IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 16, Issue 2 Ser. III (Mar. - Apr. 2019), PP 20-31
www.iosrjournals.org

Effect of Evaporator Filling Ratio on the performance of a Solar Driven Natural Vacuum Desalination System

M.I. Mahrous, H. Kotb, E.H. Amer and A.R. El-Ghalban
(Department of Mechanical Power Engineering, Faculty of Engineering, Menoufia University, Egypt)
Corresponding Author: M.I. Mahrous

Abstract: *The present study deals with an energy-efficient seawater desalination system utilizing solar energy and natural vacuum technique. A novel desalination system is proposed, developed and extensively investigated. The system uses the natural forces of gravity to create vacuum conditions. The proposed desalination system consists of a solar heated evaporator and a condenser. Detailed experimental investigation has been carried out to examine the system's technical feasibility under different operating conditions. The hourly productivity as well as the cumulative daily productivity has been measured. The effect of condenser cooling process and the amount of saline water initially contained in the evaporator has been investigated. The condenser cooling process is most efficient at a flow rate of 2 l/min. The fill ratio in the evaporator affects the system performance and the best performance is attained in case of ¼ filling ratio at the cooling water flow rate of 2 l/min. The system performance is expressed in terms of the performance ratio, total amount of freshwater and total dissolved solids in the produced fresh water. At 2 l/min cooling flow rate, a performance ratio as high as 85% has been achieved and a cumulative productivity of about 10 l/m^2.day has been obtained.*

Keywords: *Filling RatioForced Cooling,Natural Cooling,Natural Vacuum, Water Salinity.*

Date of Submission: 18-03-2019 Date of acceptance: 02-04-2019

I. Introduction

The availability of freshwater is one of the most serious problems faced by the world today. According to estimates, over a billion people today lack access to freshwater and over 2.5 billion people do not have access to basic sanitation [1]. By 2025, the situation may worsen to the extent that two-thirds of the world's population may suffer either from high or moderate water shortages [2]. Many health issues today are a direct consequence of the unavailability of clean drinking water. As such, water desalination is the only promising option to, at least partially, meet the water needs.

The major types of seawater desalination processes, in use around the world today, are the multistage flash (MSF), multi-effect distillation (MED) and the reverse osmosis (RO) process. MSF is the most popular of the desalination processes for large-scale productions. MED is older than MSF but suffered some operational problems and was limited to the maximum size of the units, and hence, it lost its popularity. RO is making rapid development and gaining increasing popularity. The choice between these desalination processes is made on technical, economical and or political grounds [3].

A novel technique for causing the phase change required for these processes was introduced in 2003, which makes use of natural vacuum distillation (NVD) [4,5]. NVD is based on the principle of attaining natural vacuum through the barometric head of a water column. Total vacuum is equivalent to a water column with a height of approximately 10.3 m. The experimental studies reported in the literature have claimed to achieve pressures as low as 0.5 kPa using NVD. The low pressure created causes the desalination to take place at low temperatures, which are easily achieved using solar energy. NVD uses the simple idea of using the barometric pressure of a column of water to create a vacuum chamber, which allows for the evaporation of water at relatively lower temperatures. If a column of water, with a sealed top, is allowed to drain into a container of water, then it stops draining after the head of the water column (approximately 10.3 m) equals the atmospheric pressure acting on the water in the container. The space above the water level in the top end will thus have a natural vacuum created. A system based on this principle is capable of creating vacuum without using any evacuation pump. Under such low-pressure conditions, saline water can be easily evaporated at low temperatures, with minimal energy input, and subsequently condensed to obtain freshwater.

The natural vacuum desalination technology (NVD) is still in the developing stages and the literature contains considerably few studies addressing different desalination systems operating under low pressure Al-Kharabsheh and Goswami, [4] have experimentally studieda solar desalination system based on an innovative passive concept, utilizing low grate solar heat. Result showed that the daily output from this system could reach 6.5 l/m^2 evaporator area, as compared to 3-4 l/m^2 from conventional flat basin solar still.

Gude et al, [6] havedeveloped a double-effect NVD system combined with the merits of multi effect desalination (MED) technology, which reuse the latent heat of vapor. The double-effect NVD system has made a productivity of 0.349 l/min including 0.189 l/min from the first evaporator and 0.16 l/min from the second evaporator. The heat source temperature was 50 to 70 ℃.

Gude et al, [7] have studied a low temperature desalination system can be produce 100 l/d of fresh water would require a solar collector area of 15 m^2 with 1 m^3 of thermal energy storage (TES) volume or 18 m^2 with 3 m^3 of TES volume.

Maroo and Goswami,[8] used the natural forces of gravity and atmospheric pressure to create a vacuum in single stage and two stage systems. When coupled with a solar collector of 1 m^2 area, a single stage system produces 0.71 l/h, while a two stage-system produces 1.12 l/h. The performance ratio obtained is 0.748 and 1.35 for a single stage and two stage system respectively. The cost of water production by this method was found to be 3 USD/m^3.

Teoman and Al Madani, [9] have studieda natural vacuum desalination (NVD) with maximum temperature difference between seawater and ambient temperature difference of approximately 20℃. The pilot model of NVD system can supply distilled water at a production rate of 1.32 l/h with a diameter of .35 m and 10.79 l/hwith a diameter of 1m.Abutayeh and Goswami, [10, 11] have studied a passive vacuum flash desalination system. Numerical simulations have been used to show the effect of flash temperature on system performance. It is concluded that increasing the flash temperature at a constant flash chamber volume is faster vacuum erosion, decreased run time, increased heater load, increased solar collection area, increased boiling point elevation, faster equilibrium attainment, and less overall evaporation. Increasing the flash temperature will increase the vacuum pressure which by definition reduces the vapor liquid equilibrium distribution coefficient of all the non-condensable gases.

Himsar, [12] has conductedexperimental and theoretical studies ona natural vacuum desalination system at varying conditions.The system performance was affected by maximum temperature in evaporator and minimum temperature in condenser. On the other hand, the surface area of heating coil and the heat recovery unit showed only a small effect.

More recently, Ambarita et al, [13] have studied the phenomenon of evaporation-condensation in an evaporation chamber of natural vacuum solar desalination using CFD simulationof the gas mixture. Mixture framework with turbulence flow was used in the simulation.

