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THE HONG KONG
POLYTECHNIC UNIVERSITY
香港理工大學

Department of Applied Physics

Final Year Project Report

Project Title

**Desalination by Solar Vapor Generation using
Black Polyvinyl Alcohol**

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Abstract

The sun and sea water are huge pools of resources, which the radiation energy and water content can be used for daily life. The water usage in Hong Kong is huge, and the expenses for the government to buy water is therefore in significant concern. The feasibility of using PVA cloth and solar vapor generation on desalination had been investigate in this project by simulating the evaporation process, which can be a low cost and clean way to obtain drinking water. This project shows the use of blackened PVA cloth in solar vapor generation, which the evaporation rate had been improved to 2.24 times of the natural evaporation rate of water. For salt water at salinity of 28%, which is a saturated solution of NaCl, the evaporation rate had been improved to 3.88 times of the natural evaporation rate under one sun.



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Chapter 1 Introduction

1.1 Water source in Hong Kong

In Hong Kong, there are only three reservoir for rainfall, with a lack of natural lake, which cannot supply all the needs of Hong Kong residents. To acquire enough water, the Hong Kong government buys water from Guangdong using about 4 billion HKD each year, as a main source of water [1]. Although the seawater is already being used for toilet flushing, the water volume needed is over 900 million each year for Hong Kong people [1]. Since Hong Kong is a coastal city, seawater can be acquired easily, desalination from seawater can be useful for increasing the source of water.

Desalination is a technique used to extract the water content from salt water. By using the huge source of seawater nearby, Hong Kong people can easily acquire water for daily use. By the mean of solar vapor generation, desalination can be achieved with higher efficiency than natural evaporation, and hopefully lower cost than other desalination methods, such as reverse osmosis [1]. Also, solar vapor generation is a passive device, which uses the solar energy as the source, instead of electricity. This is a sustainable method of obtaining clean water. In places without easy access to clean water, such as desert, solar vapor generation can be a passive device to transform muddy water to clean water.



1.2 Characteristics of Polyvinyl Alcohol (PVA) cloth

PVA is originally a water-soluble polymer from polymerization of vinyl alcohol. However, after fabricated into a cloth, it is no longer soluble, but still, its hydrophilic property remains, which makes it a potential absorbent for solar vapor generation, which need an absorber layer to perform the operation.

1.3 Objectives

The main objectives of this project includes:

- (1) Finding suitable absorbent for the solar vapor generation process in seawater desalination
- (2) Optimize the solar vapor generation effect of PVA for seawater desalination

1.4 Organization of report

In Chapter 2, literature review over the previous researches about solar vapor generation will be done. It includes the introduction to the theory about solar vapor generation and materials used, such as nanoparticles, sponges, and papers. A brief comparison among the different absorbent will be shown, which enhances the selection of material for absorbent fabrication.

In Chapter 3, the fabrication process of the absorbents, floating support, and salt water will be shown. This part will show the detailed steps to produce the samples,



including the materials and the formulation of salt water used.

In Chapter 4, the experimental setup and experiment procedures will be shown.

The components of experimental setup will be described in detail with figures

provided. For experiment procedures, the detailed steps will be given.

In Chapter 5, the result over the fabrication processes and experiments in Chapter 3 and Chapter 4 will be shown respectively, including the performance of the processes and the result of solar vapor generation simulation.

In Chapter 6, discussions over the concerns of, difficulties of, and future recommendations for the fabrication and experiments will be shown. Including the selection of methods, possible errors, and possible improvements.

In Chapter 7, a conclusion will be given. This part will briefly summarize the results and concerns of this project.



Chapter 2 Literature Review

2.1 Solar vapor generation

The idea of solar vapor generation had been introduced by many materials, including nanoparticles [2-4], plasmonic nanoshells [5], carbon nanotubes [6], thin films [7], sponges [8], and many other possible absorbents. This technique utilizes the energy from the radiation of the sun, to generate water vapors faster than natural evaporation. Since a water molecule at the water surface can escape the bulk content once it has gained enough energy, under sunlight, the molecule can absorb the radiation, and gain energy faster than that from the air, so a faster evaporation rate can be achieved [9].

Solar energy is one of the sustainable energy that can be acquired, which is a trend of the Earth's future, due to the fact the nonrenewable energy will be completely consumed eventually [9]. Therefore, this technique can possibly open up a path to utilize the solar energy and increase the sustainability of the Earth.

2.2 Heat localization

In solar vapor generation, as mentioned in Section 2.1, the energy absorbed by the water surface molecules is in great concern. By applying the concept of heat localization, the efficiency of the solar vapor generation process can be improved



greatly [10-13]. The improvement is resulted from the localization of internal energy received from the radiation, which means that the energy received from the radiation is localized at the water surface level, and being prevented from transferring to the bulk water volume:

- i. The energy received by the water content on the surface level, where is the area that evaporation can take place of. This can ensure that the energy received is used for evaporation process, which is the purpose of the device, instead of heating up the bulk water volume, which is considered to be an energy loss.
- ii. The energy transferred downward will be reduced greatly with the setup as shown in FIGURE 2.1. This is done by using a heat insulating layer inserted between the bulk water volume and the absorber layer, where the evaporation takes place.

