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Desalination device for arid areas

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ABSTRACT

The paper presents water desalination unit (WDU) based on MED-desalination method. WDU is intended for production of high quality potable water from the sea or underground water for local consumers. In hot climate areas (MENA region, Central America, South China, etc.) it could be used as the main or the only fresh water source during at least 10 months a year. The WDU could be used separately or as a part of multifunctional small scale solar system – (M4S) including also water desalinating unit and electricity unit. The main parts of the WDU (solar-thermal sub-unit, heat accumulating sub-unit and desalination sub-unit) are considered and its possible modifications are briefly discussed.

Keywords: Solar energy; Water; Desalination; Arid area; Multi-effect distillation (MED)

1. Introduction

In the regions with intensive solar irradiation the demands of local consumers (family houses, hotels, farms, hospitals, restaurants, schools, villas, apartment houses, various enterprises, etc.) in potable water, heat, electricity, steam could be satisfied at the expense of solar energy most of the time. Nevertheless, at the moment, the main part of their energy requirements is satisfied at the expense of conventional fuel. Market does not offer small scale solar devices, which can be used as the main (or only) source of water, heat and electricity for local consumers.

Creation of small scale solar powered systems for diverse applications is a complicated problem, since such systems should meet numerous and very strict requirements.

In particular, they should provide water heating up to 100°C, drinking water and electricity production, and also be capable of effective accumulation of heat, hot water, electricity. The systems should operate automatically and their efficiency should be high and not depend on ambient conditions. Application of both chemicals and water for supplementary needs should be avoided. Finally, the systems should be environment friendly and economically competitive.

Creation of such system (multifunctional small scale solar system — M4S) has been our aim the last few years. The entire system (Fig. 1) will include the devices satisfying diverse requirements of local consumers. Up to the moment we have worked out the basic devices of the system and number of specific technologies allowing essential decreasing the cost of the system manufacturing. The list of basic devices of M4S includes water heating unit, water desalination unit and electricity unit.

The paper presents the water desalination unit. The main parts of the unit are considered and its possible modifications are briefly discussed.

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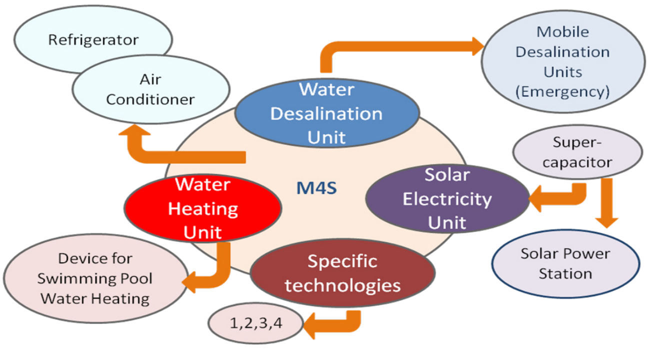

Fig. 1. Multifunctional small scale solar system (M4S).

2. Water desalination unit

2.1. Intention, desalination method, main features and composition

The water desalination unit (WDU) is intended for production of high quality potable water from the sea or underground water for local consumers. The WDU could work as a part of a multifunctional solar powered system or be used separately. In hot climate areas (MENA region, Central America, South China, etc.) it could be used as the main or the only fresh water source during at least 10 months a year.

Consideration of the features of desalination systems of different types and the results of laboratory and outdoor tests proved that multi-effect distillation (MED) method could be successfully used for small scale solar water desalination. Numerous multi-disciplinary scientific and technological researches result in creation automatically controlled, high productive, cost effective and environment friendly Water desalination unit of M4S based on MED-desalination method. The rated capacity of WDU is 2500 l of fresh water per day. The unit includes a number of original parts and technologies. Among other innovations there are high temperature solar-thermal collectors, heat water accumulator and feed water softener.

Application of high temperature solar collectors producing steam at 125°C, instead of hot water, allows implementing a number of improvings in design and operation scheme of desalination unit. First of all, using of steam as heat carrier excludes necessity to pump a lot of water through solar collectors. Then, production of steam at 125°C allows accumulation of fraction of solar heat in the form of hot water (at 120–122°C) for powering desalination process during night time (temperature of stored water drops down to 102–100°C). Desalination device operating 24 h has about three time smaller dimensions and accordingly is cheaper than that working only during the day time. Moreover, in this case using of additional water for cooling the last condenser (see below) could be avoided. Finally, the temperature range of desalination is expanded up to 100°C, and thus efficiency of the unit increases essentially.

