CHAPTER 1

Introduction

1.1 Background and Problem Statement

According to the Worldwatch Institute [1], fresh water shortages could be one of the biggest challenges for more than two-thirds of the world's population by 2025. This means that countries which are not facing the risk of water shortages presently, will still require to tackle the problem in time to come. Even though water seemly is abundant in our planet, the majority of all water sources is not desirable for human consumption as it contains too much amount of salt and harmful organisms. In fact, there is only a trivial one percent of fresh water which can be found in rivers, lakes and underground water reservoirs. Furthermore, these sources are not easily accessible in every part on earth.

Since natural sources of fresh water can only meet limited demands, the use of water treatment can hardly be overstressed. Geographically speaking, sea water constitutes two thirds of the entire earth's surface. Hence, it makes logical sense that desalination technology should be developed and used in the production of potable water. Recently, several separation processes (thermal and membrane processes) have been developed in order to produce freshwater from sea water. The main obstacle of these technologies is that they consume large quantities of energy [2] which are not available in some regions such as coastal areas, islands or other remote areas from electrical grid.

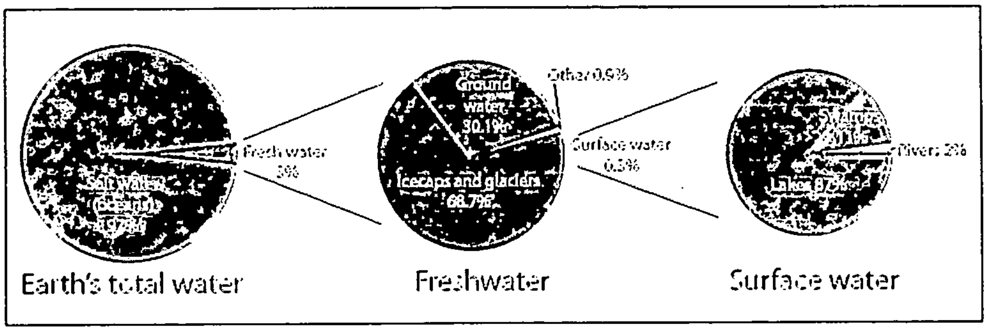

Figure 1.1 Earth's water distribution [2].

Renewable energy sources must be considered in order to solve the problem of high energy consumption. Considerable attention has been recently given to the use of solar energy as a heat source for desalination, especially in the regions which lack sufficient electrical power. The use of solar thermal energy can not only reduce fossil fuel consumption, but also be a limitless resource which generates low emissions. There are many designs of solar applications for either low or high temperature generation. However, the drawbacks of solar energy are a relatively low productivity rate and low thermal efficiency [3].

Some technologies have been developed such as the bubble pump technique which can be used to accelerate water evaporation as shown in Figure 1.2. It uses thermal energy as a replacement for mechanical energy to cause the change of the fluid position. Fluid volume increases after reserving the heat then the generated bubbles cause the upward movement of the fluid in a column. The salt solution is heated in a small quantity so that the evaporation process can be accelerated. The benefits of this system are the increased speed of evaporation without electricity requirement and it doesn't have moving part thus the process could be operated simply.

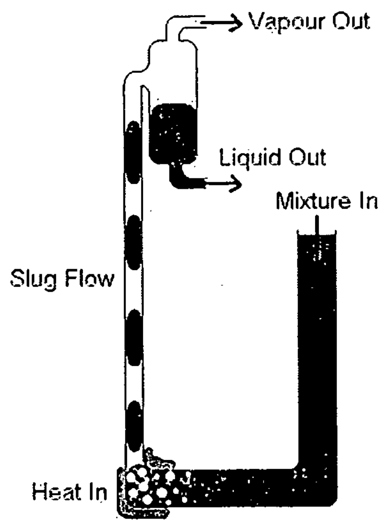

Figure 1.2 Schematic diagram of bubble pump technique [4].

This study introduces a desalination system with the use of the bubble pump technique to increase the speed of evaporation, using solar collector as a heat source. The parameters affecting the performance of the system as well as the unit cost of the distilled water are considered.

1.2 Literature Review

1.2.1 Desalination Technologies

Several separation processes have been developed in order to produce freshwater from sea water. Most of these processes are functioned based on the principle that water and salts do not separate spontaneously but need some external energy to force the separation process. Figure 1.3 shows the most common classification of these processes is based on the type of separation process adopted: thermal and membrane processes.

