Eur. J. Phys. **27** (2006) 667–673 doi:10.1088/0143-0807/27/3/019

Calcite and hematite minerals: a promising application as dew water collectors

A Vazquez, J Arias and R M Sanchez

Universidad Autonoma Metropolitana—Iztapalapa, Dep. IPH-IRE, Av. San Rafael Atlixco No. 186, Col. Vicentina CP 09340, Mexico, DF, Mexico

E-mail: zeta24_75@yahoo.com

Received 13 February 2006, in final form 22 March 2006
Published 21 April 2006
Online at stacks.iop.org/EJP/27/667

Abstract

An arrangement of plates was built using two minerals, calcite and hematite, deposited on glass (slides). The plates were placed in Chilapa de Alvarez city, in the southeast of Mexico. The goal of this work is to prove that mineral plates perform better than glass in nocturnal radiative cooling phenomena. The results obtained are that the glass/hematite plate collected 1.2–1.5 $\times$ 10^{-3} l of water and the glass/calcite plate only 0.71–0.75 $\times$ 10^{-3} l; meanwhile dew was not observed on a glass plate without minerals.

1. Introduction

Today, the majority of natural fresh water sources (rivers, lakes, wells, etc) are contaminated to some extent (by industrial waste, in populated areas, by agrarian activities, etc) or are insufficient for human demands. Water scarcity is a particularly important problem in countries with high population (Latin America, Africa, etc). One possible solution lies in secondary water sources, such as nocturnal radiative cooling. However, this secondary water source has been used rarely and is poorly documented in the literature. Since antiquity, man has tried to collect dew to obtain water, using the so-called 'air-well' devices, or Zibold condensers (Zibold 1905, Knapen 1929, Chaptal 1932). These condensers were constructed by stone piles to a height of 2.5–288 m and have been reported to produce water at rates of 19–1368 l per day. However, investigations by Nikolayev *et al* (1996) contended that air-well devices could not produce such high water yields and that the stone heaps in Feodosia (Crimea, Ukraine) actually were ancient Scythian and Greek tombs. Nevertheless, a more recent study by Kogan and Trahtman (2003) showed that Zibold condensers could produce up to 2800 l per day.

Today, it is known that the mechanism underlying nocturnal dew condensation is radiative cooling, which utilizes the transmittance through the Earth's atmosphere of thermal radiation in the wavelength interval from approximately 3–20 μm; this interval is called the 'atmospheric window'. The emitted radiation follows the Stefan–Boltzmann relation

$$P = \varepsilon\sigma T^4, \tag{1}$$

where P is the emissive power, ε is the emissivity value for a non-black body, σ is the Stefan–Boltzmann constant (5.67×10^{-8} W m^{-1} K^{-1}) and T is the body temperature. In a recent study, test radiative condensers were constructed with large planar plates (2.6 × 0.6 m inclined at a 30° angle from horizontal) of polymethylmethacrylate (plexiglas), polyethylene and glass. These have been placed in different locations and seasons of the year, to compare dew water harvest rates with respect to local meteorological parameters such as relative humidity, wind speed and cloud cover (Mileta *et al* 2004, Muselli *et al* 2004).

Another use of radiative cooling is to lower the temperature of some fluid (in contact with the emitting body) for the purpose of cooling ceilings or floors (Bliss 1961, Erell and Etzion 1992, Al-Nimr *et al* 1998, 1999, Meir *et al* 2000). This has the potential to substitute for, or partly replace traditional air conditioning and refrigeration systems etc. Radiative cooling of a given surface occurs when the surface-emitted radiation exceeds the absorbed radiation (in the absence of conduction and convection heat transfers). This is most likely to occur for clear atmospheric conditions, which improve the atmospheric transmissivity for radiation in the atmospheric window. The performance of a radiative cooling system is further enhanced if it operates in the absence of heat flux and convective heat gain from the surrounding environment. Convective heat gain is reduced when ambient temperature and wind speed are low, and also if the design reduces the air motions over the emitting surface as much as possible. Recent studies (Ali *et al* 1998, Beysens *et al* 2003, Tsilingiris 2003) have investigated the use of polymer films (acrylic, mylar, kapton, glass fibre, polyethylene and polypropylene) to obtain a greater infrared transmission. Other studies showed that shield preparation based on the use of polyethylene foils pigmented with nanocrystalline of titanium dioxide (TiO_2) improves the transmission in the atmospheric window and solar reflectance. This behaviour is due to the fact that TiO_2 is a wide band-gap semiconductor which does not absorb either in the visible or in the infrared; in addition, TiO_2 has a high refractive index of 2.57–2.74 at 0.5 μm (Nilsson and Niklasson 1995, Mastai *et al* 2001, Dobson *et al* 2003). Meanwhile Benlattar *et al* (2005) investigated the use of a cadmium telluride (CdTe) thin film as the radiative cooling material used to keep food, liquid and other materials at below ambient temperatures.