The survey of the literature reveals that limited experimental investigations are reported for desalination systems using barometric head. Technical information available from these studies is not sufficient to develop a reliable low temperature desalination system for large scale continuous operation. In this study, a new low temperature desalination system is designed, fabricated and assembled. The system feasibility is examined and an exhaustive experimental investigation is carried out to examine the performance under actual operating conditions.

II. System Description and Operating Principles

Figure (1) shows a schematic diagram of the experimental test rig. The set-up consists mainly of the evaporator, the condenser, two storage tanks and the necessary piping connections. The evaporator is designed similar to a liquid flat-plate solar collector as shown in Fig. (2). It is made from copper sheet of 0.5 mm thickness, 1 m long and 1 m width. It includes two headers and ten riser tubes made from Stainless steel 304 to avoid the formation of copper oxide due to the chemical reaction between saline water and copper.Two headers, 19 mm diameter each, are connected with ten riser tubes of 9.5 mm diameter. The whole assembly is placed inside a wooden frame with 5 cm thermal insulation at the bottom and sides. A single glass cover is placed at the top. The evaporator is supported on a frame such that it makes a fixed tilt angle of 30 degrees to the horizontal. A sight glass tube is attached to the evaporator in order to indicate the water level inside the evaporator. The condenser is a shell and coil as shown in Fig. (3). The condenser is made of Stainless-steel tube having 1.5 m length, 10.2 cm inner diameter and a thickness of 2 mm. Sixteen annular fins of 25 cm diameter and 0.6 mm thickness are fixed on the outer surface of the condenser tube. A coil tube 1.25 cm diameter and 1.25 m length made of copper is placed inside the condenser tube to provide a flow passage of the cooling medium in case of using water as cooling medium. Further, a liquid-vapor separator has been added between the evaporator exit and the condenser inlet. The condenser is connected to the evaporator by a flange made especially for this purpose to make sure that no air leaks into the device and maintain the system vacuum tight. A second sight glass tube is fixed on the side of the condenser in order to show the increase in water level inside the condenser and to provide an indication of the productivity. Two plastic storage tanks are used in the set-up; one for the saline water and the other is for the fresh water. The condenser and the evaporator are kept at a height of about 10 meters above ground level. The pipes connecting the evaporator and the condenser to the storage tanks are 2.5 cm diameter and are made of PVC. Ball valves are used to isolate the system components where needed and an air vent is provided at the highest point in the set-up to vent out air during system evacuation.

The test rig is equipped with suitable measuring devices. Transducers for measuring the components of solar radiation, the temperatures at different positions, the vapor pressure inside the condenser, the water salinity, the wind speed and the fresh water productivity have been used. Solar radiation incident in the plane of the evaporator has been measured using Eppley PSP pyranometer (±0.5% accuracy). A shading ring arrangement has been used with the solar pyranometer for measuring the diffuse radiation while an Eppleypyrheliometer has been used to measure the beam radiation at normal incidence. Calibrated thermocouples of type T (±1.0°C accuracy) have been fixed at different positions as illustrated in figures. (2) and (3). The vapor pressure is measured by using a vacuum pressure transducer ranging from 0 to 1 bar absolute (±0.1% accuracy). The productivity is calculated by measuring the difference in the water level inside the condenser using the sight glass tube during a certain period of time.Then, the accumulated water volume is calculated. The thermocouples and other sensors are connected to data acquisition system interfaced to a computer. The data acquisition system provides a cold junction compensation for temperature measurements and allows a variable scan rate starting from one sample per second. All sensors are scanned and recorded every minute and a time average of 10 minutes has been programmed for all channels.

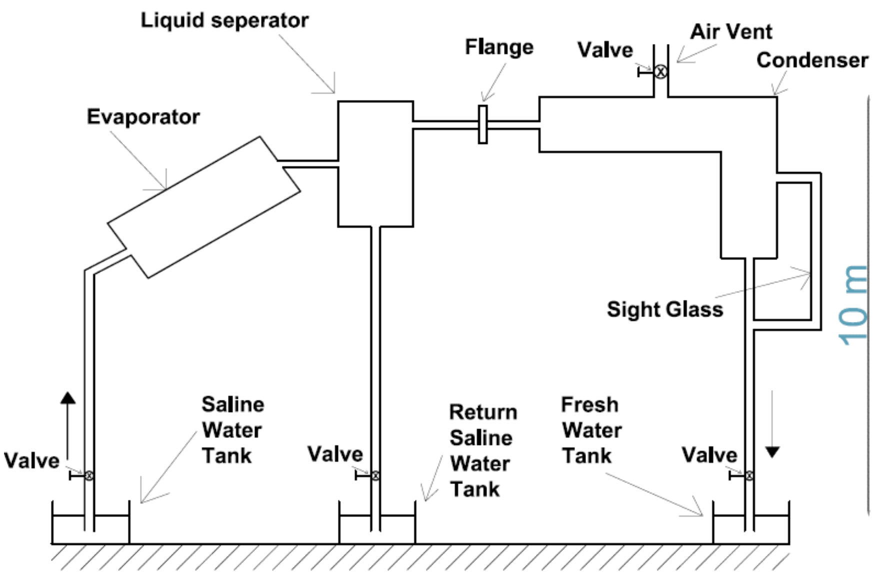
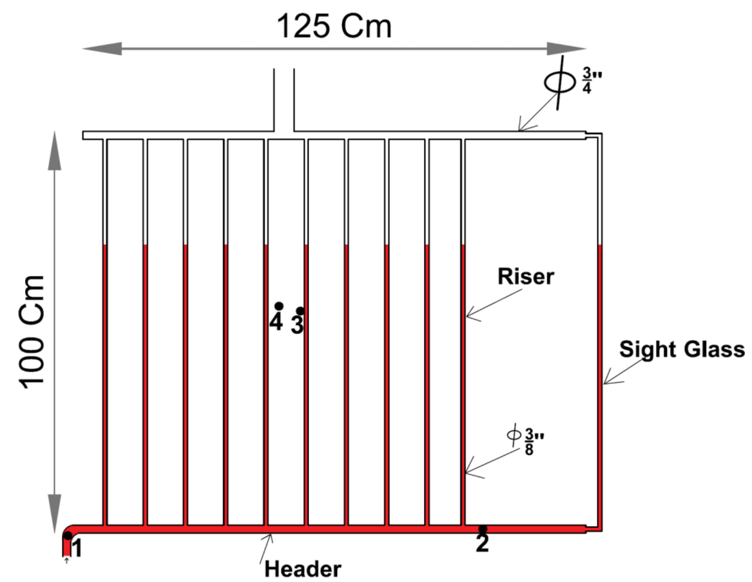


