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การนำน้ำกลับคืนมาจากการบำบัดน้ำระบายทิ้งเข้มข้น จากระบบแยกเกลือจากน้ำขนาดเล็กในจังหวัดนครราชสีมา

Water recovery of brine water treatment from a small-scale desalination system in Nakhon Ratchasima

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บทคัดย่อ

งานวิจัยนี้มีวัตถุประสงค์ในการนำน้ำกลับคืนมาจากการนำน้ำระบายทิ้งเข้มข้นที่ปล่อยออกจากเครื่องแยกเกลือเข้าสู่ชุดกลั่นแสงอาทิตย์ โดยออกแบบให้สามารถกักเก็บอุณหภูมิภายในชุดกลั่นที่เอื้อต่อการเปลี่ยนสถานะของน้ำระบายทิ้งเข้มข้นที่กักเก็บอยู่ภายในชุดกลั่น ไอน้ำลอยตัวสูงขึ้นไปกระทบกับแผ่นกระจกใสที่เย็นกว่าด้านบน ทำให้เกิดการกลั่นตัวเป็นหยดน้ำก่อนไหลตามความลาดเอียงลงสู่รางรับน้ำและนำกลับไปใช้ใหม่ ชุดกลั่นแสงอาทิตย์มีขนาดกว้าง 1 เมตร ลึก 1 เมตร สูง 0.5 เมตร มุมลาดเอียง 25 องศา ช่วยให้หยดน้ำไหลลงตามแนวลาดเอียงของกระจกโปร่งแสงได้โดยไม่หยดกลับลงไปในถาดของน้ำระบายทิ้งเข้มข้นที่ด้านล่างบรรจุแกลบดำ ซึ่งเลือกใช้เป็นวัสดุรองรับด้านล่างของถาดกักเก็บน้ำระบายทิ้งเข้มข้น เนื่องจากเป็นวัสดุสีดำช่วยดูดกลืนพลังงานความร้อนได้ดีหาได้ง่ายในท้องถิ่น และไม่เน่าเสียเมื่อใช้กักขังกับน้ำระบายทิ้งเข้มข้นผลทดสอบการใช้งานของชุดต้นแบบในช่วงฤดูฝนและต้นฤดูหนาวพบว่า ค่าเฉลี่ยการนำน้ำกลับคืนประมาณ 150 มิลลิลิตรต่อวันต่อชุด ระดับอุณหภูมิภายในชุดกลั่นอยู่ในช่วง 30-70.1 องศาเซลเซียส ช่วง 14.00 น. มีอุณหภูมิสูงกว่าช่วงเวลาอื่น โดยมีค่าเฉลี่ยอุณหภูมิ 70.1 องศาเซลเซียส ซึ่งระดับของอุณหภูมิภายในชุดกลั่นแสงอาทิตย์มีความสัมพันธ์โดยตรงกับปริมาณน้ำที่กลั่นได้ ความสามารถในการนำน้ำกลับคืนของชุดกลั่นต้นแบบอยู่ในช่วง 1,092–1,265 มิลลิลิตรต่อวันต่อชุด โดยค่าต่ำเกิดขึ้นในช่วงฤดูฝน และค่าสูงเกิดขึ้นในช่วงต้นฤดูหนาว อัตราการนำน้ำกลับคืน 45–55 มิลลิลิตรต่อตารางเมตรต่อวัน ชุดกลั่นแสงอาทิตย์เป็นทางเลือกที่เข้ามาช่วยลดผลกระทบจากน้ำระบายทิ้งเข้มข้นของเครื่องแยกเกลือออกจากน้ำที่เป็นปัญหาการกำจัดค่าความเค็มที่อาจส่งผลกระทบระยะยาวกับแหล่งน้ำที่ระบายออกได้ เป็นวิธีประหยัด ไม่เป็นภาระกับผู้ดูแลและงบประมาณ ปริมาณน้ำที่ได้นำกลับคืนมาได้เป็นน้ำกลั่นมีความจืดจึงนำกลับมาใช้ประโยชน์ซ้ำได้ซึ่งเป็นการสนับสนุนการใช้งานเครื่องแยกเกลือออกจากน้ำขนาดเล็กที่นำมาใช้งานบรรเทาปัญหาน้ำมีความเค็มให้กับพื้นที่ได้

คำสำคัญ: การนำน้ำกลับคืนมา, การบำบัด, น้ำระบายทิ้งเข้มข้น, การกลั่นแสงอาทิตย์, การแยกเกลือจากน้ำ, นครราชสีมา

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Abstract

This study aims to recover water from treating brine water of a small-scale desalination using a solar still. The design focuses on keeping temperatures inside at conditions suitable for water evaporation from the brine water basin. Water vapor rises and condenses into water droplets on the transparent glass cover, moving down the slope into a channel and collecting outside. The solar still is 1.0 m x 1.0 m x 0.5 m (width x depth x height) with a 25-degree slope for a transparent glass cover on top. This slope allows the water droplet to move down without reentering into the brine water basin below. The brine water was placed on top of the carbonized rice hull. The black residues can absorb heat energy by being a dark color, locally available, environmentally friendly, and stable. The test results during rainy and early winter months showed that the prototype solar still produced the average recovery water of 150 mL/day/set, with the hourly temperatures inside the chamber ranging from 30 to 70.1 Celsius. The highest inside temperature occurred at 2 PM, with an average of 70.1 Celsius. A correlation was observed between temperature and the amount of distilled water. Water recovery from the prototype ranged from 1,090 to 1,256 mL/day. Low recovery occurred in the rainy months. Estimation of water recovery rates in Nakhon Ratchasima ranged from 45 to 55 $mL/m^2/day$. The solar still provides an alternative to recover water and mitigate the direct impact of brine water discharge from the small-scale desalination in Nakhon Ratchasima from possible effect of salinity water discharge. The method is economical, less burdensome to the caretaker, and low budget. The recovery water is freshwater; thus, it can be reused and has no long-term impact. The use of solar still is an auxiliary device that can be used with small-scale desalination in areas with saline water.

