure 11. Salt Produced