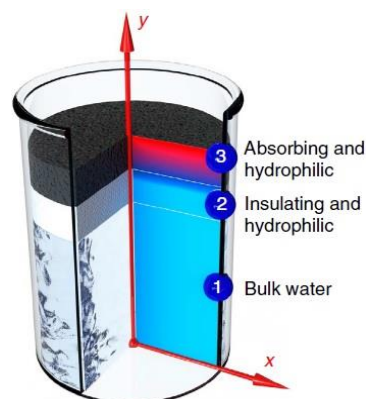


FIGURE 2.1 Layers of materials in beaker [10]



Therefore, the heat localization effect can help to reduce the heat loss to the surroundings. For example, when the bulk water volume is heated up by the energy flows downward, the heat energy will eventually lose to the air surrounding the beaker. In practical use in desalination, the bulk water content may be the sea, which means that the heat energy flowing downward is completely not usable.

2.3 Hydrophilic materials as water absorbent

A continuous solar vapor generation needs a sustainable supply of water content from the bulk volume, which means that the evaporating area itself needs to be able to absorb water, so that evaporation can take place continuously. Therefore, in theory, any absorbent can be testified for solar vapor generation purpose. Some materials, such as sponges can be both absorber and heat insulator, so only one layer is needed in the configuration, which is convenient. In contrast, some materials such as PVA cloth is not convenient, because itself cannot float on water, which needs a floating support for solar vapor generation, making a challenge in this project.

2.4 Desalination using solar vapor generation

Desalination utilizes the huge water content in the sea, to provide drinkable water for people. Combining this purpose with the sustainable solar energy, a sustainable method of drinkable water production can hopefully be obtained [10-13].



Chapter 3 Fabrication Procedures

3.1 PVA blackening by black markers

3.1.1 Markers under test

1. Water based marker
2. Oil based marker
3. Alcohol based marker

3.1.2 Application of markers on PVA clothes

The markers were applied on the PVA clothes for different number of times, including 1 time, 5 times, and 15 times on 3 lines respectively.

3.1.3 Condition of PVA cloth and drying process

After application of markers, the clothes were dried by different process:

1. Dry cloth then dried naturally
2. Dry cloth then dried by heater
3. Wet cloth then dried naturally
4. Wet cloth then dried by heater

3.1.4 Washing after drying

After drying the clothes, they undergo tap water washing for 5 minutes by hands, which ensures that the excessed or loosely painted ink is washed away



3.2 PVA blackening by cloth dye

3.2.1 Materials

1. PVA cloth (50g) of any colors
2. Dye powder (10g)
3. Table salt (NaCl) (50g)
4. Warm water (1200mL) at 40°C

3.2.2 Procedures

1. Wash the PVA cloth to ensure that it is clean and wet.
2. Put on gloves and mix the dye powder into the warm water.
3. Add table salt into the mixture and stir the mixture thoroughly.
4. Immerse the wet PVA cloth into the mixture and stir for 15 minutes.
5. Let it sit for 10 minutes, then stir again for 1 minute.
6. Repeat step 5 for 5 times.
7. Take out the dyed cloth and wash gently with clean water.
8. Wash the dyed cloth with warm soap water repeatedly, until clean soap water is resulted.



3.3 PVA adhesion on polystyrene for floating purpose

3.3.1 Materials:

1. Absorbent samples
2. Polystyrene foam
3. Heat adhesives

3.3.2 Procedures:

1. Clip 1 yellow PVA cloth and 3 polystyrene foam to fit the cylindrical shape of the beaker, as shown in FIGURE 3.1(a).
2. Adhere the 3 layers of polystyrene foam into a 3-layer cylinder by heat adhesive, as shown in FIGURE 3.1(b).
3. Adhere the absorbent sample onto the 3-layer polystyrene foam by heat adhesive.
4. Repeat Steps 1-3 by replacing yellow PVA cloth with different absorbent samples.



3.1(a)



3.1(b)

FIGURE 3.1 (a) Clipped dyed PVA cloth for adhesion; **(b)** adhered 3 layers polystyrene.

3.4 Preparation of Salt Water

3.4.1 Material:

1. Salt (NaCl)
2. Tap water

3.4.2 Procedures:

1. Weight around 150mL of tap water, and let the mass be x grams
2. Calculate the amount of NaCl y grams needed by the Equation (1):

$$y = \frac{x}{(1 - n)} - x = x\left(\frac{n}{1 - n}\right) \quad (1)$$

where n is the salinity, then add it to the water content and stir

thoroughly.



Chapter 4 Experimental Setup and Experiment Procedures

There were 4 experiments conducted, including emission spectrum measurement for light source, absorption spectrum measurement for water and salt water, light output power measurement, and simulated solar vapor generation.