Keywords: Water recovery, Treatment, Brine water, Solar still, Desalination, Nakhon Ratchasima

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1. Introduction

The widespread distribution of saline soil in northeast Thailand negatively impacts cultivation, livelihood, and the local economy due to low productivity and unsuitability for agriculture, especially in Nakhon Ratchasima province. Saline soil is soil that contains excessive amounts of water-soluble salts. Saline soil was estimated to cover about 30 percent of the total area in Nakhon Ratchasima [1], which is the province with the largest land area in Thailand, approximately 20,494 km^2 [2]. Economic crops in the province include rice, corn feed, cassava, and sugar cane. Apart from the low productivity of agricultural products, salt contents in soil cause higher salinity in groundwater and surface water than in other areas of the northeast region. As a result, the water supply production in a village mainly relies on surface water. It has difficulty removing salinity from the process, especially during the dry season, because the conventional sand filtration in the village water supply is used for turbidity removal.

The Department of Water Resources has built water treatment plants for village water supply throughout Thailand based mostly on sand filtration. The treatment plants in Nakhon Ratchasima, especially in Dan Kun Thot District, use sand filtration as a process to remove turbidity. The village water supply system cannot remove accumulated salinity from surface water during the dry season. In 2021-2022, the Department of Water Resources installed a prototype system to remove salinity in treated water supply using a membrane filtration technology as a part of a research project supported by funding from Thailand Research and Innovation (TSRI). The system is a small-scale desalination powered by solar panels. It is capable of lowering salinity in the water supply. The use of membrane technology produces brine water as a discharge and requires attention before disposal into the environment because the brine water has a high concentration of dissolved ions. Most large desalination plants are located near the sea, which is suitable for discharging the brine water back into deep water to avoid negative impact near shore. With a limited option of disposal of brine water on land or water in the area, this research proposed a brine water treatment system for a small-scale desalination system using a solar still system in Dan Kun Thot District, Nakhon Ratchasima. The system could treat brine water generated during desalination to lower the impact of brine water discharge and recover water as a product. The recovered water can be reused for other purposes, thus reducing water waste in the system.

Solar still is a simple water purification technique [3]. It uses energy from the sun to heat the water inside a closed chamber, allowing trapped heat to raise the temperature and evaporate the water into water vapor [4]. Rising water vapor accumulates on a transparent glass cover and forms water droplets through condensation on a cooler glass surface. The glass is built with a slope to facilitate water collection and prevent the water droplets from dripping back into the water reservoir. The collected water is usually clean and can be used as recovery water. The direct use of solar still is the desalination of seawater. However, it provides a low yield [3] and requires strong sunlight [5-6]. These limitations are not of concern in our case because the proposed solar still is for treating brine water from a small desalination in a village.

2. Material and Methods

2.1 Study area

The study area is Ban Nong Krathiam Tai, located in Tambol Nong Bua Takiat, Dan Kun Thot District, Nakhon Ratchasima (Figure 1). The village comprises 139 households with a population of 625 as of July 2020 [7]. Approximately 96 percent of the household in Dan Kun Thot District are farmers (Dan Kun Thot District Agriculture Office, n.d.). Almost all villagers are farmers. Rice, sugar cane, and cassava are the main crops commonly grown in the area. However, a large area in Tambol Nong Bua Takiet has a high salt level in the soil, as classified by the Department of Land Development.

2.2 Description of the small-scale desalination system in Dan Kun Thot District

The small-scale desalination system was installed at a water treatment plant as a research prototype by the Department of Water Resources in 2022. This plant uses raw water from a nearby pond, storing surface water from Lam Chiang Krai. Surface water is transported via an electric pump and sent into the process of removing turbidity in surface water with conventional water treatment. The final product is clear water, which is disinfected with a chlorine solution before being pumped to a water tower ready for service.

Figure 1 Location of the study area in Ban Nong Krathiam Tai, Dan Kun Thot District, Nakhon Ratchasima. The star symbol represents the village water treatment plant installing the small-scale desalination system.

However, the treated water has high salinity during the dry season due to less dilution of fresh water, causing complaints and discomfort because of the high salinity in the water supply. The Department of Water Resourcesplanned and tested an alternative system to remove salt molecules, which is the small-scale desalination system. The system is capable of removing salt content in the water supply at the rate of at least 6 m^3/day. Currently, it is used as an axillary system to partially dilute treating water during the dry season and operated about 2 hours daily. The actual volume of brine water was stored in a 2000L tank waiting for recovery. Water samples were taken from the tank for the experiments.

