تحت رعاية معالي رئيس مجلس الوزراء المصري المهندس شريف إسماعيل
مؤتمر تحلية المياه الحادي عشر في البلدان العربية
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Design and fabrication of a portable solar powered desalination (SPD) system for remote areas in Saudi Arabia

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Personal profile

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Higher educational

- B.Sc. In Chemical Engineering, Chemical Engineering Department, Sepuluh Nopember Institute of Technology (ITS), Surabaya, Indonesia
- M.Sc. In Chemical Engineering, Chemical Engineering Department, King Saud University, Riyadh, Saudi Arabia

Research accomplishments

1) (2009 - 2010) – "Characterization and modeling of polymer nanocomposites prepared by melt blend method" **CEREM@King Saud University**, Riyadh.
2) (2011) – "Development and Evaluation of Polyethylene Film for Covering Greenhouse in Arid Regions" (Review paper), NPST grant by **King AbdulAziz City of Science and Technology (KACST)**, Riyadh.

Research accomplishments

3) (Oct 2010 - March 2011) – “Formation of biodegradable polymeric fine particles by supercritical antisolvent precipitation process” NPST grant by **King AbdulAziz City of Science and Technology (KACST)**, Riyadh.
4) (Aug 2011 – April 2014) – “Development of a portable and automated solar-driven desalination system for remote areas in Saudi Arabia” KSU in collaboration with **Nanyang Technological University**, Singapore.
5) (May 2014 – now) – “Development and evaluation of appropriate flotation reagents for beneficiation of Saudi phosphate ores” KSU in collaboration with **Maaden Phosphate company**, Saudi Arabia.

Publications

A. Chafidz, E.D. Kerme, I. Wazeer, Y. Khalid, A. Ajbar, S.M. Al-Zahrani, *Design and fabrication of a portable and hybrid solar-powered membrane distillation system*, Journal of Cleaner Production, 133 (2016) 631-647. (IF=4.959)

A. Chafidz, S. Al-Zahrani, M.N. Al-Otaibi, C.F. Hoong, T.F. Lai, M. Prabu, *Portable and integrated solar-driven desalination system using membrane distillation for arid remote areas in Saudi Arabia*, Desalination, 345 (2014) 36-49.(IF=4.412)

A. Chafidz, S. Al-Zahrani, C.F. Hoong, T.F. Lai, M. Prabu, *An integrated solar-driven desalination system using Vacuum-Multi Effect Membrane Distillation (V-MEMD) process*, Journal of Selcuk University Natural and Applied Science, (2013) 346-353.

A. Chafidz, S. Al-Zahrani, *Portable Solar-Powered Desalination Unit for Remote Areas in Saudi Arabia*, Arab Water World Magazine, CPH World Media, Lebanon, 2013, pp. 38-39.

Earth's water distribution

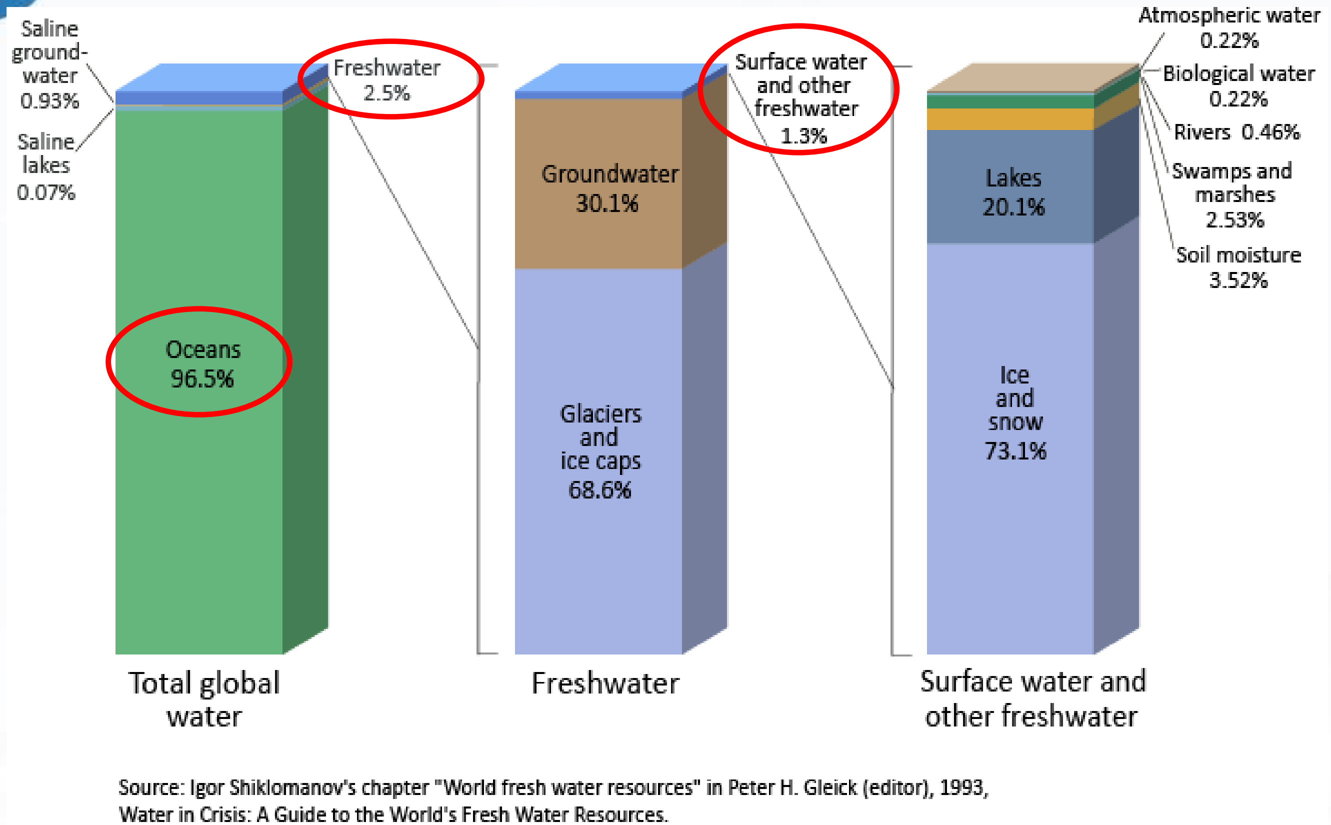
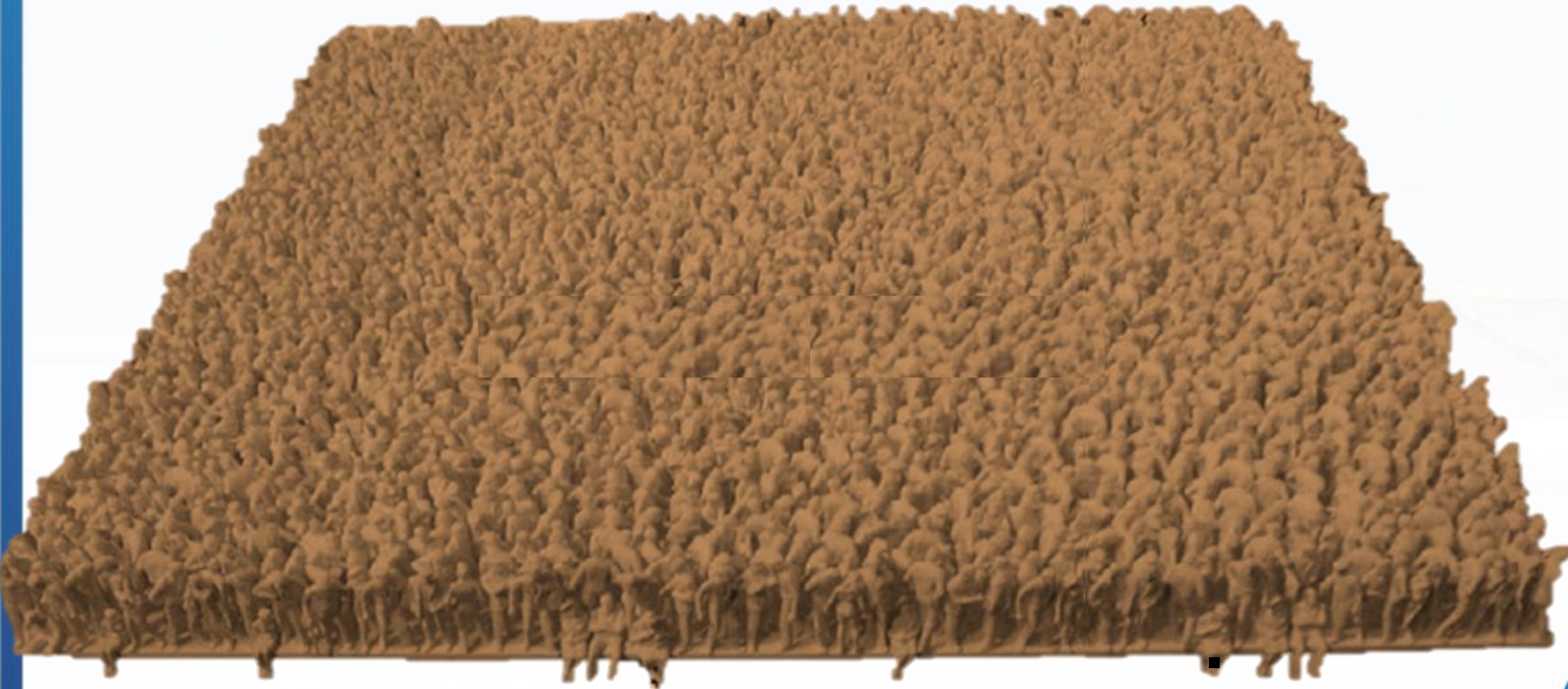


Figure 1. Distribution of Earth's water

Water are abundant resources on earth, which covering three-fourths of the earth surface. Unfortunately, about 96% of world's total water supply is seawater and only 0.005% of them are fresh surface water (e.g. rivers, lakes). Freshwater is very important sources, required by humans for drinking, agriculture, industry and any other purpose.

World population

Today, more people live on this world than ever died on it!

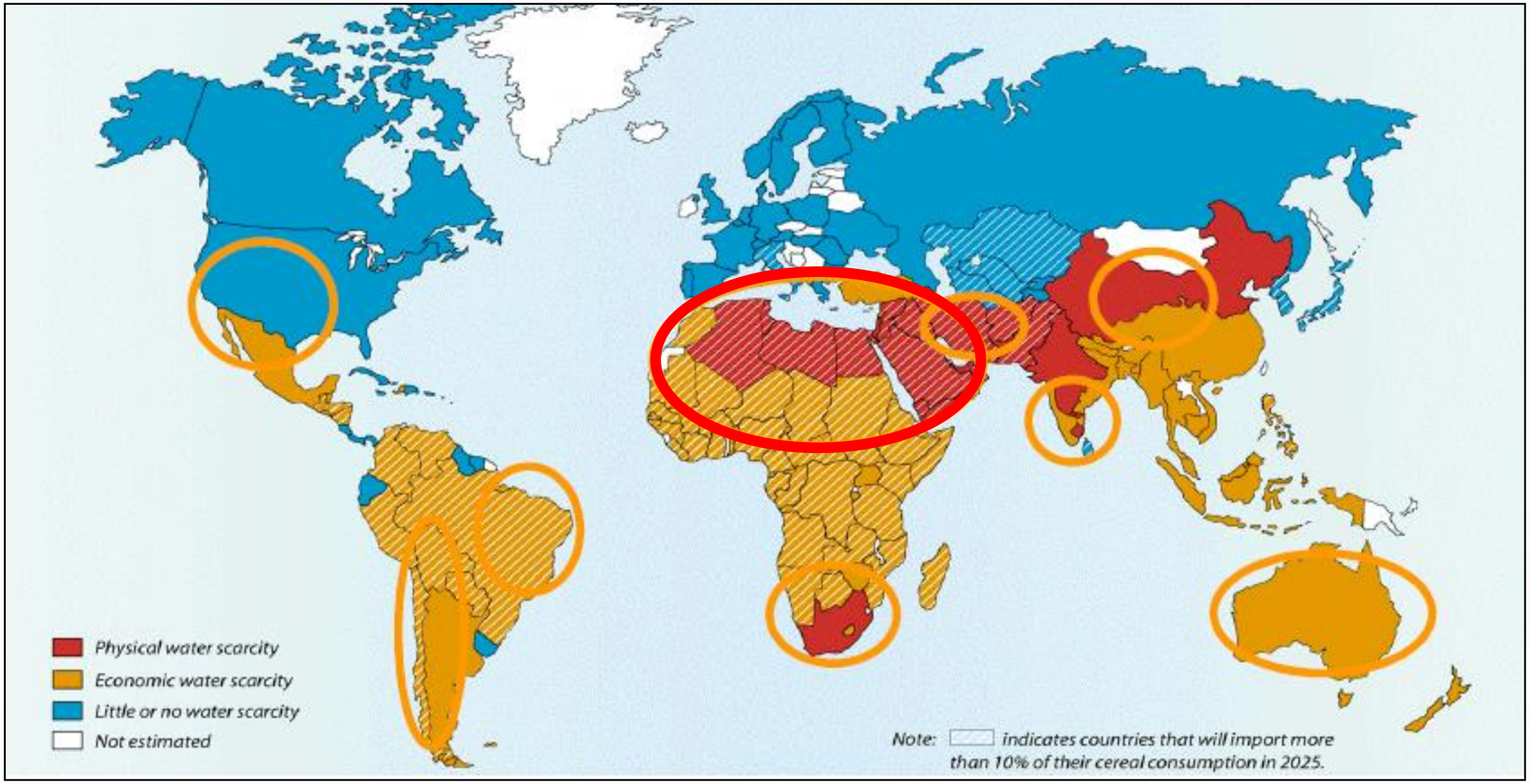


Population growth will decrease fresh water per capita availability

Water exploitation and pollution

Rapid industrial expansion have resulted in large exploitation of freshwater. Also the pollution of water resources by industrial wastes discharge, which may cause freshwater shortage.

