International Journal of Air-Conditioning and Refrigeration Vol. 17, No. 4 (2009) 123~128

An Experimental Study on the Condensation Characteristics with Solar Radiation and Tilted Angles

Byung-Chul Kim[†*], Young-Ha Koh[**], Cheun-Gi Lee[***]

[*]Department of Mechanical Engineering, Chosun University, GwangJu 501-759 Korea
[**]Department of Science & Technology Chosun College University, GwangJu 501-759 Korea
[***]Department of Mechanical Engineering Graduate School, Chosun University, GwangJu 501-759 Korea

(Received October 22, 2009; Revision received November 30, 2009; Accepted December 4, 2009)

Abstract

In this paper, effective ways to produce distilled water with solar radiation was investigated. Four different boxes of condensation systems were compared. The bottoms of the boxes were identical, but the angles of the top collecting plates were different. During the solar radiation, condensation did not occur. Condensation started when solar radiation was decreased. The maximum condensation was found when the temperatures of the top and bottom parts were equal. The condensation was continued until sunrise with gradually reduced rate. When the collecting plate angle was 45^0, condensation was the highest compared with other angles.

Key words: Solar radiation, Condensation, Boxes, Collecting plates, Distilled, Water

Nomenclature

ASR : Average of Solar Radiation [kJ/m^2]
SR : Solar Radiation [kJ/m^2]
CW : Condensed Water [*ml*]
ACW : Accumulation Condensed Water [*ml*]
IT : Inside Temperature[℃]
TG : Temperature of Glass[℃]
AW : Above Water
UW : Under Water
WS : Water Surface
WS+ : Height from Water Surface [*cm*]

1. Introduction

The global warming and abnormal temperature caused by proliferation of population, industrialization consequently those have been blamed as the main cause of droughts and flooding. Soon it led to the threat against water supply to human being.[(1)] The fresh waters around world are only 2.6% and rest 97.4% are sea water.[(2-4)] One third of the worlds population suffers from lack of water supply. Korea is also classified to water lacking country.[(5)] When the climatic disasters like flood or drought happen, people who lives in the islands confront very serious problem.[(6-8)]

There are several kinds of processes to purify the water, however, these processes have many problems, i.e. expensive in cost and difficult to maintain. Thus it was tried to ensure the purification with solar radiation could be economical and practical. For this purpose, it was produced 4 boxes with same bottom but different top collecting plate angle.[(3)] Those boxes were placed around Gwangju(latitude : 35°10 N, longitude : 126°53′ E, altitude : 70.3m) area.

The amount of condensation and the temperature were measured in each collecting plates to find the relationship between the condensation and the variables. Also, searched the characteristics of condensation to apply the baseline data for the water purifying systems.

2. Experimental devices and method

2.1 Experimental devices

The box's bottom area is 1,000×1,000mm and these box's collecting plate angles are 15^0, 30^0, 45^0, 60^0. These box's walls are fabricated with heat insulators

[†]Corresponding author. Tel.: +82 62 230 7041, Fax.: +82 62 230 7041
E-mail address: bckim@chosun.ac.kr

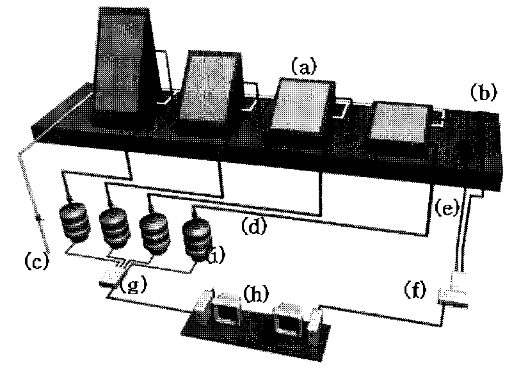

Fig. 1. (a) Boxes, (b) Pyranometer, (c) Water Supply pipe, (d) Condensation Water pipe, (e) Thermocouple, (f) Data Acquisition Unit, (g) Weighing controller, (h) Personal computer, (i) Load Cell & Water tank.