The small-scale desalination system only caters to a limited portion of the village's water supply. The system utilizes a reverse osmosis process to remove the salt content from the water at a capacity of 6 m^3 per day. As a result, it is unable to meet the water demand for the entire village. However, it serves as a research prototype for the Department of Water Resources to explore the potential for water recovery in Nakhon Ratchasima. The small-scale desalination consists of three main components: pre-treatment of hardness with ion exchange, high-pressure pump, and membrane (Figure 2).

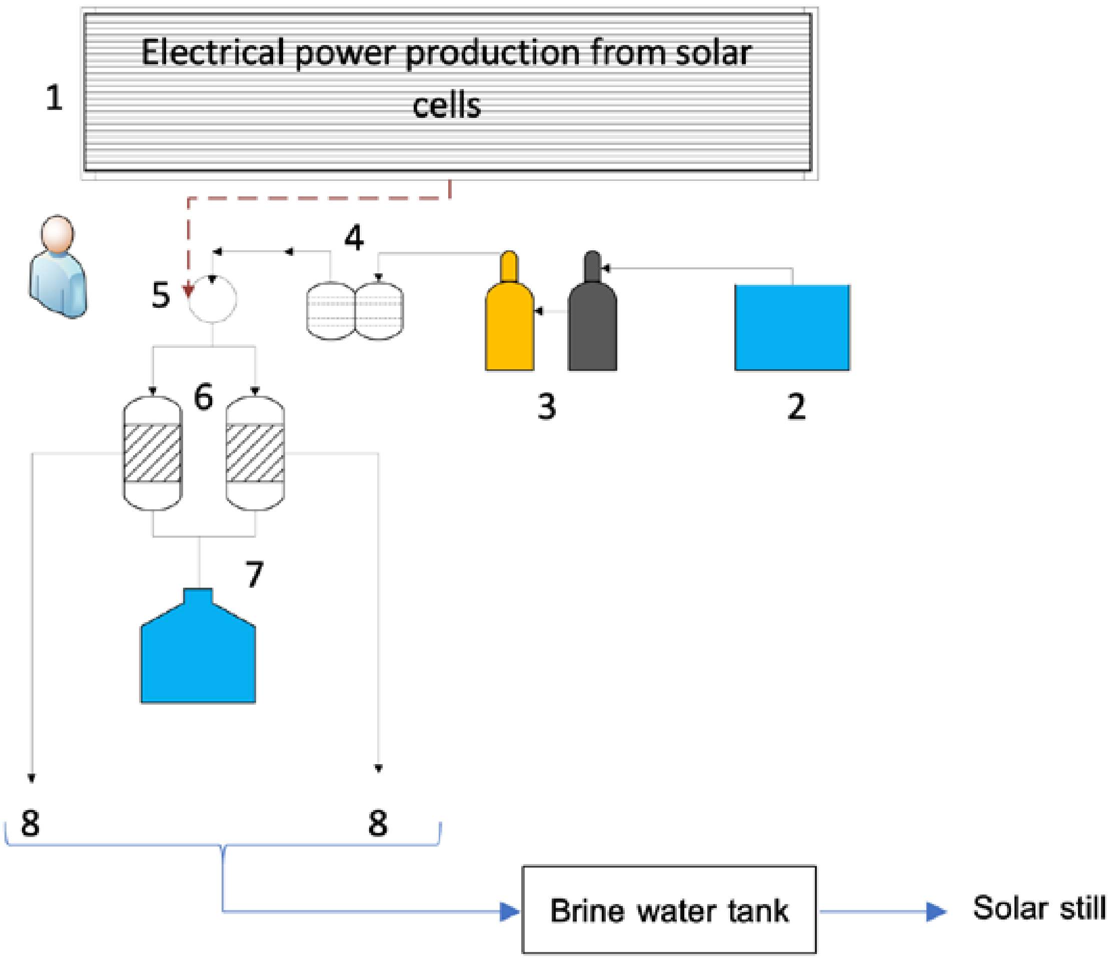

Figure 2 Schematic diagram of the small-scale desalination at Ban Nong Krathiam Tai, Dan Kun Thot District, Nakhon Ratchasima: 1 is the energy production from the solar panels, 2 is the water storage tank from clean village water supply, 3 is the pre-treatment, 4 is the dual filter, 5 is the high-pressure pump, 6 is the membrane housing units, 7 is the treated water storage tank, and 8 is the discharge of brine water.

The village water supply is pre-treated to remove residue chlorine in the pre-treatment tanks, and the dual filter removes suspended solids before entering the membrane. The system applies pressure to the feed water, forcing it through the membrane to separate the salt and other impurities from the water. The brine water, which contains concentrated salt and other byproducts, is the primary concern regarding its treatment and disposal. To evaluate water recovery, the solar still was evaluated (Figure 3).

2.3 The design of the prototype solar still

The design of the solar still was based on parameters recommended by literature [8-11] and local conditions. The body is similar to a rectangular shape but cut diagonally in half to form a slope for transparent glass. The solar still has 1.0 m in width, 1.0 m in depth, and 0.5 m in height (Figure 3). The surface area for brine water storage is 1 m^2, and the water level is set at 0.06 m. The total storage of water is 60 liters. The slope of the transparent glass is 25 degrees. Details are in Table 1 and Figures 4.

2.4 Evaluation of water recovery and treatment of brine water of the solar still

A prototype solar still was built by the Department of Water Resources according to the proposed design. The evaluation of water recovery and treatment of brine water was carried out using brine water collected from the discharge of the small-scale desalination in Dan Kun Thot District.