Global water scarcity



Source: http://images.organicjar.com/wp-content/uploads/2009/07/water_scarcity.jpg

Figure 2. Global water scarcity across the world

As noticed in the figure, Saudi Arabia and other Middle East and North Africa (MENA) countries are facing physical water scarcity.

Desalination

Figure 3. Desalination plant in Saudi Arabia

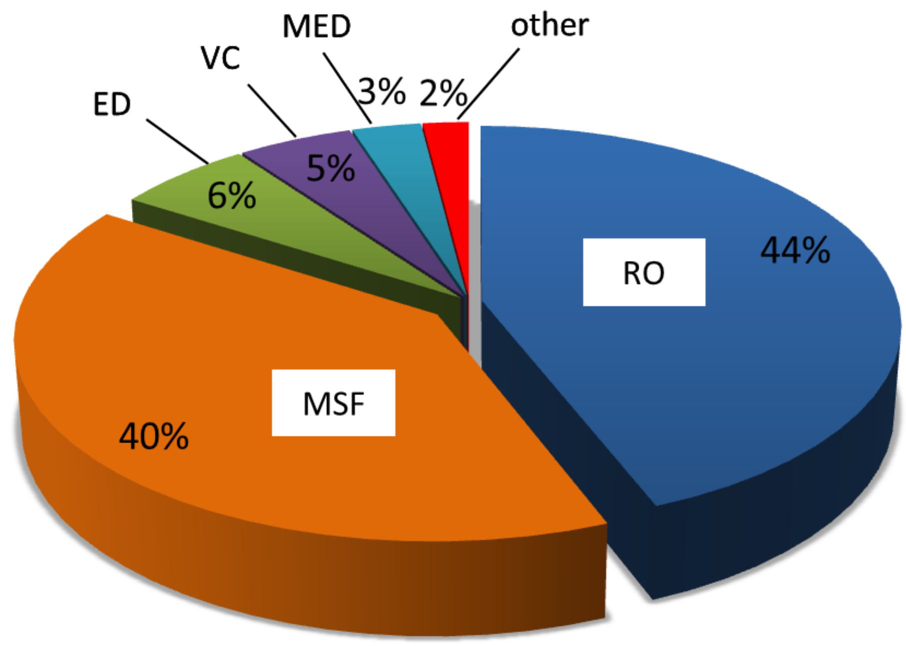


Figure 4. World's installed desalination plant by processes

Most promising method to solve this water shortage problem is by desalination process

Saudi Arabia → large-scale desalination plants account for about 24% of total world capacity and most of them are driven by fossil fuels.

Energy crisis

The problem is …

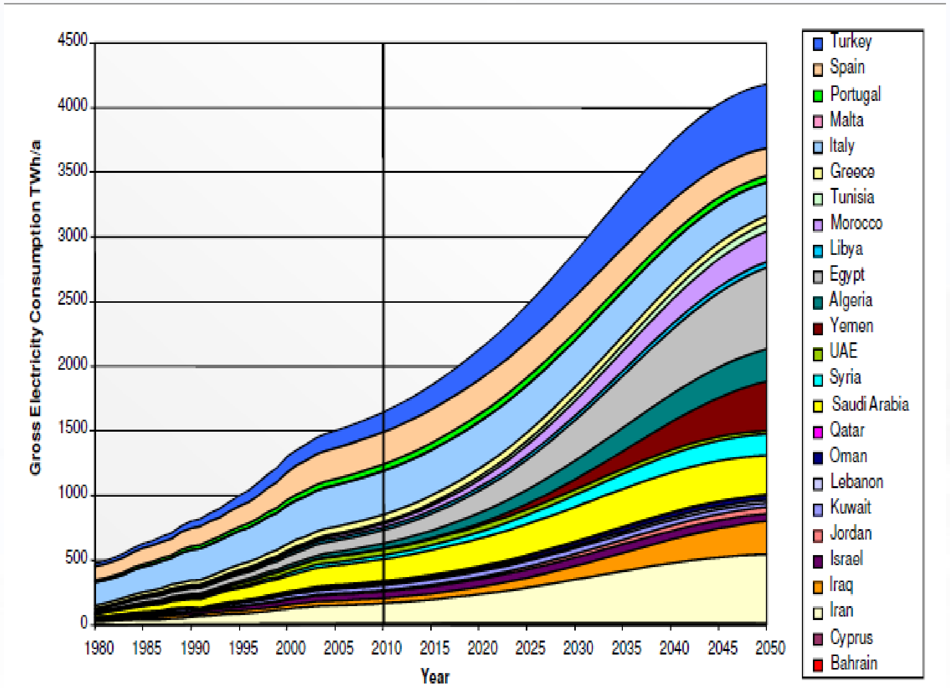


Figure 5. Expected energy demand in EU - MENA

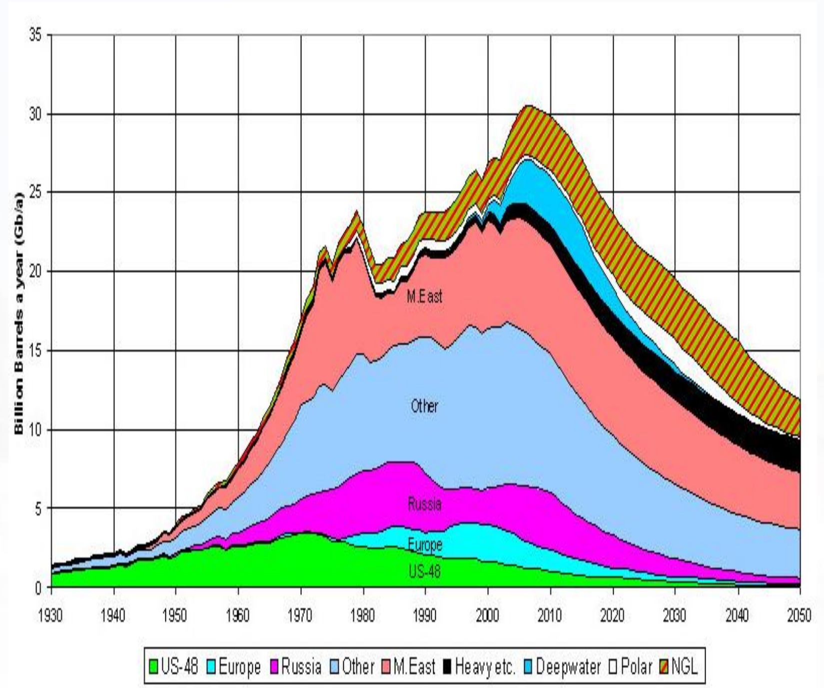


Figure 6. Oil and Gas Liquids – Scenario

Energy demand is multiplying, while fossil resources are depleted → Energy crisis

Renewable energy

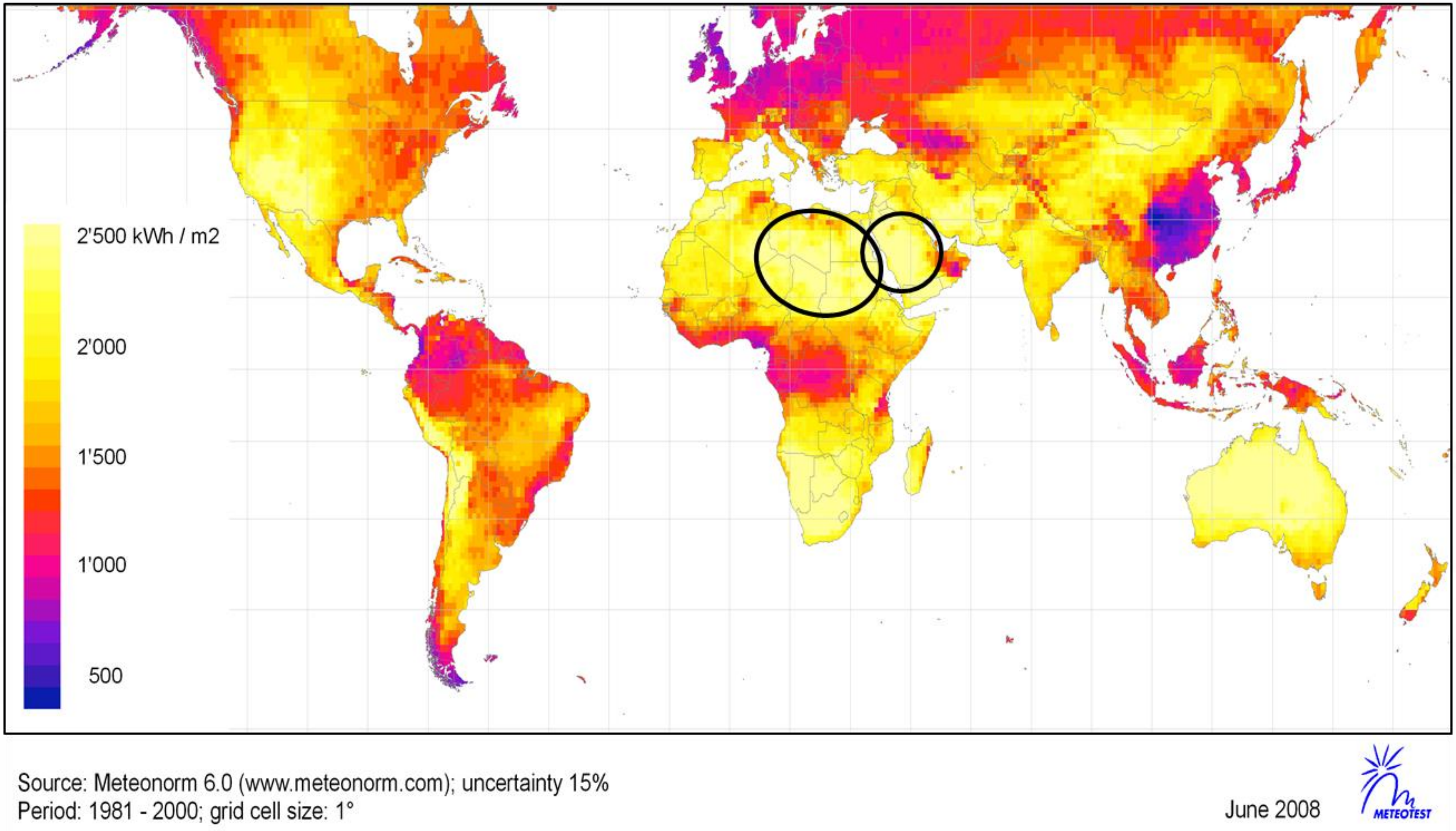
An alternative method ….

Table 1. Yearly estimated potential of different renewable energies

	Gross theoretical useful potential	Technically feasible potential	Current economic potential	Total installed capacity (2003)
Biomass	8-14 TW	6-8 TW	No data	1.6 TW
Hydraulic	4.6 TW	1.6 TW	0.8 TW	0.65 TW
Geothermal	66 TW	11.6 TW	0.6 TW	0.054 TW
Wind	20 TW	2 TW	0.6 TW	0.006 TW
Solar	600 TW	**60 TW**	0.15-7.3 TW	0.005 TW
Ocean	234 TW	No data	No data	-
Total	1030 TW (approx.)	85 (approx.)	7 TW (approx.)	2.3 (approx.)

Source: J. Blanco, et al. Review of feasible solar energy applications to water processes, Renewable and Sustainable Energy Reviews 13 (2009) 1437-1445

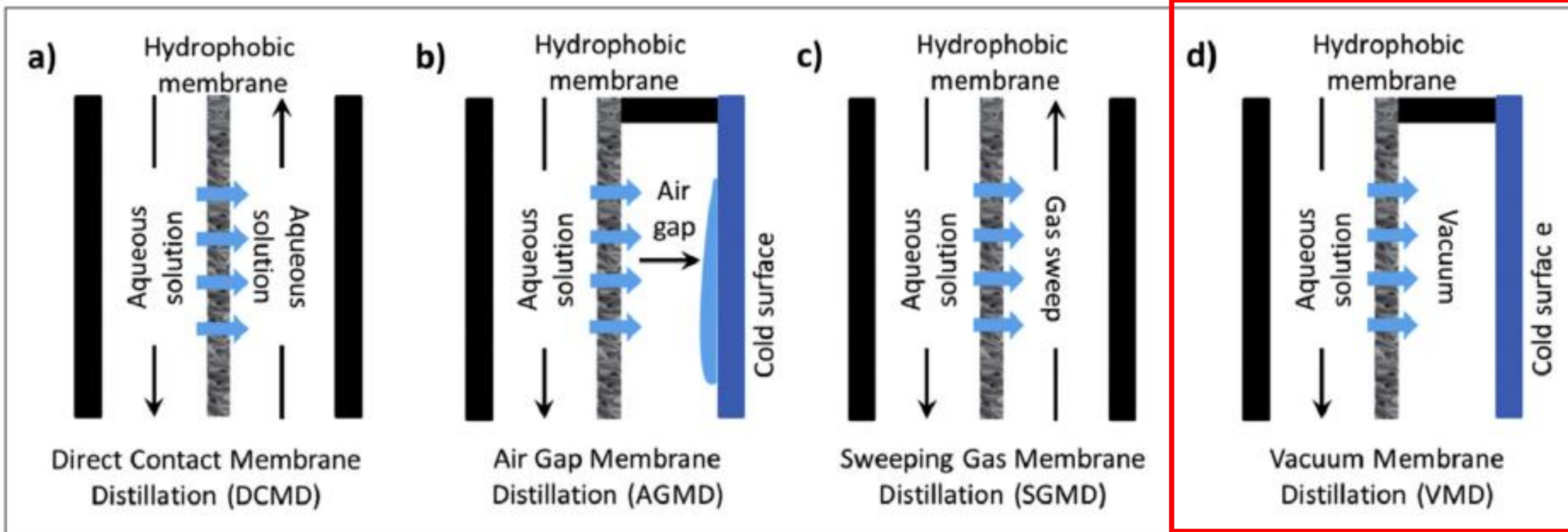
Solar energy potential



Source: http://meteonorm.com/fileadmin/user_upload/maps/world_beam_8100.png

Figure 7. Yearly sum of direct normal irradiance across the world

Membrane distillation



a) DCMD: the permeate side consists of a condensing liquid in direct contact with the membrane
b) AGMD: the condensing (cold) surface is separated from the membrane by an air gap
c) SGMD: the condensing surface is separated from the membrane by a sweeping gas
d) VMD: A vacuum is applied to the permeate side

Figure 8. Schematic diagram of four different configurations of membrane distillation (MD) membrane

One of desalination technologies that is suitable to be applied in remote arid and coastal areas is a membrane distillation (MD).

