rexresearch.com

Dew Harvesting

http://inspiringfuture.org/wordpress/2014/05/21/dew-harvesting-as-a-means-to-get-clean-drinking-water/
[Excerpts]

Gabin Koto N'Gobi's Dew Collector

The lack of water in the Northern region of his home country Benin motivated Gabin Koto N'Gobi to design a dew collector.

His prototype is made out of local materials which makes it sustainable and accessible. It harvests up to 4 liters of water per night...

[Click to enlarge]

geometrical shapes and efficiency

These designs might make you wonder about the effect of different shapes on the efficiency of dew collecting. During summer and fall 2009 experiments have been done (Pessac, France) to get an answer to this question. The results were published in "New Architectural Forms to Enhance Dew Collection" (Daniel Beysens, Filippo Broggini, Iryna Milimouk-Melnytchouk, Jalil Ouazzani, Nicolas Tixier)

a. conical

60° cone angle (30° from horizontal)

the 30° angle has been found to give the best cooling efficiency. This angle also allows water to easily flow by gravity as the gravity forces are only reduced by 50% with respect to vertical.

YIELDS: an average of 22% larger than the planar reference condenser (30% at wind speeds below 1.5 m/s to 0% above 3 m/s). The gains are larger for low dew yields.

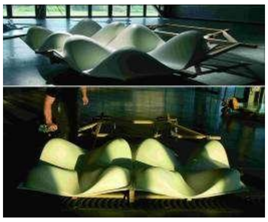
b. inverted pyramid

Here the surface also has an angle of 30° from horizontal

YIELDS: an average of 20% larger than the planar reference condenser. The gains are larger for low dew yields, these increased gains are lower though than with the conical shape.

As these shapes are somewhat unpractical when making constructions to collect dew on large scale, tests were also made with hollow shapes that could be 'tiled' on a bigger surface, like a roof. In this way the collecting surface can be increased without needing more horizontal space nor an unpractical increase of vertical space.

c. egg-box



YIELDS: an average of 10% larger than the planar reference condenser.

Note that part of the formed dew can't be collected because of the areas where the angle is too low for the drops to flow off (the flat tops of the egg bumps)

d. origami

YIELDS: an average of 120% larger than the planar reference condenser, with much higher gains for low dew yields (up to 400%)

So we can see that the geometrical shape of the collectors is of great influence to the amount of dew that can be collected. The big advantage of hollow shapes lies in the fact that influences of the wind are decreased, and thus the cooling is increased...

The ability to absorb water vapor from the atmosphere enables ticks to survive without drinking water for many months. The tick rehydrates using a three-stage process. First, it uses its foremost pair of legs to detect microregions of high humidity, such as those surrounding water droplets. Once a suitable water source is detected, the tick secretes a hydrophilic solution from its mouth. Once it is saturated, the tick draws the now hydrated secretion back into its mouth. The secretion is a hygroscopic salt solution. Once ejected from the mouth, the solution dries at low ambient humidities, leaving a crystalline substance behind. When the humidity increases, the hydrophilic crystalline substance dissolves and is swallowed back into the body of the tick. The adaptation allows exophilic ticks to absorb water vapor from close to saturation down to 43% relative humidity. Mites and soil-dwellings use a similar mechanism to absorb water vapor.-- asknature.org

footnotes:

1)
to calculate the dew point:

$Td = 243.12 * A / (17.62 – A)$

where:

$A = Log(RH / 100) / Log(2.718282) + (17.62 * Ta / (243.12 + Ta))$

RH = relative humidity (%)

Ta = air temperature (degrees celsius)

Td = dew point (degrees celsius)
2)

the OPUR condensing foil is 0.39 mm thick and made of 5.0 vol %
of TiO_2 microspheres of 0.19 µm diameter, and 2.0 vol. % of $BaSO_4$ of 0.8 µm diameter embedded in a matrix of low-density polyethylene (LDPE). It also contains approximately 1 vol % of a surfactant additive non-soluble in water. This material improves the mid-infrared emitting properties to provide radiative cooling at room temperature and efficiently reflects the visible (sun) light

---

https://hal.archives-ouvertes.fr/hal-01264194/document

Water recovery from dew
by N. Nikolayev
[PDF]

---

https://arxiv.org/ftp/arxiv/papers/0707/0707.2931.pdf

Fog and dew collection projects in croatia - arXiv.org
[PDF]

---

http://www.opur.fr/angl/publications_ang.htm
International Organization For Dew Utilization

http://www.opur.fr/fr/Arles-fr.pdf
Atmospheric Research, 57, 201-212, 2001

Water production in an ancient sarcophagus at Arles-sur-Tech (France),
D. Beysens, M. Muselli, J.-P. Ferrari, A. Junca,
[PDF]

---

http://www.opur.fr/angl/Secheresse-angl.pdf
Sécheresse, Vol. 11, n° 4, décembre 2000

The Case For Alternative Fresh Water Sources
D. Beysens, I. Milimouk
[PDF]

---

http://iramis.cea.fr/spec/Phocea/Pisp/index.php?nom=vadim.nikolayev

Vadim Nikolayev

Service de Physique de l'Etat Condensé
p. 227, Bât. 772, Orme des Merisiers
91191 Gif sur Yvette Cedex
France
tel.jpg +33 1 69 08 94 88
fax.png +33 1 69 08 87 86
email.gif vadim.nikolayev(at)cea.fr

http://inac.cea.fr/sbt/Phocea/Vie_des_labos/Ast/ast_visu.php?id_ast=432

Condensation de vapeur d'eau atmosphérique (rosée)

http://www.sciencedirect.com/science/article/pii/S0360544206002684

Collecting dew as a water source on small islands: the dew equipment for water project in Bisjevo (Croatia)
D. Beysens, O. Clus, M. Miletac, I. Milimouk, M. Muselli, V.S. Nikolayev

Abstract
In many regions and geographical settings, dew water collection can serve as a water source, supplementing rain and fog water collection. This is particularly useful when precipitation is low or lacking, especially in remote areas and islands in the dry season. A project called Dew Equipment for Water (DEW) was initiated for a 15.1 m2 roof in the island of Biševo (Croatia), equipped with commercial plastic cover selected for its superior dew collection properties. Measurements of both rain and dew water will be performed over several years and data will be correlated with meteorological data collected in situ. Preliminary measurements during the period 21 April–21 October 2005 showed that dew water contributed significantly, 26% of the total collected water.

---

http://www.aidic.it/cet/13/34/014.pdf

New Architectural Forms to Enhance Dew Collection
[PDF]

---

http://www.hydrol-earth-syst-sci.net/19/601/2015/hess-19-601-2015.pdf

Estimates of global dew collection potential on artificial surfaces
[PDF]

---

http://link.springer.com/article/10.1007/s40899-015-0038-z
Sustainable Water Resources Management, March 2016, Volume 2, Issue 1, pp 71–86

A review: dew water collection from radiative passive collectors to recent developments of active collectors
B. Khalil, et al.

Abstract
Dew water is water droplets formed due to condensation of atmospheric water vapor on surfaces of temperature below its dew point temperature. Dew water can be seen as a nonconventional source of water and may be exploited in regions where weather conditions favor dew formation and inadequate supply and quality of water is a prevalent problem. There are two main types of dew condenser, the apparatus used to collect dew water, namely radiative (also called passive) and active condensers. Radiative passive collectors rely on exploiting the physical processes responsible for dew formation to collect dew water without any additional energy input. Previous studies indicate that a 1 m2 radiative condenser yields between 0.3 and 0.6 L/day of dew water in arid and semi-arid regions. Active condensers have been designed as an alternative method of collection that produces higher yields by using additional energy inputs. Several designs of active condensers have been patented for which the yield can reach 20 L/day for portable devices, and up to 200,000 L/day for larger agricultural water devices. Active condensers are also known as atmospheric water generators, dehumidifiers, and air to water devices. Most of the active condensers are based on a regenerative desiccant that attracts and holds large volumes of water from the air or on a means of cooling the condensing surface below the dew point temperature (refrigeration circuit). The larger yields and wider range of environmental conditions in which dew can be collected make active condensers a promising option as an alternative or supplemental source of water in water scarce regions. The aim of this paper was to provide a comprehensive review of radiative and active condensers, including dew formation processes, methods of dew collection, and parameters that influence the dew collection. Subsequently, patents of active condensers were reviewed to ascertain how they ca n be integrated with different types of renewable energy and to assess the potential use of such integrated systems as a sustainable source of water in regions that suffer water scarcity and/or as a sustainable source of water for agriculture.

Introduction

Dew water collection can be considered as a non-conventional source of water which can enhance water supply in certain climates/regions. Hence, it can be considered as a possible alternative or supplementary source of water in many water scarce regions of the world where weather conditions favor dew formation. The atmospheric air can be considered as a huge renewable reservoir of water which can be used as a water source everywhere on the earth (Hamed et al. 2010). The amount of water in air is assessed as 14,000 km3, while the amount of fresh water in the earth is about 1200 km3 (Hamed et al. 2010). Despite this significant volume of potentially extractable fresh water in many places where weather conditions favor dew formation, dew water collection systems are rare, suggesting dew collection is an under-explored alternative for providing good quality water.

Current dew water collectors are divided into two main types: radiative (or passive) and active dew water condensers. Research on radiative condensers started in the early 1960s (Gindel 1965). Since then, research has focused on the condenser materials, architecture, influence of meteorological parameters, and other factors that affect the volume of dew water collected using radiative condensers. According to the radiative energy available for condensation, the upper limit of dew yield is 0.8 L/day/m2 (Monteith and Unsworth 1990). However, the maximum recorded yields of dew water in arid and semi-arid climates typically fall within a range of 0.3–0.6 L/day/m2 of surface area (Muselli et al. 2009; Maestre-Valero et al. 2011; Lekouch et al. 2012). Studies conducted in more humid climates showed lower yield; for example, in a perennial grassland environment in the Netherlands, the maximum water collected was 0.19 L/day/m2 (Jacobs et al. 2008); for a humid tropical island in French Polynesia, the maximum amount was 0.23 L/day/m2 (Clus et al. 2008); and in an agricultural environment near an urban area in Sainte-Anne-de-Bellevue, QC, Canada, the maximum amount was 0.37 L/day/m2 (Khalil et al. 2015).

Early designs for active dew condensers were developed in the 1930s, but innovation has increased since the commercialization of mechanical refrigeration (Wahlgren 2000). Active condensers are now considered an innovative option for locally managed water supply systems in areas with water quality and/or quantity problems (Wahlgren 2000). Active condensers work in a manner similar to that of a dehumidifier to extract water from the air. Although they are more effective than the radiative condensers in terms of water yield per day, they require a source of energy which makes their operating costs much higher than those of radiative condensers which do not require an energy source. However, recent active condensers are designed to minimize the energy required or make use of renewable energy resources that can be integrated into the condenser. For example, most modern solar stills integrate additional solar cells to provide supplementary energy to the system (Bundschuh and Hoinkins 2012). Active condensers are also often equipped with filtration and purification units such as ozone treatment units. The water yield of active condensers varies depending on the design/purpose; yields fall within the range of 15–50 L/day for a small portable drinking water unit to up to 200,000 L/day for larger agricultural scale designs (Peters et al. 2013). In this paper, a comprehensive review for different radiative and active condensers was provided and their potential for agricultural uses was discussed.

Radiative systems

Understanding the principles of dew formation is important for designing both effective radiative as well as active dew condensers that exploit these processes to collect dew. Dew formation is a natural occurrence where a phase transition from gaseous to liquid water occurs on an exposed surface (Beysens 1995; Agam and Berliner 2006). Dew formation is affected by several factors such as vapor pressure, air temperature, relative humidity, and wind speed. The vapor pressure is defined as the pressure exerted by the gaseous water in equilibrium with its liquid phase at a given temperature (McCabe et al. 1993). If the pressure increases, it will reach a maximum point where, passed that point, there will be a net loss of molecules from the atmosphere (i.e., condensation). This maximum pressure reached by the water vapor is called the saturation vapor pressure and is the point where the atmosphere is completely saturated with water molecules. The saturated vapor pressure is a function of the air temperature, and their relationship can be described by the following equation (Alnaser and Barakat 2000):

es=0.611exp(17.27(Ta-273)Ta-36)
(1)

where es is the saturated vapor pressure in kPa and Ta represents the ambient temperature in Kelvin.

When a constant atmospheric pressure is assumed, an increase or decrease in ambient temperature will also increase or decrease the saturated vapor pressure. If air is cooled at constant humidity to become saturated, the corresponding temperature at a given point is called the dew point temperature. If the temperature of an exposed surface is equal to or lower than the dew point temperature, condensation will occur (Agam and Berliner 2006). Moreover, if the exposed surface is maintained at a lower temperature than the air above it, according to Eq. (1), the saturated vapor pressure will be lower near that surface. This difference in vapor pressure is the gradient for mass transfer to take place since the water molecules in the atmosphere will go from high to low vapor pressure, allowing condensation to occur near the exposed surface without bringing the bulk of the air to its dew point temperature.

The dew formation rate depends on the amount of water vapor in the air; this amount is related to the absolute humidity (i.e., the amount of gaseous molecules in the air) and the difference between the dew point and ambient temperature. This notion is expressed by the relative humidity (RH), which is defined as the amount of water vapor in the air at a given temperature with respect to the maximum amount of water vapor that the air can hold at that same temperature. It can also be defined as the contribution made by water vapor to the total atmospheric pressure over the maximum pressure that the water vapor can exert at the current temperature (Alnaser and Barakat 2000):

RH=e(Ta)es(Ta)×100
(2)

where RH is the relative humidity in % and e is the vapor pressure in kPa. Given the definition of the dew point temperature, the relative humidity can also be expressed as follows (Alnaser and Barakat 2000):

RH=es(Td)es(Ta)×100
(3)

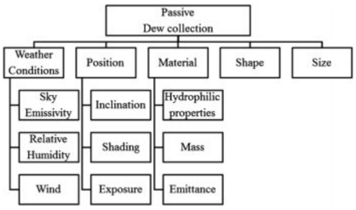
where Td is the dew point temperature in Kelvin. The RH depends on both the difference between the dew point and the ambient temperature, and the humidity of the air (Alnaser and Barakat 2000).

Based on these principles, a radiative condenser (also called a passive dew condenser) rely on exploiting the physical processes responsible for dew formation to collect dew water without any additional energy input. The surface of radiative condensers has a high emittance in the infrared region of the spectrum that allows it to cool faster than other surfaces at night-time. Therefore, to attain the required dew point temperature and induce the collection of dew water, the environmental conditions have to be conducive to surface cooling and the exposed surface (i.e., the condenser) has to be optimized to enhance cooling.

Several parameters influence radiative dew collection (Fig. 1). The imposed parameters describe the meteorological conditions that enhance or reduce the formation of dew. They are related to the physical principles behind the technology of the radiative systems. The variable parameters are the components of the condenser that are modified to optimize the collection of dew.

Fig. 1

Factors affecting dew collection



Weather conditions

Dew water condensation occurs during the early morning (Jacobs et al. 1998; Kidron 2000) when the environmental conditions are favorable. It is important to consider the dependency of dew formation on weather conditions, such as sky emissivity, relative humidity, and wind speed, in the study of dew water condensation (Beysens et al. 2003, 2006; Shank 2006).

Sky emissivity

Low emissivity through the sky is known to prevent water vapor condensing, as it does not allow radiation to escape from surfaces at ground level (Gläser and Ulrich 2013); therefore, higher emissivity is ideal for condensation to occur. Dew formation is more likely to occur under clear skies. For example, studies in continental and coastal areas showed that yield was directly proportional to atmospheric transparency and sky visibility to infrared radiation (Beysens et al. 2006; Muselli et al. 2009).

Surfaces cool at night since there is a net flux of radiation energy emitted toward the sky. This radiation lies in the infrared region of the spectrum (?, 8–13 μm), which is the region associated with thermal radiation (Alnaser and Barakat 2000). During the night, the net radiation of a surface is emitted toward the sky and a fraction of the radiation is lost to space. However, the radiative energy can partially be absorbed by the water and carbon dioxide in the atmosphere, and part of this absorbed energy is radiated back to the surface, reducing the net long wave radiative cooling effect (Beysens et al. 2007). Therefore, clear nights when there is a lot of water held in the atmosphere are more conducive to thermal cooling of radiative surfaces than cloudy nights.

As clear nights allow greater surface cooling, they are optimum for dew formation, as opposed to cloudy nights (Kidron 2000). Muselli et al. (2009) found that dew yields decreased approximately linearly with the increase of mean cloud cover, which was used as an indicator of thermal emissivity of the sky, as described by the following equation:

$h=h0(10-N-)$
(4)

where N- is the mean night-time cloud cover that was equal to 0 for clear sky and 10 for totally cloudy sky; h is the mean dew yield (mm/day) and h0 is the mean dew yield when the cloud cover was equal to zero. It is important to note that in this experiment the maximum yield did not correspond to N- being zero but to N- being approximately three. In fact, the dew yield was relatively low for the nights that were totally clear; for two sites situated in the Mediterranean basin, h0 was equal to 0.018 and 0.016 mm, which is relatively low when considering that the mean dew yield was 0.138 and 0.108 mm, respectively.