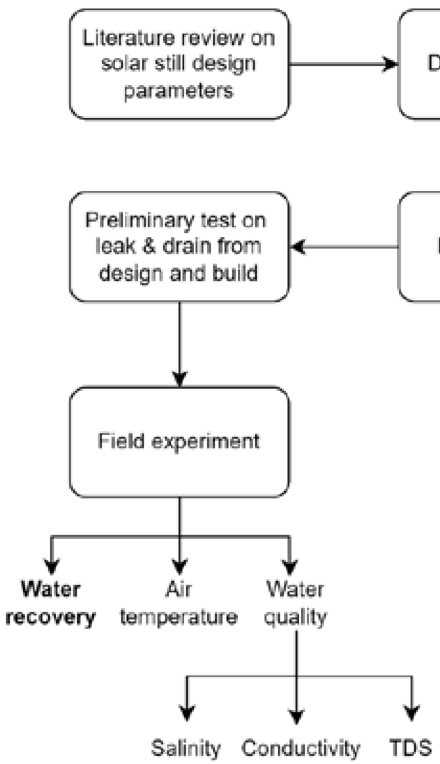

Figure 3 Steps in research on water recovery from the small-scale desalination

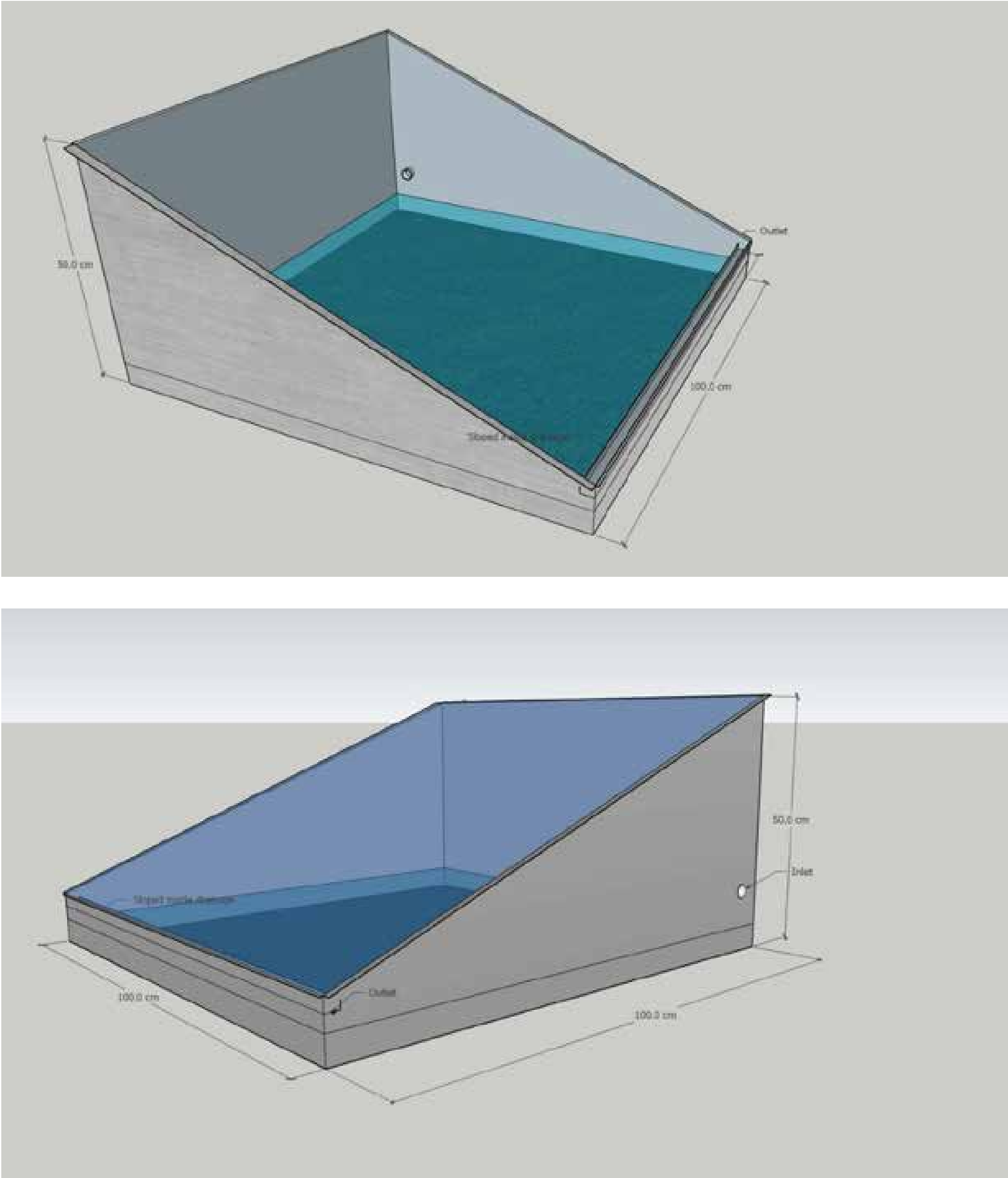

Figure 4 Drawing design of prototype solar still for water recovery and treatment of brine water: inside configuration without glass cover (top); carbonized rice hulls in dark color submerged in brine water (light color); drain channel at the lower end, outside configuration with glass cover (bottom)

Table 1 Parameters used in the design of a solar still for water recovery and treatment of brine water from small-scale desalination in Nakhon Ratchasima

Design parameters	Design values
Width x Depth x Height	1 m x 1 m x 0.5 m
The surface area of distillation	1 m^2
Height of brine water basin	0.06 m
Total brine water volume	60 L
The slope of the transparent glass cover	25 degrees
Thickness of the transparent glass cover	0.5 cm
Heat-absorbing material	Carbonized black rice husk granules (0.02 m in depth)
Height of heat-absorbing material	2 cm
Material of construction	Aluminum

Water salinity, conductivity, and total dissolved solids (TDS) were measured from the brine water and recovery water using water quality sensors (YSI Pro30 and ProDSS, YSI Inc., OH, USA). The temperature inside the solar still was measured by a thermometer.