Membrane distillation (MD) is a hybrid process that combines both thermal distillation and membrane process and it is best described as a trans-membrane evaporation process.

Portable solar-powered desalination system

We have developed a portable and hybrid solar-powered desalination system (SPMD) using MD process. The system covers the two key sources of **water** and **energy**

Figure 9. Picture of the portable solar-driven desalination system (at King Saud University)

The SPMD system is a stand-alone, portable, and hybrid system that works on the zero energy concept. The zero energy concept means that the system does not require external energy sources or electricity from the grid system, thus it is more self-sustainable

Portable solar-powered desalination system

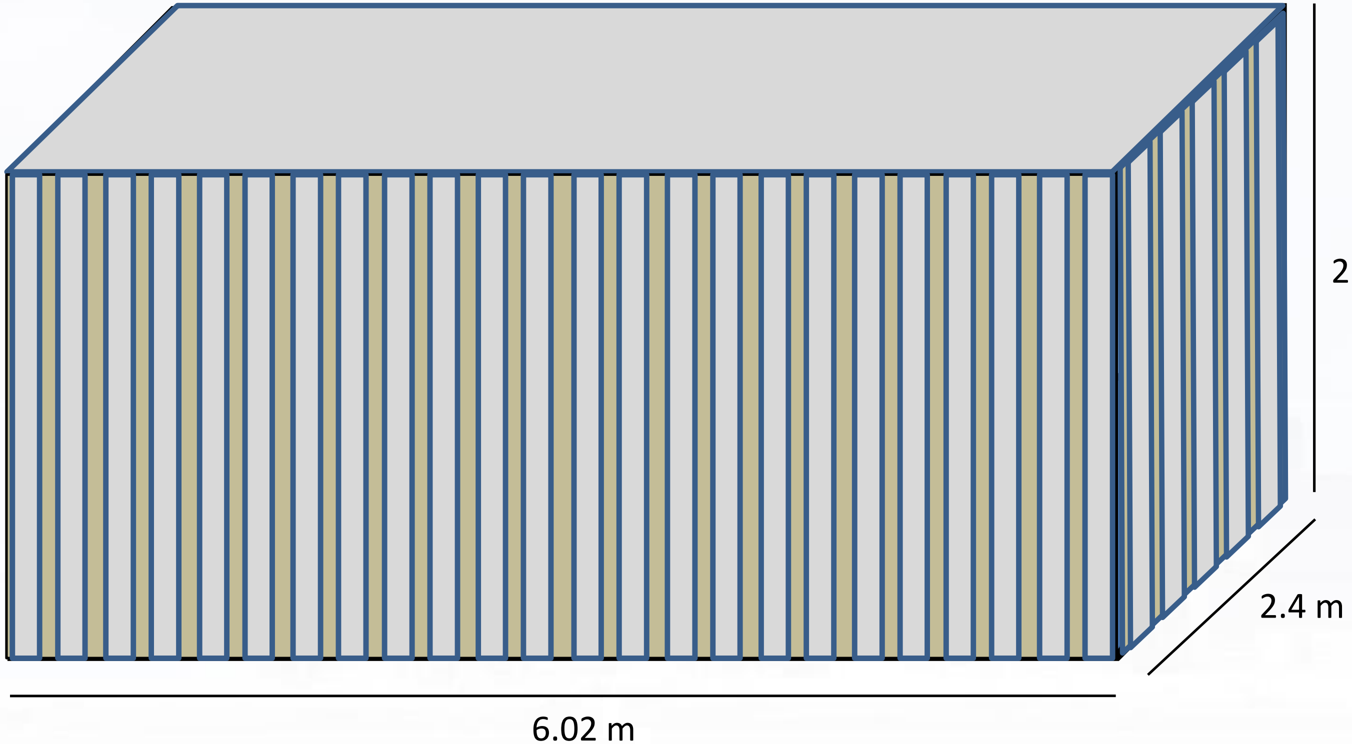


Figure 10. The layout of the container

Ultrafiltration cartridge (pre-filter) Hollow fibre, hydrophilic modified PAN

The system is designed to be able to operate in remote areas. For portability purpose, a typical 20 ft container is used. All the equipment are mounted on the container, even for the seawater tank. The figure shows the layout and dimensions of the container. We also use ultrafiltration cartridge to pre-filter the seawater feed.

Portable solar-powered desalination system

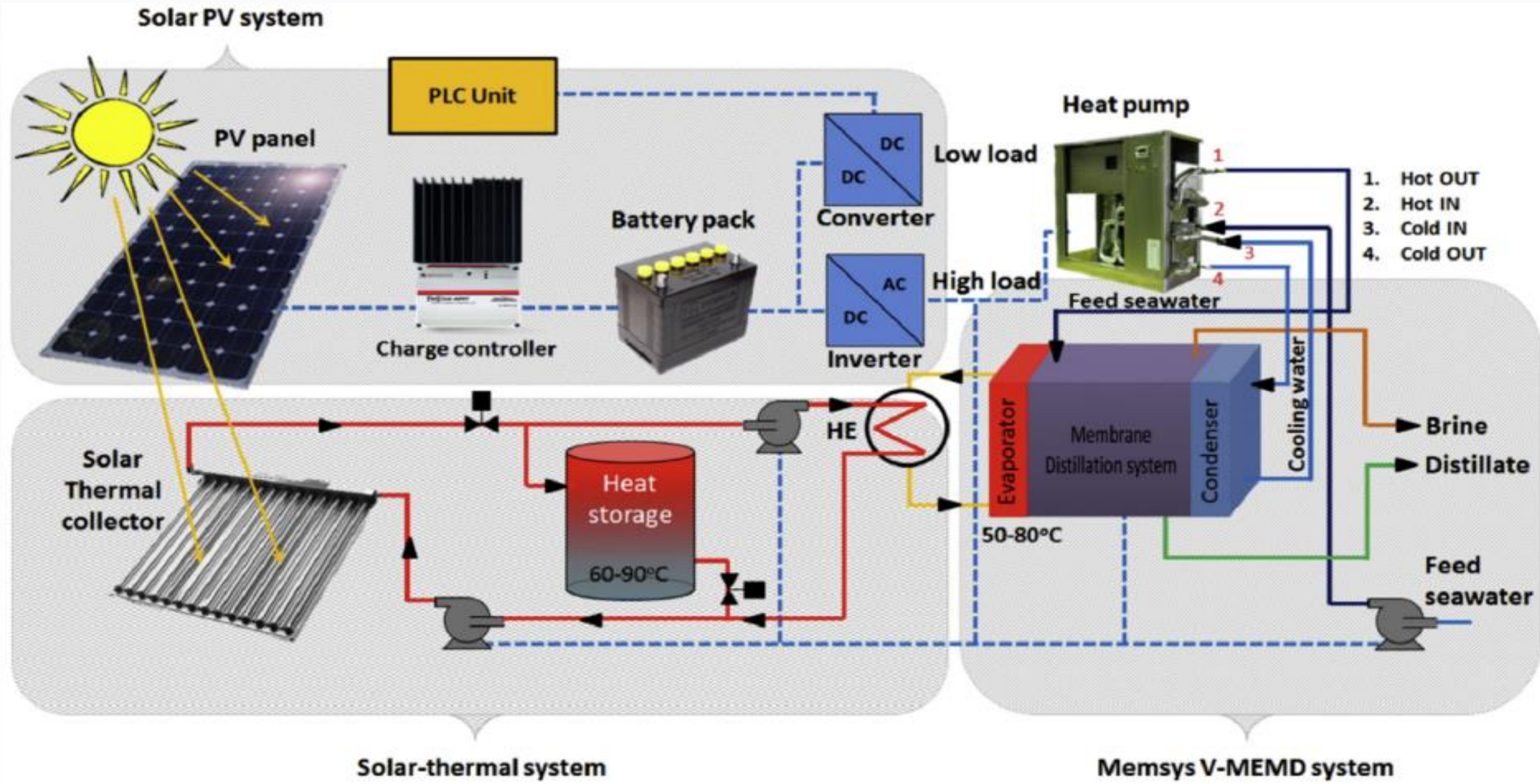


Figure 11. Schematic block diagram of the solar-powered membrane distillation (SPMD) system

The system consists of three major components or subsystems: solar-thermal system, solar photovoltaic (PV) system, and Memsys V-MEMD unit. These components are integrated or interconnected