The WDU is composed of solar-thermal sub-unit, heat accumulating sub-unit and desalination sub-unit (Fig. 2). Desalination sub-unit of WDU could be powered alternatively by liquid fuel, gas, waste heat, electricity. WDU in this modification is suitable for application as a stationary fresh water source, or as a mobile device installed in jeeps, tracks, etc.

2.2. Solar-thermal sub-unit

The solar thermal sub-unit absorbs solar irradiation and produces steam providing operation of the desalination sub-unit.

The main parts of solar-thermal sub-unit are high temperature tubular through evacuated solar collectors. The collectors are composed of thin stainless steel tube, selective absorbing layer covering the outer surface of the tube and a glassy jacket limiting the evacuated space around the tube. The selective absorbing layer is formed in gas discharge plasma. It does not exfoliate and does not degrade up to the temperature 700–800°C. Thus, collectors stay without any damage if the temperature of the collector tube grows tremendously due to accidental termination of water flow through it (In the Middle East area the temperature of non cooled collector tube increases up to 380–400°C.). The selective properties of the collector absorbing surfaces remain sufficiently high (absorption > 93%, self emission < 10%), even after numerous overheating of such type.

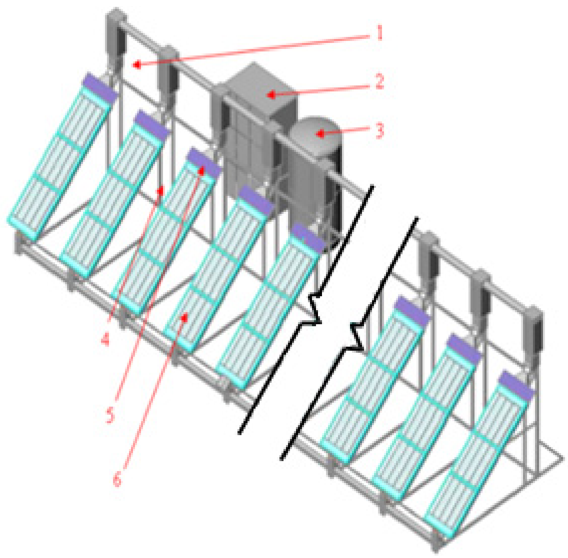

Fig. 2. Water desalination unit (15 frames, 45 solar modules). 1 – Solar thermal subunit, 2 – Desalinating subunit, 3 – Heat accumulating subunit, 4 – Triangular frame, 5 – PV-cell, 6 – Solar module.

Each module (Fig. 3) has solar absorbing area of 1 m^2. Three modules connected in series are installed on the supporting triangular frame with help of two (upper and lower) bearing assemblies. The bearing assemblies are fixed coaxially on the frame. Special mechanism provides orientation of the modules to the sun during the day (Fig. 4) and turning the modules back to the "morning" position after the sunrise. Totally solar-thermal sub-unit comprises 15 frames with 45 solar modules. Only one turning mechanism is used for solar orientation of all modules. The sensor watching the sun and controlling the turning mechanism is located on the middle frame. Accuracy of the orientation to the sun is within ±1.5%. Solar thermal sub-unit includes as well the PV-cells powering electrical devices of the Unit: pumps, gauges, sensors, etc. PV-cells are installed on the upper edges of the solar modules. Tracking the sun provides 25-30% higher productivity of PV-cells in comparison with the stationary ones.

Due to application of high temperature evacuated collectors, sunlight concentration and solar tracking

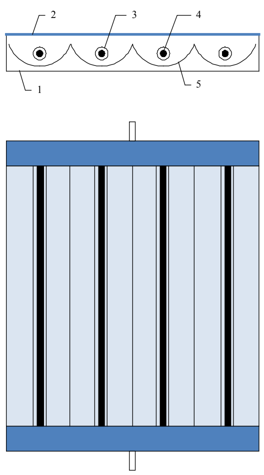

Fig. 3. Solar module containing solar collectors and mirror concentrators. 1 –frame, 2 – dust protecting glass 3 – collector glass jacket, 4 – stainless steel tube with heat carrier, 5 – mirror reflector.

