Solar Sorption System for Extraction of Water from Desert Air Operated in Real Environment

Tomáš Matuška, Vladimír Zmrhal, Bořivoj Šourek, Petr Wolf, Pavel Pelán
Czech Technical University, Prague (Czech Republic)

Abstract

A prototype of solar sorption system for extraction of water from air in hot and dry desert conditions has been designed and built. The system is fully autonomous, the energy for operation is supplied from solar photovoltaic, photovoltaic-thermal and photothermal collectors. Testing of the experimental system was performed in real environment conditions in the desert in central part of the United Arab Emirates. Despite the testing revealed significantly reduced performance of PV system, the potential of water production from the air has been proved. The average autonomous production 80 litres per day during the autumn season was monitored.

Keywords: sorption, photovoltaics, solar thermal

1. Introduction

Extraction of the water from air and its mineralization can be applied as a source of potable water in specific conditions. There is number of methods of water extraction from the air (Wahlgren, 2001), but only two has found practical applications so far: direct condensation of humidity from air and application of sorption process to concentrate humidity. While direct condensation units cannot harvest significant amount of water in case of extremely dry deserts, desiccants are applied in the process to increase the humidity of the processed air.

Water harvesting system based on the adsorption process has been developed. Sorption air handling unit has been tested in laboratory to validate mathematical model for performance simulations (Matuška et al., 2018). Model of the unit has been finally used to design the energy components to power the whole system. To operate the unit autonomously in the desert environment, only renewable energy sources available in the desert were considered. Finally, the experimental prototype has been built to perform testing the autonomous operation in desert climate (United Arab Emirates).

2. Autonomous water extraction system

An experimental system for extraction of water from ambient air consists of number of components, each with a specific function (see Figure 1). The sorption air handling unit uses rotary desiccant wheel with silicagel surface to adsorb the water molecules from ambient air flowrate 2000 m^3/h. Dehumidified air flows back to ambient environment. Ambient air with significantly lower flowrate 1000 m^3/h is used for regeneration of desiccant. Before entering rotary heat exchanger, the air flow is heated to high temperature up to 80 °C. Water molecules are released from the silicagel surface into regeneration air flow. Thus, regeneration air is humidified to higher humidity ratio and cooled down by the physical process (heat recovery, humidification). Humid air finally enters the cooler with low surface temperature (5 °C) and water vapour easily condenses as liquid water.

The whole system was proposed for autonomous operation. Heat recovery and use of local renewable energy were in focus of the design from the beginning. The sorption unit integrates the internal chiller (heat pump) based on the refrigerant R134a in order to achieve high temperatures up to 80 °C for regeneration at condenser side. Variable speed compressor allows a control of the unit at variable conditions and to reduce power input of the unit when needed. The heat from cooling at evaporator is recovered for preheating of the regeneration air. To further reduce the power consumption of the unit additional heat exchangers are applied: a) liquid cooler for precooling of regeneration air after desiccant wheel and b) additional heater to achieve high temperatures of regeneration air

doi:10.18086/eurosun.2020.12.05 Available at http://proceedings.ises.org

at the entrance to desiccant wheel. The additional cooler is connected to cold water storage (2 x 1000 m^3). Solar system with unglazed photovoltaic-thermal collectors (77 m^2) has been designed as a source of renewable cooling energy using the night radiative cooling (towards desert clear sky). The additional heater is connected to hot water storage (1 x 1000 m^3) as a part of solar thermal system based on vacuum flat-plate collectors (22 m^2). These components are complemented with photovoltaic modules (20 m^2) and LiFePO4 battery pack (nominal capacity 33,6 kWh) to balance the electric production and load. The peak power of photovoltaic system (PVT collectors, PV modules) is 16,8 kW_p. Designed water production at autonomous operation of the system is about 100 l/day in extreme desert conditions in yearly average according to simulations (Matuska et al., 2018). Simplified scheme of the system is shown in Figure 1 with indicated temperature level within the process.