Recovery water from the solar still was hourly collected via silicone tubing for every experiment. The experiment was repeated 10 times. An electronic balance was used to weight the water volume (ENTRIS 423i-1S, Sartorius Lab Instruments, GmbH, Goettingen, Germany). Water quality was performed when the volume of recovery water reached 300 ml. Standard solutions were used to calibrate the instrument according to protocol recommended by the manufacturer (YSI Inc., OH, USA).

3. Results and discussion

3.1 Performance of the solar still design on water recovery

The solar still design with a 25-degree slope of the transparent glass allowed the water vapor to condense on the glass surface and helped prevent the formed water droplet from moving downward without dripping back into the brine water basin. The slope is sufficient for the prototype to perform three functions: heat trap, condensation surface, and water droplet formation. The surface area of 1 m^2 exposed brine water to sunlight, which was large enough to recover water from brine water discharged of the small-scale desalination used in the village. With a 0.06 m height of brine water level, the recovery capacity was 60 L in each batch. The prototype held temperatures inside the chamber between 27.9 and 71.4 Celsius during the rainy and early winter months. High temperatures inside the chamber accelerated evaporation of water from the brine water.

Using carbonized rice hulls was an excellent material to facilitate the absorption of solar radiation inside the solar still. It has a dark color that is good for heat absorption, stable, cheap, and ubiquitous. The carbonized rice hull did not become waste after use because it can be mixed with soil or diluted with rice hulls and used as a soil amendment in the areas [12]. The estimated cost to build a solar still was about 2,128 Baht, excluding labor. About 92 percent were the cost of a sheet of stainless steel and glass cover.

3.2 Water recovery from brine water treatment of the solar still

A solar still prototype was built and tested by the Department of Water Resources in Nakhon Ratchasima. Two testing periods were between the rainy season in August and September and the early winter months in October and November 2023 (Figure 5).

Figure 5 The prototype solar still was tested for water recovery and treatment of brine water from a small-scale desalination. Digital thermometer was placed inside (arrow).

Recovery water volume was collected and measured. The highest water recovery occurred at 2 PM in rainy and early winter months (Figure 6), as high as 71.4 Celsius, coinciding with a higher 2.2 mL water recovery during this afternoon hour. A similar pattern of temperature levels inside the solar still was observed in both periods, low at night and early morning. However, lower temperatures occurred in the rainy season due to cloudy and occasional rain.

The total volume of distilled water ranged from 1014–1185 mL/day during the rainy and early winter months. Lower daily water recovery occurred in the rainy season, or about 170 mL less. However, the distilled water from solar still in other studies was higher in other literature, with maximum of 3070 mL/day [10,13-15].

Temperature is clearly a factor of water recovery in the prototype solar still experiment. The relationship between distilled water and temperatures was relatively strong in rainy and early winter months, with the r^2 of 0.84–0.87 (Figures 7 and 8). The prototype solar still could remove brine water and produce distilled water at the rate of 1.0 mL/hour on average under the temperature ranges found during the experiment. However, if the prototype could keep a higher temperature inside the chamber, the water removal rate would be faster. Thus, the design should focus on conditions that can sustain high temperatures. Using trapped heat inside a closed chamber is a treatment method for brine water and is capable of recovering the water for further use.

3.3 Characteristic of recovery water

Brine water from a desalination process is known to have high total dissolved solids (TDS) and conductivity [8]. This project measured both water parameters from brine water discharged from the small-scale desalination and compared it with the recovery water collected from the prototype solar still. Water salinity was also measured because it is the focus of water treatment and recovery in this project. The conductivity of brine water ranged from 3921 to 4518 μS/cm and TDS between 2295 and 2711 mg/L. Salinity in brine water ranged from 1.9 to 2.1 ppt.

Recovery water collected from the prototype solar still was measured in the same manner, and the results showed that lower concentrations of all three parameters were observed in both seasons (Figures 9 and 10). Conductivity was between 4.3 and 5.2 μS/cm (99% reduction), while TDS remained low at 3.1 to 4.3 mg/L (99% reduction). Salinity was not detected. These numbers were lower than the limits set by the Royal Irrigation Department's discharges into the irrigation water, conductivity less than 2000 μS/cm for conductivity, and less than 1300 mg/L for TDS [16]. Tap water usually has conductivity between 500 and 800 μS/cm [17]. The recovery water was formed from the condensation process using heat energy trapped inside the solar still chamber.