The discrepancy between mean dew yield and yield when skies were clear can be explained by the fact that a clearer sky also corresponded to drier air (Muselli et al. 2009), showing that a certain level of absolute humidity is required for dew condensation to occur. For example, it has been found that the frequency at which dew events occurred in humid environments was 20 % higher than in semi-arid Mediterranean climates, which resulted in a higher cumulative dew water formation during the summer in the humid environment (5.58 L/m2/summer) than in the semi-arid environment (3.5 L/m2/summer) (Clus et al. 2008). In addition, a study in Morocco concluded that circulation of humid marine air was an important factor controlling dew yield (Lekouch et al. 2012), again showing the importance of atmospheric water content for dew condensation.

However, the absolute humidity of the atmosphere also affects the emissivity of the sky, with radiation being reduced when absolute humidity is high. For example, the high absolute humidity in environments such as wetland ecosystems or tropical climates hinders dew formation (Clus et al. 2008; Xu et al. 2013). Conversely, the drier Mediterranean climate allows for higher dew yields (Clus et al. 2008).

Relative humidity

The relative humidity is highly correlated to dew water yields. In a study comparing two large (30 m2 in area) passive dew condensers in Ajaccio, France, Muselli et al. (2006) found that the limiting value of humidity below which dew did not form was 80.7 and 79.3 % for both condensers. Similarly in southwest Morocco, Lekouch et al. (2012) found that water mostly condensed when the relative humidity was between 74 and 92 %. In the same study, the authors defined the relationship between the relative humidity and the air and dew point temperature difference as (LeKouch et al. 2012):

$\ln(RH)=k(Ta-Td)$
(5)

where k is a constant that varied only slightly with the air temperature Ta in Kelvin. This relationship was found to be important since nearly all the data points were below the line described by the equation (Clus et al. 2008; Lekouch et al. 2012):

$h=h'?T0[?T0-(Td-Ta)]$
(6)

where h' is the maximum yield for one night (L/m2/day) and ?T0 was the maximum difference in temperature between the surface of the condenser and the air (Clus et al. 2008; Lekouch et al. 2012). The ?T0 can be used as a measure of the performance of the dew condenser in a specific location; for example, ?T0 was used to compare the efficiency of dew collection in three locations: Morocco, Zadar and Komiza (Croatia). In Morocco it was found that the maximum temperature difference between the surface of the condenser and the air temperature was -5.3 °C, whereas the difference was slightly greater in the two locations situated in the Adriatic area of the Mediterranean basin; in Zadar it was -9.2 °C, and in Komiza it was -8.0 °C (Muselli et al. 2009; Lekouch et al. 2012). Thus, it can be concluded that the surface of the condenser cooled to a greater extent in the Adriatic locations than in Morocco.

The linear relationship described in Eq. (6) suggests that the difference between air and dew point temperature, or the relative humidity, can be the main parameter that limits the dew yield. In fact, several studies have found a linear relationship between the dew yield and difference between the air and dew point temperature and, therefore, a logarithmic relationship with the relative humidity (Sharan et al. 2007; Muselli et al. 2009). However, Muselli et al. (2009) did not find this linearity statistically significant. Muselli et al. (2009) concluded that the relative humidity alone was not enough to model dew yield, and that the night net radiation was another important parameter in the formation of dew on condensers.

Wind speed

Wind has both a hindering and enhancing effect on dew condensation. It is necessary to bring humid air, but also reduces radiative cooling by increasing the heat exchange between the warmer air and the surface of the collector (Beysens et al. 2003). Gandhidasan and Abualhamayel (2005) suggested that in dry conditions, strong winds do not favor dew condensation. In a study conducted in the humid tropical island of French Polynesia, dew yields declined rapidly for wind velocities higher than 3 m/s, and dew was almost absent for velocities higher than 4 m/s (Clus et al. 2008). Similarly, the limiting wind speed for condensation in the Adriatic area of the Mediterranean basin was 4.7 m/s, according to a study conducted in Zadar (Muselli et al. 2009). Therefore, protecting the condenser from direct wind can be beneficial for improving dew condensation. On the other hand, low wind speeds are necessary to bring atmospheric water vapor to the surface of the condenser; a study in southwest Morocco found that dew formed when wind was in the range of 0.15–0.7 m/s (Lekouch et al. 2012).

The technology behind radiative dew water collection system is relatively simple as it relies on exploiting the physical processes of dew formation, and no additional energy input is necessary. However, the radiative cooling power of passive dew collectors is a function of the weather (ambient temperature, relative humidity, and cloud cover), which affects yield in relatively complex ways. Overall, however, the ideal weather conditions are usually found in arid and semi-arid climates, which also tend to be water scarce. By implementing this technology, it will be possible to produce drinkable water with no additional energy input and consequently with a very small footprint. However, due to the very particular weather conditions necessary for maximum condensation of dew (i.e., relative humidity ~80 %, and cloud cover and wind speed low but greater than zero), the water yield per day is typically relatively low and difficult to predict. This makes dew collection using radiative condensers a non-reliable water source, although optimizing condenser design can go some way to improving yields.

Design of radiative dew condensers

Given the dependence of radiative systems on the dew formation physical processes, their design has to be optimized to allow surface cooling without any external energy input. In particular, there are a number of factors that must be optimized to increase the yield. First, it is important to maximize the infrared wavelength emitting properties of the condensing surface to allow surface cooling at night. Second, absorption of the visible light must be reduced to prevent daytime warming of the condenser, which means having a higher reflectivity in the visible part of the spectrum (i.e., white materials). Third, the heating effect of the wind must be reduced by lowering its velocity, which is usually achieved by having a tilt angle on the condenser or a specific shape. Fourth, a hydrophilic surface is needed to recover most of the water, so it can be collected in a container, and to avoid evaporation of the water in the early morning. Finally, it is important to have a light condenser to reduce heat inertia, making it easier to change the temperature of the surface, and to have good insulation to avoid heat transfer from the ground (Beysens et al. 2006, 2007; Clus et al. 2009). This said, it is possible to divide the optimization factors of the design and location of radiative systems into the material, shape, and size of the collector, and its position.

Surface material

Dew formation is influenced by the properties of the material used for the surface of the condenser. By selecting the appropriate material, the energy barrier at the liquid–vapor interface can be lowered to enhance water recovery. Alnaser and Barakat (2000) tested three different types of materials and the results showed that aluminum had the highest potential use as a dew water collecting surface, followed by glass and polyethylene. They came to the conclusion that a polished surface enhances dew collection by letting the water easily run along the surface. Kidron (2010) found that a smooth Plexiglas surface collected 0.21 L/m2/day of dew water, compared to a rough surface that collected 0.1 L/m2/day.

Another property that affects dew condensation is the mass of the material, which affects the ability of the condenser to lower its temperature, since condensers with a higher mass have higher thermal inertia. For this reason, insulation beneath the condenser is necessary to prevent heat transfer between the soil (or the condenser frame) and the surface sheet of the dew condenser (Beysens 1995; Nikolayev et al. 1996). For example, a study in North West India of plain, uninsulated corrugated galvanized iron roofs measured a maximum cooling temperature of 2 °C, while a condenser that was thermally insulated using a foil with a higher emissivity had a maximum cooling of around 3.4–3.7 °C.

In addition to being light, having high wetting properties, and being thermally insulated from the ground, the condenser material needs to have a high emittance in the infrared region of the spectrum to enhance its cooling properties (Alnaser and Barakat 2000). The standard foil recommended by the International Organization for Dew Utilization (OPUR) is a white hydrophilic foil of titanium dioxide and barium sulfate microspheres embedded in polyethylene. The OPUR standard foil is said to improve emitting properties in the near infrared region by providing radiative cooling at normal ambient temperatures. At the same time, it reflects visible light, thus increasing the time for dew collection in the early morning. Maestre-Valero et al. (2011) compared the standard white hydrophilic foil recommended by the OPUR (yield 17.36 L) with a low-cost black polyethylene foil (BF) used for mulching in horticulture (yield 20.76 L). The OPUR foil and BF foil had the same emissivity in the wavelength of 7–14 μm (e = 0.976). However, the BF had a higher emissivity in the wavelength of 2.5–7 μm (BF: 0.996; OPUR foil: 0.833) and 14–25 μm (BF: 0.998; OPUR foil: 0.990). The better performance of the BF showed that the increase of emissivity in the infrared spectrum resulted in a higher yield than an increase in the surface hydrophilic properties. This indicates the importance of the emittance of the material, with high emittance being needed not only in the near infrared spectrum but also in the entire mid-infrared spectrum (Maestre-Valero et al. 2012).

Shape

The shape of the dew water collector and its influence on water yield has been studied in terms of simple hollow structures and non-plane sheets. Dew collection from hollow funnel-like structures showed an increase in the collector efficiency compared to a 1 m2 standard planar collector. This standard collector is a polyethylene sheet embedded with microspheres of titanium dioxide and barium sulfate tilted at a 30° angle to the horizontal. Beysens et al. (2012) hypothesized that hollow forms reduced the heat exchange between the air and the condenser surface by reducing free convection; it was found that a cone half-angle of 30° gave the best results among all the tested inclinations (25°, 30°, 35°, 40°, and 50°). In a grassland area in the Netherlands, an inverted pyramid with an angle of 30° collected 20 % more water than a standard 1 m2 planar dew collector (Jacobs et al. 2008).

Similarly, a simulation done under typical meteorological conditions (i.e., clear sky, ambient temperature of 15 °C and relative humidity of 85 %) showed that a funnel shaped condenser with a half-angle of 30° had a higher performance by 40 % compared to the reference plate. The funnel shape was found to reduce the flow of warm air and block the heavier cold air at the bottom, thus avoiding natural convention (Clus et al. 2009).

Concerning non-planar collectors, three shapes of sheet with different relief have been tested: egg-box, origami and multi-ridge. The origami structure compared to the egg-box structure showed better performance because the egg-box structure hindered the flow of dew water due to its flat top (Beysens et al. 2012). The multi-ridge condenser did not show any difference in performance compare to a flat reference condenser, but when the wind speed increased above 1.5 m/s, the multi-ridge condenser showed an increase in efficiency of 40 % (Clus et al. 2009).

Size

The size of the condenser has been found to influence its performance. For example, an on-ground 900 m2 condenser showed a decrease in yield of 42 % compared to four 1 m2 standard condensers. It was suggested that the large size of the condenser allowed the foil to fold, which increased water stagnation, thus affecting the radiative cooling effect (Sharan et al. 2007). However, Kidron (2010) found that a decrease in size from a 0.16 to a 0.01 m2 condenser reduced the yield from 0.25 to 0.15 L. The reduction in size on both axes (e.g., from 10 cm by 10 cm to 5 cm by 5 cm) showed a greater decrease in yield than when one axis was kept constant (e.g., from 20 cm by 10 cm to 10 cm by 10 cm). This suggests that there is a border effect that reduces the efficiency of the condenser surface toward the edges. This issue has not yet been explored in detail.

Position

The position of the dew condenser, in terms of its inclination, shading and exposure, influences the condensation of water. First, it was found that an angle of 30° with respect to the horizon was the optimal inclination to minimize the heat exchange effect caused by wind, increase the water recovery by gravitational force and not hinder the visibility to the sky that is needed for radiation cooling. For example, a study in Grenoble, France, found that when the condenser was inclined at an angle of 30°, the yield of dew water increased by up to 20 % when compared to a nearby horizontal reference plate (Beysens et al. 2003).

Second, studies of dew condensation showed different results for condensers in the sunlight and in the shade. For example, an experiment in Israel showed higher yields in the shaded areas (Kidron 2000). Furthermore, in north-west India, water condensation was 35 % higher for a condenser that remained longer in the shade than for one exposed to sunlight (Sharan et al. 2007).

Finally, studies showed that exposure to the sky also affected condensation rates by being related to radiative cooling. A site surrounded by high altitude topography will have the infrared radiation that the condenser emits reflected back by the hills or mountains (Beysens et al. 2007). For example, a study comparing an uphill site with a downhill site showed that the yield from the latter was 40 % lower than that of the uphill site (Kidron 2000). In addition, Muselli et al. (2006) showed that a condenser exposed from the sides had a higher yield (mean dew yield: 0.118 L/day) than one that was enclosed and closer to the ground (mean dew yield: 0.111 L/day).

The optimization of radiative condensers allows yield to be increased by changing the design of the condenser from a flat plate to more complex shapes and materials. First, an optimal inclination of 30° decreases the heating effect of wind on the condenser (force convection) and enhances water collection by gravity. In addition, an inverted hollow structure such as a cone or pyramid reduces the negative consequences of convection even further, including free convection. However, producing a hollow structure is more complicated than producing plane condensers. Second, the emittance properties of the material can significantly enhance dew condensation. The standard OPUR sheet has been shown to increase the cooling of the condensing surfaces; however, since the sheet is specially manufactured for research purposes, the cost is quite elevated. Maestre-Valero et al. (2011) studied a low-cost polyethylene foil that is commonly used in agriculture, which produced better results than the OPUR sheet. This suggests that there is further potential to lower the price of the material used as a surface collector while increasing the efficiency of the collector. Finally, the scaling up of the condenser from the 1 m2 standard has shown a decrease in efficiency of about 40 % (Sharan et al. 2007), which does not allow for the collection of high volumes of dew water.

Active condensers

Given the low yields of radiative condensers and the specific environmental conditions required for dew formation, active condensers may be a viable alternative. Although relative humidity is a significant factor in the efficiency of active condensers (Peters et al. 2013), active condensers are less affected by variation in conditions such as sky emissivity, wind speed, and topographic cover than radiative condensers. Thus, they can potentially be operational under a wider range of weather conditions (Peters et al. 2013).

Active condensers can be classified into personal scale devices that can generate 15–50 L of water per day, or larger industrial scale machines, which can produce up to 200,000 L/day (Peters et al. 2013; Khalil et al. 2014). The yield of active condensers is much higher than of radiative condensers, but active condensers typically have a high energy demand. Despite this drawback, active condensers can be useful as a supplementary water source in circumstances where water supply from other sources is limited, such as an alternative source of potable water.

Active dew condensers typically use cooling condensation or regenerative desiccation to bring trapped air to the dew point temperature, thus causing the water vapor to condense for collection. Early active condenser technology used simple designs to maintain collection surfaces at cool temperatures for a longer period of time than can be achieved in radiative condensers. Subsequent technological development focused on using regenerative desiccants, which are subdivided into solar regeneration, heat exchanger coupled, and dual air pathways, and cooling condensation technology, which is further divided into ground-coupled, portable, vehicle compatible and seawater cooling. Each of these design types has benefits and drawbacks, as discussed below.

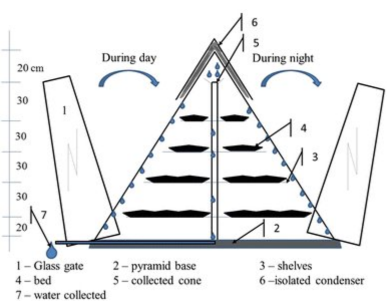
Regenerative desiccant materials

Regenerative desiccant technologies use hygroscopic materials (substances that can attract and hold water molecules through adsorption or absorption) to increase the volume of dew collected. Silica gel and zeolite are commonly used in active condensers. The capacity of hygroscopic materials to hold amounts of water greater than their own mass theoretically makes the active condensers more effective at extracting and retaining water than radiative condensers. Furthermore, low dew points can be achieved without potential freezing at moderately low operation costs. However, initial costs of desiccant materials are high and the desiccant beds must be replaced periodically. Regenerative desiccant condensers typically include a bed of hygroscopic material that can be exposed to humid air, and a stimulus source, such as solar power or heat exchangers, to extract the water content for collection in built-in or external reservoirs. It should be emphasized that some apparatuses (e.g., solar regeneration) depend on solar radiation for heating the desiccant and do not require an additional source of energy. These apparatuses cannot be considered as active condensers, but were included in this section as one of the types of regenerative desiccant condensers.

Solar regeneration

Initial designs of this type consisted of a solid or liquid desiccant that absorbed water vapor from moist air, which was subsequently recovered by heating the desiccant and condensing the evaporated water (Hamed et al. 2010). For example, an apparatus that used a high surface area of wood exposed to the nighttime air absorbed moisture of up to 30 % of the dry wood's weight. During the daytime, the wood was stored in an area with large windows and glass ceilings to allow the sun's heat to evaporate the moisture from the wood. The air was then expelled to an area in the shade where the moisture condensed and was collected in a reservoir. The air was recirculated back to the wood to carry more moisture and flow back to repeat the cycle (Altenkrich 1938). Several setups used different desiccants, such as saw wood (Altenkrich 1938), silica gel (Dunkak 1949; Ackerman 1968; Hamed et al. 2011), and recycled newspapers (Krumsvik 1998). For instance, a glass pyramid shape apparatus with a multi-shelf solar system to extract water from humid air was explored by Kabeel (2007). Saw wood and cloth were examined as beds and were saturated with 30 % concentrated calcium chloride solution. During the night, the pyramid glass sides were opened to allow the desiccant to absorb moist air and during the day, the glass sides were closed to extract the moisture from the bed by solar radiation. Water evaporates and condenses on the top of the pyramid and is collected through a middle cone and through the glass inclined sides to an external reservoir (Fig. 2). The pyramid shape with multi-shelves doubled the amount of collected water compared with a solar desiccant/collector system with horizontal and corrugated beds.