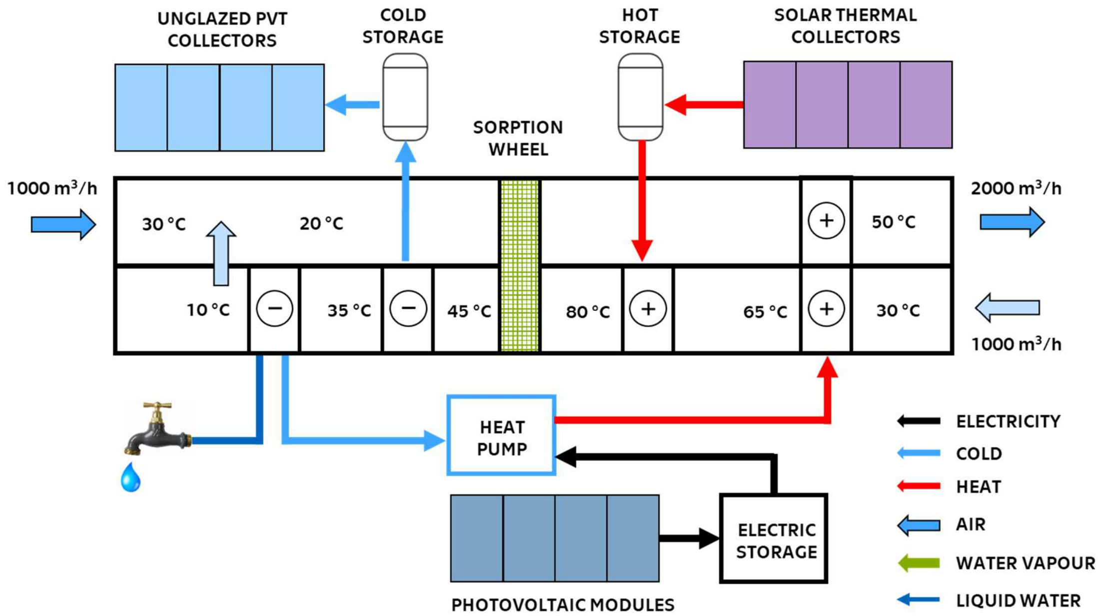

Fig. 1: Scheme of autonomous system for water extraction from desert air

The system has been designed and built as modular with two containers (see Figure 2): production container and energy container coupled with solar roof (solar collectors and PV modules) to be built above both containers. Production container contains the sorption air handling unit, demi-water storage and mineralization unit. It can be operated as potable water generator alone when connected to external electrical grid (3 x 63 A). The energy container together with solar roof is the energy source for production container. It includes battery pack, water storage tanks and hydraulic circuits. Plug and play electric and hydraulic connectors have been used to interconnect the containers.

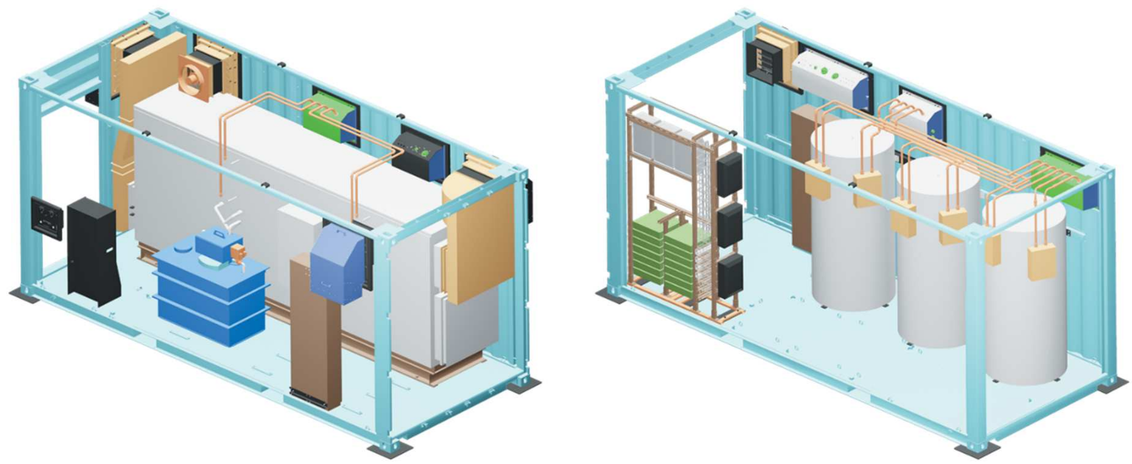

Fig. 2: Water extraction system: production container (left), energy container (right)

