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Ambient energy for low-cost water desalination

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Abstract

The paper presents the results of a feasibility study to assess the potential of ambient energy in producing low-cost desalinated water. The proposed method uses conventional off-the-shelf desalination equipment linked up to an innovative energy harvesting system made of extruded aluminium planks which form part of the building and which is able to provide low-cost energy for the desalination process. The most common energy collection system forms an engineered roof of a building. Water is pumped through this roof to collect solar and ambient energy that can then be used for a variety of applications. Results from an EC-funded feasibility study to assess the potential of using ambient energy to produce fresh water from seawater are presented here. It is felt that the technology offers good potential for water desalination in arid and semi-arid regions of the world where there is an abundance of solar and ambient energy.

Keywords: Ambient energy; Low-cost energy; Water desalination; Heat pumps; Flash evaporation

1. Introduction

In this paper the specific concern of water is investigated and a solution proposed that has the potential to produce commercial-scale desalination equipment for areas of the world where there is a severe shortage of water. The basis of the system is to use an innovative endothermic energy harvesting collector that has been designed and patented by Ambient Energy Systems Ltd. These collectors are central to the proposed water desalination technology and form a liquid-filled roof or wall cladding that is in thermal contact with the atmosphere. Unlike passive solar collection panels that require direct sunlight, the ambient system works on temperature differences that work both day and night and even when air temperatures are below freezing. Heat energy originating from the atmosphere is redistributed by a heat pump and

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used in a variety of applications, such as providing space heating, hot water and energy for driving a variety of industrial processes. In this paper the use of the Ambient technology for water desalination is considered.

The collection surfaces can be architecturally integrated into building structures in an easy and natural manner. Figs. 1 and 2 show two demonstration sites that have been set up on the Isle of Wight, UK. Fig. 1 shows a small converted barn which has an ambient roof. When such ambient roof structures or wall cladding cannot be utilized, it is possible to use ambient stand-alone structures, as shown in Fig. 2, for the St Catherine's Lighthouse case.

Ambient energy collectors have been shown to provide cheap and abundant amounts of energy, which could be used for desalination in temperate climates using conventional flash evaporation equipment. In the UK, for example, solar radiation can be in the region of approximately 600–800 W/m^2 and for a normal roof size of 50 m^2 this equates to collected energy of 30–40 kW. This energy is passed to a thermal store and used directly or via a heat pump to drive the desalination process. The ambient solution proposed here works on this principle and is seen as a viable method that can link to standard commercially available desalination equipment. Before discussing the ambient desalination system, we present a brief state of the art in desalination.

2. State-of-the-art desalination

2.1. Multi-effect distillation (MED)

Various applications of MED have been patented since 1840; indeed, it was the most common type of desalination until MSF took over in about 1960 [2]. The essential feature is that brine evaporates in a series of heated tubes before the resulting steam condenses in a condenser. Examples abound in the literature: for instance, among many others is a 72 m^3/d plant in Spain [1], an 85 m^3/d in Abu Dhabi [1,3], and a 20– 1500 m^3/d plant supplied by solar pond water at 60–70°C in Tunisia [4].

It has been said [5] that MED is not suitable for production rates of less than 100 m^3/d because of the need for qualified maintenance and electricity supply, according to UAE/German experience. However, it is more commonly thought (see, e.g., [6]) that MED may replace MSF at most scales in future, even for outputs of greater than 1000 m^3/d and in energy-rich Saudi Arabia [7]; this is endorsed by a recommendation [8] that a pressed plate in a falling film (PPFF) type of MED is already generally better than MSF. That their solar components tend to remain maintenance-free — even after 14 years of continuous use in Abu Dhabi [9] — is a distinct bonus.

2.2. Multi-stage flash (MSF) evaporation

The essential feature of the MSF system is that brine is heated prior to being flash-evaporated in a low-pressure chamber before the resulting steam condenses in a condenser. As for MED, it has been said [5] that MSF is not suitable for production rates of less than 100 m^3/d because of the need for qualified maintenance and electricity supply. The literature supports this with references to a 500 m^3/d plant in Italy [10], a 1500 m^3/d plant in Tunisia [1,4] and an energy-intensive 6715 m^3/d plant in Jersey [11]. Other large plants are described in Kuwait [12–14], Saudi Arabia [15] and Spain [16].