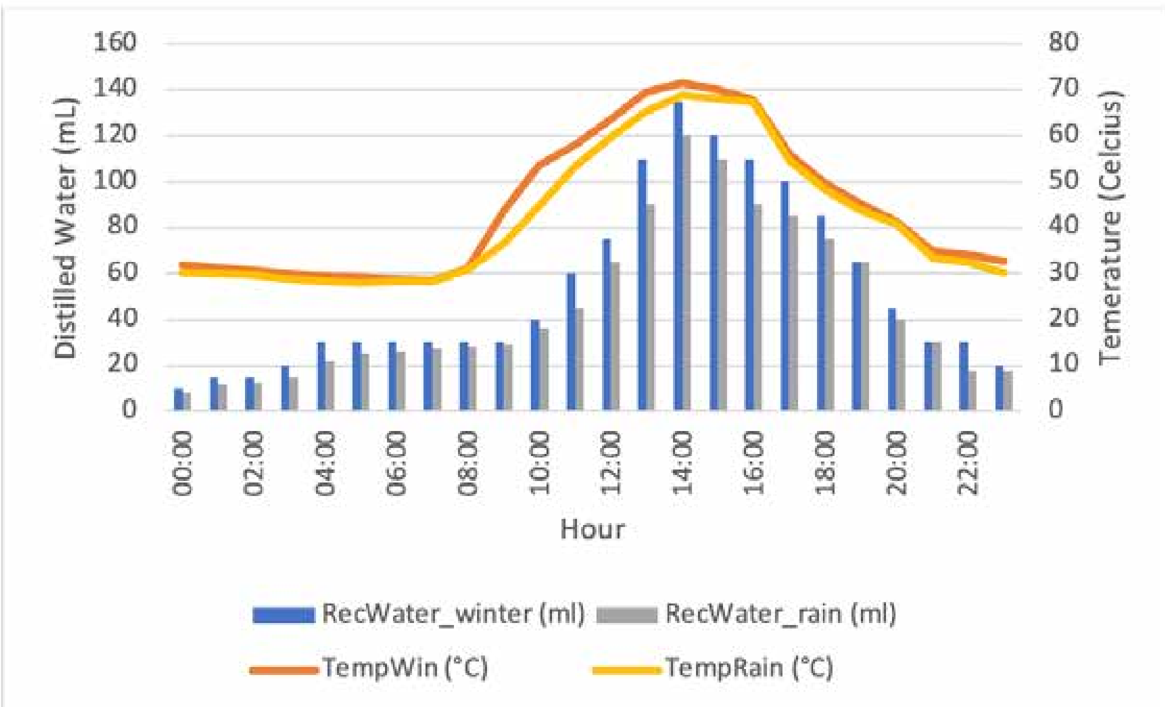

Figure 6 Hourly temperatures (Celsius) inside the solar still and water recovery as distilled water (mL) during rainy and early winter months in Nakhon Ratchasima.

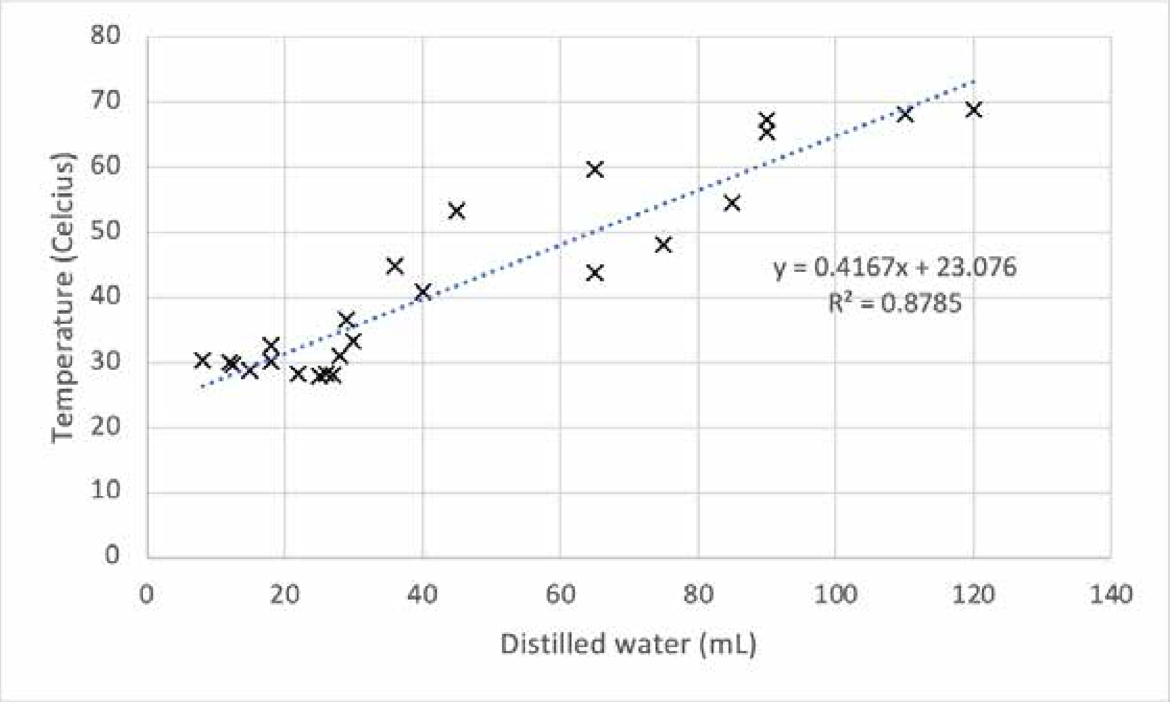

Figure 7 Temperatures inside the chamber of the solar still and distilled water produced in rainy months.