Schematic diagram of the system

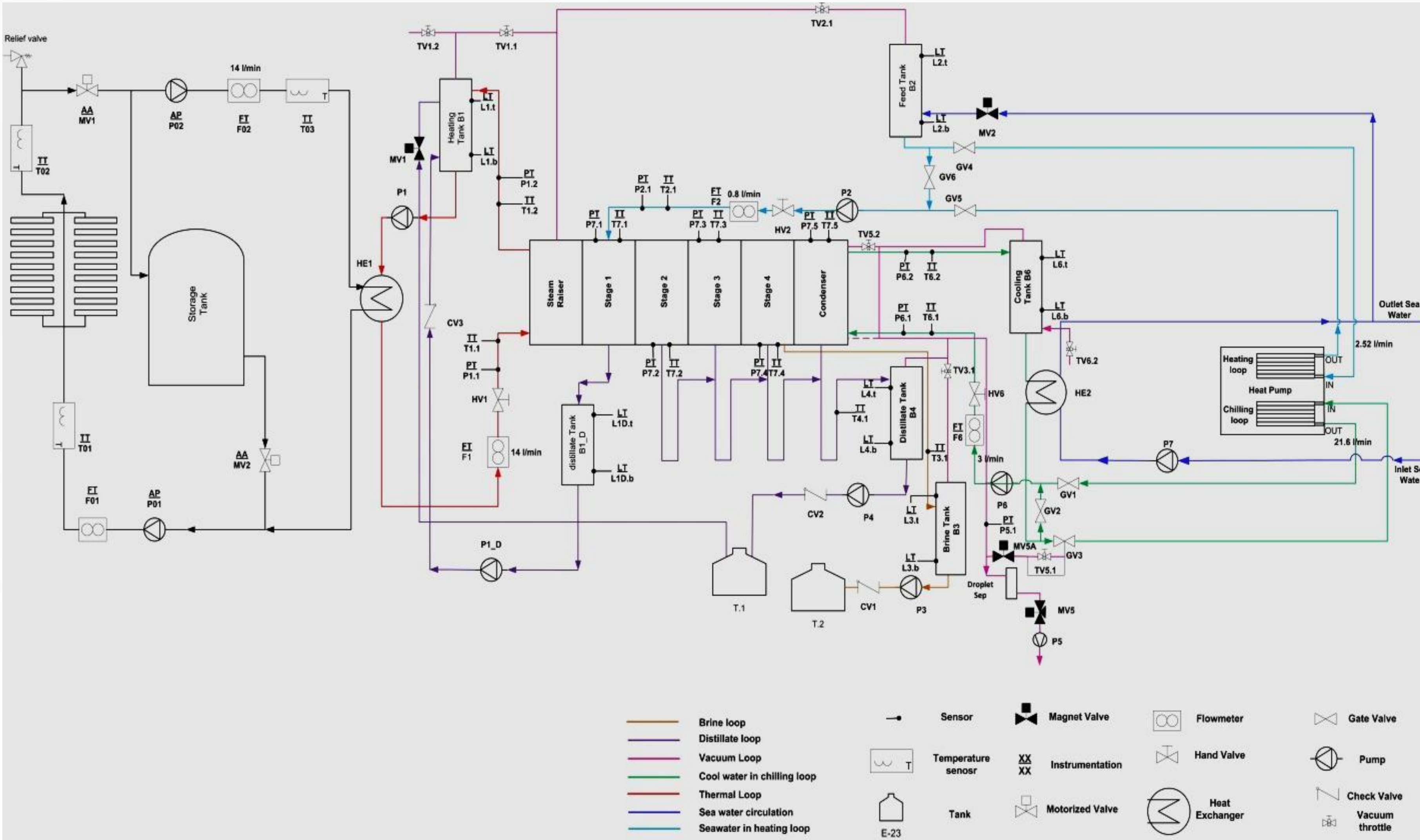


Figure 12. Schematic diagram of solar-powered desalination system

Portable solar-powered desalination system

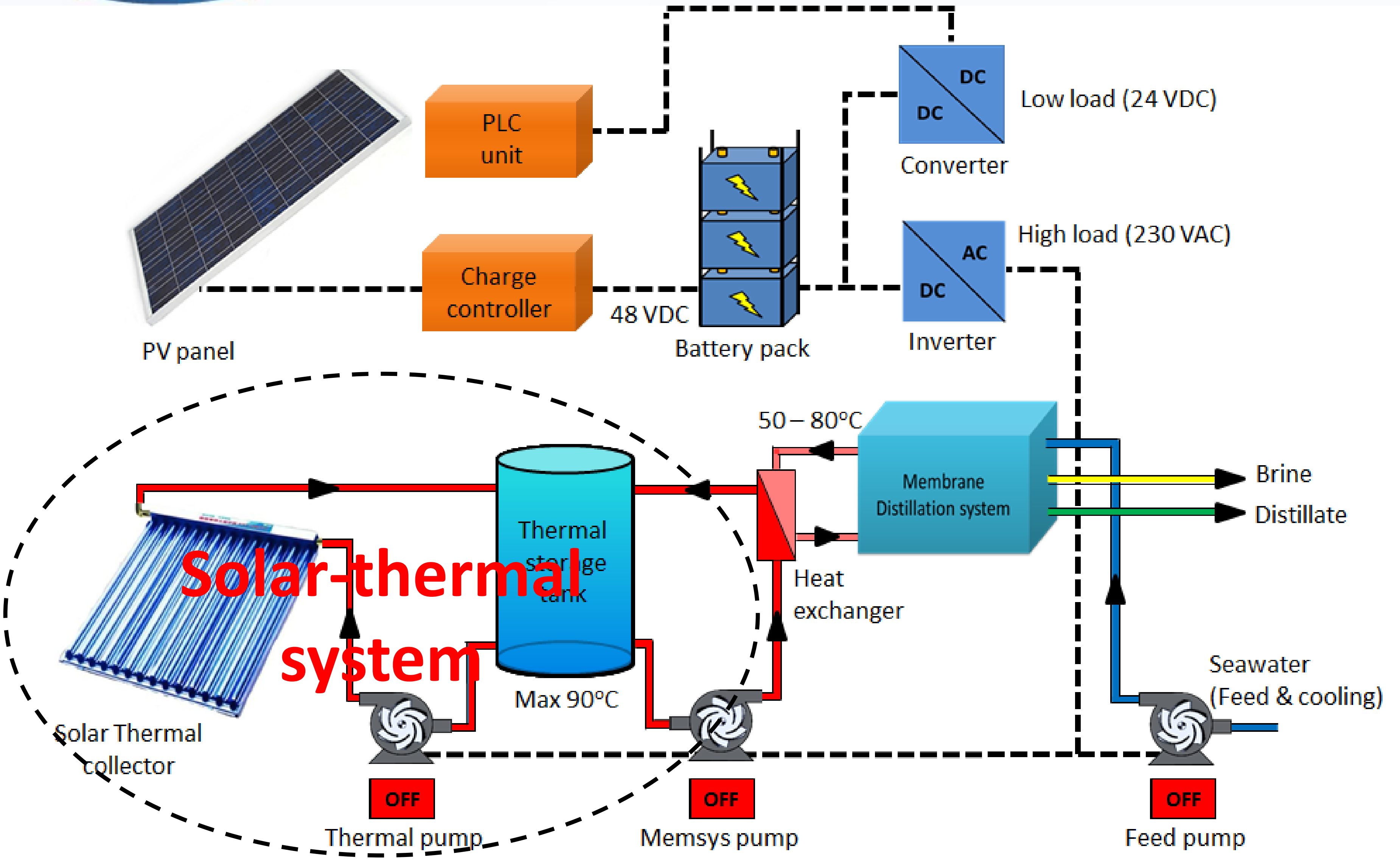


Figure 13. Flow diagram of the portable solar-driven desalination system (simplified)

Solar-thermal system

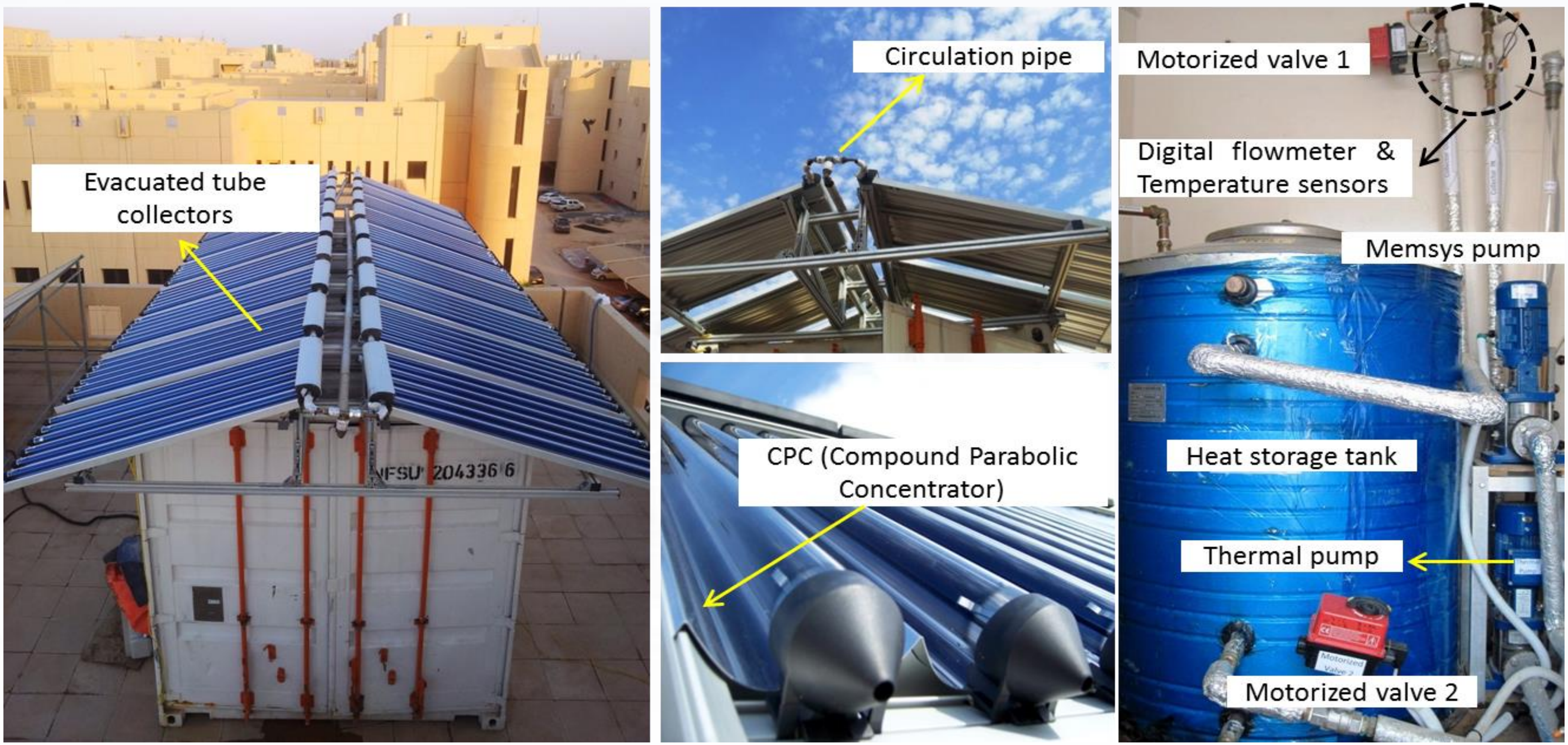


Figure 14. Overview of solar thermal system

The thermal collectors were mounted on the top of the container. The thermal collector used was evacuated tube collector with total of 18 panel. The system also has thermal storage tank, the thermal and memsys pump, two motorized valve, digital flowmeter and temperature sensors

Solar-thermal system

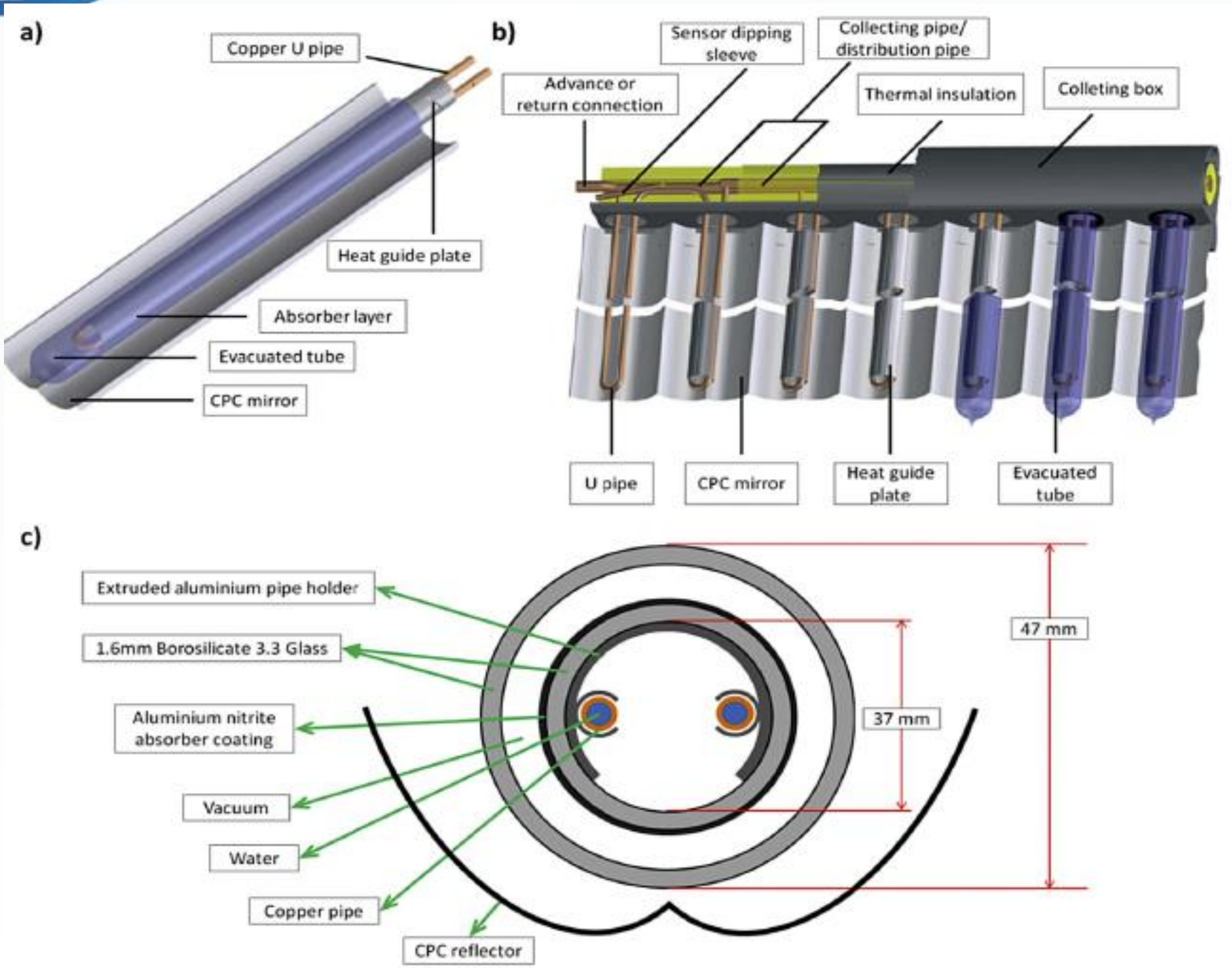


Figure 15. a) A single evacuated tube. **b)** A set of evacuated tubes with collecting box. **c)** A cross-section of evacuated tube and CPC reflector

Portable solar-powered desalination system

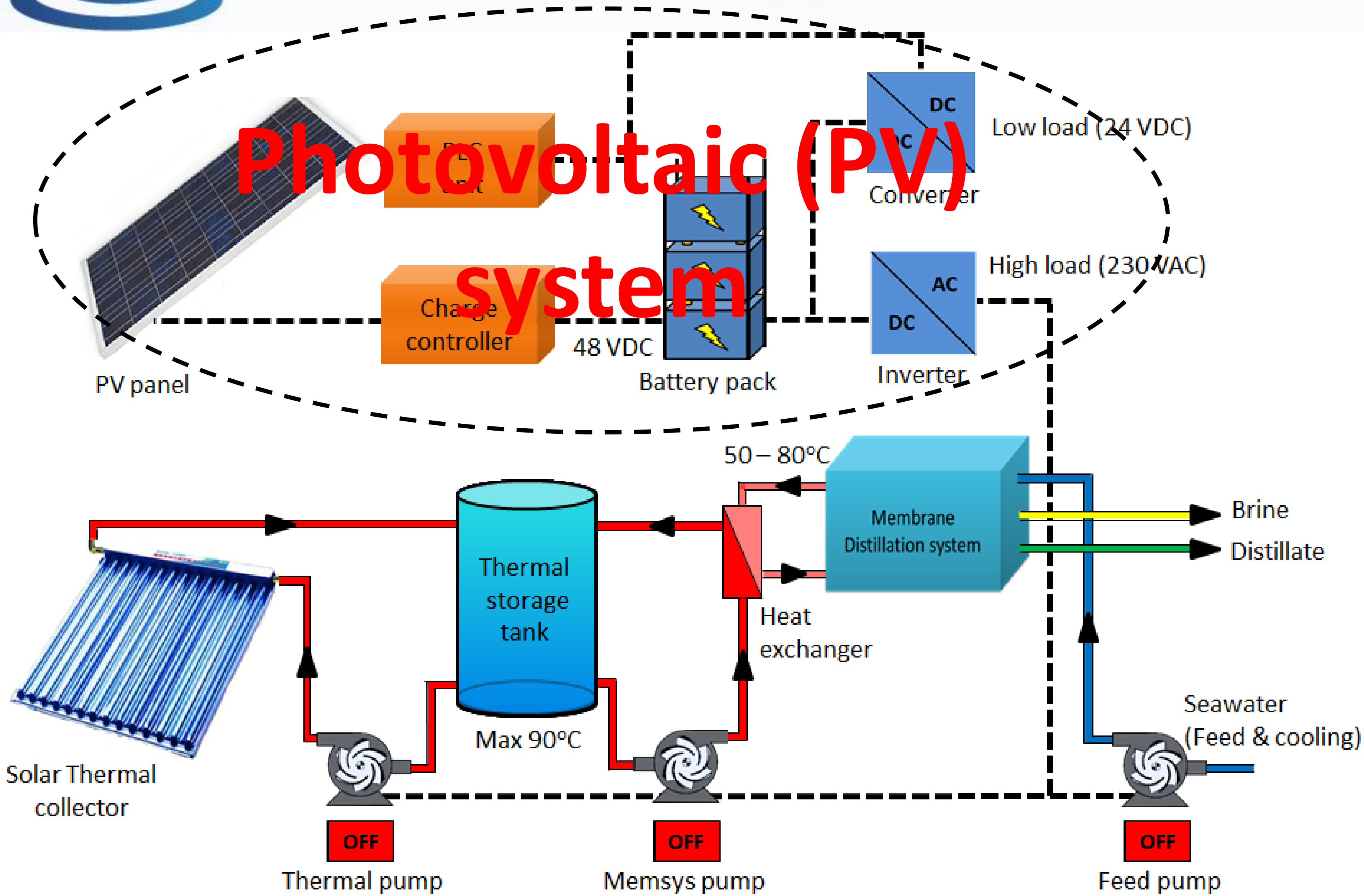


Figure 16. Flow diagram of the portable solar-driven desalination system (simplified)