2.3. Reverse osmosis (RO)

The essential feature of RO is that brine is forced under pressure through a series of membranes that physically remove salt molecules and other impurities. It is not suited for low levels of production [5], other than when modified with a disc-tube module which can

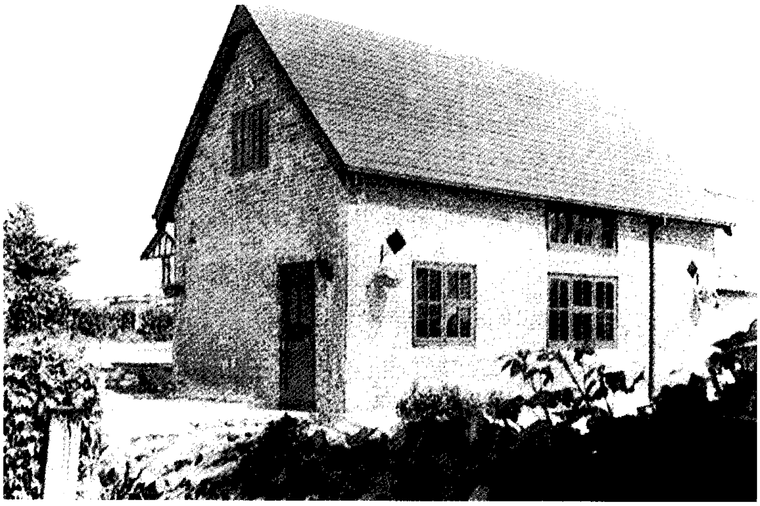

Fig. 1. Ambient roof on a small building on the Isle of Wight.

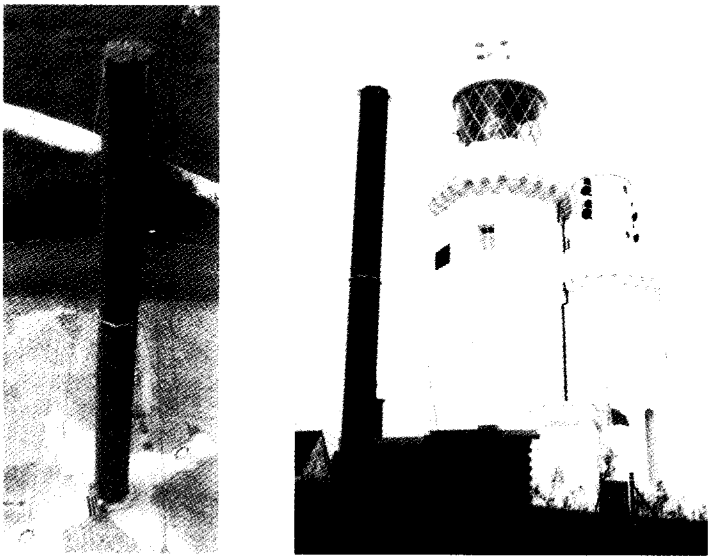

Fig. 2. Ambient™ stand-alone structure for St Catherine's Lighthouse, Isle of Wight.

allow it to produce fairly economically down to 2 m^3/d [17]. Examples of its widespread use occupy much space in the literature, e.g., in Saudi Arabia [18], St Croix in the West Indies [19], Oman [20], Kuwait [12,21], the Canary Islands [22], Jersey [11] and Israel, where it is the only form of desalination [23].

Although power for the pressure generation can come from conventional compressors, it can also be created from wind [14] or photovoltaics

(PVs) [19,20]. Unfortunately in many areas, high-silica intake waters or other aggressive impurities can cause severe and irreversible membrane fouling [24]. This can be dealt with by pretreatment of the intake water as described for plants in Kuwait [21,25] where halogenated aromatic compounds are removed, and Antigua and Barbuda in the West Indies [13].

2.4. Solar distillation

Potable water has been distilled from seawater for centuries, often using solar ponds for preheating; however, reference to it only became commonplace during the last few decades. For instance, solar stills are said to have been used in Australia since 1966 [26], while they produce 30 m^3/d from seawater at Gwadar in Pakistan [27] and also operate on seawater at Shiraz University in Iran [28]. Solar distillation using a multi-stage stacked tray plant with solar collection is practised in Delhi [29] at a latitude of 28.6°N where the optimum solar collector inclination has been found to be 20° and that of the still glass cover 15° [30]. In Turkey there is a solar distillation plant using an outside passive condenser [31].

2.5. Important issues in efficient desalination

Many desalination plants of all kinds, except RO, use direct day-time solar energy to preheat intake waters, commonly to between 60°C and 80°C, and thereby enhance their efficiency. For instance, a MSF plant in Tunisia takes in brackish water pre-heated to 60–70°C in a solar pond [4] and direct solar thermal collectors preheat feed waters to 60–80°C for very small multi-effect ambient pressure desalination plants in the UAE [5]. In turn, intake water is naturally preheated to 60–90°C by geothermal energy for an aero evapo-condensation plant in Tunisia [9,32].

One Italian low-temperature MSF plant requires very little preheating — though it would benefit from it — as it can produce 500 m^3/d at only 8°C above ambient brine temperature [10]. MED plants also require brine at only 70°C [6]. At the other end of the scale, at a test circuit with thermal power of 3 MW at the European Solar Research Centre Plataforma Solar de Almeria, intake water is warmed by heat recovered from hot air at up to 700°C sucked through steel mesh at the centre of a mirrored heliostat [33].