Because, TiO_2 and CdTe are expensive, toxic and require careful handling, we propose the minerals calcite and hematite (which have the same volcanic origin as that of TiO_2 and are available in our local region) as alternative effective radiative cooling materials. For this study, calcite and hematite were deposited on glass slides and placed in an expanded polystyrene base in conjunction with a baseline test of a glass plate without mineral deposition. The baseline represents a typical setup for a dew collector. This arrangement was located in Chilapa de Alvarez city, Guerrero State (Mexico) at 17° 19′–17° 42′ N, 98° 58′–99° 17′ E for an overnight study. The plate and air temperatures and relative humidity were measured each hour, from 16:00 LT (local time) to 9:00 LT the next day. Results from 4 days are presented: the first for 4 March 2005 when the plates did not show water condensation and the others for 30 March, 16 April and 28 April 2005 when the plates did show water condensation.

2. Experimental setup

Calcite was ground to obtain grains with an average diameter of 1×10^{-4} m with a standard deviation of 2% (estimated using image processing software from Optimas Corp., MD, USA), and deposited in a 1 mm thick layer on a glass slide of 0.025 × 0.075 m that was subsequently

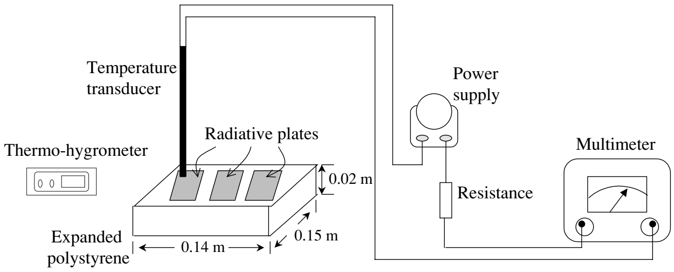


Figure 1. Schematic diagram of the experimental system.

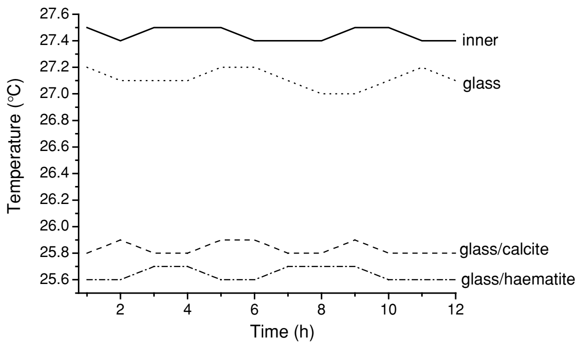
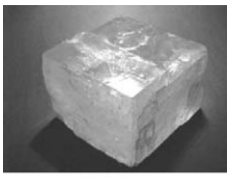


Figure 2. Results from the simulator box.

Table 1. General mineral information.

Specimen	Chemical formula	Hardness	Uses
 Haematite	$(Fe,Ti)_2O_3$	5–6	Main source of iron Jewelry Decoration
 Calcite	$CaCO_3$	2–2.5	Main source of calcium Fertilizers Paints

covered with a plastic resin. It was not possible to grind hematite because of its hardness (table 1); therefore, flat hematite pieces were chosen and placed in contact on their undersides with the slide. In addition, a slide without either of the minerals was also studied. The reference slide is hereafter termed the glass slide. These ‘radiative plates’ were all embedded in an expanded polystyrene base to isolate them from heat transmission by contact with any surface or floor.

