Feasibility study of a brine boiling machine by solar energy

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Abstract. This study presented the technical and operational feasibility of brine boiling machine by using solar energy instead of firewood or husk for salt production. The solar salt brine boiling machine consisted of a boiling chamber with an enhanced thermal efficiency through use of a solar brine heater. The stainless steel solar salt brine boiling chamber had dimensions of 60 cm x 70 cm x 20 cm. The steel brine heater had dimensions of 70 cm x 80 cm x 20 cm. The tilt angle of both the boiling chamber and brine heater was 20 degrees from horizontal. The brine temperature in the reservoir tank was 42°C with a flow rate of 6.64 L/h discharging into the solar boiling machine. It was found that the thermal efficiency and overall efficiency of the solar salt brine boiling machine were 0.63 and 0.38, respectively at a solar irradiance of 787.6 W/m\textsuperscript{2}. The results shows that the potential of using solar energy for salt production system is feasible.

1. Introduction

The northeast of Thailand is home to the largest rock salt producers in the country. There are areas having the rock salt, salty groundwater, sandstone, or shale mixed with salt underground, creating an obstacle to agriculture \cite{1}. For this reason, such saline areas have been used for salt production to generate income for farmers. Ban Dung District, Udon Thani Province, is an area in which salt can be produced. It has an area of approximately 800 hectares and is owned by 180 farmers. There are two processes for making salt. The first is the salt field method. The second is the salt boiling method. More than 250,000 tons of salt is produced here annually with a market value of approximately 100 to 150 million baht. As such, salt production is the major industry of Ban Dung District \cite{2}.

The preferred process to produce the salt is the boiling method, as it requires less area and labor. This is especially true in the rainy season when it is not possible to use the salt field method. Nevertheless, the boiling method requires costly fuel. In the past years, firewood was used as fuel. This is rarely done at present due to stricter regulations for use of forest resources. Currently, the preferred fuel is rice husks (figure 1). Burning rice husks generates greenhouse gases, dust pollution and heat. Additionally, rice husks have high transportation costs as there are delivered from remote areas. Additionally, transportation of rice husks consumes fossil fuels. Should the availability of rice husks decrease, the amount of salt produced will be reduced accordingly.

Solar energy can be considered an infinitely renewable energy source. Furthermore, it is a clean energy as it creates no pollution to the environment, unlike fossil energy. There have been numerous practical applications of solar energy. They employ either the use of energy from the sun’s rays, or use of solar thermal energy. The intensity of solar irradiation in Thailand is high from January to April, approximately 20 MJ/m\textsuperscript{2}-day \cite{3}. However, solar energy in Thailand creates very high levels of heat in
comparison to the countries in the temperate zone, where the irradiation is more common [4]. This study presented the technical and operational feasibility of brine boiling machine by using solar energy instead of firewood or husk to produce salt in Northeastern Thailand.

![Figure 1. An oven used for burning rice husks to generate heat for producing salt by the boiling method.](image)

2. Experimental apparatus description

The solar salt brine boiling system in this study consisted of solar salt brine boiling chamber used with a solar brine heater or called flat plate collector to increase the efficiency of the system [5,6]. Details of the study are as follows.

2.1. Solar salt brine boiling system

The principle of solar salt brine boiling system is similar to solar distillation. Its purpose is to separate water from dissolved substances using heat [7] but its desired product is the salt in brine. In this research, brine water was mixed between water with salt (ratio of 2:1). The brine water was poured into a brine heater that was connected to a salt brine boiling chamber (figure 2) to increase the brine’s temperature before releasing it into the salt brine boiling chamber. The temperature of brine in the brine heater was near the boiling point of water.

The heater increased the brine temperature before allowing it to flow into the solar salt brine boiling chamber. The brine heater was a solar collector consisting of 15 stainless steel tubes, each 600 mm long. Their inner diameter was 20 mm and they were placed in a 700 mm x 800 mm insulated box. The stainless steel tubes were connected and the total tube length was 9000 mm. The outer surfaces of the tubes were painted black and covered by a black metal sheet. The inside of the brine heater was insulated with fiberglass. The brine heater was covered with 3 mm thick transparent glass on the upper side. The brine heater was tilted at a 20° angle from horizontal which was the optimal annual tilt angle for Udon Thani [8,9]. The brine was fed to the heater from a reservoir into the stainless steel tubes from below and removed from the top after the heating process.

The photography of the solar salt brine boiling chamber is shown in figure 3. It was constructed from a stainless steel box with dimensions of 500 mm (width) 700 mm (length) and 70 mm (height), and its surface was black painted. It was insulated with fiberglass and ethylene rubber. The upper side was covered by a 3 mm thick sheet of transparent glass. The solar salt brine boiling chamber’s surface was tilted 20° from the horizontal to allow condensing water to run down the condensate channel. The brine feed came from the brine heater and went into the distribution tube which has a longitudinal slot that was 50 mm wide with 0.5 mm diameter hole for each slot. The brine then ran through this slot onto the black absorption tray as a thin film [10]. Using the absorption tray is an easy method for collecting salt at the end of the process. Solar energy transferred heat to the absorption tray. The water evaporated and then condensed when it came in contact with the cool glass cover and flowed into the condensate channel. Only crystalline salt remained on the absorption tray.
Figure 2. The solar salt brine boiling machine showing its brine heater (A) and salt brine boiling chamber (B).

Figure 3. The experimental solar salt brine boiling chamber includes condensate channel (1), distribution tube (2) and black absorption tray (3).