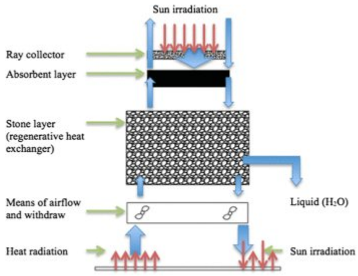
Fig. 2
Glass pyramid with shelves (open during night and closed during day)



Similar setups have used silica gel contained within a breather, which is a vented housing that allows air exchange with the atmosphere due to temperature and pressure differences between the two. The breather housing was coated with a dull, dark finish to allow for maximum heat absorption during the day. The heated silica gel inside was then activated, which allowed release of the water content, creating warm moist air that flowed out of the breather and condensed. The gel sat on a slotted bed, which was sufficient to allow it to collect moisture during the night-time (Dunkak 1949). Similar mechanisms can be found in different designs, such as several cone shaped thin sheets of metal stacked vertically with a desiccant in the middle. During the night, the ends of the metal sheets were raised so that the desiccant was exposed to the cool, moist air, and condensed during the day (Ackerman 1968). Recycled newspapers have also been used as desiccants housed in glass pyramid chambers (Krumsvik 1998).

Collectors with regenerative desiccant materials have been designed for use in a wide range of environments, and have been optimized by altering the desiccant used and the design of the collector. For example, for humid tropical regions with large temperature differences, Groth and Hussmann (1979) described a device comprising a glass sun-ray collecting top layer, followed by a coarse, granular silica gel absorbent layer, followed by a layer of non-absorbent materials, such as stones, that was stacked 3–5 m high (Fig. 3). At the bottom, fans supplied and withdrew air. This device could be 100–200 m in width and up to 15 m in length. Cool, moist nighttime air was channeled from the bottom up so that it passed the non-absorbent layer and cooled before reaching the absorbent layer, where water adsorbed to the silica. During the day, hot air flowed in the reverse order and reverse direction. The moisture desorbed from the silica gel flowed downwards into the stones (heat exchange layer) and condensed on contact with the cool surface, then flowed into a reservoir. The air flow in this phase could also be aided by a radiator (Groth and Hussmann 1979). This structure could collect 10–15 L of water per square meter of adsorbing surface over 24 h.

Fig. 3
A simplified illustration of the device proposed by Groth and Hussmann (1979)

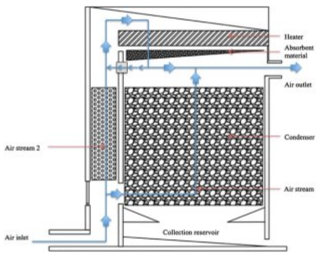


For application on a larger scale in desert regions, Klemic (2005) detailed an apparatus containing a frame 1–6 m high, which held a net of superabsorbent polymer, preferably of a grain size of 50–1000 microns. This polymer was capable of absorbing moisture of several times its own weight, which was released with the application of solar power. The condensate water was collected in a trough located directly below the net. This device can be used for fog clearance and odor removal in addition to water generation, and the frame can be built from local, widely available materials.

Heat exchanger coupled desiccants

Regenerating desiccant beds with heat exchangers removed the time constraints associated with solar power and led to more control over the amount of energy supplied to regenerate the desiccants. For example, Michel and Bulang (1981) described an apparatus containing a sun collector, an adsorbent layer with a desiccant bed, and an air baffle, followed by a condenser (Fig. 4). A grated collection reservoir was located below the condenser, as well as fans below the sun collector to channel air through. Air intake was in the air baffle zone, which was open during the night to contain air inside. Upon entry, the air flow was split into two, with one partial air stream being channeled through the condenser and heat storage reservoir to cool it. The second stream is directed into the adsorbent layer, where its moisture was adsorbed. The two streams connected before exiting through the air outlet port. In the daytime phase, the water was desorbed and condensed. The air flaps were closed and mirrors concentrated sun rays to heat the air inside. Heating the adsorbent released moisture to two streams of air. One went down to the condenser layer and relinquished some of the moisture, which condensed as water droplets and was heated in the process. The warm air was recycled back through the adsorbent layer and continued to pick up more moisture. Ito et al. (1981) described similar designs with multiple desiccant beds.

Fig. 4
A visual representation the aforementioned apparatus described by Michel and Bulang (1981). Air stream represents the first air stream that is directed through the condenser and heat storage reservoir and Air stream 2 represents the partial air stream that is directed through the absorbent material



Dual air paths and chambers

Newer designs with regenerative desiccants used multiple pathways and chambers, the purpose of which was to maximize moisture extraction and increase the efficiency of batch processing. Such designs included portable sized devices that could be coupled to mobile energy sources, such as automobiles. For example, Tongue's (2007) desiccant wheel required a heat source such as that from a vehicle exhaust to provide heat to an air loop, where a heat exchanger heated the air within the loop. On one side of the loop was dry air and on the other was the humid air passage. The moist air in the second passage flowed to a condenser, from where the subsequent condensate dripped through a pipe to a reservoir, where it was filtered further before being dispensed (Call et al. 2009). An air blower channeled ambient air into a desiccant bed, the air from which was then released via heat from an energy conversion device. With the addition of heat, the high temperature, high humidity air was desorbed, passed over a condenser and collected as water droplets. The energy conversion device can be excess heat from a vehicle's motor.

Rodriguez and Khanji (2012) described another dual chambered device that incorporated a water treatment step. The closed chamber received air funneled in through fans, which was then heated to 75–82 °C and exposed to a desiccant that had been pre-absorbed with moisture from the ambient air. The hot air was humidified and then passed over condenser coils, which collected water condensate that dripped into a collection tank. The computer control extra heated the desiccant once per day to decontaminate it, and ambient air from the open air chamber was infused within it to supply the moisture. The collected water was exposed to UV light and then pumped through filters containing carbon and zinc or silver activated zeolite, before being collected in a final reservoir that rested on Peltier plates to allow the water to cool before dispensing. Water sensors could shut off or shift the output of processed water when the reservoirs were full. Ellsworth (2013) described a desiccant that included porous support material and hydroscopic absorbent dispersed within the support material. Materials such as PVA foam with calcium chloride as a chemical desiccant resulted in increased moisture adsorbing properties.

Cooling condensation systems

The second common class of active condensers contain the components of a refrigeration system to provide a cooled surface for condensation to occur, such as in a reverse cycle air conditioner (Graham and Dybvig 1946). These devices often contain a compressor, condenser, and evaporator connected by conduits that carry a refrigerant. These, in addition to pressure valves, air inlets and outlets, and water reservoirs, are generally housed in a rectangular container. The advantages offered by this approach include low initial costs, and low operating and maintenance costs. In addition, the refrigeration mechanism allows for dew collection even at times when the ambient temperature is greater than the dew point temperature, potentially making them more efficient than radiative condensers. The disadvantages include potential icing of evaporator coils and low cost-effectiveness during periods of low air flow. However, these problems have been addressed in newer models by insulation and programmable cycling compressors, respectively.
Designs using cooling liquids

Coanda and Coanda (1956) described a housing with orientable entry and exit points for wind, located near large water bodies, where warm, moist air is prevalent. Inside the housing was the first cooling radiator coil, which was connected via conduits to a second coil located beneath the soil surface that was in contact with cooler temperatures. A cooling liquid was driven through the coils by a windmill. The warm air entering the housing was cooled as it flowed through the coils, such that condensed water droplets flowed down the coils and were piped via conduits into a dispensing reservoir.

Portable atmospheric water generators also use cooling liquids to acquire potable water from ambient air of varying temperature and humidity conditions, and typically generate between 20 and 50 L of water per day. They also contain built-in filtration systems that remove the need for separate water treatment, making them an asset to regions without such infrastructure. Air is funneled into the device via fans through an air filter that screens out debris. Inlet air passes through evaporator and condenser coils aided by a compressor to remove the water vapor by condensation from the air. Evaporators induce liquid refrigerant vaporization, allowing the air to cool the air and the water to condense into a reservoir for collection. A compressor and condenser allow the refrigerant to return to its liquid state. The condensate is collected on a collecting pan and channeled into a reservoir where UV light is applied to kill 99.9 % of microorganisms (Reidy 1992a, b). Once sufficient water has collected, it is passed through a water filter into a second reservoir where secondary UV light exposure is applied. Processing is halted if either of the UV lights malfunction or when filters require replacement or cleaning, as detected by an air pressure sensor. Sensors detect and stop water output once the external or internal containers are full and the flow of water can be shifted to secondary containers (Reidy 1992a, b).

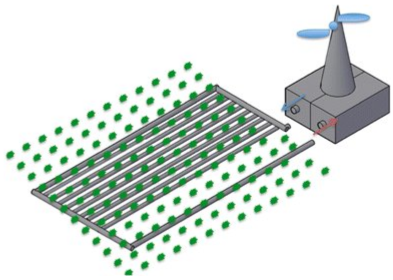
A programmable microchip set can be used to operate the generator. In addition to being programmed to display alerts during compromised operations, such as when the air filters need replacing, the microchip can be coupled to a thermostat and humidistat. These can be programmed to process air of a given temperature and humidity level so as to maximize the water yield for a given amount of energy needed to operate the generator. For example, at 24 °C and 50 % relative humidity, up to a 3.79 L of water can be produced within 12 min (Reidy 1993). Similar designs incorporate ionic air filters and activated charcoal water filters to remove volatile organic compounds, and heat strips to prevent freezing of water when atmospheric temperatures drop below 0 °C (LeBleu 1997, 1998).

Subsequent designs allowed the collected water to be cooled or heated, as well as to be recirculated to prevent stagnation. Insulation and heating measures were also added to prevent rusting and icing of the condensing coils (e.g., Zakryk 2000; Lloyd and Baier 2002). Design modifications to prevent stagnation included a spinning reservoir that was cylindrical at the top and conical at the bottom; the vortex created by the spinning water prevented stagnation and accumulation of sediment. Additional forms of filtration included melamine deep filters and charcoal black filters. The water was chilled or heated and pumped to be dispensed from a spout located at the top (Dagan 2003). Water dispensing can be either gravity assisted or accomplished through the use of small pumps (Faqih 2004). Versatile designs can be a standalone indoor or outdoor unit, wall-mounted, mobile or attached to a vehicle (Engel and Clasby 2004; Foss 1973).

Ground-coupled heat exchangers

The ground can also be used as a heat sink to naturally induce condensation. However, one disadvantage of this approach is that underground tubes are susceptible to contamination and are difficult to clean. Courneya (1982) described an apparatus that contained a cold heat exchanger buried beneath the surface of soil or a body of water that was at or near subsurface temperature. An above ground, water collecting funnel channeled air into the system, through the heat exchanger, out through the outlet valve, and into a reservoir that collected the condensate. The outlet valve could be regulated to increase residence time of the air inside the heat exchanger to allow for sufficient condensate to form. O'Hare (1984) described a simpler apparatus that operated by the same principle with solely a blackbody pipe that extended beneath the surface (Fig. 5). In addition, Smith (1984) described a housing with a turbine and evaporator conduit. The turbine was connected to an electrical generator that powered the refrigeration system. The unit was mounted on a tower such that it automatically rotated to point toward the wind. The cooling of the evaporator caused the air to sink and leave the unit at a lower position to where it entered, leading to denser air. A similar design contained a chamber located 6' below the surface, which contained fans that helped circulate air within several conduits. When air temperature is higher or lower than ground temperature, a gradient is established and water is trapped and condensed (Rogers and Midgett 1980).

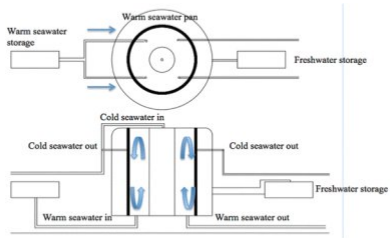
Fig. 5
An illustration of O'Hare's (1984) ground-coupled heat exchanger apparatus with the rotatable turbine tower introduced by Smith



Seawater cooling

Craven's (2008) invention generated fresh water from deep cold ocean water at altitudes above sea level (Fig. 6). It included a first stage with a siphon, collecting tank and supporting structure. The irrigation piping in the siphon transported the deep ocean water high up the insulated irrigation pipe condenser, which retained the coolness of the water, and allowed the air outside to condense onto it. The layered irrigation pipes were made of materials with properties that allow them to function as a heat exchanger.

Fig. 6
Craven's seawater cooling system (Craven 2008). The top figure represents an aerial view, while the bottom figure illustrates a profile view of the system



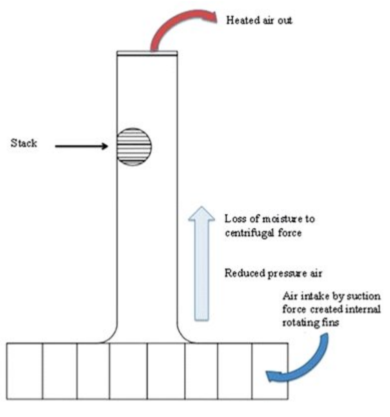
Cooling using dual airflows

Bulang (1980) described a device that took moist nighttime air and divided it into two partial air flows. The first partial air flow passed through a water-absorbing material, such as silica gel. 75 g of water could be absorbed for 100 g of the silica gel. The second partial gas flow passed through a heat accumulator where heat was transferred to it. The accumulator was deheated and the second partial gas flow was discharged. In the second stage during the daytime, a flow of moist gas that had been heated by a solar-energy collector was passed through the moisture laden water absorber from step 1. This gas flow absorbed the moisture from the absorber, creating a second warmer and more humid gas flow. This gas was passed over the deheated heat accumulator, where heat was transferred to the accumulator and moisture condensed on its surface. The flow of gas was discharged and the condensate was collected. Hussmann's (1982a, b) similar device used four stages. In the first stage cool humid atmospheric air was used to cool the first heat condenser and moisten an adsorbent medium. In the second stage, warm solar heated air was used to expel moisture from the adsorbent and carry the moisture into the first heat storage condenser, where the moisture condensed and released its heat. In the third stage, a second stream of cool humid air was used to cool the second heat condenser and moisten the first adsorbent. In the fourth phase, a second stream of warm solar heated air was used to harness moisture from the adsorbent and condense it over the second heat storage condenser. The stream of air in the second phase was preheated by the second heat storage condenser from the fourth phase. The stream of hot air in the fourth phase was preheated by the first heat storage condenser, in addition to solar radiation, and this heat was also used to expel all moisture from the adsorbent.

Other methods

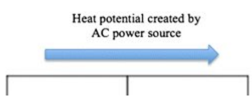
Ockert (1978) proposed the 'Tornook' device, which was a tall stack with an extended base (Fig. 7). Air intake was through the base, which contained inlets that imparted a rotational velocity to the air. The resulting air had a reduced pressure and the density difference aided in continuing the flow. This also led to rapid moisture loss from the air, which was precipitated due to the centrifugal force in the vortex. The remaining air was heated to be released from the top of the stack, and the resulting pressure differential allowed for new air to enter from the base. High humidity resulted in a stronger vortex.

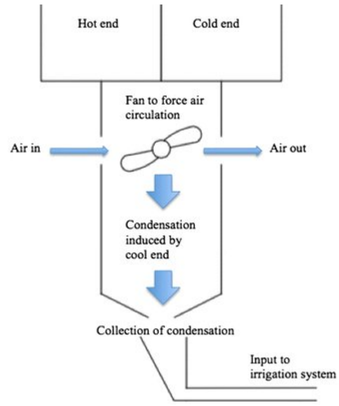
Fig. 7
A conceptual profile view of the Tornook device Ockert (1978)



Peltier systems, which consist of a unit that transfers heat from one side to the other powered by electricity, have been used to provide water directly to plants for irrigation. Biancardi (1982) described a Peltier system that contained a housing, a condensation member and a pair of electrical probes. The probes were stuck in the soil such that the condensation member resided above the soil. In addition, a thermocouple such as a Peltier crystal, which contains a hot and cold side when electricity is conducted, was included. The hot side contained a heat sink and the cold side contained a conductor that removed heat from the conduction member, making it cooler. The cooled conduction member allowed condensation of moisture from the atmosphere; this condensation was then channeled into a small collection reservoir and subsequently into the soil (Muñoz-García et al. 2013). The electricity source for the system could be a battery or an AC current source. Similarly, Tircot's (1985) apparatus utilized the Peltier effect and had a hot end that was in contact with a heat dissipater and a cold end in contact with a thermally insulated condenser powered by an AC current (Fig. 8). Air entered the chamber and induced the condensation of water into droplets that were collected in an external reservoir. A fan and thermometer can also be used to force air and detect temperatures inside the chamber to ensure adequate processing.

Fig. 8
Conceptual representation of Tircot's Peltier system





Large-scale designs

Faqih (2005) offered several prototypes for collecting water for human, animal and irrigation purposes using flat, vertical or conical condensation surfaces. Evaporator coils were installed behind the condenser surfaces, where humid air lost moisture on contact with the surface; the condensation collected on these surfaces dripped down into a collection pan. The water could then be filtered and appropriated for use. These devices used thermo-acoustic engines, which use high intensity sound waves to generate superhot gas molecules that transfer their energy to coils and then expand and cool, rather than standard refrigeration systems.

Implications for optimization and use of active condensers

Regions where low technology systems are more appropriate tend to use passive radiative condensers or solar-energy based regenerative desiccant condensers. However, active condensers may prove useful in regions and situations where conventional sources of water are not available and a higher yield is required, such as for providing potable water for isolated communities in arid regions or insular areas. The usefulness of active condensers depends on their design and intended application. For instance, active condensers using cooling condensation technology generally provide the benefit of being more portable than regenerative desiccation systems. Traditionally, desiccants allowed for function of condensers at lower dew point temperatures because there was no concern that the condenser coils would freeze. However, insulation and programmable chipsets have allowed for the design of condensers that can remain functional at lower temperatures as well as perform within certain temperature ranges, so as to be more efficient depending on the local climate. The trend in regenerative desiccants has been to couple them with heat exchangers to improve their regeneration capabilities and enhance the yield.