Solar Photovoltaic (PV) system

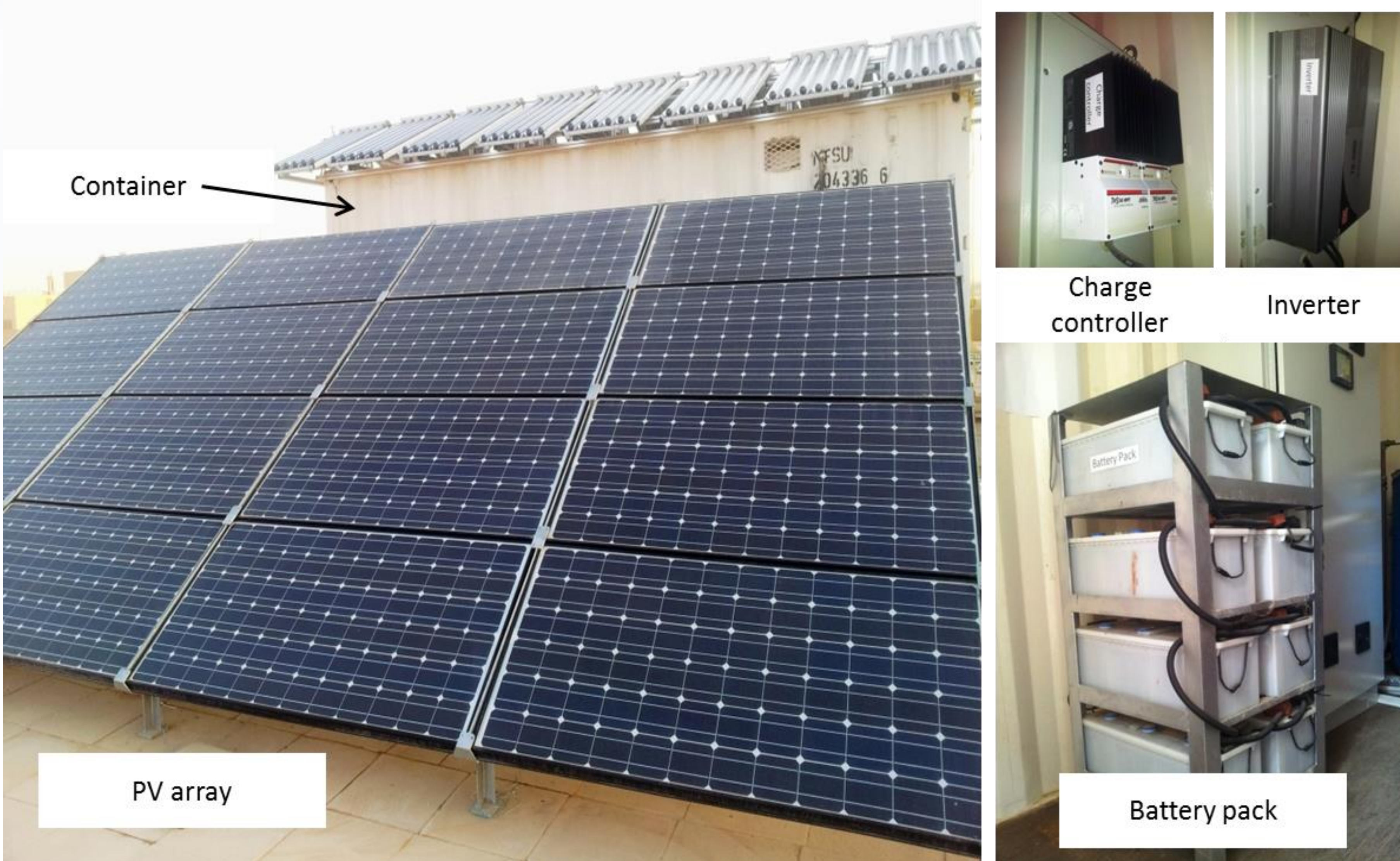


Figure 17. Overview of solar photovoltaic (PV) system

Portable solar-powered desalination system

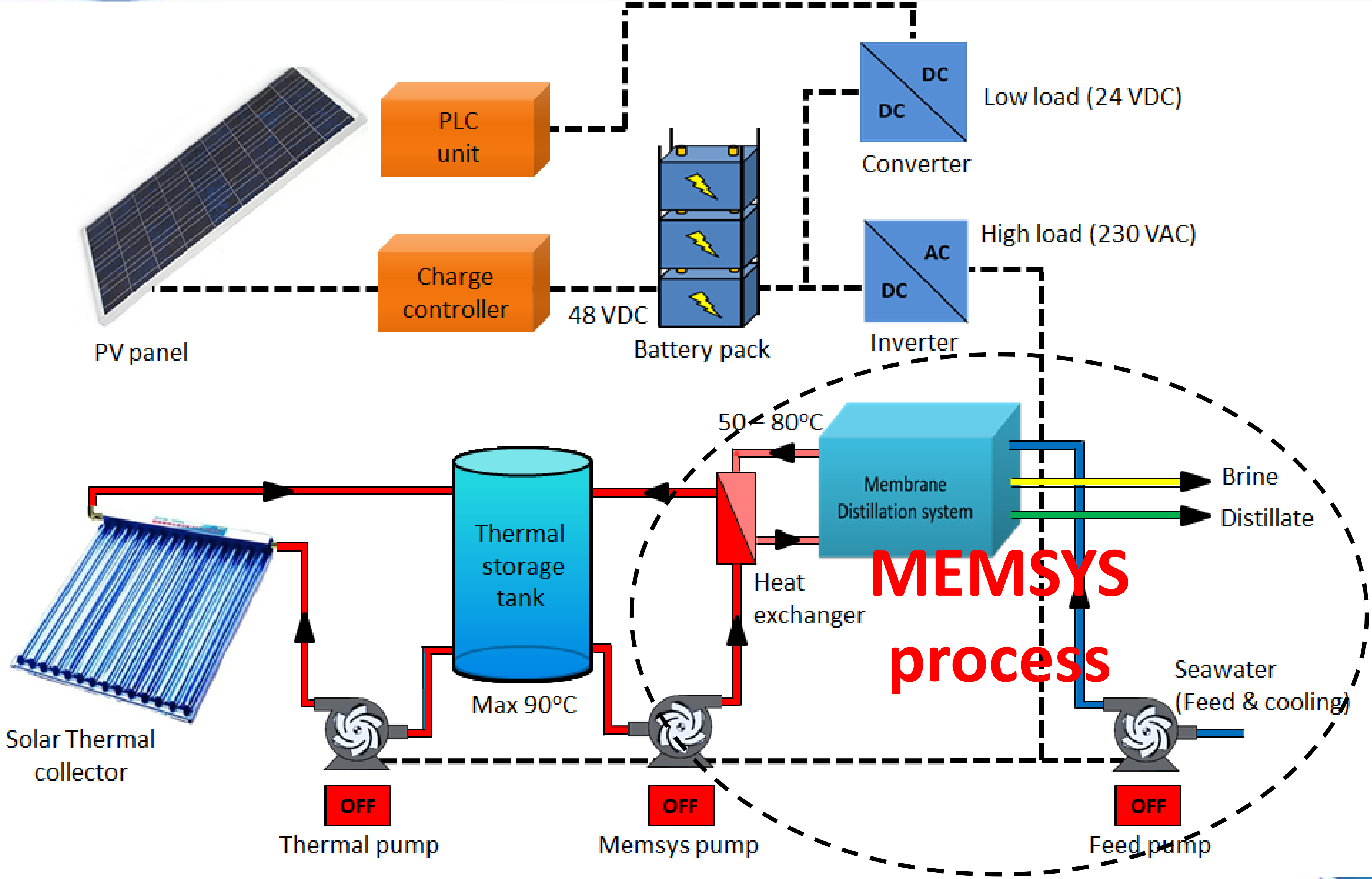
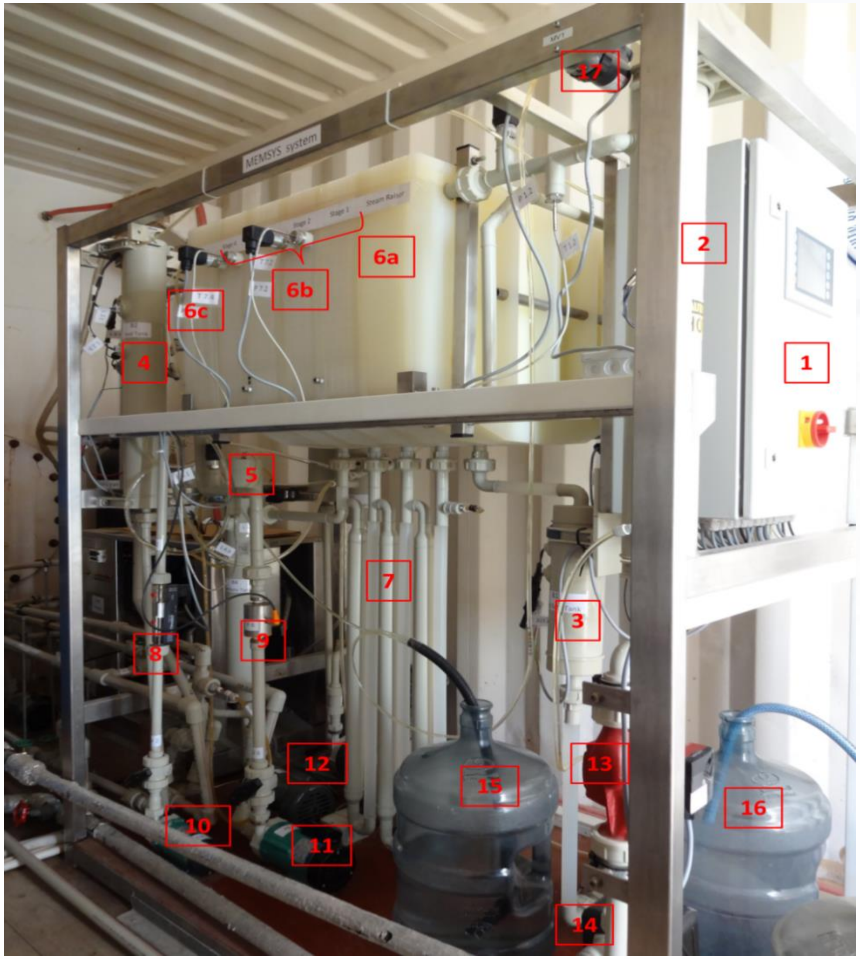


Figure 18. Flow diagram of the portable solar-driven desalination system (simplified)

Memsys Vacuum-Multi Effect Membrane Distillation (V-MEMD) system



No.	Equipment
1.	BnR PLC
2.	Heating tank (B1)
3.	Distillate tank (B1D)
4.	Feed tank (B2)
5.	Distillate tank (B4)
6a.	Steam raiser
6b.	Multi-effect stages
6c.	Condenser
7.	Distillate syphon
8.	Flowmeter feed (F2)
9	Flowmeter cooling loop (F6)
10	Feed pump (P2)
11.	Cooling pump (P6)
12.	Distillate discharge pump (P4)
13.	Heating loop pump (P1)
14.	Heat exchanger (HE2)
15.	Make up water
16.	Distillate collector
17.	Magnetic valve (MV1)