4.1 Emission spectrums measurement for light source

4.1.1 Components (as shown in FIGURE 4.1(a-c)):

1. Light source under test
2. Software, Ocean Spectra Suite, installed in computer, to translate the optical signal to numerical data
3. Spectrometer with data cable and optical fiber
4. White paper



4.1(a)



4.1(b)



4.1(c)

FIGURE 4.1 (a) JV Tech Fiber Spectrometer; (b) Optical Fiber; (c) Data cable.



4.1.2 Procedures:

1. Point the optical fiber to the measurement position. If the counts is too high, where an overload occurs, as shown in FIGURE 4.1(d), point the fiber further away from the center of the source, until no overload occurs.
2. Hold the fiber pointing position, and pause the software, then the fiber can be put down.
3. Save the spectrum data.
4. Repeat Steps 1-3 for light sources reflected by a white paper and scattered through a white paper.

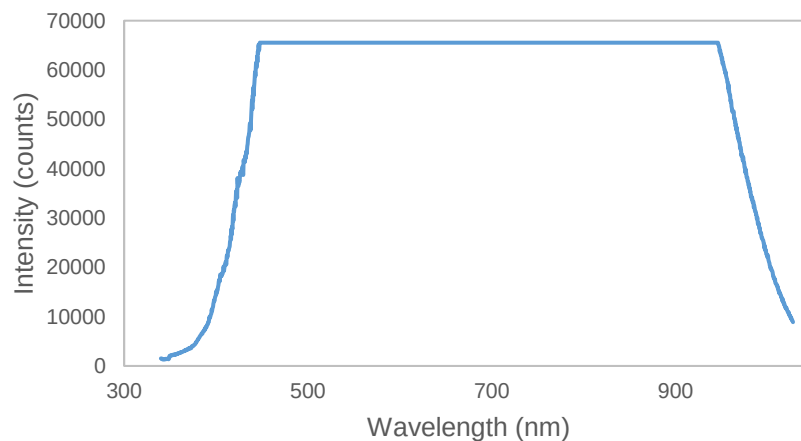


FIGURE 4.1(d) Emission spectrum of High Pressure Mercury Lamp, obtained by direct detection



4.2 Absorption spectrums measurement

There are two sets of baseline material and material under test in this experiment, with the same set of procedures:

- i. By using air as baseline, measure the absorbance of tap water.
- ii. By using tap water as baseline, measure the absorbance of salt water with salinities of 3.5% and 10.5% respectively.

4.2.1 Components:

1. SHIMADZU UV-2550, which emit ultraviolet light through liquid sample then measure the reduction in intensity of light to analyze the absorption of a particular wavelength. It needs to acquire a baseline information as a reference, to measure the reduction in intensity of the light.
2. Salt water with different NaCl concentration, including salinity of 3.5% and 10.5% respectively prepared in Section 3.4.
3. Tap water



FIGURE 4.2 SHIMADZU UV-2550.

4.2.2 Procedures:

1. Turn on the SHIMADZU UV-2550, and wait for configuration for around 5-10 minutes.
2. Clean 2 cuvettes by distilled water and alcohol alternatively for 3 times.
3. After the machine is ready, put the 2 cuvettes both with baseline material into the scanning chamber, then scan the baseline information in wavelength range of 400nm to 800nm.
4. Replace the baseline material in 1 cuvette by the material under test, and scan for the absorbance information of the material under test in wavelength range of 400nm to 800nm.
5. Save the absorbance information graph.

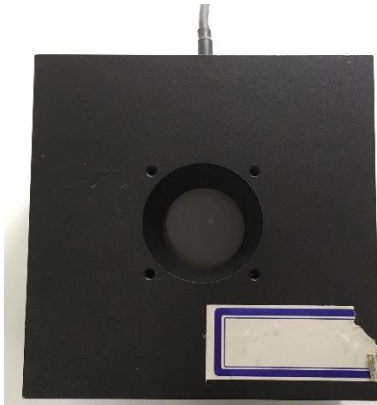


6. Repeat Steps 2-6 by for different baseline material and material under test, or Steps 4-6 for same baseline material and different material under test.

4.3 Positioning of light source and beaker

4.3.1 Components:

1. Light source under test
2. Optical power meter
3. Light sensor



4.3(a)



4.3(b)

FIGURE 4.3 (a) Light Sensor; (b) Optical power meter.



4.3.2 Procedures:

1. Power on the optical power meter, and configure the central wavelength to 635nm.
2. Set zero for the background light source.
3. Turn on the light source under test for 10 minutes to warm up.
4. Elevate the light sensor, until the level of the sensor is the same as the opening of the beaker.
5. Adjust the height of the light source under test, or the light sensor together with the beaker, so that the sensor and the beaker opening levels are always the same, until the reading of the optical power meter is around 0.49087W. By assuming that the light intensity of one sun is 1000Wm^{-2} , the equivalent reading of one sun intensity, P_{eq} on the optical power meter can be calculated by Equation (2):

$$P_{eq} = 1000A = 1000\pi\left(\frac{25\text{mm}}{2}\right)^2 \quad (2)$$

where A is the area of light sensor, which has a diameter of 25mm.