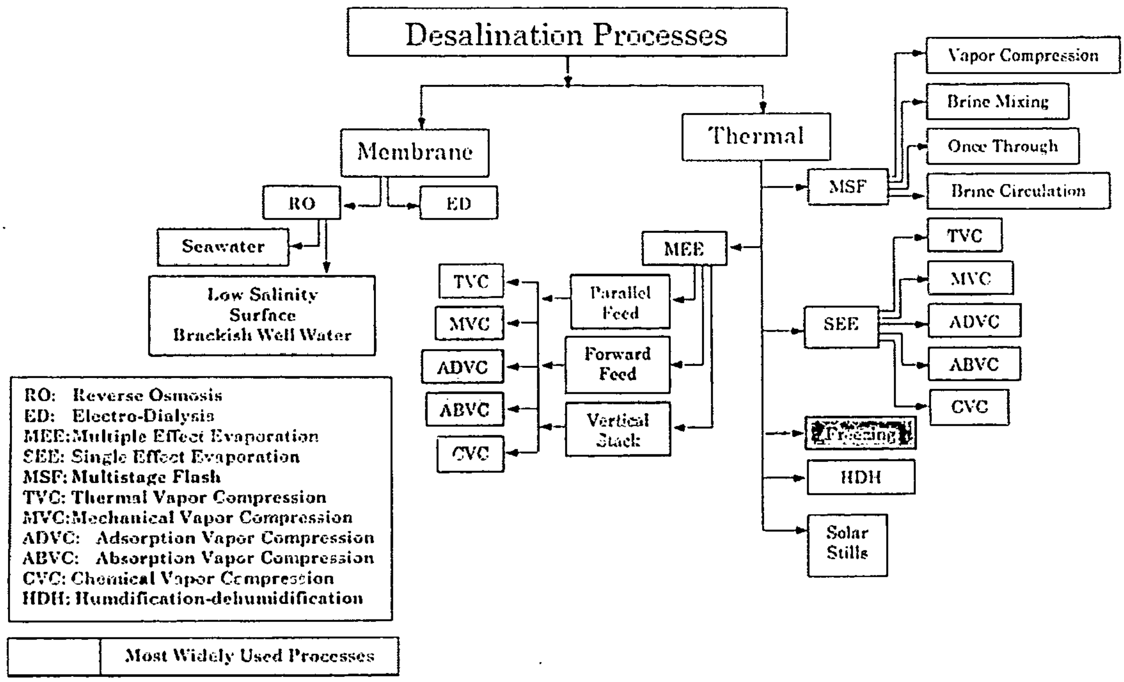

Figure 1.3 Thermal and membrane desalination processes [5].

The membranes for the desalination group contain Reverse Osmosis (RO) and Electro dialysis (ED) which are challenging for small scale demands. Even though it requires a lesser amount of energy to process salt water than by the thermal desalination group but RO plants are equipped with many machines which require lots of skilled labors to control. ED is often used only to produce high quality water as it consumes high electricity. Therefore, membrane processes through RO and ED might not be financially feasible for most countries suffering from water scarcities. For the main thermal desalination processes, these include multi-stage flash desalination (MSF), multiple-effect distillation (MED), and mechanical vapor compression (MVC). MSF and MED systems are commonly built in cogeneration plants where power and water are produced all together, while the MVC system is functioned solely by electrical power. They require a large amount of energy, around 10-15 kWh/m^3 [2], which makes it uneconomical to be a standalone plant.

In summary, the discussion has shown that both thermal and membrane processes are not feasible for some countries where small scale demands are needed due to high energy consumption. Thus, solar energy as a heat source for desalination may be another solution.

1.2.2 Solar Energy Applications for Distillation

One of the leading practices used in the distillation of sea water is solar heat. Malik [6] proven that the developments in the use of solar energy is ideally suited for desalination when the demand of fresh water is not too large. An application of this technique was the design of Mehta [7] as viewed in Figure 1.4. The designed model with dimensions of 30 cm in height, 65 cm in length and 125 cm in breath could distill 1.5 liters of fresh water from 14 liters of dirty water within 6 hours. The study also found that the efficiency of the unit was 64.37%.

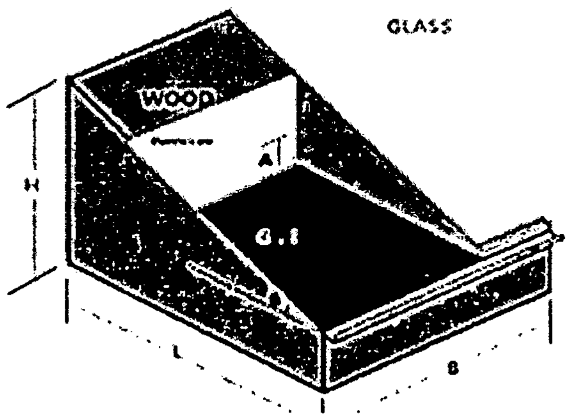

Figure 1.4 Designed model of solar distillation system [7].