Solar energy for pre-heating can be intensified in parabolic trough collectors (PTCs), which condense it at the focal point of a parabola-shaped mirror. Such an example is at the European Solar Research Centre Plataforma Solar de Almeria [33]. Experience with a Spanish MSF plant using a similar PTC supply, which operates through the day but gives way to conventional power at night, has led to the belief that: "The possible effect of future PTC cost reductions and conventional energy costs increasing on the competitiveness of solar energy in MSF plants is remarkable" [16]. This is supported by several other cost comparisons between PTC and conventional supplies to MED and MSF plants [34].

To meet the needs of populations typically consuming 120 l/person/d of potable water [26], desalinated water production rates vary over a huge range from less than 2 m^3/d from solar plants in Tunisia [34] and Fuerte Ventura [3] to 150,000 m^3/d from nuclear plants in China [35,36], and beyond. Towards the lower end of these extremes a typical reference from Tunisia is made to a production rate of 3.6 m^3/d per 1 m^2 of solar collector surface; there it is suggested that MSF or MED plants using solar pond water at 60–70°C could increase this to 20–1500 m^3/d [4]. Another small plant in Pakistan produces 30 m^3/d [27].

A little further up the scale we see 72 m^3/d being produced from a MED plant in Spain [1], 75.7 m^3/d from a PV-powered RO plant at Fredericksted on St Croix in the West Indies [19] and 85 m^3/d from a MED plant in Abu Dhabi [1]. Another 85 m^3/d plant in Abu Dhabi takes in seawater at 55,000 ppm using evacuated tube, flat-plate collectors with an 1862 m^2 absorption area, which are incorporated into a multiple-effect stack-type evaporator (MES) with a 300 m^3 thermally stratified night-time heat accumulator [3]. Medium-sized plants follow: 500 m^3/d is produced in Italy from a MSF plant with a brine temperature only 8°C above ambient [10], while about 1200 m^3/d comes from a RO plant in the Canary Islands [24] and 6000 m^3/d from a SWRO plant in Jersey, which replaced a 6715 m^3/d MSF plant there because it was found that such conventional thermal plants are too energy intensive [11]. Whatever the scale of its individual plants, Saudi Arabia is the world's leading producer of desalinated water, with 25.9% of the world total in 1996 [7].

Production costs vary extensively depending on a wide range of factors, not the least being location (remoteness), scale, salinity of intake and produced water and, of course, degree of solar assistance. At the cheaper end, for instance, in a well populated area of Cyprus in which until recently drought occurred every 5.4 years [37] but has for the last 4 years become an annual event, desalinated water was being produced in 1997 from a medium-sized plant with solar trough parabolic collectors at 300°C and back-up fossil fuel to compensate for diurnal variations, for only C£0.89/m^3 [37]; indeed, more recently a cost of only £0.70 m^3 has been quoted for a proposed RO plant in the Caribbean. In a similar situation in Spain, the production cost is reported to be US\$1.64/m^3 [33] and the operating production cost in Abu Dhabi is also about US\$2/m^3 though the total cost, including capital amortization, is about US\$9/m^3 [3].

On the other hand, at remote sites in Tunisia and Fuerte Ventura, costs as high as US\$80/m^3 for very small plants producing less than 1 m^3/d have been reported [38]. The amortization of additional drilling and pumping costs to acquire brackish intake waters from bore-holes also tends to increase cost as noted for PV-powered RO plants on St Croix [19], RO and electrodialysis plants in Jordan [39], several plants using brackish groundwater in Tunisia, at least one with coupling of a solar pond to a MSF plant [1], and more specifically a small SMCEC plant there [40].

3. Ambient energy water desalination

As already stated in Section 2.2, the main principle of flash evaporation relies on the fact that the brine and air are fed into a chamber in which a vacuum is created, thereby lowering the evaporation temperature of the feed water. The feed water is introduced into this evaporation section through an orifice and is distributed in every second plate channel, as shown in Fig. 3. The hot water from the Ambient roof is fed directly or via the energy store and the heat pump into the remaining channels so that heat can be transferred to the feed water for evaporation to take place. Having reached the boiling temperature, feed water is subjected to a vacuum and the mixture of generated vapour and brine enters a separation vessel where the brine is separated from the vapour and extracted by a combined brine/air ejector. The seawater supplied by the combined cooling/ejector water pump distributes itself into the remaining channels that are absorbing the heat being transferred from the condensed vapour. The fresh water produced is extracted by a fresh water pump and fed to a collection tank. Further details of the desalination system are described in the report produced for the EC [41].