Which are 50mm thick. The inner surfaces were painted in black except the top. The top plate is made by reinforced glass. When water evaporates and condensates on the glass surface, distilled water comes down to the bottom of the glass and gathers through the hole set on the side. Then the amount was measured. These boxes are faced toward the south, and set up to a pyranometer and thermocouples on the same level both inside and outside of the devices.

2.2 Experimental method

Pour the same amount of water with same temperature in the boxes. After the water is stabilized, we measured the solar radiation, temperature, and condensation every hour. The amount of solar radiation are compared and referenced by the meteorological measurement. Temperatures were measured by DA-100^+ Data logging system which were made by the YOKOGAWA Cooperation. Condensation is measured by load cell.

3. Experimental result and discussion

3.1 Solar radiation and condensation

Fig. 2 shows the a graph of relation between solar radiation and condensation within 12 months from November, 2008 to October, 2009.

This study shows that solar radiation is changed by weather conditions such as yellow dust in the spring, passing rain in summer, snow in the winter. Then it led to the change of condensation. The solar radiation was most in April, but steady highest during Feb - Sep; lowest in December - January.

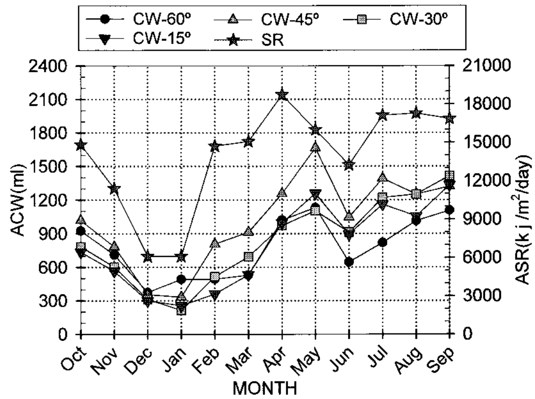

Fig. 2. The average of condensation and solar radiation by month. (October 2008~September 2009)

In June solar radiation was low because of cloudy rainy weather. Condensation amount is proportional to solar radiation. So the condensation amount was most abundant in August while condensation indicated the least in December and January. June's condensation amount is also comparatively low according to climate feature.

3.2 Time of solar radiation and water condensation

Figs. 3-5 shows May, August, and October solar radiation and condensation for one day. In these Figs, it showed before sunrise the amount of condensation slowly decreased, while sunrise condensation does not arise because of vaporization. But on the graph it seems like a small amount of condensation was gathered because of condensation in the pipe walls.

Box's temperature rises by heat radiation while solar radiation increases, so heat radiation passes maximum point. Then starts to fall and outside temperature also falls. Therefore, glass surface temperature is

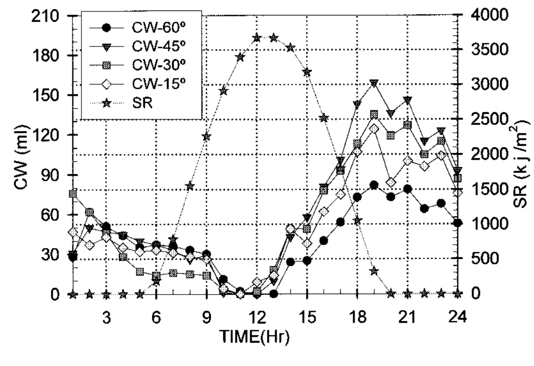

Fig. 3. Timely solar radiation and condensation on a clear day (May 31, 2009).

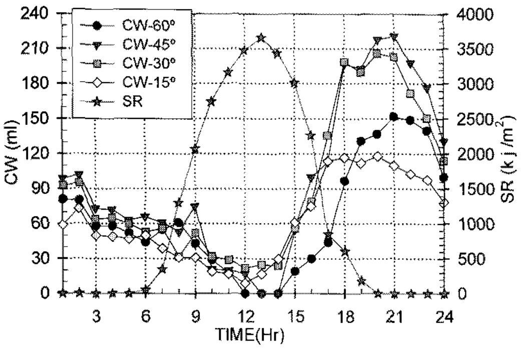

Fig. 4. Timely solar radiation and condensation on a clear day (August 6. 2009).