Fig. 1. Schematic diagram of the experimental test set-up



1-Inlet saline water temperature 2- Saline water temperature
3-Pipe surface temperature 4- Absorber temperature

Fig. 2.Schematic diagram of the evaporator

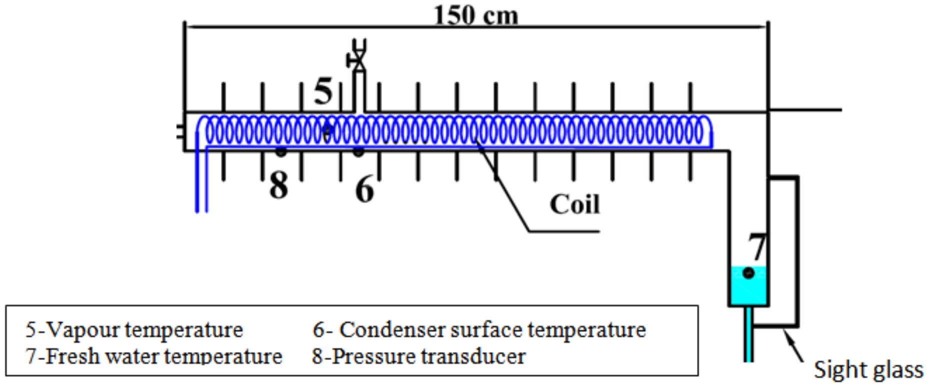


Fig. 3. Schematic diagram of the condenser

III. Results and Discussions

Several experiments have been carried out to investigate the performance of the developed system under actual weather conditions. Each experiment has been conducted for a complete day to utilize the entire sunshine duration. In a previous study, the effect of different cooling modes on the system performance has been investigated [x]. In this part of the study, the condenser has been cooled by forcing a stream of cooling water to flow in the coil placed inside the condenser. The effect of varying the flow rate of cooling water has been experimentally examined. Further, the effect of the amount of saline water contained in the evaporator on the system performance has been also investigated. The riser tubes have been filled to a certain level of its length. The volume of saline water contained in the evaporator is normalized to total volume of the evaporator leading to a ratio termed *filling ratio*. Thus, a filling ration of ¼ means the volume of water that fills the evaporator riser tubes to one fourth of its length. In other words, the filling ratio is

$$filling\ Ratio = \frac{volume\ of\ saline\ water\ contained\ in\ the\ evaporator\ when\ risers\ are\ partially\ filled}{volume\ of\ saline\ water\ that\ completly\ fills\ the\ evaporator}$$

3.1 Effect of Cooling Water Flowrate at the Same Filling Ratio

In this section of the study, the effect of cooling water flowrate is studied. The evaporator tubes have been filled with saline water to a constant filling ratio and this filling ratio is kept constant during all experiments. Experiments have been conducted for filling ratios of ¼, ½ and ¾ and the samples of the obtain results are presented for the case of ¾ filling ration. Experiments are conducted at the solar energy laboratory, Shebin El-Kom, Egypt (30.33º N, 31.00º E).

Experiments were conducted at similar atmospheric conditions as shown in Fig. 4. The figure shows steady and almost identical levels of radiation but slight differences in ambient temperatures are observed. Experiments have been carried out using three different cooling water flowrates namely 1, 2 and 3 liter/min.

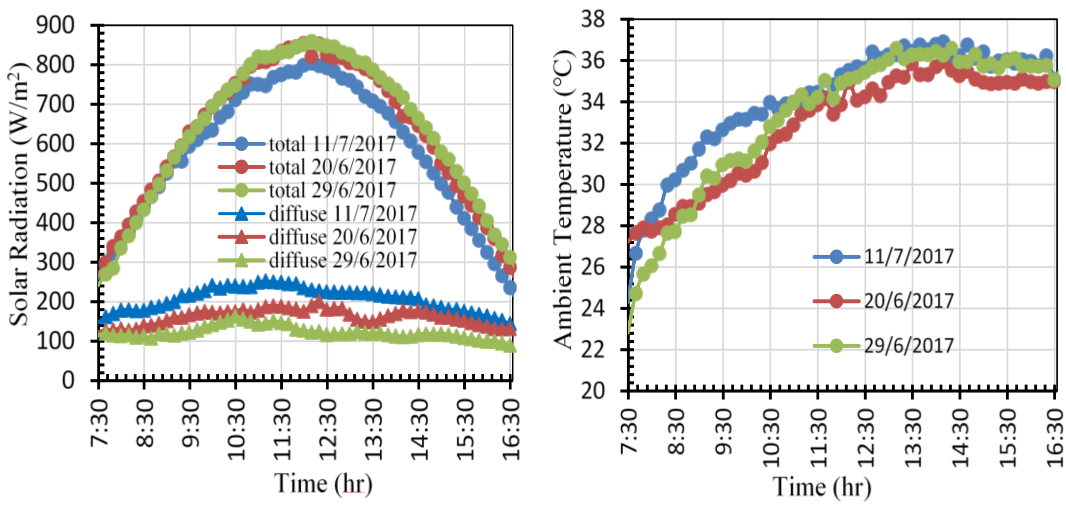


Fig. 4. Variation of solar radiation and ambient temperature with time

Figure 5 shows the variation of absorber temperature and saline water temperature with time of day. The absorber temperature in each day follows a similar trend and theirvalues are very close to each other, except for slight differences in the case of 1 l/min in the afternoon, which might be attributed to the lower solar radiation. The maximum value for each absorber temperature curve occurs around solarnoon and reaches about 62 ℃. This behavior is seen also for the saline water temperature which it reaches a maximum value after solar noon at around 2:30 PM. It could be seen from figure that the absorber and saline water temperature are not affected by change of condenser cooling water flowrate.