Milani et al. (2011) estimated that 95 % of the water costs of such technology can be attributed to energy consumption rather than the capital costs of the active condenser technology. However, this is difficult to quantify, as energy consumption varies with the design of the condenser. For example, a life-cycle assessment of active condensers in comparison to refrigerators has shown that active condensers powered by conventional, non-renewable energy sources consume more electricity for operation than refrigerators. In addition, active condensers powered by conventional sources of energy require 4–8 L of virtual water to produce one liter of potable water, excluding condensed vapor, based on the source of power (99 % of this water is a consequence of coal washing and power station cooling operations used to provide electrical power) (Peters et al. 2013). The high energy consumption also raises environmental concerns related to emission of greenhouse gases. For example, active condensers produce nearly three orders of magnitude more greenhouse gases than seawater desalination plants (Peters et al. 2013). It should be emphasized that these analyses were based on active condensers that were powered by conventional electricity sources.

Given that 99 % of the water use and greenhouse gas emissions of active condensers are associated with the power supply, the obvious way to improve these generators is to utilize renewable sources of energy, such as wind or solar. With such a power supply, the active condensers would significantly outperform sea water desalination plants on greenhouse emissions. Overall, it is likely to be environmentally safer and more cost-effective to utilize active condensers powered by renewable energy sources. Although including a solar power unit to provide the power required for active condensers will increase the capital cost, the operation costs as well as the cost per liter will be reduced significantly.

Khalil et al. (2014) suggested an independent dew water irrigation system (IDWIS), which consists of four main components: a solar power unit, active condenser(s), water reservoir, and a drip irrigation system. The design of the IDWIS consists of four steps. First, the irrigation demand is computed based on the area cultivated and the crop type. Second, the reservoir is designed to store the amount of water required for the maximum irrigation event. Third, the number of condensers is identified based on the amount of water required for the maximum irrigation event and the productivity of a single condenser. Fourth, the solar power unit is designed based on the energy required for the number of condensers identified in the third step.

Other designs utilize seawater to enhance cooling and to reduce the energy demands of cooling condensation condensers. The seawater greenhouse prototype may be a useful tool to better understand the enhanced cooling by means of seawater (Wahlgren 2000). This prototype uses cool seawater that is pumped into a greenhouse and channeled between a condenser and evaporators to enhance the cool and humid conditions in the greenhouse that are required for plant growth, as well as to produce fresh water condensate. There are certain constraints to this technology, including that the location must be coastal, capital costs are high, and water is relatively expensive at the rate of $0.005–0.012/L (Wahlgren 2000). However, these costs can be attenuated by selling the products grown inside the greenhouse for a profit.

Overall, although water production from active condensers remains relatively costly at present, active condensers are still beneficial in appropriate situations and there are several promising developments in their design that overcome key shortcomings of earlier models. However, while technological development has been extensive, little research has been conducted into design optimization for particular conditions to maximize yield. The reliability of coupled renewable energy sources and other alternative cooling mechanisms has also not been evaluated. These issues must be explored further for active dew condensers to be a reliable source of water in regions where supply and quality of water from other conventional sources are poor.

Conclusion

Dew forms on surfaces when the surface temperature is lower than the dew point temperature. For water condensation to occur; there are several environmental conditions that must be met. A high relative humidity, high sky visibility to infrared radiation, and low wind speed are required, which therefore means that the volumes of dew formed are highly variable. Radiative dew condensers rely solely on the physical processes that induce dew formation naturally. To maximize water condensation without any external source of energy, radiative condensers can be optimized in terms of their shape, size, material (hydrophilic properties, mass, infrared emittance), and position (inclination, shading, sky exposure, and orientation). Such condensers are an interesting source of alternative water because they do not require any additional energy input, and the highest yields collected—up to 0.6 mm/day/m2—are predominantly in regions of water scarcity (arid and semi-arid regions). Despite optimization, radiative condensers are still highly dependent on the weather conditions, making this a relatively unreliable source of water. In addition, yields will remain low, since the scaling up the condenser size from 1 m2 has been found to decrease efficiency.

Compared to radiative condensers, active condensers are more efficient, with daily yields proven to be considerably higher (e.g., 15–50 L/day for a small portable drinking water unit). Active condenser technology takes two main forms: regenerative desiccant materials and cooling condensation systems. The first of the two uses hygroscopic substances that can attract and hold water molecules, from which water is subsequently extracted using a specific stimulus such as solar regeneration, heat exchange, or air paths and chambers. With this type of system, higher volumes of water can be extracted from the air than can be extracted using radiative condensers. Cooling condensation systems contain the components of a refrigeration system to provide a cooled surface for condensation to occur. Similar to radiative condensers, they are optimized to lower the temperature of a specific surface to below the dew point temperature. However, the cooling condensation systems are able to create a larger temperature difference between the air temperature and the surface temperature than radiative condensers.

Thus, active condensers hold promise as an alternative or supplemental source of water in regions where conventional water supplies are limited or unavailable, due to the higher yields produced than those of radiative condensers. Nevertheless, they are more expensive and tend to have high energy demands. Several recent innovations offer solutions for reducing the energy requirements, such as coupling condensers with ground heat exchangers or vehicles, and using seawater for cooling. In addition, the majority of activity in relation to active condensers has been in technological innovation, with research into their efficiency being relatively limited compared to radiative condensers. If active condensers are to achieve their potential, research is needed to evaluate the existing technologies in terms of yield under different conditions, to optimize their design and reduce their energy requirements.

Acknowledgments

Financial support provided by Sustainable Project Funds of McGill University, as well as an NSERC Discovery Grant held by Jan Adamowski, is acknowledged.

References

Ackerman E (1968) Production of water from the atmosphere. US Patent No. 3400515

Agam N, Berliner PR (2006) Dew formation and water vapor adsorption in semi-arid environments—a review. J Arid Environ 65:572–590

Alnaser WE, Barakat A (2000) Use of condensed water vapour from the atmosphere for irrigation in Bahrain. Appl Energy 65:3–18

Altenkrich E (1938) Method of gaining water from the atmosphere. US Patent No. 2138689

Beysens D (1995) The formation of dew. Atmos Res 39:215–237

Beysens D, Milimouk I, Nikolayev V, Muselli M, Marcillat J (2003) Using radiative cooling to condense atmospheric vapour: a study to improve water yield. J Hydrol 276:1–11

Beysens D, Ohayon C, Muselli M, Clus O (2006) Chemical and biological characteristics of dew and rain water in an urban coastal area (Bordeaux, France). Atmos Environ 40:3710–3723

Beysens D, Clus O, Mileta M, Muselli M, Milimouk I, Nikolayev VS (2007) Collecting dew as a water source on small islands: the Dew Equipment for Water Project in Biseva (Croatia). Energy 32:1032–1037

Beysens D, Broggini F, Milimouk-Melnytchouk I, Ouazzani J, and Tixier N (2012) Dew architectures: dew announces the good weather. materiality in its contemporary forms: architectural perception, fabrication and conception, pp 283–292

Biancardi RP (1982) Apparatus and method for automatically watering vegetation. US Patent No. 4315599

Bulang W (1980) Process and plant for recovering water from moist gas. US Patent No. 4185969

Bundschuh J, Hoinkins J (2012) Renewable energy applications for freshwater production. CRC Press, FloridaGoogle

Call CJ, Beckius RC, Merrill EL, Hong SH, Powell M (2009) Method and apparatus for generating water using an energy conversion device. US Patent No. 7601206

Clus O, Ortega P, Muselli M, Milimouk I, Beysens D (2008) Study of dew water collection in humid tropical islands. J Hydrol 361:159–171

Clus O, Ouazzani J, Muselli M, Nikolayev VS, Sharan G, Beysens D (2009) Comparison of various radiation-cooled dew condensers using computational fluid dynamics. Desalination 249:707–7012

Coanda H, Coanda MH (1956) Device for obtaining fresh drinkable water. US Patent No. 2761292

Courneya CG (1982) Apparatus for extracting potable water. US Patent No. 4351651

Craven JP (2008) Fresh water extraction device. US Patent 7328584, US Patent and Trademark Office, Washington

Dagan A (2003) Apparatus for extracting potable water from the environment air. US Patent 6644060

Dunkak EB (1949) Solar activated dehumidifier. US Patent No. 2462952, US Patent and Trademark Office, Washington

Ellsworth J (2013) Composite desiccant and air-to-water system and method. US Patent No. 8506675

Engel DR, Clasby ME (2004) Apparatus and method for extracting potable water from atmosphere. US Patent 6755037

Faqih AAM (2004) Apparatus for the production of freshwater from extremely hot and humid air. US Patent 6684648

Faqih AAM (2005) Production of potable water and freshwater needs for human, animal and plants from hot and humid air. US Patent 6868690

Foss FD (1973) Humidifier-dehumidifier device. US Patent No. 3740959

Gandhidasan P, Abualhamayel HI (2005) Modeling and testing of a dew collection system. Desalination 180:47–51

Gindel I (1965) Irrigation of plants with atmospheric water within the desert. Nature 207:1173–1175

Gläser HJ, Ulrich S (2013) Condensation on the outdoor surface of window glazing—calculation methods, key parameters and prevention with low emissivity coatings. Thin Solid Films 532:127–131

Graham CD, Dybvig ES (1946) Refrigerating apparatus. US Patent 2401560

Groth W, Hussmann P (1979) Process and system for recovering water from the atmosphere. US Patent No. 4146372

Hamed AM, Kabeel AE, Zeidan EB, Aly AA (2010) A technical review on the extraction of water from atmospheric air in arid zones. JP J Heat Mass Transfer 4(3):213–228Google

Hamed AM, Aly AA, Zeidan EB (2011) Application of solar energy for recovery of water from atmospheric air in climatic zones of Saudi Arabia. Nat Resour 2(1):8–17Google

Hussmann P (1982a) Method and apparatus for abstracting water from air. US Patent No. 4342569

Hussmann P (1982b) Method and apparatus for recovery of water from the atmosphere. US Patent No. 4345917

Ito T, H Matsuoka, Azuma K, Y Hirayama, N Takahashi (1981) Water producing apparatus. US Patent No. 4304577

Jacobs AFG, Heusinkveld BG, Lucassen DC (1998) Temperature variation in a class A evaporation pan. J Hydrol 206:75–83

Jacobs AFG, Heusinkveld BG, Berkowicz SM (2008) Passive dew collection in a grassland area, The Netherlands. Atmos Res 87:377–385

Kabeel AE (2007) Water production from air using multi-shelves solar glass pyramid system. Renew Energy 32(1):157–172

Khalil B, Adamowski J, Rojas M, Reilly K (2014) Towards an independent dew water irrigation system for arid or insular areas. Proceedings of the ASABE international annual meeting, Montreal

Khalil B, Adamowski J, Ezzeldine M (2015) Dew water collection as non-conventional source of water. Proceedings of the 22nd Canadian hydrotechnical conference, Montreal, 29 Apr–2 May 2015

Kidron GJ (2000) Analysis of dew precipitation in three habitats within a small arid drainage basin, Negev Highlands, Israel. Atmos Res 55:257–270

Kidron GJ (2010) The effect of substrate properties, size, position, sheltering and shading on dew: an experimental approach in the Negev Desert. Atmos Res 98:378–386

Klemic J (2005) Atmospheric water absorption and retrieve device. US Patent No. 6869464

Krumsvik PK (1998) Method and device for recovering water from a humid atmosphere. US Patent No. 5846296

LeBleu TL (1997) Portable, Potable water recovery and dispensing apparatus. US Patent 5669221

LeBleu TL (1998) Portable/potable water recovery and dispensing apparatus. US Patent 5845504

Lekouch I, Lekouch K, Muselli M, Mongruel A, Kabbachi B (2012) Rooftop dew, fog and rain collection in southwest Morocco and predictive dew modeling using neural networks. J Hydrol 448–449:60–72

Lloyd DJ, Baier SE (2002) Water generating machine. US Patent 6490879

Maestre-Valero JF, Martinez-Alvarez V, Baille V, Martin-Gorriz B, Gallego-Elvira B (2011) Comparative analysis of two polyethylene foil materials for dew harvesting in a semi-arid climate. J Hydrol 410:84–91

Maestre-Valero JF, Ragab R, Martinez-Alvarez V, Bailie A (2012) Estimation of dew yield from radiative condensers by means of an energy balance model. J Hydrol 460:103–109

McCabe WI, Smith JC, Hariott P (1993) Unit operation of chemical engineering, 5th edn. McGraw Hill Chemical Engineering Series

Michel H, Bulang W (1981) Method and apparatus for the recovery of water from the atmospheric air. US Patent No. 4285702

Milani D, Abbas A, Vassallo A, Chiesa M, Al Bakri D (2011) Evaluation of using thermoelectric coolers in a dehumidification system to generate freshwater from ambient air. Chemical Eng Sci 66:2491–2501

Monteith JL, Unsworth MH (1990) Principles of environmental physics, 2nd edn. Routledge Chapman & Hall Inc., New YorkGoogle

Muñoz-García MA, Moreda GP, Raga-Arroyo MP, Marín-González O (2013) Water harvesting for young trees using Peltier modules powered by photovoltaic solar energy. Comput Electron Agric 93:60–67

Muselli M, Beyesens D, Milimouk I (2006) A comparative study of two large radiative dew water condensers. J Arid Environ 64:54–76

Muselli M, Beysens D, Mileta M, Milimouk I (2009) Dew and rain water collection in the Dalmatian Coast, Croatia. Atmos Res 92:455–463

Nikolayev VS, Beysens D, Gioda A, Milimouk I, Katiushin E, Morel JP (1996) Water recovery from dew. J Hydrol 182:19–35

O’Hare LR (1984) Ground moisture transfer system. US Patent No. 4459177

Ockert CE (1978) Device for extracting energy, fresh water and pollution from moist air. US Patent No. 4080186

Peters GM, Blackburn NJ, Armedion M (2013) Environmental assessment of air to water machines—triangulation to manage scope uncertainty. Int J Life Cycle Assess 18:1149–1157

Reidy JJ (1992a) Potable air-water generator. US Patent 5106512

Reidy JJ (1992b) Potable water generator. US Patent 5149446

Reidy JJ (1993) Potable air-water generator. US Patent 5203989

Rodriguez F, Khanji NK (2012) Low power atmospheric water generator. US Patent No. 8118912

Rogers W, Midgett P (1980) Underground heating and cooling system. US Patent No. 4234037

Shank DB (2006) Dew point temperature prediction using artificial neural networks. MS thesis, Department of Biological and Agricultural Engineering, University of Georgia, Athens

Sharan G, Beysens D, Milimouk-Melnytchouk I (2007) A study of dew water yields on galvanized iron roofs in Kothara (North-West India). J Arid Environ 69:259–269

Smith RH (1984) Apparatus and method for recovering atmospheric moisture. US Patent No. 4433552

Tircot M (1985) Apparatus for continuously metering vapours contained in the atmosphere. US Patent No. 4506510

Tongue S (2007) Water-from-air system using desiccant wheel and exhaust. US Patent 7251945

Wahlgren RV (2000) Atmospheric water vapour processor designs for potable water production: a review. Water Resour 35(1):1–22Google

Xu Y, Yan B, Zhu H, Guan J (2013) Dew condensation monitoring in a wetland ecosystem in the sanjiang plain. Fresenius Environ Bull 22(5):1351–1356Google

Zakryk JM (2000) Water collection and dispensing. US Patent 6029461, US Patent and Trademark Office, Washington

---

http://www.sciencedirect.com/science/article/pii/S0043135400002475
http://dx.doi.org/10.1016/S0043-1354(00)00247-5
Water Research, Volume 35, Issue 1, January 2001, Pages 1–22

Atmospheric water vapour processor designs for potable water production: a review

Roland V. Wahlgren

Abstract

Atmospheric water vapour processing (AWVP) technology is reviewed. These processors are machines which extract water molecules from the atmosphere, ultimately causing a phase change from vapour to liquid. Three classes of machines have been proposed. The machines either cool a surface below the dewpoint of the ambient air, concentrate water vapour through use of solid or liquid desiccants, or induce and control convection in a tower structure. Patented devices vary in scale and potable water output from small units suitable for one person's daily needs to structures as large as multi-story office buildings capable of supplying drinking water to an urban neighbourhood.

Energy and mass cascades (flowcharts) are presented for the three types of water vapour processors. The flowcharts assist in classifying designs and discussing their strengths and limitations. Practicality and appropriateness of the various designs for contributing to water supplies are considered along with water cost estimates. Prototypes that have been tested successfully are highlighted.

Absolute humidity (meteorological normals) ranges from 4.0 g of water vapour per cubic metre of surface air in the atmosphere (Las Vegas, Nevada, USA) to 21.2 g m-3 (Djibouti, Republic of Djibouti). Antofagasta, Chile has a normal absolute humidity of 10.9 g m-3. A 40% efficient machine in the vicinity of Antofagasta requires an airflow of 10 m3 s-1 to produce 3767 l of water per day. At a consumption of 50 l per person per day, 75 people could have basic water requirements for drinking, sanitation, bathing, and cooking met by a decentralized and simplified water supply infrastructure with attendant economic and societal benefits.