6. Mark the positions of the light source under test and the beaker for future use.



4.4 Simulation of Solar Vapor Generation

4.4.1 Components:

1. Light source to simulate sunlight
2. Absorbent adhered on polystyrene, prepared in Section 3.3.
3. OHAUS weight
4. Thermometer and hygrometer
5. Beaker (50mL)
6. Tap water
7. Salt water with salinity of 3.5% and 10.5% respectively prepared in Section 3.4.

4.4.2 Procedures:

If the experiment is done for tap water without absorbent, omit Step3-4.

1. Put the light source at the position marked in Section 4.3, then turn on the light source to warm up for 10 minutes. Go to Step 2a for tap water experiment, or Step 2b for salt water experiment.
2. (a) Clean the beaker and fill it fully with tap water, and make sure that the water level is at the beaker opening.

(b) Clean the beaker and dry its inner surfaces by tissue, then fill it



fully with salt water, and make sure that the water level is at the beaker opening.

3. This step must be taken place in the sink. Put the absorbent sample into the beaker slowly, with the flat surface parallel to the beaker's opening, until the level of the flat surface is at the level of the beaker opening.
4. Spill away the water covering the edges of the absorbent sample.
5. Remove any water droplet on the beaker surfaces by tissue. Including the curved inner surface at the opening.
6. Weight the sample set.
7. Mark the sample set weight, room temperature, and humidity.
8. Put the sample set at the position marked in Section 4.3, and let it sit for 1 hour.
9. Weight and mark the weight of the sample set again.
10. Repeat Steps 2-9 by using other absorbent samples.



4.5 Simulation of liquid exchange between PVA cloth and bulk water volume

4.5.1 Components:

1. PVA cloth sample
2. NaCl water at salinity 14% and 28%
3. Beaker with tap water
4. White paper with black horizontal lines spaced by 3-5mm

4.5.2 Procedures:

1. Immerse the PVA cloth sample into NaCl water at salinity 14%. Ensure the absorption of NaCl water by pressing the PVA cloth several times.
2. Put the sample on the water surface in the beaker, with the bulk water at salinity 14%.
3. Put the white paper with black lines at the back of the beaker, and observe the liquid flow in front of the beaker.
4. Repeat from Steps 1 by NaCl water at salinity 28% and bulk water remain at salinity 14%.
5. Put 3g of NaCl crystal on top of the cloth sample.
6. Let the materials sit for 24 hours and observe the change in the NaCl crystal.



Chapter 5 Results

5.1 Blackening performance by black markers on PVA cloth

A brief testing result is shown in TABLE 5.1.

TABLE 5.1 Comparison of blackening performance of different markers

Marker Types	Water resistance	Resulting effect	Markers' appearances
Water based	Low	Worst	
Alcohol based	Medium	Medium	
Oil based	Highest	Best	

Among the three markers tested, the oil based marker gives the best water resistance, and the remaining color after washing for 5 minutes.

For the different ways of painting and drying condition, the results are very similar, which give the best result by painting the cloth when it is wet. The results are the same for “dried naturally” and “dried by heater”. In FIGURE 5.1(a-c), the samples prepared by using alcohol based marker are shown for reference. In FIGURE 5.2(a-c), the samples prepared by “Wet cloth then dried by heater” are shown for comparison between the effects of difference types of markers.

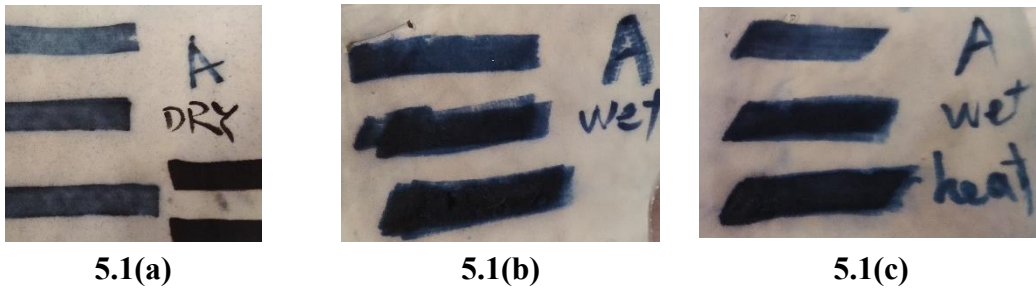


FIGURE 5.1 PVA clothes painted by alcohol based marker and undergo process (a) “Dry cloth then dried by heater”; (b) “Wet cloth then dried naturally”; (c) “Wet cloth then dried by heater”