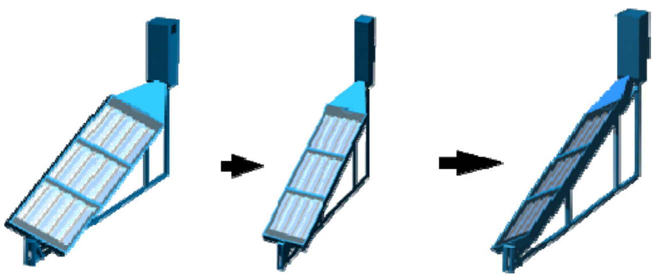

Fig. 4. Orientation of the modules to the sun during the day.

the system is capable to start the steam production in 35–40 min after beginning the operation. The average heat productivity of solar-thermal sub-unit during 8-h-long working day is not less than 90% of noon productivity.

The collectors, separators and first condenser-evaporator (effect) of desalination sub-unit constitute the near closed circuit. The circuit works with distilled water, thus scale formation in the collectors and subsequent decrease of thermal conductivity of collector tube are avoided. The steam water mixture leaving collectors enters separators and is being divided there. The water enters the collectors again and the steam is directed to heat accumulating sub-unit and to desalination sub-unit. The steam plays the role of heat carrier, and no pumps are needed for its transportation.

2.3. Heat accumulating sub-unit

The main part of heat accumulating sub-unit is pressurized tank (5 m^3, 2.5 atm.) containing distilled water. The fraction of steam produced by solar-thermal sub-unit is used for heating the water in the pressurized tank up to 120°C and remaining fraction of steam is directed immediately to desalination sub-unit. The heat collected in pressurized tank provides powering of desalination sub-unit during the night operation.

2.4. Desalination sub-unit

The main parts of desalination sub-unit are 15 effects connected in series in four vertical stocks. Simplified flow diagram of WDU for daytime operation is presented in Fig. 5 (heat accumulating subunit is eliminated). The steam coming from the solar-thermal sub-unit is condensed in the condenser of the first effect, and condensate turns back to the solar collectors.

At the expense of condensation energy the next portion of steam is produced in the evaporator of first effect which is under lessened pressure. The newly formed portion of steam enters the second effect and is condensed there and so on. All effects are pumped down to the pressure specific for given effect. The steam coming out from the last effect has temperature 52°C. It condenses in the condenser which is cooled partly with the feed water and partly with electrically powered fans. Additional water for heat rejection is not used.

The distillate leaving effects, but for the first one, reaches the evacuated tanks, used as the heat exchangers of the pre-heaters of the feed water.

Brine with salt concentration 180–200 g/l blows down to the brine collectors and then is removed from the system. The brine collectors as well act as feed water pre-heaters. Brine discharge would not be higher than 8.5, 17, and 33% of feed water, if feed water salinity is accordingly 15, 30, and 60 g/l

To prevent scale formation on the heat exchange surfaces, the feed water in the pre-heaters is heated only up