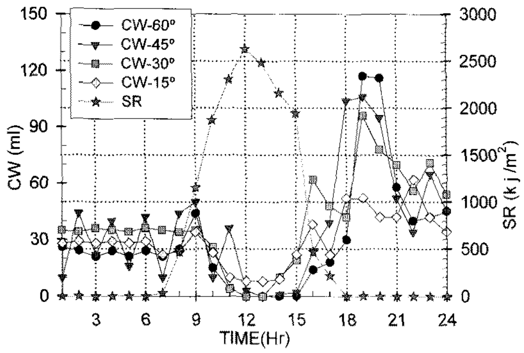

Fig. 5. Timely solar radiation and condensation on a clear day (October 30, 2009).

falling and vapor starts to condensate, then condensation amount increases and passes maximum point after sunset while solar radiation is almost zero.

Condensation has continuously occurred before solar radiation measured. Until the solar radiation reached the maximum level, inner temperature of box increased as solar radiation increased, and it caused dryness from vaporization and no condensation.

3.3 Condensation according to weather

Fig. 6 shows graph of solar radiation and accumulated condensation on a snowy day in January. It was snowing continuously except around 12.00 to 15.00. Solar radiation was measured as 1,858kJ/m^2 at 14.00 and condensation was measured as 370 *ml* using 45^0 collecting plate, 230 *ml* for 30^0 collecting plate.

Fig. 7 is a drizzle day. Solar radiation and condensation amount was little because of the rain between 9.00 to 15.00. And change of condensation was little but total amount slowly increased.

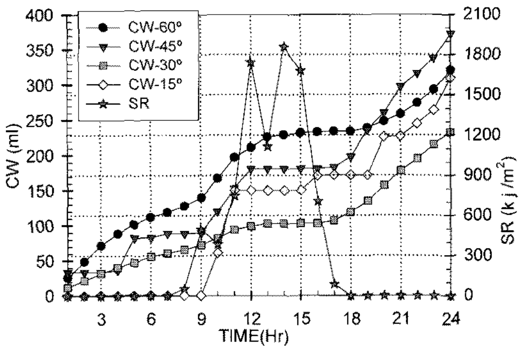

Fig. 6. Solar radiation and accumulated condensation on a snowy day(January 3, 2009).

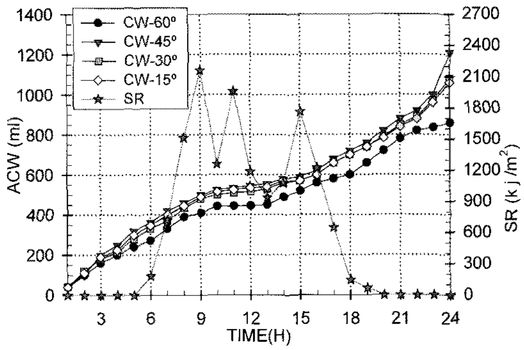

Fig. 7. Solar radiation and accumulated condensation on a drizzly day (June 3, 2009).

If collecting plate angle was 60^0 the day time condensation amount was 860 *ml* and if angle is 45^0 then day condensation amount is 1,210 *ml*. Condensation amount reached maximum level at 20 o'clock.

Fig. 8 shows relationship between solar radiation and condensation in a day in August when occurring rain started at 15.00. Before 15 o'clock amount of vaporized water was increased because of abundant solar radiation.

Suddenly temperature fall by passing rain produced rapid condensation and reached maximum level after 6 hours. Each different shows similar The condensation of each collecting plate angle similar trend, but collecting plate with an angle of 45^0 produced the most abundant condensation.

Fig. 9 shows solar radiation and condensation on cloudy days. Solar radiation is changed even in the daytime by weather condition so condensation is also produced at the same time, while the amount is not considerable.