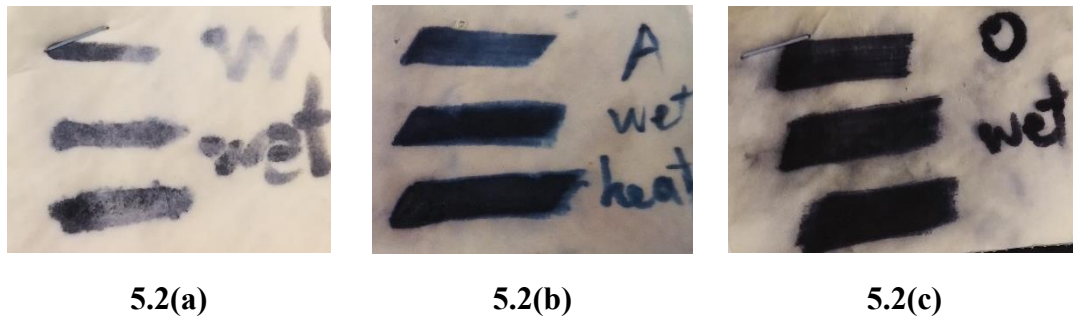


FIGURE 5.2 PVA clothes underwent process “Wet cloth then dried by heater” and painted by (a) water based marker; (b) alcohol based marker; (c) oil based marker

5.2 Blackening performance by cloth dye on PVA cloth

The appearing color of the dyed clothes is good, which is still black after washing with soap water. However, by observing the dye powder itself, dark blue is resulted by dissolving a small amount of dye powder in water, which means that the radiation absorption of the black color dye may still miss some wavelengths range.



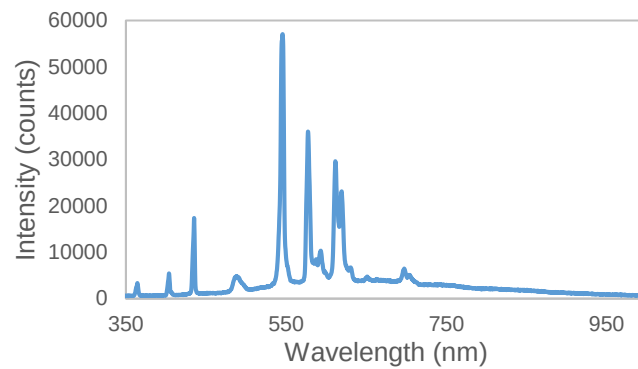
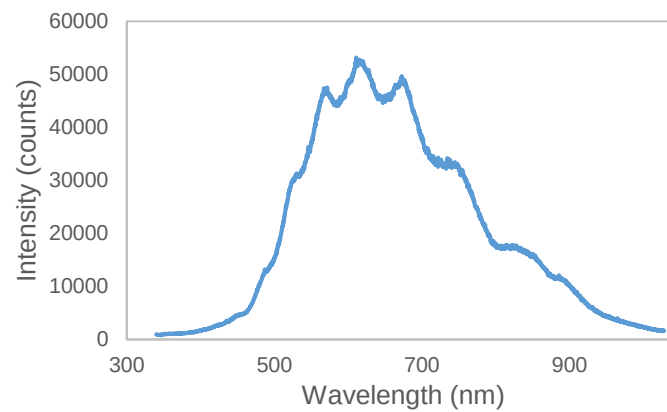
5.3(a)



5.3(b)

FIGURE 5.3 (a) Aged PVA cloth blackened by dye powder; (b) Dissolved dye powder

5.3 Emission spectrum of light sources


FIGURE 5.4 Emission spectrum of High Pressure Mercury Lamp, obtained by inclined angle of fiber

FIGURE 5.5 Emission spectrum of 230V Halogen Lamp, obtained by inclined angle of fiber



5.4 Absorption spectrum of water and salt (NaCl) water

No observable values in the absorbance graphs. For both of the experiments, in the scanned 400nm-800nm wavelength range, the graphs are almost straight horizontal lines, meaning that there is no absorption relative to the baseline material.

5.5 Positioning of light source and beaker

The light source used in this experiment is the 230V Halogen Lamp, after analyzing the spectrum characteristic. A detailed discussion on the selection of light source will be given in Section 6.4.

When the reading of the light sensor is 0.491, the height of the light bulb was 276mm above the desktop, and 186mm above the water surface.

5.6 Evaporation rate performance

5.6.1 Tap water evaporation rate

The experiment is conducted in an air-conditioned laboratory, which maintains the temperature at 21-24°C, and humidity at 60-66%. Therefore, the effect from the difference in temperature and humidity is negligible in these experiments.

**TABLE 5.2** Evaporation rate of Tap Water using different absorbing materials

Absorbent	Initial mass (g)	Final mass (g)	Diameter of irradiated surface (mm)	Evaporation rate ($\text{kg m}^{-2} \text{h}^{-1}$)
None	109.471	108.745	40	0.58
Sponge from mask	88.300	86.848	40	1.2
Pale yellow PVA	109.066	108.189	40	0.70
PVA painted by oil based marker	96.001	94.685	36	1.3
Black dyed PVA	98.950	97.796	38	1.0
Black dyed and aged PVA	95.602	94.384	37	1.1