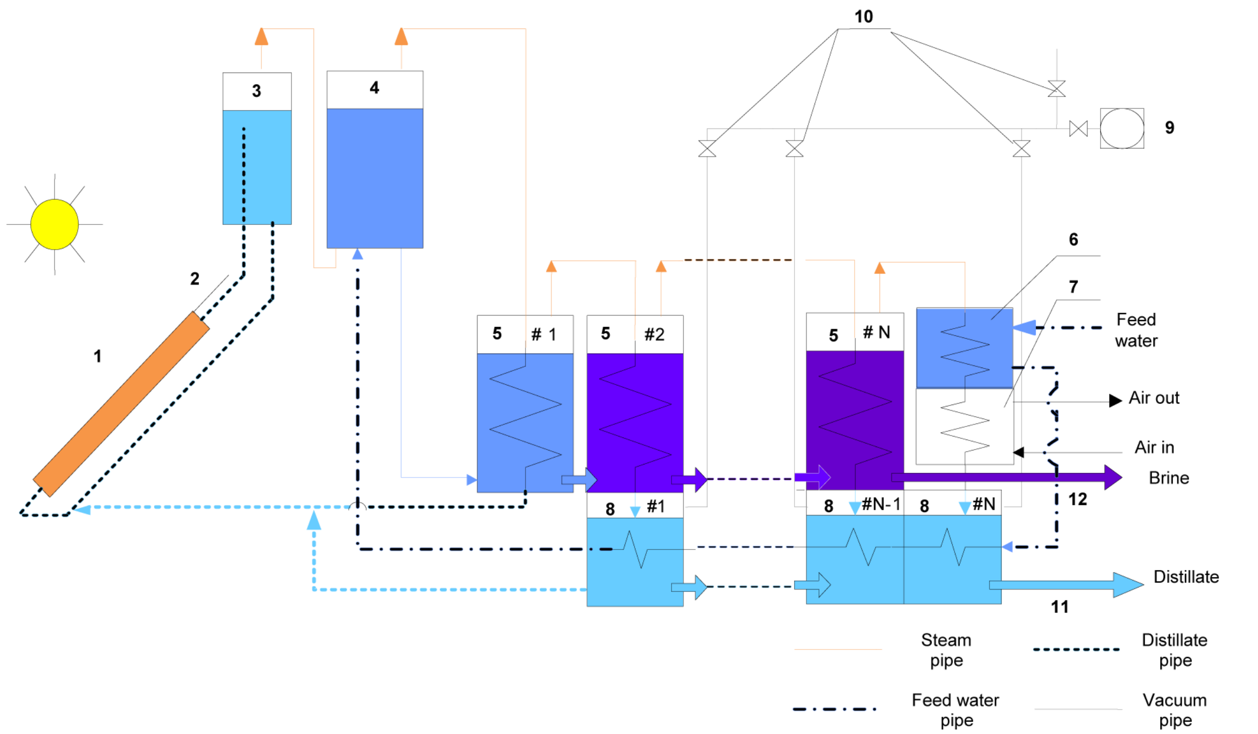

Fig. 5. Schematic flow diagram of WDU for day time operation (heat accumulating subunit is not shown). 1– Solar thermal subunit, 2 – PV-cell, 3 – Steam-water separator, 4 – Feed water softener, 5 – Effects, 6 – Last condenser (steam/water part) – First water pre-heater, 7 – Last condenser (steam/air part), 8 – Pre-heaters, 9 – Vacuum pump, 10 – Pressure valve, 11 – Distillate discharge, 12 – Brine discharge.

to 75–80°C. The feed water leaving pre-heaters enters the water softener incorporated in the Desalination Subunit. In the softener the feed water is heated up to 100°C, softened and then directed to the effects. Chemicals are not used for water softening. It is important to note that heating up to 100°C disinfects and deaerates the feed water. Microscopic particles of scale are periodically flushed out with the water from the softener in the special tank. About 5–10 l of water are used for flushing, depending on the amount of scale collected.

The feed water coming into every next effect has the temperature higher than the boiling point in it. Because of that, some fraction of entering water evaporates immediately. Created steam takes part in condensation/boiling processes in the subsequent effects. It adds about 15% of entire distillate input.

On the average, 55–60 l of product water is expected per 1 m^2 of solar absorbing area of solar modules. Salt concentration in the product water is in the range 10–100 mg/l depending on operation program. It is much lower than the upper limit of the World Health Organization specifications for drinking water, i.e. 500 mg/l.

Rated heat recovery is 72–77%, if feed water salinity is 15 g/l, and it decreases down to 65–70%, when salinity of feed water is as high as 30 g/l.

All electricity consuming devices of U4S are energized by 12 V. Total electric power consumption is about 3 kWh/d. It is satisfied by 4 m^2 of PV-cells incorporated in the solar thermal sub-unit.

The U4S is automatically controlled in all phases of its operation cycle as well as under occasional irregular conditions. The daily responsibility of the operator is limited to cleaning dust protecting glass of the solar modules, filling feed water storage tank, if any, and discharge of distillate, brine and scale from relevant storage tanks.

Experimental small scale solar powered desalination plant were successfully tested in natural conditions in Pakistan (Karachi) and Oman (Muscat).

3. Conclusion

The paper presents water desalination unit (WDU) worked out as part of multifunctional small scale solar system – (M4S) including also water desalinating unit and electricity unit. WDU is based on MED-desalination method. It is composed of solar-thermal sub-unit, heat accumulating sub-unit and desalination sub-unit.

The main features and advantages of the unit are as follows.

- Rated capacity is 2500 l/d of fresh water.
- Fresh water production per 1 m^2 of radiation absorbing surface is 55–60 l/d.
- Heat recovery is 72–77%, if feed water salinity is 15 g/l, and it is 65–70%, when salinity of feed water reaches 30 g/l.
- Feed water salinity could be as high as 100 g/l.
- Fresh water output is 91.5, 83, and 67% of feed water, if feed water salinity is accordingly 15, 30, and 60 g/l.
- Salt concentration in the product water is in the range 10–100 mg/l.
- WDU does not use additional water for supplementary needs.
- The chemicals are not used either for anti-scale treatment, or for water disinfection.
- The impact on the environment by WDU is minimal.
- WDU does not need external electricity source.
- The device is automatically controlled in all phases of its operation cycle.

Acknowledgments

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