Boxes of which collecting plate angle is 15^0 and 30° produce similar condensation.

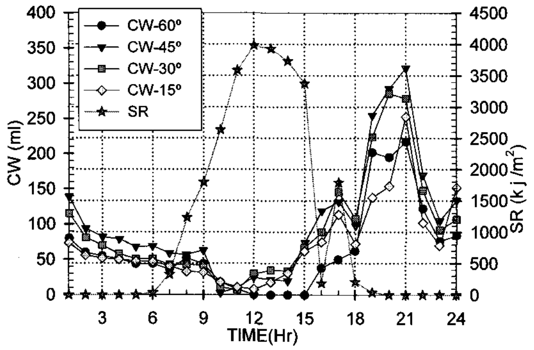

Fig. 8. Solar radiation and condensation on a rainy day (August 8, 2009).

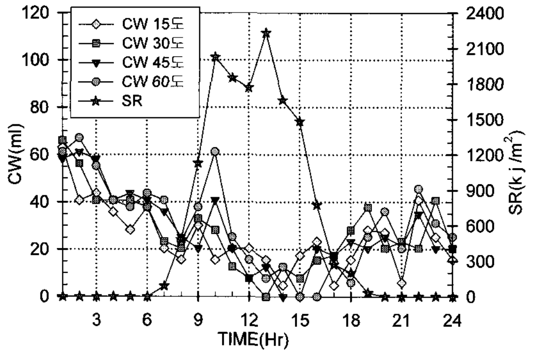

Fig. 9. Solar radiation and condensation on cloudy day (January 31, 2009).

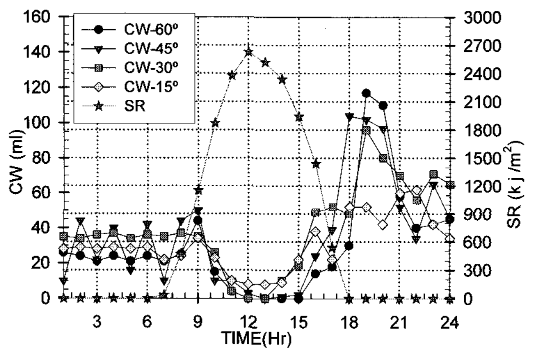

Fig. 10. Solar radiation and condensation on a clear day (October 30, 2008).

When the angle is 60^0 and 45^0 it produces more amount than when the angle is 15^0 and 30^0. 45^0 angle produces the highest amount of distilled water.

Fig. 10 show solar radiation and condensation on a clear day. Condensation amount was least before sunrise. Solar radiation was most abundant on 12 o'clock and the amount was 2,658kJ/m^2. Condensation was stopped during sunshine and start again after sunset that reached maximum level an hour after sunset, about 119 *ml* and then slowly decreases to average of roughly 30 *ml* finally.

3.4 Condensation according to collecting plate's angle

Table. 1 shows collecting plate angle and condensation by weather condition. 45^0 angle plates produce the most amount of condensation. Then it became less in order of 30^0, 15^0, 60^0. However, the more solar radiation supply was collected, the more vaporization and condensation was occurred. If the box had ideal vaporization conditions, then the amount of condensation can be maximized. The amount of condensation is in proportion to the inclination angle of the collecting plate except 60^0 angled plate. The 60^0 angled plate collected lesser amount of condensation, only 830ml, 641ml, 842ml, 331ml for clear day, cloudy day, rainy day and snowy day.

3.5 Condensation according to inside air temperature

If the angle of the collecting plate is large, the air temperature inside the box becomes high.

However, in the same height the large angle has higher inner-temperature than the small angle while upper-level of water had nearly same temperature. This showed that time delay from the difference of medium was not caused by the transfer of heat with radiant heat. This experiment shows that the time to reach the maximum inside air temperature was delayed when close to December.