The study of Niyomvas [8] was also involved in solar desalination performance. The model had a square wave tray with dimensions of 0.6 m × 0.6 m × 0.047 m. The study intended to compare the performance of the system with and without flat plate reflectors within 6 hours per day between 9:00 am – 3:00 pm. The system with flat plate reflectors could produce fresh water in a rate of 0.398 l/m^2/h, while that without flat plate reflector could get the yield with a rate of 0.305 l/m^2/h.

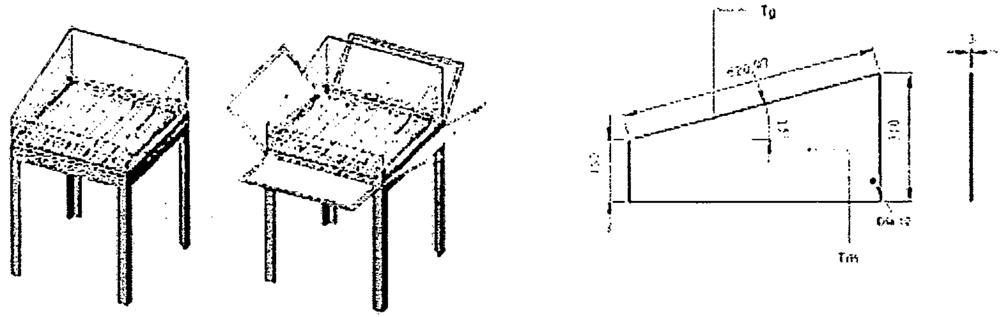

Figure 1.5 Solar distiller with flat-plate reflection [8].

These literatures showed that the use of solar energy had a low productivity rate about 2 liters per square meter per day. Therefore, improving the productivity rate is needed and in this study a bubble pump technique is applied.

1.2.3 Bubble Pump Application for Distillation

Many researches are interested in the use of bubble pump to accelerate evaporation of a solution. Most recent literatures were studied on ethanol distillation by the technique of bubble pump. Sompherk [9] designed a unit using bubble pump technique to distill ethanol as shown in Figure 1.6.

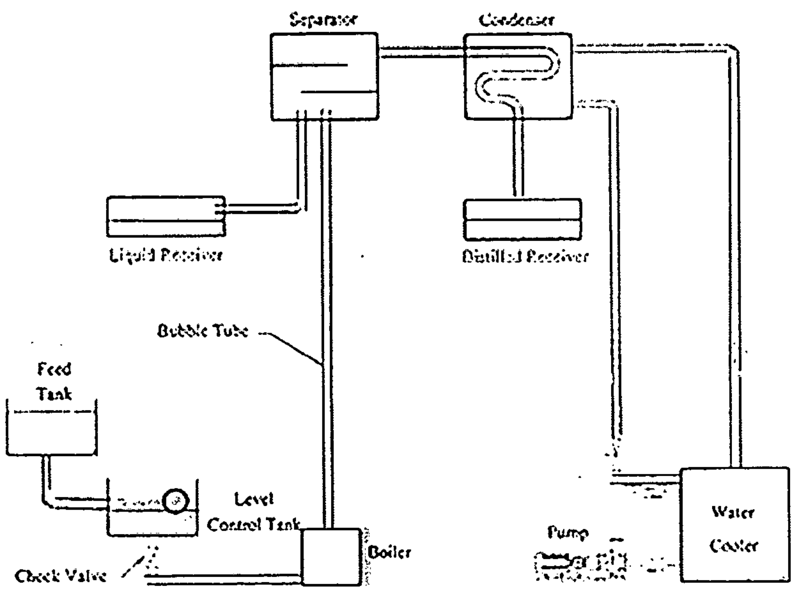

Figure 1.6 Thermal distillation by bubble pump [9].

The study aimed to investigate the parameters affecting the flow rate of the product of ethanol and its concentration, and estimate the product cost. The study also found that the flow rate and the concentration of ethanol strongly depended on inner diameter of the bubble tube, height of the bubble tube and electrical power supply. The production costs from 2.57 to 4.94 Baht/liter.

Similarly, Jittayasothon [10] correlated three parameters including initial concentration, level of solution in the evaporator and the overall heat transfer areas which affected the amount of distilled ethanol and its concentration (Figure 1.7). The testing was conducted by two distillers with different heat transfer areas of 8.35 and 3.2 m^2.