The thermal efficiency ($\eta_{th}$) of the brine heater and the salt brine boiling chamber was investigated from the ratio of the amount of power used per sq.m. ($\hat{Q}_{used}$) from the machine divided by the solar irradiance ($I$) as in equation (1). The overall efficiency ($\eta$) was the ratio of amount of evaporated brine ($S_{evap}$) compared to amount of brine taken in ($S_{in}$), as in equation (2).

$$\eta = \left( \frac{S_{evap}}{S_{in}} \times 100\% \right)$$

$$\eta_{th} = \frac{\hat{Q}_{used}}{I} \times 100\%$$

2.2. Measuring devices
Solar irradiance was measured using an EKO-MS-602 pyranometer with a HIOKI-LR-5041 voltage logger. These measurements were done in natural sunlight and the active surface of the specimen was within 5° being coplanar with the active surface of the reference device (Pyranometer) or $\theta$ angle. Air temperatures were measured in the salt brine boiling chamber. The brine temperatures were measured in the reservoir tank, at the outlet of the solar brine heater and at the inlet to the salt brine boiling chamber. The temperatures were measured using individually calibrated thermocouples (J type).

3. Experimental results
In this study, the flow rate of brine discharge into the solar salt brine boiling machine was 6.64 L/h. Experimental data was collected between the hours of 9:30 am to 2:30 pm. During this period, the weather was sunny with few clouds. Variation of the solar irradiance and the temperatures of the outdoor air, indoor air and brine in reservoir tank are shown in figure 4. Values of solar irradiance, temperature of outdoor air, indoor air and brine in reservoir tank varied from 619 W/m$^2$ to 858 W/m$^2$ (avg. of 787.6 W/m$^2$), 39°C to 50°C (avg. of 42.4°C), 34°C to 42°C (avg. of 37.8°C) and 37°C to 46°C (avg. of 42.0°C), respectively. The variation of brine temperature at the outlet of the brine heater and air temperature in stainless steel box of the salt brine boiling chamber were compared with brine temperature in reservoir tank and solar irradiance as shown in figure 5.

From figures 4 and 5 show that increasing solar irradiance led to an increase in all temperatures. Decreasing the solar irradiance produced the opposite effect. The air temperature in the salt brine boiling chamber was higher than 100°C between 10:30 am to 12:30 pm. At the same way, the brine
temperature at the brine heater outlet was higher than 80°C after one half hour of operation until end of the experiment. It was double the brine temperature in the reservoir tank. Moreover the brine heater could produce brine at temperatures greater than 60°C (57°C to 104°C, average 88°C) throughout the day at flow rate of 6.64 L/h. The maximum temperature difference between inlet and outlet temperatures of the brine heater was 66°C at 11 am. The inlet and outlet temperatures were 38°C and 104°C, respectively. That means using the brine heater would increase the capacity the solar salt brine boiling machine, since the temperature difference between brine and its boiling was decreased. Thus brine flowed down the tray and crystallized immediately as shown in figure 6 and the resulting product is shown in figure 7.

**Figure 4.** Solar irradiance and temperatures variations.

**Figure 5.** Comparison of brine temperature at outlet of brine heater and in the reservoir tank.

**Figure 6.** The solar salt brine boiling machine.

**Figure 7.** The sample of salt produced.

**Table 1.** The brine boiling machine efficiencies.

| Period                  | kg of inlet brine | kg of outlet brine | kg of produced salt (kg of brine) | kg/m²/day of produced salt | η  |
|-------------------------|-------------------|--------------------|-----------------------------------|-----------------------------|----|
| 11:00 am-1:00 pm        | 13.28             | 6.40               | 2.29 (6.88)                       | -                           | 0.52 |
| 09:30 am-11:00 am       | 19.92             | 14.14              | 1.93 (5.78)                       | -                           | 0.29 |
| 1:00 pm-2:30 pm         |                   |                    |                                   | 12.06 (12.66)              | 0.38 |
| Whole day               | 33.2              | 20.54              | 4.22                              | 12.06                       | 0.38 |

Moreover brine boiling machine efficiency was pretty high at 0.52 around noon (11:00 am -1:00 pm) but it was rather low at 0.29 on morning (09:30 – 11:00 am) and afternoon (1:00 pm– 2:30 pm).
When consider all day, salt could be produced with 36.17 kg of brine per sq.m or 12.06 kg of salt per sq.m, the results are shown in table 1. Even the amount of salt in this study was less than a conventional salt boiling system (42 kg of salt per sq.m a day [11]) but solar energy was free.

For thermal efficiency ($\eta_{th}$), the brine heater had a $\eta_{th}$ of 0.8 and it decreased to 0.63 when operated with the salt brine boiling chamber. This results might be due to increased surface area in the brine boiling chamber. Therefore, increasing brine temperature using solar energy before discharging brine to a conventional salt boiling system may be appropriate for a salt production system.

4. Conclusions
A solar salt production system in this study included a solar salt boiling chamber and solar brine heater. It was tested under the actual environmental conditions of Udon Thani Province, Thailand. The first step was to produce hot brine. To do this, brine flowed into the lower part of the solar brine heater and flowed out at the top. The second step was to produce salt. Hot brine flowed to an absorption tray in the solar salt brine boiling chamber, and then salt crystallized. The flow rate of brine was 6.64 L/h. The average brine temperature at outlet of the brine heater was 88°C. However brine temperature is a function of solar irradiance and time. The thermal efficiency and the overall efficiency of the solar salt brine boiling machine were 0.63 and 0.38, respectively at a solar irradiance of 787.6 W/m². Therefore, the feasibility of this study when using solar energy in a conventional salt production system is possible, however use the solar brine heater alone is appropriate.

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