155cm above water surface and 5cm above water surface had same temperature at 8 o'clock but at 12'o clock the former is 85℃ and the latter is 70℃. As time goes by, temperature difference between upper

Table 1. Collecting plate angle and daily condensation by weather condition.

Angle of collecting plate	Average condensation (*ml* /day)			
	Clear day	Cloudy day	Rainy day	Snowy day
15^0	1,068	685	822	259
30^0	1,254	885	958	308
45^0	1,207	903	1,047	392
60^0	830	641	842	331

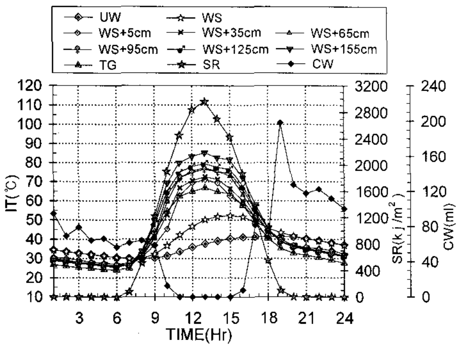

Fig. 11. Shows inside temperature and condensation of collecting plate with a 60^0 angle.

and lower was almost same and then it started to decrease. After 18 o'clock upper temperature became less than the lower, about 10℃ difference.

Change of water temperature is smaller and slower than change of inside air temperature because of the difference of heat capacity and specific heat. Condensation starts to decrease an hour after sunset and started to be produced from the minimum level just before sunrise. Condensation wasn't occurred while solar radiation was increasing but started after solar radiation passed the maximum level.

Fig. 12 shows temperature and condensation with a collecting plate angle of 45^0 on a clear day. Upper and lower air temperature difference is almost zero at 8 o'clock, but the difference between two levels, 75cm above water surface(84℃) and 15cm above water surface is roughly 16℃ at 12 o'clock.

Upper and lower temperature are the same at 18 o'clock, and after that upper is cooler than lower about 10℃ gap and the difference started to fade.

Condensation amount was slowly decreasing before sunrise, and after sunrise vaporization didn't take place. Condensation slowly increases after solar radiation reached maximum level and produced the most amount of condensation when upper and lower air temperatures became the same.

Fig. 13 shows inside temperature and condensation with a collecting plate angle of 30^0. The temperature of 35cm above water surface and 5cm above water surface is almost same as 25℃ at 8 o'clock. The difference between 35cm above water surface (70℃) and 5cm above water surface is roughly 10℃ at 12 o'clock. Around 18 o'clock the upper and the lower temperature became almost same, and then the lower was higher than the upper.

The difference started to fade until the sunrise while maintaining the gap of 10℃.

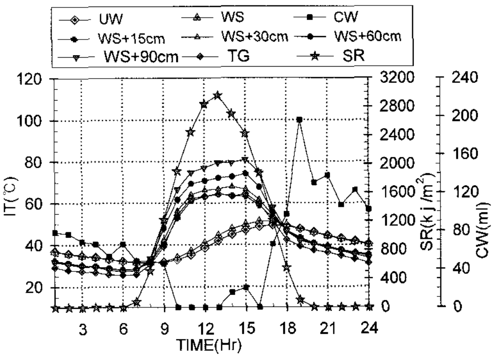

Fig. 12. Clear day's temperature and condensation with an angle of 45^0 (May 5, 2009).

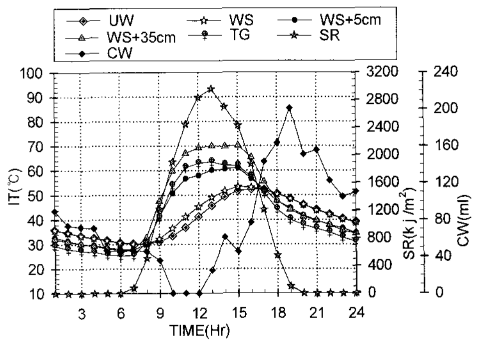

Fig. 13. Inside air temperature and condensation water of collecting plate with an angle of 30^0 on a clear day (May 5, 2009).