5.6.2 NaCl water evaporation rate

TABLE 5.3 Evaporation rate of NaCl Water with different percentage by mass

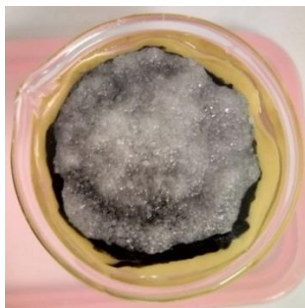
Absorbent	NaCl % by mass	Initial mass (g)	Final mass (g)	Evaporation rate ($\text{kg m}^{-2} \text{h}^{-1}$)
None	3.5%	111.589	110.774	0.65
	28%	122.041	121.645	0.32
PVA painted by oil based marker	3.5%	99.124	97.796	1.3
	14%	104.100	102.778	1.3
	28%	108.982	107.736	1.2

5.7 Liquid exchange between PVA cloth and bulk water volume

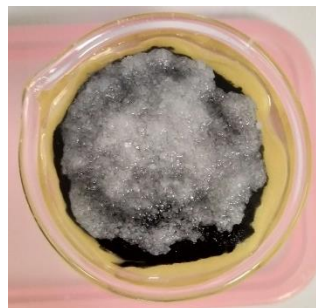
The evidence of liquid flow can be observed by the diffracted straight lines, as shown in FIGURE 5.6, pointed out by red marks.



FIGURE 5.6 Solution exchange between PVA cloth and bulk water



5.7(a)



5.7(b)



5.7(c)

FIGURE 5.7 Salt layer dissolve observation (a) started; (b) after 1 hour; (c) after 24 hours



Chapter 6 Discussions and Future Recommendation

6.1 Density of PVA

The density of PVA is 1.91 to 1.31 gcm^{-3} , which is high than that of pure water at 1 gcm^{-3} , which means that it will sink in pure water. This is similar to that in salt water, which has a slightly different density, and still lower than that of PVA.

Therefore, to make the PVA cloth to flow on top of water surface for the solar vapor generation process, a floating support must be given. In this project, the floating support selected is polystyrene foam, which has a density of 0.91 gcm^{-3} .

6.2 Blackening of PVA cloth

The PVA clothes used in this project were yellow and blue originally, which are poor radiation absorber, resulted from the reflection of the radiations in a wide range of wavelengths. They were therefore been blackened to improve the radiation absorption, which transfer energy to and evaporate the water at a higher efficiency than pale blue and pale yellow appearance.

In the blackening processes, the toxicity of materials used is being concerned. Since the water evaporated in solar vapor generation is intended to use as drink water, if there is toxic content transferred from the blackening materials to the water content evaporated, the device will fail to meet the purpose. However, in this project, the



detailed composition of the evaporated droplets had not been analyzed, which is a drawback of the project design.

6.3 Simulation of aging for PVA cloth

The pale yellow one was new and had not been used before the experiment and the pale blue one had been aged for 14 months by wetting and drying processes each day. This process is believed to be able to simulate the condition of the PVA clothes after a prolonged period of use for solar vapor generation, since the PVA cloth under sunlight needs to transfer water molecules continuously, with the surface layer undergoes drying continuously. However, this simple wetting and drying process cannot simulate two important factors under practical solar vapor generation process, including the change in temperature, and the aging after dyeing.

The pale blue PVA cloth underwent aging process under room temperature, which means that the temperature difference experienced by the cloth was not as high as that from solar vapor generation. The temperature differences can roughly be compared in TABLE 6.1.

TABLE 6.1 Comparison of practical and simulated aging

Process	Highest temperature occurs	Lowest temperature occurs
Solar vapor generation	Noon	Night
Simulated aging	Room temperature	Air conditioned



When undergoing the simulated aging process, the pale blue PVA cloth had not been dyed yet. This can possibly affect the estimation of the aging effect on the solar vapor generation ability, because the structure of the cloth affects its property, and this structure can be changed in both the aging process and dyeing process. Therefore, an ideal aging process should be taken place after dyeing process, to simulate the practical condition. Still, another cloth can be aged before dyeing, because the effect of the changes in structure in these processes may help to increase the performance.

6.4 Emission and absorption spectrum

The emission spectrum of the light source affects the energy given from the light source at the specific wavelengths. At the same time, the absorption spectrum of the substance affects the efficiency of radiation energy absorption at specific wavelength. To give a high efficiency of energy transfer from the light source to the absorber, a high portion of overlap of emission and absorption spectrums is needed. By analyzing the spectrum, the efficiency could hopefully be estimated. However, the absorption spectrum of water and salt water has no observable difference, and the water absorption spectrum is not observable too. This can be predicted by observing the sample directly. Since thin layers of water and salt are both transparent, they do not absorb most of the visible light. The non-observable absorption spectrum means that



the estimation of absorption efficiency cannot be done in this project.

In Section 4.1, the experiment was done by pointing the optical fiber to the desire position, to measure the spectrum of the source. Since the light power was too high for the spectrometer to measure, 3 methods were used to obtain readable data:

- i. Pointing the optical fiber to the light source with inclination, instead of directly to the center of the source.
- ii. A white paper was used to reflect the light, which should give almost the same spectrum in visible light wavelength range. The optical fiber obtain the light information by the reflection of light source by the white paper.
- iii. A white paper can be used to scatter the light, which should also give almost the same spectrum in visible light wavelength range. The optical fiber obtain the light information by the scattering of light source by the white paper.