---

http://www.sciencedirect.com/science/article/pii/0022169495029397
Journal of Hydrology,Volume 182, Issues 1–4, July 1996, Pages 19-35

Water recovery from dew

V.S. Nikolayev, D. Beysens, A. Gioda, I. Milimouk, E. Katiushin, J.-P. Morel

Abstract

The recovery of clean water from dew has remained a longstanding challenge in many places all around the world. It is currently believed that the ancient Greeks succeeded in recovering atmospheric water vapour on a scale large enough to supply water to the city of Theodosia (presently Feodosia, Crimea, Ukraine). Several attempts were made in the early 20th century to build artificial dew-catching constructions which were subsequently abandoned because of their low yield. The idea of dew collection is revised in the fight of recent investigations of the basic physical phenomena involved in the formation of dew. A model for calculating condensation rates on real dew condensers is proposed. Some suggestions for the 'ideal' condenser are formulated.

---

http://www.sciencedirect.com/science/article/pii/S0169809509000209
http://dx.doi.org/10.1016/j.atmosres.2009.01.004
Atmospheric Research, Volume 92, Issue 4, June 2009, Pages 455–463

Dew and rain water collection in the Dalmatian Coast, Croatia

M. Muselli, D. Beysens, M. Miletac, I. Milimouk

Abstract

Passive dew harvesting and rainwater collection requires a very small financial investment but can exploit a free, clean (outside urban/industrial zones) and inexhaustible source of water. This study investigates the relative contributions of dew and rain water in the Mediterranean Dalmatian coast and islands of Croatia, with emphasis on the dry summer season. In addition, we evaluate the utility of transforming abandoned roof rain collectors ("impluviums") to collect dew water too. Two sites were chosen, an exposed open site on the coast favourable to dew formation (Zadar) and a less favourable site in a cirque of mountains in Komiža (Vis Island). Between July 1, 2003 and October 31, 2006, dew was collected two or three times per day on a 1 m2 inclined (30°) test dew condenser, together with standard meteorological data (air temperature and relative humidity, cloud cover, windspeed and direction). Maximum yields were 0.41 mm in Zadar and 0.6 mm in Komiža. The mean yearly cumulative dew yields were found to be 20 mm (Zadar) and 9.3 mm (Komiža). Because of its physical setting, Komiža represents a poor location for dew collection. However, during the dry season (May to October), monthly cumulative dew water yield can represent up to 38% of water collected by rainfall. In both July 2003 and 2006, dew water represented about 120% of the monthly cumulative rain water. Refurbishing the abandoned impluviums to permit dew collection could then provide useful supplementary water, especially during the dry season. As an example, the 1300 m2 impluvium at Podšpilje near Komiža could provide, in addition to rain water, 14,000 L dew water per year

---

http://www.sciencedirect.com/science/article/pii/S0140196305001096
http://dx.doi.org/10.1016/j.jaridenv.2005.04.007
Journal of Arid Environments, Volume 64, Issue 1, January 2006, Pages 54–76

A comparative study of two large radiative dew water condensers

M. Muselli, D. Beysens, I. Milimouk

Abstract

In order to improve the yield of dew condensation from atmospheric vapor, two large (30 m2 in area) insulated plane radiative condensers, inclined at 30°, were installed in Ajaccio (Corsica island, France; latitude 41°55'N, longitude 8°48'E). Prototype P1 was elevated such that the underside was open and exposed. Prototype P2, however, was enclosed on all sides and closer to the ground. Both used a special radiative foil that enhances dew formation. The period of observation for P1 was July 22, 2000–November 11, 2001, and for P2 was December 10, 2001–December 10, 2003. All data were compared with respect to the same horizontal calibration plate of polymethylmethacrylate (Plexiglas) placed at 1 m above the ground on a sensitive recording balance. Water yield of both prototypes were compared and correlated against meteorological data (cloud cover, relative humidity, wind speed, condenser temperature and air temperature). Both prototypes exhibit improved performances when compared with the calibration plate: more dew days (+16% and +15% for P1 and P2, respectively); decrease of the humidity threshold (-3% and -4.4% for P1 and P2); increase of dew yields for wind speeds up to 3 m s-1. A model of the mass and thermal exchanges with the ambient air was used. Two adjustable parameters (heat and mass transfer coefficients) are used in the model. The values of these parameters were found larger than the values obtained in continental sites where dew forms with weak wind, thus emphasizing the peculiarities of dew formation in windy islands. When data are reduced with the calibration PMMA data, prototype P1 provided average water yields slightly larger than the enclosed prototype P2, a result that can be attributed to the influence of surface thermal radiation.

---

http://www.sciencedirect.com/science/article/pii/S0168169913000306
http://dx.doi.org/10.1016/j.compag.2013.01.014
Computers and Electronics in Agriculture, Volume 93, April 2013, Pages 60–67

Water harvesting for young trees using Peltier modules powered by photovoltaic solar energy

M.A. Muñoz-García, G.P. Moreda, M.P. Raga-Arroyo, O. Marín-González

Abstract

Young trees transplanted from nursery into open field require a minimum amount of soil moisture to successfully root in their new location, especially in dry-climate areas. One possibility is to obtain the required water from air moisture. This can be achieved by reducing the temperature of a surface below the air dew point temperature, inducing water vapor condensation on the surface. The temperature of a surface can be reduced by applying the thermoelectric effect, with Peltier modules powered by electricity. Here, we present a system that generates electricity with a solar photovoltaic module, stores it in a battery, and finally, uses the electricity at the moment in which air humidity and temperature are optimal to maximize water condensation while minimizing energy consumption. Also, a method to reduce the evaporation of the condensed water is proposed. The objective of the system is to sustain young plants in drier periods, rather than exclusively irrigating young plants to boost their growth.

Highlights

Water can be obtained from the moisture of the air using Peltier modules... The water obtained by electronic devices can be enough to save young trees... A computer based controller can optimize the energy consumption of a water condenser... A photovoltaic power source supplies more energy when the necessity is higher.

---

http://www.sciencedirect.com/science/article/pii/S0009250911001059
http://dx.doi.org/10.1016/j.ces.2011.02.018
Chemical Engineering Science, Volume 66, Issue 12, 15 June 2011, Pages 2491–2501

Evaluation of using thermoelectric coolers in a dehumidification system to generate freshwater from ambient air

Dia Milani, Ali Abbas, Anthony Vassalloa, Matteo Chiesa, Dhia Al Bakri

Abstract

The feasibility of using thermoelectric coolers (TECs) in a dehumidification system to condense atmospheric moisture and generate renewable freshwater was investigated. An algorithm was developed to correlate psychrometric variables at the entrance and exit of the TEC dehumidification system, determining the amount of condensable water, required energy and total cost per kL of generated water. The driving force of condensation is set to be dynamic to imitate wet-bulb variation at a pre-determined margin. The influence of relative humidity variation on saturation temperature, energy consumption, water productivity and the price of generated water in maximal thermal conditions was also determined. It found that more than 95% of the water cost was attributed to energy consumption rather than capital cost of the dehumidification system. The price of generated water is estimated to start from $82 per kL and can be integrated and programmed to top-up rainwater harvesting tanks (RHTs) productivity to entirely secure end-users freshwater demands. The main attractions of this approach include compact, safe and noiseless technology that can provide independent and clean water supply to end-users and alleviate the stress on freshwater resources and their aquatic ecosystems.

---

http://www.sciencedirect.com/science/article/pii/S0022169412005471
http://dx.doi.org/10.1016/j.jhydrol.2012.06.046
Journal of Hydrology, Volumes 460–461, 16 August 2012, Pages 103–109

Estimation of dew yield from radiative condensers by means of an energy balance model

J.F. Maestre-Valeroa, R. Ragabb, V. Martínez-Alvareza, A. Baillea

Summary

This paper presents an energy balance modelling approach to predict the nightly water yield and the surface temperature (Tf) of two passive radiative dew condensers (RDCs) tilted 30° from horizontal. One was fitted with a white hydrophilic polyethylene foil recommended for dew harvest and the other with a black polyethylene foil widely used in horticulture. The model was validated in south-eastern Spain by comparing the simulation outputs with field measurements of Tf and dew yield. The results indicate that the model is robust and accurate in reproducing the behaviour of the two RDCs, especially in what refers to Tf, whose estimates were very close to the observations. The results were somewhat less precise for dew yield, with a larger scatter around the 1:1 relationship. A sensitivity analysis showed that the simulated dew yield was highly sensitive to changes in relative humidity and downward longwave radiation. The proposed approach provides a useful tool to water managers for quantifying the amount of dew that could be harvested as a valuable water resource in arid, semiarid and water stressed regions.

Highlights

Surface temperature and dew yield of RDCs are estimated from the energy balance... Surface emissivity and emitted radiance are two key parameters when modelling dew... The applied filter was an appropriate strategy for a good performance of the model... Dew yield is very sensitivity to the meteorological input variables/parameters... Our energy balance model explained about 70% of the total variance of dew.

---

http://www.sciencedirect.com/science/article/pii/S0022169411006470
http://dx.doi.org/10.1016/j.jhydrol.2011.09.012
Journal of Hydrology, Volume 410, Issues 1–2, 15 November 2011, Pages 84–91

Comparative analysis of two polyethylene foil materials for dew harvesting in a semi-arid climate

J.F. Maestre-Valero, V. Martínez-Alvarez, A. Baille, B. Martín-Górriz, B. Gallego-Elvira

Summary

This paper analyses the dew collection performance of two polyethylene (PE) foils in a semi-arid region (Southern Spain). The dew collecting devices consisted of two commercial passive radiative dew condensers (RDCs) of 1 m2 tilted to 30°. They were fitted with two different high-emissivity PE foils: a white hydrophilic foil (WSF) recommended as standard for dew recovery comparisons by the International Organization for Dew Utilization (OPUR), and a low-cost black PE foil (BF) widely used for mulching in horticulture. Dew yield, foil surface temperature and meteorological variables (air temperature, relative humidity, downward long wave radiation and wind speed) were recorded hourly during a 1-year period from May-2009 to May-2010. The spectral emissivity of the foils was determined in laboratory in the range 2.5–25 µm and the radiance-weighed values were calculated over different intervals, indicating that BF emitted more than WSF, especially in the range 2.5–7 µm. Dew yield was well correlated with the air relative humidity and foil net radiation in both foils and was hardly detected when the relative humidity was lower than 75% or the wind speed higher than 1.5 m s-1. WSF was more sensitive to dew formation due to its hydrophilic properties, registering more dewy nights (175) than BF (163) while the annual cumulative dew yield for BF was higher (20.76 mm) than for WSF (17.36 mm) due to the higher emissivity and emitted radiance of BF. These results suggested that increasing the surface emissivity over the whole IR spectrum could be more effective for improving RDC yield performances than increasing the surface hydrophilic properties. On a practical point of view, BF could be considered as a suitable material for large scale RDCs, as in our study it presented several advantages over the reference material, such as higher dew collection performance, longer lifespan and much lower cost.

Highlights

We compare the performance of two polyethylene foil materials for dew harvesting... Dew was well correlated with the air relative humidity and foil net radiation... Black foil (BF) was more productive...Surface emissivity and hydrophylic properties are two key parameters... Our empirical relationship explained about two-thirds of the total variance of dew.

---

http://www.sciencedirect.com/science/article/pii/S0022169412002673
http://dx.doi.org/10.1016/j.jhydrol.2012.04.004
Journal of Hydrology, Volumes 448–449, 2 July 2012, Pages 60–72

Rooftop dew, fog and rain collection in southwest Morocco and predictive dew modeling using neural networks

Imad Lekoucha, Khalid Lekouch, Marc Musellic, Anne Mongruel, Belkacem Kabbachi, Daniel Beysens

Summary

Two coastal sites were investigated in an arid region of southwest Morocco to determine the amount of dew, fog and rain that could be collected from rooftops for household use. Systematic measurements were performed in Mirleft (43 m asl, 200 m from the coast) for 1 year (May 1, 2007 to April 30, 2008) and in Id Ouasskssou (240 m asl, 8 km from the coast) for three summer months (July 1, 2007 to September 30, 2007). Dew water was collected using standard passive dew condensers and fog water by utilizing planar fog collectors. The wind flow was simulated on the rooftop to establish the location of the fog collector. At both sites, dew yields and, to a lesser extent, fog water yields, were found to be significant in comparison to rain events. Mirleft had 178 dew events (48.6% of the year, 18 ± 2 L m-2 cumulated amount) and 20 fog episodes (5.5% of the year, 1.4 L m-2 with uncertainty -0.2/+0.4 L m-2 cumulated amount), corresponding to almost 40% of the yearly rain contribution (31 rain events, 8.5% of the year, 49 ± 7 mm cumulated amount). At Id Ouasskssou there were 50 dew events (7.1 ± 0.3 L m-2, 54.3% frequency), 16 fog events (6.5 L m-2 with uncertainty -0.1/+1.8 L m-2, 17.4% frequency) and six rain events (16 ± 2 mm, 6.5% frequency).

Meteorological data (air and dew point temperature and/or relative humidity, wind speed and wind direction, cloud cover) were recorded continuously at Mirleft to assess the influence of local meteorological conditions on dew and fog formation. Using the set of collected data, a new model for dew yield prediction based on artificial neural networks was developed and tested for the Mirleft site. This model was then extrapolated to 15 major cities in Morocco to assess their potential for dew water collection. It was found that the location of the cities with respect to the Atlas mountain chain, which controls the circulation of the humid marine air, is the main factor that influences dew production.

Highlights

Dew, fog and rain data collected over 1 year in two sites of south-west Morocco... Dew yield is important and amounts to about 40% of rain water... Good correlation of dew data found with only a very few meteorological data... Artificial neural network (ANN) predictive model for dew is developed and tested... ANN model to predict dew in 15 Morocco cities; RH at night controls dew production.

---

http://www.sciencedirect.com/science/article/pii/S0960148106000462
http://dx.doi.org/10.1016/j.renene.2006.01.015
Renewable Energy. Volume 32, Issue 1, January 2007, Pages 157–172

Water production from air using multi-shelves solar glass pyramid system

A.E. Kabeel

Abstract

The capability of the glass pyramid shape with a multi-shelf solar system to extract water from humid air is explored. Two pyramids were used with different types of beds on the shelves. The beds are saturated with 30% concentrated Calcium Chloride solution. The pyramid sides were opened at night to allow the bed saturated with moist air and closed during the day to extract the moisture from the bed by solar radiation. The bed in the first pyramid was made of saw wood while it is made of only cloth in the second pyramid with the same dimensions. The system was experimentally investigated at different climatic conditions to study the effect of pyramid shape on the absorption and regeneration processes. Preliminary results have shown that the cloths bed absorbs more solution (9 kg) as compared to the saw wood bed (8 kg). Adopting this approach produces 2.5 L/day m2. The use of the pyramid shape with four glass surfaces and multi-shelves enhances the produced water by 90–95% compared with solar desiccant/collector system with horizontal and corrugated beds. Results also show that the clothes bed has higher productivity than that of saw wood bed by about 5%. This is due mainly to the greater carrying solution at the onset of the experimental work. The obtained results may help in designing more efficient system.

---

http://www.sciencedirect.com/science/article/pii/S0169809507001950
http://dx.doi.org/10.1016/j.atmosres.2007.06.007
Atmospheric Research, Volume 87, Issues 3–4, March 2008, Pages 377–385
Third International Conference on Fog, Fog Collection and Dew — Fog and Dew

Passive dew collection in a grassland area, The Netherlands

A.F.G. Jacobs, B.G. Heusinkveld, S.M. Berkowicz

Abstract

Passive dew collection experiments were initiated in late 2003 in the centre of The Netherlands within a grassland area. A specially designed 1 m2 insulated planar dew collector, set at a 30° angle from horizontal, was covered with a thin (0.39 mm) polyethylene foil and subsequently replaced with 4 mm polyvinyl chloride. A second dew collector, in the shape of an inverted pyramid, was constructed to reduce the view angle to only the nighttime sky. A simple surface energy-budget model and an aerodynamic model were used to simulate the dew collected by both collectors. The planar collector collected about 90% of the dew at the grass cover while the pyramid collector collected about 1.20% of the grass cover. The aerodynamic model was able to predict the amount of collector data to within 50% for the planar collector and 60% for the inverted pyramid collector. The pyramid collector design was able to collect about 20% more dew than the inclined planar collector.

---

http://file.scirp.org/Html/4124.html
Natural Resources, 2011, 2, 8-17
doi:10.4236/nr.2011.21002

Application of Solar Energy for Recovery of Water from Atmospheric Air in Climatic Zones of Saudi Arabia

Ahmed M. Hamed, Ayman A. Aly, El-Shafei B. Zeidan

Abstract

In the present work, an investigation on the application of solar energy to heat a sandy bed impregnated with calcium chloride for recovery of water from atmospheric air is presented. The study also aimed at evaluating the effects of different parameters on the productivity of the system during regeneration. These parameters include system design characteristics and the climatic conditions. An experimental unit has been designed and installed for this purpose in climatic conditions of Ta if area, Saudi Arabia. The experimental unit which has a surface area of 0.5 m2, comprises a solar/desiccant collector unit containing sandy bed impregnated with calcium chloride. The sandy layer impregnated with desiccant is subjected to ambient atmosphere to absorb water vapor in the night. During the sunshine period, the layer is covered with glass layer where desiccant is regenerated and water vapor is condensed on the glass surface. Ambient temperature, bed temperature and temperature of glass surface are recorded. Also, the productivity of the system has been evaluated. Desiccant concentration at start of regeneration is selected on the basis of the climatic data of Al-Hada region, which is located at Taif area, Saudi Arabia. Experimental measurements show that about 1.0 liter per m2 of pure water can be regenerated from the desiccant bed at the climatic conditions of Taif. Liquid desiccant with initial concentration of 30% can be regenerated to a final concentration of about 44%. Desiccant concentration at start of regeneration is selected on the basis of the climatic data of Al-Hada region. The climate of Taif city is dry compared with that for Al-Hada region. This method for extracting water from atmospheric air is more suitable for Al-Hada region especially in the fall and winter.