Both containers are conditioned by ventilation unit (mainly for night-time) and air-conditioning unit (during sunny day-time) to maintain interior temperature below 35 °C. Containers were equipped with additional internal thermal insulation to reduce the excess cooling load. Container housing for the system has been designed for the shipment of the system to the place of testing in the real environment (United Arab Emirates). Sea transport requires tight, robust and therefore certified containers. The whole system was fitted into 20" containers with floor plan 2,4 x 6,0 m and height 2,9 m. Solar roof demounted to elements (support construction, collectors, modules) was transported inside the containers.

3. Installation and testing

The experimental system has been installed and tested at camel farm near Sweihan (about 100 km from the coast at interior part of United Arab Emirates) with desert conditions to get knowledge on system operation in real environment. Solar roof with PV modules, solar thermal collectors and unglazed PVT collectors has been erected above containers (see Figure 3). Electric and piping connections have been prepared with use of prefabricated components. Despite installation problems due to extreme summer (July-August) conditions in desert and malfunction of one inverter (replaced) the system has been finally commissioned and put to permanent operation in autumn 2019.

Monitoring system focused on sorption process (temperature / humidity of processed and regeneration air), energy performance (PV, PVT and solar thermal system production, system power load), water production at given conditions and reliability of operation (container indoor temperatures, sand filtering).

Fig. 3: Autonomous water extraction system in the front of farm (Sweihan, UAE)

4. Results

The presented results cover two weeks in October 2019 and show the operational characteristics of the experimental system. The main objective of the testing was to gain knowledge on performance potential of individual sub-systems in real operation.

4.1. PV system efficiency

Nominal efficiency of PV modules used in the system is 17,2 %, efficiency of unglazed PVT collectors is 16,9 % (both related to gross area). Daily energy production values and irradiation levels have been evaluated. Daily efficiency of electricity production by whole PV field is between 12 and 14 %. When system losses are included (inverter losses, battery charging-discharging cycles) the total efficiency of PV system results between 10 and 11 %. Low efficiency of PV system is caused by high operation temperature of PV/PVT modules and by electric losses of inverter (both considered in planning phase), but also increased electric losses of battery storage when operated above 25 °C and significant dust accumulation on solar roof (not considered in realistic way in planning phase). These results will be used for further development and design of the system.

4.2. System power load

System power load is given mainly by power input of variable speed compressor of the chiller and fans integrated in sorption air handling unit, devices for air-conditioning of the containers and fans for ventilation of containers. In dependence on operation conditions the load ranges between 5 and 11 kW during operation period of the system. Outside the operation period the power load is low between hundreds of watts during night-time (ventilation, standby) and 2,5 kW during the day (air-conditioning units). Figure 4 shows the PV power production and system power load within two evaluated weeks.

Different control strategies were tested during the testing phase. Basic strategy is to start the system before sun-dawn due to favorable conditions (humidity, lower cooling demand) with minimum power input and to use the residual energy in battery pack from previous day until state of charge is 15 %. Then the controller stops the system and waits until PV system charges the battery pack to 30 %. After this condition is met, system is started again, but power input of the compressor is controlled in a way that state of charge is maintained at value 30 %. The sorption unit is stopped in the afternoon and PV system charges the battery back to state of charge 80 to 100 % to store the energy for next morning. The graph in Figure 4 shows peaks in power load caused by compressor protection when operated at minimum speed. The compressor rotations are repeatably increased time to time to provide the sufficient oil distribution for compressor lubrication.