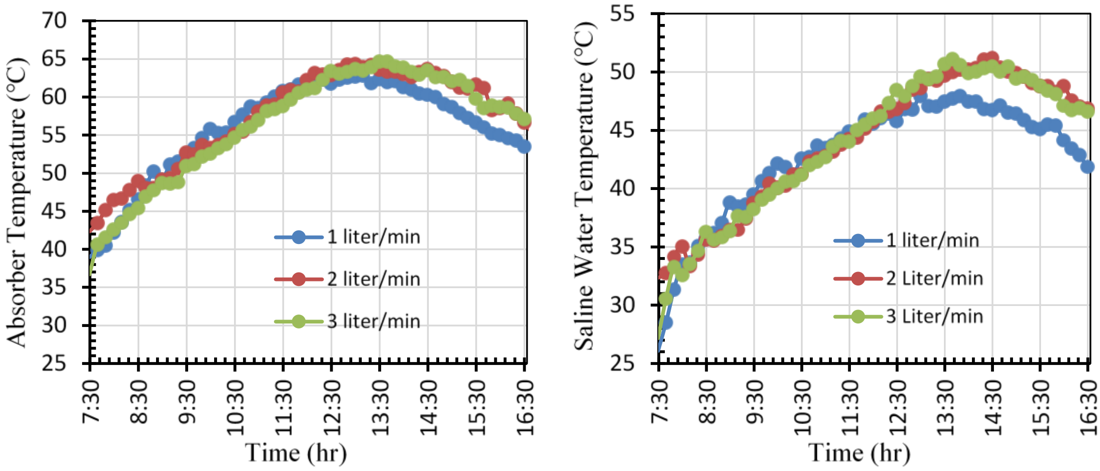


Fig. 5. Effect of cooling water flowrate on absorber temperature and saline water temperature

Fig. 6 shows the variation of vapor temperature and the condenser surface temperature with time of day at different cooling flow rates. The figure shows that the vapor temperature and condenser surface temperature are very close to each other for the cases of 2 and 3 liter/min while in case of 1 l/min, the temperatures are relatively higher.

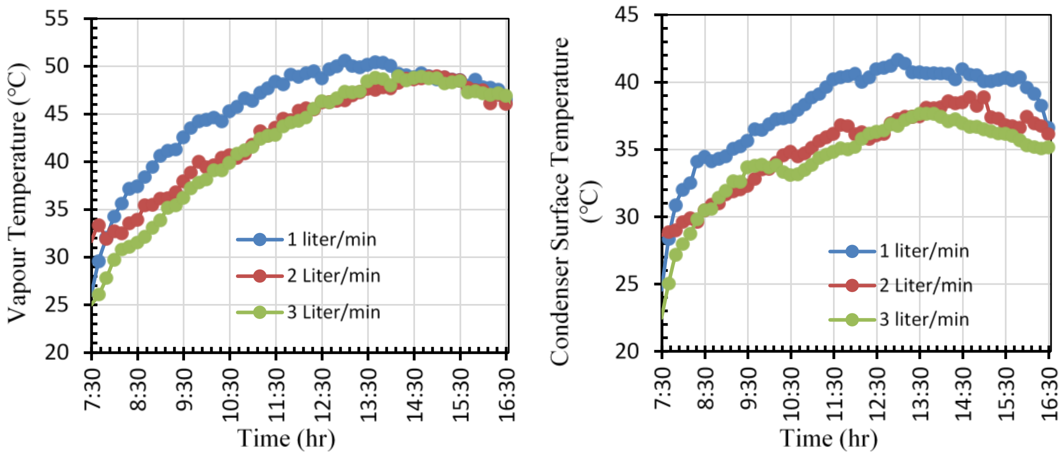


Fig. 6. Effect of cooling water flowrate on condenser temperature

The variation of condenser pressure with time of day is illustrated in Fig. 7. During the period from the start of the test until midday, the pressure in case of 2 and 3 liter per minute cooling flow rates are equal while the values corresponding to 1 liter/min are higher. This might be attributed to a high evaporation rate and a lower condensation rate. The maximum pressure difference is around 0.02 bar absolute. And the highest system pressure is about 0.12 bar absolute. The differences in pressures are reflected on the system productivity.

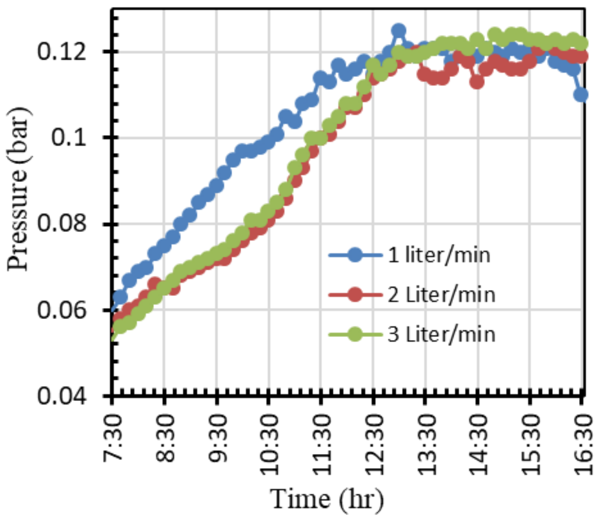


Fig. 7. Effect of cooling water flowrate on condenser pressure

The instantaneous productivity for the 2 and 3 l/min cases are nearly equal as shown in Fig. 8. At early hours, the magnitudes of the productivity in the three cases are very close. As time elapses, the values for productivity differ and the difference increases to a maximum value attained at solar noon. The instantaneous productivity is less at the lower cooling flow rate because of the lower condensation. The instantons productivity is summed up for the complete day resulting in cumulative daily productivity. The cumulative productivity for the cases 1, 2 and 3 l/min were found to be 21.8, 31.3 and 32.3 l/m^2.day respectively. Therefore, it could safely be concluded that the optimum cooling is achieved with using 2 l/min coolant flow rate. Accordingly, all the subsequent experiments will be carried out at this flowrate.