1. Introduction

Shortage of drinking water is chronic, severe, and widespread in the regions of Northern Africa, Middle East, and Central and Southern Asia. The problem of providing arid areas with fresh water can be solved by the following methods [1]:

transportation of water from other locations;

desalination of saline water (ground and under-
ground);

extraction of water from atmospheric air.

Transportation of water through these regions is usually very expensive, and desalination depends on the presence of saline water resources, which are usually rare in arid regions. Atmospheric air is a huge and renewable reservoir of water. This endless source of water is available everywhere on the earth surface. The amount of water in atmospheric air is evaluated as 14000 km3, whereas the amount of fresh water in rivers and lakes on the earth surface is only about 1200 km3 [2]. The extraction of water from atmospheric air has several advantages compared with the other methods. The extraction of water from atmospheric air can be accomplished by different methods, the most common of these methods are cooling moist air to a temperature lower than the air dew point, and absorbing water vapor from moist air using a solid or a liquid desiccant, with subsequent recovery of the extracted water by heating the desiccant and condensing the evaporated water....

---

https://www.researchgate.net/profile/Ahmed_Hamed11/publication/285533435_A_technical_review_on_the_extraction_of_water_from_atmospheric_air_in_arid_zones/links/5664970908ae192bbf90a853.pdf
JP J Heat Mass Transfer 4(3):213–228

A technical review on the extraction of water from atmospheric air in arid zones.

Hamed AM, Kabeel AE, Zeidan EB, Aly AA (2010)

[PDF]

---

http://www.nature.com/nature/journal/v207/n5002/abs/2071173a0.html
Nature 207, 1173 - 1175 (11 September 1965); doi:10.1038/2071173a0

Irrigation of Plants with Atmospheric Water within the Desert

I. Gindel

---

http://www.sciencedirect.com/science/article/pii/S0011916409008686
Desalination, Volume 249, Issue 2, 15 December 2009, Pages 707–712

Comparison of various radiation-cooled dew condensers using computational fluid dynamics

O. Clus, J. Ouazzani, M. Muselli, V.S. Nikolayev, G. Sharan, D. Beysens

Abstract

Radiation-cooled dew water condensers can serve as a complementary potable water source. In order to enhance passive dew collection water yield, a Computational Fluid Dynamics (CFD) software, PHOENICS, was used to simulate several innovative condenser structures. The sky radiation is calculated for each of the geometries. Several types of condensers under typical meteorological conditions were investigated using their average radiating surface temperature. The simulations were compared with dew yield measurements from a 1 m2 30°-inclined planar condenser used as a reference. A robust correlation between the condenser cooling ability and the corresponding dew yield was found. The following four shapes were studied: (1) a 7.3 m2 funnel shape, whose best performance is for a cone half-angle of 60°. Compared to the reference condenser, the cooling efficiency improved by 40%, (2) 0.16 m2 flat planar condenser (another dew standard), giving a 35% lower efficiency than the 30° 1 m2 inclined reference condenser, (3) a 30 m2 30°-inclined planar condenser (representing one side of a dew condensing roof), whose yield is the same as the reference collector, and (4) a 255 m2 multi-ridge condenser at the ground surface provided results similar to the reference collector at wind speeds below 1.5 m s- 1 but about 40% higher yields at wind speeds above 1.5 m s- 1.

---

http://www.sciencedirect.com/science/article/pii/S0022169408003879
http://dx.doi.org/10.1016/j.jhydrol.2008.07.038
Journal of Hydrology, Volume 361, Issues 1–2, 30 October 2008, Pages 159–171

Study of dew water collection in humid tropical islands

O. Clus, P. Ortega, M. Muselli, I. Milimouk, D. Beysens

Summary

An assessment of the potential for dew water to serve as a potable water source during a rainless season in a humid tropical climate was carried out in the Pacific islands of French Polynesia. The climate of these islands, in terms of diurnal and seasonal variations, wind and energy balance, is representative of the climate of the tropical Atlantic and Pacific oceans. Measurements were obtained at two characteristic sites of this region; a mountainous island (Punaauia, Tahiti Island) and an atoll (Tikehau, Tuamotu Archipelago). Dew was measured daily on a 30° tilted, 1 m2 plane collector equipped with a thermally insulated radiative foil. In addition, an electronic balance placed at 1 m above the ground with a horizontal 0.16 m2 condensing plate made of PolyTetraFluoroEthylene (Teflon) was used in Tahiti. Dew volume data, taken during the dry season from 16/5/2005 to 14/10/2005, were correlated with air temperature and relative humidity, wind speed, cloud cover and visible plus infrared radiometer measurements. The data were also fitted to a model.

Dew formation in such a tropical climate is characterized by high absolute humidity, weak nocturnal temperature drop and strong Trade winds. These winds prevent dew from forming unless protected e.g. by natural vegetal windbreaks. In protected areas, dew can then form with winds as large as 7 m/s. Such strong winds also hamper at night the formation near the ground of a calm and cold air layer with high relative humidity. As the cooling power is lower than in the Mediterranean islands because of the high absolute humidity of the atmosphere, both effects combine to generate modest dew yields. However, dew events are frequent and provide accumulated amounts of water attractive for dew water harvesting. Slight modifications of existing rain collection devices on roofs can enhance dew formation and collection. Dew harvesting thus appears as an attractive possibility to provide the local population with a complementary – but on occasion, essential – water resource.

---

http://www.sciencedirect.com/science/article/pii/S0360544206002684
http://dx.doi.org/10.1016/j.energy.2006.09.021
Energy, Volume 32, Issue 6, June 2007, Pages 1032–1037

Collecting dew as a water source on small islands: the dew equipment for water project in Bis?evo (Croatia)

D. Beysens, O. Clus, M. Mileta, I. Milimouk, M. Muselli, V.S. Nikolayev

Abstract

In many regions and geographical settings, dew water collection can serve as a water source, supplementing rain and fog water collection. This is particularly useful when precipitation is low or lacking, especially in remote areas and islands in the dry season. A project called Dew Equipment for Water (DEW) was initiated for a 15.1 m2 roof in the island of Biševo (Croatia), equipped with commercial plastic cover selected for its superior dew collection properties. Measurements of both rain and dew water will be performed over several years and data will be correlated with meteorological data collected in situ. Preliminary measurements during the period 21 April–21 October 2005 showed that dew water contributed significantly, 26% of the total collected water.

---

http://www.sciencedirect.com/science/article/pii/S1352231006002688
http://dx.doi.org/10.1016/j.atmosenv.2006.03.007
Atmospheric Environment, Volume 40, Issue 20, June 2006, Pages 3710–3723

Chemical and biological characteristics of dew and rain water in an urban coastal area (Bordeaux, France)

D. Beysens, C. Ohayon, M. Muselli, O. Clus

Abstract

We report on a 1-year investigation (15 January 2002–14 January 2003) in Bordeaux, France, comparing the quality of dew water with respect to rain water. The following physico-chemical and bacteriological properties of dew and rain water were measured: pH, electric conductivity, cations (Na+, K+, Ca2+, Mg++, Zn++, Cu++), anions (Cl-, SO42-, NO3-, NO2-), hardness (TH, calcical, magnesial, permanent), complete alkalimetric title, dry residue and number of colony-forming unities (CFU) at 22 and 36 °C. The CO32-, HCO3-, HPO42- concentrations were found negligible. The ionic concentrations are in general lower in dew than in rain with NO2- as a noticeable exception. The mean rain pH (5.4) is lower than dew pH (6.3). The major ions are from the nearby Atlantic Ocean (within 50 km). Average ion concentrations are found below the World Health Organization (WHO) limit requirements for potable water; dew composition is close to low mineralized commercial spring waters for the analyzed ions. The biological analyses are concerned with CFU at 22 and 36 °C. Dew is seen to exceed on various occasions the WHO limits.

---

http://www.sciencedirect.com/science/article/pii/S0022169403000258
http://dx.doi.org/10.1016/S0022-1694(03)00025-8
Journal of Hydrology, Volume 276, Issues 1–4, 15 May 2003, Pages 1–11

Using radiative cooling to condense atmospheric vapor: a study to improve water yield

Daniel Beysens, Irina Milimouk, Vadim Nikolayev, Marc Muselli, Jacques Marcillat

Abstract

An inexpensive radiative condenser for collecting atmospheric vapor (dew) was tested in Grenoble (France). The surface temperature measurements are correlated with meteorological data (wind velocity, air temperature) and compared to the corresponding surface temperature of a horizontal Polymethylmethacrylate (Plexiglas) reference plate located nearby. The condenser surface is a rectangular foil (1×0.3 m2) made of TiO2 and BaSO4 microspheres embedded in polyethylene. The foil has an angle ? with respect to horizontal. The under-side of the device, thermally isolated, faces the direction of the dominant nocturnal wind. Both a 2D numerical simulation of the air circulation around the foil and experimental measurements shows that the angle ?=30° is a good compromise between weak wind influence, large light-emission solid angle and easy drop collection. The study was conducted from November 25, 1999 to January 23, 2001. In comparison to the reference plate, it is found that water yield can be increased by up to 20% and water collection greatly facilitated.

---

http://www.sciencedirect.com/science/article/pii/S0306261999000549
http://dx.doi.org/10.1016/S0306-2619(99)00054-9
Applied Energy, Volume 65, Issues 1–4, April 2000, Pages 3–18

Use of condensed water vapour from the atmosphere for irrigation in Bahrain

W.E. Alnaser, A. Barakat

Abstract

Atmospheric moisture can be condensed as dew and used for small-scale irrigation. In Bahrain, we found that the most favourable conditions for dew condensation persist at dawn. The maximum amount of dew water can be collected in January and the least in August. Three condensation surfaces have been tested; aluminum, glass and polyethylene foils. The average quantity of dew collected on these surfaces was 1.3, 0.8 and 0.3 kg/m2 per h, respectively. The condensation rate, water vapour content of the air, and the dew points of Bahrain's climate have been reported.

---

http://www.appropedia.org/Dew_collection_roof_retrofit

Dew collection roof retrofit

Daniel Beysens

Abstract

The problem of obtaining clean drinking water is very widespread among developing nations. The atmosphere contains an abundant amount of water in the form of vapor; however it can be difficult and costly to harvest. Atmospheric water vapor processing (AWVP) is a new field of research that is developing ways to obtain that vapor. One such method is known as radiative cooling. A surface radiates heat away until it drops below the dew point, causing moisture to condense on the surface. This is a process that occurs naturally, producing dew. The proposal is to harvest the dew that naturally forms on rooftops as a source of potable water. Rooftops made out of galvanized iron, plastic, or glass, in regions that experience the right weather conditions will naturally produce a significant amount of dew. Simply by collecting this dew, a family can gather up to 2L of dew water per dew night. This work offers a primer to the topic of AWVPs, and a description of how to build a dew collection rig. Unfortunately, dewfall is not currently recorded in most standard meteorological archives; so the next step for this project is to offer a reliable means of regional assessment that is accessible to a layman.

Introduction

As the world's population increases, fresh water supplies are being tapped out. Desalination has become a necessary means of acquiring water; however current methods are usually quite costly and use fossil fuels. This is inappropriate for the developing world, where there is a serious need for increased fresh water availability. Atmospheric water vapor processing (AWVP) is a new and emerging technology in which the atmospheric water vapor is condensed and collected.[1][2][3]

Operating Principle

There is approximately 4 g of water vapor per cubic meter of air in the earth's atmosphere. This source of potable water is available virtually worldwide. AWVPs harvest this water, by condensing it from vapor to liquid.[4][5]

Advantages

It is at an early stage in development, but has the potential to provide environmentally acceptable alternatives to standard water supplies.[4][5]

Many AWVP designs favor decentralization of water distribution and avoidance of huge capital costs for infrastructure.[5]

AWVP can be made appropriate, community-managed and community-maintained for developing countries.[5]

AWVP methods are competitive with desalination plants and simpler and less expensive to operate and maintain.[5]

The amount of water produced would vary according to installation size, and be suitable to provide potable water to individuals or even thousands of people.[5]

AWVP production can take place in a wide variety of locations. Thus, expensive water distribution infrastructure can be reduced or avoided.[5]

Chemically, water vapor in the atmosphere is as clean as the air around it. Naturally occurring dew is a potable source of soft water, generally low on any mineral content.[6]...

---

http://www.sciencedirect.com/science/article/pii/S0360544206000168
Energy, Volume 31, Issue 13, October 2006, Pages 2303–2315

Application of passive radiative cooling for dew condensation

Daniel Beysens, et al.

Abstract

Dew water was collected from several passive foil-based radiative condensers established in a variety of geographic settings: continental (Grenoble, in an alpine valley, and Brive-la-Gaillarde, in the Central Massif volcanic area, both in France), French Atlantic coast (Bordeaux), eastern Mediterranean (Jerusalem, Israel), and the island of Corsica (Ajaccio, France) in the Mediterranean Sea. In Ajaccio two large 30 m2 condensers have been operating since 2000. Additional semi-quantitative dew measurements were also carried out for Komiža, island of Vis (Croatia) in the Adriatic Sea, and in Mediterranean Zadar and Dubrovnik (both in Croatia). Dew potential was calculated for the Pacific Ocean island of Tahiti (French Polynesia). The data show that significant amounts of dew water can be collected. Selected chemical and biological analyses established that dew is, in general, potable. Continued research is required for new and inexpensive materials that can enhance dew condensation.

---

http://www.nrcresearchpress.com/doi/abs/10.1139/er-2015-0035?af=R&#.WCvg-bkoFdg
Environmental Reviews, 2015, 23(4): 425-442, 10.1139/er-2015-0035

Dew as a sustainable non-conventional water resource: a critical review

Marlene Tomaszkiewicz, Majdi Abou Najm, Daniel Beysens, Ibrahim Alameddine, Mutasem El-Fadela

Abstract

Over the last 20 years, dew harvesting has evolved to fruition because of a better understanding of its physics, thermodynamics, and the radiative cooling process of condensing substrates. Although resultant yields are relatively small, dew positions itself as a viable water resources supplement because it occurs naturally and frequently in many locations globally, particularly in the absence of precipitation or when more traditional water sources are subject to depletion. Moreover, dew water is generally potable, especially in rural locations, where it is most beneficial. This review summarizes dew harvesting research achievements to date including formation processes, collection in various environments, prediction models, water quality, and applications. The paper concludes with outlining existing gaps and future research needs to improve the understanding and performance of dew harvesting in the context of adaptation to climate change.

FR2917417
Use of a composition comprising a polymeric matrix and a charge containing kaolin, e.g. for radiative cooling of the coated surface and vapor condensation of the atmospheric water, and in paints

Inventor(s): BEYSENS DANIEL; CLUS OWEN; MUSELLI MARC +

The present invention relates to the general field of materials used to promote the natural infrared radiative cooling, including employees in the construction of buildings, or in the automotive industry. More particularly, the present invention relates to materials used to achieve evacuation of calories by radiative cooling or to allow an atmospheric water vapor condensation in the form of clean liquid water for consumption. We know the importance should be attached to the energy management to develop means able to reduce energy costs and increase water resources, including drinking water in some areas. For this purpose, it is possible to use natural infrared radiative cooling of certain materials to evacuate day calories contained within a closed space, and to condense the night atmospheric moisture in the form of liquid water .

This is particularly advantageous in relatively arid regions. Such natural radiative cooling is particularly effective in a spectral window wavelength of between 8 and 14 m, commonly known in English sky window, within which the atmosphere emits only low radiation. The overall radiative received power at day ground level is broken down into ultraviolet radiation (between 0 and 0.3 m), visible (between 0.3 m and 0.7 m), near infrared (between 0.7 m and 3 m) mid-infrared (between 3 and 25 m) and far infrared (over 25 m).
By day, the atmospheric radiation at long wavelengths (infrared and far infrared means) represents 22.9% of the aggregate radiative power. At night, this radiation is 100% of the energy received. Atmospheric radiation at long wavelengths is the result of absorption by the atmosphere, especially by water vapor H2O, carbon dioxide CO2 and ozone 03, extraterrestrial or infrared radiation emitted by the ground and oceans. The gas then each re-emit an infrared spectrum according to their chemical constitution. Ozone, which broadcasts mainly in the spectral window ranging from 8 to 14 m, emits a weak infrared radiation. Most of the sky emissivity deficit is therefore observed in this window. However, at room temperature, the emission spectrum of a black body has a maximum in the same window or spectral range. It is therefore conceivable that a material having a high emissivity on the spectral window ranging from 8 to 14 m can dissipate large amounts of energy by radiative transfer to the sky which has a lower temperature due to its low emissivity this beach.
Day, a material may limit its heating if it has a high emissivity in the mid-infrared radiation, and in particular on the spectral window ranging from 8 to 14 m, combined with reflectance of the relatively large solar energy, for the ultraviolet, visible and near infrared. The radiative dissipation is especially important as it is proportional to the temperature of the surface considered. The natural radiative cooling is therefore involved in an air conditioning energy savings.