The results carried out in September 1998 indicate that the threshold above which desalina-

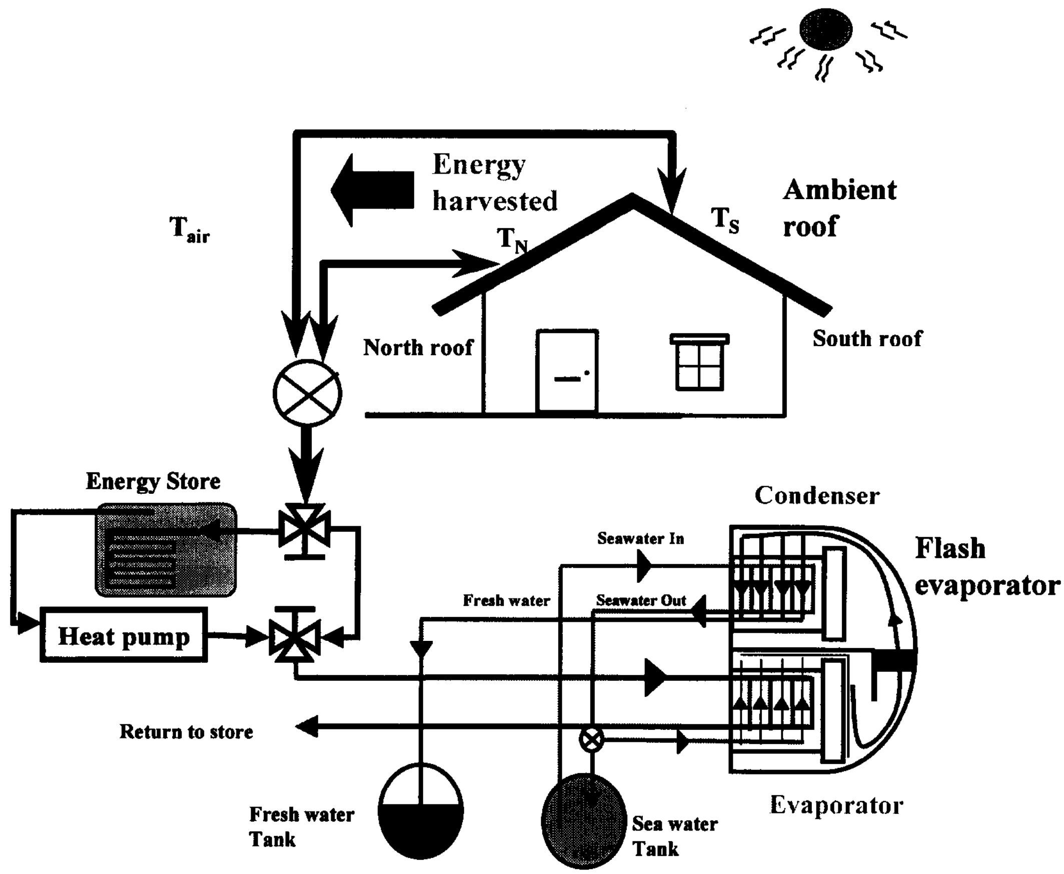

Fig. 3. Ambient energy system for water desalination.

tion occurs is approximately 42°C for feed water temperature at a flow rate of 1.1 m^3/h (for the Alfa Laval unit working at 98% vacuum). This water temperature which was used for heating the seawater resulted in an absorbed evaporator temperature of 29°C and corresponded to trials carried out with seawater fed in at 22°C.

The experimental data from the desalination studies showed that the Binfield roof delivered over 10 kW at a jacket water flow rate of 1.1 m^3/h to produce an equivalent of 0.32 m^3/d of fresh water. The energy used was harvested by approximately 26 m^2 of roof collector surface and delivered to the Alfa Laval flash evaporator unit at a rate of 393 W/m^2 of collector. From data previously collected, it is known that energy collection rates in excess of 22 kW can be extracted at the lower flow rate of 0.8 m^3/h without affecting the temperature of the collectors.

4. Conclusions

It is clear from the feasibility study that ambient energy can be used for water desalination in temperate climates. In hotter countries where there is more solar energy available, the potential for using the technology to produce low-cost desalination systems is even more significant. The application of ambient energy for water desalination is continuing, and it is intended to explore commercial-scale water desalination using MSF/MED evaporation techniques in arid and semi-arid parts of the world where there are water shortages. There is a strong need for a versatile solution that has flexibility so that small- and large-scale units are equally feasible so that systems that are readily applicable to individual users or for isolated small communities can be realized.

Other applications of the ambient technology include domestic houses, hospitals, nursing homes, hotels, schools, industrial processes, industrial and commercial buildings, swimming pools, horticultural applications, agriculture and sewage treatment. Some of these applications are being actively pursued by the University of Portsmouth/Ambient Energy Systems Group and progress will be reported in future papers.

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