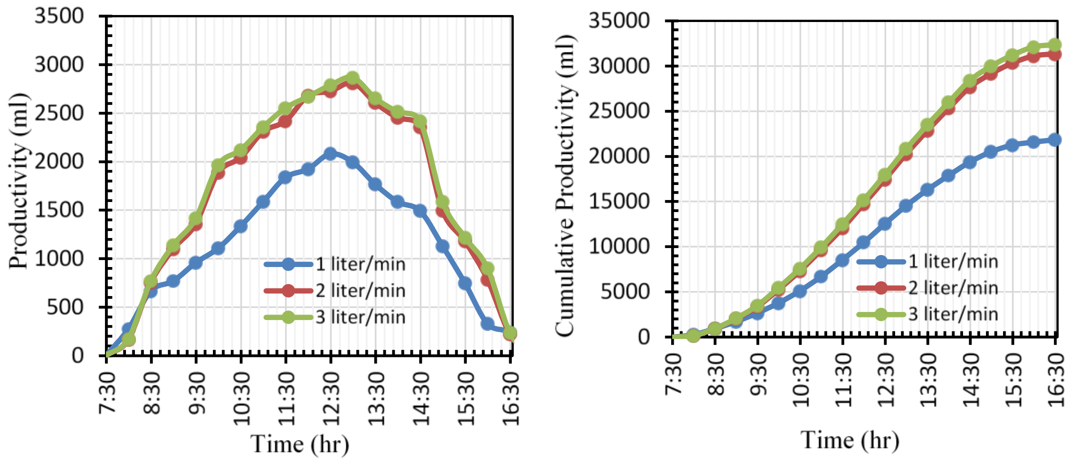


Fig. 8. Effect of cooling water flowrate on instantaneous and cumulative productivity

Samples of the fresh water produced by the system during the initial phases of experiments have been analyzed and the total dissolved solids have been evaluated. The results showed that the salt concentration of fresh water is slightly higher than the limits specified for potable water. This was attributed to the intense boiling mechanism within the thin evaporator tubes which causes the bubbles to push significant amount of saline water through the pipes of the evaporator where there is no change to form annular boiling mode in the narrow evaporator tubes. The saline water pushed to the condenser did not have sufficient time to be totally evaporated and thus some part was transferred it to the condenser and got mixed with fresh water.This problem was rectified by adding the liquid separator between the exit of the evaporator and the inlet to the condenser. The separator allows vapour only to flow to the condenser while the liquid is returned to saline water tank. The complete set of experiments has been repeated and an analysis of the TDS revealed that the fresh water produced is salt free. The TDS in fresh water is less than 30 PPM.

The following section presents a comparison experimental result of operation of the desalination unit with liquid separator being installed, using three different filling ratios in the evaporator.

3.2 Experimental Results with Different Evaporator Filling Ratios

Because of the probability that the system yield may be effect by the amount of the saline water in the evaporator therefore, it has been decided to study the effect of evaporator filling ratio on the performance of the proposed system. The filling ratios employed in experiments are ¼, ½ and ¾.Each filling ratio is kept constant and tested for a number of days and all experiments are conducted at a rate of 2 l/min for condensercooling water. The results of three experiment set are presented in the following section.

From Fig. 9 it could be seen that the three experiment sets with different filling ratios are carried out almost same conditions of solar radiation and ambient conditions except for some fluctuations in solar radiation in one the half-filled case. This slight change has no effect on the general trend of the results as will be shown next. The average value of solar radiation for three cases is about 665 W/m^2

The absorber temperature throughout the day for the three cases is illustrated in Fig. 10. It is noted that the three cases started with marginal difference between them, the maximum value for the three cases is around 57 ℃ at solar noon. The cases of ½ and ¾ filling ratios have nearly identical absorber temperature. This could be explained as follows; in all the cases there were bubble formation in the pipes, theses bubbles cause the water above it to be pushed upward. In case of ¼ filling ratio the distance travelled by the bubbles and, also the liquid above it, is longer than the other cases. As a result, longer residence time is taken, the rate heat transfer from absorber to the wet vapour is higher and the amount of water evaporated is higher too

The variation of saline water temperature for the three cases is shown in Fig. 11. A slight difference in temperature is noticed in the three cases. The maximum temperatures for ¼, ½ and ¾ filling ratio are 44 ℃, 47 ℃ and 49 ℃ respectively. In case of the ¼ filling ratio, the absorber temperature shows the lowest values. It is noted here that the difference between the cases of ½ and ¾ is more pronounced than the case of ¼ filling

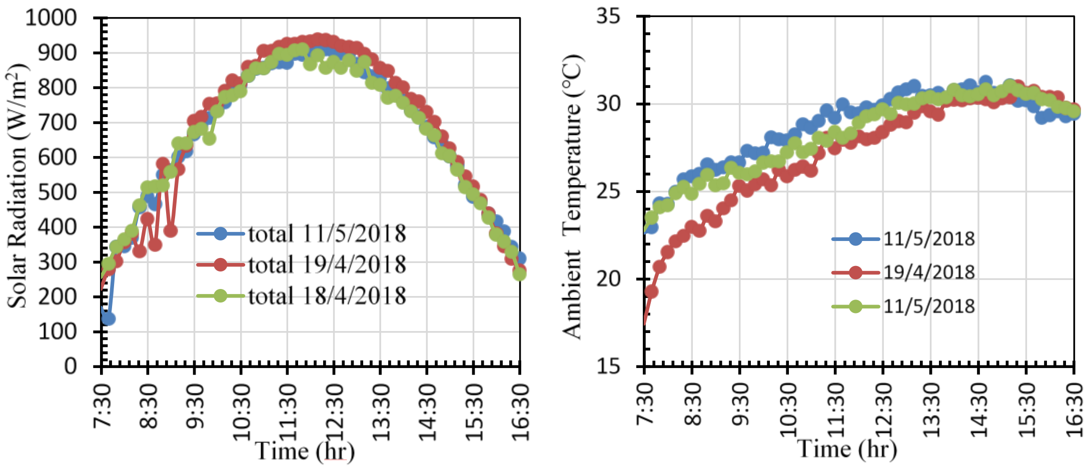


Fig. 9. Variation of measured solar radiation and ambient temperature with time at different filling ratios