At night, only the atmospheric radiation at long wavelengths (infrared and far infrared means) is present. It is therefore possible to cool the materials by several degrees below the ambient temperature by radiative dissipation of energy. Such cooling can cause atmospheric water vapor condensation in the form of liquid water can be recovered. In this field of materials provided to the radiative cooling and atmospheric water vapor condensation, known by the scientific article Light scattering coatings: Theory and application of solar W. E. Vargas et al. journal Solar Energy Materials & Solar Cells, 54, (1998) 343-350, a white opaque thermoplastic film with high emissivity on a spectral band ranging from 8 to 13 m which is obtained from a low density polyethylene (LDPE) respectively, which is 5% and 2% by volume of titanium dioxide (TiO2) and by volume of barium sulfate (BaSO4) relative to the total volume of the polyethylene. Such a thermoplastic film including major disadvantages include a main charge based on titanium dioxide which is relatively expensive, and require a relatively large thickness for its opaque character and its high infrared emissivity.

This is especially bad for the cost of such a film, and may be incompatible with mass production. Furthermore, expenses of the thermoplastic film does not provide a satisfactory resistance to ultraviolet radiation, which is particularly problematic for a film to be used outdoors. In another technical field, by US Patent US 4,075,784 discloses a thermoplastic film obtained from a high density polyethylene (HDPE) charge of 1 to 15% by weight of calcined kaolin (Al2O3.2SiO2) by weight total polyethylene, calcined kaolinite comprising between 51 and 57% by weight silica, between 40 and 46% by weight of alumina and less than 3% by weight impurities. 5 The composition of the thermoplastic film for agricultural use allows an increase of the emissivity of the infrared radiation of the materials used in manufacturing greenhouses while retaining significant transmittance of visible light in order to increase the crop yield by retention heat and reduction in the quantity of heat to be supplied to heat greenhouses.

In the field of agricultural greenhouses are also known from document US 6441059, a thermoplastic film comprising a high density polyethylene matrix (HDPE) and a plurality of suitable mineral fillers to increase the reflectance to the near infrared radiation while retaining significant transmittance of visible light to avoid getting daily high temperatures inside the greenhouse, and also limit heat loss during the night. In the above two agricultural applications, recommended thermoplastic films are intended only to limit the harmful temperature differences for crops due to radiative heat transfer ground / sky while ensuring, at visible wavelengths, the external energy supply necessary for their development.

To reduce the energy required to provide for cooling a home, known from US 6,521,038, a mixture of pigments for paint adapted to allow the increase of the reflectance of the surface coated with the paint to radiation near infrared.

Such a mixture has the drawback of being relatively expensive in so far as it requires a specific formulation for obtaining certain pigments of the mixture.

In addition, the effectiveness of this solution is low to the extent that it only limits the introduction of light radiation, and this on a few extended spectral range. The present invention therefore aims to remedy the aforementioned drawbacks by enabling a significant cooling a particularly economically surface.

More particularly, the present invention aims to obtain a substantial cooling of a surface by natural radiative dissipation, especially at night. The present invention may also be designed to ensure a water recovery, and in particular of drinking water by condensation of atmospheric water vapor during the cooling of the surface considered. The present invention also aims to achieve such radiative cooling of a surface, and possibly atmospheric water vapor condensation, stable over time. According to a first aspect, the invention relates to a use of a composition high emissivity on a spectral band ranging from 4 to 50 m, comprising a polymer matrix and at least one kaolin-based filler for radiative cooling a surface coated with said composition, and optionally the atmospheric water vapor condensation.

According to a second aspect, the invention also relates to a paint composition comprising this composition. Finally, the invention relates to a plastic film comprising this composition.

Other objects, features, aspects and advantages of the invention appear more clearly on reading the description and the various examples that follow.

Kaolin has the advantage of possessing a very high emissivity in the infrared radiation, and in particular in the range from 7.5 to 25 m. Thus, with a surface coated with the composition provided with such a burden to low optical density giving a transparent to the composition, one can obtain an important day and night cooling by radiative transfer, limiting the supply of external energy required to cool a confined space. It is easily understood that this composition is intended to be used primarily in environments where temperatures are relatively high. The composition is obtained from components available in low-cost trading. In addition, the kaolin has been recognized as safe for food contact use if the polymer matrix is in contact with food. I1 is possible to collect drinking water on the surface. Thus, the drinking water recovery on a surface coated with the composition according to the invention generates no toxicity.
Kaolin clay is a white, friable and refractory, of lamellar structure composed mainly of hydrated aluminum silicate. Alumina silicate may originate from ore in the forms kaolinite, dickite and nacrite of empirical formula Al2Si2O5 (OH) 4 or A14Si4O10 (OH) 8, the hydrated halloysite Al2O3.2SiO2.4H2O form of formula or in its form anauxite the same composition but containing a proportion of silica slightly higher than kaolinite. In its hydrated form natural marketed, its water content is generally less than 7% of the total mass and exceptionally up to 12%.

The natural form is particularly suitable for applications in water based paints.

After a calcining treatment, the water content is generally less than 1%. This form is adapted to be incorporated into plastics and paints in solvent base.

Preferably, the composition comprises from 1 to 15%, and preferably of from 3.82 to 7.83% by volume of kaolin based on the total volume of the initial polymer. Particularly interesting formulations comprise from 5.7% to 7.83% of kaolin volume relative to the total volume of the initial polymer.

Preferably, the composition comprises a pigment volume concentration from 1 to 30%, and preferably 5.90 to 12.1% by volume of kaolin based on the total volume of other non-volatile materials (mineral fillers, polymers and additives non-volatile). The pigment volume concentration (PVC) is the ratio of the pigment volume (or inorganic filler) and the total volume of non-volatile (i.e., pigments, mineral fillers and binder) present in a paint. This figure is generally expressed as a percentage. The binder volume corresponds to the volume solids content of the paint used as a basis to the mix.

The average diameter of kaolin particles may range preferably between 0.2 and 2.3 m. However, an average diameter of kaolin particles less than 0.2 m or greater than 3 m is not harmful to the radiative properties to thermal infrared wavelengths.

Such a mean diameter of kaolin particles between 0.2 m and 2.3 provides an increase in reflectance in the near infrared radiation. Indeed, the particles of inorganic fillers diffract the incident radiation wavelength close to their diameter when dispersed in a medium optical density lower than the optical density of the mineral component.

Thus, kaolin is reflective for the wavelength range between 0.2 and 2 to 3 m. Furthermore, the inhomogeneous distribution of the particle size further increases the reflectance of the composition to near infrared radiation. For use of the composition in the form of thermoplastic film include for example kaolin sold under the name GlomaxLL by Imerys with an average diameter of 1.5 m.
For use of the composition in the form of painting, there may be mentioned calcined kaolin sold under the name Blankalite 78 by the Soka society, with a median diameter of 2.0 m for a solvent-based paint, and natural kaolin atomized Blankalite 90C or 90P marketed by the company Gakkai, respectively median diameters 0.8 m and 0.2 m respectively for lower water contents at 5 to 6%.

Advantageously, the composition comprises a matrix polymer selected from polyolefins, polyvinyls, polyvinylidene, polystyrenics, acrylic and methacrylic polymers, polyamides, polyesters, polyethers, polyfluorinated; polyurethane resins, alkyd resins, epoxy resins, and phenolic resins. For example, the polymer matrix of the composition may be selected from low or high density polyethylene, polypropylene, polyvinyl chloride, polystyrene, poly (ethylene / vinyl acetate), acrylic resins, glyptal resins, and polyurethane resins.
Preferably, polyethylene is used. Include an indication polyethylenes used pursuant blowing sold under brand Lacqtene 1020 FN 24 of Atofina, or Lacqtene FE 8000 with an average density of 0.924.

In the case of low density Lacqtene FE 8000 of a medium density polyethylene of 0.924 to which is added 7% of additive brand Atmer 7340 0.925 density, percentage by weight of polymer in the final formulations are respectively 62.1 % (opaque white), 69.9% (white) and 72.4% (colorless). In another implementation, the composition may include calcite.

Calcite CaCO3 chemical formulation also having a low optical density and giving a transparent appearance to the composition, increases the emissivity thereof over the range from 6.5 to 9.5 m. Radiative cooling is increased for these wavelengths.

This mineral filler also has a low cost and has been recognized safe for food contact use. The composition comprises from 0 to 5%, and preferably from 1.52 to 1.9% calcite volume relative to the volume of the original polymer. This composition is particularly suitable for the manufacture of films. For the manufacture of paints, the composition may comprise 0 to 15%, preferably 2.2 to 3.2% of pigment volume concentration of calcite. Preferably, the average diameter of calcite particles is between 0.2 and 3 m. This range for the average diameter of the mineral calcite fillers can increase the reflectance of the composition for visible light and near infrared radiation, and specifically on the wavelength between 0.2 and 3 m.

However, an average diameter smaller or larger particles will not be harmful to the radiative properties infrared thermal wavelengths.

For use of the composition as a film or paint, can be cited as indicative calcite marketed under the name SB Polcarb by Imerys with a median diameter of 0.8 m. In one embodiment, the composition further comprises titanium dioxide. TiO2 chemical formulation of titanium dioxide may be incorporated in the polymer matrix when it is desired to use the matrix to limit day the heating of the surface coated with the composition. Indeed, the introduction of titanium dioxide allows to make white opaque composition, which allows to obtain on the visible light reflectance of a relatively high solar energy combined with high emissivity on the infrared radiation serves to limit daytime heating of the surface. The use of titanium dioxide is also eligible for food contact uses, if it is embedded in the material.
Titanium dioxide, however, a significantly higher price than kaolin and calcite, which increases the cost of the composition. The composition may comprise from 1 to 20%, and preferably from 2.4 to 5.4% by volume of titanium dioxide relative to the total volume of the initial polymer in the manufacture of thermoplastic films.

For the manufacture of paints, the composition may comprise 0 to 30%, preferably 13.9%, of pigment volume concentration of titanium dioxide. All in the form of titanium dioxide ranges micronized suitable for such formulations, the mean diameter being generally between 0.1 and 0.5 m. Advantageously, the diameter means titanium dioxide particles is between 0.20 and 0.31 m.

With such an average particle diameter of titanium particles, the reflectance of the composition is increased mainly for the ultraviolet and visible radiation. For use of the composition in the form of thermoplastic film include for example titanium dioxide marketed under the name TR28 by Huntsman means 0.21 m diameter. These particles are coated with Al2O3 to present a stability to ultraviolet radiation. An organic treatment facilitates their wetting by the polymer for a better dispersion and a higher mechanical strength of the final material. For use of the composition in the form of solvent-based paint include an indication titanium dioxide sold under the brand Ti-Pure R-105 of the company du Pont de Nemours, with an average diameter of 0.31 m. In one embodiment, the composition comprises at least one anti-ultraviolet additive (UV). These additives help prevent aging by photo-degradation of the composition used in film form or in the form of painting.

The UV stabilizing additives may be selected from the most widespread in the polymer industry, whether benzophenones type benzotiazoles, triazines, benzoxazinones, hindered benzoates, hindered amines, nickel-based, etc. . These stabilizers classes will be preferentially selected those that are accredited in temporary contact with foodstuffs. A non-exhaustive list of products that may be suitable is: Great lakes polymer additive range, type products Lowilite 94, 62, 22, 26, 27, 28, Q84 and Q21 Lowilite type nickel-based, the products of Ciba Specialty Chemicals, stabilizers Tinuvin NOR 371; Smartlight RL 1000; Tinuvin 494; Tinuvin 783.

Range of Cytec, Cyasorb UV the products; Cyasorb THT 4611. Or products Clariant H Ostavin N 391 and Gran Gran Hostavin ARO 8 and products from Rhodia brand ranges (paintings) Rhodocoat or Tolonate. Anti-UV additives are generally selected based on the polymer base used in said composition. For example, when the composition is in the form of films and includes low-density polyethylene, UV light stabilizer is chosen type based hindered amines or English Hindered Amine Light Stabilizers additive (HALS). For applying the composition in the form of thermoplastic film include for example the anti-UV additive sold under the name Tinuvin 783 by Ciba Specialty Chemicals, which is suitable for food use. Advantageously, the composition comprises 0.5 to 0.7% and preferably 0.6% by weight, said anti-UV additive based on the total weight of the composition.

This aspect of the composition must reflect the product used and the recommended mass content by the manufacturer. For applying the composition in the form of painting, proper commercial polymer matrix for outdoor use already containing such additive is sufficient. Advantageously, it is possible to impart to the coated surface from said composition of hydrophilic surface properties to promote the formation of films of water. Thus, in the case of films, the composition may comprise at least one additive which confers to the surface hydrophilic properties.

This additive will favor the condensation of water at the film surface thereby increasing the amount of water recovered.

Generally, this additive is a surfactant. Moreover, in the case of a thermoplastic film obtained by extrusion, this type of additive allows a better distribution of the inorganic fillers within the polymer matrix. During a cooling phase, this type of additive migrates to the surface and gives the composition hydrophilic properties in order to cause condensation in the form of film, which promotes the flow and the recovery of the condensed water. For applying the composition in the form of thermoplastic film, there may be mentioned the surfactant additive sold under the brand Atmer 7340 by Ciba Specialty Chemicals, which is suitable for food use.

Preferably, the composition comprises from 6 to 8% and preferably 7% by weight of said water drops anti-forming additive based on the total weight of the composition. Of course, it is also possible to provide any other industrial process capable of giving it hydrophilic properties, for example a corona treatment by dielectric barrier discharges, or also chemical treatments such as halogenation, oxidation or that chlorophosphorylation may agree provided that the legislation allows for the non-permanent contact with foodstuffs.

For an application of the composition in the form of paint, this surface hydrophilic property can also be provided by a particular step in the manufacture of said paint. Thus, the added mineral fillers, and in particular the kaolin filler, are laid out exposed by photolysis of the binder on the surface after a period of exposure to ultraviolet radiation above 30 days.

Painting acquires a highly hydrophilic character preserved over time and effective in promoting atmospheric water vapor condensation. This highly hydrophilic character also promotes gravity flow of condensed water on the surface.

According to a second aspect, the invention also relates to a paint comprising a composition as defined above. Advantageously, the paint is water-based or organic solvent. Finally, in a third aspect, the invention further relates to a plastic film comprising a composition as defined above. Preferably, the film has a thickness of between 150 and 250 m. Such a film may be obtained for example by molding, by blow molding or by extrusion. The following examples illustrate the present invention and should not be considered in any way as limiting thereof. Example 1: The Applicant has made compositions used as films and having the following formulations: Wire White Colourless low density polyethylene plastic film (LDPE) Opaque Diffusing Thickness (m) 230 200 150 Titanium dioxide (TiO2) 5 4 2.4 Volume (%) 3.82 5.7 7.83 calcined kaolin (Al203.2SiO2) Volume (%) Calcite (CaCO3) 1.52 1.54 1.9 Volume (%) Total load 37, 9 30.1 27.60 Massic (%) 20

Table 1 The volume percentages are based on the original volume of polymer introduced.

The first opaque white film formulation comprising a proportion by volume of kaolin of 3.82% corresponds to a mass percentage of 9.0% of the polymer mass originally introduced. This formulation is recommended for applications requiring maximum opacity of the film.

The film formulations comprising a proportion by volume of kaolin equal to 5.7% and 7.83% correspond to the respective weight percentages of 16.1% and 21.9% relative to the polymer mass originally introduced. The weight percentages are for guidance from the initial polymer mass for an initial polyethylene composition Lacqtene FE 8000 with an average density of 0.924 and 7% by mass of additive Atmer 7340 0.925 density).

The mechanical properties obtained for the films of Table No. l are: Plastic Film White Colourless low density polyethylene (LDPE) Opaque Diffusing Stress at 10.0 elastic limit 8.1 8.7 (MPa) Strain at limit 29 74 24 '61 2.75 elastic (%) modulus of elasticity (MPa) 240 340 560 Tensile strength 8.0 10.0 10.2 (MPa) Strain at break 71 53.0 7 30.9 (%) 17 Table 2 mechanical tests were performed according to ISO 527-3, ASTM D 882 or. The results, expressed in MPa are dimensionless since 5 reduced to the section of the test specimens.
The optical properties obtained for films comprising formulations identical to those of Table 1 and having measuring thicknesses of 200, 215 and 155 m are: Plastic film Colorless White low density polyethylene (LDPE) Opaque Diffusing Br Eur (m) 200 215 155 0.90 0.86 0.62 reflectance of visible radiation (0.38 ù 0.78 m) Table 3 Example 2:

The plaintiff has made compositions used as paints and comprising the following formulations. Because of 20 the solvent when forming the paint film, the pigment is expressed in terms pigment volume concentration (PVC), which is the ratio of the volume of the load calculated on the total volume of the dry extract of the final formulation comprising the binder, the pigments and fillers, but excluding the volume of the solvent. 1015 25 Commercial Base Type Base Base Colourless Tinted final opaque paint radiative Opaque Colorless Dye (including white white) CPV TiO2 13.9 CPV kaolin (%) 5.9 12.1 6.8 CPV CaCO3 (%) 2.2 3.0 3.2 22.0 15.1 10.0 Concentration Pigmentosa total added volume (%) Table 4 indication, if a colorless base is used, the volume proportion of binder in the extract dry the final formulation is 78.0% respectively (opaque white paint) and 84.9% (colorless paint).