Membrane frame   Foil frame

Figure 19. Overview of Memsys V-MEMD system

Memsys Vacuum-Multi Effect Membrane Distillation (V-MEMD) system

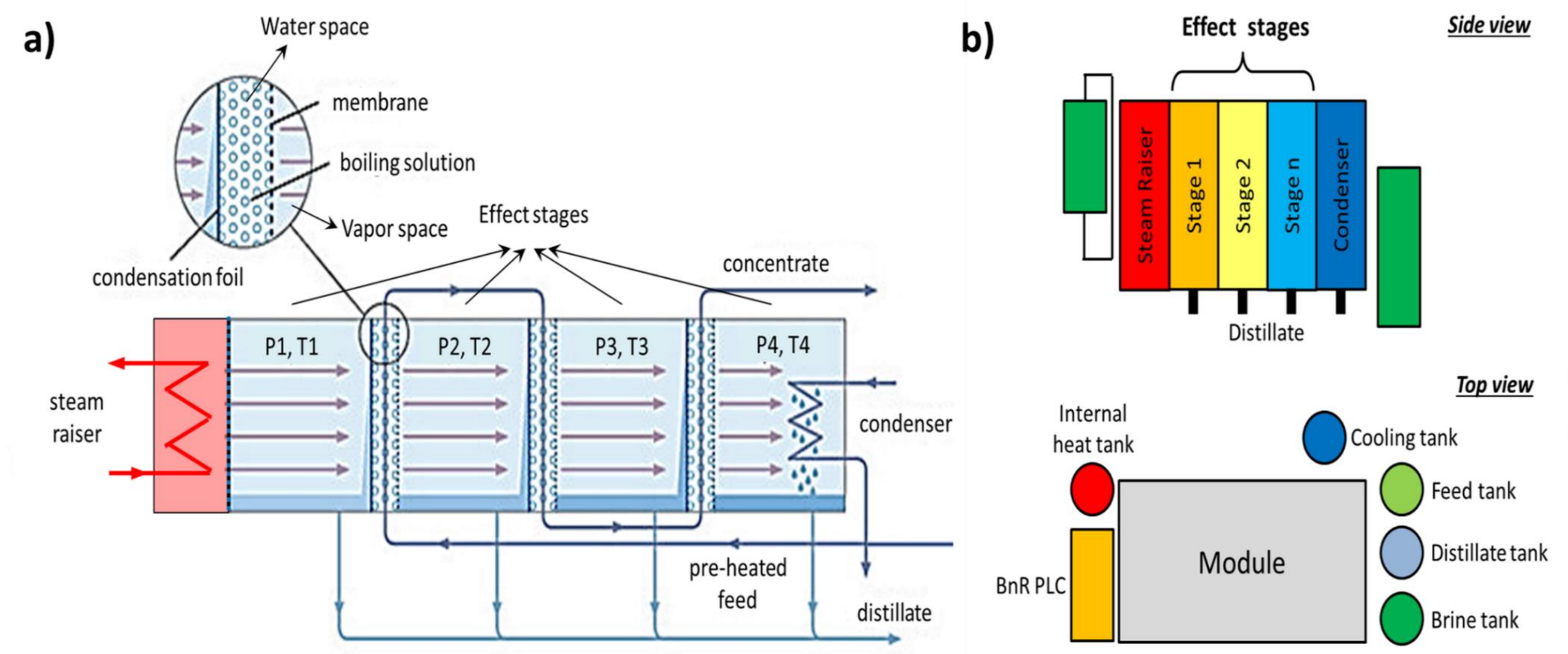
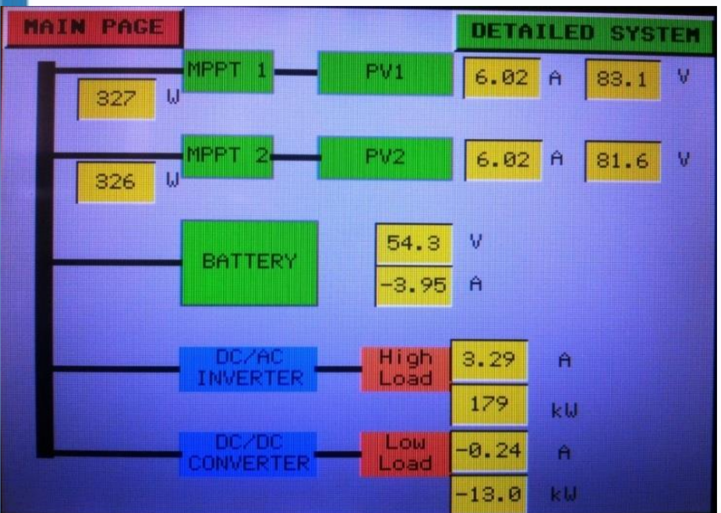


Figure 20. a) Basic principle of the Memsys process b) Schematic views of the Memsys unit (side view and top view)

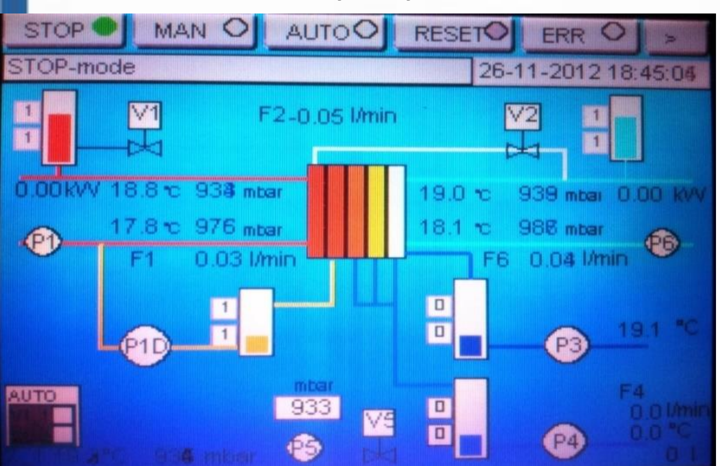
The Memsys unit consists of three main parts: ***steam raiser, condenser, and multiple effect stages***

Energy management by PLC & HMI

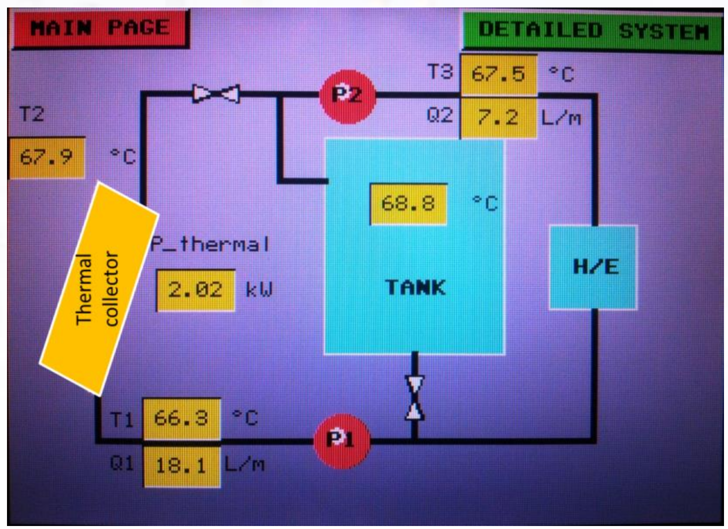
Human Machine Interface (HMI)
Photovoltaic system



Human Machine Interface (HMI)
Memsys sytem



Human Machine Interface (HMI)
Solar-thermal system



PLC Schneider

PLC BnR

Figure 21. Overview of PLC and HMI

Portable solar-driven desalination system

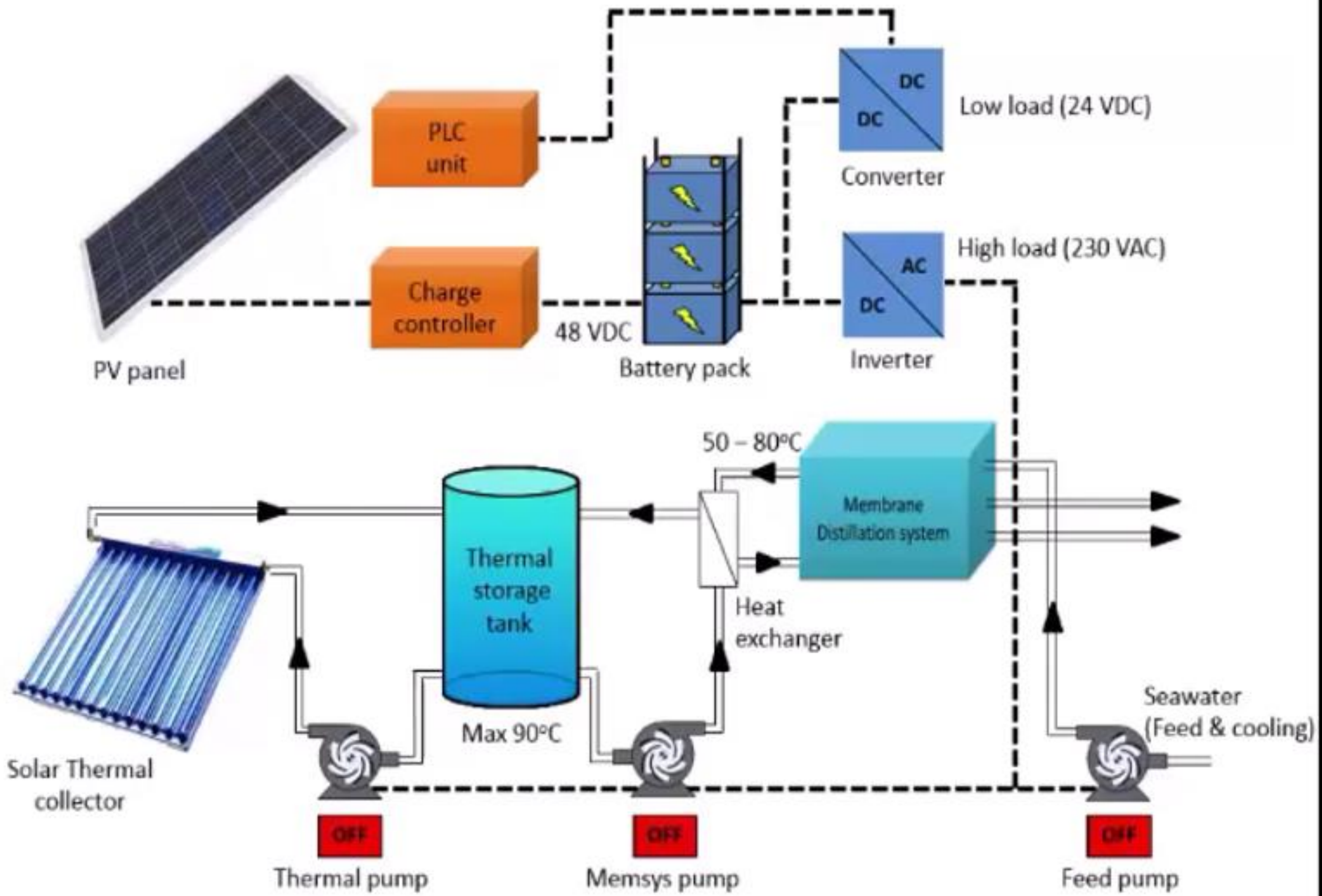
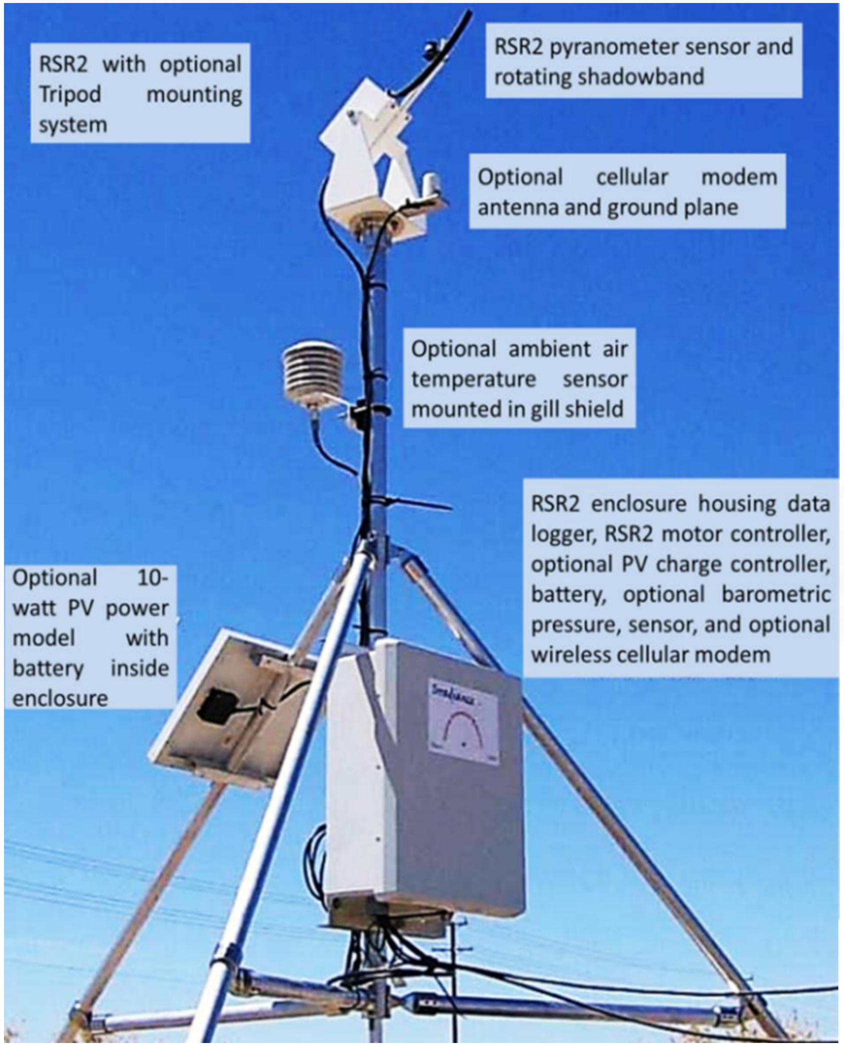


Figure 11. Flow diagram of the portable solar-driven desalination system (simplified)

Advantages of the Memsys process are :

- Energy efficient through multiple recycling of thermal energy
- Robust, because the system is automatically adjusted by the use of PLC and also small tendency for fouling and scaling
- Low operating pressure allows the use of thinner piping and reduces leakage problems and pump failure compared with the RO process
- Low investment cost, through the use of plastic materials
- Low operating cost, because: Low-grade thermal energy can be efficiently used. The electricity required for the pumping is relatively low since the Memsys operates at low pressures. There is no need for expensive water pre-treatment
- Sustainable, because the low temperature requirement makes renewable solar energy is suitable to be combined with the Memsys.
- Environmentally friendly, little needs for chemical pre-treatment of the feed water
- High quality of the distilled water, because only the water vapor can pass through the Memsys membranes
- Wide variety of application due to its modularity and ability to also deal with very highly concentrated salt solution (different solutions).