Beside the reduction effect on the counts read, the white paper can help to reduce the effect from non-uniform light at different direction from the light source. A more uniform reflected or scattered light can help to give a more stable reading on the graph.



6.5 Light source selection

There were 2 light sources used, one was a high pressure mercury lamp, and the other one was a 230V halogen lamp.

The halogen lamp was selected over the high pressure mercury lamp because the spectrum and stability of the halogen lamp is better. By reading the results from Section 5.3, and compare it with the emission spectrum of the sun in FIGURE 6.1, the spectrum of the halogen lamp matches with the sun much better. The 230V halogen lamp produces a spectrum with peak wavelength at 610.96nm, close to 635nm, a black body radiation approximation for the sun. In contrast, the high pressure mercury lamp has 4 sharp peaks in visible light range in its spectrum to produce the resulted white light, instead of a spectrum of a black body radiation observed from the sun. This result means that the use of the 230V halogen lamp can be a better simulation to the sunlight.

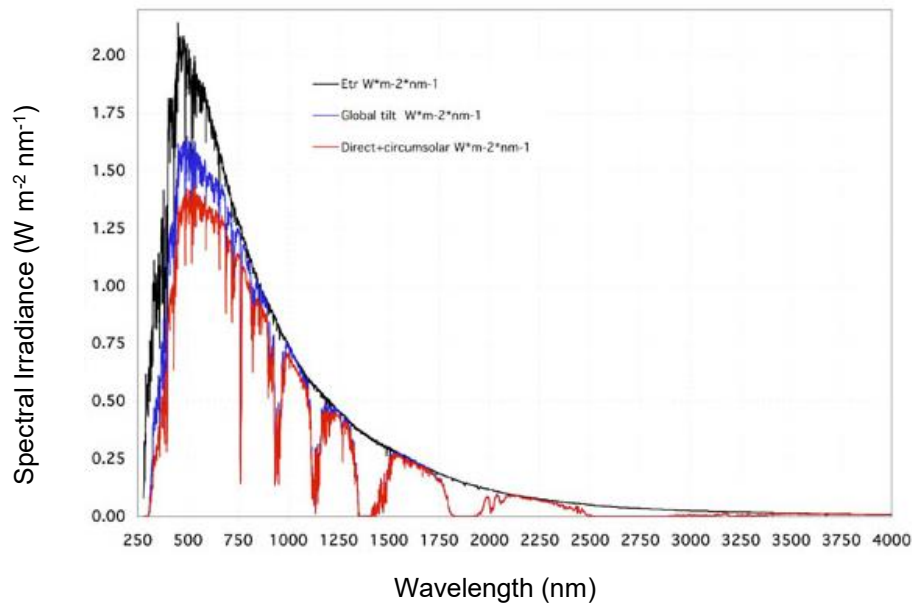


FIGURE 6.1 Emission spectrum of the sun [14]

The idea of buying the 230V halogen lamp from the market is that the lamp was designed for the reptiles living indoor as pets, which also need sunlight to maintain their health. Therefore, the lamp should have a good spectrum, as presented in Section 5.3, which benefits the simulation in this project. In addition, for any material or components selection, it is suggested to think of similar purposes of the components. For light source selection, it is convenient to use light sources which are designed to match the spectrum of the sun, such as halogen lamps for reptiles, and the lamps for color matching purposes in textiles industries. This will save a great amount of time for the light source finding and selection, and also resulting a high performance.



6.6 Positioning of light source and beaker

The optical power intensity of sunlight in practical use for solar vapor generation is around 1000Wm^{-2} , which is the optical power of one sun under opencast sky. In this project, a simulation of practical use of the device under one sun is needed, so the relative position of the light source and beaker being concerned, which affect the optical power intensity received by the absorbent surface. Therefore, in Section 4.3, the positioning of the experimental setup is marked and fixed, to give an effect of one sun on the absorbent sample. However, in the experiment in Section 4.3, the reading of the optical power meter changed very rapidly, which means that the relative position of the components will be in great concern. Since the setup is too sensitive to the positions, and devices cannot be put at exactly the same positions for each experiment, this will be an easily occurring human error. The use of a uniform light source and a set of position fixed experimental setup is greatly encouraged, to improve the stability and reliability of the experiments conducted.



6.7 Evaporation rate performance

As presented in Section 5.6, the performance of the dyed and aged pale blue PVA cloth is better than that of the dyed pale yellow PVA cloth. This is an unexpected result, because the aging was expected to damage the PVA cloth, which lead to a degradation of water content transportation. The improvement in the aged PVA cloth is believed to be unrelated to the original color of the cloth, since the resulted appearance is undistinguishable, but related to the change in structure through aging. By observing difference between the two dyed clothes, the one underwent aging has a rougher surface than the one without aging. This structure may help to improve the solar vapor generation performance by two means:

- i. Increasing the total surface area for solar vapor generation. This is possible to help the evaporation process simply by increasing the area to receive light and air contact.