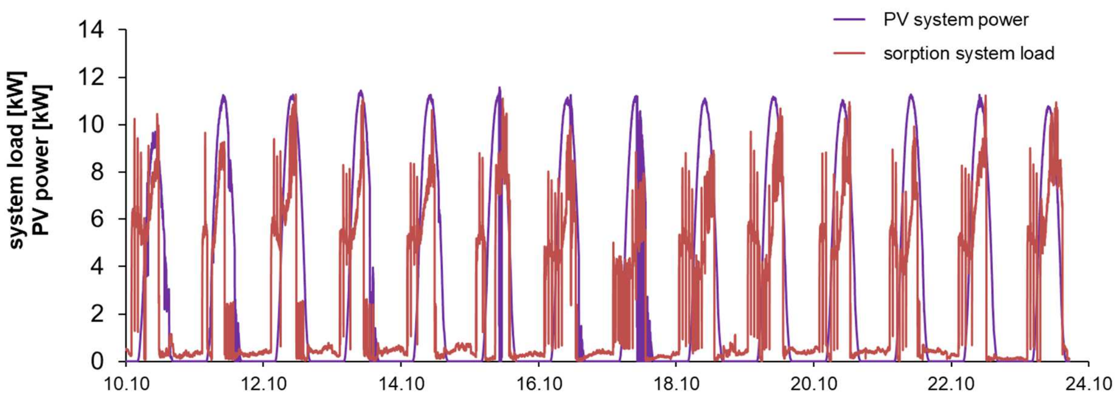

Fig. 4: PV power production and electric load of the system

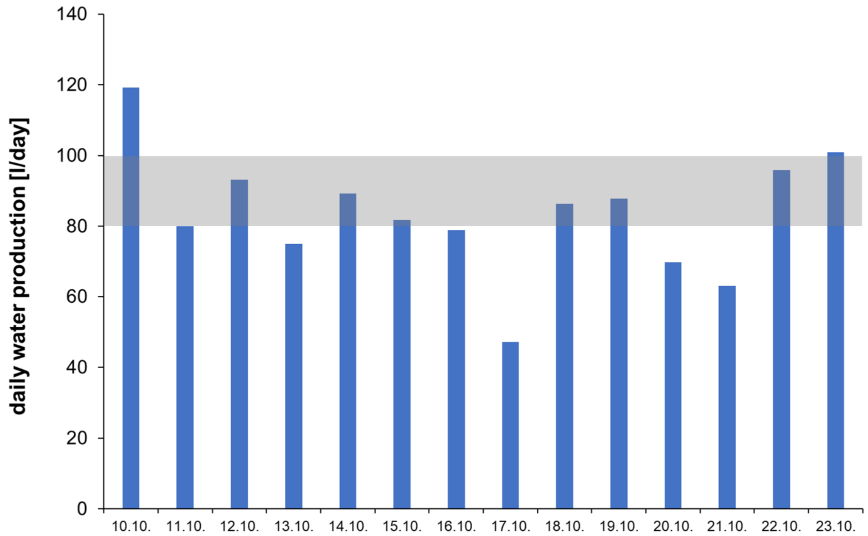

Fig. 5: Production of water in autumn season with a band of expected production

4.3. Water production

The water production (see Figure 5) of the system oscillates between 50 l/day (extreme cloudy day) and 120 l/day (extreme battery state of charge) with average around 80 litres of water per day which corresponds to autumn production potential. Water production is dependent on climate conditions and available energy (precooling from unglazed PVT system, heat for regeneration from solar thermal system, electricity from PV system).

5. Conclusion

The solar sorption system for extraction of water from air has proved functionality and potential to produce the water in desert conditions about 80 litres per day which corresponds to autumn conditions (energy, humidity). The system is fully autonomous with use of local renewable energy, no external energy was used neither for installation/commissioning or operation of the system.

The water production is heavily dependent on available energy. PV system efficiency reduced by high operation temperatures, battery losses and dust accumulation has limited the system performance. The experience from the experiments performed during testing and gained knowledge of system real performance will be used in further development of the system.

6. References

Wahlgren, R.V., 2001. Atmospheric water vapour processor designs for potable water production: a review. Water Resources 35, 1–22.

Matuska, T., Zmrhal, V., Sourek, B., 2018. Development of Solar Assisted Sorption Unit for Extraction of Water from Ambient Air in the Desert Climate. Proceedings of the ISES Eurosun 2018 Conference, Rapperswil (Switzerland), 659-664, doi: 10.18086/eurosun2018.04.22.