Small-scale tests of the SPMD system



The portable solar-powered membrane distillation (SPMD) system was temporarily placed on the rooftop of the engineering college building at KSU. Some small-scale tests were conducted to see the performance of the SPMD system.

A Rotating Shadowband Radiometer Irradiance Inc., USA) was used to measure the solar irradiation level.

Figure 22. Photograph of the rotating shadowband radiometer

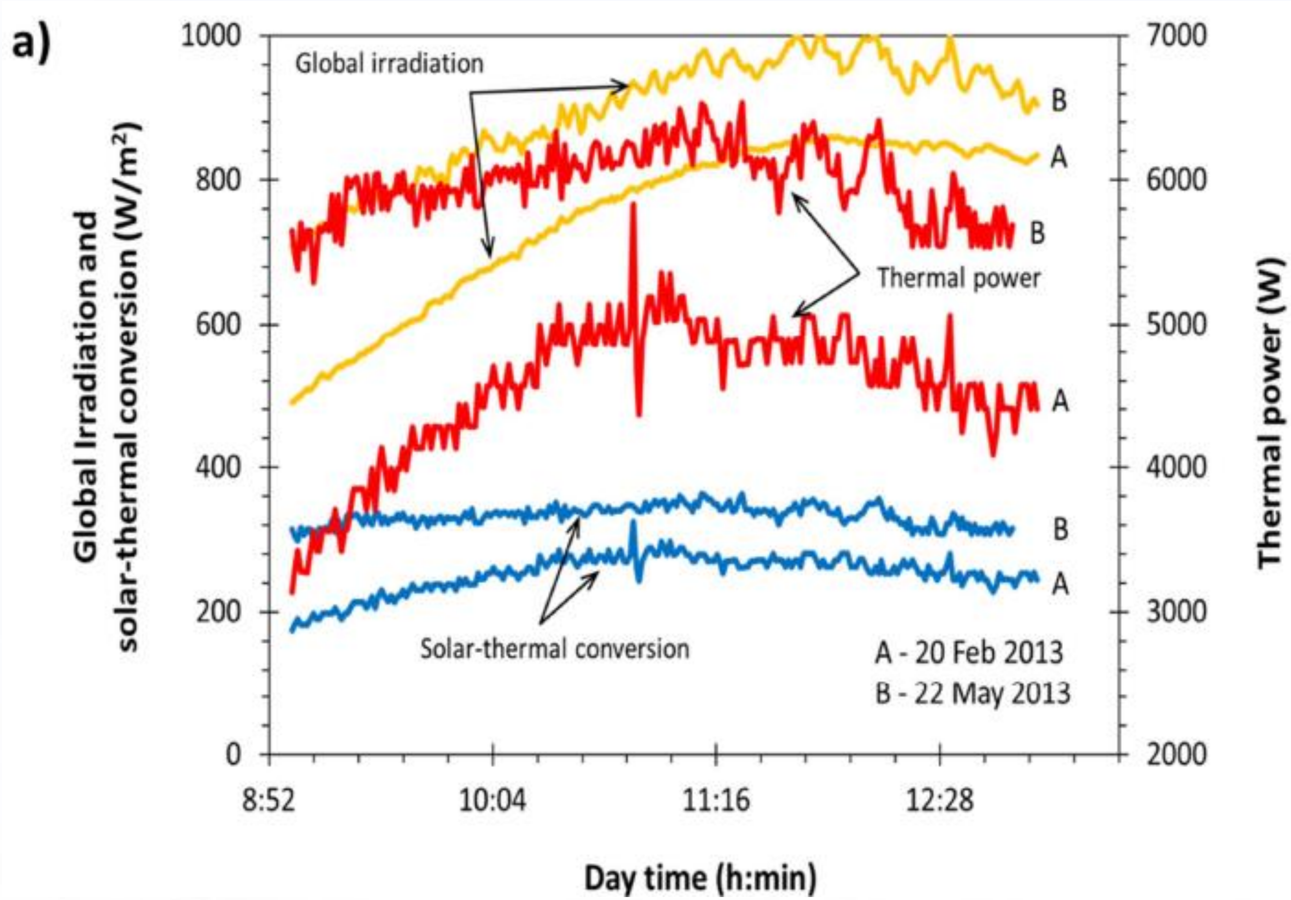


Figure 23. Solar energy harvesting and solar-thermal conversion on two different days (i.e. different global irradiation)

$$Thermal\ \ power[\mathrm{kW}] = \dot{m}_{hf}\left[\frac{\mathrm{kg}}{\mathrm{s}}\right]\cdot C_p\left[\frac{\mathrm{kJ}}{\mathrm{kg\ ^\circ C}}\right]\cdot (T_{out} - T_{in})[^\circ\mathrm{C}]$$

$$solar - thermal\ \ conversion\left(\frac{\mathrm{W}}{\mathrm{m}^2}\right) = \frac{Thermal\ \ power(\mathrm{W})}{Total\ \ aperture\ \ area\ \ of\ \ thermal\ \ collector(18\ \mathrm{m}^2)}$$

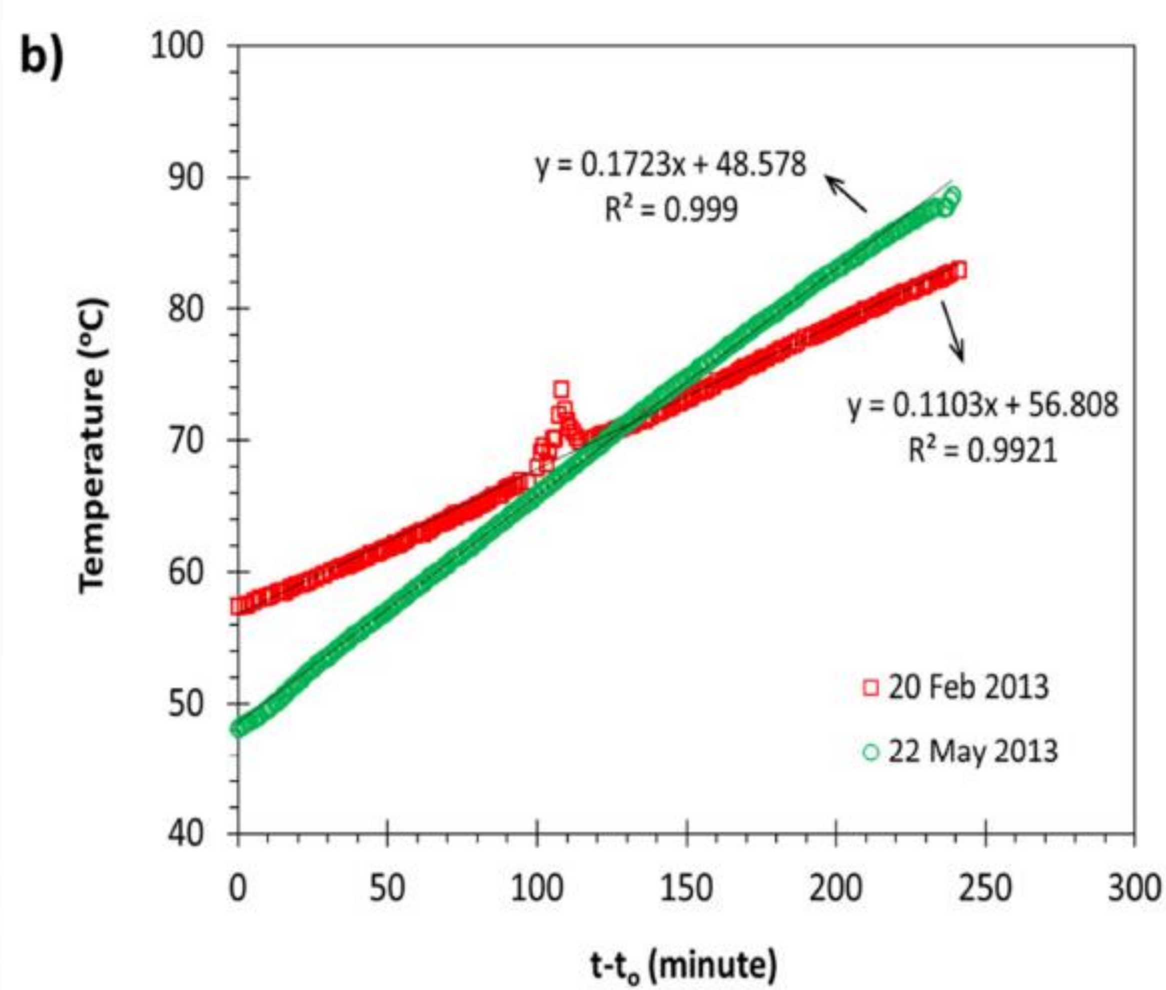


Figure 24. Solar energy harvesting and solar-thermal conversion

Consequently, the increase in the tank temperature (T_Tank) was also higher, as shown in Fig. 16b. The rate of T_Tank increment was approximately about 1.1 ^{o}C and 1.7 ^{o}C per 10 min for the Test on 20 Feb and 22 May, respectively

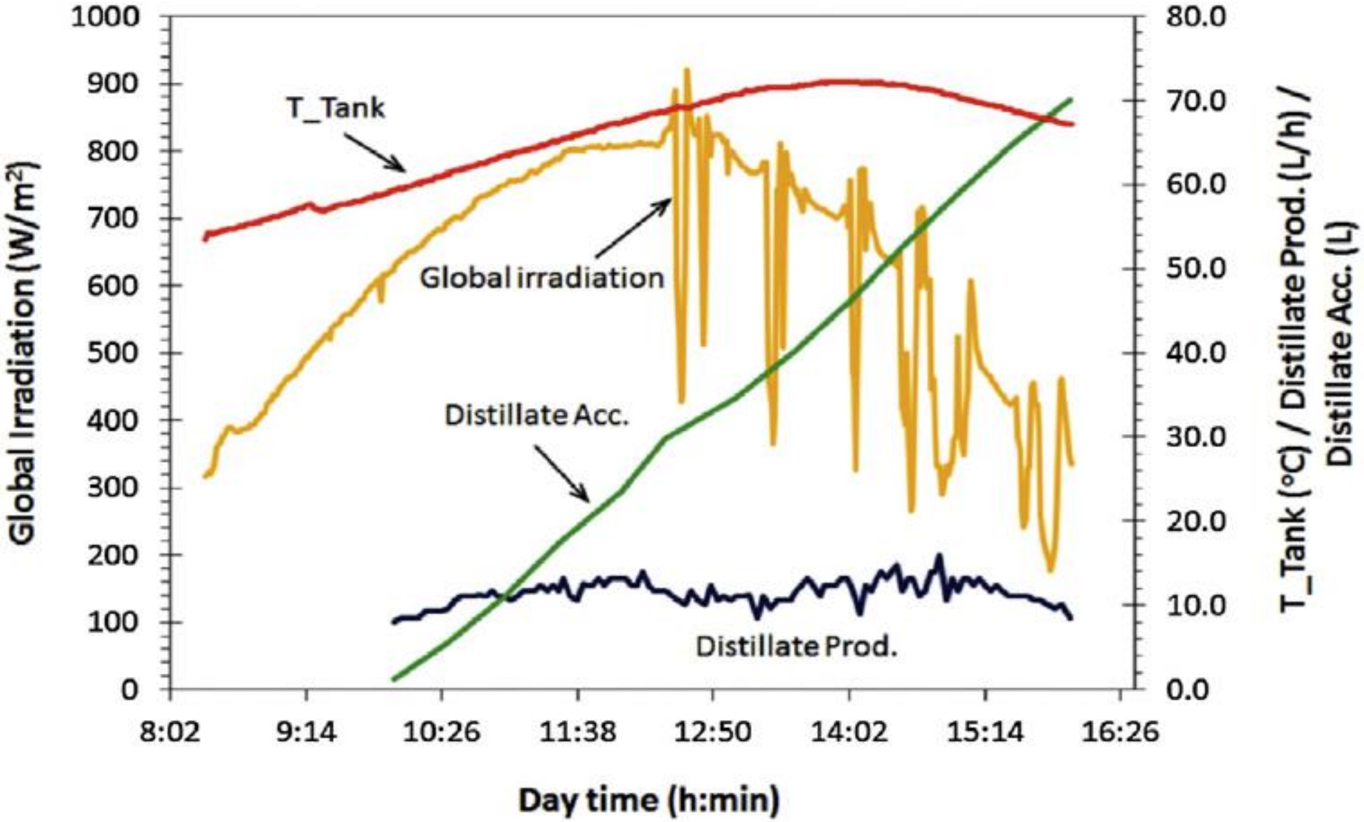


Figure 25. Performance of the desalination system during a one-day operation at King Saud University, Riyadh, KSA (Date: 18 Feb 2013 – Spring season)

The fluctuation of was due to the weather conditions, i.e. cloudy. The first 50 min were used to convert the solar energy into thermal and store the heat. The feed was brackish water with conductivity of 2490 mS/cm, the average distillate output was 11.53 L/h whereas the total volume of distillate was 70 L with conductivity of 4.7 mS/cm. This distillate output can be considered lower than other SPMD systems which is due to small capacity of the Memsys module, only 5.12 m^2. It is important to note that the current SPMD system is a prototype with only four Memsys “effect stages” (i.e. total membrane area of 5.12 m^2).