- ii. Loosening the attraction between the water molecules and the PVA clothes. This is similar to the mean from previous section, which increases the possibility of water content evaporation from the cracks in structure resulted from aging. However, this mean is resulted from the space allowing the water molecules to evaporate, instead of area. Since the transportation of



water molecules is believed to be facilitated by the hydrophilic property of

PVA cloth, which has a good attraction to water molecules.

However, the cracks can also be a drawback to solar vapor generation process, due to the excessive attraction. By undergoing aging process, the cracks in the PVA cloth allows the water molecules to evaporate easier, by lowering the attraction forces from the PVA cloth.

6.8 Use of PVA cloth on solar vapor generation

As discussed in Section 6.7, the possible benefit of aging in PVA cloth is shown, which may encourage the further investigation on the use of PVA cloth in solar vapor generation. However, as mentioned in Section 6.3, the aging process was done before the blackening, which means that the same improvement may not be observed from practical aging. Also, the number of cracks appeared on the PVA cloth is expected to increase for a prolonged period of use, which may not lead to further improvement in evaporation rate, instead, a degradation of the evaporation rate may occur, due to the reduced transportation ability of the cloth, because the cracks will become too large to make effective water molecules transportation.

When comparing the performance among dyed PVA, black sponge mask, and, oil based marker painted PVA in TABLE 5.2, the following postulation is suggested:



- i. Black PVA cloth is better than sponge to be used as an absorbent in solar vapor generation.
- ii. Larger total surface area of absorbent can give higher evaporation rate, including the porous which provide curvature on the surface.
- iii. Porous design can probably improve the hydrophilic property of the absorbent, and therefore the transportation of water molecules.
- iv. Any impurities that are trapped in the absorbent's structure will occupy the area for evaporation, and therefore lower the evaporation performance.

By summarizing the above points, an absorbent with following properties is suggested: (1) PVA cloth; (2) porous surface; (3) no or low occupation of volume by impurities. In this project, the impurities added to the PVA clothes cannot be avoided, since a black color is needed to improve the radiation absorption, but this is also a drawback for evaporation because of the occupation of dye materials in the cloth structure. By applying oil based marker, smallest effect on structure was done, but the surface was already blackened to improve the radiation absorption. However, the porous' benefits had not been investigated by applying making porous on the PVA cloth surface. For future investigation, this must be taken into consideration, because



porous not only increase the area for evaporation, but also possible to improve the hydrophilic property.

For a similar project, it is recommended that an aging of dyed cloth can be done under sun, to obtain a result of practical aging. Also, the structure of the PVA cloth can be observed using microscope, to understand the actual change in structure, and analyze the relation between the changes in structure and performance. Since PVA is not conductive, Scanning Electron Microscope (SEM) is recommended for very high resolution analysis. However, a PVA cloth has dried and wetted conditions, which should lead to very different structures. In solar vapor generation, the wetted condition is being concerned, so the SEM image must be done for a wetted PVA cloth.

6.9 Use of solar vapor generation on desalination

In desalination, the concentration of the salt water will gradually increase in the process, which leads to a decrease in evaporation rate, as shown in TABLE 5.3. This can be avoided by continuously exchanging the water volume by salt water at a lower salinity. In practical use of desalination suggested by this project, the power consumption of the device is in great concern, which means that the energy required in exchanging the water volume will affect the feasibility of the system. Therefore, in future investigation over solar vapor generation on desalination, the problem about the



increase in concentration must also be considered, to ensure the feasibility of the system.

Concerning the effect of high salinity on evaporation rate, NaCl water with different salinity was used in experiment. For NaCl, its saturation solution in water is prepared by 26% [15]. In the experiment, the 28% solution was therefore a saturated solution with some NaCl crystal. The appearance of the PVA cloth surface is shown in FIGURE 6.2, where a NaCl crystal layer is formed. To investigate the possibility of using the system as a passive device, another experiment was done to see the solution exchange between the cloth and the water volume, and the liquid flow can be observed and captured as shown in FIGURE 5.6. Also, the result of salt content exchange from between the PVA cloth and the bulk water is observed from FIGURE 5.7(a-c), showing that the salt layer can easily be dissolved, and therefore perfect in desalination.



FIGURE 6.2 NaCl layer on PVA cloth



Chapter 7 Conclusions

Sustainability is an important issue on Earth, because the resources are being consumed bit by bit. By utilizing the solar energy, the consumption progress will be slowed down greatly. In this project, the basic performance of PVA cloth used in solar vapor generation and desalination had been investigated. The performance of the PVA clothes was not as good as that of the black sponge used to fabricate mask. However, improvements including aging and foaming processes, can be done to increase the radiating area, which will improve the performance. Still, further investigation over the aging and foaming effects will be needed to compare the results with other absorbents. For desalination purpose, the system needs a constant exchange in bulk water volume, to ensure the effect of high salinity on evaporation rate can be minimized.



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