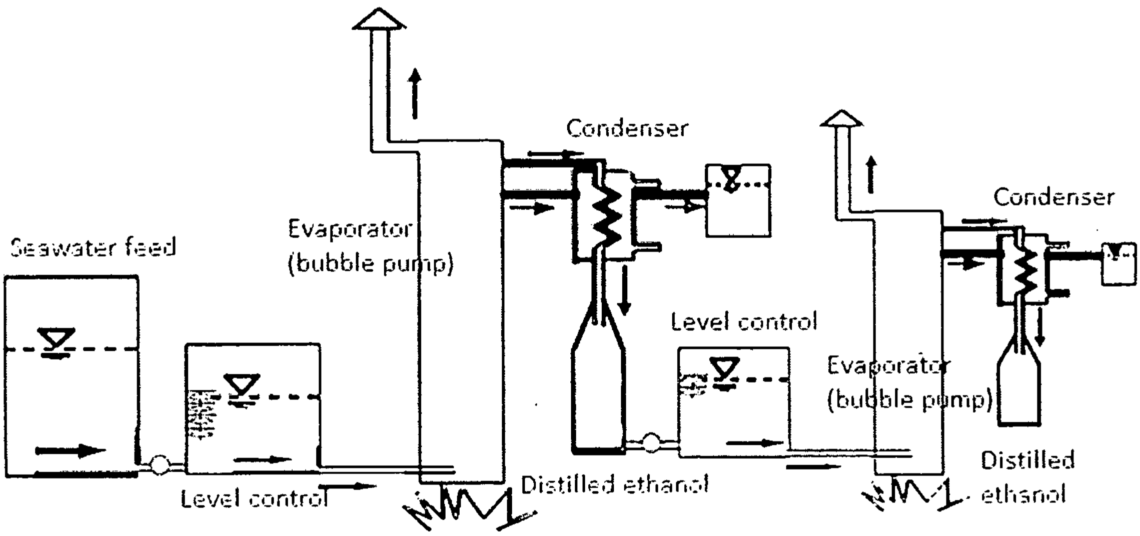

Figure 1.7 Two stages thermal distillation by bubble pump [10].

From the testing data, the correlations of the related parameters were established as:

$$\dot{m}_d = 40.328X_i^{0.12486}\left(\frac{H}{H_i}\right)^{0.74167}\left(\frac{UA}{UA_{ref}}\right)^{0.76742},$$

$$X_d = 1.6831X_i^{0.5283}\left(\frac{H}{H_i}\right)^{0.34046}\left(\frac{UA}{UA_{ref}}\right)^{-0.08947}.$$

The difference of the calculated data and the experimental results were within ±12%.

A similar concept-designed system was used by Rakhorn [11] on three kinds of fermented ethanol from rice, molasses and pineapple. LPG was used as a heat source. The objective was to compare the concentration of ethanol from these agricultural crops and find out the one that provided highest yield.

As the result, the product from molasses gave the highest concentration of ethanol (65.67% by volume) after proceeded with the bubble pump technique.

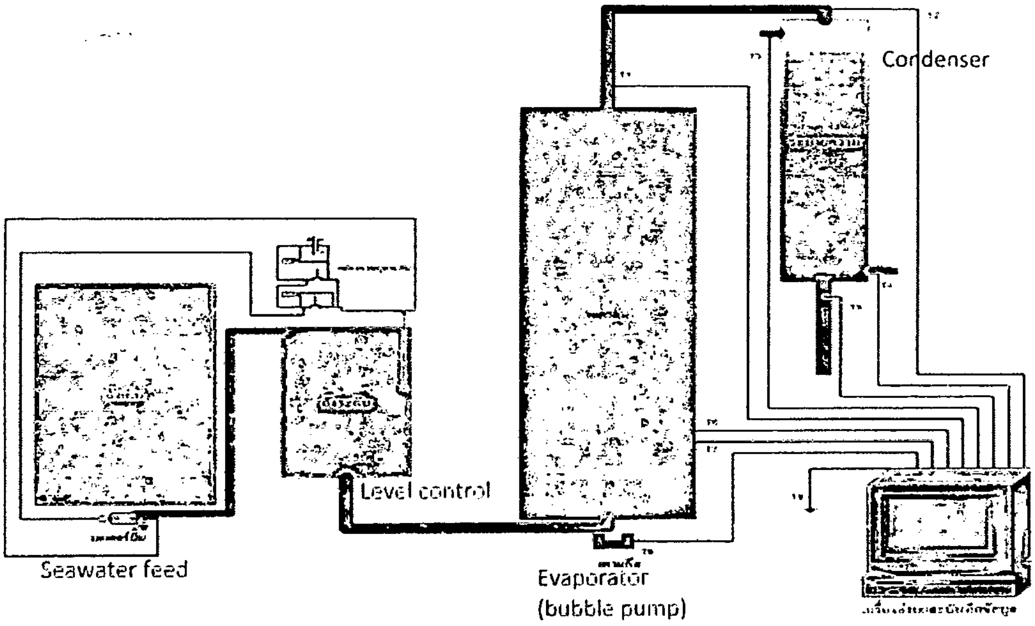

Figure 1.8 Application of thermal distillation by bubble pump [11].