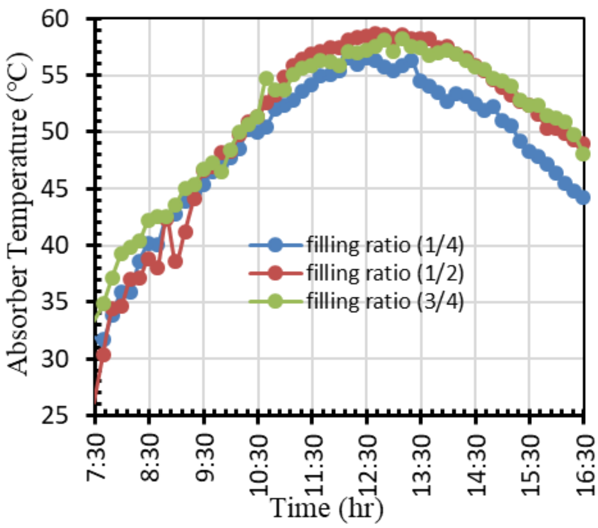


Fig. 10. Variation of absorber temperatures with time at different filling ratios

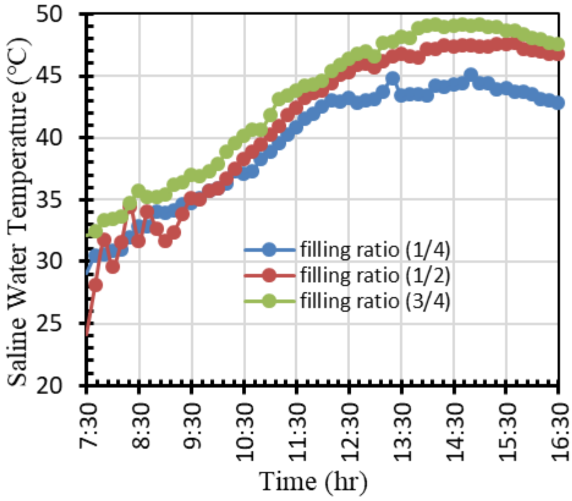


Fig. 11. Variation of saline water temperatures with time at different filling ratios

The variation of vapor temperature with time for the three cases is shown in Fig. 12. All the curves follow the same trend as the saline water, and the maximum values are41.5, 45.5 and 46.5 °Cfor ¼, ½ and ¾ filling ratios respectively.

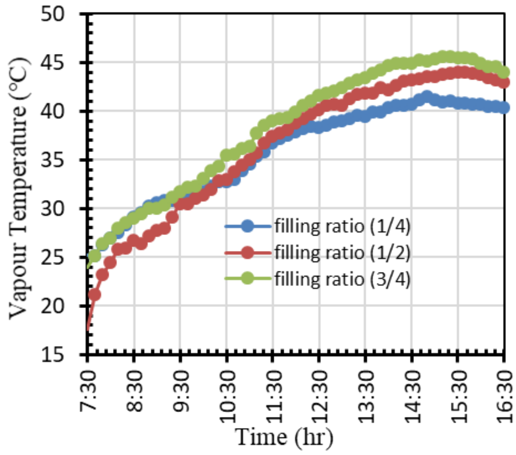


Fig. 12. Variation of vapour temperature with time at different filling ratios

The pressure in the condenser is high for the ¾ case as shown in Fig. 13, for the other two cases, the curves follow the same trend as vapour temperature and the lowest pressure is at ¼ filling ratio. The maximum measured values of the pressure for ¼, ½ and ¾ are 0.09, 0.1 and 0.11 (bar) absolute respectively.

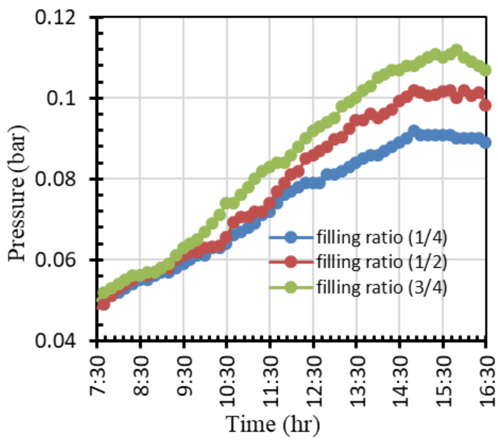


Fig. 13. Variation of condenser pressure with time at different filling ratios

The instantaneous productivity, shown in Fig. 14, indicates that during the period of the measurements, the productivity is the same for the three cases. The maximum productivity for the three cases reaches values of 848, 832 and 657 ml every half an hour (1696, 1664 and 1314 ml/h.) respectively.The cases of ¼ and ½ filling ratio have nearly the same instantaneous productivity which is obviously higher than the third case. In cases of ½ and ¼ the distance travelled by bubbles and water within the pipes is higher than in the cases of ¾ filling ratio. The amount of water contained in the pipes of the evaporator is smaller in case of ¼ filling ratio than ¾ filling ratio so the amount of evaporated water is higher for the case of ¼ filling ratio than the ¾ filling ratio at the nearly the same rate of heat absorbed. The lumped thermal capacity is small in case of ¼ and helps to enhance the evaporation.

The cumulative productivity for the three cases is shown in Fig. 15. The value of the cumulative productivities for three cases ¼, ½ and ¾ are 9.8, 9.3, 8 l/m^2.day respectively.

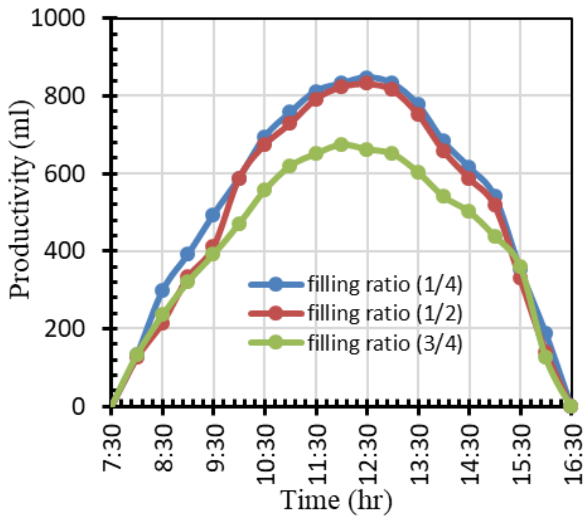


Fig. 14. Variation of instantaneous productivity with time at different filling ratios