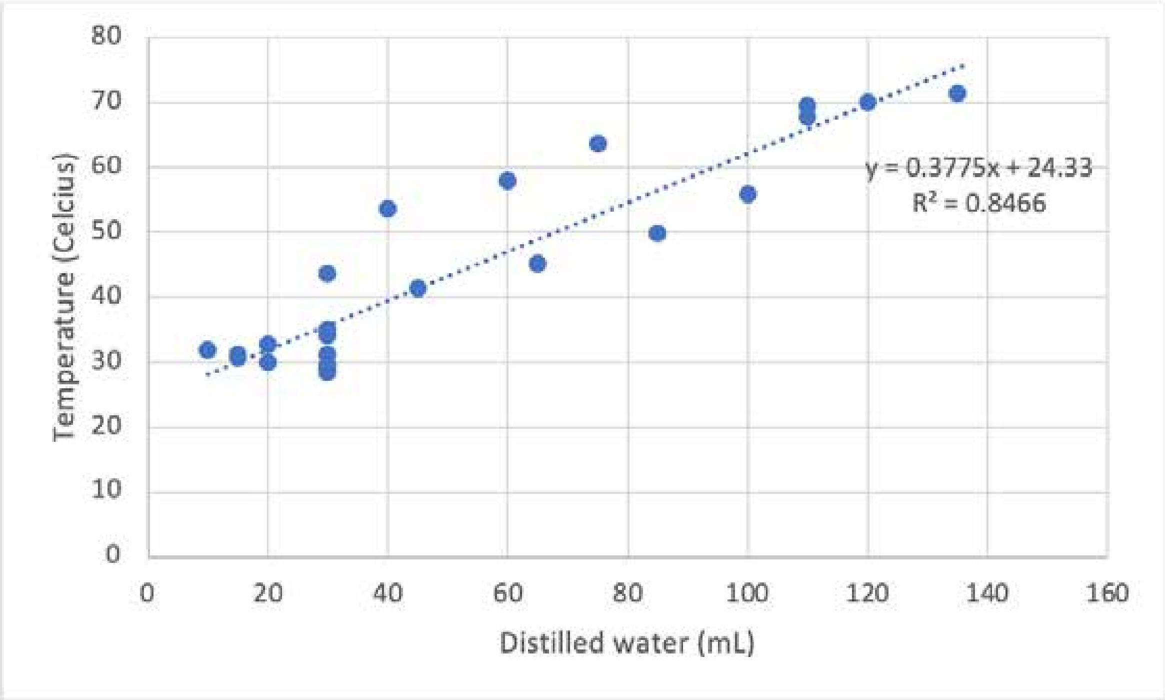

Figure 8 Temperatures inside the chamber of the solar still and distilled water produced in the early winter months.

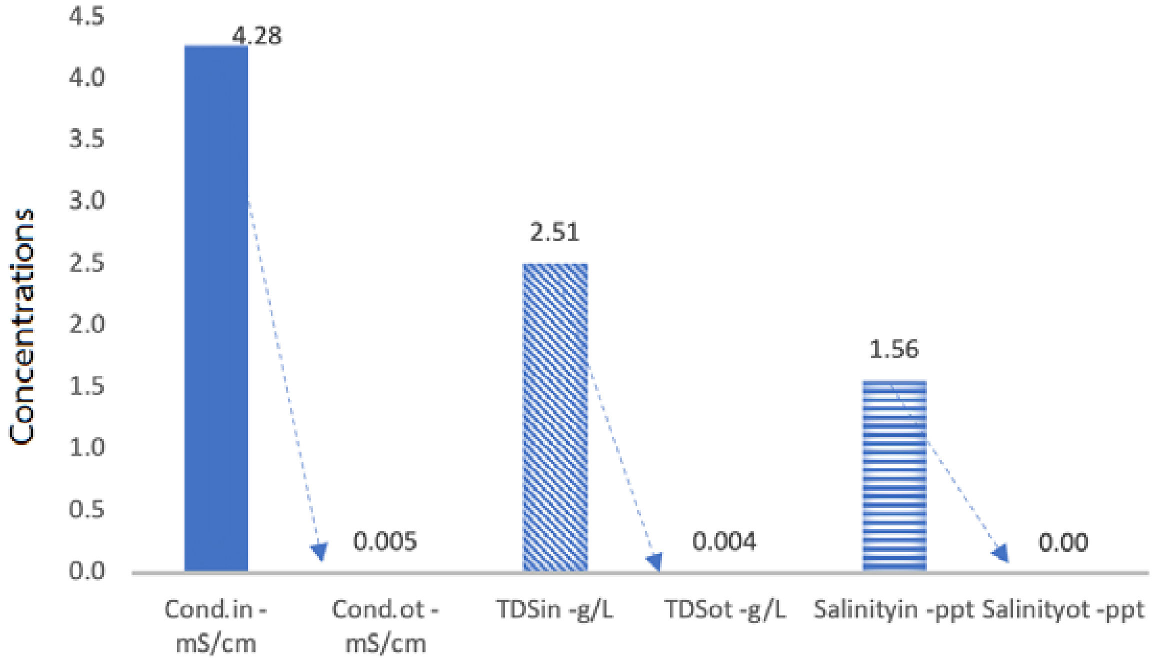

Figure 9 Conductivity (mS/cm), TDS (g/L) and salinity (ppt) of brine water (in) and recovery water (ot) during early winter months. Units were adjusted to reduce the effect of large differences in numbers.