Figure 3. Study location.

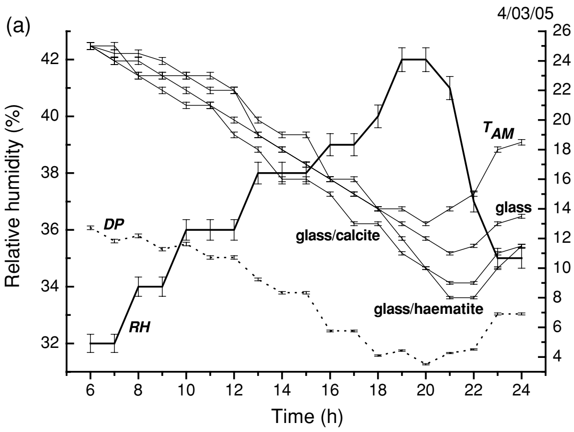


Figure 4. (a) Non-favourable and (b) favourable cases.

A sketch of the experimental system is shown in figure 1. The plate arrangement was placed outdoors overnight, and the plate temperature was measured with a temperature transducer (AD590, analog device, Norwood, MA, USA). This transducer was connected to a precision resistor of 22 ± 1% Ω value in series with a multimeter (MUL-600, Steren Inc., San Diego, CA, USA), and a dc current power source of 6 V–300 mA (Radio Shack, TX, USA).

A thermohygrometer (Thermo-Hygro A-37401-00, Cole-Parmer Co., Vernon Hills, IL, USA) measured relative humidity (RH) with ±5% accuracy, and also quantified the ambient temperature (T_{AM}) with ±0.05 °C error.

In the first experiment, the series of plates were placed within a dark plastic box 0.3 × 0.3 × 0.2 m with an aluminium cover. The internal face of the cover was painted black. The purpose of this box (called the simulator box) was to simulate a dark and cold night sky.

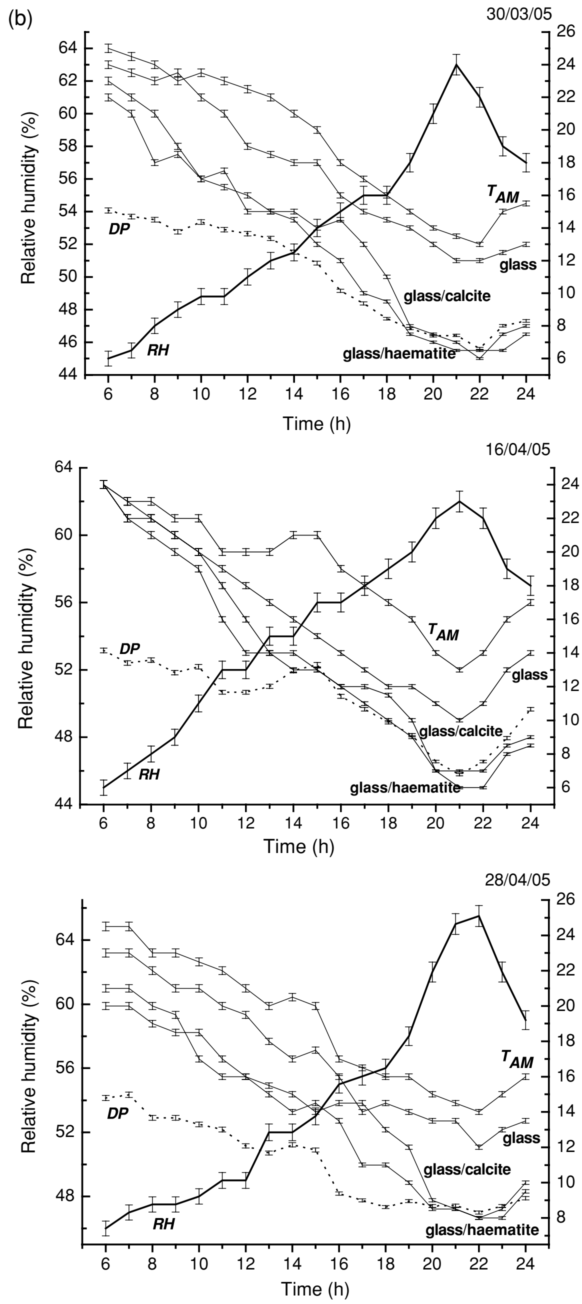


Figure 4. Continued.