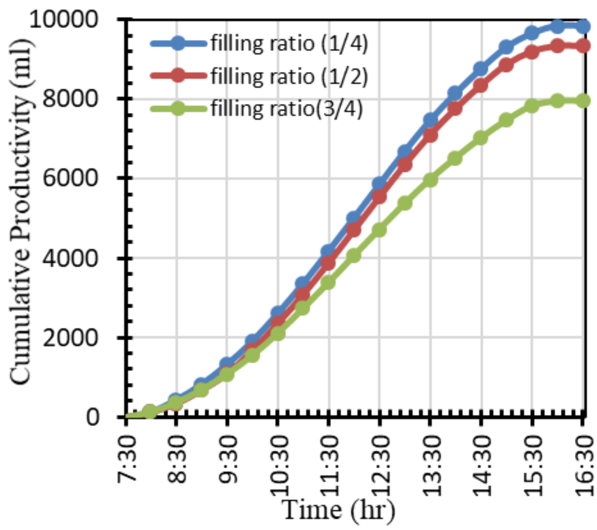


Fig. 15. Variation of cumulativeproductivity with time at different filling ratios

The system performance ratio (PR) has been used to assess the performance of the desalination process. The performance ratio is defined as,

$$PR = \frac{m_{ev} h_{fg} (T_{salinewater} \quad)}{I_T A}$$

Where m_{ev} is the mass rate of distillate (kg/s), h_{fg} is the latent heat of vaporization (kJ/kg) at the temperature (T), I_T is total solar radiation (W/m^2), and A is the collection area (m^2).

Fig. 16 presents the variation of cumulative productivity with time of day for the three filling ratios. All cases experience consistent pattern of change and their values are almost equal. The highest performance ratio is obtained for ¼ filling ratio. The average performance ratio for three cases ¼, ½ and ¾ are 0.85, 0.77 and 0.68 respectively.

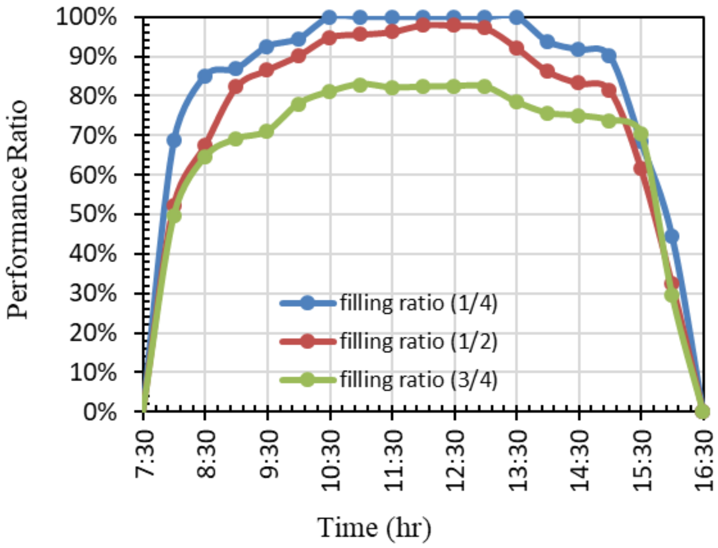


Fig. 16. Variation of performance ratio with time at different filling ratios

3.3 Effect of Water Salinity on System Performance

Better system performance is achieved at evaporator filling ratio of one fourth (¼) and employing the cooling flow rate of 2 l/min Therefore, the effect of initial salt concentration of the saline water is examined under these conditions in order to verify the technical feasibility of the proposed system. Experiments have been carried out using water salinity of 180, 10000 and 17000 ppm respectively, and the results are shown in Fig. 17. The solar radiation is nearly identical over the three days except the period from 9:30 AM to 12 PM which exhibits some fluctuations for the experiment using salinity of 17000 ppm.The daily average solar radiation for water salinity 180, 10000 and 17000 ppm is 661, 675 and 642 W/m^2 respectively.

The instantaneous productivity curves for the three cases gave the anticipated results. During the whole period of measurements, the three curves are nearly the same, except for the duration of fluctuations from 9:30 A.M to 12:30.P.M. The total productivity of fresh water for three cases 180, 10000 and 17000 are 9.8, 10.14 and 9.15 l/m2.day respectively. This difference is attributed to the fluctuations in solar radiation from 9:30 to 12:30 PM and ambient temperature. Moreover, the performance ratios for the three cases are almost the same during the whole periodof time except for the period of fluctuation. The average performance ratio for three cases is around 81%.

Accordingly, it is concluded that the performance of the system is satisfactory regardless of the initial saline concentration.The condensation process is dependent on the partial pressure of water and it does not greatly differ for different salt concentrations.The fresh water obtained from the system has been analysed, and the total salt concentration in the produced water was about 30 ppm. This value proves that the system can be used efficiently for low or medium demand of potable water.