The distiilate flux (J, L/m^2.h) →

$$J = \frac{V}{S \cdot t}$$

Where V is the volume of the distillate (L); S is the effective membrane area (m^2), and t is the running time of VMD.

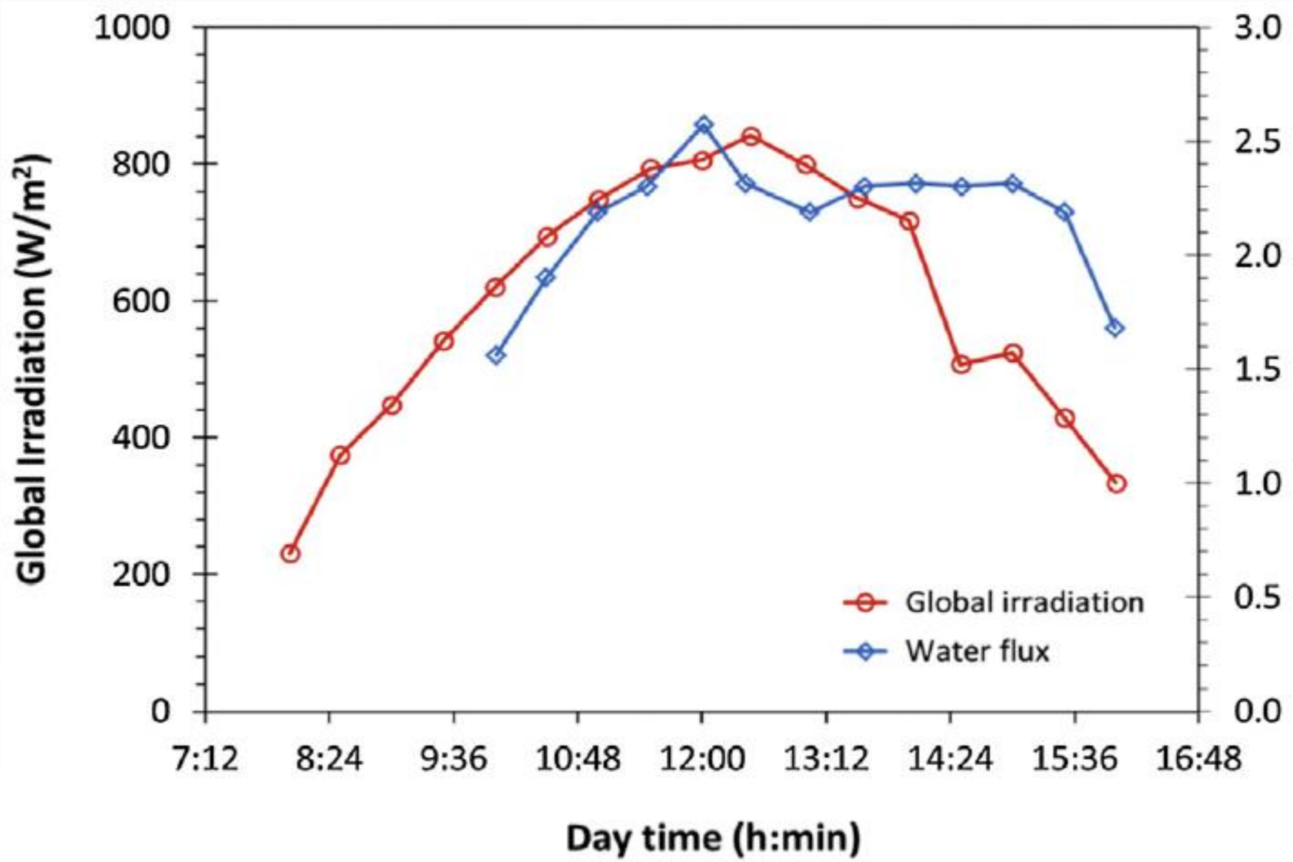


Figure 26. Performance of the desalination system during a one-day operation at King Saud University, Riyadh, KSA (Date: 18 Feb 2013 – Spring season)

The distillate flux was on the range of 1.5 -2.6 L/m^2 h, which is comparable to the others

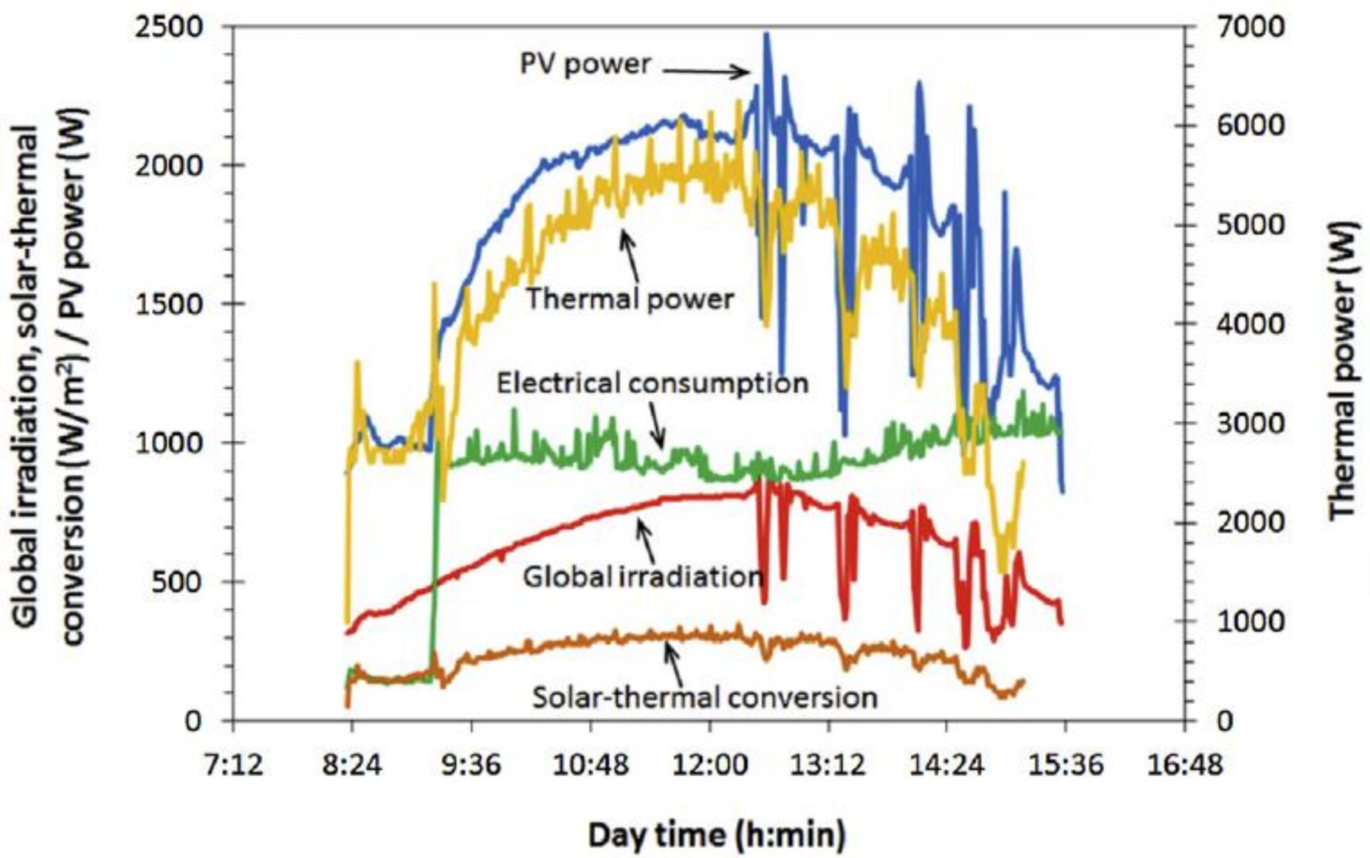


Figure 27. Solar energy harvested and converted into thermal and electrical

The figure illustrates the instantaneous solar energy that has been harvested and converted into electrical and thermal energy, and the amount of electricity consumed by the system during the test

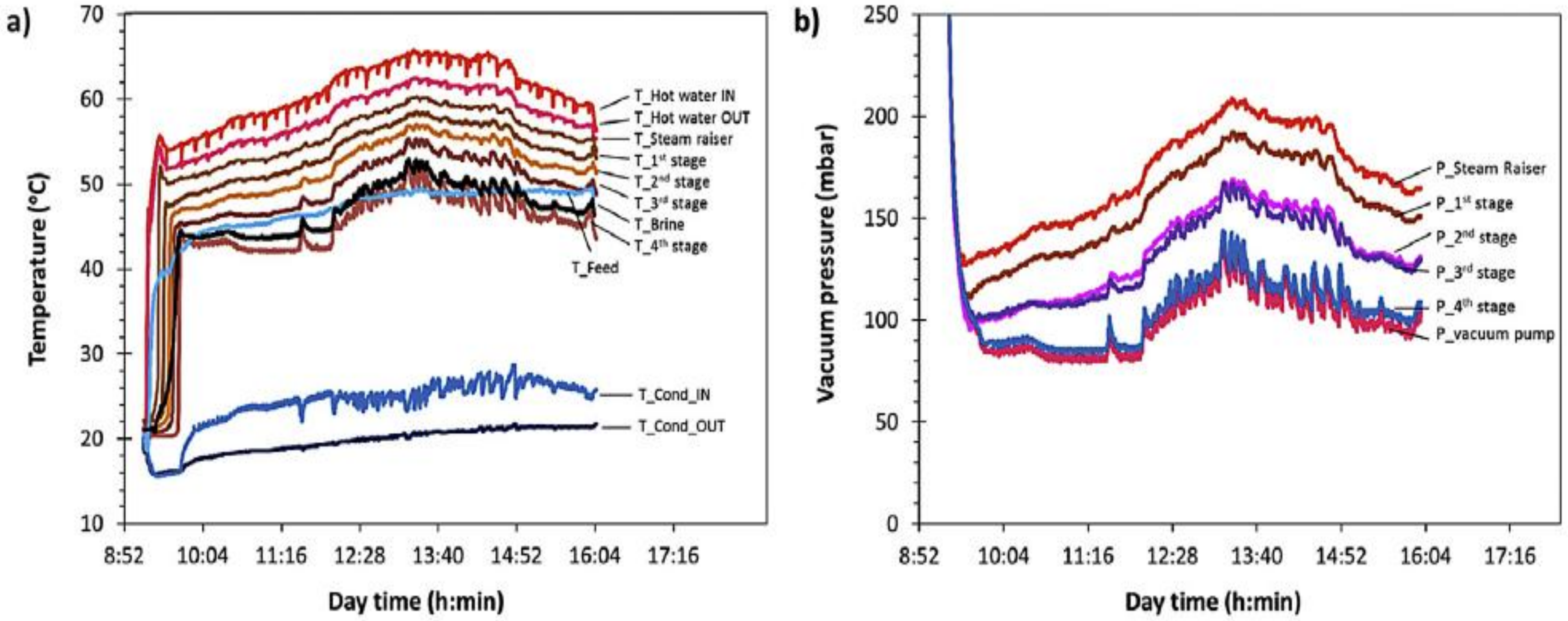


Figure 28. **a)** Temperature profile and **b)** vapor pressure profile of the Memsys unit

The figure exhibits the temperature and vapor pressure profile of the Memsys V-MEMD unit. In general, the temperature profile of the Memsys unit was greatly influenced by the global irradiation. The temperature at the 1st stage is always higher than the next stages because it is close to the steam raiser, and then decreases stage by stage: 1st stage > 2nd > 3rd > 4th

Conclusions

- The portable and hybrid SPMD system works on the zero energy concept which does not require external energy, and only utilizes solar energy for its operation. The Memsys V-MEMD unit has been successfully integrated with the solar-thermal collector and the solar-PV system.
- The test results showed that the portable SPMD system ran perfectly by only utilizing solar energy and without external energy from the grid.
- The average distillate output rate was approximately 11.53 L/h (Test on 18 Feb). The total volume of distillate output on that day was about 70 L with an approximate conductivity of 4.7 mS/cm.
- This output can be considered as a low output. However, due to its modularity, the capacity of the system can be easily increased to meet the water demand by increasing the number of the Memsys "effect stages".
- The distillate flux was in the range of 1.5-2.6 L/m2 h, which is comparable to other research studies. Other tests were also conducted to study the performance of the thermal collector.
- The solar energy converting efficiency (in percentage) of the thermal collector was quite low. The mean value of the solar energy converting efficiency from the two tests was approximately 33.6%.

Acknowledgements

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Visit by Saline Water Conversion Corporation (SWCC), KSA

Visit by Prof. from Institute of Technology Petronas, Malaysia

Visit by the Director of Research Group “Membranes and Renewable Energy”, University of Complutense of Madrid, Spain

Visit by the Managing Director of “Naked Energy Ltd.”, Guildford, United Kingdom

Visit by Prof. from King Abdullah City for Atomic and Renewable Energy (K.A. CARE), KSA

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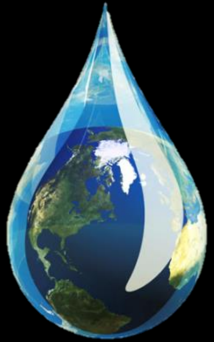
Thank  You