Temperature readings were taken hourly for a 12 h period and are shown in figure 2. The glass with hematite showed the lowest temperature ≈25.6 °C, while the reference glass slide had the highest temperature ≈27.2 °C. The calcite and hematite slide temperatures (under these conditions) were 2.0 °C lower than the box's ambient temperature. It is also important to note that for a white aluminium cover, the glass/calcite plate temperature was 0.5 °C above ambient. This indicates a sensitivity to cloudy skies.

Table 2. Climatic annual minimum average temperatures for 1945–1995 from INEGI (2005).

State	Region	Temperature (°C)
Chiapas	Chilil	14.9
	San Cristobal de las Casas	14.5
Chihuahua	Abraham Gonzalez	13.1
	Nuevo Casas Grandes	16.5
Coahuila	Carneros	15.6
Distrito Federal	Ajusco	11.4
	Tacubaya	15.2
	Gran Canal	16.8
Guerrero	Chilapa de Alvarez	20.2
	Chilpancingo de los Bravo	20.6
Oaxaca	Ayutla	13.3
Puebla	Chapulco	15.1
	Tlatlauquitepec	16.7
Zacatecas	Concepcion del Oro	15.4
	La Florida	14.9
	Pinos & Rio Grande	16.7

The dew point (DP) is (Parry 1969)

$$DP = T_{AM} - (14.55 + 0.14\ T_{AM})(1 - 0.01\ RH). \qquad (2)$$

The slides were then placed in the north zone (on the soccer field) of the Escuela Secundaria General No. 1 Jose de San Martin (figure 3). Wind speeds were 1.6–1.8 m s^{-1} as reported by the local meteorological service. The minimal temperatures for Chilapa de Alvarez city and other Mexican Republic regions are shown in table 2.

3. Results

Measured values on 4 March 2005 are shown in figure 4(a). This was an unfavourable case because the dew point was not reached and thus there was no water condensation. In contrast, on the other days shown in figure 4(b) the temperature dropped to the dew point and water condensation was observed. Condensed water on the glass/hematite plate was collected with a hypodermic syringe and measured 1.2–1.5 $\times 10^{-3}$ l, whereas the glass/calcite plate only collected 0.71–0.75 $\times 10^{-3}$ l. The glass slide did not have any condensation. Significantly, the material with black or opaque colouration, i.e. the glass/hematite plate, performed better (lower temperature). This is in agreement with the experimental results (also at night) of Doulos *et al* (2004) for granite and black concrete in Panepistimioupolis, Greece. In that study, they monitored the temperature over a 24 h period for materials with diverse surface colours.

4. Conclusions

Of the tests conduced, the most favourable collected between 0.71 and 1.50 $\times 10^{-3}$ l of water from an 8×10^{-4} m^2 surface area of slide. This corresponds to 0.89–1.88 l/m^2/day. The glass slide, which was free from minerals, did not collect any water.

These results suggest that the use of calcite and hematite minerals in the construction industry could decrease the use of air conditioning systems during periods of high ambient temperatures, and thereby decrease overall electrical demand. The regions shown in table 2 have temperatures similar to or lower than Chilapa de Alvarez city and are thus good candidates for the use of calcite and hematite radiative cooling and dew water condensation.

Acknowledgments

The authors acknowledge Escuela Secundaria General No. 1 Jose de San Martin for lending its facilities for the experimental work. In addition, the authors gratefully acknowledge Professor Ira Leifer for his comments and language revision.

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