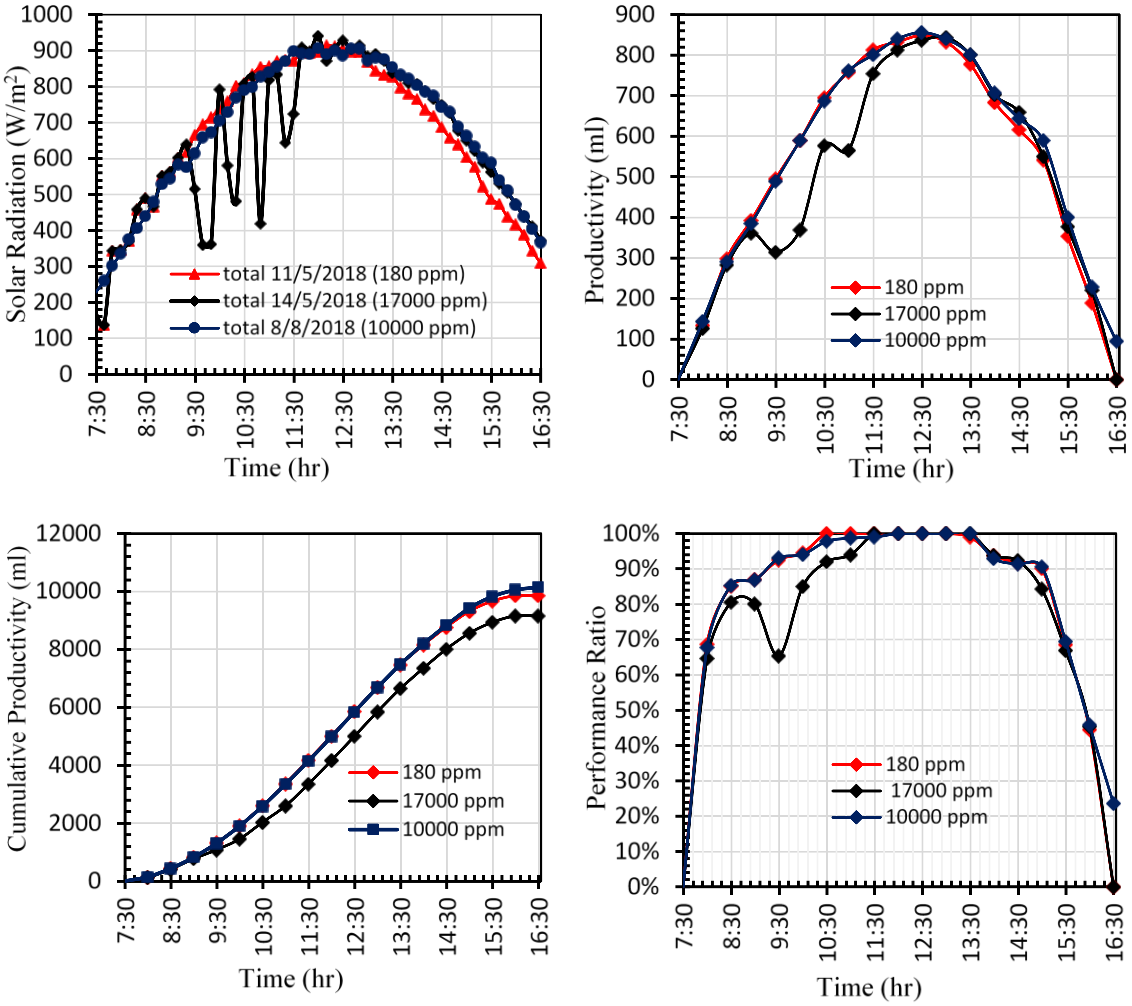


Fig. 17. Effect of water salinity on system performance

IV. Conclusions

Feasibility of round the clock operation of a low temperature desalination system powered by solar energy has been investigated. A novel system has been fabricated, assembled and equipped with necessary measuring devices. An extensive experimental investigation has been carried out to study the systemperformance under actual weather conditions. The effect of flow rate of the cooling medium and the amount of saline water in the evaporator has been investigated. The following conclusions can be drawn from the study:

1) The proposed system can achieve a natural vacuum between 0.07 to 0.114 bars absolute depending on the mode of cooling, and can produce fresh water at a relatively low temperature ranging between 39 to 49 ℃.
2) The average performance ratio for three cases ¼, ½ and ¾ are 0.85, 0.77 and 0.68 respectively.
3) The flow rate of condenser cooling water has been experimented upon and a coolant flow rate of 2 liters/min was found as an optimum value for best operation of the system. The system performance under such conditions was found competivite to other desalination systems utilizing conventional techniques.
4) The system performance depends upon the filling ratio of the evaporator, and it was found out that a filling ratio of ¼ guaranttees a better system performance. Further, to avoid boiling bubbles from reaching the condenser, a liquid separator device between the evaporator and the condenser is a simple and effective remedy for such a possible problem.
5) The feasibility of the system has been proven by producing fresh and potable water from saline water having a total dessolved solid concentration upto 17000 ppm. The salt concentration in the porduced water is around 30 ppm only.

References

[1]. Tarrass, F., and Benjelloun, M., The effects of water shortages on health and human development. Perspectives in public health, 132(5), 2012, 240-244.

[2]. Qasim, M., Darwish, N. A., Sarp, S., and Hilal, N., Water desalination by forward (direct) osmosis phenomenon: A comprehensive review. Desalination, 374, 2015, 47-69.

[3]. Vince, F., Marechal, F., Aoustin, E., and Bréant, P., Multi-objective optimization of RO desalination plants. Desalination, 222(1-3), 2008, 96-118.

[4]. Al-Kharabsheh, S., and Yogi, D., Analysis of an innovative water desalination system using low-grade solar heat. Desalination, 156(1-3), 2003, 323-332.

[5]. Liu, X. H., Zhang, X. C., Fang, Y. Q., and Zhu, M. M., The Natural vacuum desalination technology in seawater desalination. In Applied Mechanics and Materials, 675, 2014, 851-855 Trans Tech Publications.

[6]. Gude, V. G., Nirmalakhandan, N., Deng, S., and Maganti, A., Feasibility study of a new two-stage low temperature desalination process. Energy conversion and management, 56, 2012, 192-198.

[7]. Gude, V. G., Nirmalakhandan, N., Deng, S., and Maganti, A., Low temperature desalination using solar collectors augmented by thermal energy storage. Applied Energy, 91(1), 2012, 466-474.

[8]. Maroo, S. C., and Goswami, D. Y., Theoretical analysis of a single-stage and two-stage solar driven flash desalination system based on passive vacuum generation. Desalination, 249(2), 2009, 635-646.

[9]. Ayhan, T., and Al Madani, H., Feasibilty study of renewable energy powered seawater desalination technology using natural vacuum technique. Renewable energy, 35(2), 2010, 506-514.

[10]. Abutayeh, M., and Goswami, D. Y., Solar flash desalination under hydrostatically sustained vacuum. Journal of Solar Energy Engineering, 131(3), 2009, 031016.

[11]. Abutayeh, M., and Goswami, D. Y., Passive vacuum solar flash desalination. AIChE journal, 56(5), 2010, 1196-1203.

[12]. Ambarita, H., Study on the performance of natural vacuum desalination system using low grade heat source. Case Studies in Thermal Engineering, 8, 2016, 346-358.

[13]. Ambarita, H., Ronowikarto, A. D., Siregar, R. E. T., and Setyawan, E. Y., CFD Analysis of Evaporation-Condensation Phenomenon in an Evaporation Chamber of Natural Vacuum Solar Desalination. In IOP Conference Series: Materials Science and Engineering, 300(1), 2018, p. 012058.

M.I. Mahrous. “Effect of Evaporator Filling Ratio on the performance of a Solar Driven Natural Vacuum Desalination System.” IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) , vol. 16, no. 2, 2019, pp. 20-31