Condensation decreased until the sunrise, and stopped to be produced after sunrise when vaporization started, but slowly increased after solar radiation reached maximum level at 12 o'clock and decreased. It produces the most amount of condensation when upper and lower air temperatures became the same, and then slowly decreased.

Fig. 14 shows the relationship between temperature and condensation of a collecting plate angle of 15^0. Until 8 o'clock, before the sunrise, both of the temperature 5cm above water and 35cm above decreased while the former was higher than the latter. After the sunrise solar radiance started to increase, and so did the upper temperature. The upper temperature reached maximum level of 70℃ and the difference between 5cm above water surface was around 10℃ at 12 o'clock. The Upper and lower temperatures were the same at 19 o'clock and then the lower became higher than the upper.

Least amount of condensation was produced just before sunrise, and then it did not arise after sunrise when vaporization took place.

Table 2. Heat collected area for different collecting plate angle and weather condition.

Angle of plate	Heat collected area (m^2)			
	Clear day	Cloudy day	Rainy day	Snowy day
15^0	2.14	2.92	2.43	7.72
30^0	1.56	2.26	2.09	7.78
45^0	1.66	2.25	1.91	6.49
60^0	2.41	3.12	2.38	6.04

Condensation started after the solar radiation passed maximum level. Condensation produced the most when the upper and lower temperature equalized, soon it faded.

3.6 Essential bottom area and best angle of collecting plate

If one person's potable amount of water is 2,000 *ml*, the required bottom size is $1.66m^2$ with a collecting plate angle of 45^0 on a clear day. Width of $2.41m^2$ is needed when the collecting plate angle is 60^0. 45^0 collecting plate angle produced the most amount of condensation. According to experiment results, to produce essential potable water for one person per each collecting plate angles, it requires certain amount of heat-collecting area as shown in Table 2.

On cloudy day in December or January except the snowy day, it actually requires $2.25m^2$ heat-collecting area with 45^0 of collecting plate angle.

4. Conclusion

Four boxes with different collecting plate angle were manufactured and water purifying characteristics were studied. The findings of the research are summarized as:

(1) Condensation of water did not arise when solar radiation increases. It starts to arise when solar radiation is just decreasing.

(2) The maximum amount of condensation is produced when upper and lower section of air temperatures are the same after sunset. Maximum amount of condensation was continually produced before the next sunrise.

(3) The amount of condensation was the maximum for angle is 45^0 collecting plate and minimum for 15^0 collecting plate.

(4) It was required about $2.25m^2$ of heat-collecting area for 45^0 of collecting plate to produce 2,000 *ml* /day of distilled water.

Acknowledgement

This study was partially supported by research funds from Chosun University 2009.

References

[1] "International Conference for solve water-lacking", Swiss Geneva, February 1992.

[2] In analyzing database of reduce effect by solar energy using vitalize (January 2001. Korea Institute of Energy Research)

[3] Park, Y. H., Kim, B. C., "The Effect of Solar Distillation", Journal of The Korean Solar Energy Society, Vol.24, No.1, 2004, pp13-19.

[4] Kim, J. B., Ju. M. C., Yoon, E. S., Ju, M. C., Kwak, H. Y., "Demonstration study on Desalination System using Solar Energy" Journal of The Korean Solar Energy Society Vol.27, No.4, 2007, pp27-33.

[5] Jung, H. H., "Sea water desalination System using Solar Energy", Korean Journal of Air Conditioning and Refrigeration Engineering Vol.37, No.1, January 2008., pp.40-44.

[6] Back, N. C., Lee. D. W., Lee. J. K., Yoon. E. S., "Study on Practical Use of Sea water desalination System using Solar Energy", Korea Institute of Energy Research, KIER-A62432, December 2006.

[7] W.R. McCluney, "Solar Distillation of Water", Energy Note FSEC-EN-80 February 1984.

[8] Campbell, George, "How to Get Pure Drinking Water From The Sun", Popular Mechanics, Volume 157, No.3, March 1982.