If a tinted base is used, the pigment volume concentration already incorporated can be variable while the added pigment volume concentration is 10%. In the latter case, the final proportion of binder will be determined with knowledge of the total pigment volume concentration in the mixture. The pigment volume concentration of each mixture will be the same if it is a solvent-based paint or water-based.

The optical properties obtained for paints containing formulations identical to those of Table 4 and having thicknesses of 90 and 94 m are: 20 commercial basis Type brilliant Base Colourless final painting radiative Opaque white Colorless Thickness (m) 90 94 Reflectance of visible radiation (0.38> 0.80 0.62 0.78 ù m) ù Table 5 the formulations shown in tables 1 and 4 make it possible to obtain compositions having high emissivity the average reflectance and infrared radiation of relatively large solar energy to visible light and near infrared. However, a higher relative proportion of kaolin is in no way detrimental to the thermal infrared emissivity (4 ù 100 m) which is the essential property of these formulations. There is no theoretical upper limit to the incorporation of kaolin in the formulations. The materials formulated with a volume proportion of incorporated kaolin less than the values given in Tables 1 and 4 will be particularly suitable for passive radiative cooling applications and atmospheric water vapor condensation.

However, their emissivity medium and far infrared will be less, reducing their effectiveness for the above applications. The composition according to the invention is particularly suitable for use in building construction, or in the automobile industry. It is for example possible to use this composition in the form of paints for vehicle bodies automobiles, or to the walls and roofs of buildings.

Of course, it is also possible to use films comprising the composition according to the invention to coat the roofs of buildings. A particularly interesting application of such films also relates to their use on flat surfaces bearing against the ground to form condensers and recovering potable liquid water. To promote a recovery of water, it is possible to incline the surfaces relative to the ground, for example an angle of a value of 30 °

Air Well Patents

US1816592
Means to Recuperate the Atmospheric Moisture
Achille Knapen

US2138689
Method for Gaining Water out of the Atmosphere
Edmund Altenkirch

US2401560
Refrigerating apparatus
Graham CD, Dybvig ES

US2462952
Solar Activated Dehumidifier
Elmer Dunkak

US6182453
Portable, potable water recovery and dispensing apparatus
FORSBERG FRANCIS

US2761292
Device for obtaining fresh drinkable water.
Coanda H

US2779172
Thermo-electric dehumidifier
LINDENBLAD NILS E

US2919553
Combination fluid heater and dehumidifier
FRITTS ROBERT

US2944404
Thermoelectric dehumidifying apparatus
FRITTS ROBERT

US3400515
Production of water from the atmosphere
Ackerman E

US3740959
Humidifier-dehumidifier device.
Foss FD

US3889532
Fog Water Collector
Roland Pilie & Eugene Mack

US4080186
Device for extracting energy, fresh water and pollution from moist air.
Ockert CE

US4146372
Process and System for Recovering Water from the Atmosphere
Wilhelm Groth / Peter Hussmann

US4185969
Process and plant for recovering water from moist gas.
Bulang W

US4206396

Charged Aerosol Generator with Uni-Electrode Source
Alvin Marks

US4219341
Process and Plant for the Recovery of Water from Humid Air
Wilhelm Groth / Peter Hussmann

US4234037
Underground heating and cooling system.
Rogers W, Midgett

US4242112
Solar Powered Dehumidifier Apparatus
Robert Jebens

US4285702
Method and apparatus for the recovery of water from the atmospheric air.
Michel H, Bulang

US4304577
Water producing apparatus.
Ito T, H Matsuoka, Azuma K, Y Hirayama, N Takahashi

US4315599
Apparatus and method for automatically watering vegetation.
Biancardi RP

US4342569
Method and apparatus for abstracting water from air.
Hussmann P

US4345917
Method and apparatus for recovery of water from the atmosphere.
Hussmann P

US4351651
Apparatus for extracting potable water.
Courneya CG

US4374655
Humidity Controller
Philomena Grodzka, et al

US4433552
Apparatus and method for recovering atmospheric moisture
Smith RH

US4377398
Heat Energized Vapor Adsorbent Pump
Charles Bennett

US4459177
Ground moisture transfer system.
O'Hare L

US4475927
Bipolar Fog Abatement System
Hendricus Loos

US4506510
Apparatus for continuously metering vapours contained in the atmosphere.
Tircot M

US4726817
Method and Device for Recovering in Liquid Form the Water Present in the Atmosphere in Vapor Form
Roger Rippert

US5106512
Potable air-water generator.
Reidy J

US5149446
Potable water generator.
Reidy JJ

US5203989
Potable air-water generator.
Reidy JJ

US5233843
Atmospheric water extractor
Clarke / Calif

US5275643
Fog Water Collecting Device.
Yoshio Usui

US5284628
Convection towers
Melvin Prueitt

US5357865
Method of Cloud Seeding
Graeme Mather

US5395598
Convection towers
Melvin Prueitt

US5477684
Convection towers
Melvin Prueitt

US5626290
Rain Making System
Donald Kuntz

US5669221
Portable, Potable water recovery and dispensing apparatus.
LeBleu TL

US5729981
Method and Apparatus for Extracting Water

Michael Braun, Wolfgang Marcus

US5845504
Portable/potable water recovery and dispensing apparatus
LeBleu TL

US5846296
Method and device for recovering water from a humid atmosphere.
Krumsvik PK

US6029461
Water collection and dispensing.
Zakryk JM

US6156102
METHOD FOR RECOVERING WATER FROM AIR
CONRAD, WAYNE ERNEST

US6360557 / US6957543
Air Cycle Water Producing Machine
Igor Reznik

US6490879
Water generating machine.
Lloyd DJ, Baie

US6511525
METHOD & APPARATUS FOR EXTRACTING WATER FROM AIR USING A DESICCANT
SPLETZER, BARRY / CALLOW, DIANE SCHAFER

US6574979
Production of Potable Water... from Hot and Humid Air
Abdul-Rahman Faqih

US6644060
Apparatus for extracting potable water from the environment air.
Dagan A

US6684648
Apparatus for the production of freshwater from extremely hot and humid air.
Faqih AAM

US6755037
Apparatus and method for extracting potable water from atmosphere.
Engel DR, Clasby ME

US6868690
Production of potable water and freshwater needs for human, animal and plants from hot and humid air.
Faqih AAM

US6869464 / US6869469
Atmospheric water absorption and retrieve device.
Klemic J

US6945063
Apparatus and method for harvesting atmospheric moisture

US6957543 / US6360557
Air Cycle Water Producing Machine
Igor Reznik

US7251945
Water-from-air system using desiccant wheel and exhaust
Tongue S

US7306654
METHOD AND APPARATUS FOR PRODUCING POTABLE DRINKING WATER FROM AIR
HARRISON, NORMAN

US7328584
Fresh water extraction device.
Craven JP

US7601206
Method and apparatus for generating water using an energy conversion device.
Call CJ, et al

US7954335
ATMOSPHERIC WATER HARVESTERS WITH VARIABLE PRE-COOLING

US8118912
Low power atmospheric water generator.
Rodriguez F, Khanji N

US8506675
Composite desiccant and air-to-water system and method
Ellsworth J

US8627673
ATMOSPHERIC WATER HARVESTER

US2002011075
Production of Potable Water... from Hot and Humid Air

US2002029580
Apparatus and Method for... Production of Fresh Water from Hot Humid Air

US2003097763
Combination Dehydrator and Condensed Water Dispenser

US2003150483
Apparatus and Method for Harvesting Atmospheric Moisture

US2004112055
Atmospheric Vortex Engine
Louis Michaud

US2004000165
Apparatus and Method for Harvesting Atmospheric Moisture
Michael Max

US2005103615

Atmospheric Water Collection Device
Johnathan Ritchy

US2005266287
Device for Producing Water on Board of an Airplane
Claus Hoffjann & Hans-Juergen Heinrich

US2005284167
Combination Dehydrator, Dry Return Air and Condensed Water Generator/Dispenser
Michael Morgan

US2005266287
Device for Producing Water on Board of an Airplane
Claus Hoffjann & Hans-Juergen Heinrich

US2006032493
Device for Collecting Atmospheric Water
Jonathan Ritchey

US2006112709
Method and Apparatus for Collecting Atmospheric Moisture
Peter Boyle

US2006130654
Method and Apparatus for Recovering Water from Atmospheric Air
Ronald King & Norman Arrison

US2006279167
SYSTEM & METHOD, FOR RECOVERING WATER FROM AIR
TURNER, J GLENN

US2007220843
METHOD FOR EXTRACTING WATER FROM AIR, AND DEVICE THEREFOR
IKE, H / OKUHATA, N

US2008314058
Solar Atmospheric Water Harvester

US2010307181
ATMOSPHERIC MOISTURE HARVESTING

US2011232485
COMPOSITE DESICCANT AND AIR-TO-WATER SYSTEM AND METHOD
ELLSWORTH JOSEPH

CA2478896
Combination Dehydrator & Condensed Water Dispenser
Janet Morgan

CA774391
Method for Precipitating Atmospheric Water Masses
David Glew & Andrew Watson

CA497523
APPARATUS FOR EXTRACTING WATER FROM AIR
SUITER, WILL D

CA2070098
APPARATUS FOR RECOVERING WATER FROM AIR AND METHOD OF WATER RECOVERY
CONRAD, WAYNE E

CH608260
Process for Obtaining Service Water or Drinking Water...
Gotthard Frick

DE19734887 / WO9907951
Device for Obtaining Water from Air
Heinz-Dieter Buerger & Yourii Aristov

DE3313711
Process and Apparatus for Obtaining Drinking Water
Rudolf Gesslauer

EP1142835
Portable, Potable Water Recovery and Dispensing Apparatus
Francis Forsberg

EP1629157
Device for the Extraction of Water from Atmospheric Air
Frank Thielow

FR2813087
Unit Recovering Atmospheric Moisture from Vapor or Mist...
Jacques P. Beauzamy

NL1030069
Atmospheric Water Collector...
Ghassan Hanna

CH608260
Process for Obtaining Service Water or Drinking Water...
Gotthard Frick

CN2573556 // CN2573555
Solar adsorption device for obtaining water

CN1403192
High-hydroscopicity adsorbent and its prepn

UA66218
A PROCESS FOR PREPARATION OF SWEET WATER FROM AIR
NEVEDNICHENKO, PETRO SAVOVYCH / HERMAN NATALIIA PETRIVNA

AU3241078
RECOVERY OF WATER FROM AIR

AU517422B
OBTAINING WATER FROM AIR
CLUCK, A

PL257283

SEPARATOR FOR SEPARATION OF DUST AND WATER FROM AIR
FRYDEL, WALENTY

GB251689
Method of and Apparatus for Causing Precipitation of Atmospheric Moisture and for Kindred Purposes
William Haight

GB319778
Improved Means for Collecting Moisture from the Atmosphere
Achille Knapen

GB1164119
Device for Modifying Atmospheric Conditions for example, for the Inhibition or Dispersal of Fog or Mist, or to Induce Rain
Edmund Updale

GB1214720
Fog Abatement & Cloud Modification

GB251689
Method of and Apparatus for Causing Precipitation of Atmospheric Moisture and for Kindred Purposes
William Haight

GB319778
Improved Means for Collecting Moisture from the Atmosphere
Achille Knapen

GB1164119
Device for Modifying Atmospheric Conditions for example, for the Inhibition or Dispersal of Fog or Mist, or to Induce Rain
Edmund Updale

GB2064358
EXTRACTING WATER FROM AIR

GB1200221
PRODUCING FRESH WATER FROM AIR RAISED TO HIGH HUMIDITY BY EXPOSURE TO WATER VAPOR FROM CONTAMINATED SOURCES OF WATER
DOBELL, CURZON

GB2376401
Self-watering Plant Pot

RU2190448
Independent Complex for Separating Moisture from Air
O. A. Bernikov

RU2235454
Method & Apparatus for Producing Acoustic Effect upon Atmospheric Formations
E. T. Protasevich & S.A. Ryzhkin

RU2185482
Apparatus for Receiving Biologically Pure Fresh Water... out of Atmospheric Air

RU2182562
Method of Producing Biologically Active Potable Water with Reduced Content of Deuterium...

RU2146744
Method for Producing Water from Air

RU2132602
Method for Accumulating Moisture in Full Fallows

RU2151973
PROCESS OF WINNING OF WATER FROM AIR (AIR DRYING) AND GEAR FOR ITS REALIZATION
SIRENKO, V S; GORJACHEV, E A

RU2143530
DEVICE FOR PRODUCING FRESH WATER FROM AIR
KOCHETKOV, B F

RU2064036
DEVICE FOR SEPARATING WATER FROM AIR
SHAROV, VIKTOR

RU2062838
DEVICE FOR TAKING DRINKING WATER FROM AIR
KULIKOV, VIKTOR

RU2000393
APPARATUS FOR EXTRACTION OF WATER FROM AIR
SHAROV, VIKTOR V

RU2278790
Method & Apparatus for... Extraction of Water from Atmosphere...
Vladimir Krjukovskij, et al.

RU2278929
Vortex System for Condensing Moisture from Atmospheric Air
Vjacheslav Alekseev, et al.

RU2272877
Method for Obtaining Water from Air
Jurij Aristov, et al.

RU2190448
Independent Complex for Separating Moisture from Air
O. A. Bernikov

RU2235454
Method & Apparatus for Producing Acoustic Effect upon Atmospheric Formations
E. T. Protasevich & S.A. Ryzhkin

SU69751
Equipment for collecting water from air
Tygarinov

SU1751608
DEVICE FOR COLLECTING DRINKING WATER FROM AIR
DEMIDOV, VALENTIN

WO2007009184
Gust Water Trap Apparatus
Maxwell Whisson

WO2006017888
Apparatus & method for Cooling of Air
Maxwell Whisson

WO2006040370
Method of Obtaining Water from an Atmospheric Air Mass...
Alexander Ermakov

WO2006028287
Method of Water Extraction... from Atmospheric Air
Hideya Koshiyama

WO2002086245
METHOD FOR EXTRACTING WATER FROM AIR AND DEVICE FOR CARRYING OUT SAID METHOD
ROMANOVSKY, VLADIMIR FEDOROVICH

WO200184066
DEVICE FOR COLLECTING WATER FROM AIR
FAWZI, HISHAM

WO200111152
METHOD FOR OBTAINING WATER FROM AIR
LADYGIN, ANATOLY VLADIMIROVICH

WO9907951
DEVICE FOR OBTAINING WATER FROM AIR
BUERGER, HEINZ-DIETER

WO9739197
METHOD OF EXTRACTING WATER FROM AIR AND A DEVICE FOR CARRYING OUT SAID METHOD
ROMANOVSKY, VLADIMIR

WO200218859
METHOD AND APPARATUS FOR EXTRACTING WATER FROM AIR
SPLETZER, BARRY

WO200218858
METHOD AND APPARATUS FOR EXTRACTING WATER FROM AIR
SPLETZER, BARRY

WO200136885
METHOD AND APPARATUS FOR EXTRACTING WATER FROM AIR
SPLETZER, BARRY L

WO2004029372
Method & Apparatus for Collecting Atmospheric Moisture
Peter H. Boyle

WO2003104571
Device for Collecting Atmospheric Water
Jonathan Ritchey

WO9943997
System for Producing Fresh Water from Atmospheric Air

WO02094725
Method and Device for Recovery of Water from the Atmospheric Air

WO03078909
Combination Dehydrator and Condensed Water Dispenser

WO2007051886
NOVEL PLANT FOR GENERATING WATER FROM AIR
MARTINEZ, SANTIAGO JOSE ANTONIO

WO2007041804
METHOD & APPARATUS FOR EXTRACTING WATER FROM AIR CONTAINING MOISTURE
CLARKE, PETER

JP52134896
METHOD OF RECOVERING WATER FROM AIR APPARATUS THEREFORE AND PROCESS FOR PREPARING SILICAGEL AND APPARATUS THEREFORE
BUIRUHERUMU, GUROOTO

JP54047354
METHOD OF OBTAINING WATER FROM AIR IN ATMOSPHERE AND ITS DEVICE
BUORUFUGANGU, BURANGU

JP2004316183
Equipment & Method for Producing Fresh Water from Atmospheric Moisture Content
Aoki Kazuhiko, et al.

JP2004169321
METHOD FOR EXTRACTING WATER FROM AIR & APPARATUS THEREFOR
IKE, HIDETOSHI

JP 2004057890
ULTRA WATER-REPELLENT SURFACE TYPE WATER EXTRACTION DEVICE FOR EXTRACTING WATER FROM AIR & NEGATIVE ION PRODUCING DEVICE
KOSHIYAMA, HIDEYA

JP5203177
FORCE FEED SYSTEM FOR DRAIN WATER FROM AIR-CONDITIONER
AWATA, KOJI

JP59150277
PREVENTIVE DEVICE FOR SCATTERING OF WATER FROM AIR CONDITIONER
HISATAKA, SATORU

JP54127870
METHOD AND APPARATUS FOR OBTAINING WATER FROM AIR
HERUMUUTO, MIHIERU

KR20010003009
EVAPORATOR OF DRAIN WATER FROM AIR CONDITIONER IN ELEVATOR
HWANG, JONG YUN

KR20000052036
EVAPORATOR FOR DISCHARGING WATER FROM AIR CONDITIONER OF ELEVATOR
HWANG, JONG YUN

KR20010077162
NON-POWERED APPARATUS AND METHOD FOR DRAINAGE OF CONDENSATE WATER FROM AIR CONDITIONER
LEE, GWANG SEOP / LEE, MYEONG SEOP