Malawonno [12] applied bubble pump technique with a solar collector as a heat source. The study used three different types of solar collector performing in the same condition of the solar radiation, the ambient temperature, the amount or level of solution in solar collector and the alcohol concentration of the feed solution. These three types were:

- Type A – a single glazed vertical finned-and-tube flat plate collector
- Type B – a single glazed flat finned-and-tube flat plate collector (selective surface), and
- Type C – a double glazed flat finned-and-tube flat plate collector.

The objective was to find the best one in terms of the product cost.

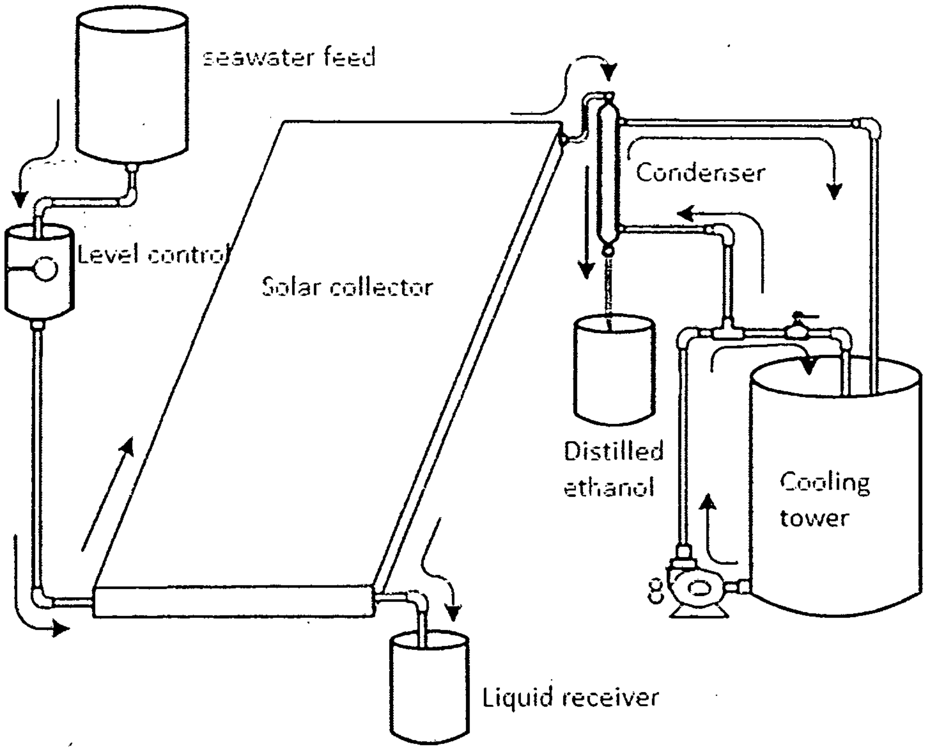

Figure 1.9 Bubble pump technique for solar distillation [12].

Based on these literatures, the bubble pump technique has been applied mostly for ethanol distillation. However, there is very little literature about the technique for sea water distillation. In this study, the concept of the bubble pump technique was applied for desalination.

1.3 Objectives

1.3.1 To investigate the parameters affecting the performance of the solar seawater desalination such as the reservoir level of the bubble tube, the initial concentration and heat supplied by the collector.

1.3.2 To develop a model to simulate the system behavior.

1.3.3 To estimate the unit cost of distilled water.

1.4 Expecting Benefit

1.4.1 The testing system can be used as a testing rig for training students or those interested in such technology.

1.4.2 The concept can lead to a prototype design for providing hygienic potable water from sea water for small needs in households or communities.

1.5 Scope of Study

1.5.1 Salt contents of water were 3%, 3.5%, and 4% by weight.

1.5.2 The experiment was done at a laboratory scale under Chiang Mai climatic condition.

1.5.3 Heat source came from an solar collector with thermal characteristics of the area = $2.8\ m^2$, $F_R(\tau\alpha)_e = 0.51$ and $F_R U_L = 3.42\ W/m^2.K$