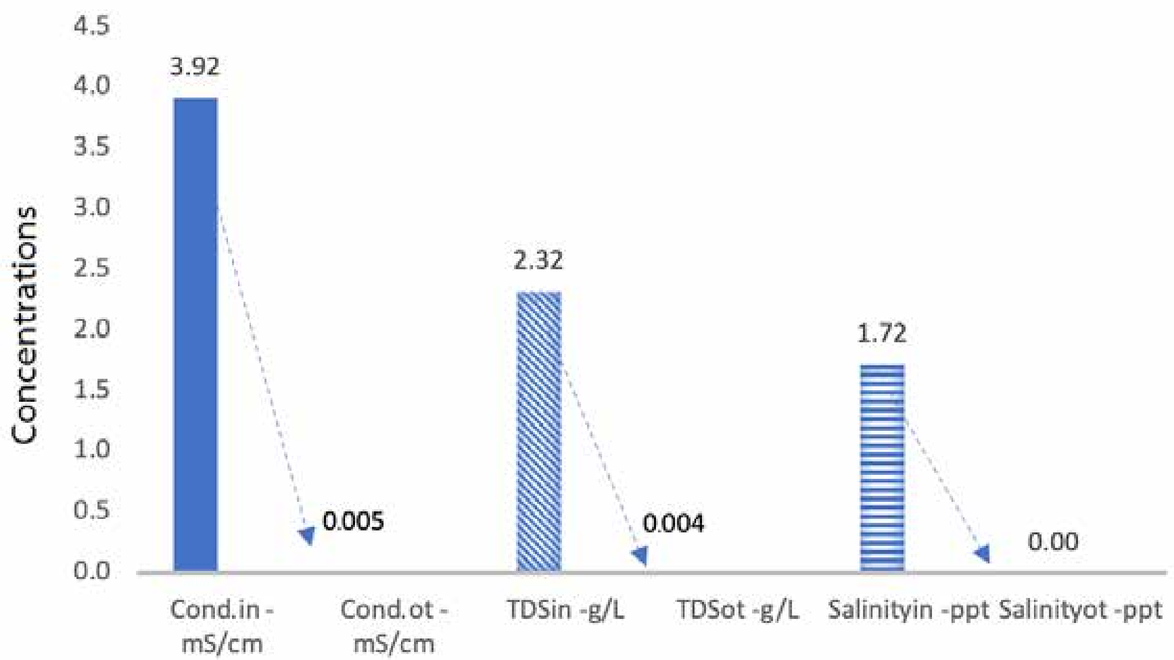

Figure 10 Conductivity (mS/cm), TDS (g/L) and salinity (ppt) of brine water (in) and recovery water (ot) during early rainy months. Units were adjusted to reduce the effect of large differences in numbers.

4. Conclusions

The design of a prototype solar still was used and evaluated water recovery and treatment of brine water discharged from a small-scale desalination in Ban Nong Kratiam Tai, Dan Kun Thot District, Nakhon Ratchasima. The prototype can recover water as a product and treat the brine water as well. The slope of 25 degrees was enough to prevent water formed on the glass surface from reentering the brine water container. At the same time, the water was able to flow down along the glass surface and collected in a draining channel as clean water. The prototype has a surface area of 1 m^2 and is capable of water recovery at 1014–1185 mL/day in rainy and early winter months. Based on these numbers, our calculations on water recovery were 12–20 days if a set of five solar stills was used as a batch of 60 L of brine water during these months. The highest temperature inside the chamber reached 70.1 Celsius, and 22 mL was the maximum water recovery at 2 PM. Maintaining high temperatures inside the solar still chamber are the main factors in water recovery as well as treatment.

The carbonized rice hull was suitable as a substrate inside the solar still as heat-absorbing material. It is also a very economical way of utilizing agricultural waste in this experiment because it is available locally, does not degrade over four months under brine water, and is biologically inert. for safe disposal in the area. Salt remaining in carbonized rice hulls may be of concern, but the study area already has widespread natural deposits of salts. Dilution with soil or rice hulls before disposal in soils may be possible. Future analysis of salts may provide insight information for extraction of valuable trace elements if there is enough sodium or lithium within salts. Recovery water had low conductivity and TDS, while water salinity was not detected because the water was the product of the condensation process inside the solar still. The results suggested that the prototype solar still was capable of water recovery and treatment of brine water discharged from the small-scale desalination. However, the rate of water recovery and treatment was less than those reported in the literature. This issue could be improved by adding a series of the solar still to recover and treat the brine water at the same time, testing a new design of the chamber size and slope for better heat accumulation, and painting the chamber with black.

This research estimated the low end of water recovery to estimate reasonable yields during rainy and early winter months in Nakhon Ratchasima. Further long-term tests during summer months may provide a higher rate of water recovery due to strong solar radiation. Replacing the small-scale desalination with a large-scale array of solar still would be very challenging to accomplish due to slow recovery or production of water to meet the demand in the village. Solar still should co-exist and work in tandem in the area with high salinity soil like Dan Kun Thot District. All the future improvements are important for keeping high temperatures in the solar still. With a limited option of disposal of brine water on land or water in the area, this research finds that the solar still is a decent method for water recovery and treatment of brine water from the small-scale desalination used in Dan Kun Thot District, Nakhon Ratchasima.

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